

# Cartography

(Essence & Applications)

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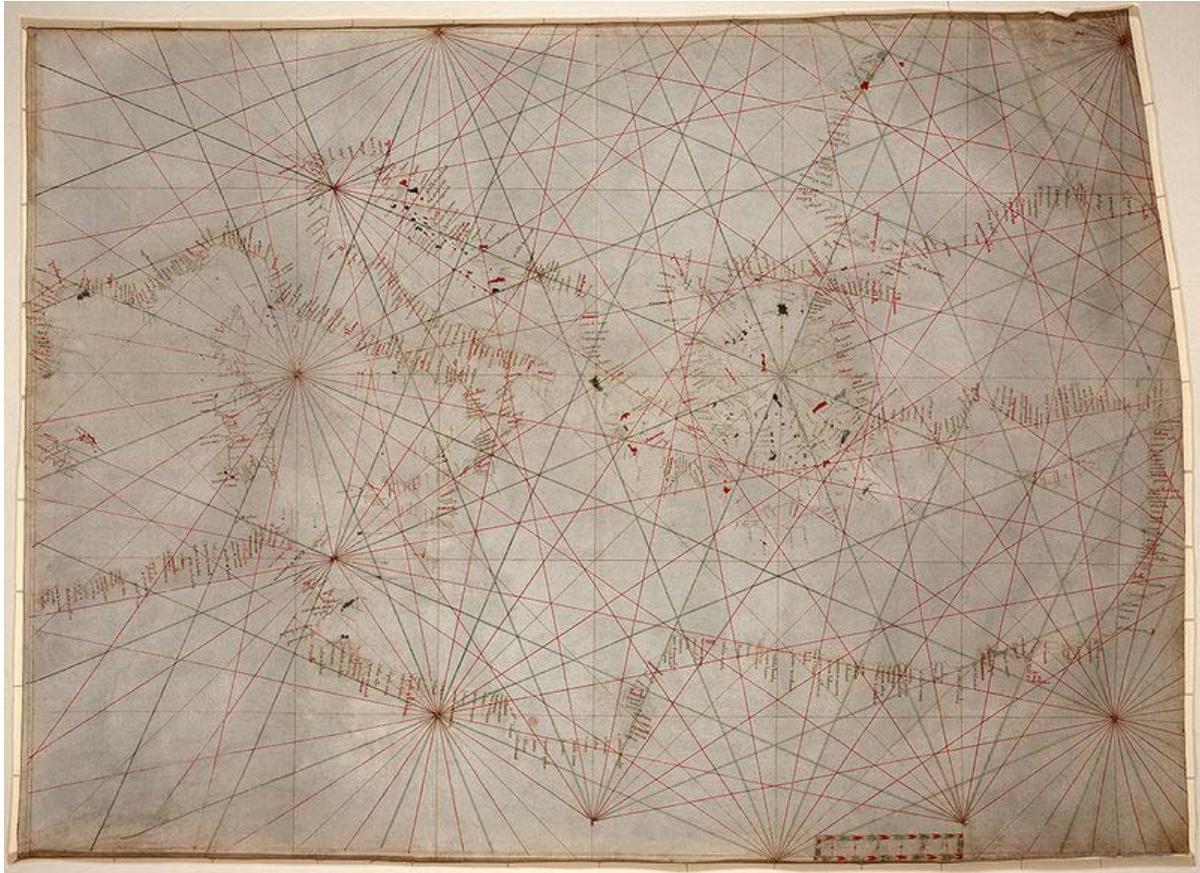
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# Introduction



A nautical chart of the Mediterranean Sea from the second quarter of the 14th century. It is the oldest original cartographic artifact in the Library of Congress.

**Cartography** is the study and practice of making maps. Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modeled in ways that communicate spatial information effectively.

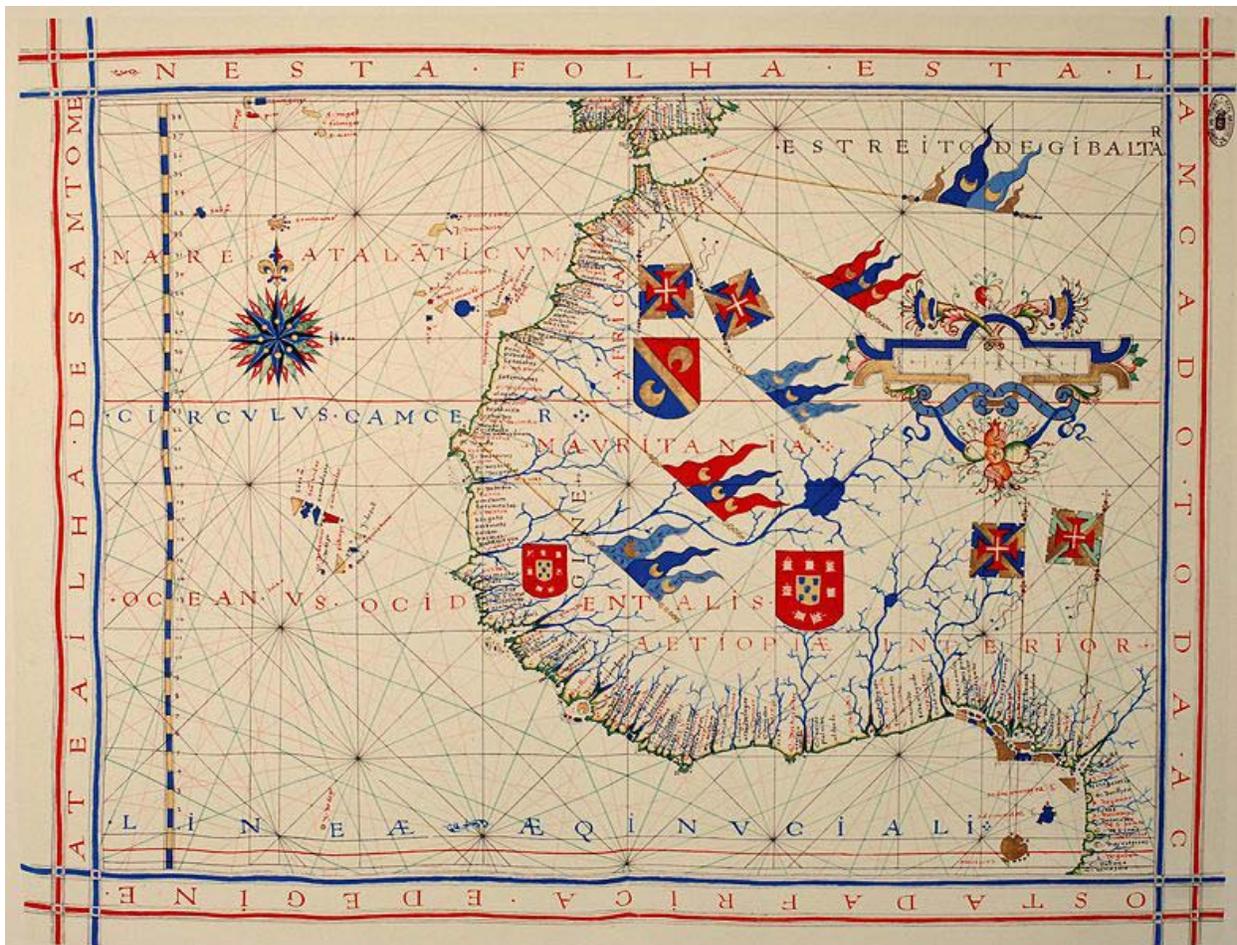
The fundamental problems of traditional cartography are to:

- Set the map's agenda and select traits of the object to be mapped. This is the concern of map editing. Traits may be physical, such as roads or land masses, or may be abstract, such as toponyms or political boundaries.

- Represent the terrain of the mapped object on flat media. This is the concern of map projections.
- Eliminate characteristics of the mapped object that are not relevant to the map's purpose. This is the concern of generalization.
- Reduce the complexity of the characteristics that will be mapped. This is also the concern of generalization.
- Orchestrate the elements of the map to best convey its message to its audience. This is the concern of map design.

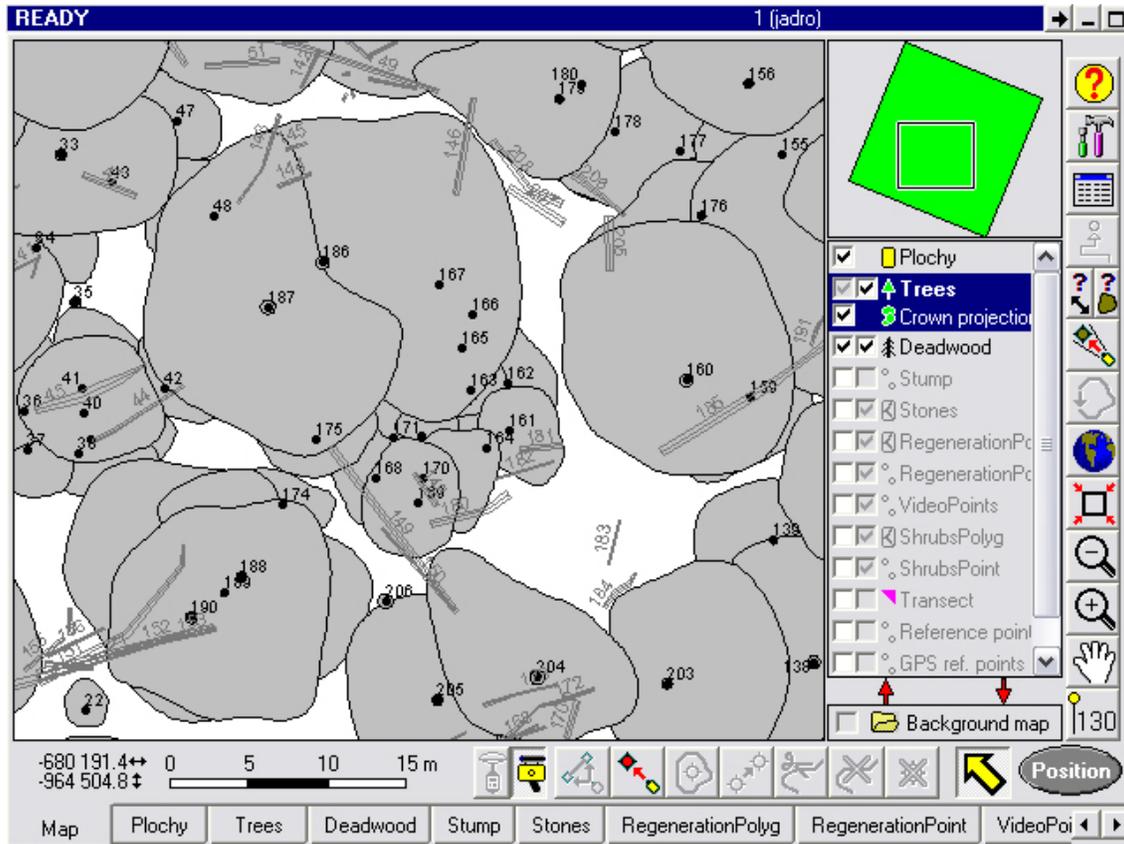
Modern cartography is closely integrated with geographic information science (GIScience) and constitutes many theoretical and practical foundations of geographic information systems.

## Technological changes



A pre-Mercator nautical chart of 1571, from Portuguese cartographer Fernão Vaz Dourado (c. 1520–c. 1580). It belongs to the so-called *plane chart* model, where observed latitudes and magnetic directions

are plotted directly into the plane, with a constant scale, as if the Earth were plane (Portuguese National Archives of Torre do Tombo, Lisbon).



Mapping can be done with GPS and laser rangefinder directly in the field (for example by Field-Map technology). Real-time map construction improve productivity and quality of mapping. Image is showing mapping of forest structure (position of trees, dead wood and canopy).

In cartography, technology has continually changed in order to meet the demands of new generations of mapmakers and map users. The first maps were manually constructed with brushes and parchment; therefore, varied in quality and were limited in distribution. The advent of magnetic devices, such as the compass and much later, magnetic storage devices, allowed for the creation of far more accurate maps and the ability to store and manipulate them digitally.

Advances in mechanical devices such as the printing press, quadrant and vernier, allowed for the mass production of maps and the ability to make accurate reproductions from more accurate data. Optical technology, such as the telescope, sextant and other devices that use telescopes, allowed for accurate surveying of land and the ability of mapmakers and navigators to find their latitude by measuring angles to the North Star at night or the sun at noon.

Advances in photochemical technology, such as the lithographic and photochemical processes, have allowed for the creation of maps that have fine details, do not distort in shape and resist moisture and wear. This also eliminated the need for engraving, which further shortened the time it takes to make and reproduce maps.

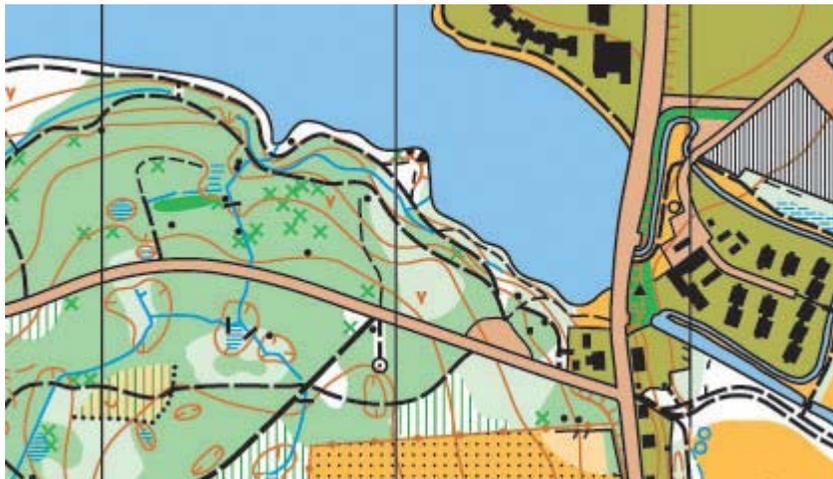
Advances in electronic technology in the 20th century ushered in another revolution in cartography. Ready availability of computers and peripherals such as monitors, plotters, printers, scanners (remote and document) and analytic stereo plotters, along with computer programs for visualization, image processing, spatial analysis, and database management, have democratized and greatly expanded the making of maps. The ability to superimpose spatially located variables onto existing maps created new uses for maps and new industries to explore and exploit these potentials.

These days most commercial-quality maps are made using software that falls into one of three main types: CAD, GIS and specialized illustration software. Spatial information can be stored in a database, from which it can be extracted on demand. These tools lead to increasingly dynamic, interactive maps that can be manipulated digitally.

With the field rugged computers, GPS and laser rangefinders, it is possible to perform mapping directly in the terrain. The construction of the map in real time improve productivity and quality of the result. **Real time mapping** is done for example with Field-map technology.

## Map types

### General vs thematic cartography



Small section of an orienteering map.



Topographic map of Easter Island.



Relief map Sierra Nevada

In understanding basic maps, the field of cartography can be divided into two general categories: general cartography and thematic cartography. General cartography involves those maps that are constructed for a general audience and thus contain a variety of features. General maps exhibit many reference and location systems and often are produced in a series. For example, the 1:24,000 scale topographic maps of the United States Geological Survey (USGS) are a standard as compared to the 1:50,000 scale Canadian maps. The government of the UK produces the classic 1:50,000 (replacing the older 1 inch to 1 mile) "Ordnance Survey" maps of the entire UK and with a range of correlated larger- and smaller-scale maps of great detail.

Thematic cartography involves maps of specific geographic themes, oriented toward specific audiences. A couple of examples might be a dot map showing corn production in Indiana or a shaded area map of Ohio counties, divided into numerical choropleth classes. As the volume of geographic data has exploded over the last century, thematic cartography has become increasingly useful and necessary to interpret spatial, cultural and social data.

An orienteering map combines both general and thematic cartography, designed for a very specific user community. The most prominent thematic element is shading, that indicates degrees of difficulty of travel due to vegetation. The vegetation itself is not identified, merely classified by the difficulty ("fight") that it presents.

## Topographic vs topological

A topographic map is primarily concerned with the topographic description of a place, including (especially in the 20th century) the use of contour lines showing elevation. Terrain or relief can be shown in a variety of ways.

A topological map is a very general type of map, the kind you might sketch on a napkin. It often disregards scale and detail in the interest of clarity of communicating specific route or relational information. Beck's London Underground map is an iconic example. Though the most widely used map of "The Tube," it preserves little of reality: It varies scale constantly and abruptly, it straightens curved tracks, and it contorts directions haphazardly. The only topography on it is the River Thames, letting the reader know whether a station is north or south of the river. That and the topology of station order and interchanges between train lines are all that is left of the geographic space. Yet those are all a typical passenger wishes to know, so the map fulfills its purpose.

## Map design



Illustrated map.

## Map purpose and informations' selection

Arthur H. Robinson, an American cartographer influential in thematic cartography, stated that a map not properly designed "will be a cartographic failure." He also claimed, when considering all aspects of cartography, that "map design is perhaps the most complex." Robinson codified the mapmaker's understanding that a map must be designed foremost with consideration to the audience and its needs.

From the very beginning of mapmaking, maps "have been made for some particular purpose or set of purposes". The intent of the map should be illustrated in a manner in which the percipient acknowledges its purpose in a timely fashion. The term *percipient* refers to the person receiving information and was coined by Robinson. The principle of figure-ground refers to this notion of engaging the user by presenting a clear presentation, leaving no confusion concerning the purpose of the map. This will enhance the user's experience and keep his attention. If the user is unable to identify what is being demonstrated in a reasonable fashion, the map may be regarded as useless.

Making a meaningful map is the ultimate goal. Alan MacEachren explains that a well designed map "is convincing because it implies authenticity" (1994, pp. 9). An interesting map will no doubt engage a reader. Information richness or a map that is multivariate shows relationships within the map. Showing several variables allows comparison, which adds to the meaningfulness of the map. This also generates hypothesis and stimulates ideas and perhaps further research. In order to convey the message of the map, the creator must design it in a manner which will aid the reader in the overall understanding of its purpose. The title of a map may provide the "needed link" necessary for communicating that message, but the overall design of the map fosters the manner in which the reader interprets it (Monmonier, 1993, pp. 93).

In the 21st century it is possible to find a map of virtually anything from the inner workings of the human body to the virtual worlds of cyberspace. Therefore there are now a huge variety of different styles and types of map - for example, one area which has evolved a specific and recognisable variation are those used by public transport organisations to guide passengers, namely urban rail and metro maps, many of which are loosely based on 45 degree angles as originally perfected by Harry Beck and George Dow.

## Naming conventions

Most maps use text to label places and for such things as a map title, legend and other information. Maps are often made in specific languages, though names of places often differ between languages. So a map made in English may use the name *Germany* for that country, while a German map would use *Deutschland* and a French map *Allemagne*. A word that describes a place, using a non-native terminology or language is referred to as an exonym.

In some cases the proper name is not clear. For example, the nation of Burma officially changed its name to Myanmar, but many nations do not recognize the ruling junta and continue to use *Burma*. Sometimes an official name change is resisted in other languages and the older name

may remain in common use. Examples include the use of *Saigon* for Ho Chi Minh City, *Bangkok* for Krung Thep and *Ivory Coast* for Côte d'Ivoire.

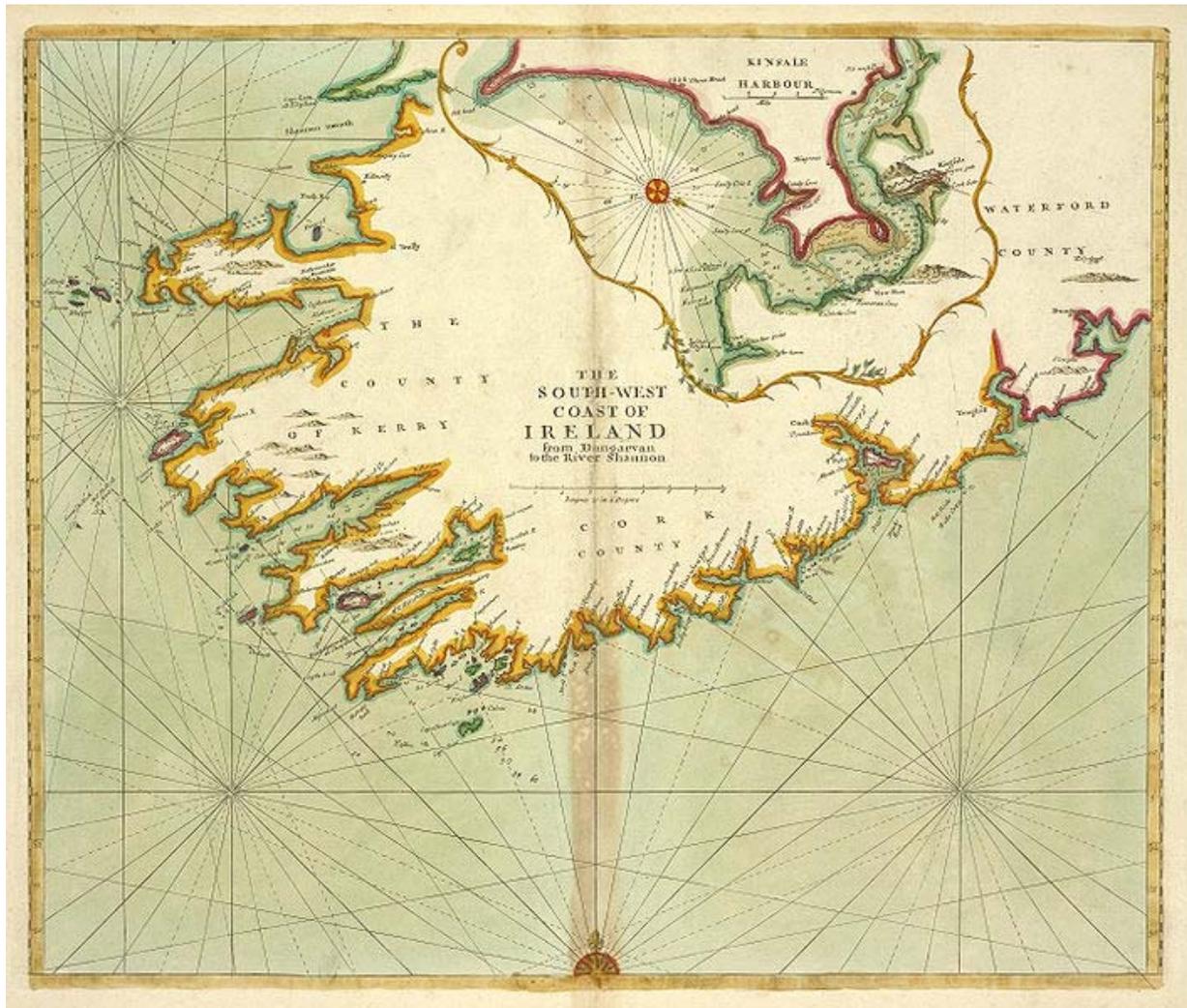
Difficulties arise, when transliteration or transcription between writing systems is required. National names tend to have well established names in other languages and writing systems, such as *Russia* for Росси́я, but for many placenames a system of transliteration or transcription is required. In transliteration, the symbols of one language are represented by symbols in another. For example, the Cyrillic letter *Р* is traditionally written as *R* in the Latin alphabet. Systems exist for transliteration of Arabic, but the results may vary. For example, the Yemeni city of Mocha is written variously in English as Mocha, Al Mukha, al-Mukhā, Mocca and Moka. Transliteration systems are based on relating written symbols to one another, while transcription is the attempt to spell in one language the phonetic sounds of another. Chinese writing is transformed into the Latin alphabet through the Pinyin phonetic transcription systems. Other systems were used in the past, such as Wade-Giles, resulting in the city being spelled *Beijing* on newer English maps and *Peking* on older ones.

Further difficulties arise when countries, especially former colonies, do not have a strong national geographic naming standard. In such cases, cartographers may have to choose between various phonetic spellings of local names versus older imposed, sometimes resented, colonial names. Some countries have multiple official languages, resulting in multiple official placenames. For example, the capital of Belgium is both *Brussel* and *Bruxelles*. In Canada, English and French are official languages and places have names in both languages. British Columbia is also officially named *la Colombie-Britannique*. English maps rarely show the French names outside of Quebec, which itself is spelled *Québec* in French.

The study of placenames is called toponymy, while that of the origin and historical usage of placenames as words is etymology.

In order to improve legibility or to aid the illiterate, some maps have been produced using pictograms to represent places. The iconic example of this practice is Lance Wyman's early plans for the Mexico City Metro, on which stations were shown simply as stylized logos. Wyman also prototyped such a map for the Washington Metro, though ultimately the idea was rejected. Other cities experimenting with such maps are Fukuoka, Guadalajara and Monterrey.

## Map symbology



A map of the southwest coast of Ireland created in the early 18th century. Notice the north arrow at the bottom of the map. Also, colors are used in the map to distinguish different geographical areas.

The quality of a map's design affects its reader's ability to extract information and to learn from the map. Cartographic symbology has been developed in an effort to portray the world accurately and effectively convey information to the map reader. A legend explains the pictorial language of the map, known as its symbology. The title indicates the region the map portrays; the map image portrays the region and so on. Although every map element serves some purpose, convention only dictates inclusion of some elements, while others are considered optional. A menu of map elements includes the neatline (border), compass rose or north arrow, overview map, bar scale, projection and information about the map sources, accuracy and publication.

When examining a landscape, scale can be intuited from trees, houses and cars. Not so with a map. Even such a simple thing as a north arrow is crucial. It may seem obvious that the top of a map should point north, but this might not be the case.

Color, likewise, is equally important. How the cartographer displays the data in different hues can greatly affect the understanding or feel of the map. Different intensities of hue portray different objectives the cartographer is attempting to get across to the audience. Today, personal computers can display up to 16 million distinct colors at a time (Jeer, 1997). This fact allows for a multitude of color options for even for the most demanding maps. Moreover, computers can easily hatch patterns in colors to give even more options. This is very beneficial, when symbolizing data in categories such as quintile and equal interval classifications.

Quantitative symbols give a visual measure of the relative size/importance/number that a symbol represents and to symbolize this data on a map, there are two major classes of symbols used for portraying quantitative properties. Proportional symbols change their visual weight according to a quantitative property. These are appropriate for extensive statistics. Choropleth maps portray data collection areas, such as counties or census tracts, with color. Using color this way, the darkness and intensity (or value) of the color is evaluated by the eye as a measure of intensity or concentration (Harvard Graduate School of Design, 2005).

## **Map generalization**

A good map has to provide a compromise between portraying the items of interest (or themes) in the *right place* for the map scale used, against the need to annotate that item with text or a symbol, which takes up space on the map medium and very likely will cause some other item of interest to be displaced. The cartographer is thus constantly making judgements about what to include, what to leave out and what to show in a *slightly* incorrect place - because of the demands of the annotation. This issue assumes more importance as the scale of the map gets smaller (i.e. the map shows a larger area), because relatively, the annotation on the map takes up more space *on the ground*. A good example from the late 1980s was the Ordnance Survey's first digital maps, where the *absolute* positions of major roads shown at scales of 1:1250 and 1:2500 were sometimes a scale distance of hundreds of metres away from ground truth, when shown on digital maps at scales of 1:250000 and 1:625000, because of the overriding need to annotate the features.

## **Cartographic errors**

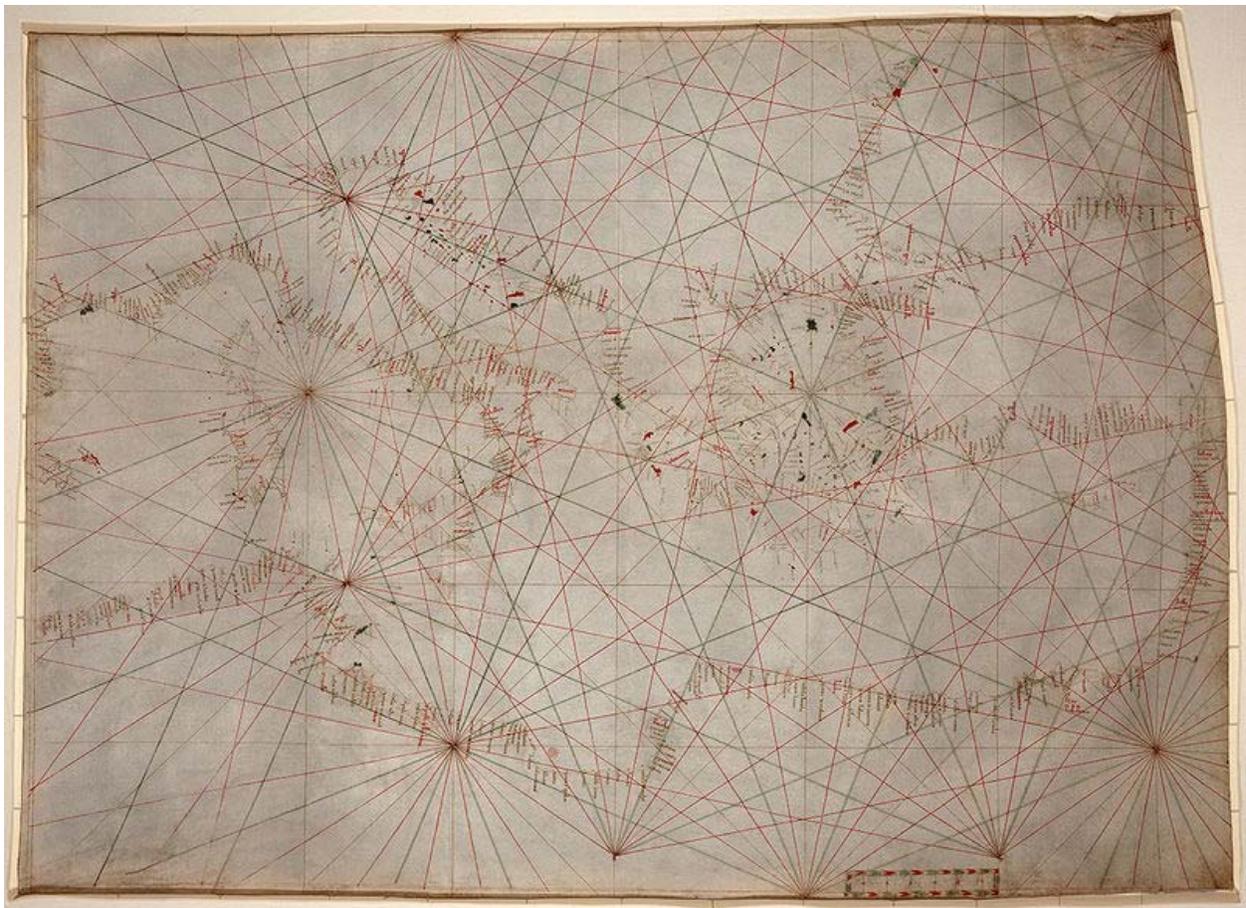
Some maps contain deliberate errors or distortions, either as propaganda or as a "watermark" helping the copyright owner identify infringement if the error appears in competitors' maps. The latter often come in the form of nonexistent, misnamed, or misspelled "trap streets". Other names and forms for this are paper townsites, fictitious entries, and copyright easter eggs.

Another motive for deliberate errors is simply cartographic graffiti or prank: a mapmaker wishing to leave his or her mark on the work. Mount Richard, for example, was a fictitious peak on the Rocky Mountains' continental divide that appeared on a Boulder County, Colorado map in

the early 1970s. It is believed to be the work of drafts man Richard Ciacci. The fiction was not discovered until two years later.

## Chapter 1

# History of Cartography



The oldest original cartographic artifact in the Library of Congress: a nautical chart of the Mediterranean Sea - second quarter of the fourteenth century

Cartography or mapmaking, has been an integral part of the human story for a long time, possibly up to 8,000 years. From cave paintings to ancient maps of Babylon, Greece, and

Asia, through the Age of Exploration, and on into the twenty-first century, people have created and used maps as the essential tools to help them define, explain, and navigate their way through the world. According to some scholars, mapping represented a significant step forward in the intellectual development of human beings and it serves as a record of the advancement of knowledge of the human race, which could be passed from members of one generation to those that follow in the development of culture. Maps began as two dimensional drawings. Although that remains the nature of most maps, modern graphics have enabled projections beyond that.

### **Earliest known maps**

The earliest known maps are of the heavens, not the earth. Dots dating to 16,500 BCE found on the walls of the Lascaux caves map out part of the night sky, including the three bright stars Vega, Deneb, and Altair (the Summer Triangle asterism), as well as the Pleiades star cluster. The Cuevas de El Castillo in Spain contain a dot map of the Corona Borealis constellation dating from 12,000 BCE.

Cave painting and rock carvings used simple visual elements that may have aided in recognizing landscape features, such as hills or dwellings. A map-like representation of a mountain, river, valleys and routes around Pavlov in the Czech Republic has been dated to 25,000 BP, and a 14,000 BP polished chunk of sandstone from a cave in Spanish Navarre may represent similar features superimposed on animal etchings, although it may also represent a spiritual landscape, or simple incisions.

Another ancient picture that resembles a map was created in the late 7th millennium BCE in Çatalhöyük, Anatolia, modern Turkey. This wall painting may represent a plan of this Neolithic village; however, recent scholarship has questioned the identification of this painting as a map.

Whoever visualized the Çatalhöyük "mental map" may have been encouraged by the fact that houses in Çatalhöyük were clustered together and were entered via flat roofs. Therefore, it was normal for the inhabitants to view their city from a bird's eye view. Later civilizations followed the same convention; today, almost all maps are drawn as if we are looking down from the sky instead of from a horizontal or oblique perspective. The logical advantage of such a perspective is that it provides a view of a greater area, conceptually. There are exceptions: one of the "quasi-maps" of the Minoan civilization on Crete, the "House of the Admiral" wall painting, dating from c. 1600 BCE, shows a seaside community in an oblique perspective.

### **Ancient Near East**

Maps in Ancient Babylonia were made by using accurate surveying techniques.

For example, a  $7.6 \times 6.8$  cm clay tablet found in 1930 at Ga-Sur, near contemporary Kirkuk, shows a map of a river valley between two hills. Cuneiform inscriptions label the features on the map, including a plot of land described as 354 iku (12 hectares) that was owned by a person called Azala. Most scholars date the tablet to the twenty-fifth to twenty-fourth century BCE; Leo Bagrow dissents with a date of 7000 BCE. Hills are shown by overlapping semicircles, rivers by lines, and cities by circles. The map also is marked to show the cardinal directions.

An engraved map from the Kassite period (fourteenth–twelfth centuries BCE) of Babylonian history shows walls and buildings in the holy city of Nippur.

In contrast, the Babylonian World Map, the earliest surviving map of the world (c. 600 BCE), is a symbolic, not a literal representation. It deliberately omits peoples such as the Persians and Egyptians, who were well known to the Babylonians. The area shown is depicted as a circular shape surrounded by water, which fits the religious image of the world in which the Babylonians believed.

Examples of maps from ancient Egypt are quite rare, however, those that have survived show an emphasis on geometry and well developed surveying techniques, perhaps stimulated by the need to re-establish the exact boundaries of properties after the annual Nile floods. The Turin Papyrus Map, dated c. 2500 BCE, shows the mountains east of the Nile where gold and silver were mined, along with the location of the miners' shelters, wells, and the road network that linked the region with the mainland. Its originality can be seen in the map's inscriptions, its precise orientation, and the use of colour.

## **Ancient Greece**

### **Early Greek Literature**

In reviewing the literature of early geography and early conceptions of the earth, all sources lead to Homer, who is considered by many (Strabo, Kish, and Dilke) as the founding father of Geography. Regardless of the doubts about Homer's existence, one thing is certain: he never was a mapmaker. The enclosed map, which represents the conjectural view of the Homeric world, was never created by him. It is an imaginary reconstruction of the world as Homer described it in his two poems the *Iliad* and the *Odyssey*. It is worth mentioning that each of these writings involves strong geographic symbolism. They can be seen as descriptive pictures of life and warfare in the Bronze Age and the illustrated plans of real journeys. Thus, each one develops a philosophical view of the world, which makes it possible to show this information in the form of a map.

The depiction of the earth conceived by Homer, which was accepted by the early Greeks, represents a circular flat disk surrounded by a constantly moving stream of Ocean (Brown, 22), an idea which would be suggested by the appearance of the horizon as it is

seen from a mountaintop or from a seacoast. Homer's knowledge of the Earth was very limited. He and his Greek contemporaries knew very little of the earth beyond Egypt as far south as the Libyan desert, the south-west coast of Asia Minor, and the northern boundary of the Greek homeland. Furthermore, the coast of the Black Sea was only known through myths and legends that circulated during his time. In his poems there is no mention of Europe and Asia as geographical concepts (Thompson, 21), and no mention of the Phoenicians either (Thompson, 40). This seems strange if we recall that the origin of the name Oceanus, a term used by Homer in his poems, belonged to the Phoenicians (Thomson, 27). That is why the big part of Homer's world that is portrayed on this interpretive map represents lands that border on the Aegean Sea. It is worth noting that even though Greeks believed that they were in the middle of the earth, they also thought that the edges of the world's disk were inhabited by savage, monstrous barbarians and strange animals and monsters; Homer's *Odyssey* mentions a great many of them.

Additional statements about ancient geography may be found in Hesiod's poems, probably written during the eighth century BCE (Kirsh, 1). Through the lyrics of *Works and Days* and *Theogony* he shows to his contemporaries some definite geographical knowledge. He introduces the names of such rivers as Nile, Ister (Danube), the shores of the Bosphorus, and the Euxine (Black Sea), the coast of Gaul, the island of Sicily, and a few other regions and rivers (Keane, 6–7). His advanced geographical knowledge not only had predated Greek colonial expansions, but also was used in the earliest Greek world maps, produced by Greek mapmakers such as Anaximander and Hecataeus of Miletus.

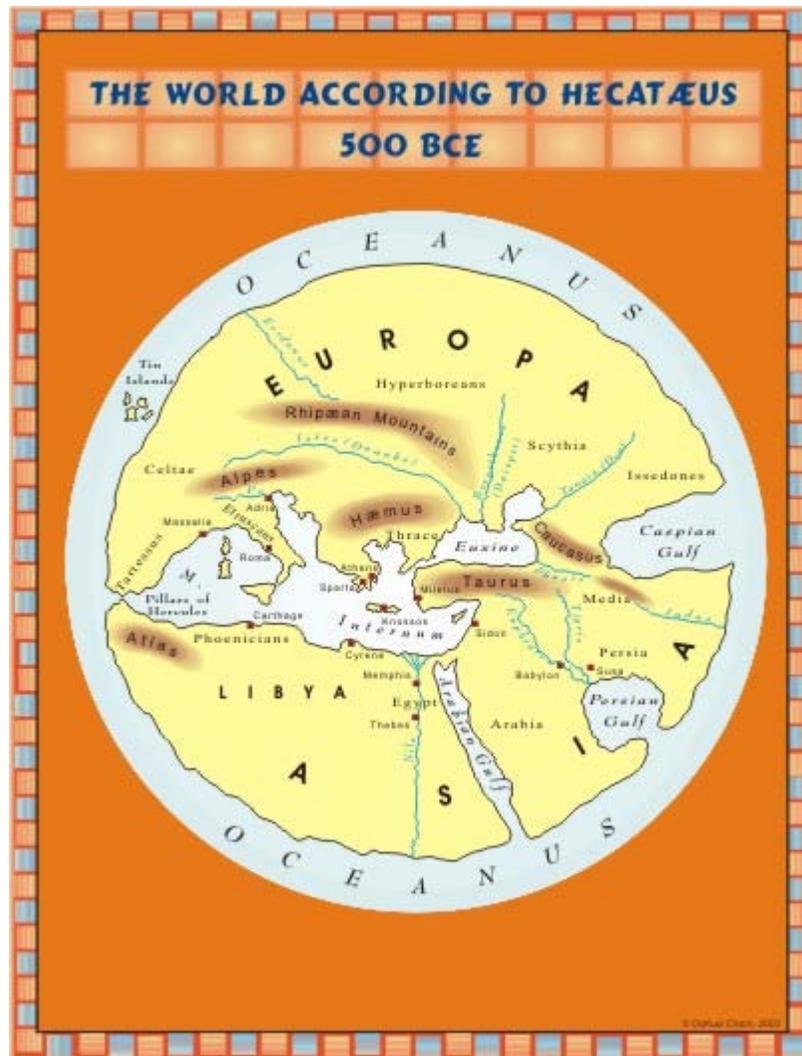
### **Early Greek maps**

In classical antiquity, maps were drawn by Anaximander, Hecataeus of Miletus, Herodotus, Eratosthenes, and Ptolemy using both observations by explorers and a mathematical approach.

Early steps in the development of intellectual thought in ancient Greece belonged to Ionians from their well-known city of Miletus in Asia Minor. Miletus was placed favourably to absorb aspects of Babylonian knowledge and to profit from the expanding commerce of the Mediterranean. The earliest ancient Greek who is said to have constructed a map of the world is Anaximander of Miletus (c. 611–546 BCE), pupil of Thales. He believed that the earth was a cylindrical form, like a stone pillar and suspended in space. The inhabited part of his world was circular, disk-shaped, and presumably located on the upper surface of the cylinder (Brown, 24).

Anaximander was the first ancient Greek to draw a map of the known world. It is for this reason that he is considered by many to be the first mapmaker (Dilke, 23). A scarcity of archaeological and written evidence prevents us from giving any assessment of his map. What we may presume is that he portrayed land and sea in a map form. Unfortunately,

any definite geographical knowledge that he included in his map is lost as well. Although the map has not survived, Hecataeus of Miletus (550–475 BCE) produced another map fifty years later that he claimed was an improved version of the map of his illustrious predecessor.

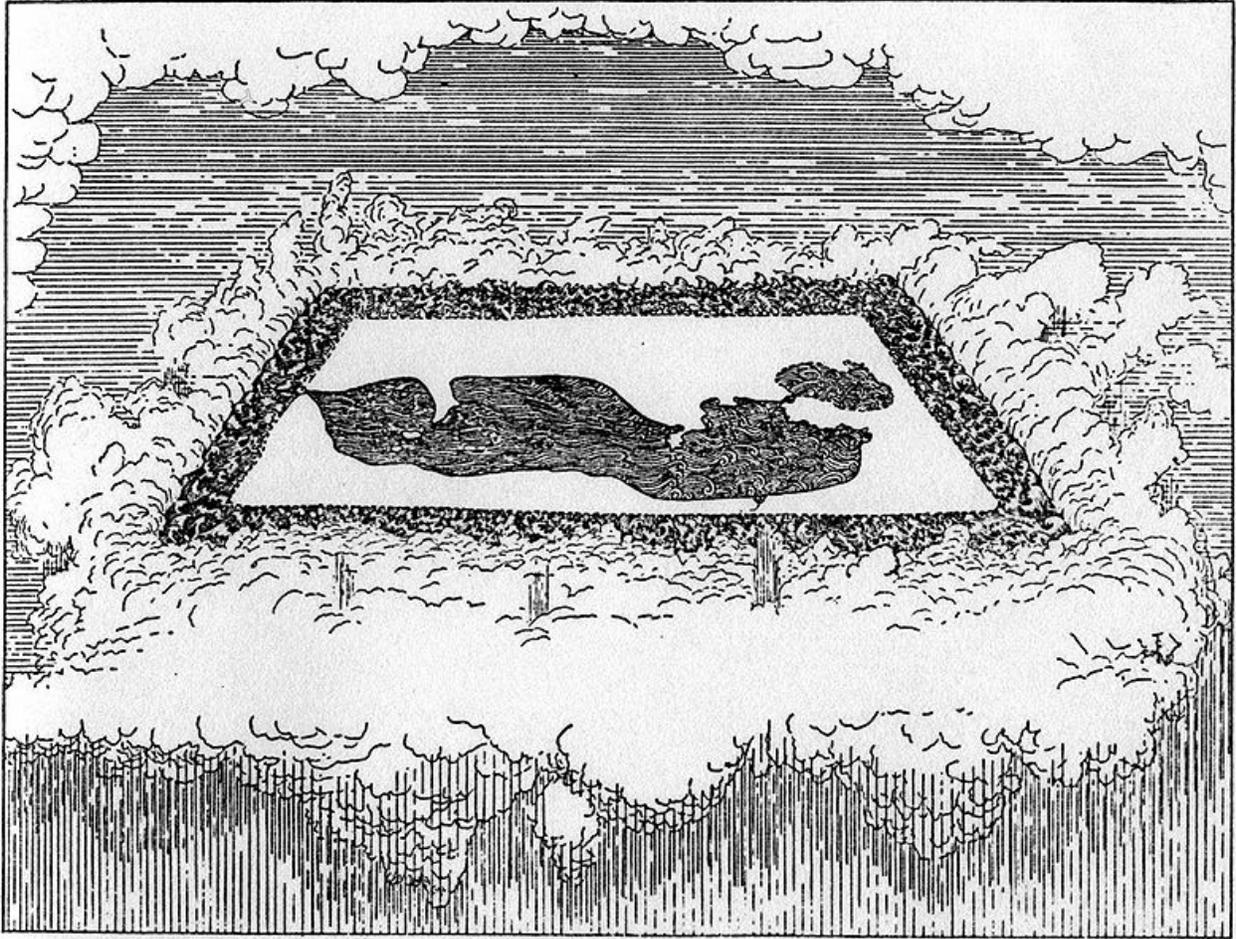


The world according to Hekataeus, 500 BCE

Hecataeus's map describes the earth as a circular plate with an encircling Ocean and Greece in the centre of the world. This was a very popular contemporary Greek worldview, derived originally from the Homeric poems. Also, similar to many other early maps in antiquity his map has no scale. As units of measurements, this map used "days of sailing" on the sea and "days of marching" on dry land (Goode, 2). The purpose of this map was to accompany Hecataeus's geographical work that was called *Periodos Ges*, or

*Journey Round the World* (Dilke, 24). *Periodos Ges* was divided into two books, "Europe" and "Asia", with the latter including Libya, the name of which was an ancient term for all of the known Africa.

The work follows the assumption of the author that the world was divided into two continents, Asia and Europe. He depicts the line between the Pillars of Hercules through the Bosphorus, and the Don River as a boundary between the two. Hecataeus is the first known writer who thought that the Caspian flows into the circumference ocean—an idea that persisted long into the Hellenic period. He was particularly informative on the Black Sea, adding many geographic places that already were known to Greeks through the colonization process. To the north of the Danube, according to Hecataeus, were the Rhipæan (gusty) Mountains, beyond which lived the Hyperboreans—peoples of the far north. Hecataeus depicted the origin of the Nile River at the southern circumference ocean. His view of the Nile seems to have been that it came from the southern circumference ocean. This assumption helped Hecataeus solve the mystery of the annual flooding of the Nile. He believed that the waves of the ocean were a primary cause of this occurrence (Tozer, 63). It is worth mentioning that a similar map based upon one designed by Hecataeus was intended to aid political decision-making. According to Herodotus, it was engraved upon a bronze tablet and was carried to Sparta by Aristagoras during the revolt of the Ionian cities against Persian rule from 499 to 494 BCE.



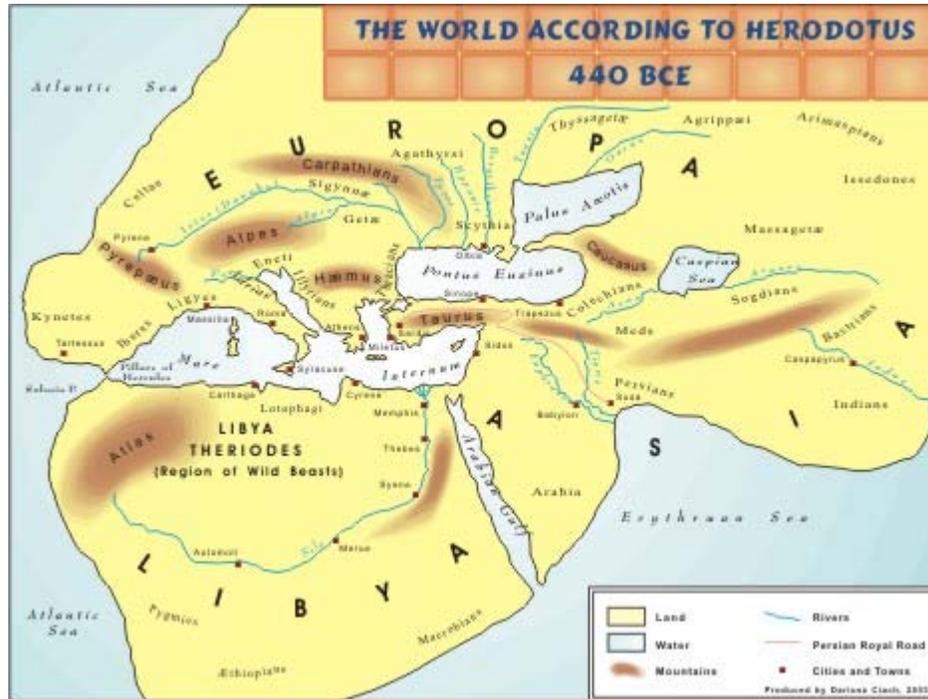
The world according to Anaximenes, c. 500 BCE

Anaximenes of Miletus (6th century BCE), who studied under Anaximander, rejected the views of his teacher regarding the shape of the earth and instead, he visualized the earth as a rectangular form supported by compressed air.

Pythagoras of Samos (c. 560–480 BCE) speculated about the notion of a spherical earth with a central fire at its core. He is also credited with the introduction of a model that divides a spherical earth into five zones. One hot, two temperate, and two cold—northern and southern. It seems likely that he illustrated his division in the form of a map, however, no evidence of this has survived to the present.

Scylax, a sailor, made a record of his Mediterranean voyages in c. 515 BCE. This is the earliest known set of Greek periploi, or sailing instructions, which became the basis for many future mapmakers, especially in the medieval period.

The way in which the geographical knowledge of the Greeks advanced from the previous assumptions of the Earth's shape was through Herodotus and his conceptual view of the world. This map also did not survive and many have speculated that it was never produced. A possible reconstruction of his map is displayed below.



The world according to Herodotus, 440 BCE

Herodotus traveled very extensively, collecting information and documenting his findings in his books on Europe, Asia, and Libya. He also combined his knowledge with what he learned from the people he met. Herodotus wrote his *Histories* in the mid-400s BCE. Although his work was dedicated to the story of long struggle of the Greeks with the Persian Empire, Herodotus also included everything he knew about the geography, history, and peoples of the world. Thus, his work provides a detailed picture of the known world of the fifth century BCE.

Herodotus rejected the prevailing view of most fifth century maps that the earth is a circular plate surrounded by Ocean. In his work he describes the earth as an irregular shape with oceans surrounding only Asia and Africa. He introduces names such as the Atlantic Sea and the Erythraean Sea. He also divided the world into three continents: Europe, Asia, and Africa. He depicted the boundary of Europe as the line from the Pillars of Hercules through the Bosphorus and the area between Caspian Sea and Indus River. He regarded the Nile as the boundary between Asia and Africa. He speculated that the extent

of Europe was much greater than was assumed at the time and left Europe's shape to be determined by future research.

In the case of Africa, he believed that, except for the small stretch of land in the vicinity of Suez, the continent was in fact surrounded by water. However, he definitely disagreed with his predecessors and contemporaries about its presumed circular shape. He based his theory on the story of Pharaoh Necho II, the ruler of Egypt between 609 and 594 BCE, who had sent Phoenicians to circumnavigate Africa. Apparently, it took them three years, but they certainly did prove his idea. He speculated that the Nile River started as far west as the Ister River in Europe and cut Africa through the middle. He was the first writer to assume that the Caspian Sea was separated from other seas and he recognised northern Scythia as one of the coldest inhabited lands in the world.

Similar to his predecessors, Herodotus also made mistakes. He accepted a clear distinction between the civilized Greeks in the centre of the earth and the barbarians on the world's edges. In his *Histories* we can see very clearly that he believed that the world became stranger and stranger when one traveled away from Greece, until one reached the ends of the earth, where humans behaved as savages.

### **Spherical Earth and Meridians**

Whereas a number of previous Greek philosophers presumed the earth to be spherical, Aristotle (384–322 BCE) is the one to be credited with proving the Earth's sphericity. Those arguments may be summarized as follows:

- The lunar eclipse is always circular
- Ships seem to sink as they move away from view and pass the horizon
- Some stars can be seen only from certain parts of the Earth.

A vital contribution to mapping the reality of the world came with a scientific estimate of the circumference of the earth. This event has been described as the first scientific attempt to give geographical studies a mathematical basis. The man credited for this achievement was Eratosthenes (275–195 BCE). As described by George Sarton, historian of science, “there was among them [Eratosthenes's contemporaries] a man of genius but as he was working in a new field they were too stupid to recognize him” (Noble, 27). His work, including *On the Measurement of the Earth* and *Geographica*, has only survived in the writings of later philosophers such as Cleomedes and Strabo. He was a devoted geographer who set out to reform and perfect the map of the world. Eratosthenes argued that accurate mapping, even if in two dimensions only, depends upon the establishment of accurate linear measurements. He was able to calculate the circumference of the Earth within 0.5 percent accuracy by calculating the heights of shadows on different parts of the Egypt at a given time. The first in Alexandria, the other further up the Nile, where reports of a well into which the sun shone only at midsummer, long existed. Proximity to

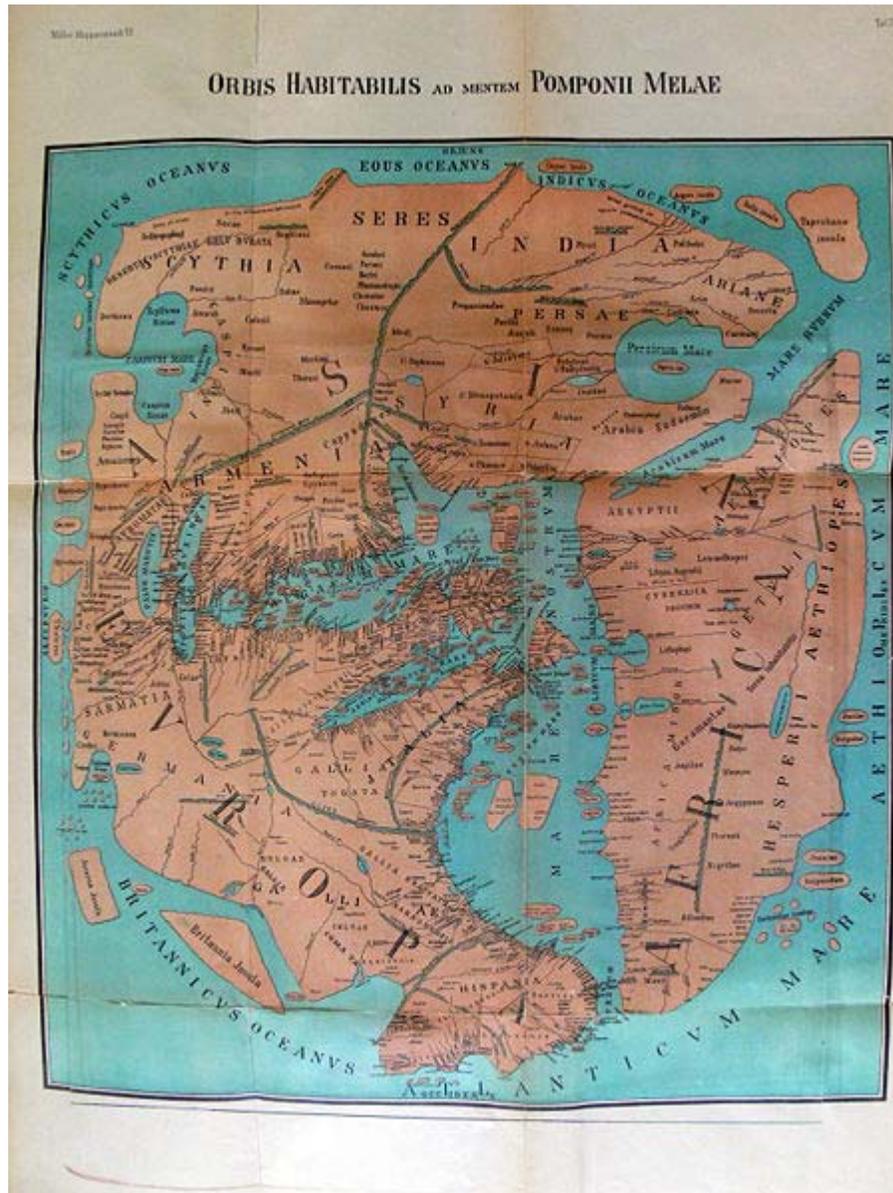
the equator being the dynamics creating the effect. He had the distance between the two shadows calculated and then their height. From this he determined the difference in angle between the two points and calculated how large a circle would be made by adding in the rest of the degrees to 360. His great achievement in the field of cartography was the use of a new technique of charting with meridians, his imaginary north–south lines, and parallels, his imaginary west–east lines. These axis lines were placed over the map of the earth with their origin in the city of Rhodes and divided the world into sectors. Then, Eratosthenes used these earth partitions to reference places on the map. He also was the first person to divide Earth correctly into five climatic regions: a torrid zone across the middle, two frigid zones at extreme north and south, and two temperate bands in between. He was also the first person to use the word "geography".

Claudius Ptolemy (90–168 CE) thought that, with the aid of astronomy and mathematics, the earth could be mapped very accurately. Ptolemy revolutionized the depiction of the spherical earth on a map by using perspective projection, and suggested precise methods for fixing the position of geographic features on its surface using a coordinate system with parallels of latitude and meridians of longitude.

Ptolemy's eight-volume atlas *Geographia* is a prototype of modern mapping and GIS. It included an index of place-names, with the latitude and longitude of each place to guide the search, scale, conventional signs with legends, and the practice of orienting maps so that north is at the top and east to the right of the map—a universal custom today.

Yet with all his important innovations, however, Ptolemy was not infallible. His most important error was a miscalculation of the circumference of the earth. He believed that Eurasia covered 180° of the globe, which convinced Christopher Columbus to sail across the Atlantic to look for a simpler and faster way to travel to India. Had Columbus known that the true figure was much greater, it is conceivable that he would never have set out on his momentous voyage.

## Roman Empire



Reconstruction of Pomponius Mela's world view.

### Pomponius Mela (c.43 AD)

Pomponius is unique among ancient geographers in that, after dividing the earth into five zones, of which two only were habitable, he asserts the existence of antichthon, inhabiting the southern temperate zone inaccessible to the folk of the northern temperate regions from the unbearable heat of the intervening torrid belt. On the divisions and

boundaries of Europe, Asia and Africa, he repeats Eratosthenes; like all classical geographers from Alexander the Great (except Ptolemy) he regards the Caspian Sea as an inlet of the Northern Ocean, corresponding to the Persian and Arabian (Red Sea) gulfs on the south.



The roman Tabula Peutingeriana.

## **5th century Roman road map**

In 2007, the Tabula Peutingeriana, a 12th century replica of a 5th century map, was placed on the UNESCO Memory of the World Register and displayed to the public for the first time. Although well preserved and believed to be an accurate copy of an authentic original, the scroll media it is on is so delicate now it must be protected at all times from exposure to daylight.

## **China**

### **Earliest extant maps from the Qin State**

The earliest known maps to have survived in China date to the 4th century BCE. In 1986, seven ancient Chinese maps were found in an archeological excavation of a Qin State tomb in what is now Fangmatian, Dangchuan Xian, in the vicinity of Tianshui City, Gansu province. Before this find, the earliest extant maps that were known came from the Mawangdui excavation in 1973, which found three maps on silk dated to the 2nd century BCE in the early Han Dynasty. The 4th century BCE maps from the State of Qin were drawn with black ink on wooden blocks. These blocks fortunately survived in soaking conditions due to underground water that had seeped into the tomb; the quality of the wood had much to do with their survival. After two years of slow-drying techniques, the maps were fully restored.

The territory shown in the seven Qin maps overlap each other. The maps display tributary river systems of the Jialing River in Sichuan province, in a total measured area of 107 by 68 km. The maps featured rectangular symbols encasing character names for the locations of administrative counties. Rivers and roads are displayed with similar line symbols; this makes interpreting the map somewhat difficult, although the labels of rivers placed in order of stream flow are helpful to modern day cartographers. These maps also feature locations where different types of timber can be gathered, while two of the maps state the distances in mileage to the timber sites. In light of this, these maps are perhaps the oldest economic maps in the world since they predate Strabo's economic maps.

### **Earliest geographical writing**

In China, the earliest known geographical Chinese writing dates back to the 5th century BCE, during the beginning of the Warring States (481–221 BCE). This was the 'Yu Gong' ('Tribute of Yu') chapter of the book *Shu Jing (Classic of History)*. The book describes the traditional nine provinces, their kinds of soil, their characteristic products and economic goods, their tributary goods, their trades and vocations, their state revenues and agricultural systems, and the various rivers and lakes listed and placed accordingly. The nine provinces in the time of this geographical work was very small in terrain size compared to what modern China occupies today. In fact, its description pertained to areas

of the Yellow River, the lower valleys of the Yangtze, with the plain between them and the Shandong Peninsula, and to the west the most northern parts of the Wei River and the Han River were known (along with the southern parts of modern day Shanxi province).

### **Earliest known reference to a map, or 'tu'**

The oldest reference to a map in China comes from the 3rd century BCE. This was the event of 227 BCE where Crown Prince Dan of Yan had his assassin Jing Ke visit the court of the ruler of the State of Qin, who would become Qin Shi Huang (r. 221–210 BCE). Jing Ke was to present the ruler of Qin with a district map painted on a silk scroll, rolled up and held in a case where he hid his assassin's dagger. Handing to him the map of the designated territory was the first diplomatic act of submitting that district to Qin rule. Instead he attempted to kill Qin, an assassination plot that failed. From then on maps are frequently mentioned in Chinese sources.

## Han Dynasty and period of division



An early Western Han Dynasty (202 BC – 9 AD) silk map found in tomb 3 of Mawangdui, depicting the Kingdom of Changsha and Kingdom of Nanyue in southern China (note: the south direction is oriented at the top, north at the bottom).

The three Han Dynasty maps found at Mawangdui differ from the earlier Qin State maps. While the Qin maps place the cardinal direction of north at the top of the map, the Han maps are orientated with the southern direction at the top. The Han maps are also more complex, since they cover a much larger area, employ a large number of well-designed map symbols, and include additional information on local military sites and the local population. The Han maps also note measured distances between certain places, but a formal graduated scale and rectangular grid system for maps would not be used—or at least described in full—until the 3rd century. Among the three maps found at Mawangdui

was a small map representing the tomb area where it was found, a larger topographical map showing the Han's borders along the subordinate Kingdom of Changsha and the Nanyue kingdom (of northern Vietnam and parts of modern Guangdong and Guangxi), and a map which marks the positions of Han military garrisons that were employed in an attack against Nanyue in 181 BCE.

An early text that mentioned maps was the *Rites of Zhou*. Although attributed to the era of the Zhou Dynasty, its first recorded appearance was in the libraries of Prince Liu De (c. 130 BCE), and was compiled and commented on by Liu Xin in the 1st century CE. It outlined the use of maps that were made for governmental provinces and districts, principalities, frontier boundaries, and even pinpointed locations of ores and minerals for mining facilities. Upon the investiture of three of his sons as feudal princes in 117 BCE, Emperor Wu of Han had maps of the entire empire submitted to him.

From the 1st century CE onwards, official Chinese historical texts contained a geographical section (*Diliji*), which was often an enormous compilation of changes in place-names and local administrative divisions controlled by the ruling dynasty, descriptions of mountain ranges, river systems, taxable products, etc. From the time of the 5th century BCE *Shu Jing* forward, Chinese geographical writing provided more concrete information and less legendary element. This example can be seen in the 4th chapter of the *Huainanzi* (Book of the Master of Huainan), compiled under the editorship of Prince Liu An in 139 BCE during the Han Dynasty (202 BCE–202 CE). The chapter gave general descriptions of topography in a systematic fashion, given visual aids by the use of maps (*di tu*) due to the efforts of Liu An and his associate Zuo Wu. In Chang Chu's *Hua Yang Guo Chi* (*Historical Geography of Szechuan*) of 347 CE, not only rivers, trade routes, and various tribes were described, but it also wrote of a 'Ba Jun Tu Jing' ('Map of Szechuan'), which had been made much earlier in 150 CE.

Local mapmaking such as the one of Szechuan mentioned above, became a widespread tradition of Chinese geographical works by the 6th century, as noted in the bibliography of the *Sui Shu*. It is during this time of the Southern and Northern Dynasties that the Liang Dynasty (502–557 CE) cartographers also began carving maps into stone steles (alongside the maps already drawn and painted on paper and silk).

### **Pei Xiu, the 'Ptolemy of China'**

In the year 267, a Pei Xiu (224–271) was appointed as the Minister of Works by Emperor Wu of Jin, the first emperor of the Jin Dynasty. Pei is best known for his work in cartography. Although map making and use of the grid existed in China before him, he was the first to mention a plotted geometrical grid and graduated scale displayed on the surface of maps to gain greater accuracy in the estimated distance between different locations. Pei outlined six principles that should be observed when creating maps, two of which included the rectangular grid and the graduated scale for measuring distance.

Historians compare him to the Greek Ptolemy for his contributions in cartography. However, Howard Nelson states that, although the accounts of earlier cartographic works by the inventor and official Zhang Heng (78–139) are somewhat vague and sketchy, there is ample written evidence that Pei Xiu derived the use of the rectangular grid reference from the maps of Zhang Heng. Robert Temple also asserts that Zhang created a mathematical reference grid for maps before Pei Xiu.

Later Chinese ideas about the quality of maps made during the Han Dynasty and before stem from the assessment given by Pei Xiu, which was not a positive one. Pei Xiu noted that the extant Han maps at his disposal were of little use since they featured too many inaccuracies and exaggerations in measured distance between locations. However, the Qin State maps and Mawangdui maps of the Han era were far superior in quality than those examined by Pei Xiu. It was not until the 20th century that Pei Xiu's 3rd century assessment of earlier maps' dismal quality would be overturned and disproven. The Qin and Han maps did have a degree of accuracy in scale and pinpointed location, but the major improvement in Pei Xiu's work and that of his contemporaries was expressing topographical elevation on maps.

### **Sui and Tang dynasties**

In the year 605, during the Sui Dynasty (581–618), the Commercial Commissioner Pei Ju (547–627) created a famous geometrically gridded map. In 610 CE Emperor Yang of Sui ordered government officials from throughout the empire to document in gazetteers the customs, products, and geographical features of their local areas and provinces, providing descriptive writing and drawing them all onto separate maps, which would be sent to the imperial secretariat in the capital city.

The Tang Dynasty (618–907) also had its fair share of cartographers, including the works of Xu Jingzong in 658 CE, Wang Mingyuan in 661 CE, and Wang Zhongsi in 747 CE. Arguably the greatest geographer and cartographer of the Tang period was Jia Dan (730–805), whom Emperor Dezong of Tang entrusted in 785 to complete a map of China with her recently former inland colonies of Central Asia, the massive and detailed work completed in 801 CE, called the *Hai Nei Hua Yi Tu* (Map of both Chinese and Barbarian Peoples within the (Four) Seas). The map was 30 ft long (9.1 m) and 33 ft high (10 m) in dimension, mapped out on a grid scale of 1-inch (25 mm) equaling 100 li (unit) (the Chinese equivalent of the mile/kilometer). Jia Dan is also known for having described the Persian Gulf region with great detail, along with lighthouses that were erected at the mouth of the Persian Gulf by the medieval Iranians in the Abbasid period (refer to article on Tang Dynasty for more).

## Song Dynasty

During the Song Dynasty (960–1279 CE) Emperor Taizu of Song ordered Lu Duosun in 971 CE to update and 're-write all the Tu Jing in the world', which would seem to be a daunting task for one individual, who was sent out throughout the provinces to collect texts and as much data as possible. With the aid of Song Zhun, the massive work was completed in 1010 CE, with some 1566 chapters. The later *Song Shi* historical text stated (Wade-Giles spelling):

“ Yuan Hsieh (d. +1220) was Director-General of governmental grain stores. In pursuance of his schemes for the relief of famines he issued orders that each pao (village) should prepare a map which would show the fields and mountains, the rivers and the roads in fullest detail. The maps of all the pao were joined together to make a map of the tu (larger district), and these in turn were joined with others to make a map of the hsiang and the hsien (still larger districts). If there was any trouble about the collection of taxes or the distribution of grain, or if the question of chasing robbers and bandits arose, the provincial officials could readily carry out their duties by the aid of the maps. ”



The *Yu Ji Tu*, or *Map of the Tracks of Yu Gong*, carved into stone in 1137, located in the Stele Forest of Xian. This 3 ft (0.91 m) squared map features a graduated scale of 100 li for each rectangular grid. China's coastline and river systems are clearly defined and precisely pinpointed on the map. Yu Gong is in reference to the Chinese deity described in the geographical chapter of the *Classic of History*, dated 5th century BCE.

Like the earlier Liang Dynasty stone-stele maps (mentioned above), there were large and intricately carved stone stele maps of the Song period. For example, the 3 ft (0.91 m) squared stone stele map of an anonymous artist in 1137 CE, following the grid scale of

100 li squared for each grid square. What is truly remarkable about this map is the incredibly precise detail of coastal outlines and river systems in China (refer to Needham's Volume 3, Plate LXXXI for an image). The map shows 500 settlements and a dozen rivers in China, and extends as far as Korea and India. On the reverse, a copy of a more ancient map uses grid coordinates in a scale of 1:1,500,000 and shows the coastline of China with great accuracy.

The famous 11th century scientist and polymath statesman Shen Kuo (1031–1095) was also a geographer and cartographer. His largest atlas included twenty three maps of China and foreign regions that were drawn at a uniform scale of 1:900,000. Shen also created a three dimensional raised-relief map using sawdust, wood, beeswax, and wheat paste, while representing the topography and specific locations of a frontier region to the imperial court. Shen Kuo's contemporary, Su Song (1020–1101), was a cartographer who created detailed maps in order to resolve a territorial border dispute between the Song Dynasty and the Liao Dynasty.

### **Ming and Qing dynasties**

The Da Ming hunyi tu map, dating from about 1390, is in multicolour. The horizontal scale is 1:820,000 and the vertical scale is 1:1,060,000.

In 1579, Luo Hongxian published the Guang Yutu atlas, including more than 40 maps, a grid system, and a systematic way of representing major landmarks such as mountains, rivers, roads and borders. The Guang Yutu incorporates the discoveries of naval explorer Zheng He's 15th century voyages along the coasts of China, Southeast Asia, India and Africa.

From the 16th and 17th centuries, several examples survive of maps focused on cultural information. Gridlines are not used on either Yu Shi's Gujin xingsheng zhi tu (1555) or Zhang Huang's Tushu bian (1613); instead, illustrations and annotations show mythical places, exotic foreign peoples, administrative changes and the deeds of historic and legendary heroes. Also in the 17th century, an edition of a possible Tang Dynasty map shows clear topographical contour lines. Although topographic features were part of maps in China for centuries, a Fujian county official Ye Chunji (1532–1595) was the first to base county maps using on-site topographical surveying and observations.

The Korean made Kangnido based on two Chinese maps, which describes the Old World.

### **Mongol Empire**

In the Mongol Empire, the Mongol scholars with the Persian and Chinese cartographers or their foreign colleagues created maps, geographical compendium as well as travel accounts. Rashid-al-Din Hamadani described his geographical compendium, "Suvar al-

aqalim", constituted volume four of the Collected chronicles of the Ilkhanate in Persia. His works says about the borders of the seven climes (old world), rivers, major cities, places, climate, and Mongol yams (relay stations). The Great Khan Khubilai's ambassador and minister, Bolad, had helped Rashid's works in relation to the Mongols and Greater Mongolia proper. Thanks to Pax Mongolica, the easterners and the westerners in Mongol dominions were able to gain access to one another's geographical materials.

The Mongols required the nations they conquered to send geographical maps to the Mongol headqarter.

One of medieval Persian work written in northwest Iran can clarify the historical geography of Mongolia where Genghis Khan was born and united the Mongol and Turkic nomads as recorded in native sources, especially the Secret History of the Mongols.

Map of relay stations, called "yam", and strategic points existed in the Yuan Dynasty. The Mongol cartography was enriched by traditions of ancient China and Iran which were now under the Mongols.

Because the Qaghan's (Great Khan) court often requested other three Mongol khanates to send their maps, the Empire of the Great Khan was able to publish a map describing the whole Mongol world in c.1330. This is called "Hsi-pei pi ti-li tu". The map includes the Mongol dominions including 30 cities in Iran such as Ispahan and the Ilkhanid capital Soltaniyeh, and Russia (as "Orash") as well as their neighbors, e.g. Egypt and Syria.

## **India**



The pundit (explorer) cartographer Nain Singh Rawat (19th century CE) received a Royal Geographical Society gold medal in 1876.

Early forms of cartography in India included legendary paintings; maps of locations described in Indian epic poetry, for example the *Ramayana*. These works contained descriptions of legendary places, and often even described the nature of the mythological inhabitants of a particular location.

The Indians made maps related to both their holy scriptures, the Puranas, and for astronomy. Indian cartographic traditions also covered the locations of the Pole star, and other constellations of use. These charts may have been in use by the beginning of the Common Era for purposes of navigation.

Detailed maps of considerable length describing the locations of settlements, sea shores, rivers, and mountains were also made. The 8th century scholar *Bhavabhuti* conceived paintings which indicated geographical regions.

European scholar Francesco I reproduced a number of ancient Indian maps in his magnum opus *La Cartografia Antica dell India*. Out these maps, two have been reproduced using a manuscript of *Lokaprakasa*, originally compiled by the polymath Ksemendra (Kashmir, 11th century CE), as a source. The other manuscript, used as a source by Francesco I, is titled *Samgrahani*. The early volumes of the *Encyclopedia Britannica* also described cartographic charts made by the Dravidian people of India.

Maps from the *Ain-e-Akbari*, a Mughal document detailing India's history and traditions, contain references to locations indicated in earlier Indian cartographic traditions. Another map describing the kingdom of Nepal, four feet in length and about two and a half feet in breadth, was presented to Warren Hastings. In this map the mountains were elevated above the surface, and several geographical elements were indicated in different colors.

### **Islamic cartography**

In the Middle Ages, Muslim scholars continued and advanced on the mapmaking traditions of earlier cultures. Most used Ptolemy's methods; but they also took advantage of what explorers and merchants learned in their travels across the Muslim world, from Spain to India to Africa, and beyond in trade relationships with China, and Russia.

An important influence in the development of cartography was the patronage of the Abbasid caliph, al-Ma'mun, who reigned from 813 to 833. He commissioned several geographers to remeasure the distance on earth that corresponds to one degree of celestial meridian. Thus his patronage resulted in the refinement of the definition of the mile used by Arabs (*mīl* in Arabic) in comparison to the *stadion* used by Greeks. These efforts also enabled Muslims to calculate the circumference of the earth. Al-Mamun also commanded the production of a large map of the world, which has not survived, though it is known that its map projection type was based on Marinus of Tyre rather than Ptolemy.

Also in the 9th century, the Persian mathematician and geographer, Habash al-Hasib al-Marwazi, employed the use spherical trigonometry and map projection methods in order to convert polar coordinates to a different coordinate system centred on a specific point on the sphere, in this the Qibla, the direction to Mecca. Abū Rayhān Bīrūnī (973–1048) later developed ideas which are seen as an anticipation of the polar coordinate system. Around 1025 CE, he describes a polar equi-azimuthal equidistant projection of the celestial sphere. However, this type of projection had been used in ancient Egyptian star-maps and was not to be fully developed until the 15 and 16th centuries.

In the early tenth century, Abū Zayd al-Balkhī, originally from Balkh, founded the "Balkhī school" of terrestrial mapping in Baghdad. The geographers of this school also wrote extensively of the peoples, products, and customs of areas in the Muslim world, with little interest in the non-Muslim realms. The "Balkhī school", which included geographers such as Estakhri, al-Muqaddasi and Ibn Hawqal, produced world atlases, each one featuring a world map and twenty regional maps.

Suhrāb, a late tenth century Muslim geographer, accompanied a book of geographical coordinates with instructions for making a rectangular world map, with equirectangular projection or cylindrical cylindrical equidistant projection. The earliest surviving rectangular coordinate map is dated to the 13th century and is attributed to Hamdallah al-Mustaḡfi al-Qazwini, who based it on the work of Suhrāb. The orthogonal parallel lines were separated by one degree intervals, and the map was limited to Southwest Asia and Central Asia. The earliest surviving world maps based on a rectangular coordinate grid are attributed to al-Mustawfi in the 14th or 15th century (who used intervals of ten degrees for the lines), and to Hafiz-i-Abri (d. 1430).

Ibn Battuta (1304–1368?) wrote "Rihlah" (Travels) based on three decades of journeys, covering more than 120,000 km through northern Africa, southern Europe, and much of Asia.

### **Regional cartography**

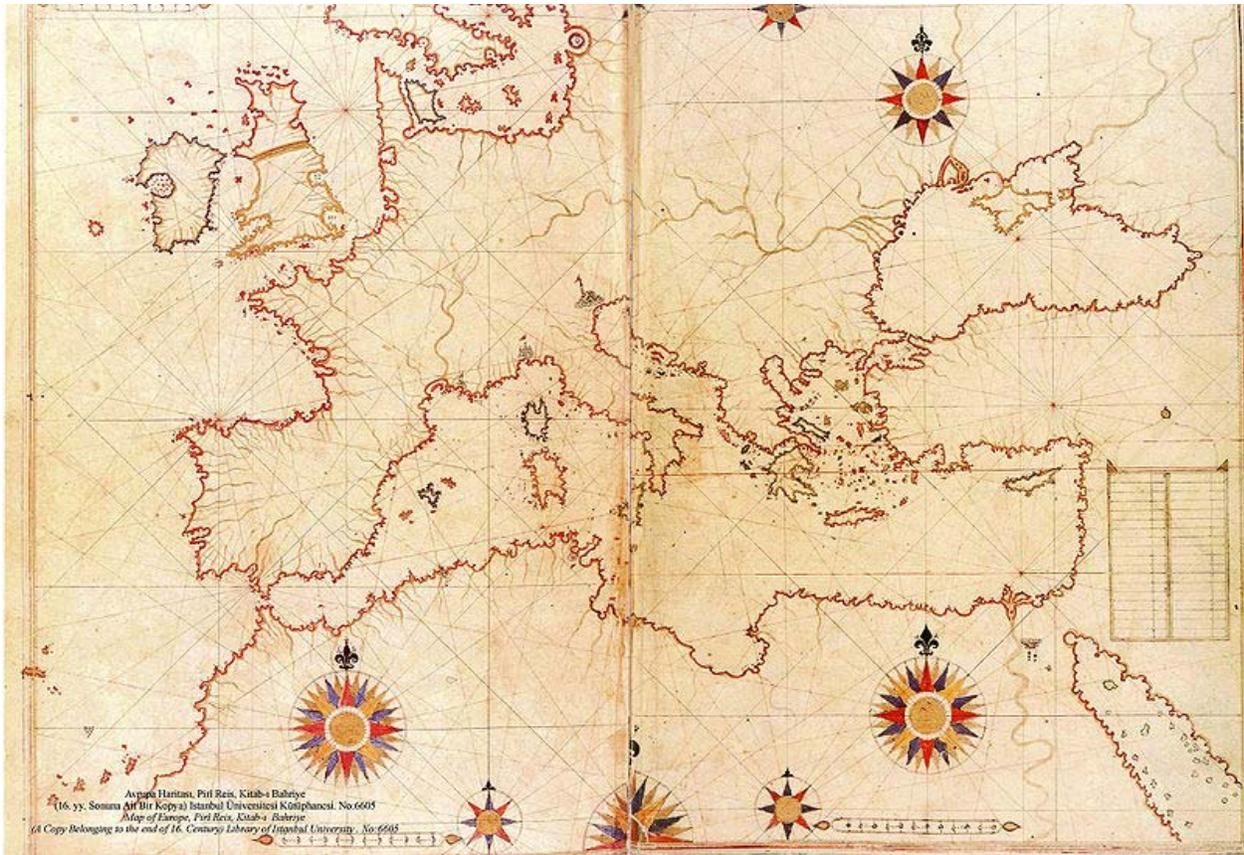
Islamic regional cartography is usually categorized into three groups: that produced by the "Balkhī school", the type devised by Muhammad al-Idrisi, and the type that are uniquely found in the *Book of curiosities*.

The maps by the Balkhī schools were defined by political, not longitudinal boundaries and covered only the Muslim world. In these maps the distances between various "stops" (cities or rivers) were equalized. The only shapes used in designs were verticals, horizontals, 90-degree angles, and arcs of circles; unnecessary geographical details was eliminated. This approach is similar to that used in subway maps, most notable used in the "London Underground Tube Map" in 1931 by Harry Beck.

Al-Idrīsī defined his maps differently. He considered the extent of the known world to be 160° in longitude, and divided the region into ten parts, each 16° wide. In terms of latitude, he portioned the known world into seven 'climes', determined by the length of the longest day. In his maps, many dominant geographical features can be found.



The *Tabula Rogeriana*, drawn by Muhammad al-Idrisi for Roger II of Sicily in 1154. Note that the north is at the bottom, and so the map appears "upside down" compared to modern cartographic conventions.



Part of the Piri Reis map (1513) showing Europe and the Mediterranean Basin.



Surviving fragment of the first World Map of Piri Reis (1513) showing parts of the Americas.

***Book on the appearance of the Earth***

Muhammad ibn Mūsā al-Khwārizmī's *Kitāb ṣūrat al-Arḍ* ("Book on the appearance of the Earth") was completed in 833. It is a revised and completed version of Ptolemy's *Geography*, consisting of a list of 2402 coordinates of cities and other geographical features following a general introduction.

Al-Khwārizmī, Al-Ma'mun's most famous geographer, corrected Ptolemy's gross overestimate for the length of the Mediterranean Sea (from the Canary Islands to the eastern shores of the Mediterranean); Ptolemy overestimated it at 63 degrees of longitude, while al-Khwarizmi almost correctly estimated it at nearly 50 degrees of longitude. Al-Ma'mun's geographers "also depicted the Atlantic and Indian Oceans as open bodies of water, not land-locked seas as Ptolemy had done." Al-Khwarizmi thus set the Prime Meridian of the Old World at the eastern shore of the Mediterranean, 10–13 degrees to the east of Alexandria (the prime meridian previously set by Ptolemy) and 70 degrees to the west of Baghdad. Most medieval Muslim geographers continued to use al-Khwarizmi's prime meridian. Other prime meridians used were set by Abū Muhammad al-Hasan al-Hamdānī and Habash al-Hasib al-Marwazi at Ujjain, a centre of Indian astronomy, and by another anonymous writer at Basra.

### ***Tabula Rogeriana***

The Arab geographer, Muhammad al-Idrisi, produced his medieval atlas, *Tabula Rogeriana* or *The Recreation for Him Who Wishes to Travel Through the Countries*, in 1154. He incorporated the knowledge of Africa, the Indian Ocean and the Far East gathered by Arab merchants and explorers with the information inherited from the classical geographers to create the most accurate map of the world in pre-modern times. With funding from Roger II of Sicily (1097–1154), al-Idrisi drew on the knowledge collected at the University of Cordoba and paid draftsmen to make journeys and map their routes. The book describes the earth as a sphere with a circumference of 22,900 miles (36,900 km) but maps it in 70 rectangular sections. Notable features include the correct dual sources of the Nile, the coast of Ghana and mentions of Norway. Climate zones were a chief organizational principle. A second and shortened copy from 1192 called *Garden of Joys* is known by scholars as the *Little Idrisi*.

On the work of al-Idrisi, S. P. Scott commented:

"The compilation of Edrisi marks an era in the history of science. Not only is its historical information most interesting and valuable, but its descriptions of many parts of the earth are still authoritative. For three centuries geographers copied his maps without alteration. The relative position of the lakes which form the Nile, as delineated in his work, does not differ greatly from that established by Baker and Stanley more than seven hundred years afterwards, and their number is the same. The mechanical genius of the author was not inferior to his erudition. The celestial and terrestrial planisphere of silver which he constructed for his royal patron was nearly six feet in diameter, and weighed four hundred and fifty pounds; upon the one side the zodiac and the constellations, upon the other—divided for convenience into segments—the bodies of land and water, with the respective situations of the various countries, were engraved."

## **Piri Reis map**

The Ottoman cartographer Piri Reis published navigational maps in his *Kitab-ı Bahriye*. The work includes an atlas of charts for small segments of the mediterranean, accompanied by sailing instructions covering the sea. In the second version of the work, he included a map of the Americas. The Piri Reis map drawn by the Ottoman cartographer Piri Reis in 1513, is the oldest surviving map to show the Americas. His map of the world was considered the most accurate in the 16th century.

## **Pacific Islands**

The Polynesian peoples who explored and settled the Pacific islands in the first two millenniums AD used maps to navigate across large distances. A surviving map from the Marshall Islands uses sticks tied in a grid with palm strips representing wave and wind patterns, with shells attached to show the location of islands. Other maps were created as needed using temporary arrangements of stones or shells.

## **European cartography**



The Gough Map, a road map of 14th century Britain

## Medieval maps and the Mappa Mundi

Medieval maps in Europe were mainly symbolic in form along the lines of the much earlier Babylonian World Map. Known as Mappa Mundi (cloth of the world) these maps were circular or symmetrical cosmological diagrams representing the Earth's single land mass as disk-shaped and surrounded by ocean.

Roger Bacon's investigations of map projections and the appearance of portolano and then portolan charts for plying the European trade routes were rare innovations of the period. The *Carta Pisana* portolan chart, made at the end of the 13th century (1275–1300), is the oldest surviving nautical chart (that is, not simply a map but a document showing accurate navigational directions).

## The Age of Exploration



World Map by Juan de la Cosa, the first map showing the Americas.

In the Renaissance, with the renewed interest in classical works, maps became more like surveys once again, while the discovery of the Americas by Europeans and the subsequent effort to control and divide those lands revived interest in scientific mapping methods. Peter Whitfield, the author of several books on the history of maps, credits European mapmaking as a factor in the global spread of western power: "Men in Seville, Amsterdam or London had access to knowledge of America, Brazil, or India, while the native peoples knew only their own immediate environment" (Whitfield).

- **15th century:** The monk Nicholas Germanus wrote a pioneering *Cosmographia*. He added the first new maps to Ptolemy's *Geographica*. Germanus invented the Donis map projection where parallels of latitude are made equidistant, but meridians converge toward the poles.
- **c. 1485:** Portuguese cartographer Pedro Reinel made the oldest known signed Portuguese nautical chart.
- **1492:** German merchant Martin Behaim (1459–1507) made the oldest surviving terrestrial globe, but it lacked the Americas.
- **1492:** Cartographer Jorge de Aguiar made the oldest known signed and dated Portuguese nautical chart.



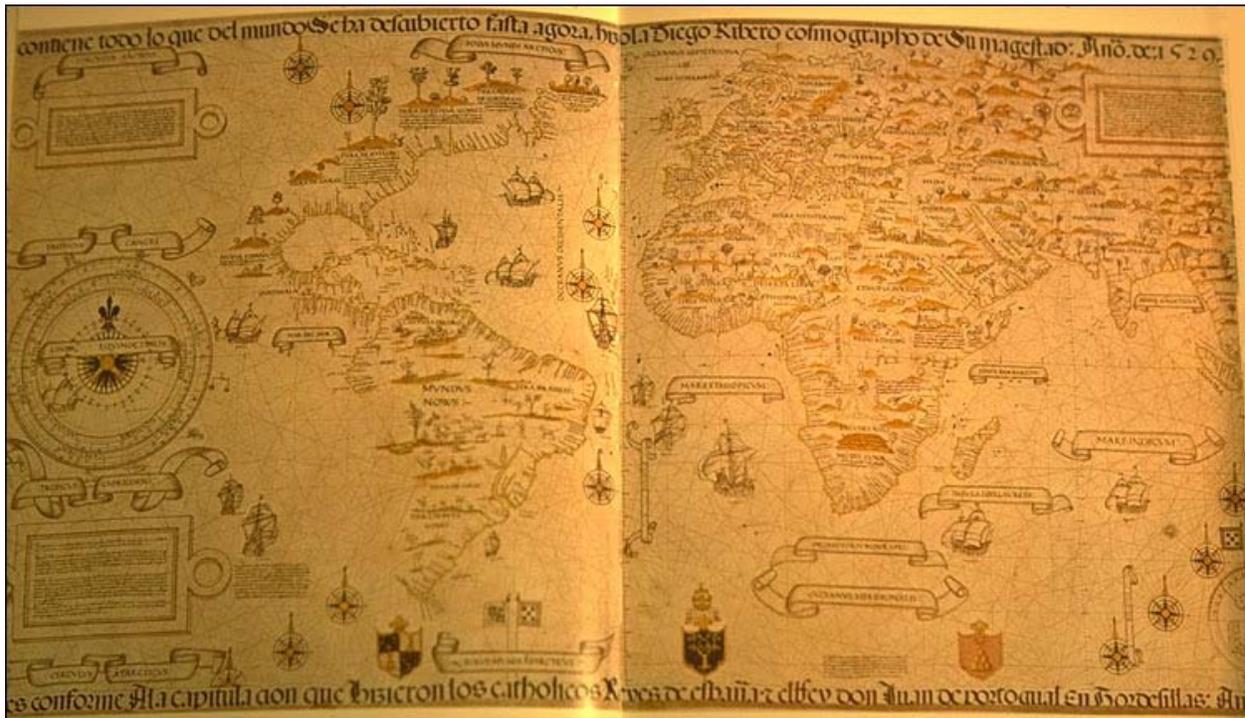
Nautical chart by Pedro Reinel (c. 1504), one of the first based on astronomical observations and to depict a scale of latitudes.

### First maps of the Americas

The Spanish cartographer and explorer Juan de la Cosa sailed with Christopher Columbus. He created the first known cartographic representations showing both the Americas as well as Africa and Eurasia.

- **1502:** Unknown Portuguese cartographer made the Cantino planisphere, the first nautical chart to implicitly represent latitudes.
- **1504:** Portuguese cartographer Pedro Reinel made the oldest known nautical chart with a scale of latitudes.
- **1507:** Martin Waldseemüller's World Map was the first to use the term America for the Western continents (after explorer Amerigo Vespucci).
- **1519 :** Portuguese cartographers Lopo Homem, Pedro Reinel and Jorge Reinel made the group of maps known today as the Miller Atlas or Lopo Homem - Reinéis Atlas.

## Diogo Ribeiro map (1527)



World Map by Diogo Ribeiro, the first world map based on empirical latitude observations.

Diogo Ribeiro, a Portuguese cartographer working for Spain, made what is considered the first scientific world map: the 1527 Padrón real, the first world map based on empiric latitude observations. The layout of the map (*Mapamundi*) is strongly influenced by the information obtained during the Magellan-Elcano trip around the world. Diogo's map delineates very precisely the coasts of Central and South America. The map shows, for the first time, the real extension of the Pacific Ocean. It also shows, for the first time, the North American coast as a continuous one (probably influenced by the Esteban Gómez's exploration in 1525). It also shows the demarcation of the Treaty of Tordesillas.

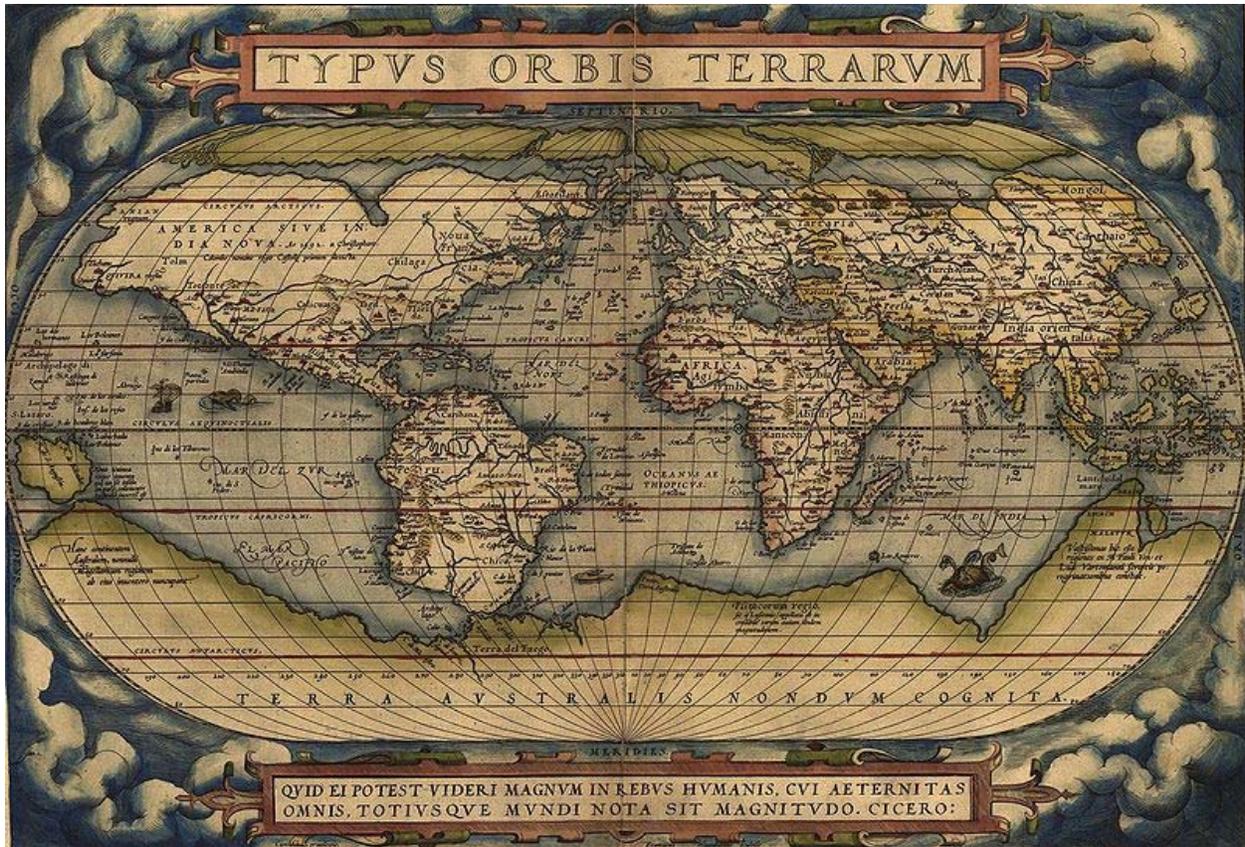


**Mercator world map** *Nova et Aucta Orbis Terrae Descriptio ad Usum Navigantium Emendate* (1569)

### **Gerardus Mercator (1569)**

Gerardus Mercator (1512–1594) was a Flemish cartographer who in his quest to make the world “look right” on the maps invented a new projection, called the Mercator projection. The projection was mathematically based and the Mercator maps gave much more accurate maps for world-wide navigation than any until that date. As in all cylindrical projections, parallels and meridians are straight and perpendicular to each other. In accomplishing this, the unavoidable east-west stretching of the map, is accompanied by a corresponding north-south stretching, so that at every point location, the east-west scale is the same as the north-south scale, making the projection conformal.

The development of the Mercator projection represented a major breakthrough in the nautical cartography of the 16th century. However, it was much ahead of its time, since the old navigational and surveying techniques were not compatible with its use in navigation. The Mercator projection would over time become the conventional view of the world that we are accustomed to today.



In 1570 Abraham Ortelius created the "first modern atlas".

### Ortelius and the first Atlas

- **1570:** Antwerp cartographer Abraham Ortelius published the *Theatrum Orbis Terrarum*, the first modern atlas.
- **1608:** Captain John Smith published a map of Virginia's coastline.
- **1670s:** The astronomer Giovanni Domenico Cassini began work on the first modern topographic map in France. It was completed in 1789 or 1793 by his grandson Cassini de Thury.

### Enlightenment and scientific map-making

- **1715:** Herman Moll published the Beaver Map, one of the most famous early maps of North America, which he copied from a 1698 work by Nicolas de Fer
- **1763–1767:** Captain James Cook mapped Newfoundland.

## **Modern cartography**

The Vertical Perspective projection was first used by the German map publisher Matthias Seutter in 1740. He placed his observer at ~12,750 km distance. This is the type of projection used today by Google Earth.

The final form of the Equidistant Conic projection was constructed by the French astronomer Joseph-Nicolas Delisle in 1745.

The Swiss mathematician Johann Lambert invented several hemispheric map projections. In 1772 he created the Lambert Conformal Conic and Lambert Azimuthal Equal-Area projections.

The Albers Equal-Area Conic projection features no distortion along standard parallels. It was invented by Heinrich Albers in 1805.

In the United States in the 17th and 18th centuries, explorers mapped trails and army engineers surveyed government lands. Two agencies were established to provide more detailed, large-scale mapping. They were the U.S. Geological Survey and the United States Coast and Geodetic Survey (now the National Geodetic Survey under the National Oceanic and Atmospheric Association).

The Greenwich prime meridian became the international standard reference for cartographers in 1884.

During the 1900s, maps became more abundant due to improvements in printing and photography that made production cheaper and easier. Airplanes made it possible to photograph large areas at a time.

Two-Point Equidistant projection was first drawn up by Hans Maurer in 1919. In this projection the distance from any point on the map to either of the two regulating points is accurate.

The Loximuthal projection was constructed by Karl Siemon in 1935 and refined by Waldo Tobler in 1966.

Since the mid-1990s, the use of computers in mapmaking has helped to store, sort, and arrange data for mapping in order to create map projections.

## Chapter 2

# Map Projection

A **map projection** is any method of representing the surface of a sphere or other shape on a plane. Map projections are necessary for creating maps. All map projections distort the surface in some fashion. Depending on the purpose of the map, some distortions are acceptable and others are not; therefore different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties. There is no limit to the number of possible map projections.

### Background

For simplicity, here we usually assume that the surface to be mapped is the surface of a sphere. However, the Earth and other sufficiently large celestial bodies are generally better modeled as oblate spheroids, and small objects such as asteroids may have irregular shapes. These other surfaces can be mapped as well. Therefore, more generally, a map projection is any method of "flattening" into a plane a continuous surface having curvature in all three spatial dimensions.

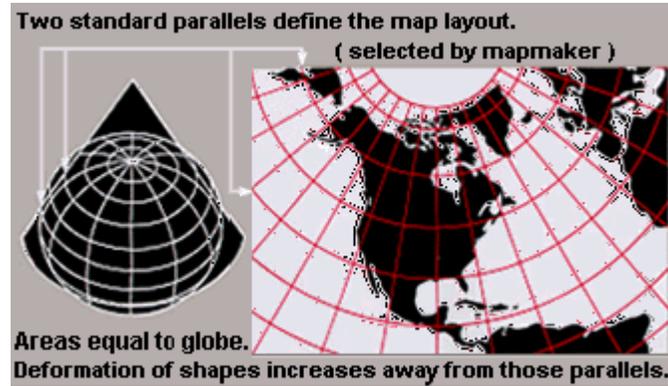
*Projection* as used here is not limited to perspective projections, such as those resulting from casting a shadow on a screen. Rather, any mathematical function transforming coordinates from the curved surface to the plane is a projection.

Carl Friedrich Gauss's Theorema Egregium proved that a sphere cannot be represented on a plane without distortion. Since any method of representing a sphere's surface on a plane is a map projection, all map projections distort. Every distinct map projection distorts in a distinct way. The study of map projections is the characterization of these distortions.

A map of the earth is a representation of a curved surface on a plane. Therefore a map projection must have been used to create the map, and, conversely, maps could not exist without map projections. Maps can be more useful than globes in many situations: they are more compact and easier to store; they readily accommodate an enormous range of scales; they are viewed easily on computer displays; they can facilitate measuring properties of the terrain being mapped; they can show larger portions of the Earth's

surface at once; and they are cheaper to produce and transport. These useful traits of maps motivate the development of map projections.

### **Metric properties of maps**



An Albers projection shows areas accurately, but distorts shapes.

Many properties can be measured on the Earth's surface independently of its geography. Some of these properties are:

- Area
- Shape
- Direction
- Bearing
- Distance
- Scale

Map projections can be constructed to preserve one or more of these properties, though not all of them simultaneously. Each projection preserves or compromises or approximates basic metric properties in different ways. The purpose of the map determines which projection should form the base for the map. Because many purposes exist for maps, many projections have been created to suit those purposes.

Another major concern that drives the choice of a projection is the compatibility of data sets. Data sets are geographic information. As such, their collection depends on the chosen model of the Earth. Different models assign slightly different coordinates to the same location, so it is important that the model be known and that the chosen projection be compatible with that model. On small areas (large scale) data compatibility issues are more important since metric distortions are minimal at this level. In very large areas (small scale), on the other hand, distortion is a more important factor to consider.

## **Which Map is Best?**

Cartographers have long despaired over publishers' inapt use of the Mercator. As a 1943 New York Times editorial states, "...*The time has come to discard [the Mercator] for something that represents the continents and directions less deceptively... Although its usage... has diminished... it is still highly popular as a wall map apparently in part because, as a rectangular map, it fills a rectangular wall space with more map, and clearly because its familiarity breeds more popularity.*"

The Peters map controversy motivated the American Cartographic Association (now Cartography and Geographic Information Society) to produce a series of booklets (including *Which Map is Best*) designed to educate the public about map projections and distortion in maps. In 1989 and 1990, after some internal debate, seven North American geographic organizations adopted the following resolution, which rejected all rectangular world maps, a category that includes both the Mercator and the Gall–Peters projections:

WHEREAS, the earth is round with a coordinate system composed entirely of circles, and

WHEREAS, flat world maps are more useful than globe maps, but flattening the globe surface necessarily greatly changes the appearance of Earth's features and coordinate systems, and

WHEREAS, world maps have a powerful and lasting effect on people's impressions of the shapes and sizes of lands and seas, their arrangement, and the nature of the coordinate system, and

WHEREAS, frequently seeing a greatly distorted map tends to make it "look right,"

THEREFORE, we strongly urge book and map publishers, the media and government agencies to cease using rectangular world maps for general purposes or artistic displays. Such maps promote serious, erroneous conceptions by severely distorting large sections of the world, by showing the round Earth as having straight edges and sharp corners, by representing most distances and direct routes incorrectly, and by portraying the circular coordinate system as a squared grid. The most widely displayed rectangular world map is the Mercator (in fact a navigational diagram devised for nautical charts), but other rectangular world maps proposed as replacements for the Mercator also display a greatly distorted image of the spherical Earth.

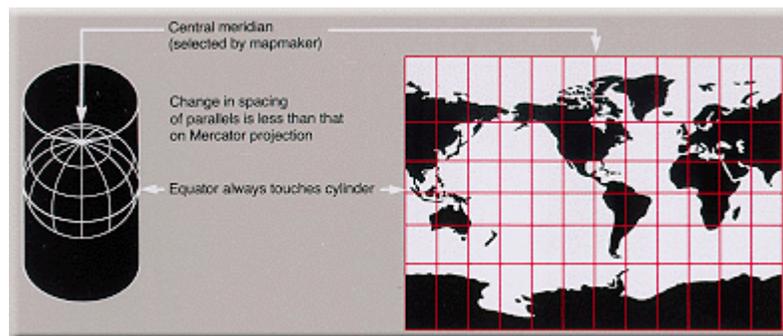
## **Construction of a map projection**

The creation of a map projection involves three steps:

1. Selection of a model for the shape of the Earth or planetary body (usually choosing between a sphere or ellipsoid). Because the Earth's actual shape is irregular, information is lost in this step.
2. Transformation of geographic coordinates (longitude and latitude) to Cartesian (x,y) or polar plane coordinates. Cartesian coordinates normally have a simple relation to eastings and northings defined on a grid superimposed on the projection.

Some of the simplest map projections are literally projections, as obtained by placing a light source at some definite point relative to the globe and projecting its features onto a specified surface. This is **not** the case for most projections which are defined **only** in terms of mathematical formulae that have no direct physical interpretation.

### Choosing a projection surface

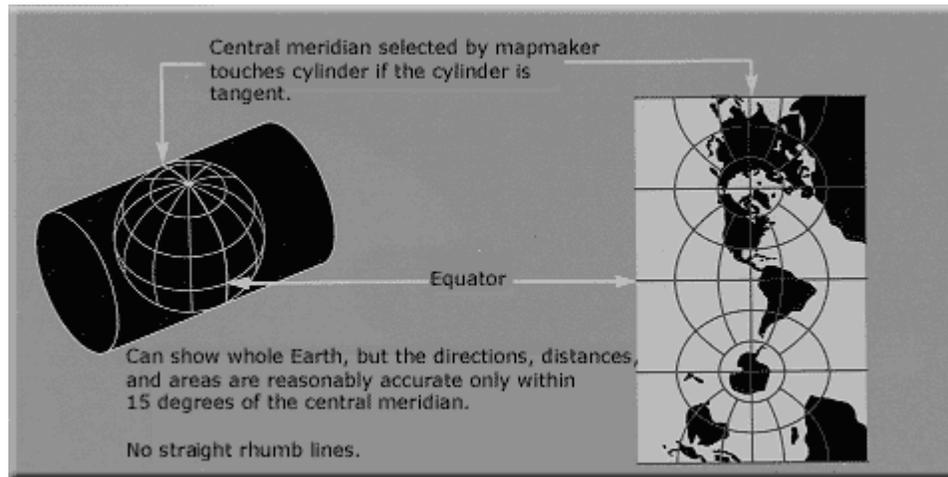


A Miller cylindrical projection maps the globe onto a cylinder.

A surface that can be unfolded or unrolled into a plane or sheet without stretching, tearing or shrinking is called a *developable surface*. The cylinder, cone and of course the plane are all developable surfaces. The sphere and ellipsoid are not developable surfaces. As noted in the introduction, any projection of a sphere (or an ellipsoid) onto a plane will have to distort the image. (To compare, one cannot flatten an orange peel without tearing or warping it.)

One way of describing a projection is first to project from the Earth's surface to a developable surface such as a cylinder or cone, and then to unroll the surface into a plane. While the first step inevitably distorts some properties of the globe, the developable surface can then be unfolded without further distortion.

## Aspects of the projection



This transverse Mercator projection is mathematically the same as a standard Mercator, but oriented around a different axis.

Once a choice is made between projecting onto a cylinder, cone, or plane, the **aspect** of the shape must be specified. The aspect describes how the developable surface is placed relative to the globe: it may be *normal* (such that the surface's axis of symmetry coincides with the Earth's axis), *transverse* (at right angles to the Earth's axis) or *oblique* (any angle in between). The developable surface may also be either *tangent* or *secant* to the sphere or ellipsoid. Tangent means the surface touches but does not slice through the globe; secant means the surface does slice through the globe. Insofar as preserving metric properties goes, it is never advantageous to move the developable surface away from contact with the globe, so that possibility is not discussed here.

## Scale

A globe is the only way to represent the earth with constant scale throughout the entire map in all directions. A map cannot achieve that property for any area, no matter how small. It can, however, achieve constant scale along specific lines.

Some possible properties are:

- The scale depends on location, but not on direction. This is equivalent to preservation of angles, the defining characteristic of a conformal map.
- Scale is constant along any parallel in the direction of the parallel. This applies for any cylindrical or pseudocylindrical projection in normal aspect.
- Combination of the above: the scale depends on latitude only, not on longitude or direction. This applies for the Mercator projection in normal aspect.

- Scale is constant along all straight lines radiating from a particular geographic location. This is the defining characteristic of an equidistant projection such as the Azimuthal equidistant projection. There are also projections (Maurer, Close) where true distances from *two* points are preserved.

### **Choosing a model for the shape of the Earth**

Projection construction is also affected by how the shape of the Earth is approximated. In the following discussion on projection categories, a sphere is assumed. However, the Earth is not exactly spherical but is closer in shape to an oblate ellipsoid, a shape which bulges around the equator. Selecting a model for a shape of the Earth involves choosing between the advantages and disadvantages of a sphere versus an ellipsoid. Spherical models are useful for small-scale maps such as world atlases and globes, since the error at that scale is not usually noticeable or important enough to justify using the more complicated ellipsoid. The ellipsoidal model is commonly used to construct topographic maps and for other large and medium scale maps that need to accurately depict the land surface.

A third model of the shape of the Earth is called a geoid, which is a complex and more or less accurate representation of the global mean sea level surface that is obtained through a combination of terrestrial and satellite gravity measurements. This model is not used for mapping due to its complexity but is instead used for control purposes in the construction of geographic datums. (In geodesy, plural of "datum" is "datums" rather than "data".) A geoid is used to construct a datum by adding irregularities to the ellipsoid in order to better match the Earth's actual shape (it takes into account the large scale features in the Earth's gravity field associated with mantle convection patterns, as well as the gravity signatures of very large geomorphic features such as mountain ranges, plateaus and plains). Historically, datums have been based on ellipsoids that best represent the geoid within the region the datum is intended to map. Each ellipsoid has a distinct major and minor axis. Different controls (modifications) are added to the ellipsoid in order to construct the datum, which is specialized for a specific geographic regions (such as the North American Datum). A few modern datums, such as WGS84 (the one used in the Global Positioning System GPS), are optimized to represent the entire earth as well as possible with a single ellipsoid, at the expense of some accuracy in smaller regions.

### **Classification**

A fundamental projection classification is based on the type of projection surface onto which the globe is conceptually projected. The projections are described in terms of placing a gigantic surface in contact with the earth, followed by an implied scaling operation. These surfaces are cylindrical (e.g. Mercator), conic (e.g., Albers), or azimuthal or plane (e.g. stereographic). Many mathematical projections, however, do not neatly fit into any of these three conceptual projection methods. Hence other peer

categories have been described in the literature, such as pseudoconic, pseudocylindrical, pseudoazimuthal, retroazimuthal, and polyconic.

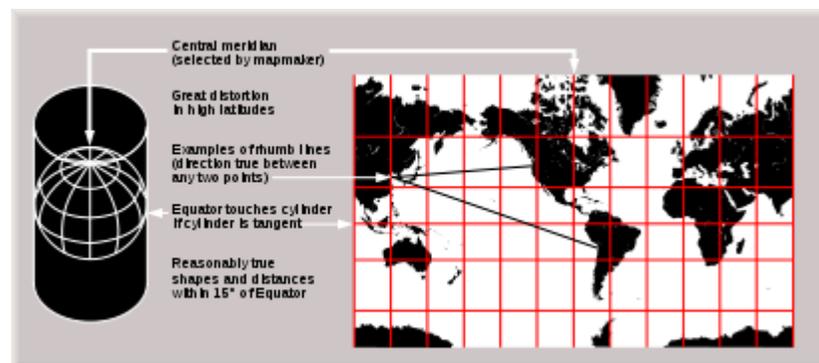
Another way to classify projections is according to properties of the model they preserve. Some of the more common categories are:

- Preserving direction (*azimuthal*), a trait possible only from one or two points to every other point
- Preserving shape locally (*conformal* or *orthomorphic*)
- Preserving area (*equal-area* or *equiareal* or *equivalent* or *authalic*)
- Preserving distance (*equidistant*), a trait possible only between one or two points and every other point
- Preserving shortest route, a trait preserved only by the gnomonic projection

NOTE: Because the sphere is not a developable surface, it is impossible to construct a map projection that is both equal-area and conformal.

## Projections by surface

### Cylindrical



The Mercator projection shows courses of constant bearing as straight lines.

The term "normal cylindrical projection" is used to refer to any projection in which meridians are mapped to equally spaced vertical lines and circles of latitude (parallels) are mapped to horizontal lines.

The mapping of meridians to vertical lines can be visualized by imagining a cylinder (of which the axis coincides with the Earth's axis of rotation) wrapped around the Earth and then projecting onto the cylinder, and subsequently unfolding the cylinder.

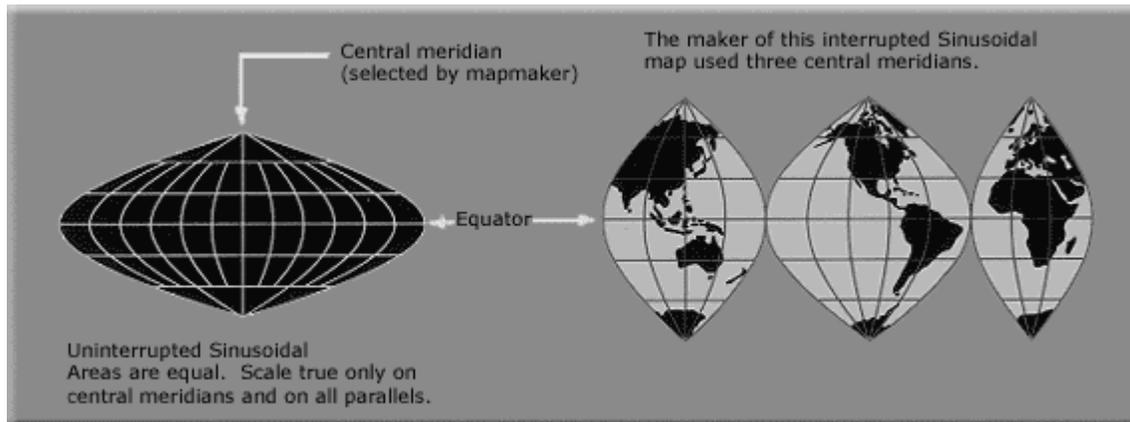
By the geometry of their construction, cylindrical projections stretch distances east-west. The amount of stretch is the same at any chosen latitude on all cylindrical projections, and is given by the secant of the latitude as a multiple of the equator's scale. The various cylindrical projections are distinguished from each other solely by their north-south stretching (where latitude is given by  $\phi$ ):

- North-south stretching is equal to the east-west stretching (secant  $\phi$ ): The east-west scale matches the north-south scale: conformal cylindrical or Mercator; this distorts areas excessively in high latitudes.
- North-south stretching growing rapidly with latitude, even faster than east-west stretching (secant<sup>2</sup>  $\phi$ ): The cylindric perspective (= central cylindrical) projection; unsuitable because distortion is even worse than in the Mercator projection.
- North-south stretching grows with latitude, but less quickly than the east-west stretching: such as the Miller cylindrical projection (secant $[4\phi/5]$ ).
- North-south distances neither stretched nor compressed (1): equidistant cylindrical or plate carrée.
- North-south compression precisely the reciprocal of east-west stretching (cosine  $\phi$ ): equal-area cylindrical (with many named specializations such as Gall–Peters or Gall orthographic, Behrmann, and Lambert cylindrical equal-area). This divides north-south distances by a factor equal to the secant of the latitude, preserving area but heavily distorting shapes.

In the first case (Mercator), the east-west scale always equals the north-south scale. In the second case (central cylindrical), the north-south scale exceeds the east-west scale everywhere away from the equator. Each remaining case has a pair of identical latitudes of opposite sign (or else the equator) at which the east-west scale matches the north-south-scale.

Normal cylindrical projections map the whole Earth as a finite rectangle, except in the first two cases, where the rectangle stretches infinitely tall while retaining constant width.

## Pseudocylindrical



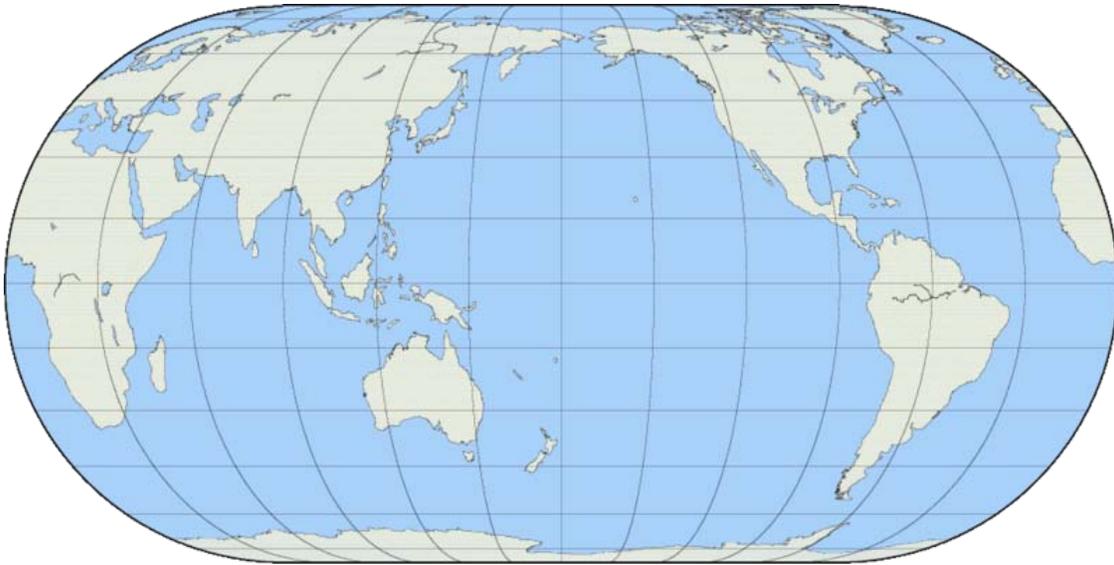
A sinusoidal projection shows relative sizes accurately, but grossly distorts shapes. Distortion can be reduced by "interrupting" the map.

Pseudocylindrical projections represent the *central* meridian and each parallel as a single straight line segment, but not the other meridians. Each pseudocylindrical projection represents a point on the Earth along the straight line representing its parallel, at a distance which is a function of its difference in longitude from the central meridian.

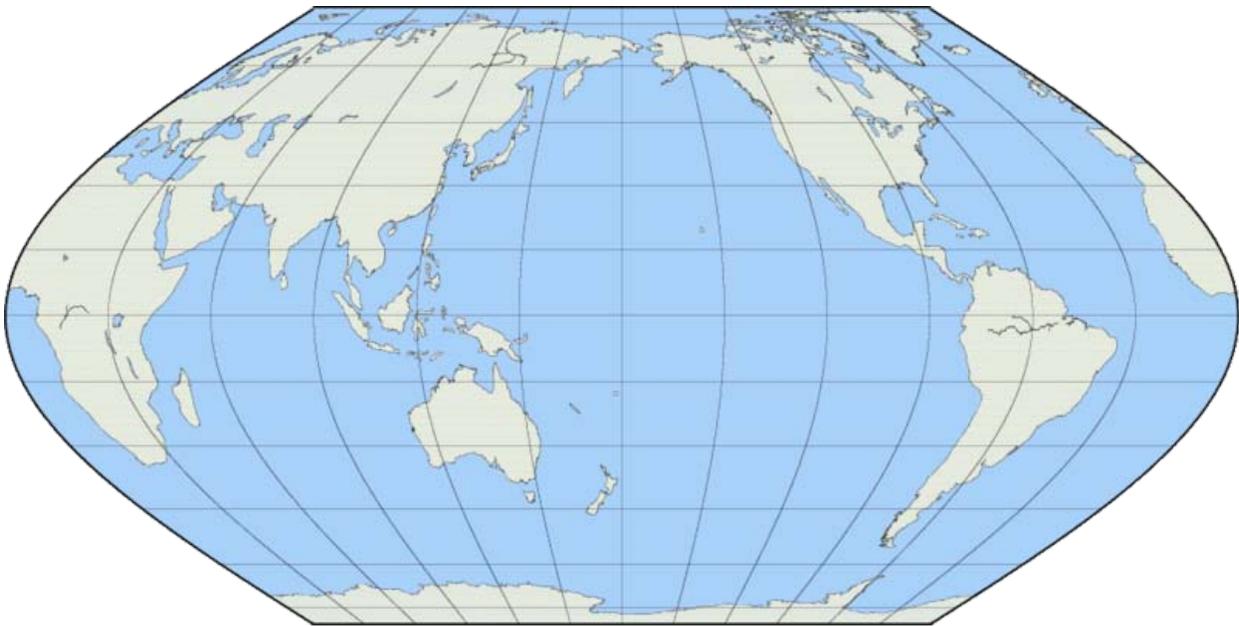
- Sinusoidal: the north-south scale and the east-west scale are the same throughout the map, creating an equal-area map. On the map, as in reality, the length of each parallel is proportional to the cosine of the latitude. Thus the shape of the map for the whole earth is the region between two symmetric rotated cosine curves.

The true distance between two points on the same meridian corresponds to the distance on the map between the two parallels, which is smaller than the distance between the two points on the map. The true distance between two points on the same parallel – and the true area of shapes on the map – are not distorted. The meridians drawn on the map help the user to realize the shape distortion and mentally compensate for it.

- Collignon projection, which in its most common forms represents each meridian as 2 straight line segments, one from each pole to the equator.
- Mollweide
- Goode homolosine
- Eckert IV



Eckert VI



- Kavrayskiy VII
- Tobler hyperelliptical

### Hybrid

The HEALPix projection combines an equal-area cylindrical projection in equatorial regions with the Collignon projection in polar areas.

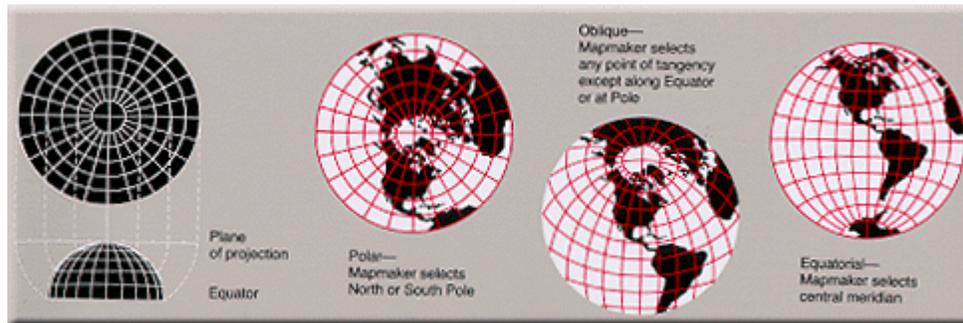
## Conical

- Equidistant conic
- Lambert conformal conic
- Albers conic

## Pseudoconical

- Bonne
- Werner cordiform designates a pole and a meridian; distances from the pole are preserved, as are distances from the meridian (which is straight) along the parallels
- Continuous American polyconic

## Azimuthal (projections onto a plane)



An azimuthal projection shows distances and directions accurately from the center point, but distorts shapes and sizes elsewhere.

Azimuthal projections have the property that directions from a central point are preserved (and hence, great circles through the central point are represented by straight lines on the map). Usually these projections also have radial symmetry in the scales and hence in the distortions: map distances from the central point are computed by a function  $r(d)$  of the true distance  $d$ , independent of the angle; correspondingly, circles with the central point as center are mapped into circles which have as center the central point on the map.

The mapping of radial lines can be visualized by imagining a plane tangent to the Earth, with the central point as tangent point.

The radial scale is  $r'(d)$  and the transverse scale  $r(d)/(R \sin(d/R))$  where  $R$  is the radius of the Earth.

Some azimuthal projections are true perspective projections; that is, they can be constructed mechanically, projecting the surface of the Earth by extending lines from a

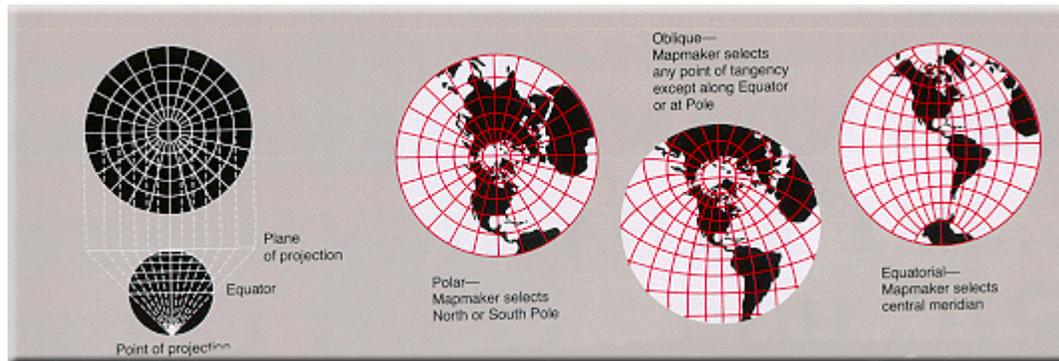
point of perspective (along an infinite line through the tangent point and the tangent point's antipode) onto the plane:

- The gnomonic projection displays great circles as straight lines. Can be constructed by using a point of perspective at the center of the Earth.  $r(d) = c \tan(d/R)$ ; a hemisphere already requires an infinite map,
- The General Perspective Projection can be constructed by using a point of perspective outside the earth. Photographs of Earth (such as those from the International Space Station) give this perspective.
- The orthographic projection maps each point on the earth to the closest point on the plane. Can be constructed from a point of perspective an infinite distance from the tangent point;  $r(d) = c \sin(d/R)$ . Can display up to a hemisphere on a finite circle. Photographs of Earth from far enough away, such as the Moon, give this perspective.
- The azimuthal conformal projection, also known as the stereographic projection, can be constructed by using the tangent point's antipode as the point of perspective.  $r(d) = c \tan(d/2R)$ ; the scale is  $c/(2R \cos^2(d/2R))$ . Can display nearly the entire sphere on a finite circle. The full sphere requires an infinite map.

Other azimuthal projections are not true perspective projections:

- Azimuthal equidistant:  $r(d) = cd$ ; it is used by amateur radio operators to know the direction to point their antennas toward a point and see the distance to it. Distance from the tangent point on the map is proportional to surface distance on the earth (; for the case where the tangent point is the North Pole, see the flag of the United Nations)
- Lambert azimuthal equal-area. Distance from the tangent point on the map is proportional to straight-line distance through the earth:  $r(d) = c \sin(d/2R)$
- Logarithmic azimuthal is constructed so that each point's distance from the center of the map is the logarithm of its distance from the tangent point on the Earth. Works well with cognitive maps.  $r(d) = c \ln(d/d_0)$ ; locations closer than at a distance equal to the constant  $d_0$  are not shown (, figure 6-5)

## Projections by preservation of a metric property



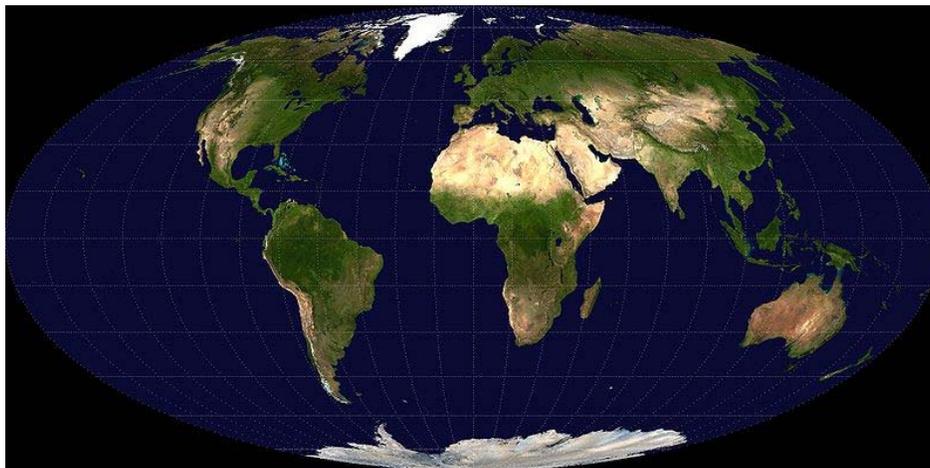
A stereographic projection is conformal and perspective but not equal area or equidistant.

### Conformal

Conformal map projections preserve angles locally:

- Mercator - rhumb lines are represented by straight segments
- Stereographic - shape of circles is conserved
- Roussilhe
- Lambert conformal conic
- Quincuncial map
- Adams hemisphere-in-a-square projection
- Guyou hemisphere-in-a-square projection

### Equal-area



The equal-area Mollweide projection

These projections preserve area:

- Gall orthographic (also known as Gall–Peters, or Peters, projection)
- Albers conic
- Lambert azimuthal equal-area
- Lambert cylindrical equal-area
- Mollweide
- Hammer
- Briesemeister
- Sinusoidal
- Werner
- Bonne
- Bottomley
- Goode's homolosine
- Hobo-Dyer
- Collignon
- Tobler hyperelliptical

## Equidistant

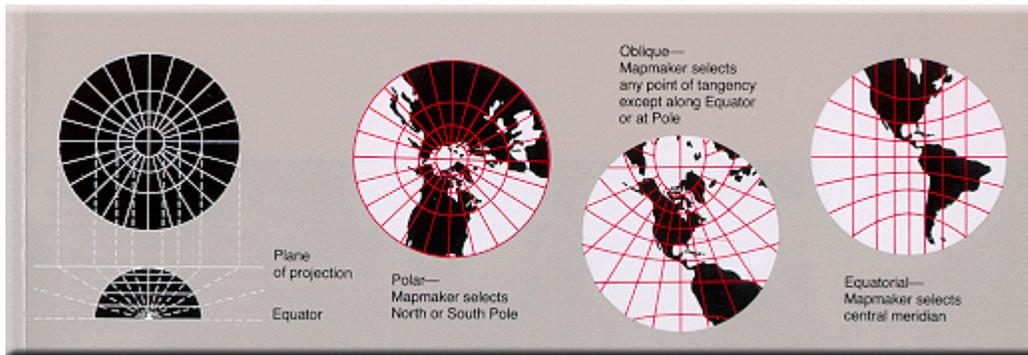


A two-point equidistant projection of Asia

These preserve distance from some standard point or line:

- Equirectangular - distances along meridians are conserved
- Plate carrée - an Equirectangular projection centered at the equator
- Azimuthal equidistant - distances along great circles radiating from centre are conserved
- Equidistant conic
- Sinusoidal - distances along parallels are conserved
- Werner cordiform distances from the North Pole are correct as are the curved distance on parallels
- Soldner
- Two-point equidistant: two "control points" are arbitrarily chosen by the map maker. Distance from any point on the map to each control point is proportional to surface distance on the earth.

## Gnomonic



The Gnomonic projection is thought to be the oldest map projection, developed by Thales in the 6th century BC

Great circles are displayed as straight lines:

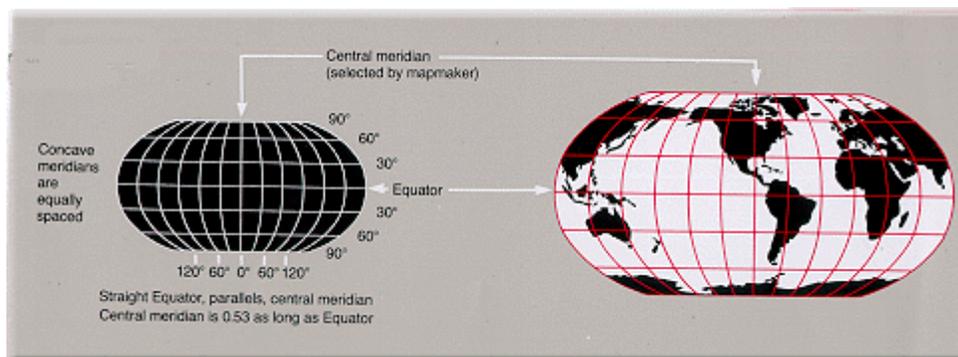
- Gnomonic projection

## Retroazimuthal

Direction to a fixed location B (the bearing at the starting location A of the shortest route) corresponds to the direction on the map from A to B:

- Littrow - the only conformal retroazimuthal projection
- Hammer retroazimuthal - also preserves distance from the central point
- Craig retroazimuthal *aka* Mecca or Qibla - also has vertical meridians

## Compromise projections



The Robinson projection was adopted by National Geographic Magazine in 1988 but abandoned by them in about 1997 for the Winkel Tripel.

Compromise projections give up the idea of perfectly preserving metric properties, seeking instead to strike a balance between distortions, or to simply make things "look right". Most of these types of projections distort shape in the polar regions more than at the equator:

- Robinson
- van der Grinten
- Miller cylindrical
- Winkel Tripel
- Buckminster Fuller's Dymaxion
- B.J.S. Cahill's Butterfly Map
- Steve Waterman's Butterfly Map
- Kavrayskiy VII
- Wagner VI
- Chamberlin trimetric
- Oronce Fine's cordiform

## Chapter 3

# Essence of Cartography

## Atlas



A political and physical map of the world from 2006

An **atlas** is a collection of maps; it is typically a map of Earth or a region of Earth, but there are atlases of the other planets (and their satellites) in the solar system. Atlases have traditionally been bound into book form, but today many atlases are in multimedia formats. In addition to presenting geographic features and political boundaries, many atlases often feature geopolitical, social, religious and economic statistics.

## "Atlas" mythology

The origin of the term atlas is a common source of misconception, perhaps because two different mythical figures named 'Atlas' are associated with map making.

- King Atlas, a mythical King of Mauretania, also known as Aparajit in Hinduism, was according to legend a wise philosopher, mathematician and astronomer who supposedly made the first celestial globe. It was this Atlas whom Gerardus Mercator was referring to when he first used the name 'Atlas', and he included a depiction of the King on the title-page.
- However, the more widely known Atlas is a figure from Greek mythology. He is the son of the Titan Iapetus and Clymene (or Asia), and brother of Prometheus. Atlas was punished by Zeus and made to bear the weight of the heavens (the idea of Atlas carrying the Earth is not correct according to the original myth) on his back, on top of Mt. Tam. One of Heracles's labours was to collect the apples of the Hesperides, guarded by Ladon. Heracles went to Atlas and reasoned with him. Eventually, Atlas agreed to collect the apples, and Heracles was left to carry the weight. Atlas tried to leave Heracles there, but Heracles tricked him and Atlas was left to carry the heavens forever. In his epic *Odyssey*, Homer refers to this Atlas as "one who knows the depths of the whole sea, and keeps the tall pillars who hold heaven and earth asunder".

In works of art, this Atlas is represented as carrying the heavens or the Celestial Sphere, on his shoulders. The earliest such depiction is the Farnese Atlas, now housed at the Museo Archeologico Nazionale Napoli in Naples, Italy. This figure is frequently found on the cover or title-pages of atlases. This is particularly true of atlases published by Dutch publishers during the second half of the seventeenth century. The image became associated with Dutch merchants, and a statue of this figure adorns the front of the World Trade Center in Amsterdam.

The first publisher to associate the Titan Atlas with a group of maps was Lafreri, on the title-page to "Tavole Moderne Di Geografia De La Maggior Parte Del Mondo Di Diversi Autori ..." However, he did not use the word "atlas" in the title of his work.

## Modern atlas

With the coming of the global market, publishers in different countries can reprint maps from plates made elsewhere. This means that the place names on the maps often use the designations or abbreviations of the language of the country in which the feature is located, to serve the widest market. For example, islands near Russia have the abbreviation "O." for "ostrov", not "I." for "island". This practice differs from what is standard for any given language, and it reaches its extremity concerning transliterations

from other languages. Particularly, German mapmakers use the transliterations from Cyrillic developed by the Czechs which are hardly used in English-speaking countries.

### **Online Atlas of Canada**

Natural Resources Canada (NRC) provides an interactive online atlas, the Atlas of Canada to the general public. Similar to the Statistics Canada website, the Natural Resources Canada site offers a wide range of free download-able data through the linked site Geo Gratis. The Atlas of Canada has been around since 1906 and offers maps on the natural environment, people and society, the economy, history, climate change, freshwater and health, as well as reference, archival and topographic maps. Also available through the Atlas of Canada website is the Learning Resources tab, which provides interactive and non-interactive lesson plans for grades as low as 6 and as high as 12. In cartography many scholars are interested in how information or phenomenon from the real world can be better represented on a map. The key word being re-present, since maps bring to life a situation that has already occurred in the past to the present. The Atlas of Canada complies with cartography in that it is targeted toward educating youths in elementary and high school, which would develop their cognitive representation skills. Although there are some aspects of the website that can be improved upon. These are mostly fine details, but some times the smallest changes make the largest impacts and part of growing and developing a better functioning education tool requires improvements. **Pro** - Downs and Liben, 1988 write about maps being opaque and it requires skills, which are taught before they can be read and understand properly. They believe that something that does not have prior context has to be learned because without cognitive representations misinterpretations of maps is easily done. The Online Atlas of Canada supports this really well by providing numerous lessons plans under its *Learning Resources* tab **Con** - The Atlas of Canada is largely promoted as a learning tool for students to become more knowledgeable in GIS, poor colors used in their thematic maps could be influencing bad practices. Some of the sites thematic maps have unsatisfying color schemes based on the fact that the colors are too close in richness, making it difficult to decipher one color from the color above or below it. One of the ways Harrower and Brewer suggest to combat this issue is to utilize an online tool called the ColourBrewer, which assists map makers in picking the best suitable colours.

### **Selected general atlases**

Some cartographically or commercially important atlases include the following:

17th century and earlier

- *Atlas Novus* (Blaeu, Netherlands, 1635–1658)
- *Atlas Maior* (Blaeu, Netherlands, 1662–1667)
- *Cartes générales de toutes les parties du monde* (France, 1658–1676)

- *Dell'Arcano del Mare* (England/Italy, 1645–1661)
- *Piri Reis map* (Ottoman Empire, 1570–1612)
- *Theatrum Orbis Terrarum* (Ortelius, Netherlands, 1570–1612)
- *Klencke Atlas* (1660; world's largest book)
- *The Britannia* (John Ogilby, 1670–1676)

#### 18th century

- *Atlas Nouveau* (Amsterdam, 1742)
- *Britannia Depicta* (London, 1720)
- *Cary's New and Correct English Atlas* (London, 1787)

#### 19th century

- *Andrees Allgemeiner Handatlas* (Germany, 1881–1939; in the UK as *Times Atlas of the World*, 1895)
- *Rand McNally Atlas* (United States, 1881–present)
- *Stielers Handatlas* (Germany, 1817–1944)

#### 20th century

- *Atlante Internazionale del Touring Club Italiano* (Italy, 1927–1978)
- *Atlas Mira* (Russia, 1937–present)
- *Gran Atlas Aguilar* (Spain, 1969/1970)
- *Historical Atlas of China* (China)
- *National Geographic Atlas of the World* (United States, 1963–present)
- *Pergamon World Atlas* (1962/1968)
- *Times Atlas of the World* (United Kingdom, 1895–present)

#### 21st century

- *North American Environmental Atlas*

# Globe



A modern raised-relief world globe



A Baroque era celestial globe



1765 de l'Isle globe, showing a fictional Northwest passage.

A **globe** is a three-dimensional scale model of Earth (**terrestrial globe**) or other spheroid celestial body such as a planet, star, or moon. It may also refer to a spherical representation of the celestial sphere, showing the apparent positions of the stars and constellations in the sky (**celestial globe**). The word "globe" comes from the Latin word *globus*, meaning round mass or sphere.

## Terrestrial and planetary

A globe is the only geographical representation that has negligible distortion over large areas, with the exception of the two-dimensional Dymaxion Map; all flat maps are created using a map projection that inevitably introduces an increasing amount of distortion the larger the area that the map shows. A typical scale for a terrestrial globe is roughly 1:40 million.

Sometimes a globe has relief, showing topography; in the case of a globe of the Earth the elevations are exaggerated, otherwise they would be hardly visible. Most modern globes are also imprinted with parallels and meridians so that one can (if only approximately due to scale) tell the coordinates of a specific point on the surface of the planet.

## Celestial

Celestial globes show the apparent positions of the stars in the sky. They omit the Sun, Moon and planets because the positions of these bodies vary relative to those of the stars, but the ecliptic, along which the Sun moves, is indicated.

A potential issue arises regarding the "handedness" of celestial globes. If the globe is constructed so that the stars are in the positions they actually occupy on the imaginary celestial sphere, then the star field will appear back-to-front on the surface of the globe (all the constellations will appear as their mirror images). This is because the view from Earth, positioned at the centre of the celestial sphere, is of the *inside* of the celestial sphere, whereas the celestial globe is viewed from the *outside*. For this reason, celestial globes may be produced in mirror image, so that at least the constellations appear the "right way round". Some modern celestial globes address this problem by making the surface of the globe transparent. The stars can then be placed in their proper positions and viewed *through* the globe, so that the view is of the inside of the celestial sphere, as it is from Earth.

## History

The sphericity of the Earth was established by Hellenistic astronomy in the 3rd century BCE, and the earliest terrestrial globe appeared from that period. The earliest known example is the one constructed by Crates of Mallus in Cilicia (now Çukurova in modern-day Turkey), in the mid-2nd century BCE.

No terrestrial globes from Antiquity or the Middle Ages have survived. An example of a surviving celestial globe is part of a Hellenistic sculpture, called the Farnese Atlas, surviving in a 2nd century AD Roman copy in the Naples Museum, Naples, Italy.

Early terrestrial globes depicting the entirety of the Old World were constructed in the Islamic Golden Age. One such example was constructed in the 9th century by Muslim geographers and cartographers working under the Abbasid caliph, Al-Ma'mun. Another example was the terrestrial globe introduced to Beijing by the Persian astronomer, Jamal ad-Din, in 1267.

The oldest surviving terrestrial globe is credited to Martin Behaim in Nürnberg, Germany, in 1492. A facsimile globe showing America was made by Martin Waldseemueller in 1507. Another early globe, the Hunt-Lenox Globe, ca. 1507, is thought to be the source of the phrase "Here be dragons." Another "remarkably modern-looking" terrestrial globe of the Earth was constructed by Taqi al-Din at the Istanbul observatory of Taqi al-Din during the 1570s.

An unusually high proportion of vintage 20th century world globes feature the Australian town of Birdum, which no longer exists but once held an important position at the end of the Northern Australian Railway.

## **Manufacture**

Mass-produced globes are typically covered by a printed paper map. The most common type has long, thin gores (strips) of paper that narrow to a point at the North Pole and the South Pole. Then a small disk is used to paper over the inevitable irregularities at the poles. The more gores there are, the less stretching and crumpling is required to make the paper map fit the sphere. From a geometric point of view, all points on a sphere are equivalent – one could select any arbitrary point on the Earth, and create a paper map that covers the Earth with strips that come together at that point and the antipodal point.

A globe is usually mounted at a 23.5° angle on bearings. In addition to making it easy to use this mounting also represents the angle of the planet in relation to its sun and the spin of the planet. This makes it easy to visualize how days and seasons change.

## **Notable examples**

- The Unisphere in Queens, New York, at 120 feet (36.6 meters) in diameter, is the world's largest global structure.
- Eartha, currently the world's largest rotating globe (41 feet in diameter), at the Delorme headquarters in Yarmouth, Maine
- The Mapparium, 30 foot walk-in globe at the Christian Science complex in Boston, intended to be viewed from within.
- The Babson globe in Wellesley, Massachusetts, a 26-foot-diameter (7.9 m) globe which originally rotated on its axis and on its base to simulate day and night and the seasons
- The giant globe in the lobby of The News Building in New York City.

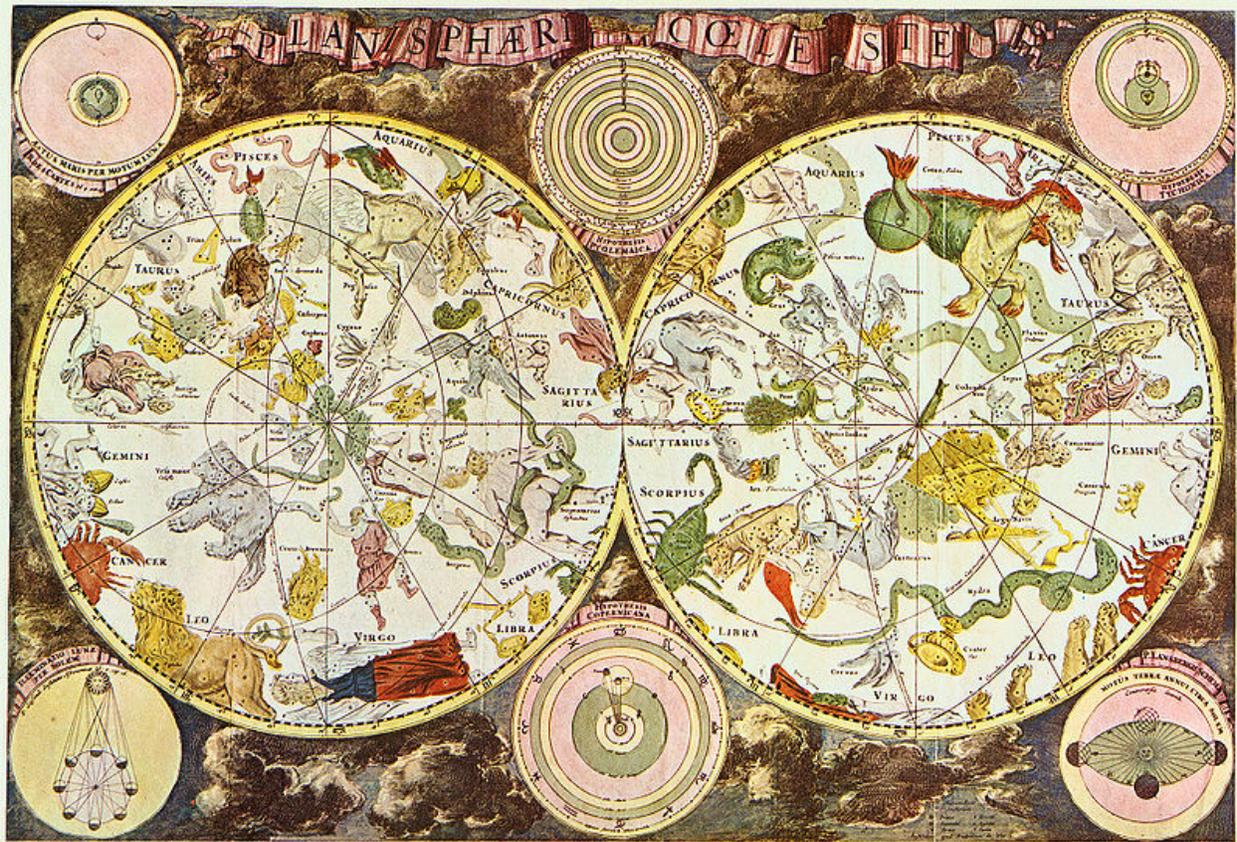
- The Hitler Globe, also known as the Führer globe, was formally named the Columbus Globe for State and Industry Leaders. Two editions existed during Hitler's lifetime, created during the mid-1930s on his orders. (The second edition changed the name of Abyssinia to Italian East Africa). These globes were "enormous" and very costly. According to the New York Times, "the real Columbus globe was nearly the size of a Volkswagen and, at the time, more expensive." Several still exist, including three in Berlin: one at a geographical institute, one at the Märkisches Museum, and another at the Deutsches Historisches Museum. The latter has a Soviet bullet hole through Germany. One of the two in public collections in Munich has an American bullet hole through Germany. There are several in private hands inside and out of Germany. A much smaller version of Hitler's globe was mocked by Charlie Chaplin in *The Great Dictator*, a film released in 1940.

## Map

A *map* is a visual representation of an area—a symbolic depiction highlighting relationships between elements of that space such as objects, regions, and themes.

Many maps are static two-dimensional, geometrically accurate (or approximately accurate) representations of three-dimensional space, while others are dynamic or interactive, even three-dimensional. Although most commonly used to depict geography, maps may represent any space, real or imagined, without regard to context or scale; e.g. Brain mapping, DNA mapping, and extraterrestrial mapping.

## Geographic maps



A celestial map from the 17th century, by the Dutch cartographer Frederik de Wit.

Cartography, or *map-making* is the study, and often practice of crafting representations of the Earth upon a flat surface, and one who makes maps is called a cartographer.

Road maps are perhaps the most widely used maps today, and form a subset of navigational maps, which also include aeronautical and nautical charts, railroad network maps, and hiking and bicycling maps. In terms of quantity, the largest number of drawn map sheets is probably made up by local surveys, carried out by municipalities, utilities, tax assessors, emergency services providers, and other local agencies. Many national surveying projects have been carried out by the military, such as the British Ordnance Survey (now a civilian government agency internationally renowned for its comprehensively detailed work).

In addition to location information maps may also be used to portray contour lines (isolines) indicating constant values of elevation, temperature, rainfall etc.

## Orientation of maps



*The Hereford Mappa Mundi*, about 1300, Hereford Cathedral, England. A classic "T-O" map with Jerusalem at centre, east toward the top, Europe the bottom left and Africa on the right.

The orientation of a map is the relationship between the directions on the map and the corresponding compass directions in reality. The word "orient" is derived from Latin *oriens*, meaning East. In the Middle Ages many maps, including the T and O maps, were drawn with East at the top (meaning that the direction "up" on the map corresponds to

East on the compass). Today, the most common – but far from universal – cartographic convention is that North is at the top of a map. Several kinds of maps are often traditionally not oriented with North at the top:

- Maps from non-Western traditions are oriented a variety of ways. Old maps of Edo show the Japanese imperial palace as the "top", but also at the centre, of the map. Labels on the map are oriented in such a way that you cannot read them properly unless you put the imperial palace above your head.
- Medieval European T and O maps such as the Hereford Mappa Mundi were centred on Jerusalem with East at the top. Indeed, prior to the reintroduction of Ptolemy's *Geography* to Europe around 1400, there was no single convention in the West. Portolan charts, for example, are oriented to the shores they describe.
- Maps of cities bordering a sea are often conventionally oriented with the sea at the top.
- Route and channel maps have traditionally been oriented to the road or waterway they describe.
- Polar maps of the Arctic or Antarctic regions are conventionally centred on the pole; the direction North would be towards or away from the centre of the map, respectively. Typical maps of the Arctic have 0° meridian towards the bottom of the page; maps of the Antarctic have the 0° meridian towards the top of the page.
- Reversed maps, also known as Upside-Down maps or South-Up maps, reverse the "North is up" convention and have South at the top.
- Buckminster Fuller's Dymaxion maps are based on a projection of the Earth's sphere onto an icosahedron. The resulting triangular pieces may be arranged in any order or orientation.
- Modern digital GIS maps such as ArcMap typically project north at the top of the map, but use math degrees (0 is east, degrees increase counter-clockwise), rather than compass degrees (0 is north, degrees increase clockwise) for orientation of transects. Compass decimal degrees can be converted to math degrees by subtracting them from 450.

## Scale and accuracy



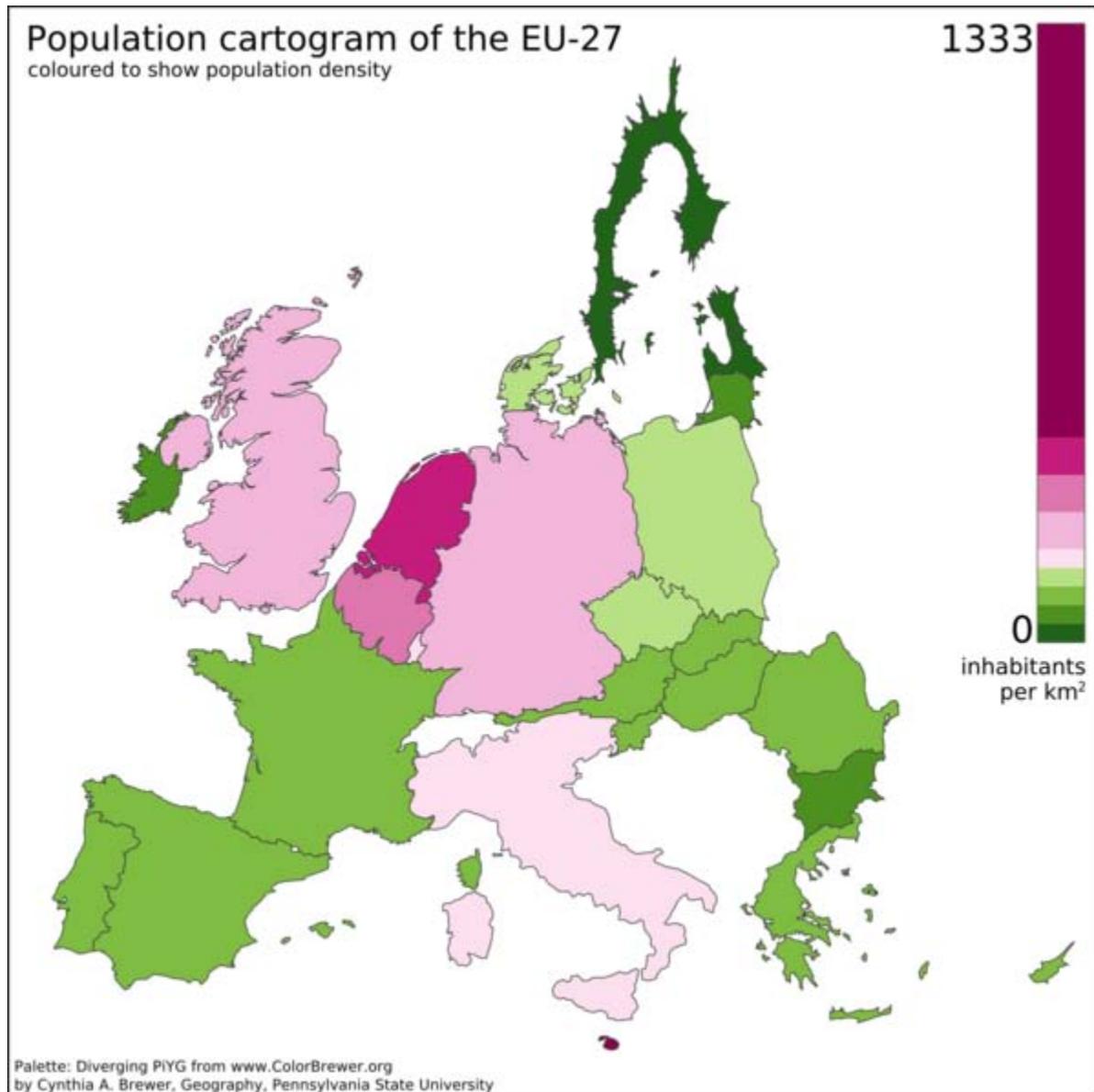
A 'global view map' of Europe, Middle East and Africa.

Many, but not all, maps are drawn to a scale, expressed as a ratio such as 1:10,000, meaning that 1 of any unit of measurement on the map corresponds exactly, or approximately, to 10,000 of that same unit on the ground. The scale statement may be taken as exact when the region mapped is small enough for the curvature of the Earth to be neglected, for example in a town planner's city map. Over larger regions where the curvature cannot be ignored we must use map projections from the curved surface of the Earth (sphere or ellipsoid) to the plane. The impossibility of flattening the sphere to the plane implies that no map projection can have constant scale: on most projections the best we can achieve is accurate scale on one or two lines (not necessarily straight) on the projection. Thus for map projections we must introduce the concept of point scale, which is a function of position, and strive to keep its variation within narrow bounds. Although the scale statement is nominal it is usually accurate enough for all but the most precise of measurements.

Large scale maps, say 1:10,000, cover relatively small regions in great detail and small scale maps, say 1:10,000,000, cover large regions such as nations, continents and the whole globe. The large/small terminology arose from the practice of writing scales as numerical fractions: 1/10000 is larger than 1/10000000. There is no exact dividing line between large and small but 1/100000 might well be considered as a medium scale. Examples of large scale maps are the 1:25000 maps produced for hikers; on the other hand maps intended for motorists at 1:250,000 or 1:1,000,000 are small scale.

It is important to recognise that even the most accurate maps sacrifice a certain amount of accuracy in scale to deliver a greater visual usefulness to its user. For example, the width of roads and small streams are exaggerated when they are too narrow to be shown on the map at true scale; that is, on a printed map they would be narrower than could be

perceived by the naked eye. The same applies to computer maps where the smallest unit is the pixel. A narrow stream say must be shown to have the width of a pixel even if at the map scale it would be a small fraction of the pixel width.



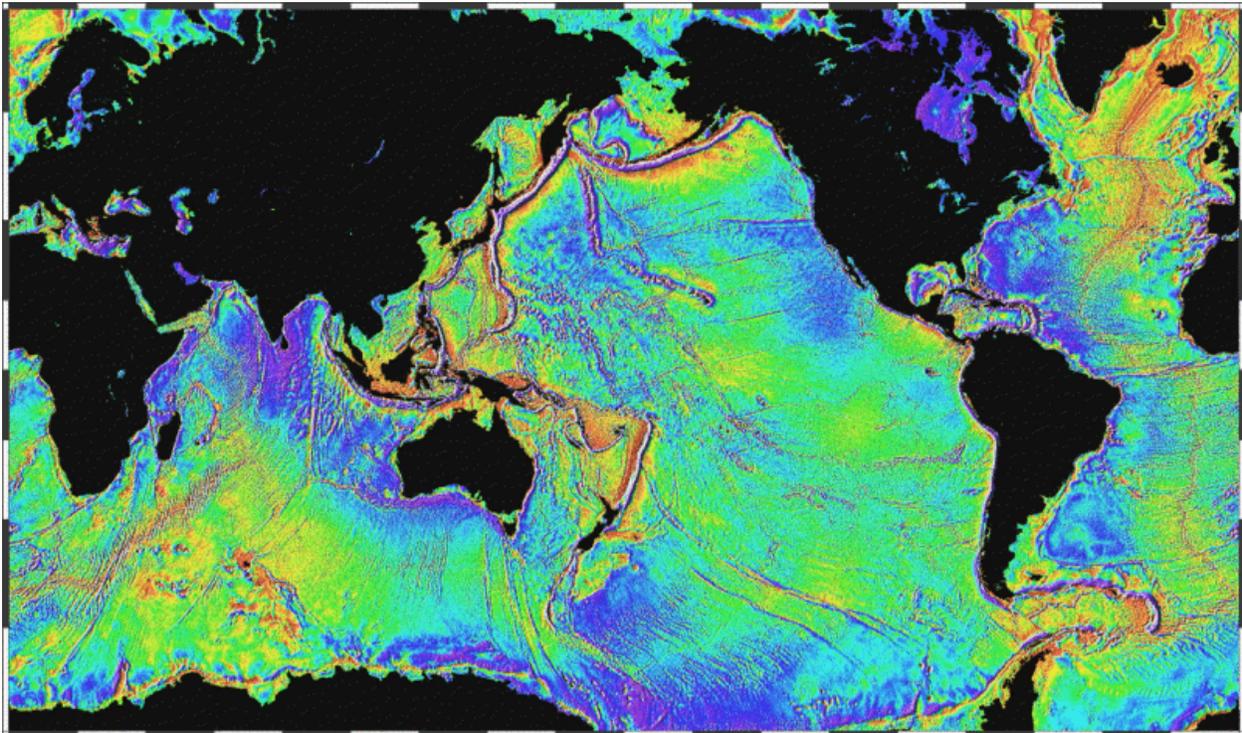
Cartogram: The EU distorted to show population distributions.

Some maps, called cartograms, have the scale deliberately distorted to reflect information other than land area or distance. For example, this map of Europe has been distorted to show population distribution, while the rough shape of the continent is still discernible.

Another example of distorted scale is the famous London Underground map. The basic geographical structure is respected but the tube lines (and the River Thames) are smoothed to clarify the relationships between stations. Near the center of the map stations are spaced out more than near the edges of map.

Further inaccuracies may be deliberate. For example, cartographers may simply omit military installations or remove features solely in order to enhance the clarity of the map. For example, a road map may may not show railroads, smaller waterways or other prominent non-road objects, and even if it does, it may show them less clearly (e.g. dashed or dotted lines/outlines) than the main roads. Known as decluttering, the practice makes the subject matter that the user is interested in easier to read, usually without sacrificing overall accuracy. Software-based maps often allow the user to toggle decluttering between ON, OFF and AUTO as needed. In AUTO the degree of decluttering is adjusted as the user changes the scale being displayed.

### Map types and projections



Map of large underwater features. (1995, NOAA)

Maps of the world or large areas are often either 'political' or 'physical'. The most important purpose of the political map is to show territorial borders; the purpose of the physical is to show features of geography such as mountains, soil type or land use.

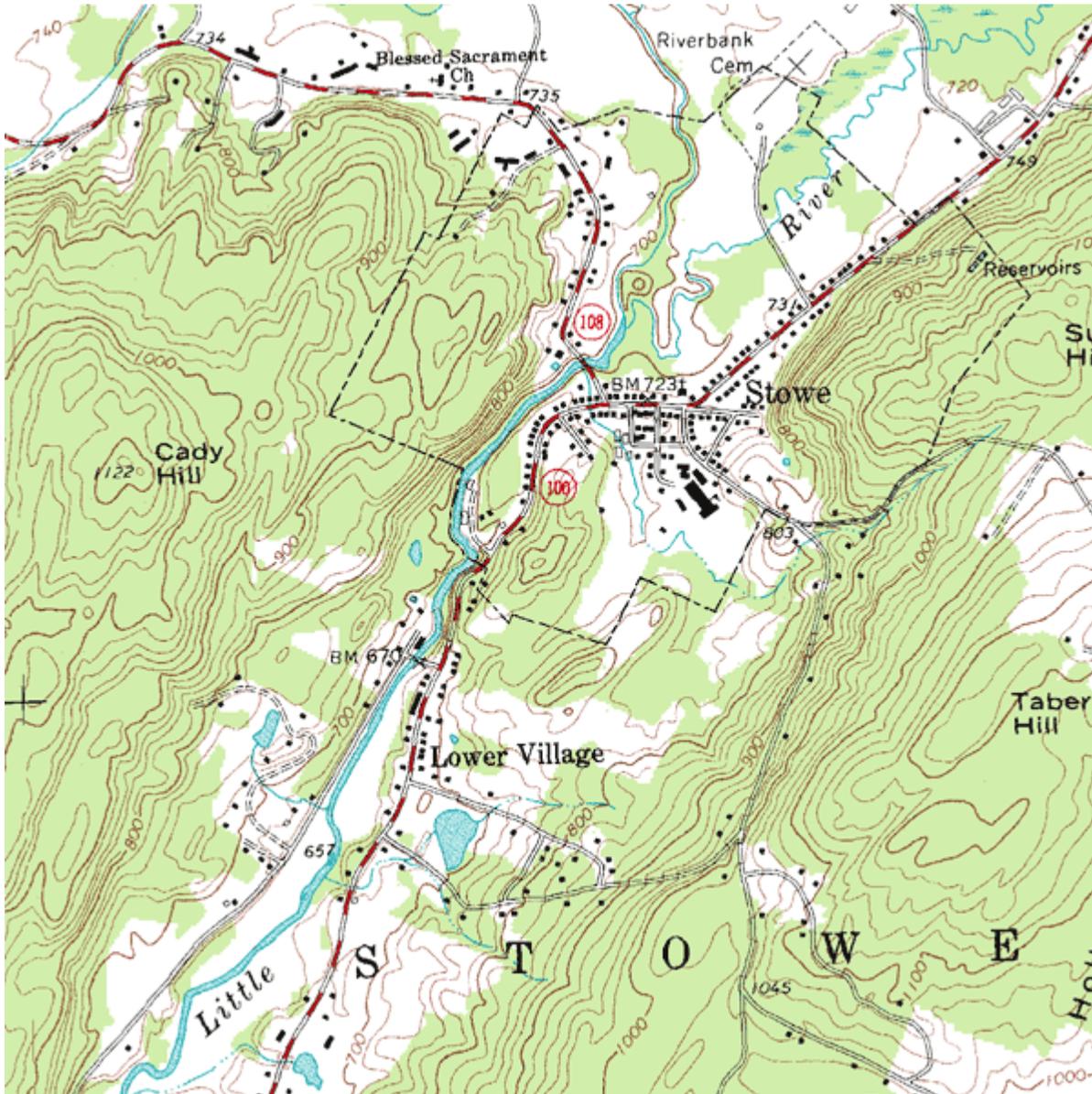
Geological maps show not only the physical surface, but characteristics of the underlying rock, fault lines, and subsurface structures.

Maps that depict the surface of the Earth also use a projection, a way of translating the three-dimensional real surface of the geoid to a two-dimensional picture. Perhaps the best-known world-map projection is the Mercator projection, originally designed as a form of nautical chart.

Aeroplane pilots use aeronautical charts based on a Lambert conformal conic projection, in which a cone is laid over the section of the earth to be mapped. The cone intersects the sphere (the earth) at one or two parallels which are chosen as standard lines. This allows the pilots to plot a great-circle route approximation on a flat, two-dimensional chart.

- Azimuthal or Gnomonic map projections are often used in planning air routes due to their ability to represent great circles as straight lines.
- Richard Edes Harrison produced a striking series of maps during and after World War II for Fortune magazine. These used "bird's eye" projections to emphasise globally strategic "fronts" in the air age, pointing out proximities and barriers not apparent on a conventional rectangular projection of the world.

## Electronic maps



A USGS digital raster graphic.

From the last quarter of the 20th century, the indispensable tool of the cartographer has been the computer. Much of cartography, especially at the data-gathering survey level, has been subsumed by Geographic Information Systems (GIS). The functionality of maps has been greatly advanced by technology simplifying the superimposition of spatially located variables onto existing geographical maps. Having local information such as rainfall level, distribution of wildlife, or demographic data integrated within the map

allows more efficient analysis and better decision making. In the pre-electronic age such superimposition of data led Dr. John Snow to discover the cause of cholera. Today, it is used by agencies of the human kind, as diverse as wildlife conservationists and militaries around the world.



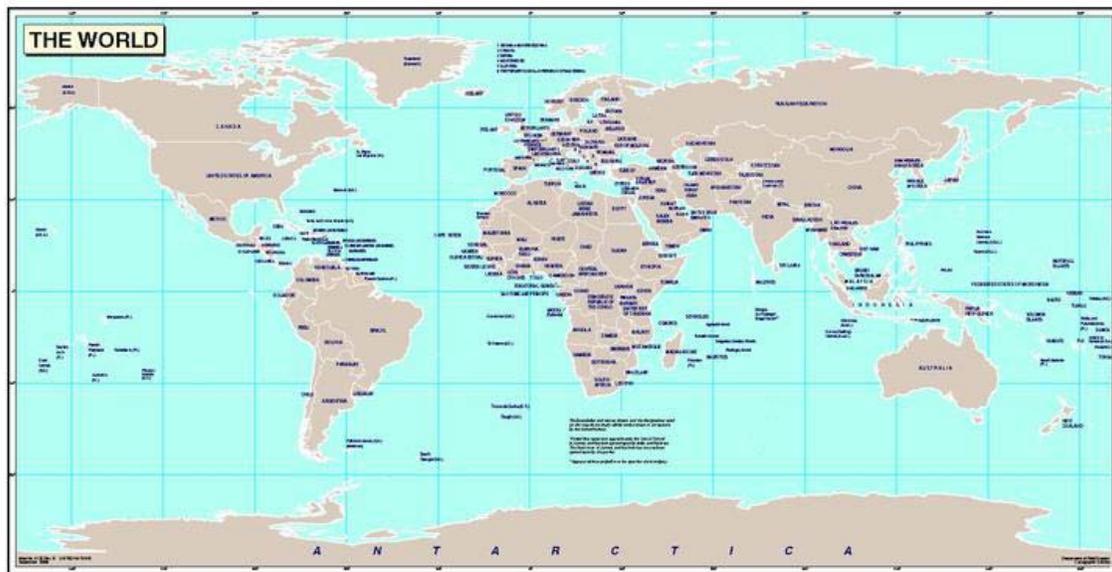
Relief map Sierra Nevada

Even when GIS is not involved, most cartographers now use a variety of computer graphics programs to generate new maps.

Interactive, computerised maps are commercially available, allowing users to *zoom in* or *zoom out* (respectively meaning to increase or decrease the scale), sometimes by replacing one map with another of different scale, centered where possible on the same point. In-car global navigation satellite systems are computerised maps with route-planning and advice facilities which monitor the user's position with the help of satellites. From the computer scientist's point of view, zooming in entails one or a combination of:

1. replacing the map by a more detailed one
2. enlarging the same map without enlarging the pixels, hence showing more detail by removing less information compared to the less detailed version

- enlarging the same map with the pixels enlarged (replaced by rectangles of pixels); no additional detail is shown, but, depending on the quality of one's vision, possibly more detail can be seen; if a computer display does not show adjacent pixels really separate, but overlapping instead (this does not apply for an LCD, but may apply for a cathode ray tube), then replacing a pixel by a rectangle of pixels does show more detail. A variation of this method is interpolation.



A world map

For example:

- Typically (2) applies to a Portable Document Format (PDF) file or other format based on vector graphics. The increase in detail is, of course, limited to the information contained in the file: enlargement of a curve may eventually result in a series of standard geometric figures such as straight lines, arcs of circles or splines.

- (2) may apply to text and (3) to the outline of a map feature such as a forest or building.
- (1) may apply to the text as needed (displaying labels for more features), while (2) applies to the rest of the image. Text is not necessarily enlarged when zooming in. Similarly, a road represented by a double line may or may not become wider when one zooms in.
- The map may also have layers which are partly raster graphics and partly vector graphics. For a single raster graphics image (2) applies until the pixels in the image file correspond to the pixels of the display, thereafter (3) applies.

### **Conventional signs**

The various features shown on a map are represented by conventional signs or symbols. For example, colors can be used to indicate a classification of roads. These signs are usually explained in the margin of the map, or on a separately published characteristic sheet.

### **Labeling**

To communicate spatial information effectively, features such as rivers, lakes, and cities need to be labeled. Over centuries cartographers have developed the art of placing names on even the densest of maps. Text placement or name placement can get mathematically very complex as the number of labels and map density increases. Therefore, text placement is time-consuming and labor-intensive, so cartographers and GIS users have developed automatic label placement to ease this process.

### **Non geographical spatial maps**

Maps exist of the solar system, and other cosmological features such as star maps. In addition maps of other bodies such as the Moon and other planets are technically not *geological* maps.

### **Non spatial maps**

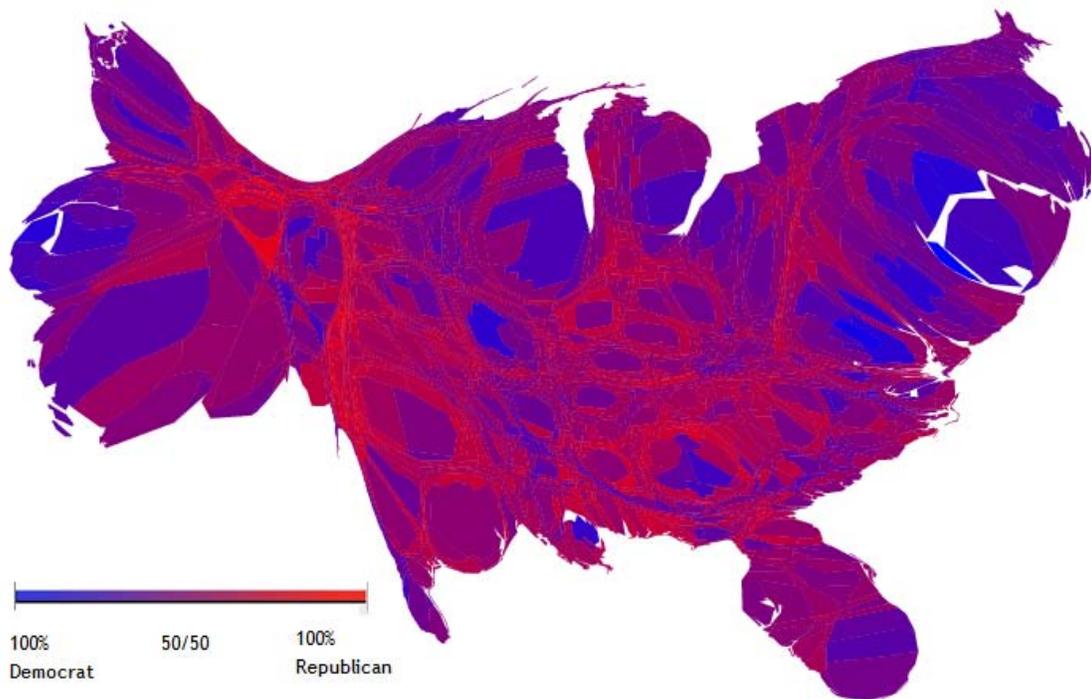
Many diagrams such as Gantt charts display logical relationships between items, and do not display spatial relationships at all.

Many maps are topological in nature, and the distances are completely unimportant, and only the connectivity is significant.

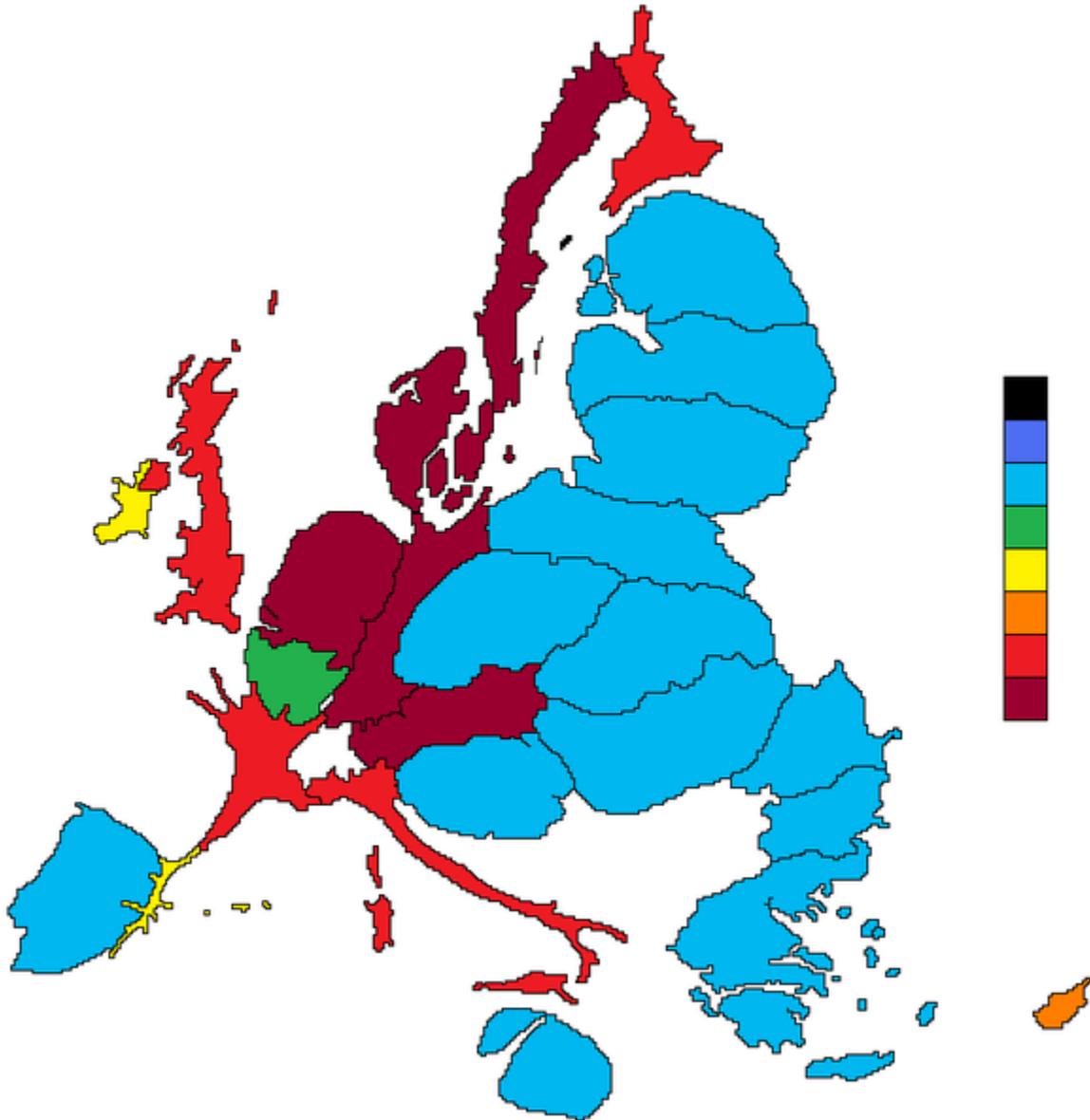
## Chapter 4

# Types of Maps

## Cartogram



Area cartogram of the United States, with each county rescaled in proportion to its population. Colors refer to the results of the 2004 U.S. presidential election popular vote.



Cartogram showing Open Europe estimate of total European Union net budget expenditure in euros for the whole period 2007-2013 per capita, based on Eurostat 2007 population estimates (Luxembourg not shown).

**Net contributors** ■ -5000 to -1000 euro per capita ■ -1000 to -500 euro per capita ■ -500 to 0 euro per capita

## Net recipients

 0 to 500 euro per capita  500 to 1000 euro per capita  1000 to 5000 euro per capita  5000 to 10000 euro per capita  10000 euro plus per capita  n/a

A **cartogram** is a map in which some thematic mapping variable – such as travel time or Gross National Product – is substituted for land area or distance. The geometry or space of the map is distorted in order to convey the information of this alternate variable. There are two main types of cartograms: area and distance cartograms.

## Area cartograms

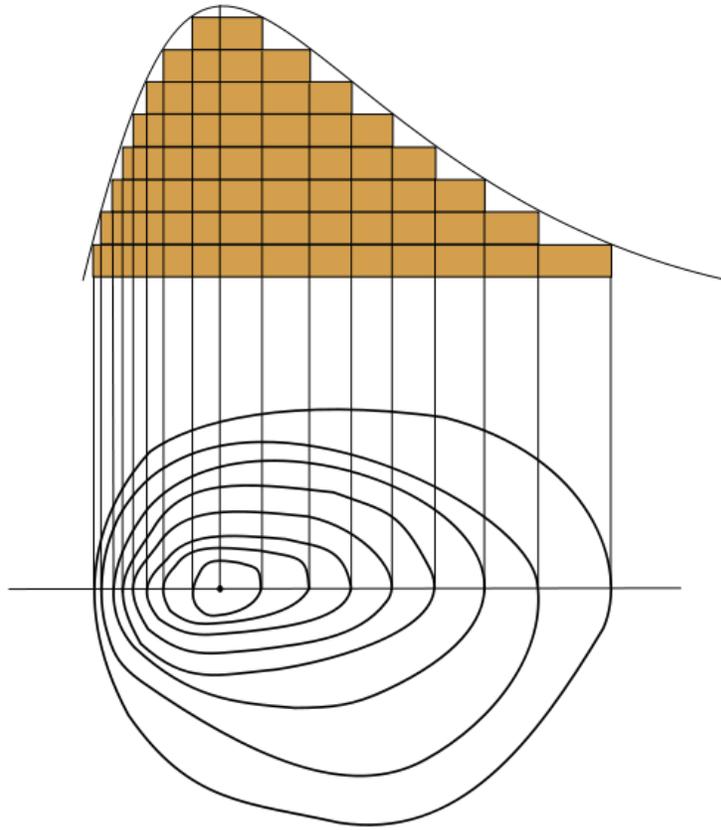
An area cartogram is sometimes referred to as a *value-by-area map* or an *isodemographic map*, the latter particularly for a *population cartogram*, which illustrates the relative sizes of the populations of the countries of the world by scaling the area of each country in proportion to its population; the shape and relative location of each country is retained to as large an extent as possible, but inevitably a large amount of distortion results. Other synonyms in use are *anamorphic map* and *density-equalizing map*. The German word for cartogram is *Kartenanamorphote*, not *Kartogramm*.

## Distance cartogram

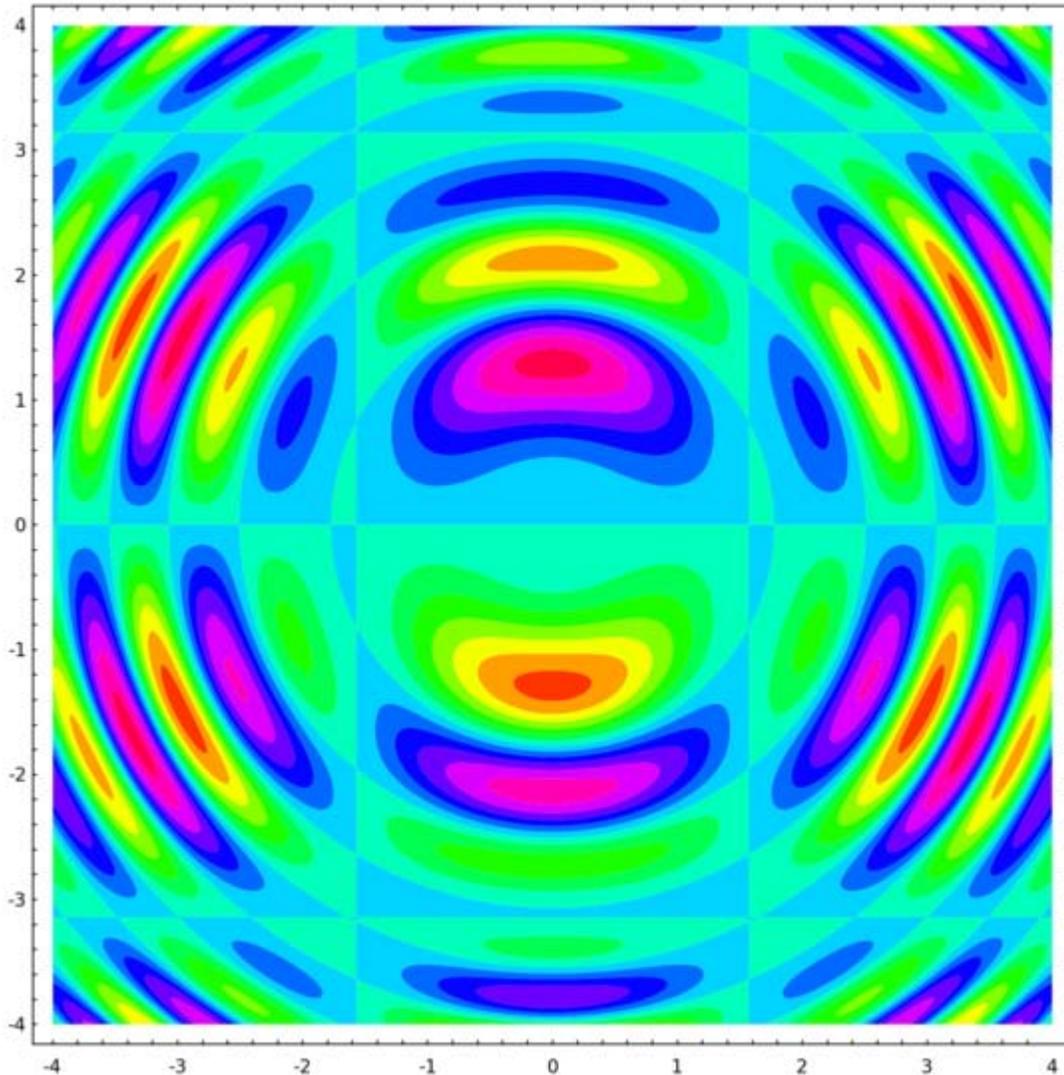
A distance cartogram may also be called a *central-point cartogram*. This form is typically used to show relative travel times and directions from vertices in a network.

One of the first cartographers to generate cartograms with the aid of computer visualization was Waldo Tobler of UC Santa Barbara in the 1960s. Prior to Tobler's work, cartograms were created by hand (as they occasionally still are). A number of software packages generate cartograms. Two examples of computer-generated cartograms are shown on the right.

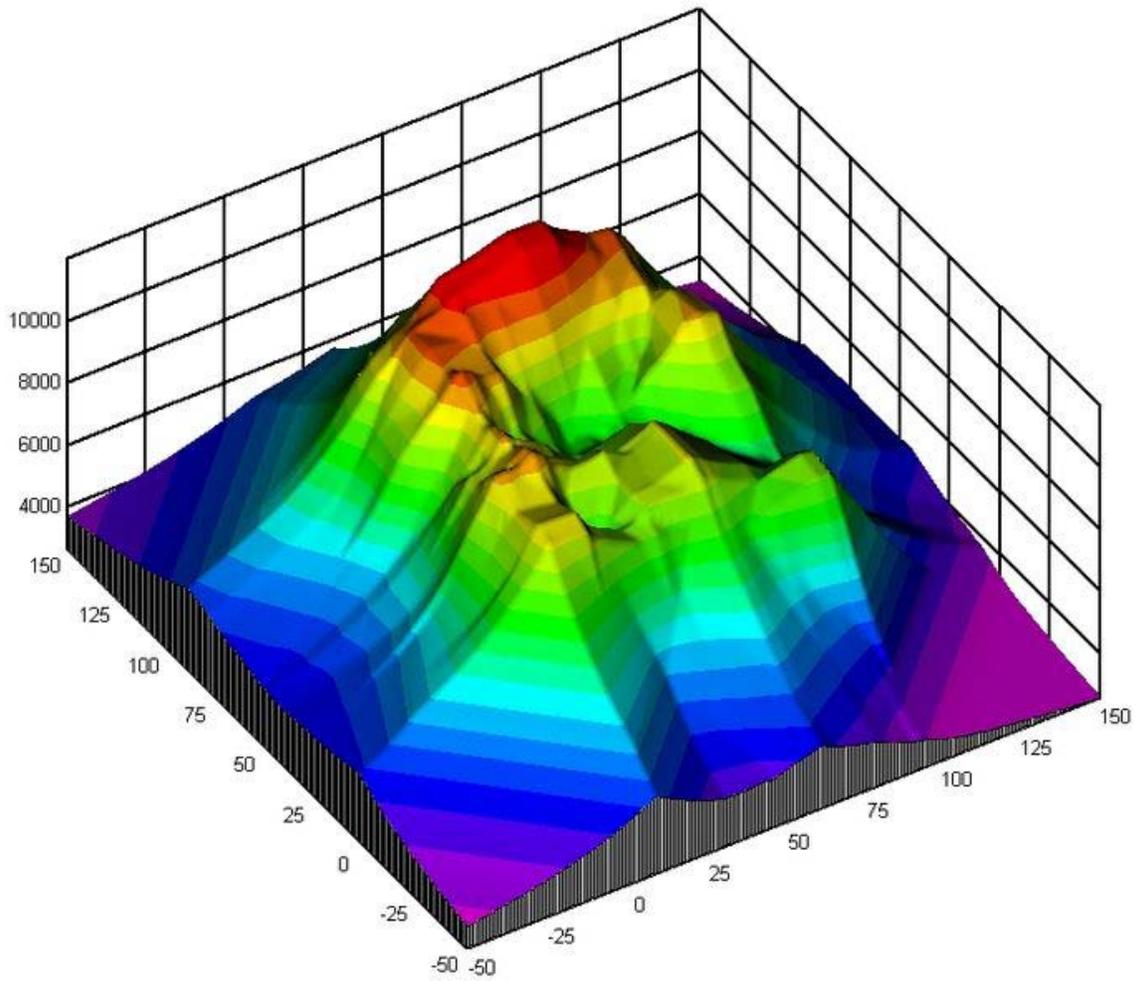
# Contour line



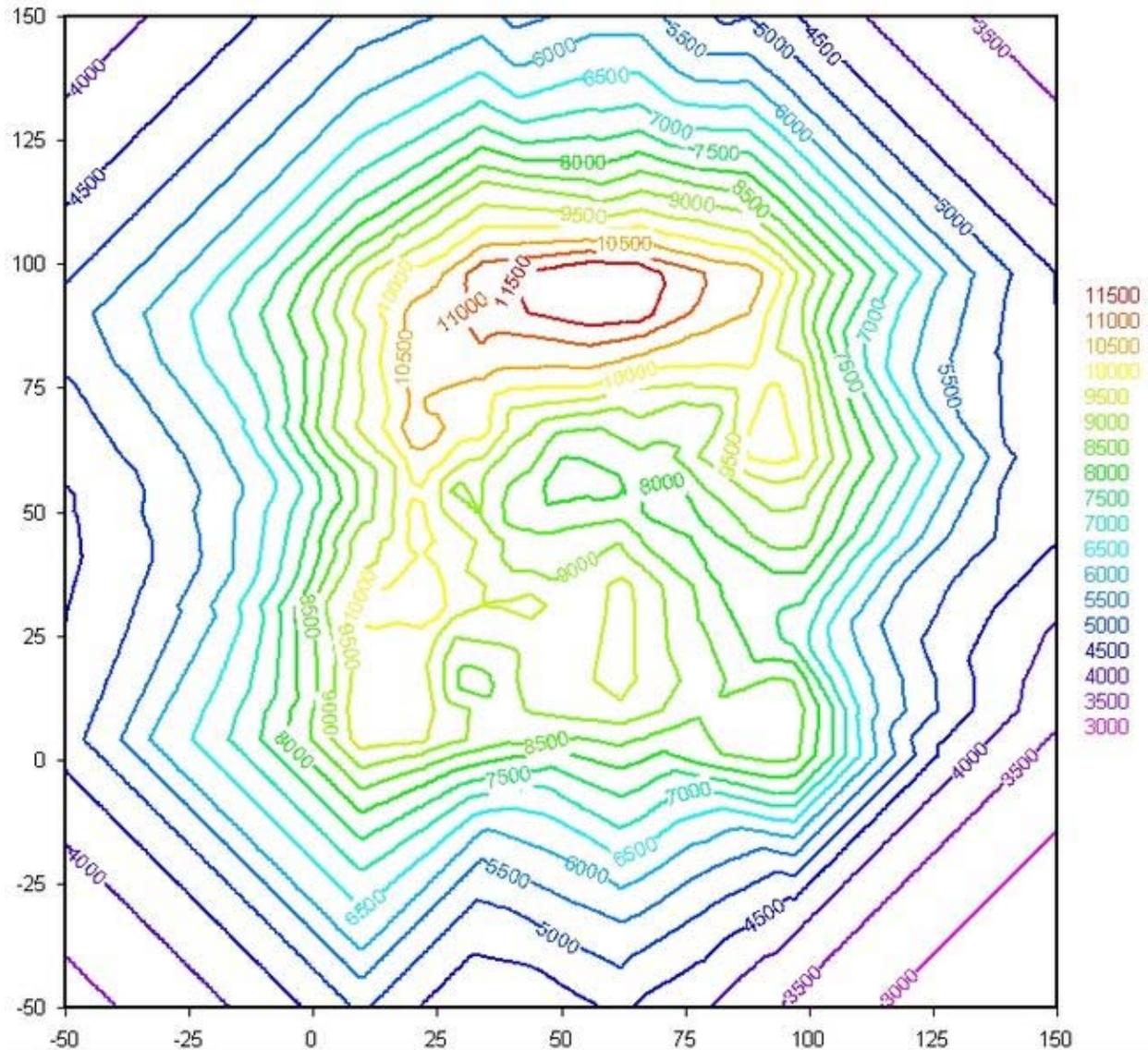
The bottom part of the diagram shows some contour lines with a straight line running through the location of the maximum value. The curve at the top represents the values along that straight line.



A mathematical contour plot of the function  $f(x,y)=\sin(x^2+y^2)\cos(x)\sin(y)$ . Along the x-axis at  $-\pi/2$  and  $\pi/2$  it is constant zero, as it is on the y-axis at all integer multiples of  $\pi$ —hence the lines; the origin-centered circles are  $x^2+y^2 = \pi$ ,  $x^2+y^2 = 2\pi \dots$



A Three Dimensional Contour Graph



A Two Dimensional Contour Graph

A **contour line** (also **isoline** or **isarithm**) of a function of two variables is a curve along which the function has a constant value. In cartography, a contour line (often just called a "contour") joins points of equal elevation (height) above a given level, such as mean sea level. A **contour map** is a map illustrated with contour lines, for example a topographic map, which thus shows valleys and hills, and the steepness of slopes. The **contour interval** of a contour map is the difference in elevation between successive contour lines.

More generally, a contour line for a function of two variables is a curve connecting points where the function has the same particular value. The gradient of the function is always

perpendicular to the contour lines. When the lines are close together the magnitude of the gradient is large: the variation is steep. A level set is a generalization of a contour line for functions of any number of variables.

Contour lines are curved or straight lines on a map describing the intersection of a real or hypothetical surface with one or more horizontal planes. The configuration of these contours allows map readers to infer relative gradient of a parameter and estimate that parameter at specific places. Contour lines may be either traced on a visible three-dimensional model of the surface, as when a photogrammetrist viewing a stereo-model plots elevation contours, or interpolated from estimated surface elevations, as when a computer program threads contours through a network of observation points of area centroids. In the latter case, the method of interpolation affects the reliability of individual isolines and their portrayal of slope, pits and peaks.

### **Types of contour lines**

Contour lines are often given specific names beginning "iso-" (from Greek *ἴσος* (*isos*), meaning 'equal') according to the nature of the variable being mapped, although in many usages the phrase "contour line" is most commonly used. Specific names are most common in meteorology, where multiple maps with different variables may be viewed simultaneously. The prefix "iso-" can be replaced with "isallo-" to specify a contour line connecting points where a variable changes at the same *rate* during a given time period (also termed as *isobar*).

The words *isoline* and *isarithm* (from *αριθμός* or *arithmos*, meaning 'number') are general terms covering all types of contour line. The word *isogram* (from *γράμμα* or *gramma*, meaning 'something written or drawn') was proposed by Francis Galton in 1889 as a convenient generic designation for lines indicating equality of some physical condition or quantity; but it commonly refers to a word without a repeated letter.

An **isogon** (from *γωνία* or *gonia*, meaning 'angle') is a contour line for a variable which measures direction. In meteorology and in geomagnetics, the term *isogon* has specific meanings which are described below. An **isocline** (from *κλίνειν* or *klinein*, meaning 'to lean or slope') is a line joining points with equal slope. In population dynamics and in geomagnetics, the terms *isocline* and *isoclinic line* have specific meanings which are described below.

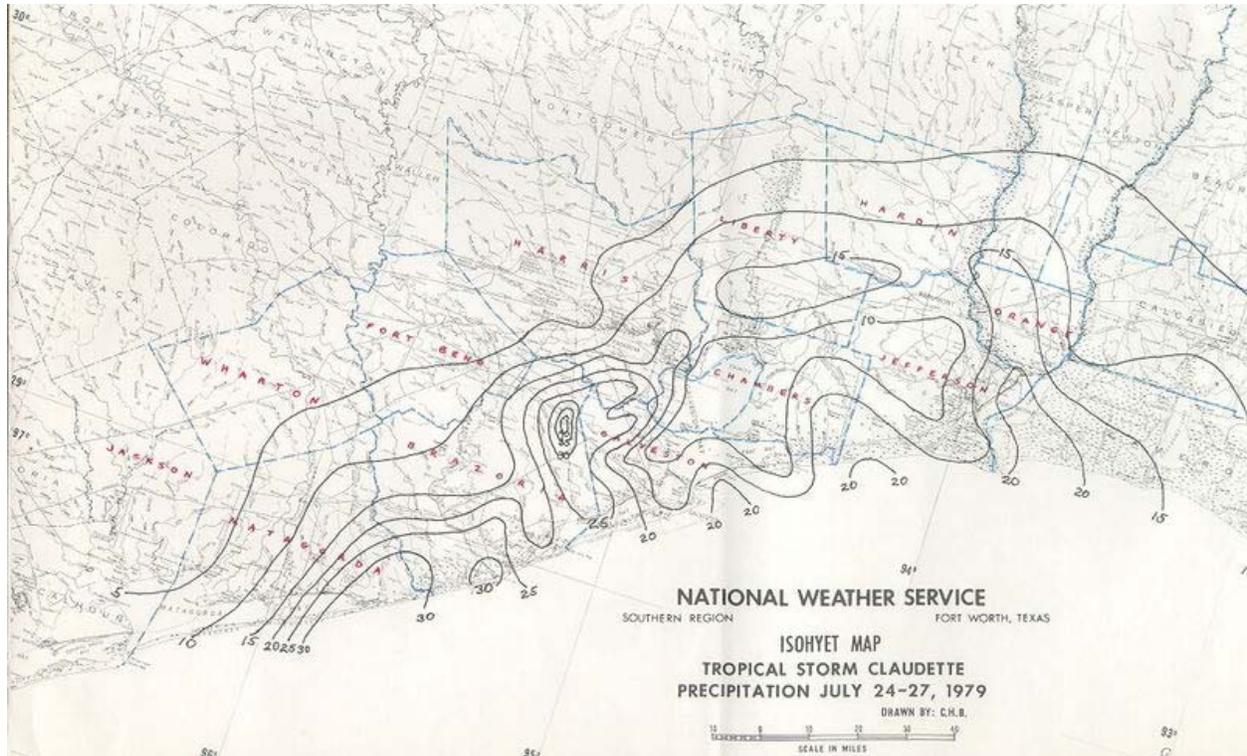
### **Isopleths**

In geography, the word *isopleth* (from *πλήθος* or *plethos*, meaning 'quantity') is used for contour lines that depict a variable which cannot be measured at a point, but which instead must be calculated from data collected over an area. An example is population density, which can be calculated by dividing the population of a census district by the

surface area of that district. Each calculated value is presumed to be the value of the variable at the centre of the area, and isopleths can then be drawn by a process of interpolation. The idea of an isopleth map can be compared with that of a choropleth map.

In meteorology, the word *isopleth* is used for any type of contour line.

## Meteorology



Isohyetal map

Meteorological contour lines are based on generalization from point data received from weather stations. Weather stations are seldom exactly positioned at a contour line (when they are, this indicates a measurement precisely equal to the value of the contour). Instead, lines are drawn to best approximate the locations of exact values, based on the scattered information points available.

Meteorological contour maps may present collected data such as actual air pressure at a given time, or generalized data such as average pressure over a period of time, or forecast data such as predicted air pressure at some point in the future

Thermodynamic diagrams use multiple overlapping contour sets (including isobars and isotherms) to present a picture the major thermodynamic factors in a weather system.

### ***Barometric pressure***

An **isobar** (from *βαρος* or *baros*, meaning 'weight') is a line of equal or constant pressure on a graph, plot, or map; an isopleth or contour line of pressure. More accurately, isobars are lines drawn on a map joining places of equal average atmospheric pressure reduced to sea level for a specified period of time. In meteorology, the barometric pressures shown are reduced to sea level, not the surface pressures at the map locations. The distribution of isobars is closely related to the magnitude and direction of the wind field, and can be used to predict future weather patterns. Isobars are commonly used in television news weather reporting, though more commonly in Europe than in the United States.

An **isostere** is a line of constant atmospheric density. An **isoheight** or **isohypse** is a line of constant geopotential height on a constant pressure surface chart.

## Temperature and related subjects



The 10°C mean isotherm in July, marked by the red line, is commonly used to define the Arctic region border

An **isotherm** (from *θερμη* or *thermē*, meaning 'heat') is a line that connects points on a map that have the same temperature. Therefore, all points through which an isotherm passes have the same temperatures at the time indicated. Generally, isotherms representing 5°C or 10°F temperature differences are used, but any interval may be chosen.

An **isogeotherm** is a line of equal mean annual temperature. An **isoheim** is a line of equal mean winter temperature, and an **isother** is a line of equal mean summer temperature.

An **isohel** (from *ἥλιος* or *helios*, meaning 'sun') is a line of equal or constant solar radiation.

### ***Precipitation and air moisture***

An **isohyet** or **isohyetal line** (from *ὑετος* or *huetos*, meaning 'rain') is a line joining points of equal precipitation on a map. A map with isohyets is called an **isohyetal map**.

An **isohume** is a line of constant relative humidity, while a **isodrosotherm** (from *δρσοος* or *drosos*, meaning 'dew', and *θερμη* or *therme*, meaning 'heat') is a line of equal or constant dew point.

An **isoneph** is a line indicating equal cloud cover.

An **isochalaz** is a line of constant frequency of hail storms, and an **isobront** is a line drawn through geographical points at which a given phase of thunderstorm activity occurred simultaneously.

Snow cover is frequently shown as a contour-line map.

### ***Wind***

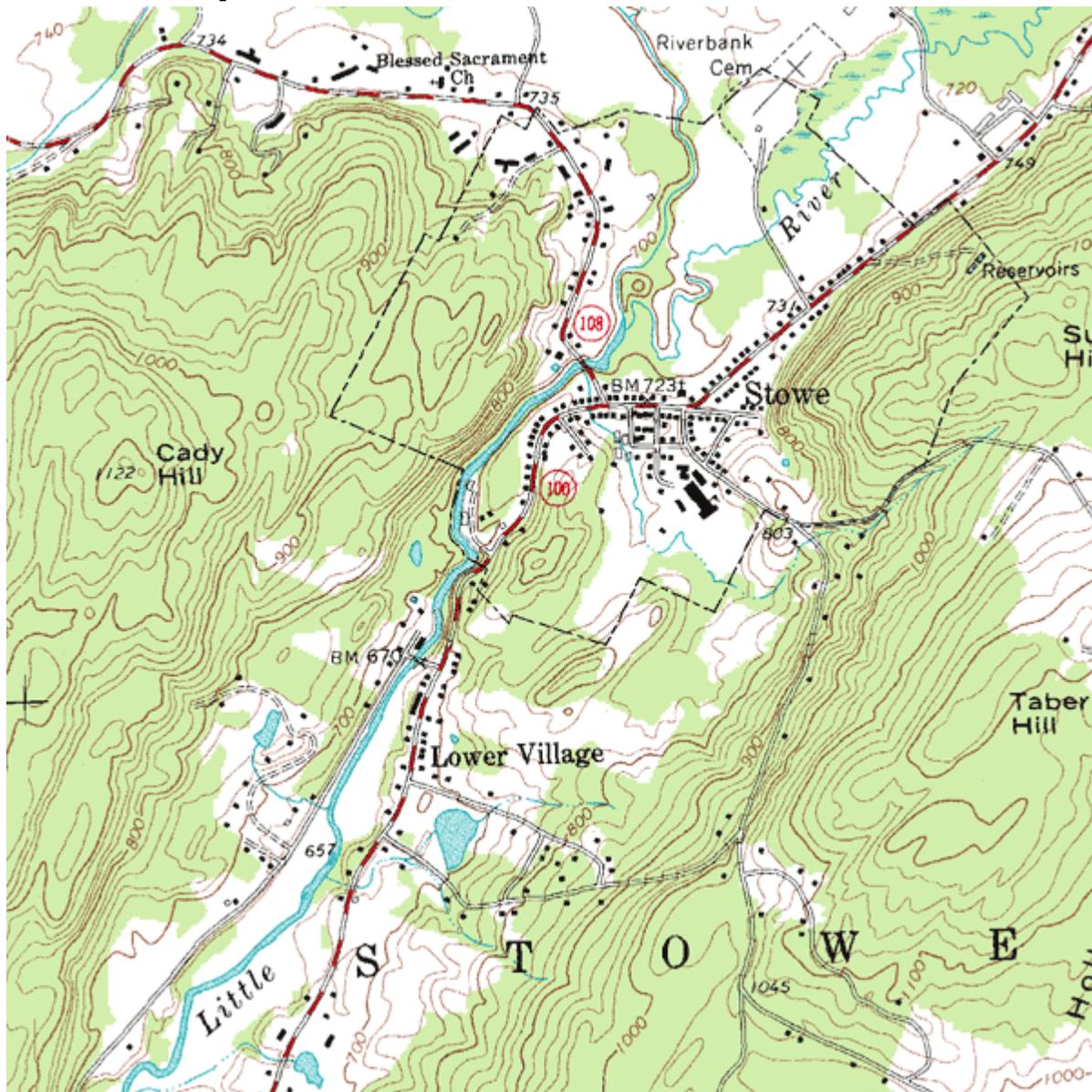
An **isotach** (from *ταχ* or *tach*, meaning 'speed') is a line of constant wind speed. In meteorology, the term **isogon** refers to a line of constant wind direction.

### ***Freeze and thaw***

An **isoplectic** line denotes equal dates of ice formation each winter, and an **isotac** denotes equal dates of thawing.

## Physical geography and oceanography

### *Elevation and depth*



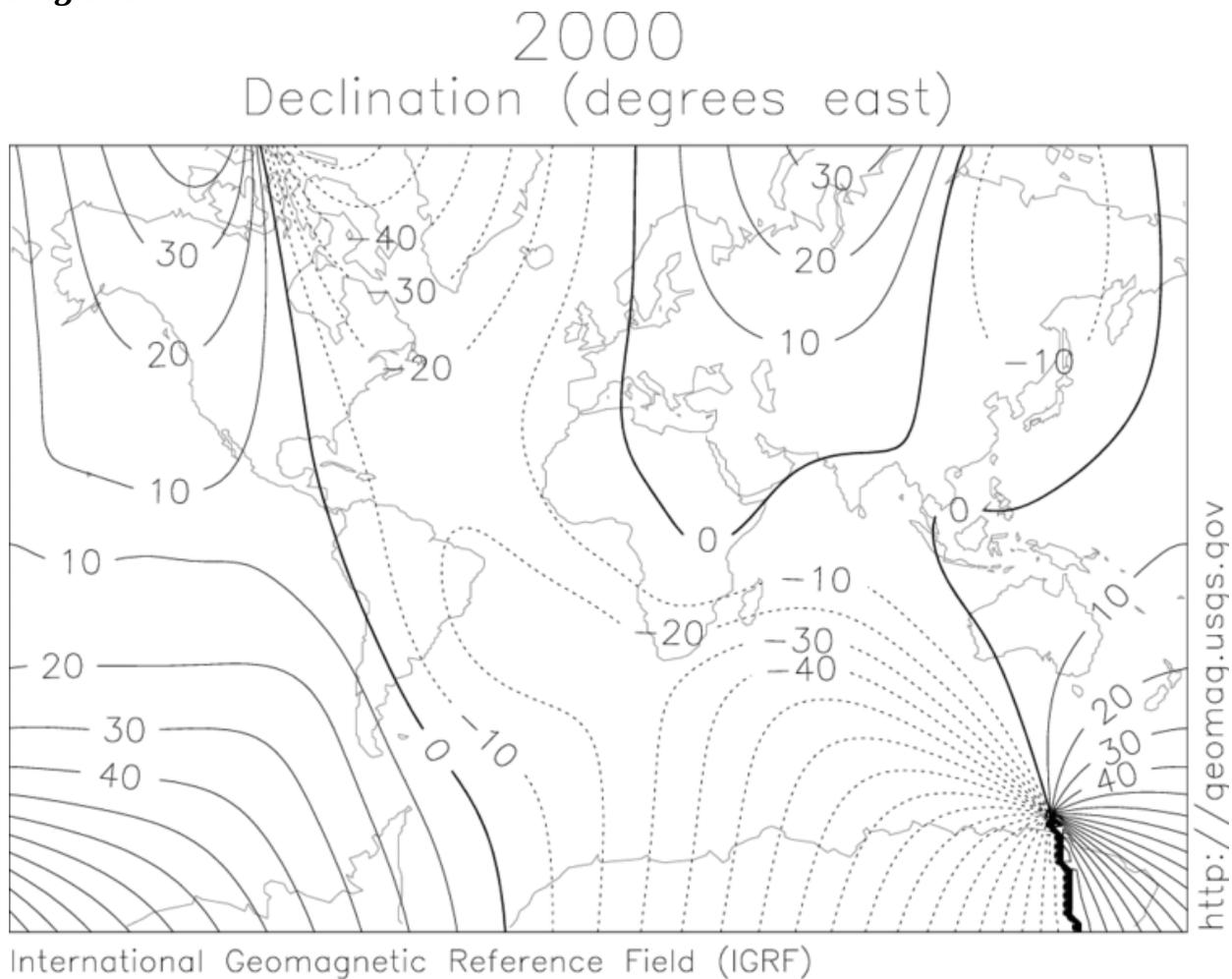
Topographic map of Stowe, Vermont. The brown contour lines represent the elevation. The contour interval is 20 feet.

Contours are one of several common methods used to denote elevation or altitude and depth on maps. From these contours, a sense of the general terrain can be determined. They are used at a variety of scales, from large-scale engineering drawings and architectural plans, through topographic maps up to continental-scale maps.

"Contour line" is the most common usage in cartography, but isobath for underwater depths on bathymetric maps and **isohypse** for elevations are also used. The process of drawing isohypse contour lines on a map is called *isoplethion*.

In cartography, a **contour interval** is any space between contour lines, representing a difference in elevation between the lines. When calculated as a ratio against the map scale, a sense of the hilliness of the terrain can be derived.

### **Magnetism**



Isogonic lines for the year 2000. The agonic lines are thicker and labeled with "0".

In the study of the Earth's magnetic field, the term **isogon** or **isogonic line** refers to a line of constant magnetic declination, the variation of magnetic north from geographic north. An **agonic line** is drawn through points of zero magnetic declination.

An **isoclinic line** connects points of equal magnetic dip, and an **acclinic line** connects those where the magnetic dip is zero.

An **isodynamic line** (from *δύναμις* or *dynamis* meaning 'power') connects points with the same intensity of magnetic force.

## ***Oceanography***

Besides ocean depth, oceanographers use contour to describe diffuse variable phenomena much as meteorologists do with atmospheric phenomena. In particular, **isobathotherms** are lines showing depths of water with equal temperature, **isohalines** show lines of equal ocean salinity, and **Isopycnals** are surfaces of equal water density.

## **Geology**

Various geological data are rendered as contour maps in structural geology, sedimentology, stratigraphy and economic geology. Contour maps are used to show the below ground surface of geologic strata, fault surfaces (especially low angle thrust faults) and unconformities. Isopach maps use **isopachs** (lines of equal thickness) to illustrate variations in thickness of geologic units.

## **Environmental science**

In discussing pollution, density maps can be very useful in indicating sources and areas of greatest contamination. Contour maps are especially useful for diffuse forms or scales of pollution. Acid precipitation is indicated on maps with **isoplats**. Some of the most widespread applications of environmental science contour maps involve mapping of environmental noise (where lines of equal sound pressure level are denoted **isobels**), air pollution, soil contamination, thermal pollution and groundwater contamination.

## **Social sciences**

In economics, contour lines can be used to describe features which vary quantitatively over space. An **isochrone** shows lines of equivalent drive time or travel time to a given location. An **isotim** shows equivalent transport costs from the source of a raw material, and an **isodapane** shows equivalent cost of travel time.

Indifference curves are used to show bundles of goods to which a person would assign equal utility. In political science an analogous method is used in understanding coalitions (for example the diagram in Laver and Shepsle's work).

In population dynamics, **isocline** refers to the set of population sizes at which the rate of change, or partial derivative, for one population in a pair of interacting populations is zero.

Isolines can also be used to delineate qualitative differences. An **isogloss**, for example, is used in mapping the geographic spread of linguistic features.

Contour lines are also used in non-geographic charts in economics. An **isoquant** is a line of equal production quantity, and an **isocost** shows equal production costs.

### **Thermodynamics, engineering, and other sciences**

Various types of graphs in thermodynamics, engineering, and other sciences use isobars (for showing constant pressure), isotherms (for constant temperature), isochors (for constant specific volume), or other types of iso-lines (or curves), even though these graphs are usually not related to maps. Such iso-lines are useful for representing more than two dimensions (or quantities) on two-dimensional graphs. Common examples in thermodynamics are some types of phase diagrams.

**Isoclines** are used to solve ordinary differential equations.

In interpreting radar images, an **isodop** is a line of equal Doppler velocity, and an **isoecho** is a line of equal radar reflectivity.

### **Other phenomena**

- isochasm: aurora equal occurrence
- isochor: volume
- isodose: radiation intensity
- isophene: biological events occurring with coincidence such as plants flowering
- isophote: illuminance

### **History**

The idea of lines that join points of equal value was rediscovered several times. In 1701, Edmond Halley used such lines (isogons) on a chart of magnetic variation. The Dutch engineer Nicholas Cruquius drew the bed of the river Merwede with lines of equal depth (isobaths) at intervals of 1 fathom in 1727, and Philippe Buache used them at 10-fathom intervals on a chart of the English Channel that was prepared in 1737 and published in 1752. The use of such lines to describe a land surface (contour lines) was studied theoretically by Ducarla in 1771, and Charles Hutton used them when calculating the volume of a hill in 1777. In 1791, a map of France by J. L. Dupain-Triel used contour lines at 20-metre intervals, hachures, spot-heights and a vertical section. In 1801, the

chief of the Corps of Engineers, Haxo, used contour lines at the larger scale of 1:500 on a plan of his projects for Rocca d'Aufo.

By around 1843, when the Ordnance Survey started to regularly record contour lines in Great Britain and Ireland, they were already in general use in European countries. Isobaths were not routinely used on nautical charts until those of Russia from 1834, and those of Britain from 1838.

When maps with contour lines became common, the idea spread to other applications. Perhaps the latest to develop are air quality and noise pollution contour maps, which first appeared in the USA, in approximately 1970, largely as a result of national legislation requiring spatial delineation of these parameters. In 2007, Pictometry was the first to allow users to dynamically generate elevation contour lines to be laid over oblique images.

### **Technical construction factors**

To maximize readability of contour maps, there are several design choices available to the map creator, principally line weight, line color, line type and method of numerical marking.

**Line weight** is simply the darkness or thickness of the line used. This choice is made based upon the least intrusive form of contours that enable the reader to decipher the background information in the map itself. If there is little or no content on the base map, the contour lines may be drawn with relatively heavy thickness. Also, for many forms of contours such as topographic maps, it is common to vary the line weight and/or color, so that a different line characteristic occurs for certain numerical values. For example, in the topographic map above, the even hundred foot elevations are shown in a different weight from the twenty foot intervals.

**Line color** is the choice of any number of pigments that suit the display. Sometimes a sheen or gloss is used as well as color to set the contour lines apart from the base map. Line colour can be varied to show other information.

**Line type** refers to whether the basic contour line is solid, dashed, dotted or broken in some other pattern to create the desired effect. Dotted or dashed lines are often used when the underlying base map conveys very important (or difficult to read) information. Broken line types are used when the location of the contour line is inferred.

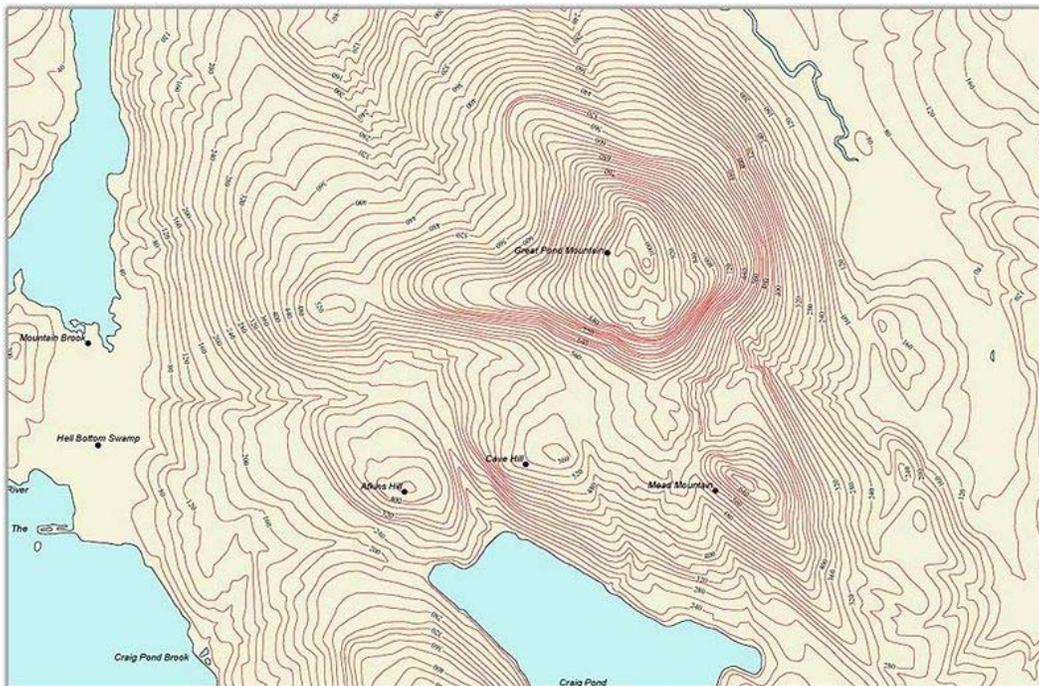
**Numerical marking** is the manner of denoting the arithmetical the values of contour lines. This can be done by placing numbers along some of the contour lines, typically using interpolation for intervening lines. Alternatively a map key can be produced associating the contours with their values.

If the contour lines are not numerically labeled and adjacent lines have the same style (with the same weight, color and type), then the direction of the gradient cannot be determined from the contour lines alone. However if the contour lines cycle through three or more styles, then the direction of the gradient can be determined from the lines. The orientation of the numerical text labels is often used to indicate the direction of the slope.

### **Plan view versus profile view**

Most commonly contour lines are drawn in plan view, or as an observer in space would view the Earth's surface: ordinary map form. However, some parameters can often be displayed in profile view showing a vertical profile of the parameter mapped. Some of the most common parameters mapped in profile are air pollutant concentrations and sound levels. In each of those cases it may be important to analyze (air pollutant concentrations or sound levels) at varying heights so as to determine the air quality or noise health effects on people at different elevations, for example, living on different floor levels of an urban apartment. In actuality, both plan and profile view contour maps are used in air pollution and noise pollution studies.

### **Labeling contour maps**



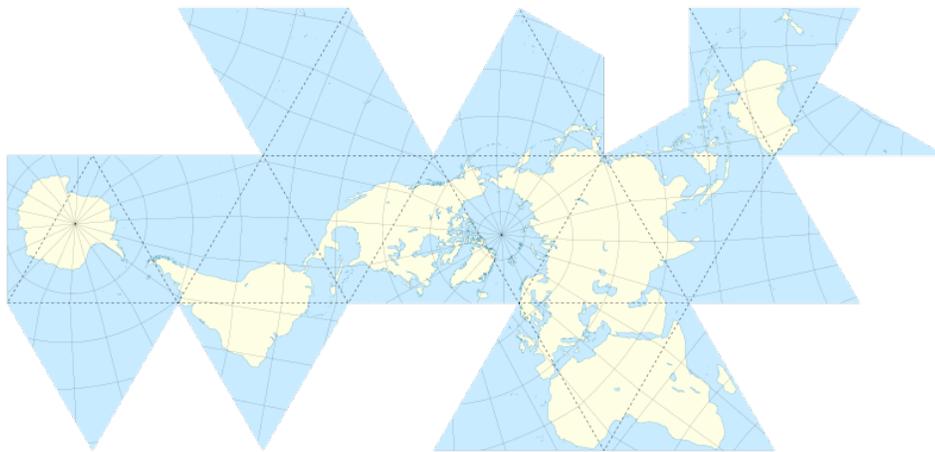
Contour map labeled aesthetically in an "elevation up" manner.

Labels are a critical component of elevation maps. A properly labeled contour map helps the reader to quickly interpret the shape of the terrain. If numbers are placed close to each other, it means that the terrain is steep. Labels should be placed along a slightly curved

line "pointing" to the summit or nadir, from several directions if possible, making the visual identification of the summit or nadir easy.

Manual labeling of contour maps is a time-consuming process, however, there are a few software systems that can do the job automatically and in accordance with cartographic conventions, called automatic label placement.

## **Dymaxion map**



Unfolded Dymaxion map with nearly-contiguous land masses



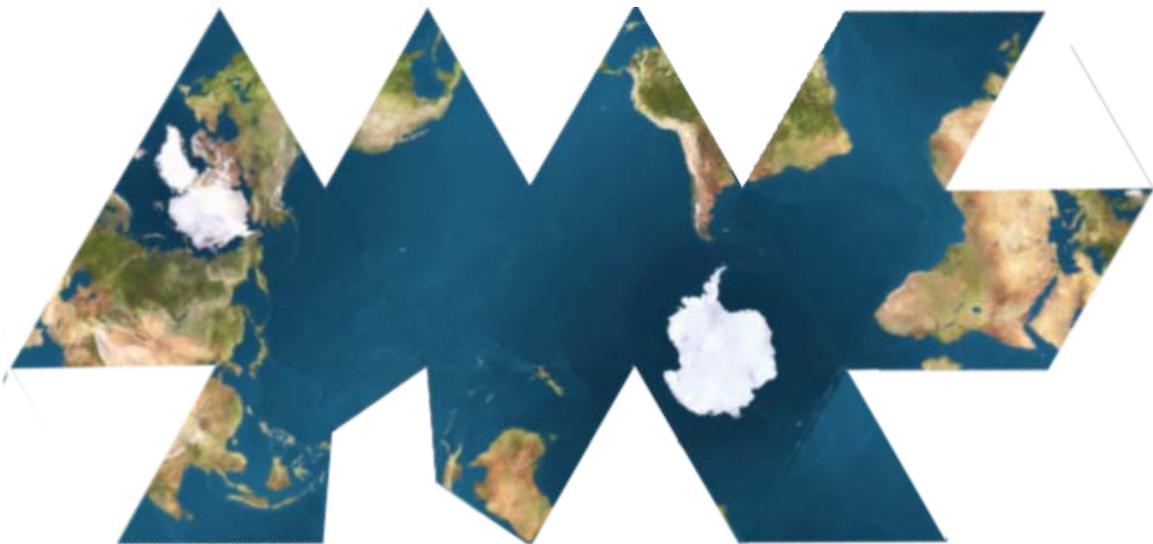
Unfolded Dymaxion map with nearly-contiguous land masses



Dymaxion map as an unfolded icosahedron



Another rendering of a Dymaxion map



This icosahedral net shows connected oceans surrounding Antarctica

The **Dymaxion map** or **Fuller map** is a projection of a world map onto the surface of a polyhedron, which can then be unfolded to a net in many different ways and flattened to

form a two-dimensional map which retains most of the relative proportional integrity of the globe map.

It was created by Buckminster Fuller, and patented by him during 1946, the patent application showing a projection onto a cuboctahedron. The 1954 version published by Fuller with the title **The AirOcean World Map** used a slightly modified but mostly regular icosahedron as the base for the projection, and this is the version most commonly referred to today. The name *Dymaxion* was applied by Fuller to several of his inventions.

The Dymaxion projection is intended only for representations of the entire globe. It is not a gnomonic projection, whereby global data expands from the center point of a tangent facet outward to the edges. Instead, each triangle edge of the Dymaxion map matches the scale of a partial great circle on a corresponding globe, and other points within each facet shrink toward its middle, rather than enlarging to the peripheries.

### **Properties**

Fuller claimed that his map had several advantages over other projections for world maps.

It has less distortion of relative size of areas, most notably when compared to the Mercator projection; and less distortion of shapes of areas, notably when compared to the Gall–Peters projection. Other compromise projections attempt a similar trade-off.

More unusually, the Dymaxion map does not have any "right way up". Fuller argued frequently that in the universe there is no "up" and "down", or "north" and "south": only "in" and "out". Gravitational forces of the stars and planets created "in", meaning 'towards the gravitational center', and "out", meaning "away from the gravitational center". He attributed the north-up-superior/south-down-inferior presentation of most other world maps to cultural bias.

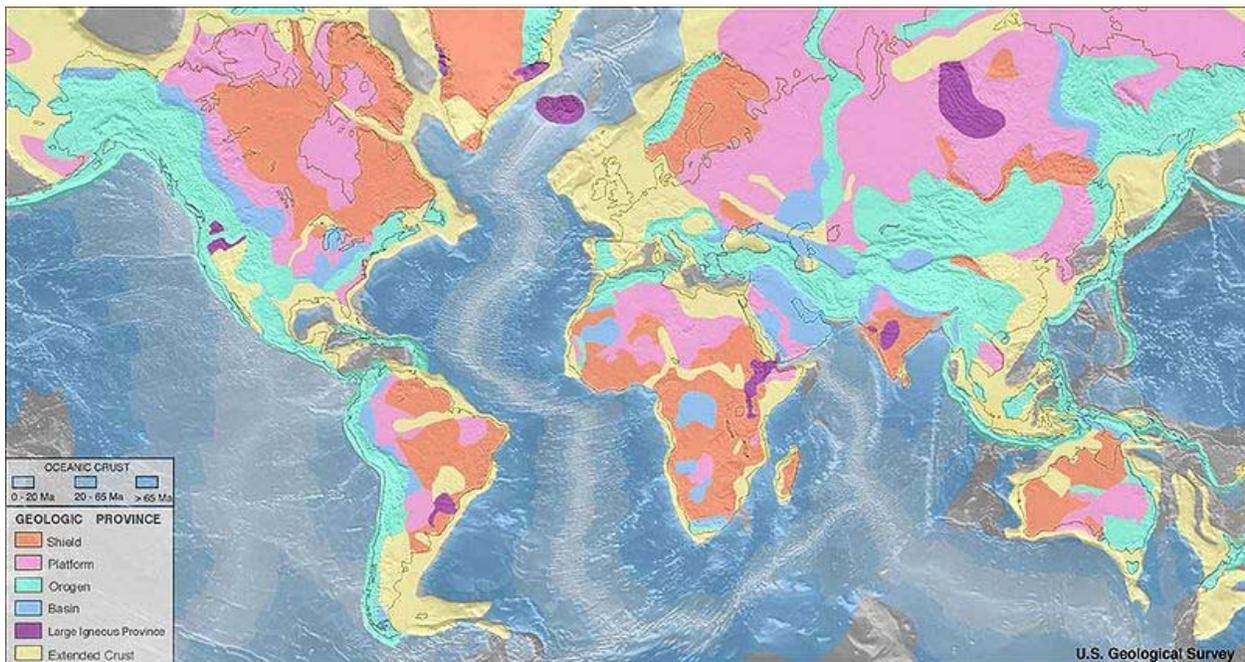
Fuller intended the map to be unfolded in different ways to emphasize different aspects of the world. Peeling the triangular faces of the icosahedron apart in one way results in an icosahedral net that shows an almost contiguous land mass comprising all of earth's continents – not groups of continents divided by oceans. Peeling the solid apart in a different way presents a view of the world dominated by connected oceans surrounded by land.

Showing the continents as "one island earth" also helped Fuller explain, in his book *Critical Path*, the journeys of early seafaring people, who were in effect using prevailing winds to circumnavigate this world island.

## Impact

A 1967 Jasper Johns painting, "*Map (Based on Buckminster Fuller's Dymaxion Airocean World)*", depicting a Dymaxion map, hangs in the permanent collection of the Museum Ludwig in Cologne.

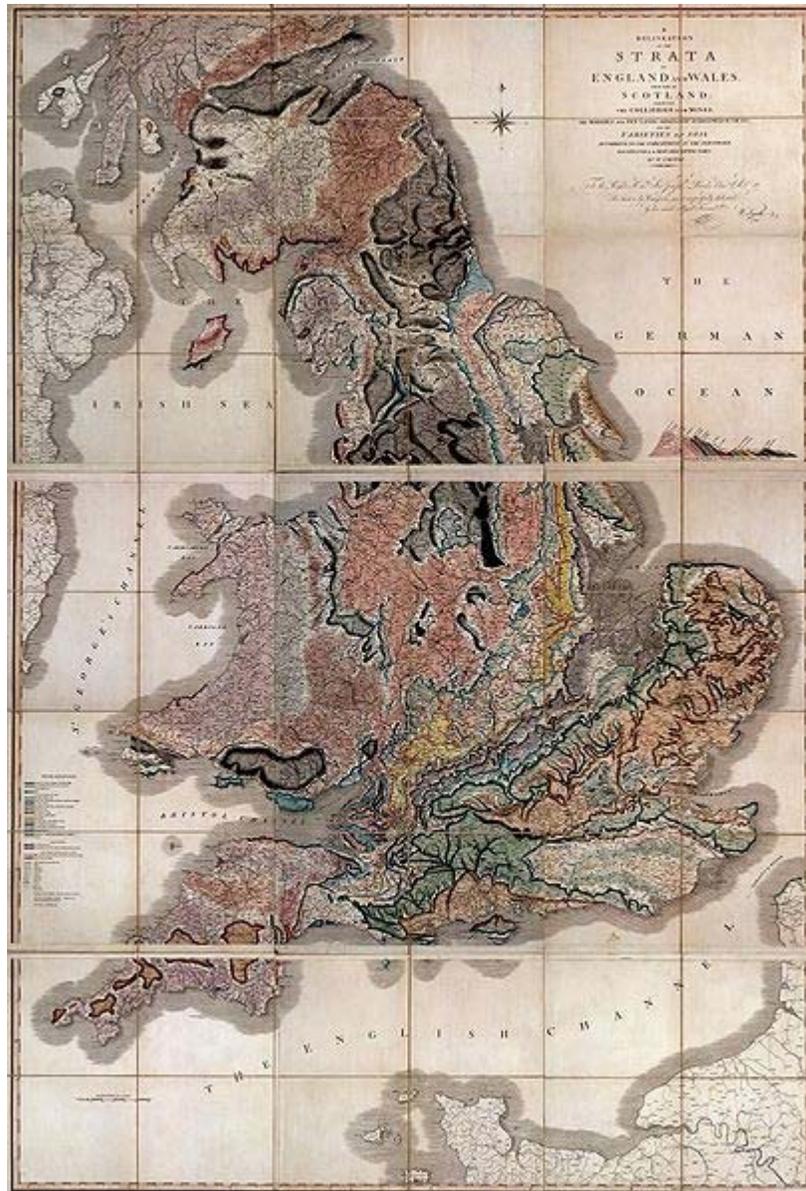
## Geologic map



Mapped global geologic provinces

A **geologic map** or **geological map** is a special-purpose map made to show geological features. Rock units or geologic strata are shown by color or symbols to indicate where they are exposed at the surface. Bedding planes and structural features such as faults, folds, foliations, and lineations are shown with strike and dip or trend and plunge symbols which give these features' three-dimensional orientations.

Stratigraphic contour lines may be used to illustrate the surface of a selected stratum illustrating the subsurface topographic trends of the strata. Isopach maps detail the variations in thickness of stratigraphic units. It is not always possible to properly show this when the strata are extremely fractured, mixed, in some discontinuities, or where they are otherwise disturbed.



William Smith's geologic map

## Lithologies

Rock units are typically represented by colors. Instead of (or in addition to) colors, certain symbols can be used. Different geologic mapping agencies and authorities have different standards for the colors and symbols to be used for rocks of differing types and ages.

## Orientations



A standard Brunton Geo, used commonly by geologists

Geologists take two major types of orientation measurements (using a hand compass like a Brunton compass): orientations of planes and orientations of lines. Orientations of planes are often measured as a "strike" and "dip", while orientations of lines are often measured as a "trend" and "plunge".

Strike and dip symbols consist of a long "strike" line, which is perpendicular to the direction of greatest slope along the surface of the bed, and a shorter "dip" line on side of the strike line where the bed is going downwards. The angle that the bed makes with the horizontal is along the dip direction is written next to the dip line. In the azimuthal system, strike and dip are often given as "STRIKE / DIP" (for example: 347/15, for a strike that is slightly West of North and a dip of 15 degrees below the horizontal).

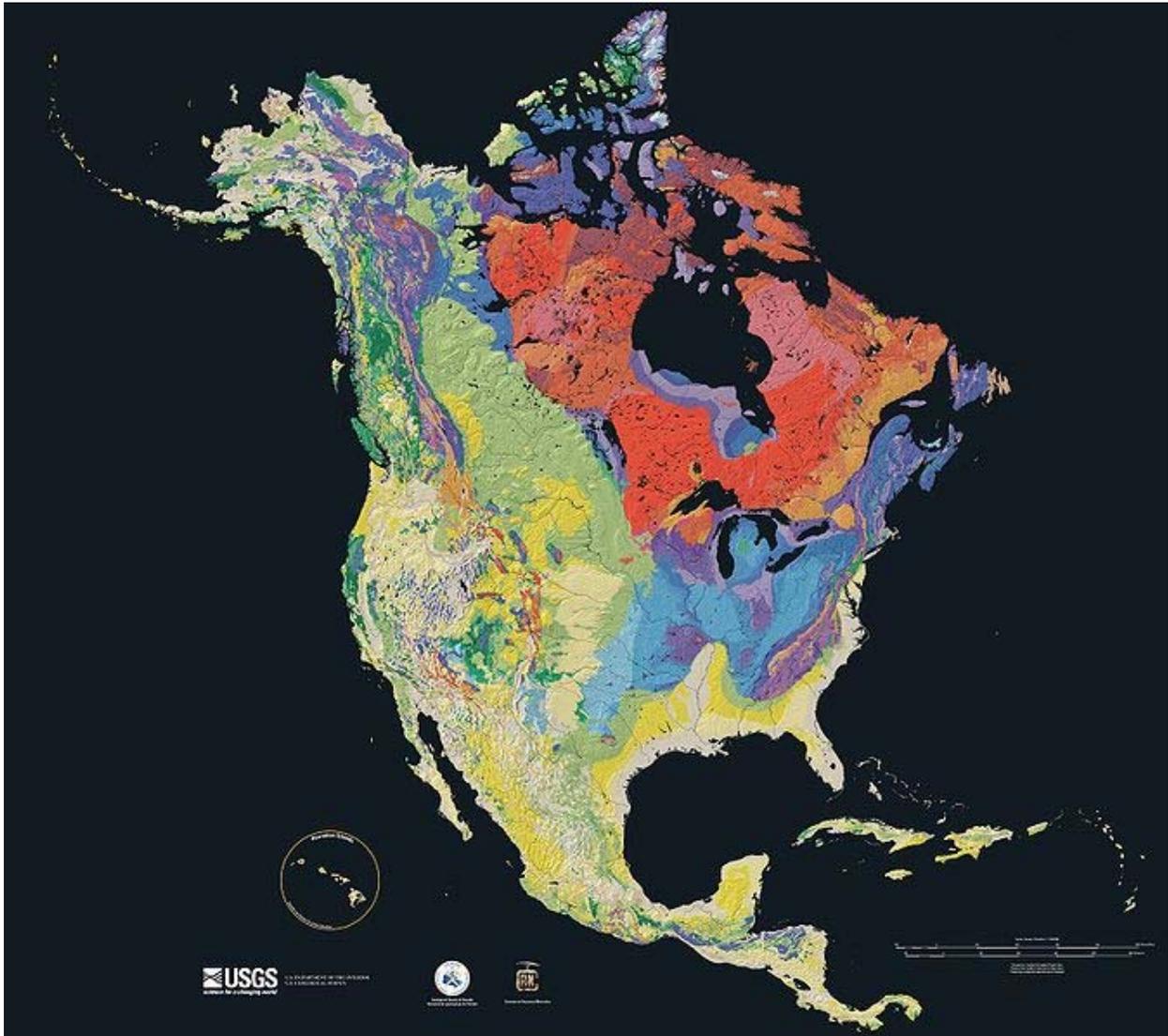
Trend and plunge are used for linear features, and their symbol is a single arrow on the map. The arrow is oriented in the downgoing direction of the linear feature (the "trend") and at the end of the arrow, the number of degrees that the feature lies below the horizontal (the "plunge") is noted. Trend and plunge are often notated as PLUNGE → TREND (for example: 34 → 86 indicates a feature that is angled at 34 degrees below the horizontal at an angle that is just East of true South).

## **History**

The oldest preserved geologic map is the Turin papyrus, made around 1150 BCE for gold deposits in Egypt.

The first geologic map of Great Britain was created by William Smith in 1815.

## Maps and mapping across the globe



Geologic map of North America superimposed on a shaded relief map

### United States

In the United States, geologic maps are usually superimposed over a topographic map (and at times over other base maps) with the addition of a color mask with letter symbols to represent the kind of geologic unit. The color mask denotes the exposure of the immediate bedrock, even if obscured by soil or other cover. Each area of color denotes a geologic unit or particular rock formation (as more information is gathered new geologic units may be defined). However, in areas where the bedrock is overlain by a significantly thick unconsolidated burden of till, terrace sedimentss, loess deposits, or other important feature, these are shown instead. Stratigraphic contour lines, fault lines, strike and dip

symbols, are represented with various symbols as indicated by the map key. Whereas topographic maps are produced by the United States Geological Survey in conjunction with the states, geologic maps are usually produced by the individual states. There are almost no geologic map resources for some states, while a few states, such as Kentucky, are extensively mapped geologically.

## **United Kingdom**

In the United Kingdom the term *geological map* is used. The UK and Isle of Man have been extensively mapped by the British Geological Survey since 1835; a separate Geological Survey of Northern Ireland (drawing on BGS staff) has operated since 1947.

Two 1:625,000 scale maps cover the basic geology for the UK. More detailed sheets are available at scales of 1:250,000, 1:50,000 and 1:10,000. The 1:625,000 and 1:250,000 scales show both onshore and offshore geology (the 1:250,000 series covers the entire UK continental shelf), whilst other scales generally cover exposures on land only.

Sheets of all scales (though not for all areas) fall into two categories:

Superficial deposit maps (previously known as *solid and drift* maps) show both bedrock *and* the deposits on top of it.

Bedrock maps (previously known as *solid* maps) show the underlying rock, without superficial deposits.

The maps are superimposed over a topographic map base produced by Ordnance Survey, and use symbols to represent fault lines, strike and dip or geological units, boreholes etc. Colors are used to represent different geological units. Explanatory booklets (memoirs) are produced for many sheets at the 1:50,000 scale.

Small scale thematic maps (1:1,000,000 to 1:100,000) are also produced covering geochemistry, gravity anomaly, magnetic anomaly, groundwater, etc.

Although BGS maps show the National Grid and employ an OS base map, sheet boundaries are not based on the grid. The 1:50,000 sheets originate from earlier 'one inch to the mile' (1:63,630) coverage utilising the pre-grid Ordnance Survey One Inch Third Edition as the base map. Current sheets are a mixture of modern field mapping at 1:10,000 redrawn at the 1:50,000 scale and older 1:63,630 maps reproduced on a modern base map at 1:50,000. In both cases the original OS Third Edition sheet margins and numbers are retained. The 1:250,000 sheets are defined using lines of latitude and longitude, each extending 1° north-south and 2° east-west.

## Singapore

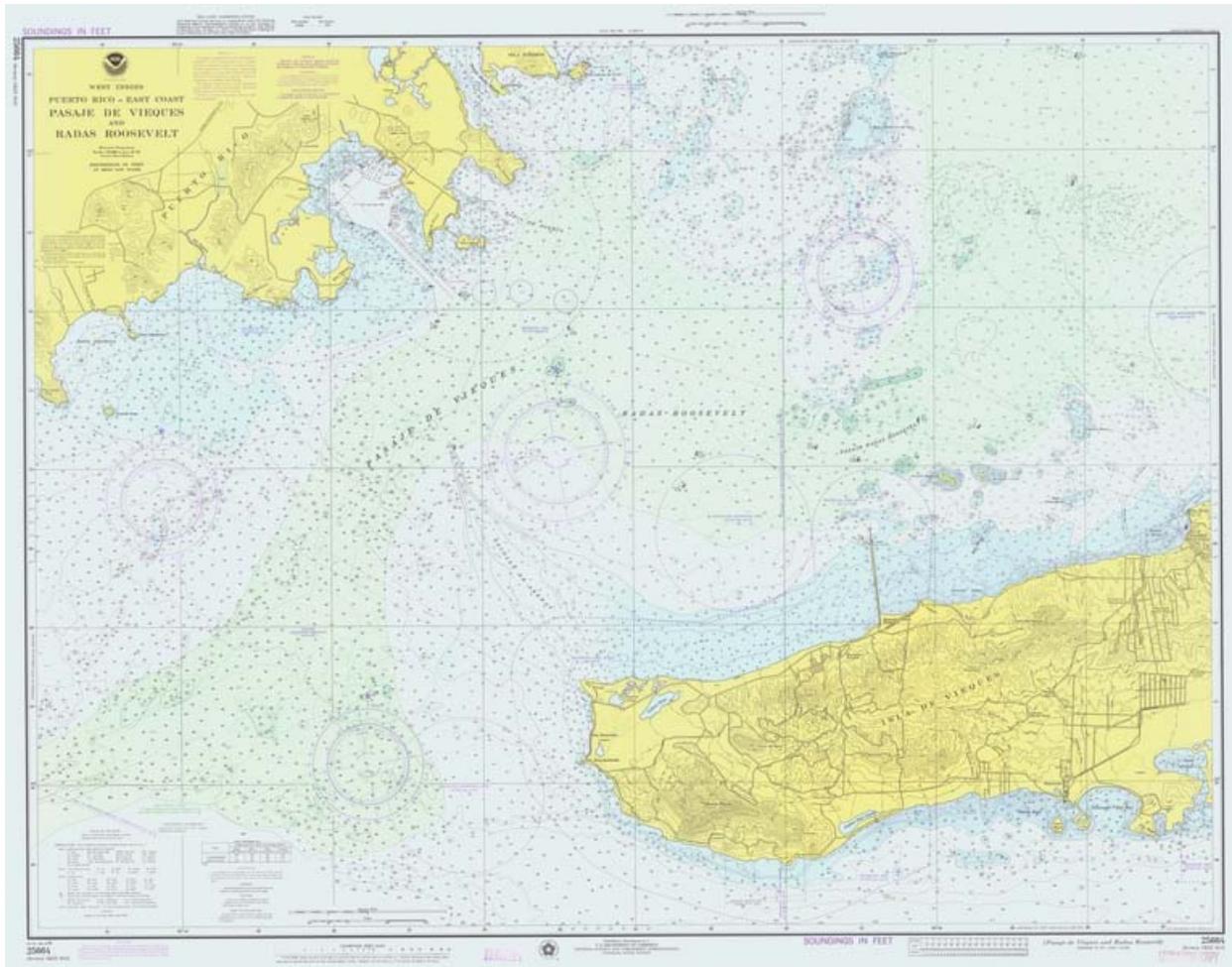
The first geologic map of Singapore was produced in 1974, produced by the then Public Work Department. The publication include a locality map, 8 map sheets detailing the topography and geological units, and a sheet containing cross sections of the island.

Since 1974, for 30 years, there were many finding reported in various technical conferences on new found geology islandwide, but no new publication was produced. In 2006, Defence Science & Technology Agency, with their developments in underground space promptly started a re-publication of the Geology of Singapore, second edition. The new edition that was published in 2009, contains a 1:75,000 geology map of the island, 6 maps (1:25,000) containing topography, street directory and geology, a sheet of cross section and a locality map.

The difference found between the 1976 Geology of Singapore report include numerous formations found in literature between 1976 and 2009. These include the Fort Canning Boulder Beds and stretches of limestones.

## Nautical chart

A **nautical chart** is a graphic representation of a maritime area and adjacent coastal regions. Depending on the scale of the chart, it may show depths of water and heights of land (topographic map), natural features of the seabed, details of the coastline, navigational hazards, locations of natural and man-made aids to navigation, information on tides and currents, local details of the Earth's magnetic field, and man-made structures such as harbours, buildings, and bridges. Nautical charts are essential tools for marine navigation; many countries require vessels, especially commercial ships, to carry them. Nautical charting may take the form of charts printed on paper or computerised electronic navigational charts. Recent technologies have made available paper charts which are printed "on demand" with cartographic data that has been downloaded to the commercial printing company as recently as the night before printing. With each daily download, critical data such as Local Notice to Mariners is added to the on-demand chart files so that these charts will be 100% up to date at the time of printing.



A 1976 United States NOAA chart of part of Puerto Rico

### **Sources and publication of nautical charts**

Nautical charts are based on hydrographic surveys. As surveying is laborious and time-consuming, hydrographic data for many areas of sea may be dated and not always reliable. Depths are measured in a variety of ways. Historically the sounding line was used. In modern times, echo sounding is used for measuring the seabed in the open sea. When measuring the safe depth of water over an entire obstruction, such as a shipwreck, the minimum depth is checked by sweeping the area with a length of horizontal wire. This ensures that difficult to find projections, such as masts, do not present a danger to vessels navigating over the obstruction.

Nautical charts are issued by the national hydrographic offices in many countries. These charts are considered "official" in contrast to those made by commercial publishers. Many hydrographic offices provide regular, sometimes weekly, manual updates of their

charts through their sales agents. Individual hydrographic offices produce national chart series and international chart series. Coordinated by the International Hydrographic Organization, the international chart series is a worldwide system of charts ("INT" chart series), which is being developed with the goal of unifying as many chart systems as possible.

There are also commercially published charts, some of which may carry additional information of particular interest, e.g. for yacht skippers.

### Free nautical charts



OpenSeaMap - the free nautical chart

The US National Oceanic and Atmospheric Administration is now offering complete detailed nautical charts for free download for home printing for the entire US coast. The charts are continuously updated. This should improve the safety at sea, while reducing

costs for mariners. Note, however, that these print-at-home charts will typically not offer the detail that "full size" NOAA charts do.

Marine GeoGarage is the first nautical chart web portal in the Cloud. The website allows to freely view seamless georeferenced nautical raster chart layers issued from different Hydrographic Services (NOAA US, Linz NZ, DNH Brazil) upon Google Maps imagery. Additional free features are available for the user (voyage planning, waypoint and route monitoring with transfer to GPS, bearing and distance calculations).

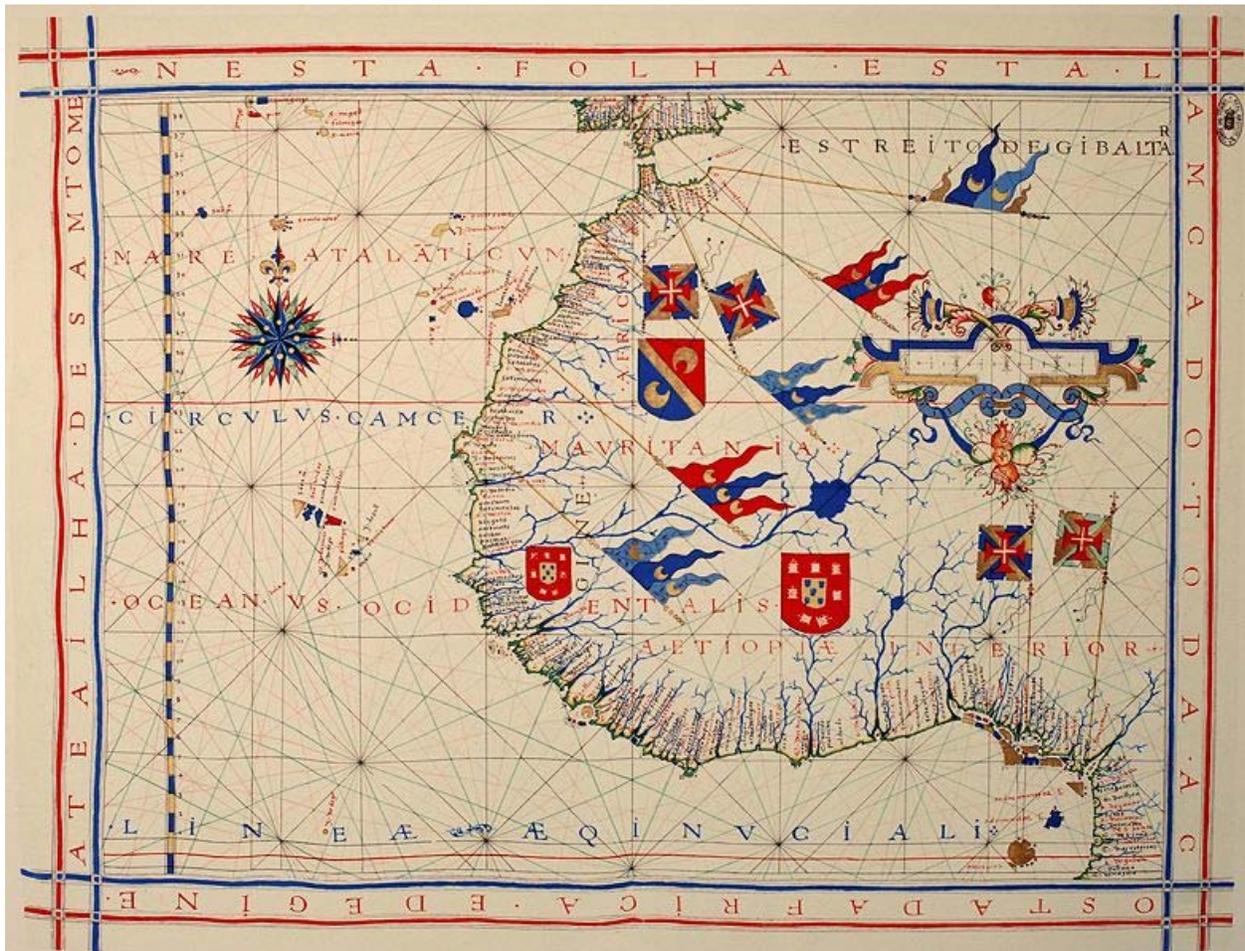
### **Chart correction**

The nature of a waterway depicted by a chart may change, and artificial aids to navigation may be altered at short notice. Therefore, old or uncorrected charts should never be used for navigation. Every producer of nautical charts also provides a system to inform mariners of changes that affect the chart. In the United States, chart corrections and notifications of new editions are provided by various governmental agencies by way of Notice to Mariners, Local Notice to Mariners, Summary of Corrections, and Broadcast Notice to Mariners. In the U.S., NOAA also has a printing partner who prints the "POD" (print on demand) NOAA charts, and they contain the very latest corrections and notifications at the time of printing. Radio broadcasts give advance notice of urgent corrections.

A good way to keep track of corrections is with a *Chart and Publication Correction Record Card* system. Using this system, the navigator does not immediately update every chart in the portfolio when a new *Notice to Mariners* arrives, instead creating a card for every chart and noting the correction on this card. When the time comes to use the chart, he pulls the chart and chart's card, and makes the indicated corrections on the chart. This system ensures that every chart is properly corrected prior to use. A prudent mariner should obtain a new chart if he or she has not kept track of corrections and his chart is more than several months old.

Various and diverse methods exist for the correction of electronic navigational charts.

## Map projection, positions, and bearings



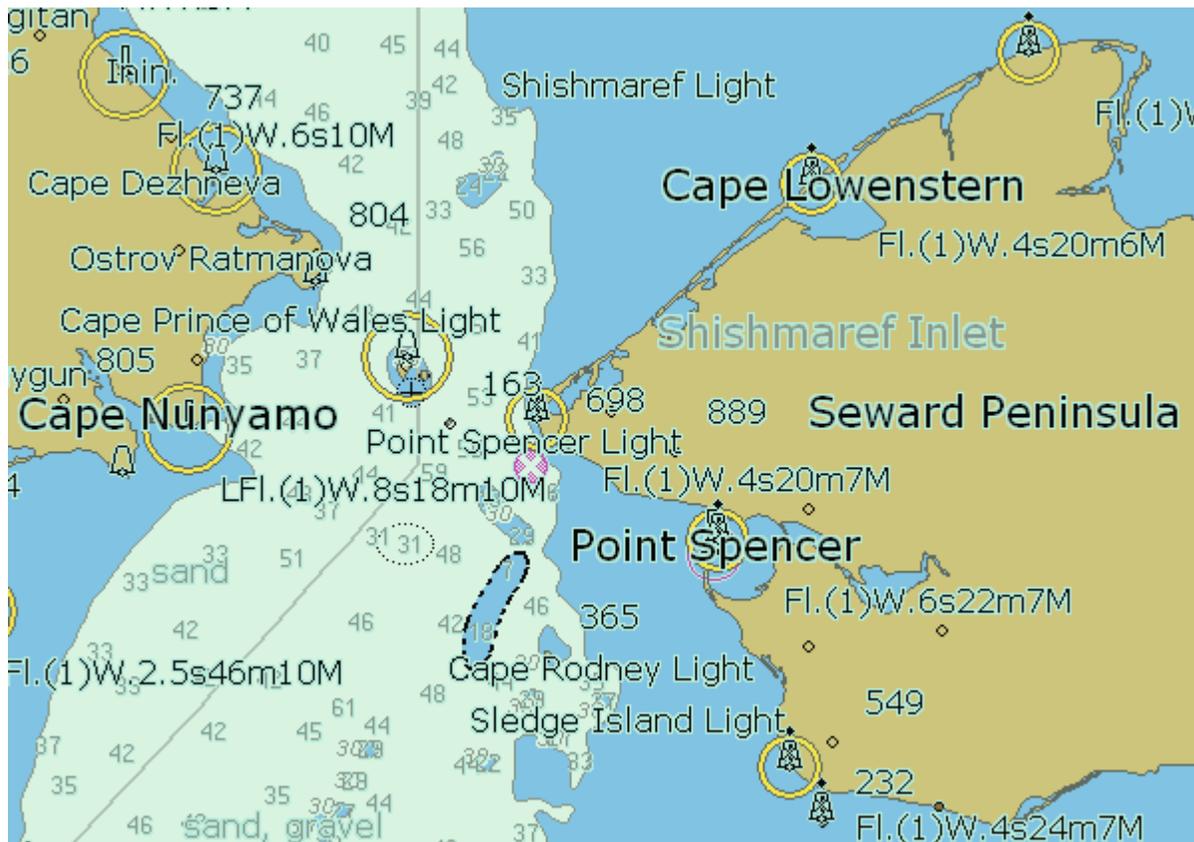
A pre-Mercator nautical chart of 1571, from Portuguese cartographer Fernão Vaz Dourado (c. 1520-c.1580). It belongs to the so-called *plane chart* model, where observed latitudes and magnetic directions are plotted directly into the plane, with a constant scale, as if the Earth's surface were a flat plane (Portuguese National Archives of Torre do Tombo, Lisbon)

The Mercator projection is almost universally used in nautical charts. There are however some exceptions for very large or small scales where projections such as the gnomonic projection may be used. Since the Mercator projection is conformal, that is, bearings in the chart are identical to the corresponding angles in nature, bearings may be measured from the chart to be used at sea or plotted on the chart from measurements taken at sea.

Positions of places shown on the chart can be measured from the longitude and latitude scales on the borders of the chart, relative to a map datum such as WGS 84.

A bearing is the angle between the line joining the two points of interest and the line from one of the points to the north, such as a ship's course or a compass reading to a landmark. On nautical charts, the top of the chart is always true north, rather than magnetic north, towards which a magnetic compass points. Most charts include a compass rose depicting the variation between magnetic and true north.

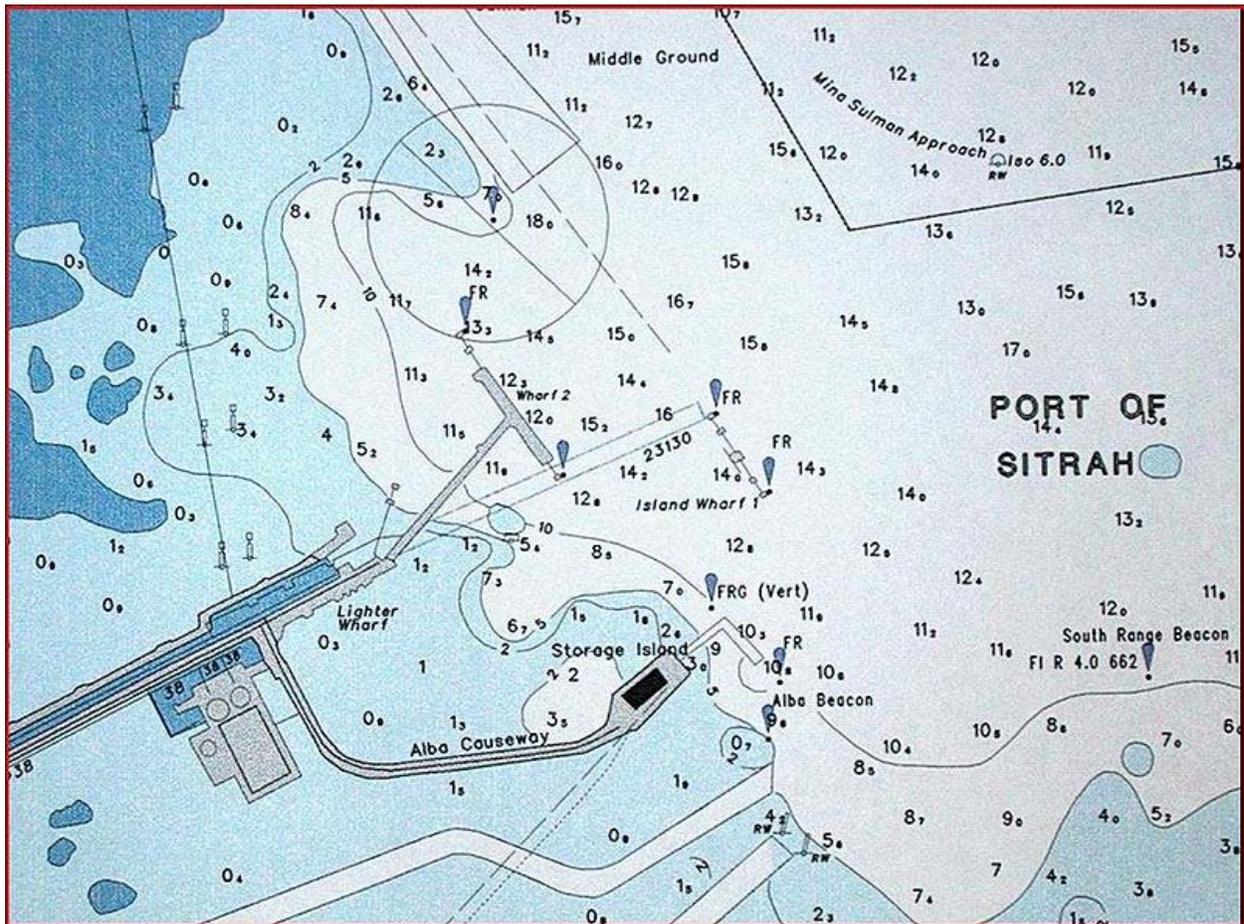
### Electronic and paper charts



Portion of an electronic chart of the Bering Strait

Conventional nautical charts are printed on large sheets of paper at a variety of scales. Mariners will generally carry many charts to provide sufficient detail for the areas they might need to visit. Electronic navigational charts, which use computer software and electronic databases to provide navigation information, can augment or in some cases replace paper charts, though many mariners carry paper charts as a backup in case the electronic charting system fails.

## Labeling nautical charts



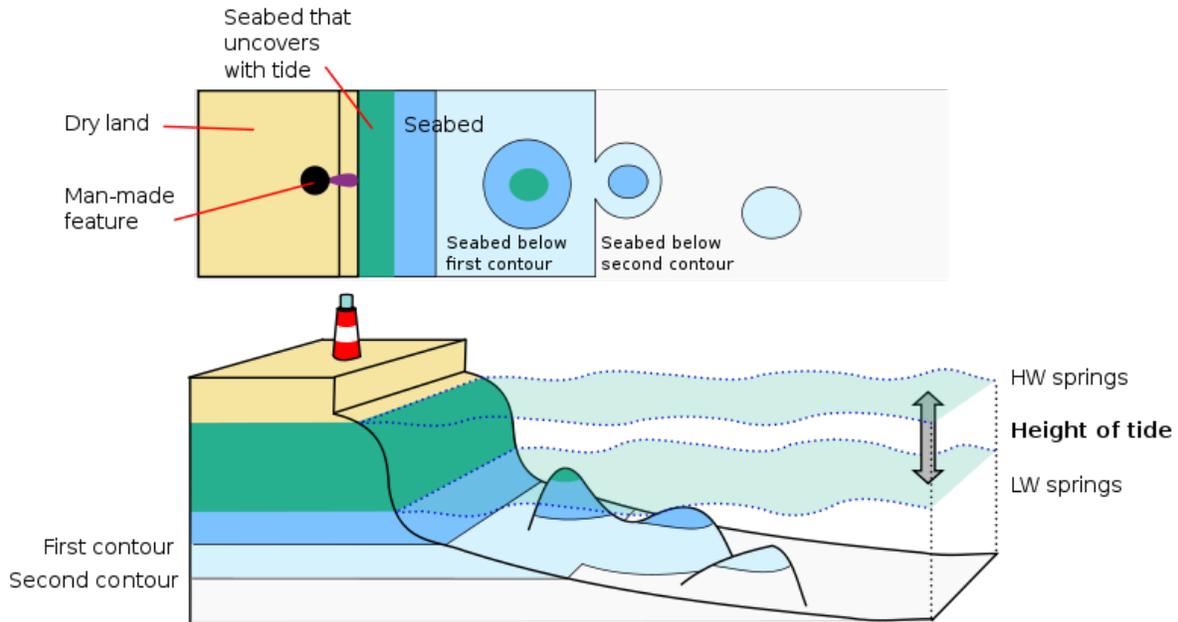
Automatically labeled nautical chart

Nautical charts must be labeled with navigational and depth information. There are a few software solutions in the market that do label placement automatically for any kind of map or chart.



Colours distinguish between man-made features, dry land, sea bed that dries with the tide and seabed that is permanently underwater and indicate water depth.

## Depths



## Use of colour in British Admiralty charts

Depths which have been measured are indicated by the numbers shown on the chart. Depths on charts published in most parts of the world use metres. Older charts, as well as those published by the United States government, may use feet or fathoms. Depth contour lines show the shape of underwater relief. Coloured areas of the sea emphasise shallow water and dangerous underwater obstructions. Depths are measured from the chart datum, which will be stated on the chart; this is often the depth of the lowest tide caused by gravity alone which is known as the "Lowest Astronomical Tide".

## Tidal information

Tidal races and other strong currents have special chart symbols. Tidal flow information may be shown on charts using tidal diamonds, indicating the speed and bearing of the tidal flow during each hour of the tidal cycle.

# Reversed map



A reversed map



The Blue Marble photograph in its original orientation

A **reversed map**, also known as an **Upside-Down map** or **South-Up map**, is a map where south is up, north is down, east is left and west is right. Thus the Southern Hemisphere at the top of the map instead of the bottom. These maps are just as accurate as traditionally oriented maps, because the position of North at the top of maps is arbitrary. Such maps have been made in several cultures and time periods. The convention that North is at the top (and East at the right) on most modern maps was established by the astronomer Ptolemy and was widely adopted by other cartographers.

In modern times, reversed maps are made as a learning device or to illustrate Northern Hemisphere bias. Different from simply turning a north-up map upside down, a reversed map has the text oriented to be read with south up. Uruguayan constructivist artist Joaquín Torres García created several works depicting a map of South America with the southern point at the top.

An example of the "north-up" convention in use is related to the famous "Blue Marble" photograph of the Earth, taken from on board Apollo 17. The image was originally oriented with the south pole at the top, with the island of Madagascar visible just left of center, and the continent of Africa at its right. However, the image was turned upside-down to fit the traditional view.

Reversed maps often have Indonesia placed in the center while Europe and the Americas are placed to the sides, although there are reversed maps centered on the Prime Meridian. Ordinary north-up maps in East Asia also often have the Americas on the right, showing the Pacific ocean whole while cutting through the Atlantic ocean.

There are many other maps with non-standard orientation, such as medieval T and O maps, polar maps, and Dymaxion maps.

# Thematic map



Edmond Halley's *New and Correct Chart Shewing the Variations of the Compass* (1701), the first chart to show lines of equal magnetic variation.

A **thematic map** is a type of map or chart especially designed to show a particular theme connected with a specific geographic area. These maps "can portray physical, social, political, cultural, economic, sociological, agricultural, or any other aspects of a city, state, region, nation, or continent".

## **Overview**

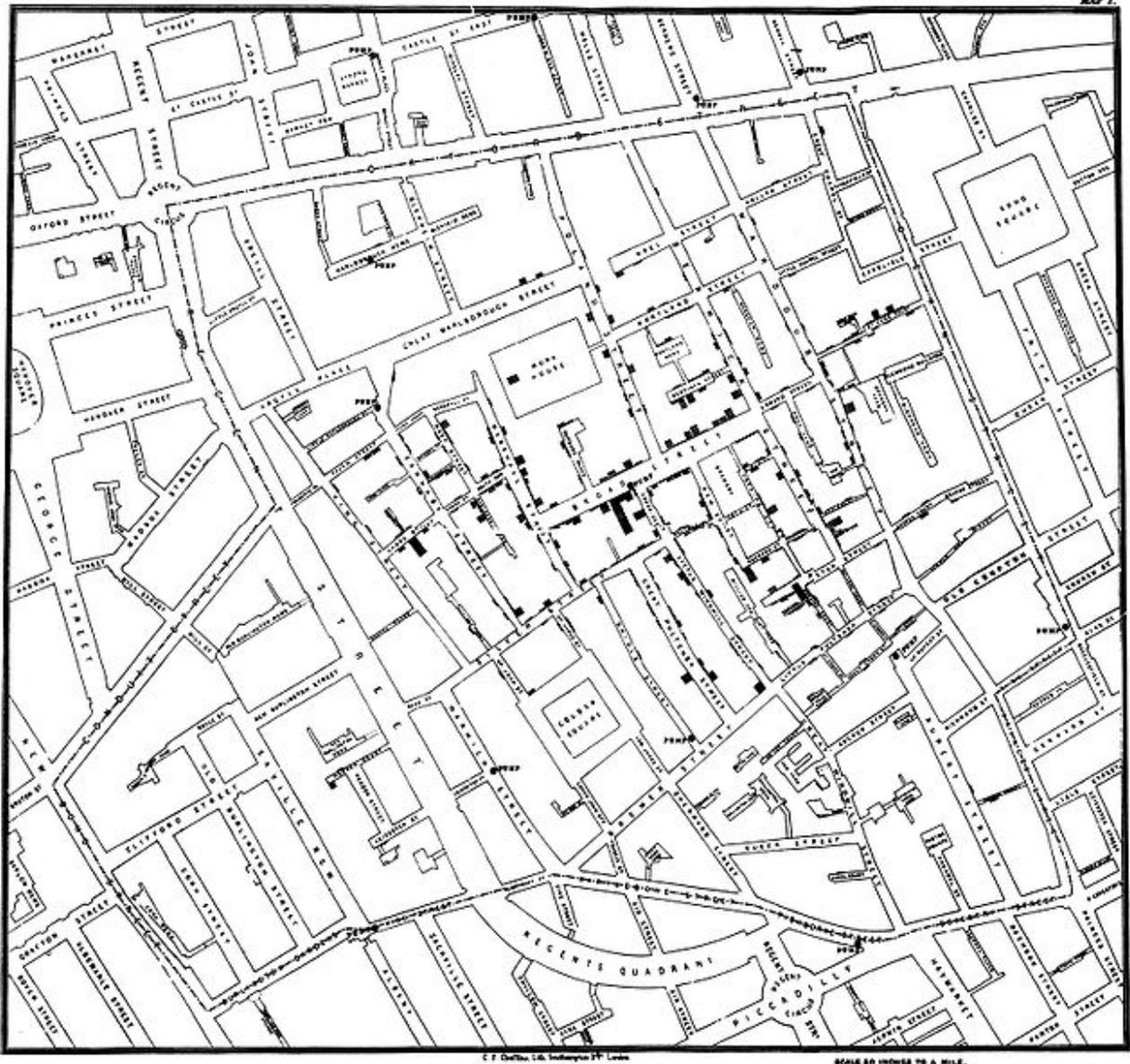
A thematic map is a map that focuses in a specific idea or theme. A thematic map illustrates a particular subject and contrasted the general map, in which the variety of geological and geographical phenomena regularly appear together. The contrast between the both of them lies in the fact thematic maps use the base data as coastlines, boundaries and places, only as point of reference for the phenomenon being mapped. In general maps the base data as landforms, lines of transportation, settlements, and political boundaries are there for their own sake.

Thematic maps also emphasize spatial variation of one or a small number of geographic distributions. These distributions may be physical phenomena such as climate or human characteristics such as population density and health issues. Barbara Petchenik described the difference as "in place, about space." While general reference maps show where something is in space, thematic maps tell a story about that place.

Thematic map are sometimes referred to as graphic essays that portray spatial variations and interrelationships of geographical distributions. Location, of course, is also important to provide a reference base of where selected phenomena are occurring.

## **History**

An important cartographic element preceding thematic mapping was the development of accurate base maps. Improvements in accuracy proceeded at a gradual pace, and even until the mid-17th century, general maps were usually of poor quality. Still, base maps around this time were good enough to display appropriate information, allowing for the first thematic maps to come into being.



John Snow's Cholera map about the cholera deaths in London in the 1840s, published 1854.

An early contributor to thematic mapping was the English astronomer Edmond Halley (1656–1742). His first significant cartographic contribution was a star chart of the constellation of the Southern Hemisphere, made during his stay on St. Helena and published on 1686. In that same year he also published his first terrestrial map in an article about trade winds, and this map is called the first meteorological chart. In 1701 he published the "New and Correct Chart Shewing the Variations of the Compass", see first image, the first chart to show lines of equal magnetic variation.

Another example of early thematic mapping comes from London physician John Snow. Though disease had been mapped thematically, Snow's cholera map in 1854 is the best known example of using thematic maps for analysis. Essentially, his technique and methodology anticipate principles of a geographic information system (GIS). Starting with an accurate base map of a London neighborhood which included streets and water pump locations, Snow mapped out the incidents of cholera death. The emerging pattern centered around one particular pump on Broad Street. At Snow's request, the handle of the pump was removed, and new cholera cases ceased almost at once. Further investigation of the area revealed the Broad Street pump was near a sewer line.

Another 19th century example of thematic maps, according to Friendly (2008), was the earliest known choropleth map in 1826 created by Charles Dupin. Based on this work Louis-Léger Vauthier (1815–1881) developed the population contour map, a map that shows the population density by contours or isolines.

### **Uses of thematic maps**

Thematic maps serve three primary purposes.

- First, they provide specific information about particular locations.
- Second, they provide general information about spatial patterns.
- Third, they can be used to compare patterns on two or more maps.

Common examples are maps of demographic data such as population density. When designing a thematic map, cartographers must balance a number of factors in order to effectively represent the data. Besides spatial accuracy, and aesthetics, quirks of human visual perception and the presentation format must be taken into account.

In addition, the audience is of equal importance. Who will “read” the thematic map and for what purpose helps define how it should be designed. A political scientist might prefer having information mapped within clearly delineated county boundaries (choropleth maps). A state biologist could certainly benefit from county boundaries being on a map, but nature seldom falls into such smooth, man-made delineations. In which case, a dasymetric map charts the desired information underneath a transparent county boundary map for easy location referencing.

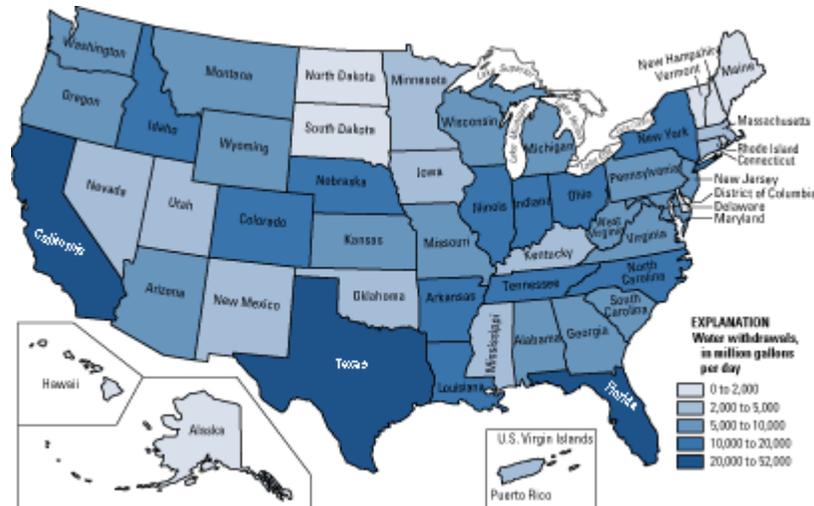
### **Data terminology**

A thematic map is **univariate** if the non-location data is all of the same kind. Population density, cancer rates, and annual rainfall are three examples of univariate data.

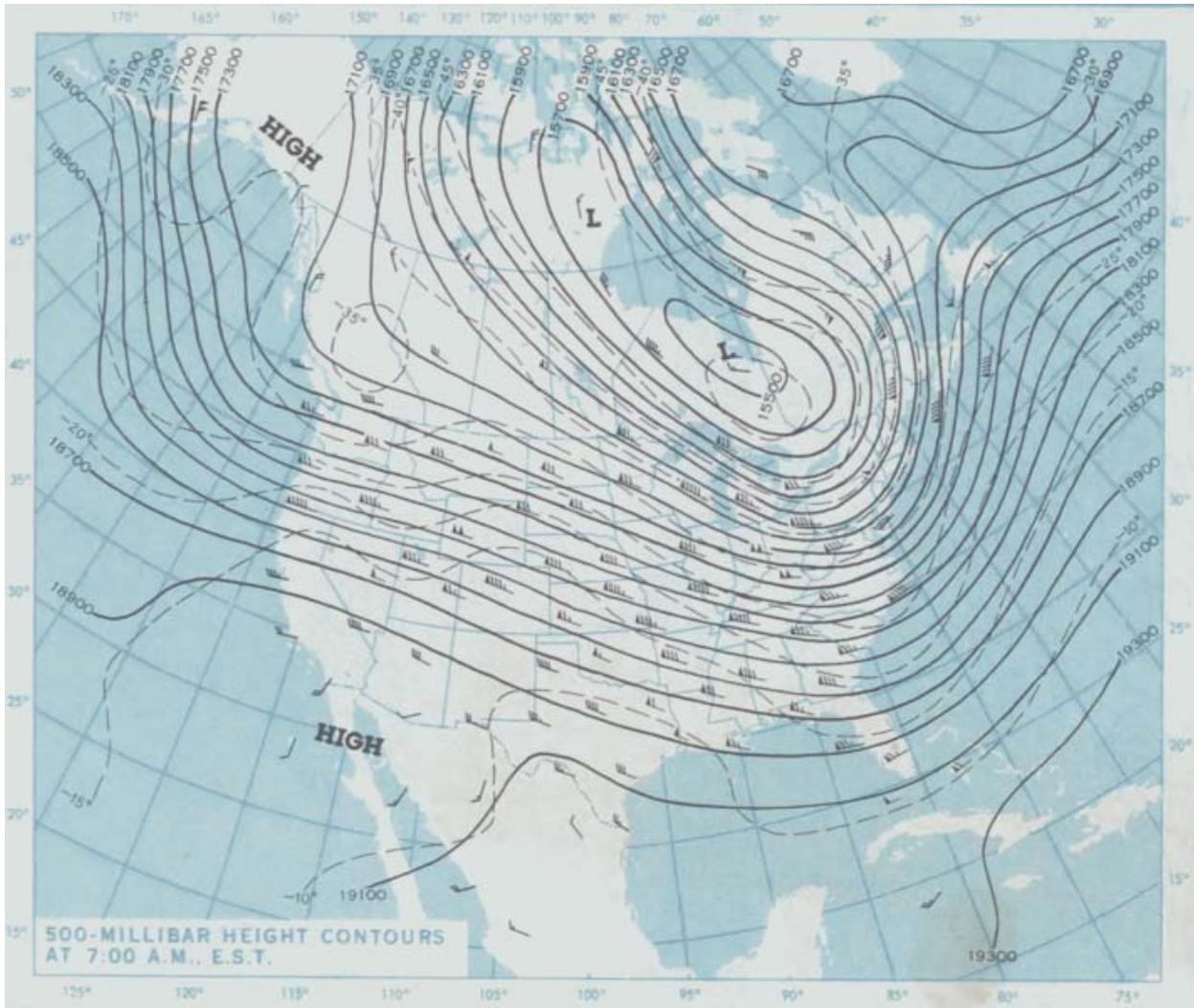
Bivariate mapping shows the geographical distribution of two distinct sets of data. For example, a map showing both rainfall and cancer rates may be used to explore a possible correlation between the two phenomena.

More than two sets of data leads to **multivariate** mapping. For example, a single map might show population density in addition to annual rainfall and cancer rates.

### Methods of thematic mapping



Choropleth map of water use.



Isarithmic map of barometric pressure.



Dasymetric map of climate and plant hardiness zones.

Cartographers use many methods to create thematic maps, but five techniques are especially noted.

### **Choropleth**

Choropleth mapping shows statistical data aggregated over predefined regions, such as counties or states, by coloring or shading these regions. For example, countries with higher rates of infant mortality might appear darker on a choropleth map. This technique assumes a relatively even distribution of the measured phenomenon within each region.

## **Proportional symbol**

The proportional symbol technique uses symbols of different sizes to represent data associated with different areas or locations within the map. For example, a disc may be shown at the location of each city in a map, with the area of the disc being proportional to the population of the city.

## **Isarithmic**

Isarithmic maps, also known as contour maps, depict smooth continuous phenomena such as precipitation.

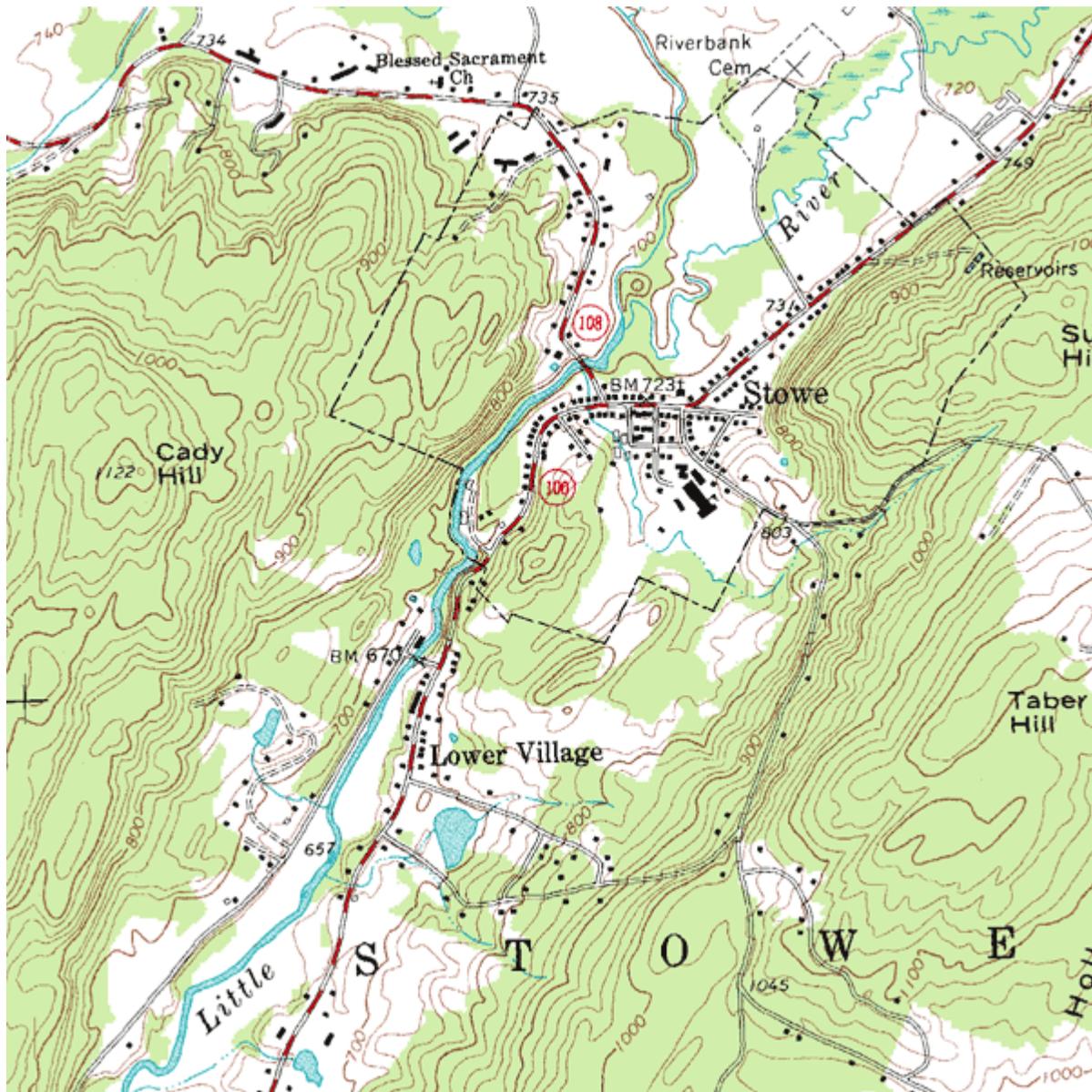
## **Dot**

A dot may be used to locate each occurrence of a phenomenon, as in Dr. Snow's map where each dot represented one death due to cholera. Where appropriate, a dot may indicate any number of entities, for example, one dot for every 100 voters.

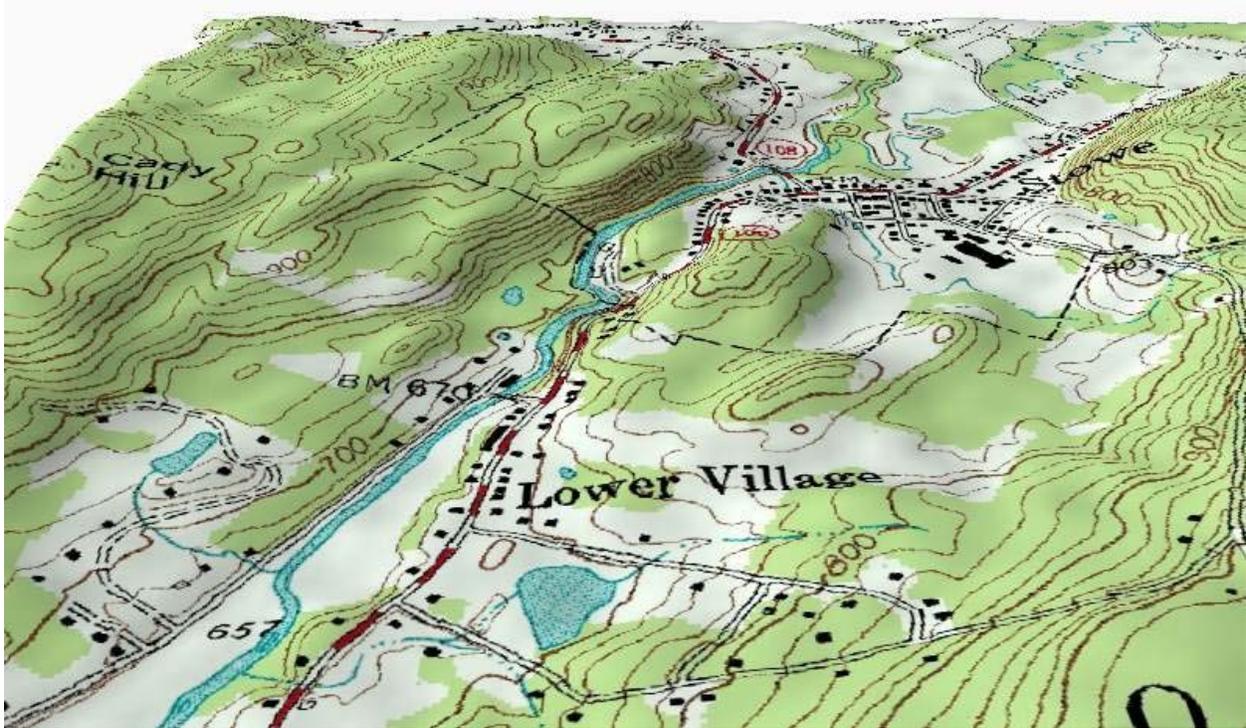
## **Dasymetric**

A dasymetric map is similar to a choropleth map, but one in which the regions are not predefined but chosen so that the distribution of the measured phenomenon within each region is relatively uniform. The boundaries may be much sharper than in an isarithmic map. For example, planning regulations may lead to adjacent regions in a dasymetric map of population density being internally homogeneous but at opposite extremes. These maps are more difficult to generate and less common than other types.

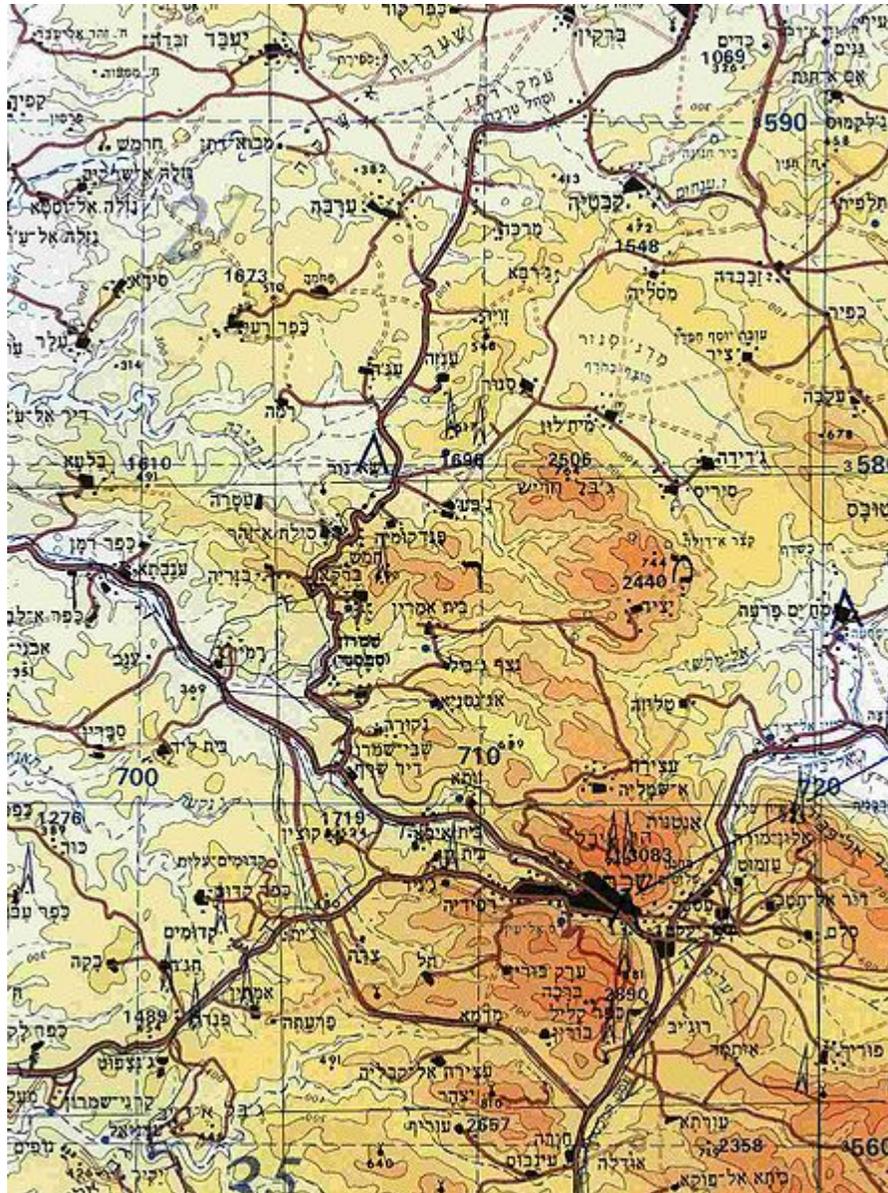
# Topographic map



A topographic map with contour lines



Part of the same map in a perspective shaded relief view illustrating how the contour lines follow the terrain



Section of topographical map of Nablus area (West Bank) with contour lines at 100-meter intervals. Heights are colour-coded

A **topographic map** is a type of map characterized by large-scale detail and quantitative representation of relief, usually using contour lines in modern mapping, but historically using a variety of methods. Traditional definitions require a topographic map to show both natural and man-made features. A topographic map is typically published as a map series, made up of two or more map sheets that combine to form the whole map.

The Canadian Centre for Topographic Information provides this definition of a topographic map:

A topographic map is a detailed and accurate graphic representation of cultural and natural features on the ground.

Other authors define topographic maps by contrasting them with another type of map; they are distinguished from smaller-scale "chorographic maps" that cover large regions, "planimetric maps" that do not show elevations, and "thematic maps" that focus on specific topics.

However, in the vernacular and day to day world, the representation of relief (contours) is popularly held to define the genre, such that even small-scale maps showing relief are commonly (and erroneously, in the technical sense) called "topographic".

The study or discipline of topography, while interested in relief, is actually a much broader field of study which takes into account all natural and man made features of terrain.

## **History**

Topographic maps are based on topographical surveys. Performed at large scales, these surveys are called topographical in the old sense of topography, showing a variety of elevations and landforms. This is in contrast to older cadastral surveys, which primarily show property and governmental boundaries. The first multi-sheet topographic map series of an entire country, the *Carte géométrique de la France*, was completed in 1789. Topographic surveys were prepared by the military to assist in planning for battle and for defensive emplacements (thus the name and history of the United Kingdom's Ordnance Survey). As such, elevation information was of vital importance.

As they evolved, topographic map series became a national resource in modern nations in planning infrastructure and resource exploitation. In the United States, the national map-making function which had been shared by both the Army Corps of Engineers and the Department of the Interior migrated to the newly created United States Geological Survey in 1879, where it has remained since.

## **Uses**

Topographic maps have multiple uses in the present day: any type of geographic planning or large-scale architecture; earth sciences and many other geographic disciplines; mining and other earth-based endeavours; and recreational uses such as hiking or, in particular, orienteering, which uses highly detailed maps in its standard requirements.

## **Map conventions**

The various features shown on the map are represented by conventional signs or symbols. For example, colors can be used to indicate a classification of roads. These signs are usually explained in the margin of the map, or on a separately published characteristic sheet.

Topographic maps are also commonly called *contour maps* or *topo maps*. In the United States, where the primary national series is organized by a strict 7.5 minute grid, they are often called *topo quads* or quadrangles.

Topographic maps conventionally show topography, or land contours, by means of contour lines. Contour lines are curves that connect contiguous points of the same altitude (isohypse). In other words, every point on the marked line of 100 m elevation is 100 m above mean sea level.

These maps usually show not only the contours, but also any significant streams or other bodies of water, forest cover, built-up areas or individual buildings (depending on scale), and other features and points of interest.

Today, topographic maps are prepared using photogrammetric interpretation of aerial photography, LIDAR and other Remote sensing techniques. Older topographic maps were prepared using traditional surveying instruments.

## **Publishers of national topographic map series**

Most countries have some sort of national mapping program. Those listed below are only a small selection. Several commercial vendors supply international topographic map series.

### **Australia**

The National Mapping Information Group of Geoscience Australia is the Australian Government's national mapping agency. It provides topographic maps and data to meet the needs of the sustainable development of the nation. The Office of Spatial Data Management provides an online free map service MapConnect. These topographic maps of scales 1:250,000 and 1:100,000 are available in printed form from the Sales Centre. 1:50,000 and 1:25,000 maps are produced in conjunction with the Department of Defence.

### **Canada**

The Centre for Topographic Information produces topographic maps of Canada at scales of 1:50,000 and 1:250,000. They are known as the National Topographic System (NTS).

A government proposal to discontinue publishing of all hardcopy or paper topographic maps in favor of digital-only mapping data was shelved in 2006 after intense public opposition.

## **Denmark**

The National Survey and Cadastre of Denmark is responsible for producing topographic and nautical geodata of Denmark, Greenland and the Faroe Islands.

## **Finland**

The National Land Survey of Finland produces the Topographic Database (accuracy 1:5000-1:10 000) and publishes topographic maps of Finland at 1:25,000 and 1:50,000. In addition topographic maps can be viewed by using a free map service MapSite

## **France**

The Institut Géographique National (IGN) produces topographic maps of France at 1:25,000 and 1:50,000. In addition, topographic maps are freely accessible online, through the Géoportail website.

## **Germany**

In principle, each federal state (*Bundesland*) is in charge of producing the official topographic maps. In fact, the maps between 1:5,000 and 1:100,000 are produced and published by the land surveying offices of each federal state, the maps between 1:200,000 and 1:1,000,000 by a federal office - the Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt am Main.

## **Greece**

Topographic maps for general use are available at 1:50,000 and 1:100,000 from the *Hellenic Military Geographical Service (HMGS)*. They use a national projection system called EGSA'87, which is a Transverse Mercatorial Projection mapping Greece in one zone. A few areas are also available at 1:25,000. Some private firms sell topographic maps of national parks based on HMGS topography.

## **India**

The Survey of India is responsible for all topographic control, surveys and mapping of India.

## **Japan**

The Geographical Survey Institute of Japan is responsible for base mapping of Japan. Standard map scales are 1:25,000, 1:50,000, 1:200,000 and 1:500,000

## **New Zealand**

Land Information New Zealand is the government agency responsible for providing up-to-date topographic mapping. LINZ topographic maps cover all of New Zealand, offshore islands, some Pacific Islands and the Ross Sea Region. The standard issue *NZTopo* map series was published September 2009 at 1:50,000 (*NZTopo50*), and 1:250,000 (*NZTopo250*). Vector data from the New Zealand Topographic Database (*NZTopo*) is also available.

## **Pakistan**

The responsibility for topographic mapping and aerial photography lies with the Surveyor General of Pakistan [SGP]. Established in 1947, the Survey of Pakistan (SOP) is based in Rawalpindi with a number of regional offices distributed at urban centers throughout Pakistan. SGP is a civil organization which, for security reasons, is headed by a Surveyor General and works under the strict control of Army General Headquarters (GHQ). Colonel C.A.K. Innes-Wilson, a Royal Engineers officer who joined the Survey of India which mapped the subcontinent, was the first Surveyor General of Pakistan.

All departments which require topographic maps make their request to SGP and many are permanently registered with it for mapping and aerial photographs procurement. The SOP performs these functions under the auspices of the Ministry of Defence (MOD). Organisationally, the SOP is overseen by the Surveyor General (SG) who is a direct military appointee and a senior uniformed officer. The SG reports directly to the Secretary of Defence. Under the SG are two Deputy SG's (I and II) who manage the operational departments of the agency and a Senior Technical Advisor. These departments are divided into Regional Directorates for Topographic Mapping including the Northern region centred in Peshawar, Eastern region (Lahore), Western region (Quetta) and finally, the Southern region in Karachi. Responsibility for fields surveys and the maintenance/update of topographic maps are sub-divided according to these geographic areas.

Three other operational directorates exist within the SOP which include the Directorate of Photogrammetry (Rawalpindi), Directorate of Printing and Map Publications (Rawalpindi) and the Directorate of the Survey Training Institute (Islamabad). The Photogrammetry Directorate is responsible for the commissioning and flying of aerial photography, followed by map interpretation and production from these source data.

## **Spain**

The Instituto Geográfico Nacional (IGN) is responsible for the official topographic maps. It does use six scales that cover all the Spanish territory: 1:25,000, 1:50,000, 1:200,000, 1:500,000, 1:1,000,000 and 1:2,000,000. The commonest scale is the first one, which utilizes the UTM system.

## **South Africa**

The Chief Directorate: National Geo-spatial Information (CD:NGI) produces three topographic map series, each covering the whole country, at scales 1:50 000, 1:250 000, and 1:500 000.

## **Switzerland**

Swisstopo (the Federal Office of Topography) produces topographic maps of Switzerland at seven different scales.

## **United Kingdom**

The Ordnance Survey (OS) produces topographic map series covering the United Kingdom at 1:25,000 and 1:50,000 scales. The 1:25,000 scale is known as the "Explorer" series, and include an "OL" (Outdoor Leisure) sub-series for areas of special interest to hikers and walkers. It replaced the "Pathfinder" series, which was less colourful and covered a smaller area on each map. The 1:50,000 scale is known as the "Landranger" and carries a distinctive pink cover. More detailed mapping as fine as 1:10000 cover some parts of the country. The 1:25K and 1:50K metric scales are easily coordinated with standard romer scales on currently available compasses and plotting tools. The Ordnance Survey maintains a mapping database from which they can print specialist maps at virtually any scale.

## **United States**

The United States Geological Survey (USGS), a civilian Federal agency, produces several national series of topographic maps which vary in scale and extent, with some wide gaps in coverage, notably the complete absence of 1:50,000 scale topographic maps or their equivalent. The largest (both in terms of scale and quantity) and best-known topographic series is the 7.5-minute, 1:24,000 scale, quadrangle — a non-metric scale virtually unique to the United States.