Mountains

Joseph F. Schwietering, *Stratigrapher*

The peaks of the earth are born of the depths of the earth.

With a nickname like "The Mountain State," there can be little doubt that mountains have a special influence on the hearts and minds of West Virginians. Mountains add immeasurably to the majesty and beauty of the State. They have a large role in determining where we live, what routes we travel, how we earn a living.

Although we see them every day, just how much do we know about mountains? How do they form? When do they form? Why are there different types?

Most of us are aware that mountains are large masses of rocks and soil that rise more or less steeply above surrounding areas. Custom and the way people perceive terrain determine what is and what is not called a mountain. A mountain to some is just another hill to others. This being the case, a safe definition is: a region is "mountainous" when the relief (difference in elevation) exceeds a value between 500 and 1,000 feet.

Seldom does a mountain occur as an isolated entity. Most occur with other mountains to form chains or ranges. Except for volcanos, this article will deal with mountain ranges, not isolated peaks.

Mountain Building

Mountains are produced by forces in the earth that cause parts of the earth's crust to rise while others sink. Uplift of the crust, combined with chemical and physical erosion by air, water, and ice over millions of years, produces the spectacular scenery found in mountains.

At the very high temperatures and pressures found miles below the earth's surface, rocks can actually flow when density differences are produced by differential heating and cooling of parts of the mantle and *lithosphere* (Figure 1). The flowing of rocks in the mantle and lithosphere subject parts of the crust to *tension* (pulling apart), while other parts are subjected to *compression* (squeezing together). Rocks are relatively weak and brittle under tension, and consequently crust under tension tends to break up into giant blocks. Rocks are stronger under compression, but when the compressive forces get very large, rocks deform by flowing, folding, and breaking.

Four Types of Mountains

Mountains can be classified into four types: volcanos, fault-block mountains, complex mountains, and erosional mountains.

Volcanos are built up by liquid and solid rock erupting from the earth's interior (Figure 2). Liquified rock is called *magma* when it is within the earth, and *lava* when it flows onto the earth's surface or is blown into the air. Ash and cinders ejected during an eruption of a volcano, are called *pyroclastics.* The interlayering of lava and pyroclastics around a vent forms the cone we call a volcano. Volcanos range in size from small cones several hundred feet in diameter and a hundred or so feet high to gigantic features like the Hawaiian Islands. (Locations mentioned are shown in Figure 6.) While there are no volcanos in West Virginia today, they may have been present in the western part of the State more than 550 million years ago. Ash deposits from ancient volcanos to the east are found in the State.

Fault-block mountains are formed by the movement of large crustal blocks along faults formed when tensional forces pull apart the crust (Figure 3). Tension is often the result of uplifting part of the crust; it can also be produced by opposite-flowing convection cells in the mantle (see Figure 1). Fault-block mountains are present in the Great Basin of the southwestern United States. They may have been present in the western and central parts of West Virginia about 550 million years ago.

Complex mountains are formed when the crust is subjected to very large compressive forces (Figure 4). Under large compressive forces and *moderately high* temperatures and pressures, parts of the crust are bent into large folds and broken into slices that slide over underlying rocks. The slices of the rock slide away from the source of compression. Such complex mountains are present in West Virginia's eastern panhandle.

In those parts of complex mountains where the crust is subjected to large compressive forces and *very high* temperatures and pressures, the original rocks change to *metamorphic* rocks. Also *igneous* rocks (formed from magma) may be

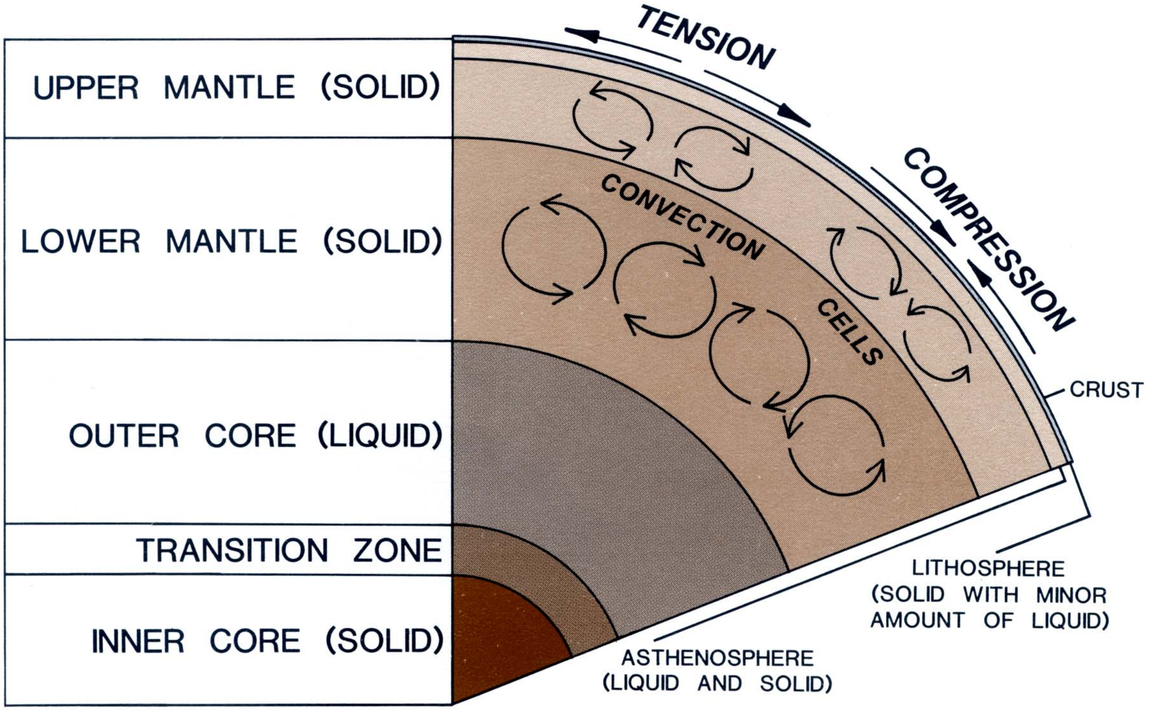


Figure 1. Major subdivisions of the earth. The asthenosphere, a mixture of liquid and solid rocks, lies within the upper mantle between depths of about 62 and 155 miles (100 and 250 kilometers). Above the asthenosphere is the lithosphere, up to 62 miles (100 kilometers) thick and made up mostly of solid rock. It contains the uppermost part of the mantle and the crust. Convection cells in the lower and upper mantle produce areas of tension and compression in the crust. In convection cells, solid rock slowly flows in a manner similar to the way a ductile metal flows when it is stretched into a wire or thin sheet. Imagine a lava lamp in which the material flows at extremely slow rates (centimeters per year) at very high temperatures and pressures.

(All illustrations by Renee LaValle unless noted)

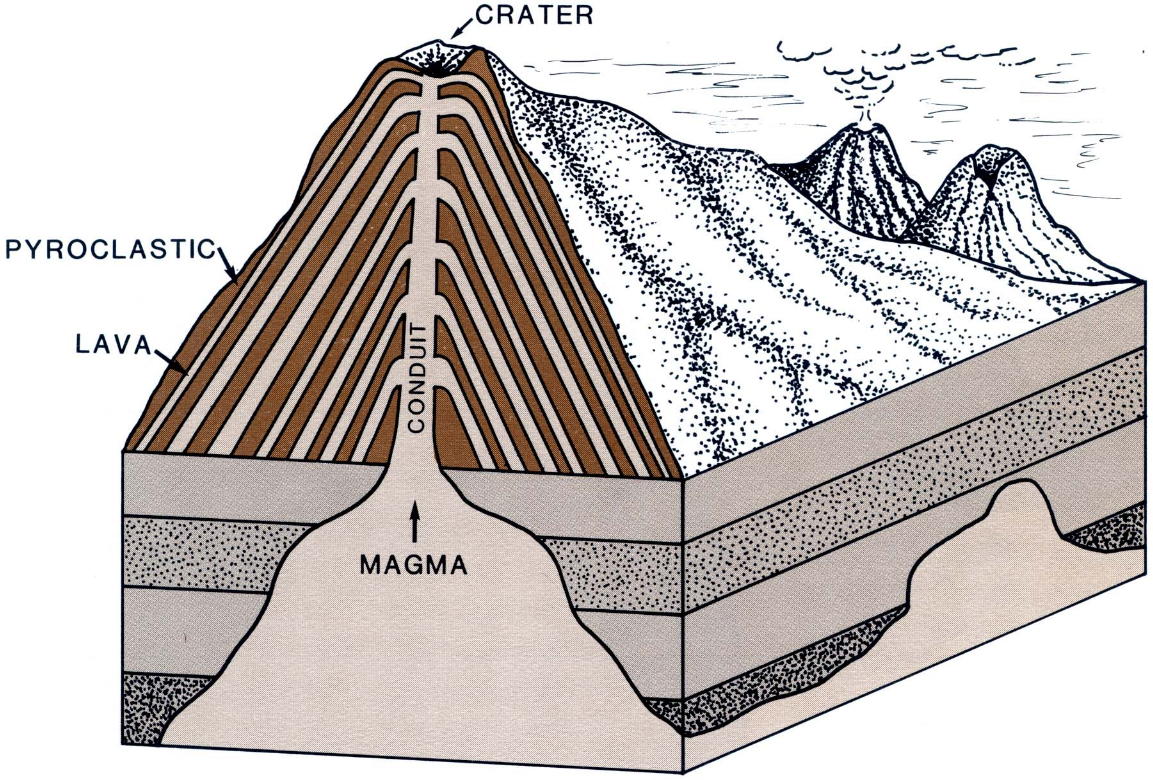
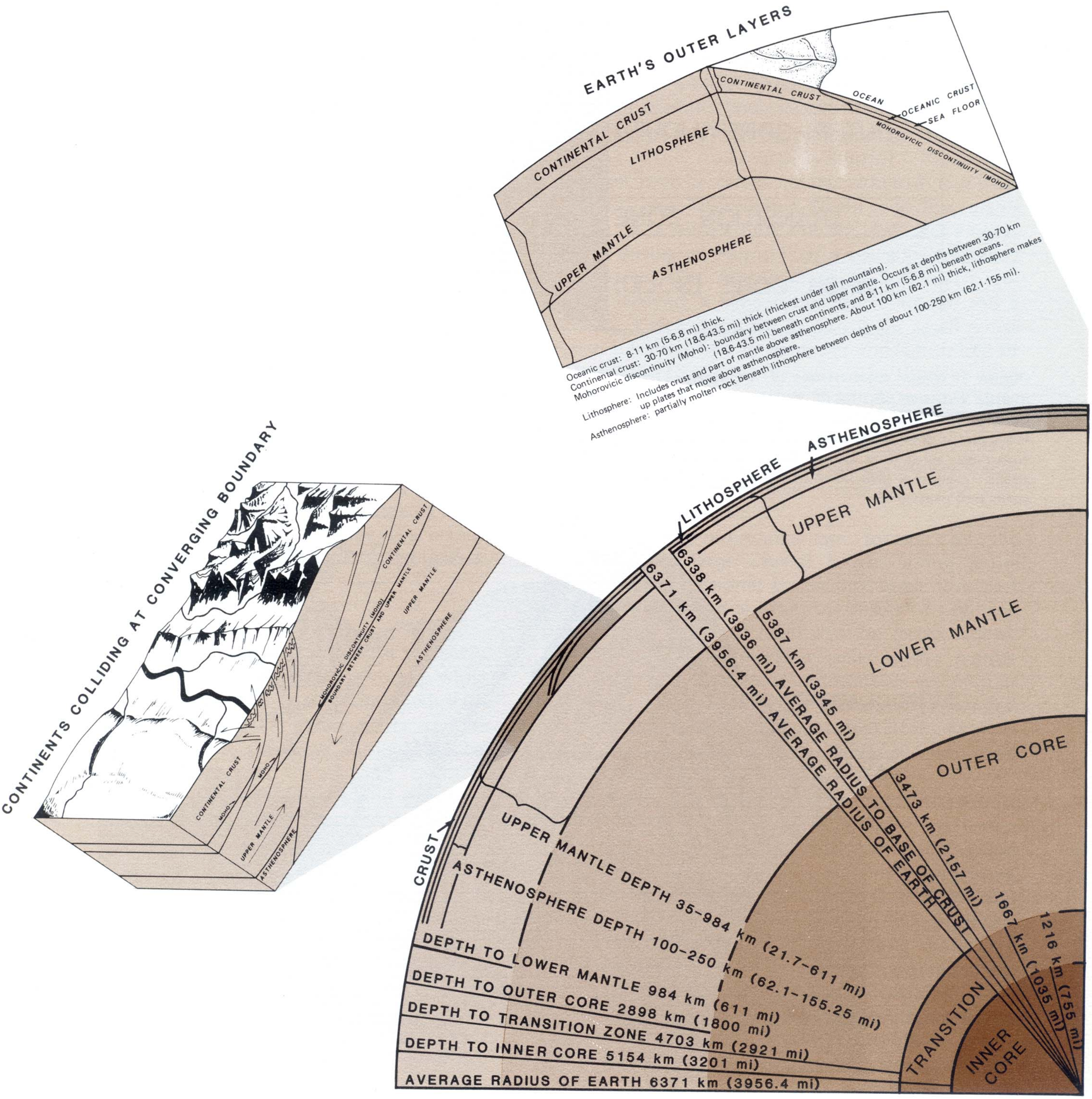
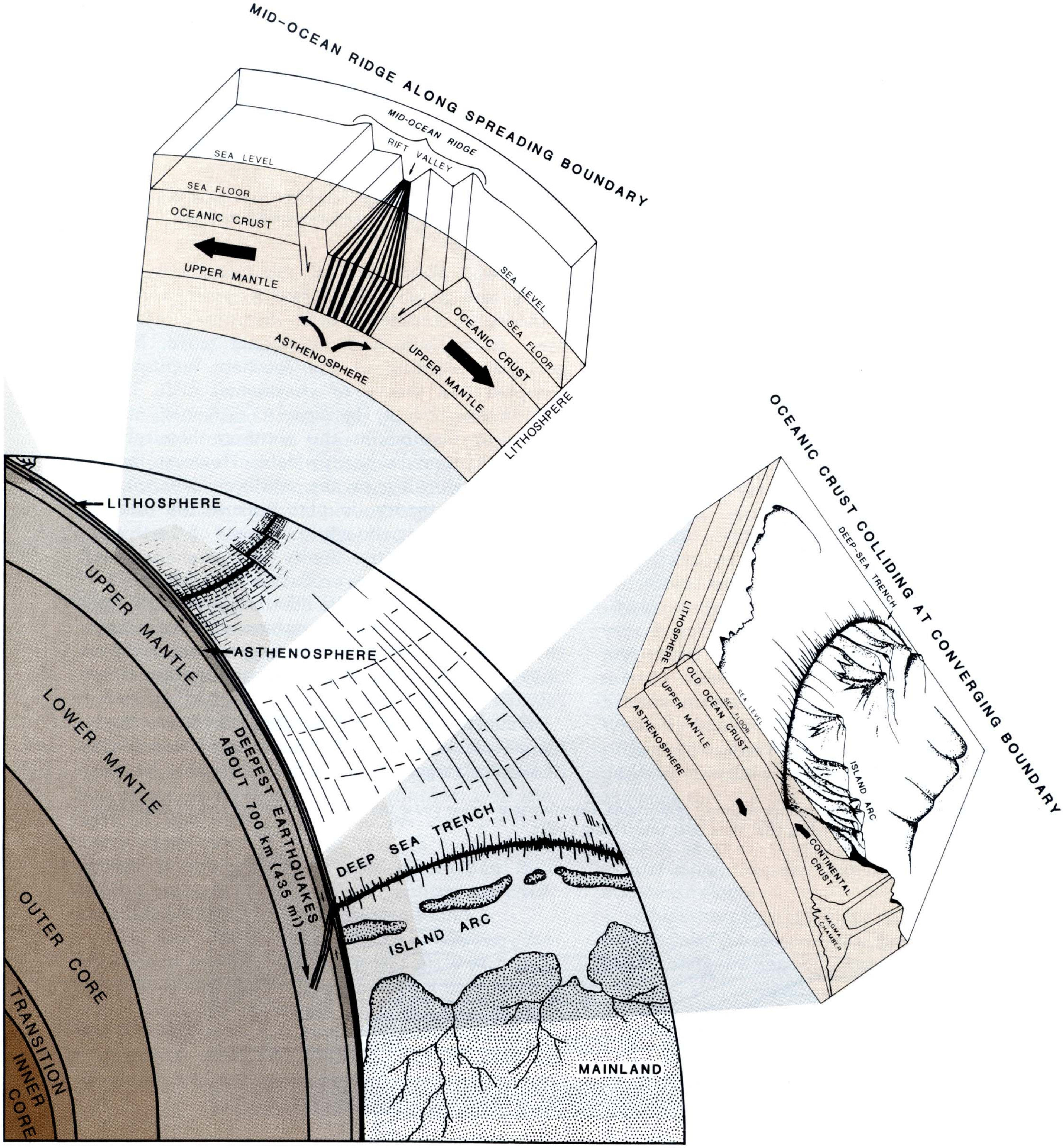


Figure 2. Generalized cutaway showing the growth of a volcano.


EARTH'S OUTER LAYERS
CONTINENTAL CRUST
OCEAN
OCEANIC CRUST
SEA FLOOR
MOHOROVICIC DISCONTINUITY (MOHO)
LITHOSPHERE
UPPER MANTLE
ASTHENOSPHERE
Oceanic crust: 8-11 km (5-6.8 mi) thick.
Continental crust: 30-70 km (18.6-43.5 mi) thick (thickest under tall mountains).
Mohorovicic discontinuity (Moho): boundary between crust and upper mantle. Occurs at depths between 30-70 km (18.6-43.5 mi) beneath continents, and 8-11 km (5-6.8 mi) beneath oceans.
Lithosphere: Includes crust and part of mantle above asthenosphere. About 100 km (62.1 mi) thick, lithosphere makes up plates that move above asthenosphere.
Asthenosphere: partially molten rock beneath lithosphere between depths of about 100-250 km (62.1-155 mi).
CONTINENTS COLLIDING AT CONVERGING BOUNDARY
CONTINENTAL CRUST
MOHOROVICIC DISCONTINUITY (MOHO) BOUNDARY BETWEEN CRUST AND UPPER MANTLE
UPPER MANTLE
ASTHENOSPHERE
MOHO
LITHOSPHERE
ASTHENOSPHERE
UPPER MANTLE
LOWER MANTLE
OUTER CORE
TRANSITION
INNER CORE
CRUST
6338 km (3936 mi) AVERAGE RADIUS TO BASE OF CRUST
6371 km (3956.4 mi) AVERAGE RADIUS OF EARTH
5387 km (3345 mi)
3473 km (2157 mi)
1667 km (1035 mi)
1216 km (755 mi)
UPPER MANTLE DEPTH 35–984 km (21.7–611 mi)
ASTHENOSPHERE DEPTH 100–250 km (62.1–155.25 mi)
DEPTH TO LOWER MANTLE 984 km (611 mi)
DEPTH TO OUTER CORE 2898 km (1800 mi)
DEPTH TO TRANSITION ZONE 4703 km (2921 mi)
DEPTH TO INNER CORE 5154 km (3201 mi)
AVERAGE RADIUS OF EARTH 6371 km (3956.4 mi)

This cutaway illustration is an overview of the internal layers of the earth, their relationships to one another, and (in the enlarged diagrams) the processes involved in mountain building. The geologic terminology used here, and the concepts depicted, are explained in detail in the text.



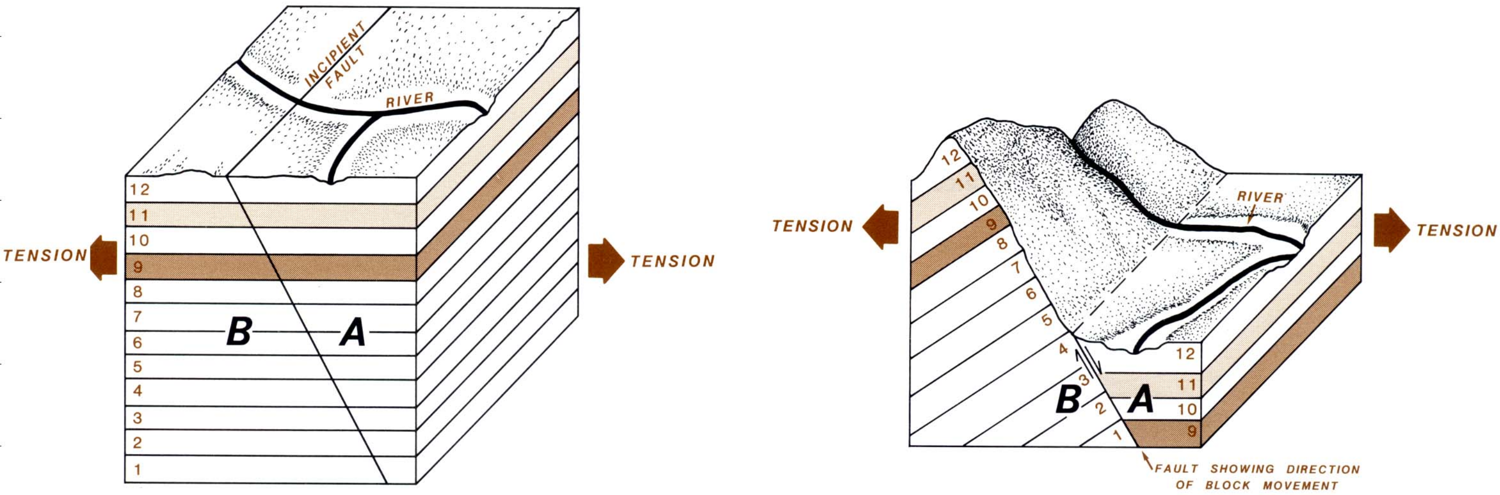


Figure 3. Formation of fault-block mountains. At left shows a fracture developing in rocks subjected to tension. At right is the same area with mountains produced by the dropping of segment A, tilting of segment B, and erosion by the river.

injected into the complex mountains. The Appalachian Mountains, the Alps, and the Himalayas are examples of complex mountains formed in this manner.

Erosional mountains are formed by erosion of uplifts like the Black Hills in western South Dakota and extensive plateaus like the Appalachian Plateau in the eastern United States (which includes western West Virginia). In both of these areas, rivers have carved complex systems of hills and mountains in the uplifted rocks (Figure 5).

Location of Mountains

To understand why mountains occur where they do, we must first understand *continental drift*, *sea-floor spreading*, and *plate tectonics*.

During the 19th century, people began to speculate about the "fit" of the eastern coastlines of the Americas with the western coastlines of Africa, Europe, and Greenland (Figure 6). In time it was suggested that continents might break apart and drift about the surface of the earth.

Around World War I, the German meteorologist and geophysicist Alfred Wegener proposed a theory of continental drift, including a mechanism to explain how continents move. Many geologists working in the southern hemisphere accepted this theory of continental drift, or a modification of it, because it explained many geological features in the southern hemisphere that were otherwise unexplainable. However, many geologists working in the northern hemisphere rejected the theory, in part because the earth's crust is not strong enough to do some of the things required of it by the theory. For example, one proposed mechanism required continents to plow through the mantle like ships through the seas. The crust is not strong enough to do that. Other mechanisms were advanced to meet these objections, but for various reasons they too were rejected by many geologists.

Since World War II, mapping of the ocean floor has revealed that all oceans contain at least one set of parallel ridges separated by a rift valley, collec-

Figure 4. Hypothetical complex (compressional) mountains. Compressive forces cause parts of the crust (A and B) to be bent into large folds and broken into slices that slide over underlying rocks.

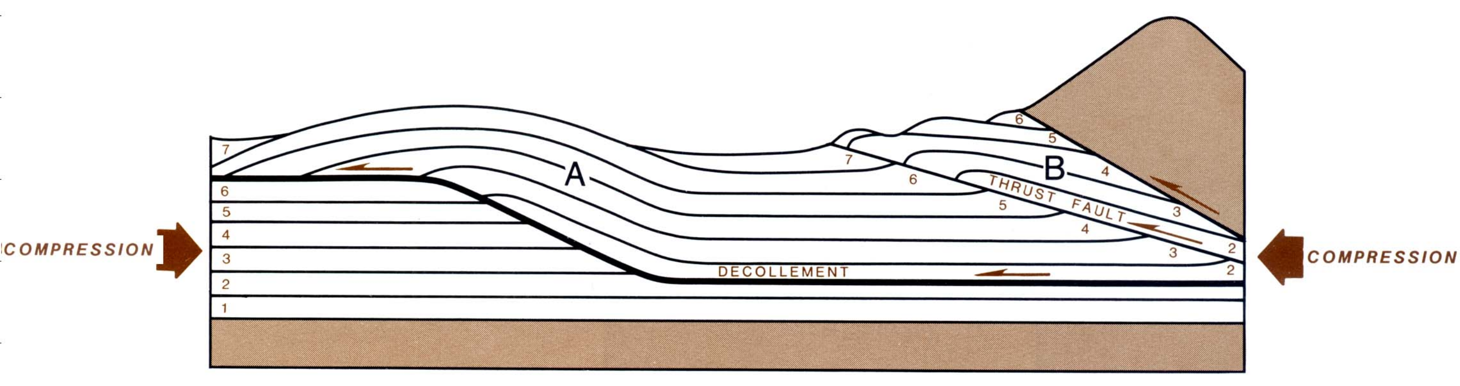
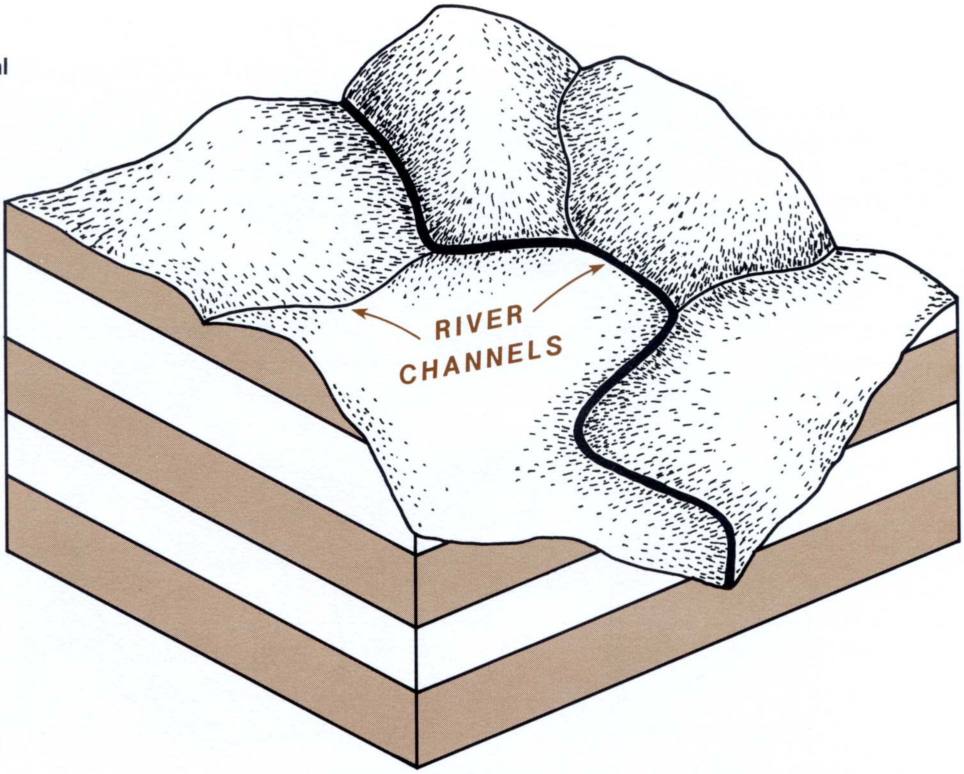


Figure 5. Hypothetical erosional mountains.



tively called a *mid-ocean ridge* (see Figure 7). In time it was found that these mid-ocean ridges are joined together into an extensive mountain range that passes through all the oceans (Figure 6). In the Atlantic Ocean, the mid-ocean ridge "fits" with the coast of Africa, Europe, Greenland, and the Americas.

This research also showed the importance of the differences between oceanic crust and continental crust in understanding continental drift, sea-floor spreading, plate tectonics, and mountain building. Oceanic crust is chemically similar to the underlying mantle, and is thinner and denser than continental crust. Continental crust differs chemically from oceanic crust and the mantle. Both types of crust float on the denser mantle. It was also found that oceanic crust is youngest near the axes of mid-ocean ridges, and becomes progressively older away from the axes. In none of the oceans is there oceanic crust older than 250 million years. On the other hand, continental crust over three billion years old has been found.

As this information became available, the theories of sea-floor spreading and plate tectonics were developed. These theories answer most of the objections raised to earlier proposed mechanisms which attempted to account for continental drift. Continental drift, and its supporting theories of sea-floor spreading and plate tectonics, are now accepted as valid by most geologists throughout the world. These theories help explain the origin and location of mountains.

According to the theory of sea-floor spreading, new ocean crust is formed by the injection of liquid and solid rocks from the underlying mantle into fractures along mid-ocean ridges (Figure 7). For example, Iceland is on top of the Mid-Atlantic Ridge. It was formed, and is still growing, in this way. As new crust moves away from the axis of the mid-ocean ridge, it fuses with the part of the mantle that overlies the *asthenosphere* and becomes part of the lithosphere (Figures 1 and 7). While new ocean crust forms along mid-ocean ridges, old ocean crust sinks into the mantle along deep-sea trenches (Figure 9). Since there is no evidence that the earth is expanding or shrinking, it follows that along any great circle on the earth's surface, as much crust is consumed back into the mantle along deep-sea trenches as is formed along mid-ocean ridges.

The lithosphere is divided into *plates* that move horizontally on top of the asthenosphere. These plates interact along three types of boundaries:

1) *spreading boundaries*, where new ocean crust is formed along mid-ocean ridges (Figure 7);
2) *converging boundaries*, where continents

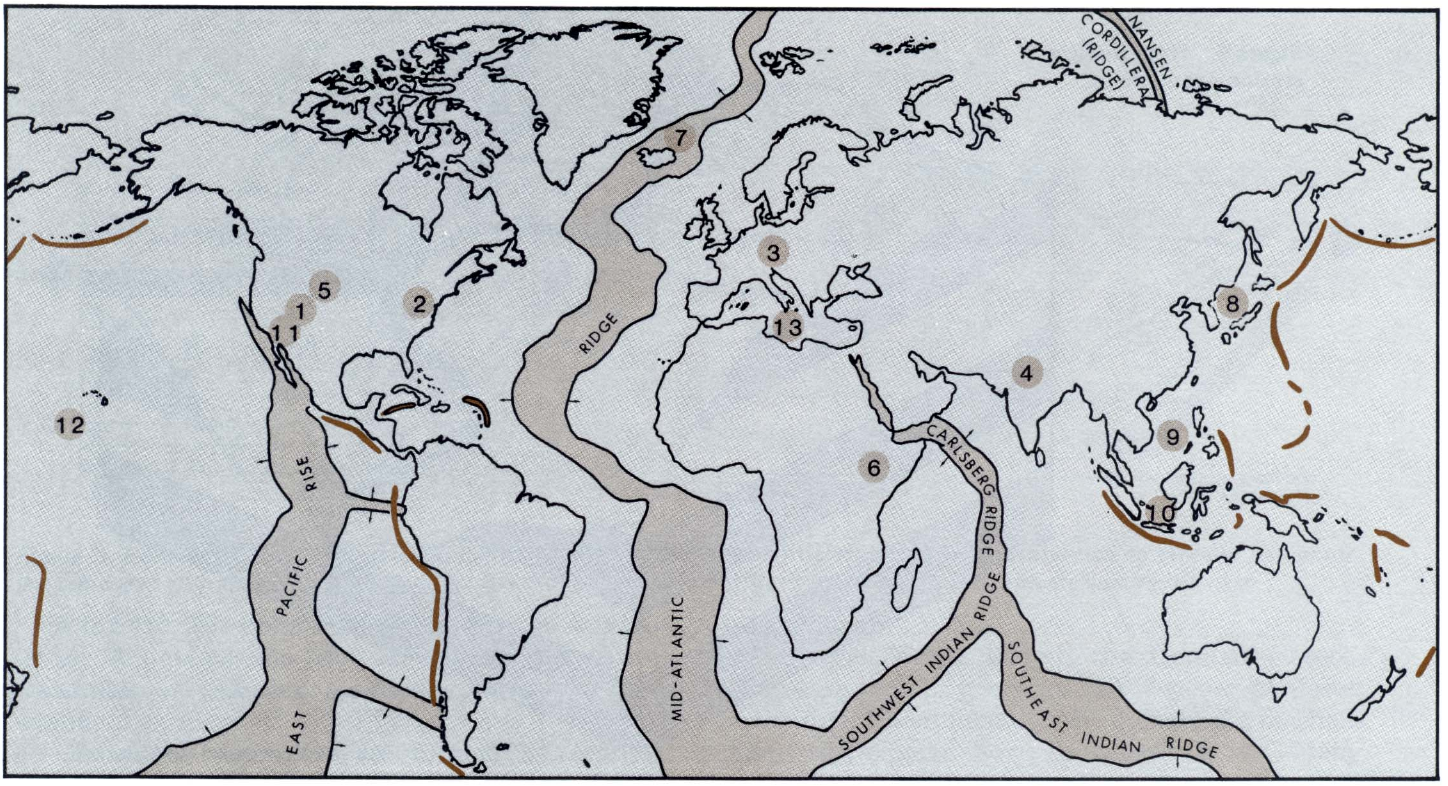
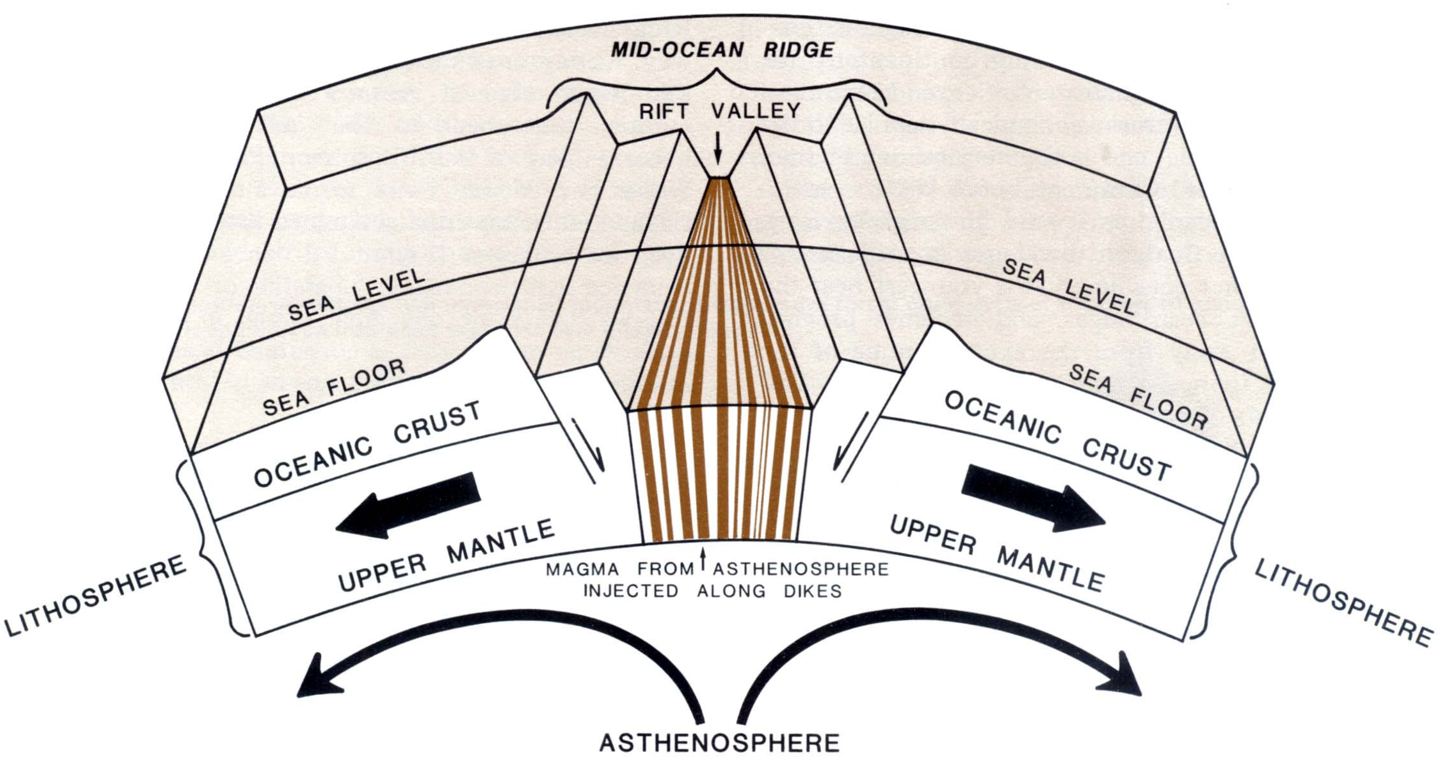


Figure 6. Location of mid-ocean ridges, deep-sea trenches, directions of plate motion, and places mentioned in the text: 1—Great Basin; 2—Appalachian Mountains; 3—Alps; 4—Himalayas; 5—Black Hills; 6—East African Rift; 7—Iceland; 8—Japan; 9—Philippines; 10—Indonesia; 11—San Andreas Fault; 12—Hawaiian Islands; 13—Crete and Thera.

Figure 7. A spreading boundary where new ocean crust is formed along a mid-ocean ridge. As lithospheric plates move away from each other, magma and solid rock from the mantle are injected along dikes.



collide (Figure 8) or where, in ocean basins, old ocean crust sinks into the mantle along deep-sea trenches (Figure 9); and

3) *conservative boundaries*, where plates slide past each other along fractures (faults) (Figure 10). Crust is neither formed nor destroyed along conservative boundaries.

Many of earth's mountain ranges are located along plate boundaries, or former plate boundaries. Spreading boundaries produce mountains along rifts like the East African Rift (Figure 6), and along mid-ocean ridges. Volcanos and fault-block mountains are common along boundaries. Most of the mountains along mid-ocean ridges are underwater, but a few volcanos along these ridges rise above sea level.

Converging boundaries in ocean basins produce volcanos and complex mountains associated with deep-sea trenches (island arcs like those of Japan, the Philippines, and Indonesia; see Figure 6). Continents are less dense than oceanic crust and the underlying mantle, so when continents collide along converging boundaries, they do not sink into the mantle. Instead, the edges of the continents crumple and thicken as they are fused together (Figure 8). In the process, complexly folded and faulted mountains such as the Alps, Himalayas, and Appalachians are formed (Figure 6).

Fault-block mountains and complex mountains occur along conservative boundaries where plates slide past each other. Both types of mountains are found along the San Andreas Fault in California (Figure 10). This fault (actually a series of faults) is part of the complex system of folds and faults that occur along the boundary between the Pacific Ocean Plate and the North American Plate.

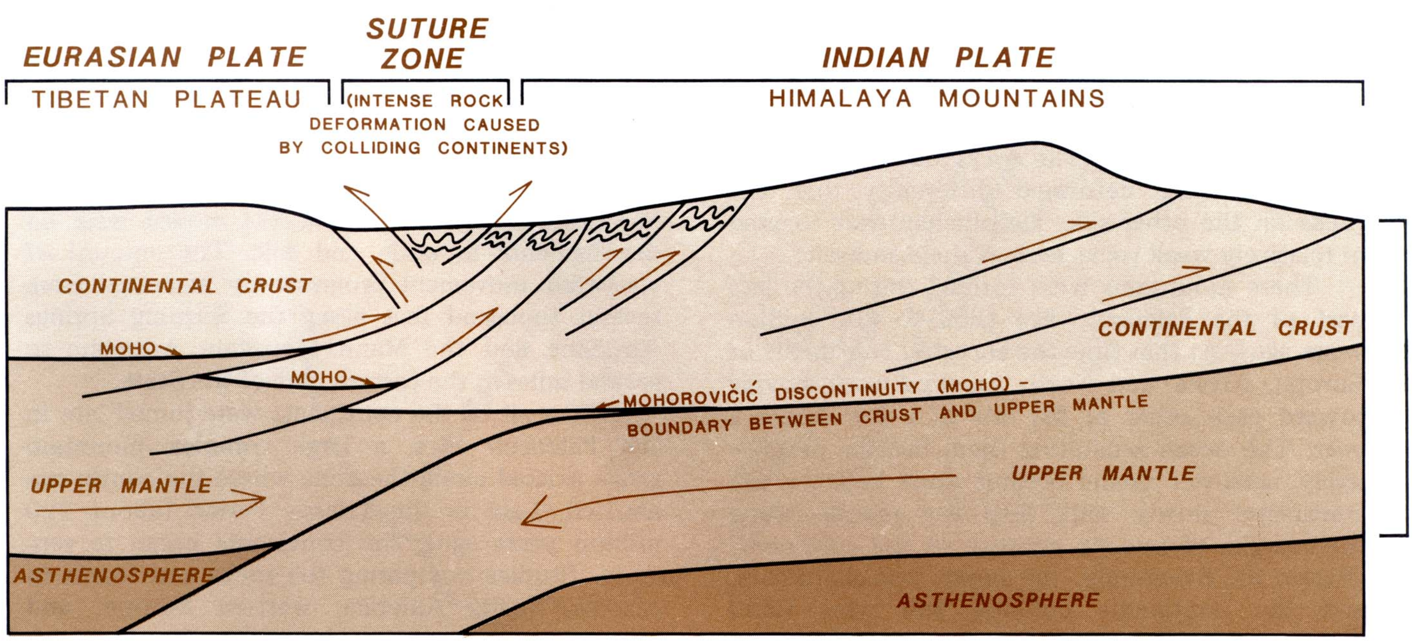
Volcanos can occur along any type of plate boundary. They can also occur in the middle of a plate over *hot spots*, plumes of very hot rock rising through the mantle. The Hawaiian Islands have formed over such a hot spot. The islands are spread out in a line because the Pacific Ocean Plate moves over a hot spot. At present it is not known for sure whether just the plate moves, or both the plate and the hot spot move. The island of Hawaii, today directly over the hot spot, is still growing at the southeast end of the chain. The oldest island formed over this hot spot, Midway, now at the northwest end of the chain, consists of a coral reef on top of an extinct volcano. Midway is now slowly sinking into the ocean because the lithosphere is not strong enough to support its weight.

Mountains in West Virginia

Both complex mountains and erosional mountains are present in West Virginia. The Allegheny Front and the St. Clair Fault form a dividing line between the two types (Figure 11).

The complex mountains are located along and east of the Allegheny Front and the St. Clair Fault. The Allegheny Front is a high, east-facing escarpment (cliff or steep slope). The St. Clair

Figure 8. Schematic diagram of a converging boundary where two continents collide (in this case the Indian Subcontinent is colliding with the Eurasian Continent).



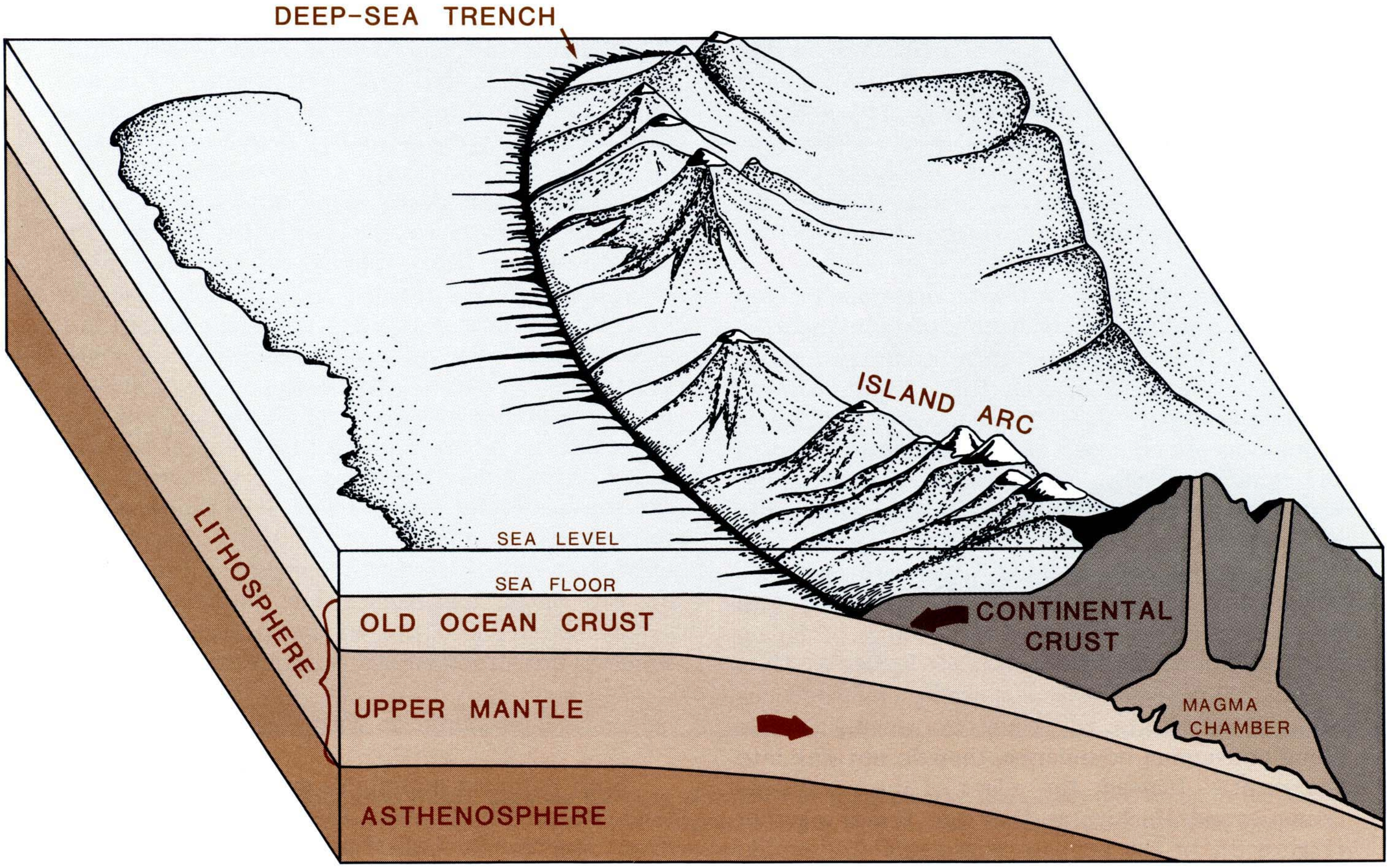


Figure 9. A converging boundary, where old ocean crust sinks back into the mantle along a deep-sea trench.

Fault is the westernmost fault in the Valley and Ridge Province in West Virginia, an area that contains long, northeast-southwest oriented valleys separated by equally long parallel ridges.

West Virginia's complex mountains consist of large folds that have broken into slices and pushed westward over other slices (Figure 4). These slices are thousands of feet thick and many miles long. The whole complex slid west on a series of faults called a *decollement*. The rocks on one side of a decollement are deformed differently than the rocks on the other side. Decollements are located in relatively weak rocks such as shale and salt.

These mountains were formed during the late part of the Paleozoic Era (250 to 300 million years ago). At that time the ancestral continents of Europe, Africa, and North America were moving toward each other at the rate of a few inches a year. The ocean separating them became progressively narrower as the oceanic crust between the continents slowly sank into the mantle along the margin of one or another of the continents (Figure 9). Eventually, the ocean was eliminated, and the continents collided and were fused together. The closing of the ocean and the fusing of the continents provided the compressive force that formed the rumpled Valley and Ridge Province and the complexly faulted folds in the Appalachian Plateau. A modern example of such a fusing of continents is the joining of the Indian Subcontinent to the southern part of the Eurasian Continent and the formation of the Himalaya Mountains (Figure 8).

It should be noted that all of West Virginia east of the Burning Springs Anticline and the Mann Mountain Anticline (Figure 11) moved west on decollements in shale and salt. The amount of westward movement progressively increased from several thousand feet along the Burning Springs Anticline and the Mann Mountain Anticline to several miles in the eastern part of the State.

When all of the continents were joined late in the Paleozoic Era, a large complex mountain range existed along the zone where the continents abutted. Late in the Triassic Period (about 220 million years ago), the continents began to separate. Studies comparing the rocks and fossils in eastern North America, western Europe, and

Figure 10. Schematic diagram of a conservative boundary, where one plate slides past another plate along a fracture (in this case, California's San Andreas Fault).

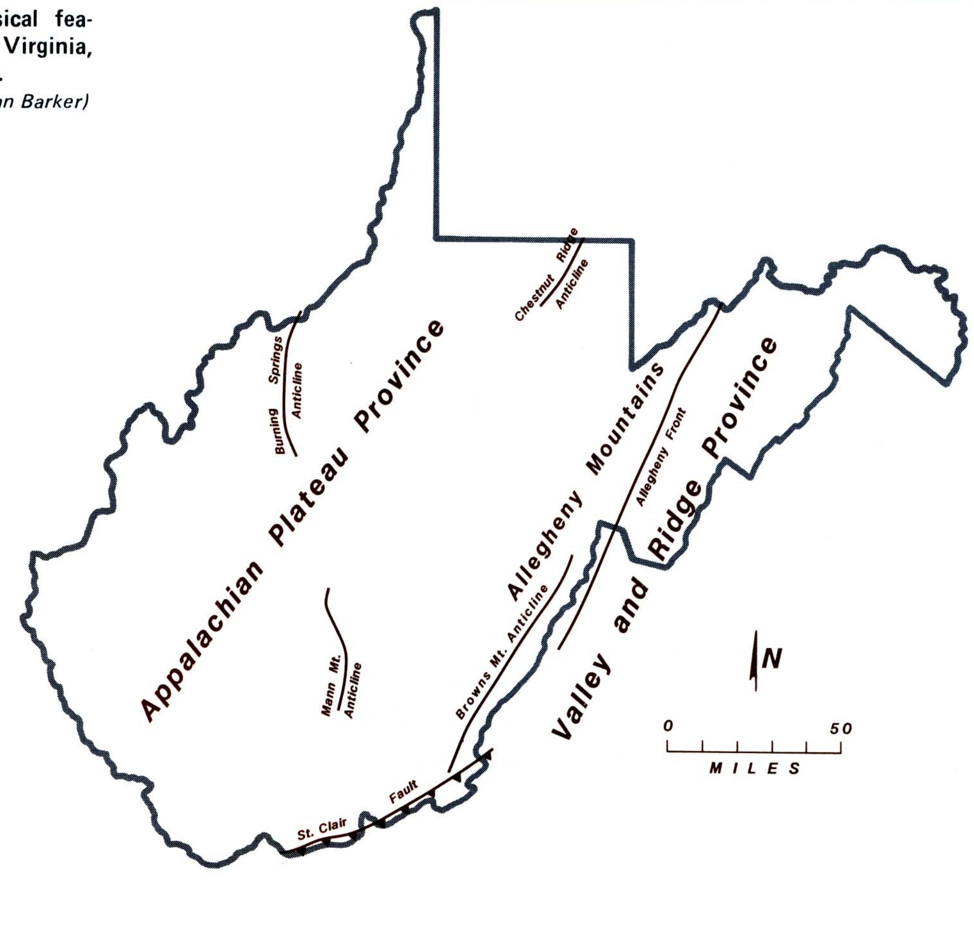
The Earth's Crust and Atlantis

The difference in density between continental crust, ocean crust, and mantle is evidence that a large continent such as the mythical Atlantis could not have existed in the Atlantic Ocean. There is no way that a light continent could sink into denser oceanic crust or the even denser mantle. It would be like a cork sinking into mercury. Nor is there any evidence that a continent in the Atlantic Ocean disappeared as a result of a gigantic eruption. In fact, the myth about Atlantis may be just a story concocted by Plato.

It might be that the story of Atlantis is based upon the fact that part of a volcanic island located in the Aegean Sea, about 80 miles north of Crete (see Figure 6), did explode during an eruption. (This island's Greek name is Thira or Thera; the Italian name is Santorini.) Some speculate that an eruption of this volcano caused great destruction to the Mycenaean Civilization in Crete about 1400 BC. Perhaps Plato used the oral history of this eruption, and the destruction caused by it, as the basis for his story about Atlantis.

Plato describes Atlantis in two dialogues, *Timaeous* and *Critias*. In *Timaeous*, Critias reports that he heard the story from his grandfather, who heard the story from his father, who heard the story from Solon. It is suggested that Solon, a famous Greek leader, as he traveled in Egypt heard about an island exploding and killing many people. The Greeks may have mistranslated the dimensions of the island and the number of people killed, reporting the island to be much larger than it really was. Such confusion often occurs today between the British "billion" (1,000,000,000,000) and the United States "billion" (1,000,000,000).

Figure 11. Physical features of West Virginia, mentioned in text.
(Illustration by Dan Barker)



northwestern Africa indicate that the line of separation did not exactly conform to the line of fusion. As a result, during the separation of the continents and the opening of the Atlantic Ocean, parts of ancestral Europe and Africa were left attached to North America, and parts of ancestral North America were left attached to Europe and Africa. For example, what is now the Florida peninsula was formerly part of northwestern Africa.

West of the Allegheny Front and the St. Clair Fault, erosional mountains and hills were formed as rivers and streams eroded the Appalachian Plateau. A few mountainous features in the plateau (Chestnut Ridge, Burning Springs Anticline, Mann Mountain Anticline, Browns Mountain Anticline, and others; see Figure 11) are folded and faulted mountains.

The mountains that formed when all of the continents were joined 250 to 300 million years ago have long since been eroded away. The mountains we see today in the Valley and Ridge Province and the Appalachian Plateau are the result of uplift and erosion that began 30 to 50 million years ago. The mountains east of the Allegheny Front and the St. Clair Fault are considered to be complex and not erosional mountains because of the complex relations between the folds and faults.

Further Reading

This list is only an introduction to the numerous popular and technical books and articles written about mountains.

The New Earth: F. Alexander, R. E. Harrison, and A. Petrucelli, in **Smithsonian**, January 1975, p. 1-22.

Mountain: P. C. Badgley, in **Encyclopedia Americana**, 1985, Grolier, Inc., p. 573-580.

The Times Atlas of the Oceans: A. Couper (ed.), 1983, Times Books, 272 p.

Volcanos and the Earth's Interior, Readings from Scientific American: R. Decker and B. Decker (eds.), 1982, W. W. Freeman & Co., 141 p.

Encyclopedia of Earth Series, Volume III, The Encyclopedia of Geomorphology: R. W. Fairbridge (ed.), 1968, Dowden, Hutchinson, & Ross, Inc., 1295 p.

Dance of the Continents: J. W. Harrington, 1983, J. P. Tarcher, Inc., 254 p.

Principles of Physical Geology (2nd ed.): A. Holmes, 1965, Ronald Press Co., 1288 p.

The Volcano That Shaped the Western World: J. Lear, in **Saturday Review**, November 5, 1966, vol. 49, p. 57-66.

Continents in Collision: R. Miller, 1983, Time-Life Books, 176 p.

National Geographic Atlas of the World (4th ed.): 1975, National Geographic Society, 330 p.

The Making of a Continent: R. Redfern, 1983, Times Books, 242 p.

Mountain: in **Science and Technology Illustrated**, 1984, vol. 17, Encyclopedia Britannica, Inc., p. 2134-2137.

Continental Landforms: in **The New Encyclopedia Britannica, Macropaedia** (15th ed.), 1986, vol. 16, p. 747-813.

The New York Times Atlas of the World: 1980, Times Books, 128 p.

The Times Atlas of the World (6th ed.): 1980, Times Books, 267 p.

The Earth's Hot Spots: G. E. Vink, W. J. Morgan, and P. R. Vogt, in **Scientific American**, April 1985, vol. 252, no. 4, p. 50-57.

Legends of the Earth, Their Geologic Origin: D. B. Vitaliano, 1973, Indiana University Press, 305 p.