

GEOGRAPHY OF VOLCANIC ZONES AND DISTRIBUTION OF ACTIVE VOLCANOES

V. Yu. Kirianov

Institute of Volcanic Geology and Geochemistry RAS, Petropavlovsk-Kamchatsky, Russia

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Summary

Volcanic eruptions are the most awesome and powerful display of nature's force. Every

year about 50 volcanoes throughout the world are active above sea level. There are more than 500 active volcanoes (those that have erupted at least once within recorded history) in the world. A map of the world's active volcanoes shows them to be distributed unequally on Earth's surface, concentrated in some areas and completely lacking in others. Some volcanoes crown island areas near the continents, others form chains of islands in the deep ocean basins.

About 62% of all active volcanoes in the world are located around the margins of the Pacific Ocean, although their distribution along this rim is irregular. Continental margin volcanism is connected with geologically young mountain fold belts. Belts of intracontinental volcanism extending from southeastern Europe through the Mediterranean, southern Asia, and into the East Indies archipelago, and the African–Arabian mountain belt crossing the African continent. The Hawaiian Islands provide the best example of an “intraplate” volcanic chain, developed by the northwest-moving Pacific plate passing over an inferred “hot spot” that initiates the volcano-formation process. More or less isolated volcanoes occur within each of the three great oceanic regions of the world, the Pacific, the Atlantic, and the Indian Ocean and the eastern continental margin of Eurasia.

1. Introduction

Volcanism is an extremely powerful process of melting, differentiation, and segregation in the hot interior of planets that has been ongoing on Earth since the initial stages of its evolution over 4 billion years ago. Volcano eruptions on land in the last century alone have produced one and half billion tons of material per year, while the volume of basalts erupted by submarine volcanoes in mid-ocean rifts and along fracture zones is several times higher. Earth's hydrosphere and atmosphere are composed to a large extent of water vapor, carbon dioxide, and other volatiles that originated from volcanic emanations throughout the long history of the planet. Volcanic eruptions constitute one of the more dangerous natural hazards in the world, as illustrated by such eruptions as Vesuvius in AD 79, which ruined Pompeii and Herculaneum; the explosion of Krakatoa in Indonesia in 1883; and the directed blast of Mt. St. Helens volcano (USA) in 1980. Millions of people in the world live in the vicinity of active volcanoes. Cities such as Naples in Italy, Kagoshima in Japan, Hilo on Hawaii, and many others are located near active volcanoes as are densely populated agricultural districts in Indonesia, the Philippines, Japan, Mexico, and other countries. Assessment of the hazard through the prediction of eruptions and an understanding of their power and character allows vitally important protective measures to be undertaken.

Traditionally a volcano has been termed “active” if it has historically recorded eruption(s). But different volcanic regions have different duration of historical record; in Italy for example, the earliest known documented eruption of Etna volcano goes back to 1500 BC while in Kamchatka historical records of eruption began from the eighteenth century. Moreover, many volcanoes are remote from human habitation and have only poorly documented historic eruptions. Volcanic eruption repose periods are often many hundreds of years, and major eruptions may be separated by thousands of years. Szakacs suggested the following empirical redefinition of an active volcano: “A

volcano is termed active if it has erupted at least once during the last 10 000 years or, alternatively, 5000 or 2000 years as demonstrated by any scientific method.”

Many catalogues and listings of active volcanoes and their eruptions have been made. Among the first such list was that published by the geographer Varenius (Bernhard Varen) in 1650. In more modern times, the German volcanologist Sapper produced a monumental catalog of the world’s volcanoes in 1917. By 1960, the Volcanological Society of Japan began recording the new eruptions of the world by publishing a yearly Bulletin of Volcanic Eruptions. More immediate notification of eruptions began in 1968 when the Smithsonian Institution started the Center for Short-Lived Phenomena. Renamed the Scientific Event Alert Network (SEAN) by the Smithsonian in 1975, this group now issues a monthly Bulletin describing current eruptive activity.

Volcanism is truly one of the grand forces of nature that has greatly affected the environment of the world in which we live. One of the keys to understanding volcanic processes is to study the distribution of volcanoes and the geologic setting in which they occur. A map of the world’s active volcanoes shows them to be distributed unequally on the earth’s surface, concentrated in some areas and completely lacking in others.

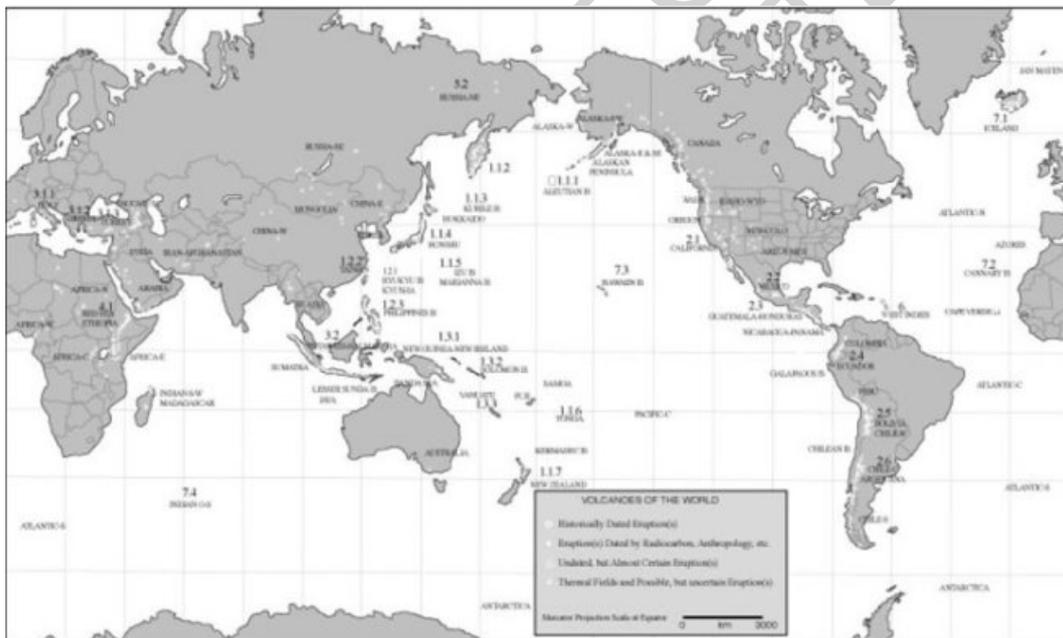


Figure 1. Distribution of volcanoes of the world
From T. Simkin and L. Siebert (1994)

This distribution characteristic has been correlated with structures of almost global proportions as well as those with purely local geologic conditions. Another highly visible feature of the global distribution of volcanoes is their concentration around the margin of the Pacific Ocean forming the so-called “Ring of Fire”

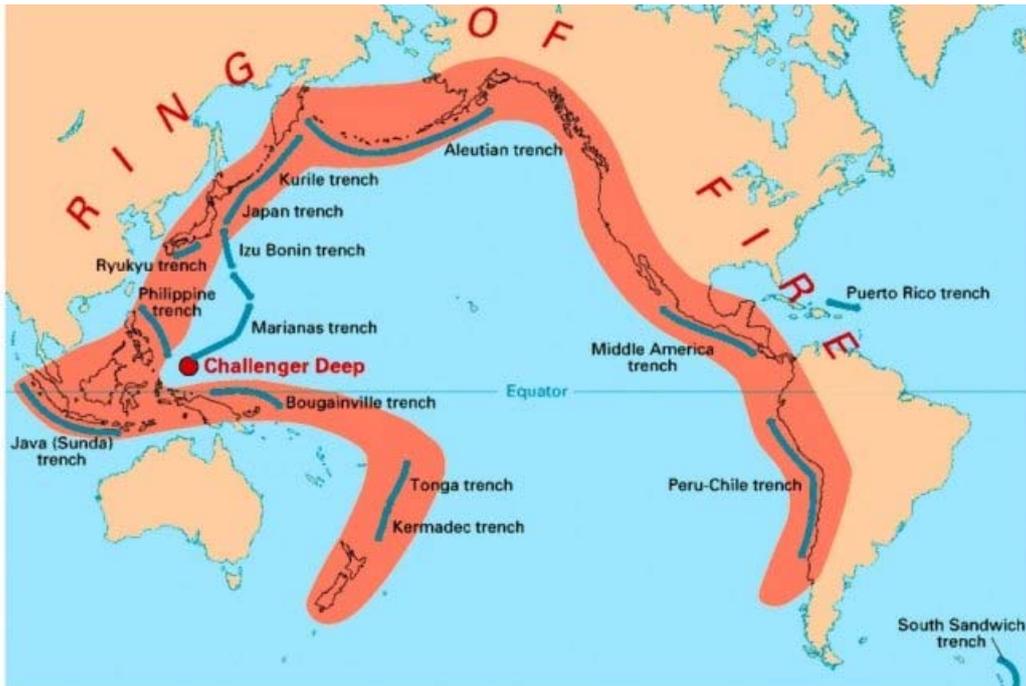


Figure 2. Volcanic arcs and oceanic trenches partly encircling the Pacific Basin form the so-called Ring of Fire, a zone of volcanic eruptions (archive USGS)

About 62% of all active volcanoes in the world are located around the margins of the Pacific Ocean, although their distribution along this rim is irregular. The East Pacific Island Arc, for example, includes 45% of the world's active volcanoes while the Central and South America segments contain only 17% of the volcanoes. About 14% of the volcanoes are located in the Indonesian Islands arc while, of the remaining 24%, 3% are located in the mid-Pacific Ocean, 1% in mid-Indian Ocean islands, 13% on mid-Atlantic Ocean islands, and the last 7% scattered through the Mediterranean Sea and Central Asia (Turkey, Iraq, etc.) and the inner part of continents, for example, the African Rift. It is possible to divide the volcanoes of the world into seven regions as follows: (1) volcanoes of the Pacific Ocean island arcs and Alaska continental rim, (2) volcanoes of the East Pacific continental rim, (3) volcanoes of alpine-Indonesian mountain belt, (4) volcanoes of East African-Arabian belt, (5) volcanoes of the rifts and mountains of Eurasia, (6) volcanoes of the West Indies island arc, and (7) volcanoes of the ocean floor.

2. Volcanoes of the Pacific Ocean Island Arcs and Alaska Continental Rim

Island arcs are one of the more intriguing features on Earth's surface. Many theories had been offered in the past to explain them, but the concept of seafloor spreading as developed in the 1960s and 1970s provides the best explanation for their origin and associated volcanism. The Pacific Ocean island arcs consist of chains of volcanic islands hundreds to thousands of kilometers long located above deep-seated megacrust faults that reach deep into Earth's mantle and are marked by the deep trenches of the world's oceans. Many of these island chains intersect to form the famous Pacific ring of fire, which extends for thousands of kilometers across Earth's surface. Thousands of volcanoes along this ring have been active in the Quaternary and at least 380 of them are considered to be presently active. In the north Pacific, the Aleutian Island arc

continues onto the continental margin of Alaska forming the composite Aleutian volcanic arc.

Active volcanoes along the west margin of the Pacific Ocean are concentrated along a variety of island arcs with these definitions. Frontal arcs are as long as 3000–4000 km and result from subduction of oceanic crust on the oceanic side of the arc; they are accompanied by deep ocean trenches. Various arc systems intersect each other at angles up to 90°. That part of the arc located behind such intersections lack recent volcanic activity and the active volcanoes are generally located along the ocean side of the arc. Inner arcs consists of a double line of islands up to 1500–2000 km in length and the volcanoes occur on the inner side of the arc. Volcanic activity is less intense and, indeed, recent volcanic activity is missing along some inner arcs (i.e., Southeastern New Guinea arc). Reverse arcs reflect subduction and a deep-sea trench located along the continental side of the islands and occur only in the southwestern part of the Pacific.

2.1. Frontal Island Arcs of the Pacific Ocean

2.1.1. Aleutian Island and Alaska Continental Margin Arc

The Aleutian island arc consists of over 100 islands extending for 1740 km across the North Pacific Rim and linked to the continental margin arc of the Alaska Peninsula



Figure 3. Volcanoes of Alaska and the Aleutian Islands
From C. Neal and R. McGimsey (1996)

This is a relatively young arc, having been formed in the last 45 million years. Alaska hosts within its borders over 80 major volcanic centers that have exhibited activity in

the past 10 000 years (i.e., the Holocene). Most of these centers are associated with what is called the Aleutian volcanic arc, which extends 2500 km from Buldir Island in the western Aleutian Islands to Hayes volcano 145 km west of Anchorage in the Alaska–Aleutian Range. Other Holocene volcanic centers in Alaska occur mainly in the islands of the Bering Sea, the Wrangell Mountains, southeastern Alaska, and isolated occurrences in the interior.

At least 32 of these volcanic centers in the Aleutian volcanic arc have historic eruptions, which in Alaska means within the past 200 years, the period in which explorers, travelers, and inhabitants kept written records. Mount Wrangell (4316 m), in east-central Alaska, and seven other volcanic centers in the Aleutian arc possibly have been active historically based on poorly documented reports. An additional seven volcanic centers, all in the Aleutian arc, have no reported historic activity but do have active fumaroles. Most of Alaskan volcanoes lie in sparsely populated areas and only one Alaskan eruption is thought to have caused fatalities.

2.1.2. Kamchatka Volcanic Arc

The Kamchatka volcanic arc, located on the Kamchatka peninsula, is a part of the geologically complex Kamchatka-Kurile Island arc, which extends about 2000 km from the Koryak Highlands to Hokkaido Island in Japan and contains 68 active volcanoes, about 12% of the total number of active volcanoes in the ring of fire.

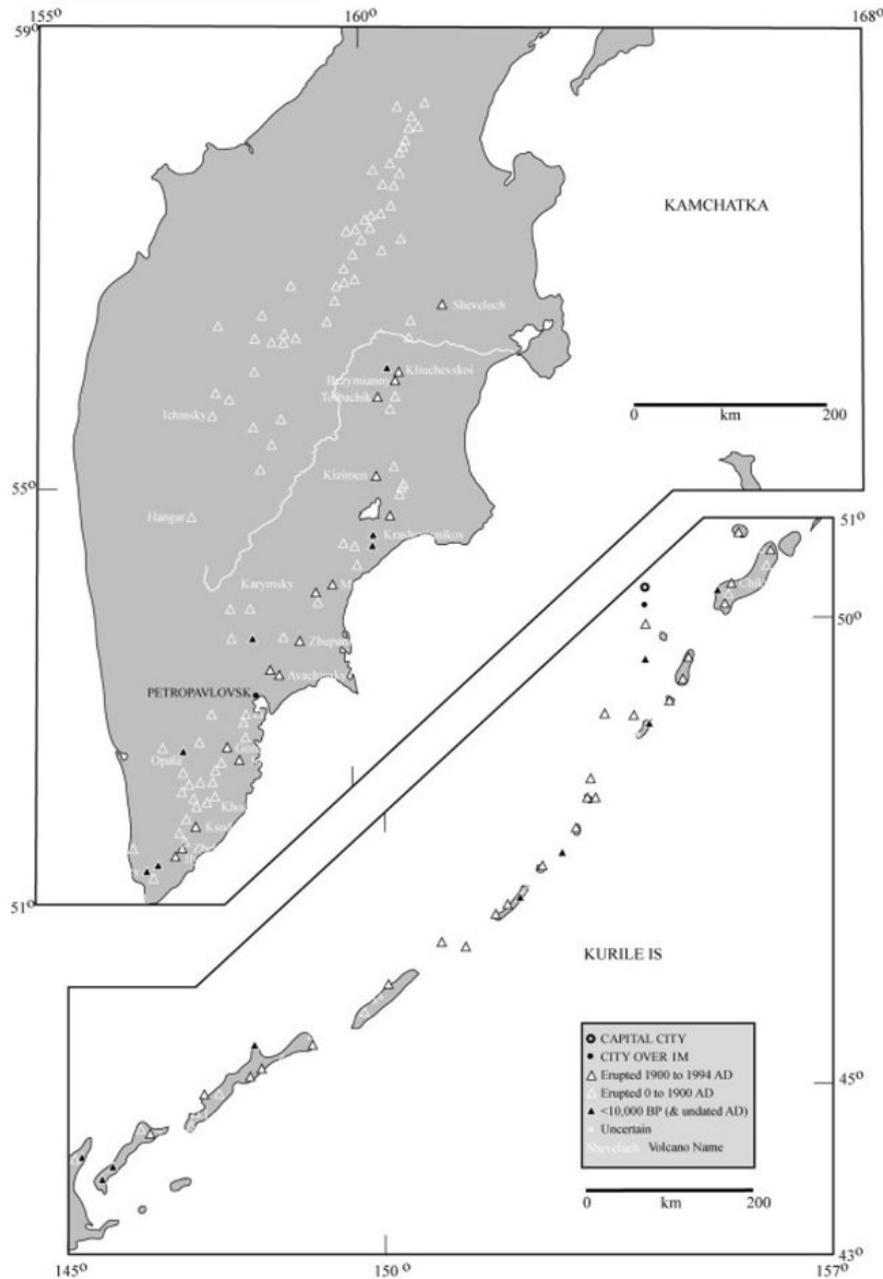


Figure 4. Volcanoes of Kamchatka and Kuriles
From T. Simkin and L. Siebert (1994)

These volcanoes eject an estimated average 240 million tons of material annually. The largest volcanoes in the Kuril–Kamchatka belt are located in Kamchatka.

The 29 active Kamchatkan volcanoes are obviously a link in the “Pacific ring of fire” but comprise only 2% (about 700 km) of the overall length and about 8% of the overall number of active volcanoes in the ring of fire. Volcanism in Kamchatka has a long record beginning in the Cretaceous with intense activity recorded over large areas of Kamchatka for the last 2–2.5 million years (Late Pliocene). Kamchatka is a terrain of accreted island arcs; volcanism has moved eastward with time producing two main

volcanic belts, the Sredinny range and the eastern volcanic belt. Most of the active volcanoes are located in the eastern volcanic belt and are the source for two or three eruptions each year. Among the best known of these volcanoes is Kliuchevskoi volcano, the highest active volcano in Eurasia at an altitude of 4750 m above sea level. The first eruption from Kliuchevskoi was reported by Russian explorers they first reached the Kamchatka peninsula in 1697. This voluminous volcano is relatively young with an age of about 7000 years. Other well-known volcanoes include Bezymianny (2870 m), which is located near Kliuchevskoi volcano, the site of a catastrophic eruption in 1956. A long-duration fissure eruption at Tolbachik volcano (3085 m) in 1975–1976 produced about 1 km³ of lava. The most active of Kamchaka's volcanoes is Karymsky (1650 m) located 110 km north of Petropavlovsk–Kamchatsky; the most recent eruptive cycle from this volcano began in 1996 and continues in 2000.

2.1.3. Kurile Island Arc

This arc, which consists of two parallel ridges (Bolshoi and Maly) with a total length of 1200 km, is characterized by tholeiitic lavas of andesite and andesite–basalt composition. All Quaternary volcanism in the Kurile Islands is part of the same magmatic cycle with an evolution from shield to stratovolcano to caldera. The youngest stratovolcanoes of precaldera stage are submarine and located near the islands. The maximum elevation of individual volcanoes is 1500–1800 m above sea level with the exception of Alaid volcano, which reaches an elevation of 2300 m above sea level. The last major eruption of Alaid volcano occurred in 1981. The most active volcanoes of the Kurile Islands are Sarychev Peak (1146 m) and Ebeko (1138 m). The total number of volcanoes in the Kurile Islands is 104, of which 39 are active. Near the Kurile Islands, 47 submarine volcanoes have been identified by their morphology.

2.1.4. Japan Island Arc

This arc extends in a southerly direction from the southwestern part of Hokkaido Island through Honshu Island for a total length of 2700 km.

Most volcanoes in this region result from subduction of westward-moving oceanic crust under the Asian Plate. The part of the arc located between Hokkaido Island and Hakone preserve near Tokyo constitute the Nasu linear zone of active volcanoes. Ten volcanoes are located along this 1000 km long zone, the most famous of which are Bandai San (1819 m) and Usu (692 m).

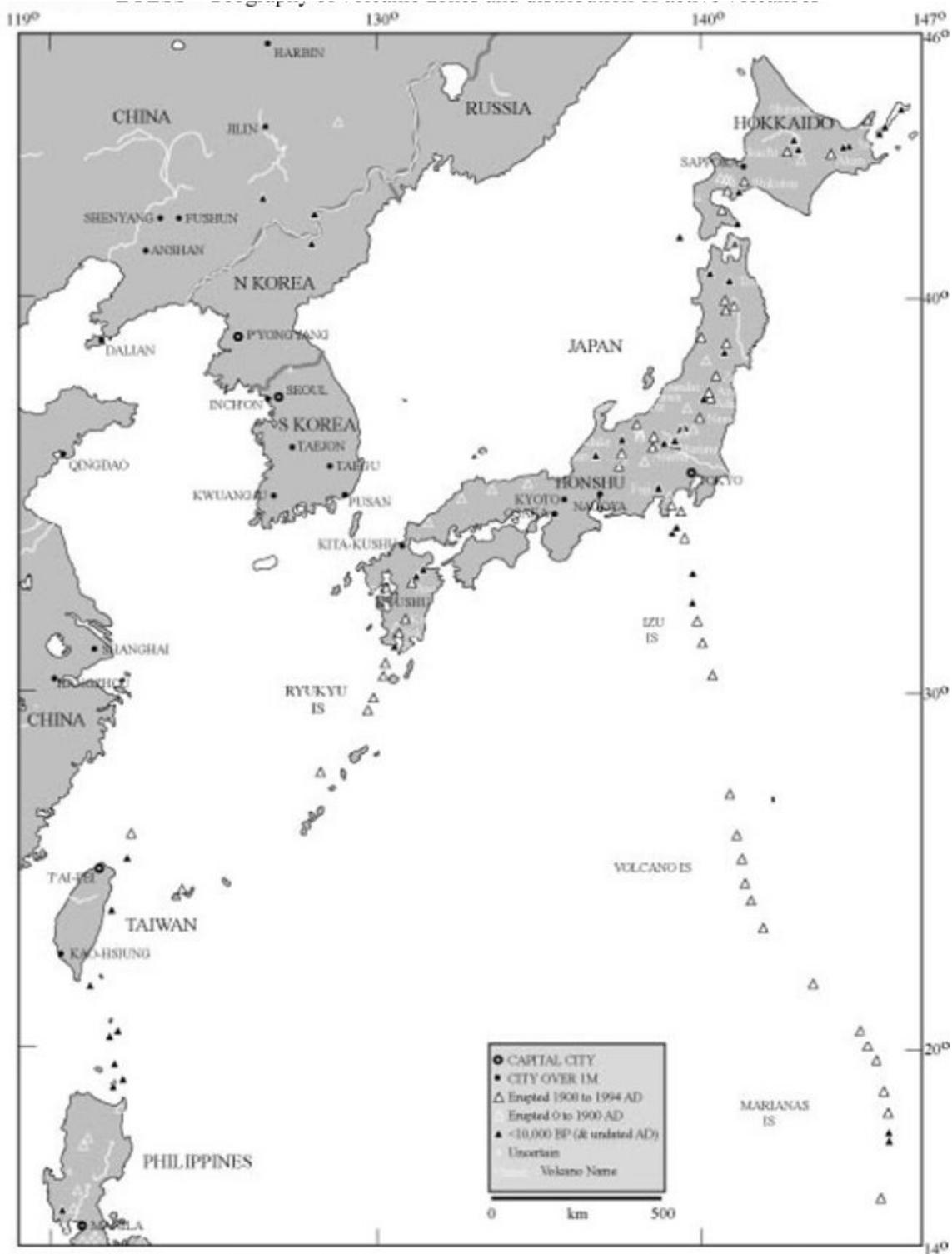


Figure 5. Volcanoes of Japan, Taiwan, and Marianas
From T. Simkin and L. Siebert (1994)

2.1.5. Bonin–Marianas Island Arc

The Fuji volcanic zone which includes the famous Fujiama Volcano, the highest

mountain in Japan at 3776 m above sea level lies at the intersection of the Japan island arc with the major Fossa Magna graben structural feature in the vicinity of Tokyo Bay and marks the northern end of the over 4000 km long Marianas–Bonin arc. The Fuji zone also includes Asama (2250 m) and other volcanoes. Most volcanoes in this region result from subduction of westward-moving oceanic crust under the Asian Plate.

The northern part of this arc, including the Bonin Islands, actually forms a straight line extending for 1500 km, including the Fuji zone on Honshu Island in Japan. The part of the arc consisting of the Marianas Volcano Islands in contrast is strongly curvilinear. Near the Marianas Islands, the arc divides into two subparallel ridges. South of the arc, volcanic activity is entirely submarine. The active volcanoes Mihara in Oshima, Miyake-jima, Mikura, and Aoga-shima lie on the Bonin part of arc while the Uraccas, Asuncion, Alamagan, and Guguan volcanoes are located on the Marian part of the arc. This region has the largest number of submarine volcanoes and reported submarine eruptions.

2.1.6. Tonga–Kermadec Ridge

This is a strongly linear feature rather than an arc and has a length of 3000 km (Figure 1). Active volcanoes, seven in the north part and two in the south, are located along the crest of the ridge. Numerous submarine eruptions have been detected offshore of this ridge.

2.1.7. New Zealand Island Arc

This arc is a continuation of the Tonga-Kermadec Ridge to the southwest for 1500 km (Figure 1). New Zealand contains the world's largest concentration of youthful rhyolitic volcanoes, and voluminous ignimbrite sheets blanket much of the North Island. Active volcanoes are located north of New Zealand, the most famous of which is Taravera (1110 m) whose the 1886 eruption resulted in numerous craters along a 15 km long fissure. The North Island of New Zealand is bisected by the Taupo volcanic zone, which is marked by high heat flow, geothermal areas, and many volcanoes. The highest New Zealand volcano is Ruapehu at 2796 m above sea level. The continuation of these frontal arcs along the western part of the Pacific basin are represented by a series of islands, which connect New Zealand with Victoria Land in Antarctic at Mt. Erebus volcano (3794 m).

Despite its size, Antarctica ranks below all other regions in number of dated eruptions. Sometime between 1825 and 1828, sealers documented an eruption at Deception Island, a natural harbor formed by caldera collapse. In 1839, whalers discovered an eruption in progress in the Balleny Islands. Two years later, Mount Erebus was erupting when this, the most active volcano in the region, was first sighted.

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Biographical Sketch

Vladimir Kirianov is Deputy Director of the Institute of Volcanic Geology and Geochemistry, Russian Academy of Sciences (Petropavlovsk-Kamchatsky, Russia). His research interest has focused on the study of volcanic ashes, reconstruction of volcanic activity, impact of volcanic eruptions on climate, and volcanic hazards. He has also studied volcanic ash and aviation safety problems across the North Pacific, working in close cooperation with the Alaska Volcano Observatory for the past 10 years. He has been the leader of KVERT (Kamchatka Volcanic Eruption Response Team) since 1993. Dr. Kirianov has conducted fieldwork in many volcanic areas around the world including Russia, Nicaragua, Mexico, USA, Japan, and Iceland). At the present time, Dr. Kirianov works at the INTAARI Company (St. Petersburg) and teaches at St. Petersburg State University (Geological Department).