

VOLCANISM: GEOLOGICAL AND GEOGRAPHIC PERSPECTIVES

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Summary

The distribution of volcanic zones and active volcanoes on the Earth is described. The main region of the active volcanism is the Pacific “belt of fire”, which extends from New Zealand across Melanesia, Kamchatka, the Aleutian Islands and southward along the western coast of the Americas to Southern Chile. Other groups of active volcanoes are situated in the Mediterranean region, Asia Minor, Central Asia, Mongolia, Northern China and joins the Pacific belt. The comparison between the active volcanism on continents (orogenic and platform areas) and in the oceans (abyssal hills, guyots, fracture zones on the oceanic bottom) is described. Different types of volcanic rocks associated with the active volcanic zones and the types of tectonic structures are characterized.

1. Introduction

Of all the natural phenomena which man has had opportunity to look upon, none equals the volcanic eruption in grandeur or in beauty. Whoever has had the good fortune to witness one of the great eruptions will recall that picture with wonder and amazement all his life and retain the deepest impression from it.

There is no part of the earth that has not been the scene of volcanic activity at some time in the past. Lava flows appear among the oldest known rocks and among rocks of all later ages.

Volcanoes have been playing an increasingly significant part in the life of humanity. They have created many parts of continents, most of the islands in the oceans; the water on the surface of the earth and the atmosphere took hundreds of millions of years to form, freed from the body of the earth thanks to volcanoes and hot springs. It has been established that the greatest density of the agricultural population is to be found where there have been eruptions of ash, and that the majority of arable land and the earth's surface gained its fertility from this ash. Volcanoes are a powerful source of thermal energy, enormous energy reserves for the future. A few decades ago the idea of using a volcano as a steam-boiler for a power-station would have seemed the wildest fantasy. Today the capture of volcanic energy which is wasted by nature is one of the tasks that are now facing scientists. The day is not far off when the reserves of energy inside each volcano will be calculated like the reserves of oil and coal.

As science and technology progress the points of contact between volcanoes and humans grow ever more frequent. To come face to face with an active volcano means to touch upon a wide variety of scientific, philosophical and aesthetic problems.

Volcanism is restricted to certain geographic areas and certain geologic environments; and there is no doubt that in the past also it was restricted to similar environments, the geographical location of which shifted with the gradual evolution of the earth's crust. The generation and rise of magma are determined by the geological processes that are continually modifying the earth's surface, heaving up folded or faulted mountain ranges, elevating the crust in broad arches where former folded mountains have been eroded away, or tearing open the crust in great rifts that may extend for hundreds or thousands of miles. Indeed, volcanism is an integral part of these events, and an understanding of volcanism will aid greatly in understanding the fundamental forces that bring them about.

2. Geographical distribution

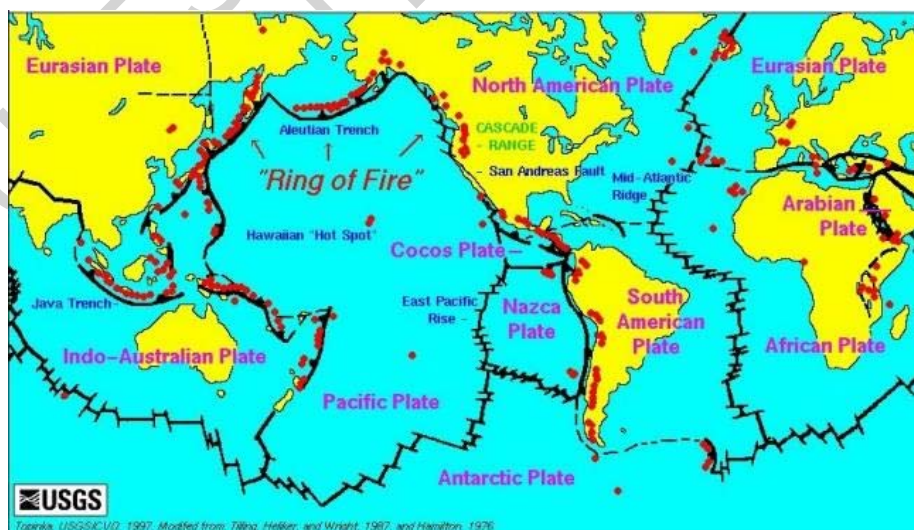


Figure 1. The distribution of active volcanoes (red points) on the Earth. (After <http://vulcan.wr.usgs.gov>. (Glossary). Plate Tectonics /Maps/map_plate_tectonics_world.html

At present, a vast majority of active and recently extinct volcanoes are concentrated in a belt that encircles the Pacific Ocean and coincides in a general way with regions of recent mountain building. This "belt of fire" extends from New Zealand northward through Melanesia into eastern Indonesia, the Philippines, Japan, and Kamchatka, eastward through the Aleutian Islands and southern Alaska, and southward along the western coast of the Americas to southern Chile (Figure 1). Volcanoes in Antarctica complete the circle. To be sure, there are gaps in the line, such as that from Alaska to southern British Columbia, and northern California to Mexico, but these gaps are to a considerable extent more apparent than real and due largely to the short span of history in those areas. Volcanoes have been active in them in the not-distant past.

Currently, the hypotheses of sea-floor spreading and "plate tectonics" are gaining wide acceptance, although they certainly cannot as yet be considered proven, and important objections to them have been raised. Briefly, the concept is as follows. Large rigid plates of lithosphere (the crust and uppermost part of the earth's mantle) are considered to move laterally over an asthenosphere (zone of lower rigidity) beneath. The lithosphere plates move outward from broad ridges, or "rises," most of which are beneath the oceans. The outward flow of heat on the ridge is generally several times as great as it is in adjacent areas, and it appears probable that the ridge is the result of local heating and expansion of the underlying mantle. Outward movement of the plates at approximately right angles to the ridge tears the lithosphere apart along the crest of the ridge, and magma rises into the tensional rift creating new lithosphere, partly by volcanic eruptions and partly by very numerous shallow intrusions. Such a zone is the Mid-Atlantic Ridge, and other mid-ocean ridges such as the East Pacific Rise are thought to be similar. The rate of broadening of the lithosphere over the ridge ranges from less than an inch per year on parts of the Mid-Atlantic Ridge to greater than 8 cm per year on parts of the East Pacific Rise. Since other evidence demonstrates that the earth's circumference cannot be increasing at a rate equal to more than a small portion of this, if it is increasing at all, it follows that lithosphere must be destroyed elsewhere at a rate approximately equal to that of creation of new lithosphere on the ridges. This destruction occurs at the distal edges of the plates, where the lithosphere plunges downward beneath the edges of the bordering plates along underthrust fault zones, commonly called "Benioff zones" after the seismologist, Hugo Benioff, who first demonstrated their existence. This "subduction" of the lithosphere commonly occurs at the boundary between ocean and continent. The downward-moving oceanic plate may scrape off an accumulation of sedimentary and associated volcanic rocks against the edge of the overriding continental plate, and this scraped-off mass, together with sedimentary material on the edge of the continental plate, may be crushed and thickened into belts of folded mountains. The entire edge of the Pacific Ocean, with its festoons of folded mountain ranges, is of this nature, and it is worthwhile noting the common association of volcanic activity with the folded belts. The subduction zones may, however, be located within the continents or within the oceans, instead of at their border, and such volcanic island arcs as the Mariana and Tonga Islands, with oceanic crust on both sides of them, are thought to mark intra-oceanic subduction zones.

The cause of the movement of the lithosphere plates away from the ridge crests and of their sinking in the subduction zones is still very uncertain. Most commonly the outward movement is attributed to convection currents, rising beneath the ridge and moving

outward in the top of the asthenosphere and rafting along the overlying lithosphere, but there is also a possibility that the motion is caused partly, or even entirely, by sliding due to gravity, of the plate down the slope of the ridge. In the subduction zone the lithosphere may be dragged down by a descending convection current or pushed down by the sliding crust behind it; or it may sink, because of its greater specific gravity, into less dense heated asthenosphere beneath; or all three mechanisms may contribute. As the lithosphere plate descends, it is presumably transformed into asthenosphere, but partial melting may release magma which moves upward through the edge of the overlying plate. The movement of the lithosphere away from the ridge may be in part, or even wholly, the result of dragging by the sinking lithosphere in the subduction zone. Obviously, the whole mechanism remains highly hypothetical. Further discussion of plate tectonics is not warranted here.

About 150 volcanoes have been active in British Columbia and Yukon during Pleistocene and Holocene (Recent) time. Most are cinder cones and associated basaltic lava flows resembling those of Paricutin and probably formed by single eruptions, but at least 20 are composite volcanoes formed by repeated eruptions ranging in composition from basalt through andesite and dacite to rhyolite. One of the latter, Mt Edziza, consists of a basaltic shield formed during Pliocene time, overlain by a complex of andesite, dacite, and rhyolite domes formed during the Pleistocene, surrounded by about 30 very young basaltic cinder cones and associated lava fields. At least three eruptions of the latter have taken place during the last 1800 years. Farther south, the Aiyansh Volcano produced a cinder cone and a lava flow of alkalic basalt with an area of about 39 square kilometers and a volume of about 0.4 cubic kilometers only about 220 years ago.

In the Mohave Desert of southeastern California several cinder cones and associated lava flows of alkalic basalt, including Mt Pisgah and Amboy Crater, were formed during Pleistocene and Holocene time. Farther north, in Death Valley, the Ubehebe Craters also are very recent. In the northern end of the Owens Valley the Bishop ignimbrite erupted only about 700,000 years ago. Still later are the Mono Craters to the north and basaltic cinder cones and lava flows along the foot of the Sierra Nevada to the south. The basalt flow of Devil's Postpile, within the Sierra Nevada, is of Pleistocene age.

A very important spur of the circum-Pacific belt extends eastward through Indonesia in the region where the folded mountain ranges of southern Asia join the structures of the Pacific Rim. The loop of volcanoes that extends through the Lesser Antilles, east of the Caribbean Sea, probably should be regarded as an eastern outlier of the circum-Pacific belt. The Scotia arc also is a loop of folded mountains swinging eastward into the Atlantic from Cape Horn and connecting with the Palmer Peninsula of Antarctica, with active volcanoes in the South Sandwich Islands at the eastern end of the arc and at least two active volcanoes close to the Palmer Peninsula. About three quarters of the earth's active volcanoes lie in the Pacific girdle as thus defined, and 14 per cent are in Indonesia alone.

Still other groups of active volcanoes lie in the Mediterranean region, northern Asia Minor, the vicinity of the Red Sea, and central Africa. Most of the latter are associated with the great Rift Valleys within which lie Lakes Victoria, Tanganyika, Albert,

Edward, Malawi and Kivu. At the head of the Gulf of Guinea on Africa's west coast, Cameroon Mt. is one of a line of volcanoes that is continued offshore by Fernando Poo, Principe, Sao Tome, and Annobon Islands. Beyond Lake Chad, 2400 km inland but on the same alignment, is the Tibesti region with its recently extinct volcanoes. The classical volcanoes of the Mediterranean are mostly in Italy, west of the Apennine Mts.; but in the Cyclades Islands southeast of the peninsula of Greece lies Santorin (Thera) Volcano, a great eruption of which may have been largely responsible for the destruction of the Minoan civilization. Mt. Ararat, of Biblical fame, is one of the volcanoes of northern Asia Minor, but it does not appear to have erupted in historical times.

Only about 17 per cent of the known active volcanoes of the world lie within the true ocean basins; 83 per cent are continental. The locations of known submarine eruptions are shown in Figure 1, as well as those of active island volcanoes. However, the proportion of known eruptions in the oceans to those on the continents is certainly misleadingly small. Many historic submarine eruptions, and even some eruptions above sea level on remote islands, must have escaped observation, and still more have gone unrecorded. Not only is the area of the ocean very large and the chance of a literate observer being in the right place at the right time very small, but eruptions at deep-ocean depths probably seldom produce recognizable disturbances at the surface. A great deal of volcanic activity has taken place in the ocean basins in the past. There is little question that the floors of the deep-ocean basins consist very largely of basaltic lava flows, and although some of them are probably moderately old, many are geologically young. A. Rittmann hazards the opinion that submarine volcanism has been at least equal to, and probably greater than, that of the continent.

About 1,000 islands are scattered within the Pacific Ocean basin, excluding the numerous islands around the edges that actually belong to the margins of the continents. Some of the islands consist of volcanic rock and are obviously volcanoes; some are still active, and others are in various stages of erosional dissection. Other islands consist of reef limestone and limy sand. It has long been believed that the latter islands are simply caps of limestone on volcanic pedestals, and this has now been confirmed by both seismic surveys and drilling. The limestone ranges from a few hundred to nearly 1,500 meters in thickness, but the mountain below it consists of basalt lava. All of the mid-ocean islands are primarily volcanic. However, only a small proportion of the volcanic mountains are high enough to emerge as islands. H.W. Menard estimates that the Pacific Basin contains about 10,000 seamounts more than 1,000 meters high but not high enough to reach the sea surface. In addition, there may be as many as 100,000 abyssal hills less than 1,000 meters high. In form, the seamounts closely resemble subaerial shield volcanoes. They are broadly rounded with slopes ranging from about 25 to 5° merging into the surrounding ocean floor. In plan, they range from nearly circular to ovoid or lobate, again resembling the outlines of the island shield volcanoes. The summits of many, if not most, are indented by steep-walled craters 300 to 1000 meters across and up to 180 meters deep. Some craters have flat floors probably formed by flooding with lava. There is little doubt that most, if not all, of them are in fact shield volcanoes. The abyssal hills are closely similar in form, and most of them also are almost certainly small shield volcanoes, though some may be up-domings of the ocean floor above shallow intrusive bodies (laccoliths). Indeed, relief maps of many parts of

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Biographical Sketch

Arthur Ja. Saltykovsky was born in 1934; Professor of Geology. He have graduated Geochemical
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