

Volcanoes: Source, Kinds and Eruptions

An Online Continuing Education Course for Engineers

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Volcanoes: Source, Kinds and Eruptions

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Course Content

1.0 Introduction

From the human perspective, volcanic eruptions are some of the most spectacular and destructive geological phenomena. Their onsets are usually sudden, often very violent, of undetermined duration and they are essentially uncontrollable. Because of these inherent characteristics volcanic eruptions have been shrouded throughout most of human history in a fog of mystery and fanciful speculation. Whenever and wherever they occurred they struck fear and apprehension equally into the imagination of the mighty and the humble alike.

More recently, geologists have recognized that volcanic activity has also helped shape the surface of the earth and sculpted much of the natural beauty of the land. Volcanism has also produced a great deal of the mineral wealth and the fertile soils that we now extract and exploit at and near the surface of the earth. Despite this recognition, it may be surprising for most people to learn that it is only since the second half of the twentieth century that finally a sound and scientific understanding of this mighty natural phenomenon began to develop and be grounded on sound systematic and technical principles.

Below is a brief historical background explaining the origin of the word *volcano* and the mythology associated with its periodic rumblings.

2.0 Historical Background

The word volcano is derived from the name “*Vulcano*”, a small volcanic island located in the Mediterranean: Tyrrhenian Sea, about 25 km north of Sicily. It is the southernmost of the eight Aeolian Islands, has an area of 21 square kilometers, rises to about 500 meters above sea level, and contains several active volcanic centers. The island itself was named after Vulcan, the Roman god of fire. People living at that time believed that Vulcano was the chimney of the forge of Vulcan, the blacksmith of the Roman gods. They thought that the hot lava, rock fragments and clouds of dust erupting from Vulcano came from Vulcan’s forge as he beat out thunderbolts for Jupiter, king of the gods, and fabricated weapons for Mars, the god of war. Figure 1, below, is a location map of Vulcano in the Tyrrhenian Sea, within the Mediterranean.



Figure 1: Location Map for the Island Vulcano in the Tyrrhenian Sea, within the Mediterranean.

Also, many ancient accounts ascribe volcanic eruptions to the actions of gods or devils. To the ancient Greeks, the apparently capricious powers of volcanoes could only be attributed to the acts of angry gods determined to punish the sinners and warn the unrepentant. During the middle Ages, the German astronomer Johannes Kepler (1571-1630) believed that volcanoes were ducts for the Earth's tears. Another contrasting early idea was proposed by the Jesuit Athanasius Kircher (1602–1680), who witnessed eruptions of Mount Etna, Stromboli and Vesuvius. He proposed and published his view of an Earth with a central interconnected fire stoked by the burning of sulfur, bitumen and coal.

All the way up to the first part of the twentieth century various propositions continued to be advanced to explain why a volcano would erupt unpredictably. Even following the awareness that compression and radioactive materials may be the sources of heat and elevated temperatures deep within the earth, their contributions were specifically discounted in the explanation of volcanic eruptions. The favored explanation at that time was that strong chemical reactions and a small amount of molten rocks contributed to the spewing of fluid materials onto the surface of the earth.

The following section describes our present understanding of the internal structure of the earth based on information that has been developed since the second half of the twentieth century.

2.1 Internal Structure of the Earth

The cores of mountain ranges expose rocks that have in the past been buried at depths of several miles. A few underground mines extend over a mile in depth, and a few oil wells have been drilled to depths that are greater than five miles. These distances are miniscule when compared to the radius of the

earth. Our present day knowledge about the deep interior of the earth is mostly derived from indirect derivations and deductions based on:

- Gravity measurements on its surface,
- The earth's rotation and motions from which its moments of inertia can be deduced,
- The period of its free oscillation,
- From the propagation of seismic (earthquake) waves through it, and
- From volcanic eruptions that bring melted rocks and gases from the lower crust and upper mantle up to its surface.

Today we know that the earth has a dense core with a radius of about 3,400 km, a lighter mantle that is about 2,900 km thick, and a still lighter crust that is mostly rigid and up to 60 km in thickness. Figure 2, below, is a cross section of the earth that is consistent with modern data and our present state of knowledge.

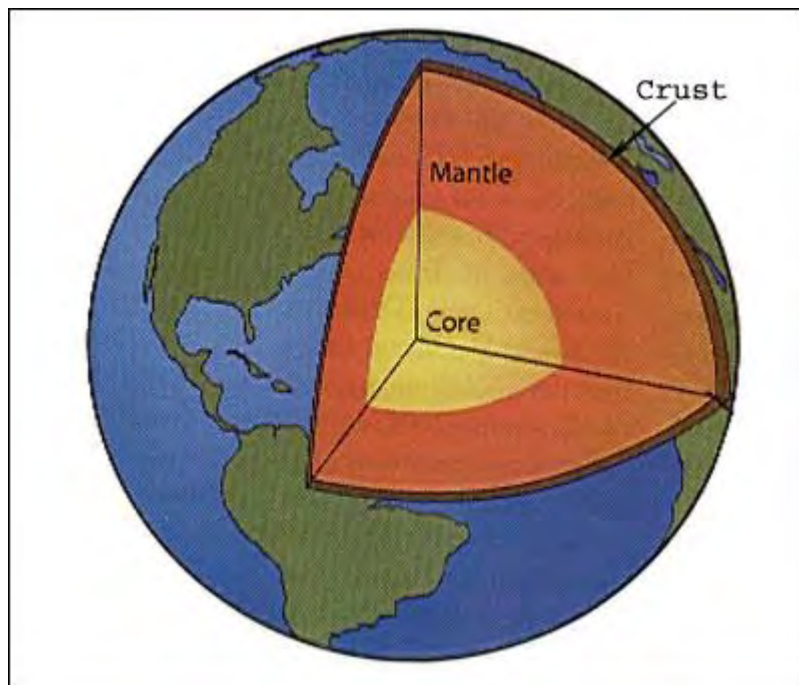


Figure 2: The Earth is composed of concentric spherical shells: crust, mantle and core (not to scale).

2.2 The Crust

Overlying the mantle, and separated from it by a sharp discontinuity (the Mohorovicic, known also as Moho, discontinuity), is the lighter solid crust that consist mostly of relatively low density silicates (density less than 3.0 g/cm^3). The crust is the rock base on which we live and from which we derive all our resources, plants, minerals, metals and fuels. The continental crust ranges in thickness from about 35 km to as much as 60 km under mountain ranges and has a density of 2.7 g/cm^3 . On the other hand,

the oceanic crust, which underlies the oceanic basins, is only about 5-10 km thick and has a density of 3.0 g/cm^3 .

2.3 The Mantle

The mantle is a major and distinct region that extends into the interior of the earth from the base of the crust to a depth of about 1,800 miles. Our knowledge of the mantle was developed in part on evidence provided by the behavior of P (compression) and S (shear) seismic waves recorded between 700 and 7,000 miles from the origin of earthquakes. At the Moho, the boundary between the crust and mantle, the velocity of the P and S waves increase sharply. For P waves from about 4.5 miles per second to about 5.5 miles per second, and for S waves from about 2.7 to 3.0 miles per second. This sharp increase is an indication that the composition of the material at this boundary changes suddenly. Although we have no direct evidence of the exact composition of the mantle, the change suggests an appreciable increase in overall density.

We know that the mantle is mostly solid because it transmits S waves, which do not propagate in liquids or fluids. Furthermore, the speed of S waves increases with depth within the mantle. These observations were used to conclude that the rigidity of the mantle increases with depth. The mantle is composed of dense mafic minerals (with an upper mantle density of about 3.3 g/cm^3 and a lower mantle density of about 5.8 g/cm^3).

2.4 The Core

The core is a distinct region that extends from the base of the mantle, 1,800 miles beneath the crust, to about 4,000 miles, which is at the center of the earth. The analysis of seismographic records from earthquakes at distances greater than 7,000 miles reveal that the core has two parts:

- Outer region about 1,400 miles thick, and
- Inner region with a radius of about 800 miles.

Observations indicate that both P and S waves penetrate through 1,800 miles into the earth. However, below that depth they enter a material that delay the P waves and eliminate the S waves altogether. Since S waves can travel through solids only, the outer region of the core must not be a solid. It is believed to be a liquefied high-density fluid. Additional support of this conclusion is provided by the P waves which travel at a retarded speed through the outer core region. Then, at a depth of about 3,200 miles, they suddenly speed up again. This increase in velocity is indicative that the inner core is solid. By analogy with meteorites the core is thought to be very dense and composed of an iron-nickel alloy.

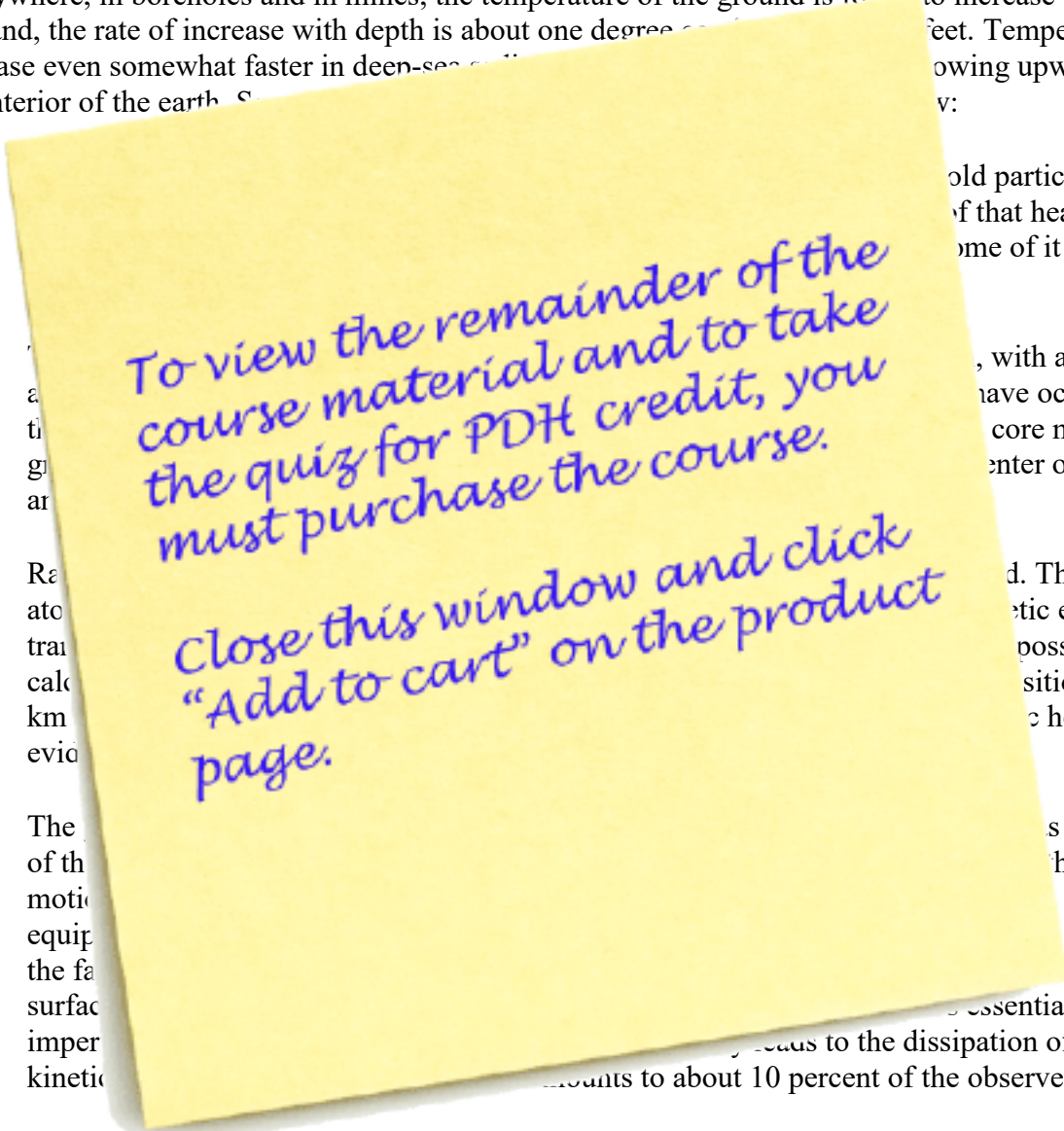
Of all the natural elements that make up the earth, only iron and nickel are heavy enough to account for the density of the core at the prevailing high temperatures and pressures at the center of the earth. Density jumps abruptly from 5.5 grams per cubic centimeter at the bottom of the lower mantle to 9.5 grams per cubic centimeter in the outer core and 13.5 grams per cubic centimeter in the inner core. For this reason it is believed that the core is composed predominantly of an iron-nickel alloy, which is molten in the outer core and solid in the inner core.

Now that we have defined the internal structure of the earth, the next sections will address our present understanding of the processes that are taking place within it and how these will lead to the development and the eruption of volcanoes.

3.0 Heat Sources within the Earth

Everywhere, in boreholes and in mines, the temperature of the ground is found to increase downward. On land, the rate of increase with depth is about one degree Celsius per 30 feet. Temperatures increase even somewhat faster in deep-sea borings. The following upward from the interior of the earth is:

- ...old particles. This ... of that heat must have ... some of it may have
- ... with a heavy core ... have occurred at ... core may have ... enter of the earth
- ... d. These sub- ... etic energy is ... possible to ... sition about 30 ... c heat
- ... s the position ... he orbital ... leading to ... on its ... essentially elastic, ... leads to the dissipation of the earth's ... amounts to about 10 percent of the observed heat flow



3.1 Heat Transfer and Convection

The heat transfer through the earth is not instantaneous. Heat generated now at great depth may not reach the surface until a much later time. The earth is quite large, and its thermal diffusivity quite small. In other words, rocks are good insulators and conduction alone could not cause appreciable cooling of its deeper parts. The slowness with which heat is transferred through rocks is of great interest and has geological consequences, because it influences the rate at which geological processes,