Appendix B

Country and regional profiles of volcanic hazard and risk (Part Two)

This is a low resolution download of the second half of Appendix B comprising the following sections of the report:

- Region 8 – Japan, Taiwan, Marianas
- Region 9 – Kuril Islands
- Region 10 – Kamchatka and Mainland Asia
- Region 11 - Alaska
- Region 12 – Canada and Western USA
- Region 13 – Hawaii and Pacific Ocean
- Region 14 – Mexico and Central America
- Region 15 – South America
- Region 16 – West Indies
- Region 17 – Iceland and Arctic Ocean
- Region 18 – Atlantic Ocean
- Region 19 - Antarctica

Please also see www.cambridge.org/volcano#resources for the high resolution download, where you can also download the individual regions.

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Region 8: Japan, Taiwan, Marianas

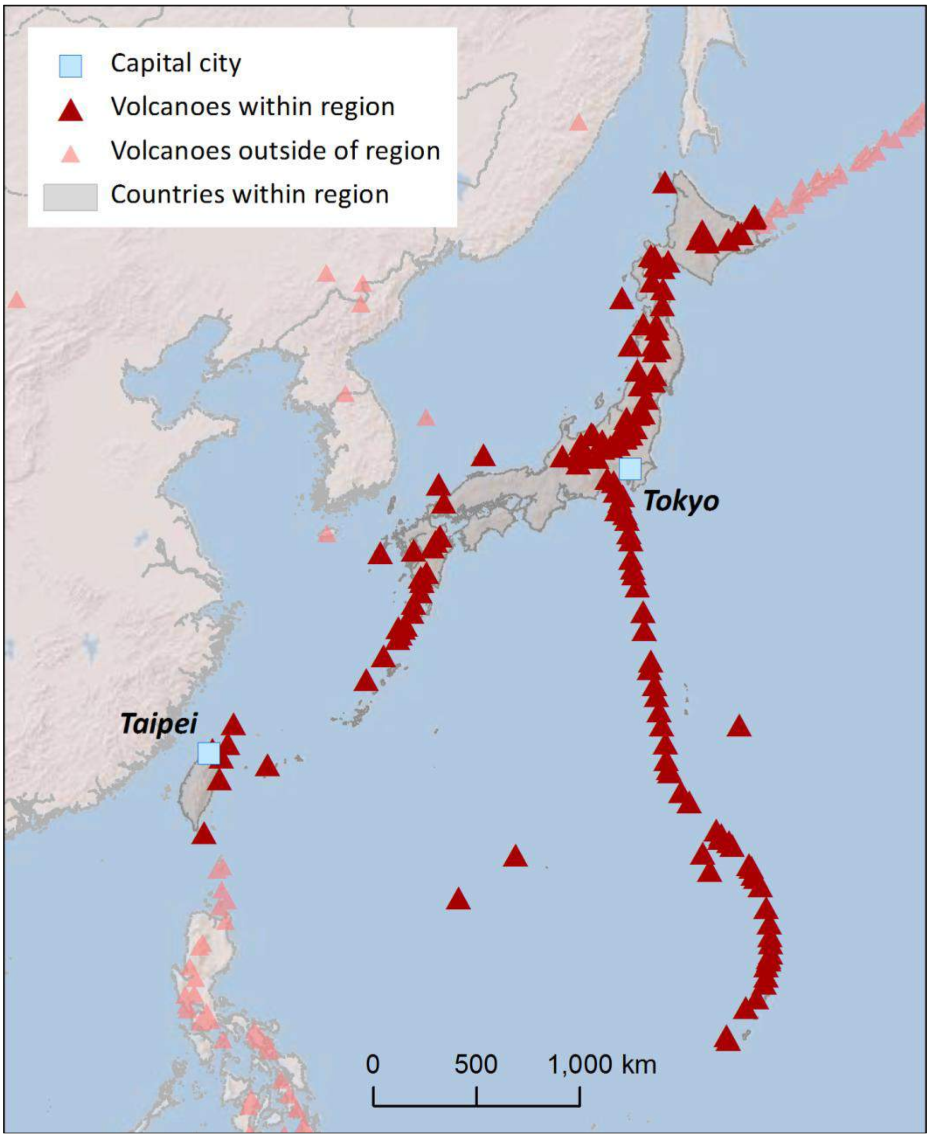

Figure 8.1 The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 8: Japan, Taiwan and the Marianas comprises volcanoes through the main Japanese arc, the Izu Islands, Marianas Islands and the Ryuku Islands. Taiwan is considered here, separately to China. Three countries are represented here. All are included in this regional discussion and individual country profiles are provided.

Country	Number of volcanoes
Japan	114
Taiwan	8
USA – Marianas	21

Table 8.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

143 volcanoes are located in Japan, Taiwan and the Marianas. Most of these volcanoes are in Japan. Although at the junction of a number of plates, volcanism in this region can broadly be described as related to the subduction of the Pacific Plate beneath the Eurasian Plate.

A large number (26) of submarine volcanoes are located in this region, along the Izu-Marianas arc. Subaerial volcanoes vary in form throughout the region, though most (64) are stratovolcanoes and complex volcanoes. The rock type through this region is dominantly andesitic, though ranges from basaltic to rhyolitic.

A range of activity styles and magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 7. About 75% of eruptions here have been small, at VEI 0 to 2, however 117 eruptions (over 10%) have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have largely been restricted to Japan, with just three in the Marianas Islands. The largest Holocene eruption in this region was the VEI 7 eruption of the Akahoya tephra from Kikai, in about 4350 BC. This eruption produced pyroclastic flows that travelled 100 km across the sea and produced widespread ash fall, devastating southern and central Kyushu.

Seventy-seven volcanoes have historical records of 874 eruptions, 97% of which were dated through direct observations. The large number of geological age (pre-1500 AD) eruptions reflects a relatively detailed Holocene record achieved through significant tephrochronological studies. 6% of historical events have produced pyroclastic flows and 8% have resulted in lahars. A further 8% have produced lava flows.

About 9% of historical eruptions (77) have resulted in loss of life. Most volcanoes have a small proximal population, largely reflecting the number of submarine volcanoes. About a quarter of volcanoes have a high local population. The risk levels reflect the varying population size and assigned hazard scores. Eleven volcanoes here are classed at Risk Level III (24% of classified volcanoes), reflecting large population sizes and frequent and/or large explosive eruptions. All Risk Level III volcanoes are in Japan.

Monitoring and research groups are active in Japan, Taiwan and the Marianas Islands, with monitoring focussed on the volcanoes of higher risk.

Volcano Facts

Number of Holocene volcanoes	143
Number of Pleistocene volcanoes with M≥4 eruptions	91
Number of volcanoes generating pyroclastic flows	52 (160 eruptions)

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Number of volcanoes generating lahars	39 (98 eruptions)
Number of volcanoes generating lava flows	47 (188 eruptions)
Number of eruptions with fatalities	85
Number of fatalities attributed to eruptions	22,770
Largest recorded Pleistocene eruption	The largest recorded Quaternary explosive eruption occurred at 87 ka with the eruption of Unit 4 from Aso in Japan.
Largest recorded Holocene eruption	The M8.1 Akahoya tephra eruption of Kikai in 7330 BP is the largest recorded Holocene eruption in LaMEVE in this region. Even at M7.2 which the volume indicates, this would still be the largest eruption in the region.
Number of Holocene eruptions	1,481 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	77
Number of historical eruptions	874

Number of volcanoes	Primary volcano type	Dominant rock type
12	Caldera(s)	Andesitic (8), Dacitic (2), Rhyolitic (2)
64	Large cone(s)	Andesitic (48), Basaltic (15), Dacitic (1)
8	Lava dome(s)	Andesitic (5), Dacitic (1), Rhyolitic (2)
8	Shield(s)	Andesitic (5), Basaltic (2), Dacitic (1)
4	Small cone(s)	Andesitic (1), Basaltic (2)
26	Submarine	Andesitic (8), Basaltic (5), Dacitic (3), Rhyolitic (2), Unknown (8)

Table 8.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	40

Table 8.3 Average recurrence interval (years between eruptions) for small and large eruptions in Japan, Taiwan and the Marianas.

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The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 40 years.

Eruption Size

Eruptions are recorded through the Japan, Taiwan and Marianas region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with about 50% of all Holocene eruptions classed as such. Just over 10% of eruptions here are explosive at VEI ≥4.

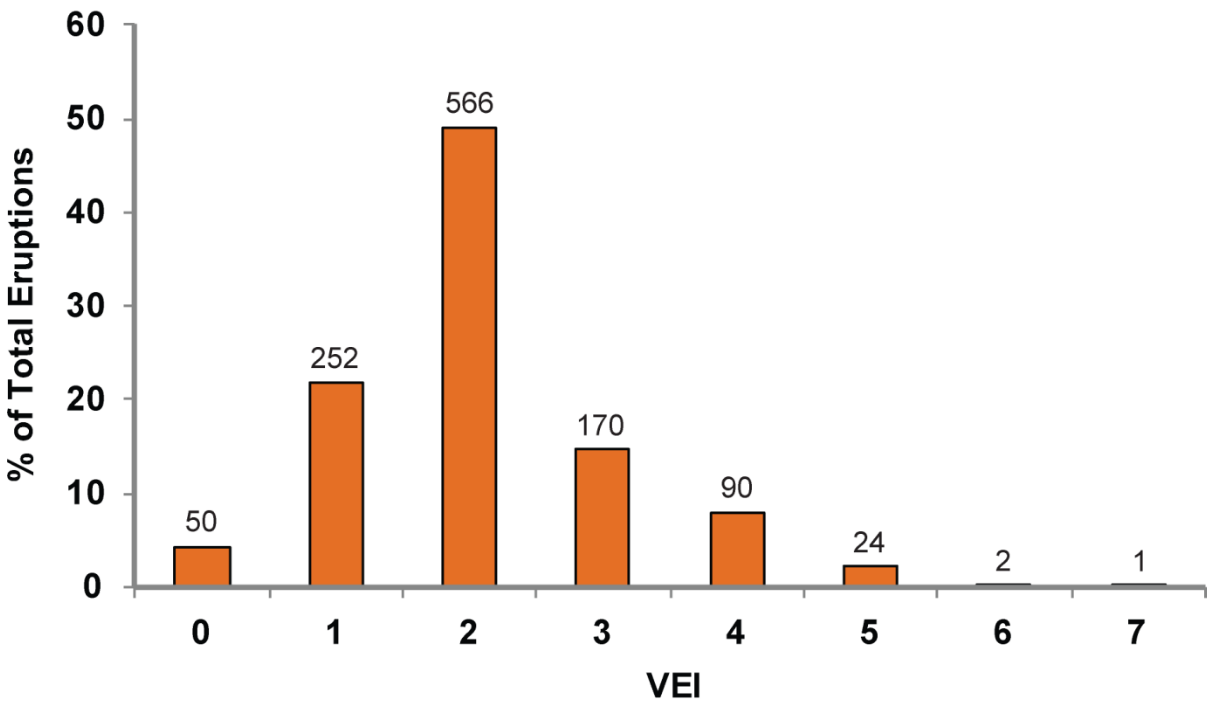

Figure 8.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 326 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	150,587,372
Gross Domestic Product (GDP) per capita (2005 PPP $)	30,660 (Japan)
Gross National Income (GNI) per capita (2005 PPP $)	32,545 (Japan)
Human Development Index (HDI) (2012)	0.912 (Very High, Japan)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	1,234,976 (0.82 %)
Number (percentage) of people living within 30 km of a Holocene	17,144,484 (11.39 %)

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volcano	
Number (percentage) of people living within 100 km of a Holocene volcano	72,295,057 (48.01 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	35
Number of ports within 100 km of a volcano	107
Total length of roads within 100 km of a volcano (km)	44,523
Total length of railroads within 100 km of a volcano (km)	7,645

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CLASSIFIED	**Hazard III**	Pagan; Anatahan	Aogashima	Tokachidake; Rausudake	Hakusan; Niigata-Yakeyama; Towada; Hachijojima; Mashu	Fujisan; Hokkaido-Komagatake; Toya (Usu)	Aira; Unzendake; Shikotsu	
	Hazard II		Suwanosejima; Kuchinoerabujima; Kikai		Kirishimayama; Yakedake; Kurikomayama; Chokaisan; Akita-Komagatake; Akita-Yakeyama; Iwakisan	Ibusuki Volcanic Field; Asamayama; Kusatsu-Shiranesan; Bandaisan; Zaozan		
	Hazard I	Farallon de Pajaros	Io-Torishima; Myojinsho; Izu-Torishima; Ioto; Fukutoku-Oka-no-Ba; Shiretoko-Iozan	Miyakejima; Akan	Nikko-Shiranesan; Nasudake; Azumayama; Hakkodasan	Asosan; Izu-Oshima		
UNCLASSIFIED	**U – HHR**	**Sumisujima**; **Nishinoshima**; **Kaitoku Seamount; Minami-Hiyoshi; Fukujin; Kasuga; Ahyi; Supply Reef; Asuncion; Agrigan**; Guguan; **South Sarigan Seamount**	**Submarine Volcano NNE of Iriomotejima**; Yokoate-jima; **Nakanoshima**; **Kita-Ioto; Kita-Fukutokutai; Oshima-Oshima; Ruby; NW Rota-1**	**Esan**; Taisetsuzan; Maruyama; Unnamed (281030)	**Ontakesan**; **Midagahara**; Hiuchigatake	**Kujusan**; **Adatarayama**; **Iwatesan**; **Osorezan**; Kuttara; Kueishantao	**Izu-Tobu**	
	U- HR	Alamagan	Kuchinoshima; Mikurajima	Megata; **Niijima**; **Kozushima**; Rishirizan	Abu; Sanbesan; Norikuradake; Numazawa; Hachimantai; Toshima; Niseko; Yoteizan; Kussharo	Fukue; Yokodake; Myokosan; Nantai; Omanago Group; Takaharayama; Naruko	Yonemaru-Sumiyoshiike; Yufu-Tsurumi; **Hakoneyama;** Harunasan	Tatun Group
	U- NHHR	**Sofugan; Suiyo Seamount; Mokuyo Seamount; Sarigan; Doyo Seamount; Kaikata Seamount;** Unnamed; **Nikko**; Minami Kasuga; NW Eifuku; Daikoku; Tenchozan; Unnamed (281010); Unnamed (281011); Zengyu; Unnamed (284138); Unnamed (284139); Maug Islands; **Zealandia Bank**	Akuseki-jima; Kogaja-jima; Kurose Hole; Kita-Bayonnaise; Unnamed (281020); East Diamante; **Esmeralda Bank**; Forecast Seamount; Seamount X	Shikaribetsu Group	Oki-Dogo; Washiba-Kumonotaira; Unnamed (281040)	Shiga; Akagisan; Hijiori		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 8.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Cassified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
8	6
26	5
31	4
13	3
29	2
35	1

Table 8.5 The number of volcanoes in Japan, Taiwan and the Marianas classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
11	III
17	II
18	I
97	Unclassified

Table 8.6 The number of volcanoes in the Japan, Taiwan and Marianas region classified at each Risk Level.

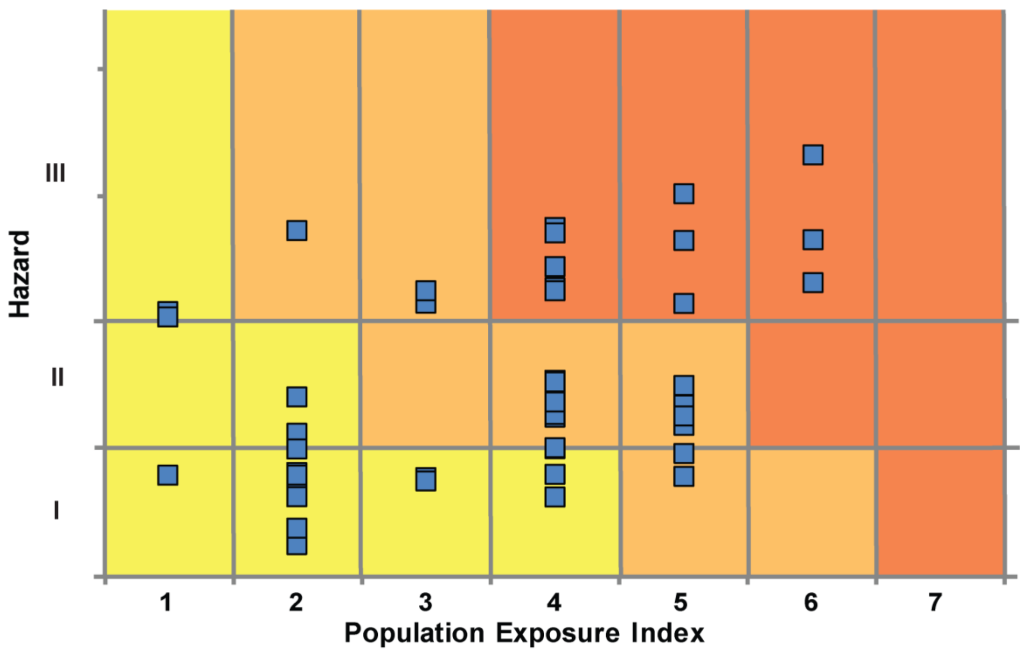

Figure 8.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional Monitoring Capacity

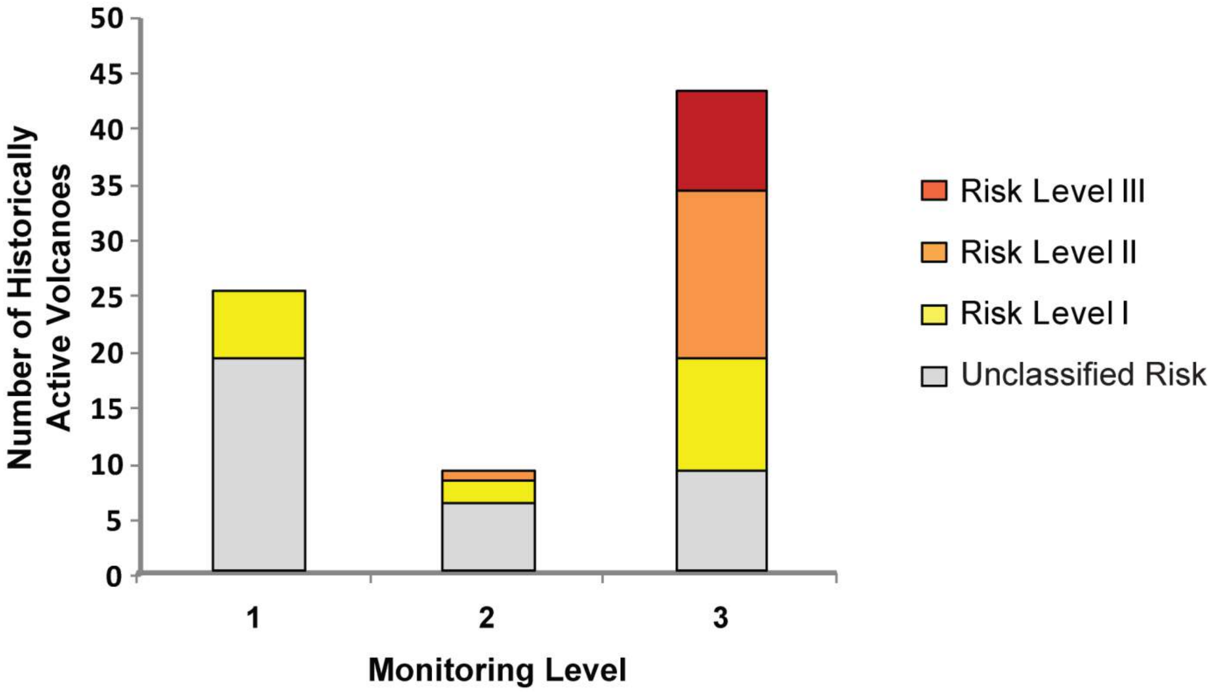

Figure 8.4 The monitoring and risk levels of the historically active volcanoes in Taiwan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Japan

Description

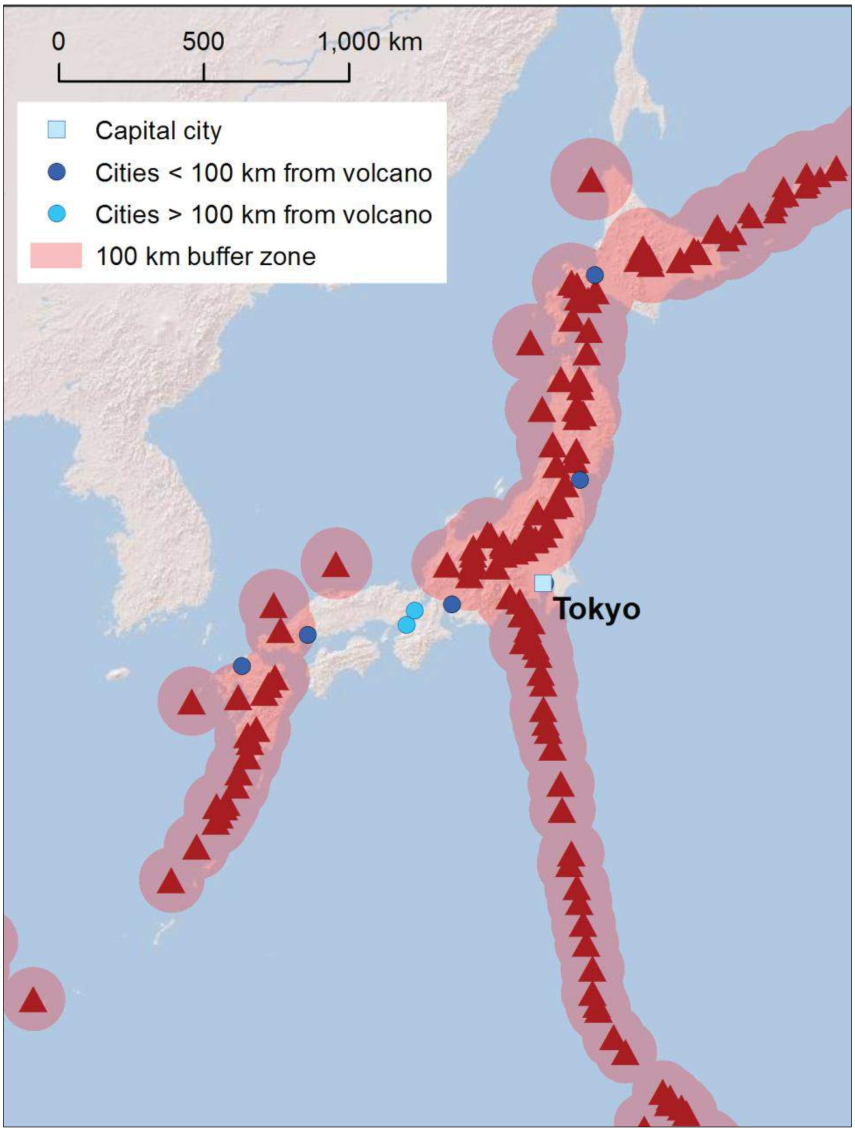

Figure 8.5 Distribution of volcanoes. The capital and largest cities in Japan are shown.

130 Holocene volcanoes are listed in Volcanoes of the World 4.0 as located throughout the islands of Japan. The subduction of the Pacific Plate beneath the Eurasian and Philippine Plates has given rise to extensive volcanism, with a range of volcano types. Subaerial volcanism is dominated by andesitic stratovolcanoes, complexes and calderas, and extensive submarine volcanism occurs throughout the Izu-Ogasawara and Ryuku Islands.

The current listing of volcanoes in VOTW4.0 differs from that of the Geological Survey of Japan and Japan Meteorological Agency (JMA), who consider 110 volcanoes to have had Holocene activity. The most recent activity at the remaining volcanoes is considered to have been Pleistocene in age. Some discrepancies are present in the classification and naming of the volcanoes between the two datasets. Here, for consistency and reproducibility we continue to use the VOTW4.0 dataset.

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Japan has an extensive Pleistocene record of large explosive eruptions, with 91 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M8.4 Aso 4 eruption of about 90,000 years ago, which produced extensive air fall and pyroclastic flows which covered much of Kyushu.

VOTW4.22 records Holocene activity at 102 volcanoes with 1,455 eruptions of VEI 0 to 7. The remaining volcanoes having activity of suspected though unconfirmed Holocene age. This size range demonstrates the range in activity in Japan, from small events to very large explosive eruptions. About 8% of eruptions here are recorded at VEI ≥4. About 11% of eruptions have records of producing pyroclastic flows. However, most commonly, small eruptions of VEI 0 – 2 are recorded. The largest Holocene eruption occurred about 7,000 years ago with the eruption of the Akahoya tephra from Kikai caldera, located south of Kyushu. This eruption produced pyroclastic flows which travelled 100 km across the sea to Kyushu.

Of the Holocene record, about 60% of the eruptions have been recorded post-1500 AD, with 846 historic eruptions of VEI 0 to 5 from 72 volcanoes. A smaller percentage of these eruptions are VEI ≥4, with about 3% being classed as such. This reflects both the longer recurrence intervals for eruptions of this size and the preservation of large deposits preferentially to small. Five VEI 5 eruptions have occurred historically, including one at Fuji in 1707, which deposited ash in nearby Tokyo.

In total, throughout Japan about 50% of the population live within 100 km of one or more Holocene volcano. The size of the local population varies at each volcano, with about equal numbers of volcanoes having small, moderate and high PEI values. The hazards are also variable. Fatalities are recorded in about 9% of historical eruptions, although none have been recorded since the 1990s.

The Japan Meteorological Agency (JMA) is the primary volcano monitoring institute in Japan. The JMA has worked with local governments to consider volcano disaster prevention measures and has implemented alert levels. The Coordinating Committee for Prediction of Volcanic Eruption (CCPVE) selected 47 volcanoes which required improvements to the monitoring and observation systems and is undertaking these improvements. Continuous monitoring is now in place at all 47 volcanoes using dedicated seismic and deformation networks, in addition to other techniques. Individual observatories of Usu Volcano Observatory, Shimabara Volcano Observatory, Asama Volcano Observatory, Kirishima Volcano Observatory, Aso Volcano Observatory, Sakurajima Volcano Observatory and Izu-Oshima Volcano Observatory have been set up by Universities. Multiple research and monitoring institutions work on the volcanoes of Japan, including the JMA, Volcanological Society of Japan, Universities (Tohoku University, Hokkaido University, Earthquake Research Institute in University of Tokyo, Kyoto University, Kyushu University etc), National Organisations (National Research Institute for Earth Science and Disaster Prevention, Japan Coast Guard, Geological Survey of Japan, etc) and other local institutes.

Monitoring data from each volcano is sent to the Volcanic Observations and Information Center in the JMA, where Volcanic Warnings are issued. Warnings are given for residential areas, non-residential areas near the crater and around the crater. These warnings include descriptions of the observed monitoring data and activity. Warnings are provided to the Japan Coast Guard, the Ministry of Land, Infrastructure, Transport and Tourism, the media, emergency services, the NTT

(Nippon Telegraph and Telephone Corporation), prefectural offices and the public. Volcanic Alert Levels of 1 to 5 are given with clear descriptions of appropriate action to take. These Levels and the warnings given depend on the level of activity and the area affected. The regional VAAC is also notified when appropriate.

See also:

Japan Meteorological Agency Volcanic Warnings:
/www.data.jma.go.jp/svd/vois/data/tokyo/STOCK/kaisetsu/English/level.html

National Research Institute for Earth Science and Disaster Prevention: www.bosai.go.jp/e/

National Catalogue of the Active Volcanoes in Japan, 4th Edition (JMA):
www.data.jma.go.jp/svd/vois/data/tokyo/STOCK/souran_eng/menu.htm

GSJ Quaternary volcano database: gbank.gsj.jp/volcano/Quat_Vol/volcano_list.html

Volcano Facts

Number of Holocene volcanoes	130
Number of Pleistocene volcanoes with M≥4 eruptions	95
Number of volcanoes generating pyroclastic flows	51
Number of volcanoes generating lahars	39
Number of volcanoes generating lava flows	42
Number of fatalities caused by volcanic eruptions	?>22,770
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M8.4 eruption 4 of Aso, which occurred about 90,000 years ago.
Largest recorded Holocene eruption	The eruption of the Akahoya tephra from Kikai volcano at 7330 BP is recorded as M8.1. The volume of this event indicates that the magnitude should be recalculated at M7.2, however this still would be classed as the largest eruption in Japan in the Holocene.
Number of Holocene eruptions	1,455 confirmed eruptions.
Recorded Holocene VEI range	0 -7 and unknown
Number of historically active volcanoes	72
Number of historical eruptions	846

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Number of volcanoes	Primary volcano type	Dominant rock type
13	Caldera(s)	Andesitic (9), Dacitic (2), Rhyolitic (2)
77	Large cone(s)	Andesitic (57), Basaltic (17), Dacitic (1), Unknown (2)
7	Lava dome(s)	Andesitic (4), Dacitic (1), Rhyolitic (2)
8	Shield(s)	Andesitic (5), Basaltic (2), Dacitic (1)
4	Small cone(s)	Andesitic (1), Basaltic (2)
21	Submarine	Andesitic (8), Basaltic (5), Dacitic (3), Rhyolitic (2), Unknown (3)

Table 8.7 The number of volcanoes in Japan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	127,157,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	30,660
Gross National Income (GNI) per capita (2005 PPP $)	32,545
Human Development Index (HDI) (2012)	0.912 (Very High)

Population Exposure

Capital city	Tokyo
Distance from capital city to nearest Holocene volcano	83.3 km
Total population (2011)	127,469,543
Number (percentage) of people living within 10 km of a Holocene volcano	622,818 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	9,381,463 (7.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	61,363,766 (48.1%)

Ten largest cities, as measured by population and their population size (2010, from UNdata data.un.org):

Tokyo	8,945,695
Yokohama	3,688,773
Osaka	2,665,314
Nagoya	2,263,894
Sapporo	1,913,545
Kobe	1,544,200

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Kyoto	1,474,015
Fukuoka	1,463,743
Kawasaki	1,425,512
Saitama	1,222,434

Infrastructure Exposure

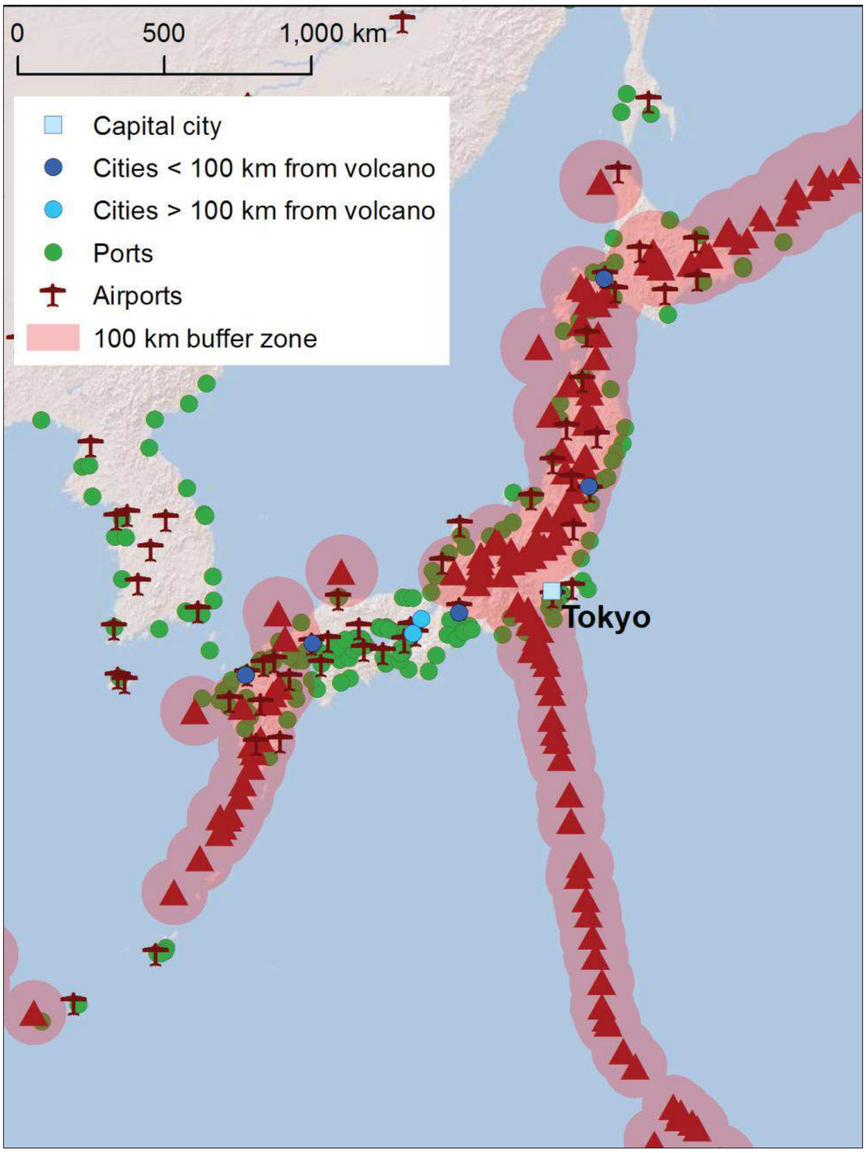

Figure 8.6 The location of the volcanoes in Japan and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	30
Number of ports within 100 km of a volcano	99
Total length of roads within 100 km of a volcano (km)	41,982
Total length of railroads within 100 km of a volcano (km)	7,097

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Holocene volcanoes are distributed throughout Japan, placing large parts of the country within 100 km of these volcanoes. Many of the largest cities in Japan, including the capital, Tokyo, lie within 100 km of one or more volcanoes. This means that most of the critical infrastructure is exposed, including nearly 100 ports, 30 airports including international airports, and a very extensive road and rail network linking the islands.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption records of Japan's volcanoes. About 40% of the volcanoes here have enough data in their records to permit the calculation of the hazard, and these volcanoes are classified across all three hazard levels, with approximately equal numbers of volcanoes in each level.

Over 60% of the volcanoes have large uncertainties associated with the classification of the Hazard level due to incomplete or sparse eruption records, and these are therefore unclassified. Indeed, about a third of the unclassified volcanoes have no records of confirmed eruptions during the Holocene, though of these, six have had episodes of apparent unrest since 1900 AD suggestive of active systems. A further third of the unclassified volcanoes have Holocene records of eruptions before 1500 AD, and the remaining third have had historical activity, including 15 volcanoes with eruptions since 1900 AD. Twelve of the unclassified volcanoes have Holocene records of large magnitude, VEI ≥4 eruptions.

The PEI ranges from low to high, with approximately equal numbers of low PEI, moderate PEI and high PEI volcanoes. Some of the volcanoes with the highest hazard also have the highest PEI. The classified volcanoes categorise in all three risk levels, with 11 classed at Risk Level III. Sakurajima (Aira), with the highest Hazard level in Japan also has a very high local population, with over 110,000 living within 10 km, making this a Risk Level III volcano.

*Table 8.8 (next page): Identity of Japan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

CLASSIFIED	**Hazard III**		Aogashima	Tokachidake; Rausudake	Hakusan; Niigata-Yakeyama; Towada; Hachijojima; Mashu	Fujisan; Hokkaido-Komagatake; Toya (Usu)	Aira; Unzendake; Shikotsu	
	Hazard II		Suwanosejima; Kuchinoerabujima; Kikai; Chachadake [Tiatia]; Etorofu-Yakeyama [Grozny Group]		Kirishimayama; Yakedake; Kurikomayama; Chokaisan; Akita-Komagatake; Akita-Yakeyama; Iwakisan	Ibusuki Volcanic Field; Asamayama; Kusatsu-Shiranesan; Bandaisan; Zaozan		
	Hazard I		Io-Torishima; Myojinsho; Izu-Torishima; Ioto; Fukutoku-Oka-no-Ba; Shiretoko-Iozan; Moyorodake [Medvezhia]	Miyakejima; Akan	Nikko-Shiranesan; Nasudake; Azumayama; Hakkodasan	Asosan; Izu-Oshima		
UNCLASSIFIED	**U – HHR**	**Sumisujima**; **Nishinoshima**; **Kaitoku Seamount; Minami-Hiyoshi**; **Fukujin**; **Kasuga**	**Submarine Volcano NNE of Iriomotejima**; Yokoate-jima; **Nakanoshima**; **Kita-Ioto**; **Kita-Fukutokutai; Oshima-Oshima;** Tomariyama [Golovnin]; **Raususan [Mendeleev];** Etorofu-Atosanupuri [Atosanupuri]; Sashiusudake [Baransky]; Chirippusan [Chirip]	**Esan**; Taisetsuzan; Maruyama	**Ontakesan**; **Midagahara**; Hiuchigatake	**Kujusan**; **Adatarayama**; **Iwatesan**; **Osorezan**; Kuttara	**Izu-Tobu**	
	U- HR		Kuchinoshima; Mikurajima; Moekeshiwan [Lvinaya Past]	Megata; **Niijima**; **Kozushima**; Rishirizan	Abu; Sanbesan; Norikuradake; Numazawa; Hachimantai; Toshima; Niseko; Yoteizan; Kussharo	Fukue; Yokodake; Myokosan; Nantai; Omanago Group; Takaharayama; Naruko	Yonemaru-Sumiyoshiike; Yufu-Tsurumi; **Hakoneyama;** Harunasan	
	U- NHHR	**Sofugan; Suiyo Seamount; Mokuyo Seamount; Doyo Seamount; Kaikata Seamount;** Unnamed; **Nikko**; Minami Kasuga; NW Eifuku; Daikoku; Tenchozan; Odamoisan [Tebenkov]	Akuseki-jima; Kogaja-jima; Kurose Hole; Kita-Bayonnaise; Ruruidake [Smirnov]; Berutarubesan [Berutarube]; Nishihitokappuyama [Bogatyr Ridge]; Unnamed (290061); Rucharuyama [Golets-Tornyi Group]; Rakkibetsudake [Demon]	Shikaribetsu Group	Oki-Dogo; Washiba-Kumonotaira	Shiga; Akagisan; Hijiori		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

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Volcano	Population Exposure Index	Risk Level
Aira	6	III
Unzendake	6	III
Shikotsu	6	III
Fujisan	5	III
Hokkaido-Komagatake	5	III
Toya	5	III
Ibusuki Volcanic Field	5	II
Asosan	5	II
Asamayama	5	II
Kusatsu-Shiranesan	5	II
Bandaisan	5	II
Zaozan	5	II
Izu-Oshima	5	II
Hakusan	4	III
Niigata-Yakeyama	4	III
Towada	4	III
Hachijojima	4	III
Mashu	4	III
Kirishimayama	4	II
Yakedake	4	II
Kurikomayama	4	II
Chokaisan	4	II
Akita-Komagatake	4	II
Akita-Yakeyama	4	II
Iwakisan	4	II
Nikko-Shiranesan	4	I
Nasudake	4	I
Azumayama	4	I
Hakkodasan	4	I
Tokachidake	3	II
Rausudake	3	II
Miyakejima	3	I
Akan	3	I
Aogashima	2	II
Chachadake [Tiatia]	2	I
Etorofu-Yakeyama [Grozny Group]	2	I
Fukutoku-Oka-no-Ba	2	I
Io-Torishima	2	I
Ioto	2	I
Izu-Torishima	2	I
Kuchinoerabujima	2	I
Kikai	2	I
Moyorodake [Medvezhia]	2	I
Myojinsho	2	I
Shiretoko-Iozan	2	I
Suwanosejima	2	I

Table 8.9 Classified volcanoes ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 15 volcanoes; Risk Level II – 17 volcanoes; Risk Level III – 11 volcanoes.

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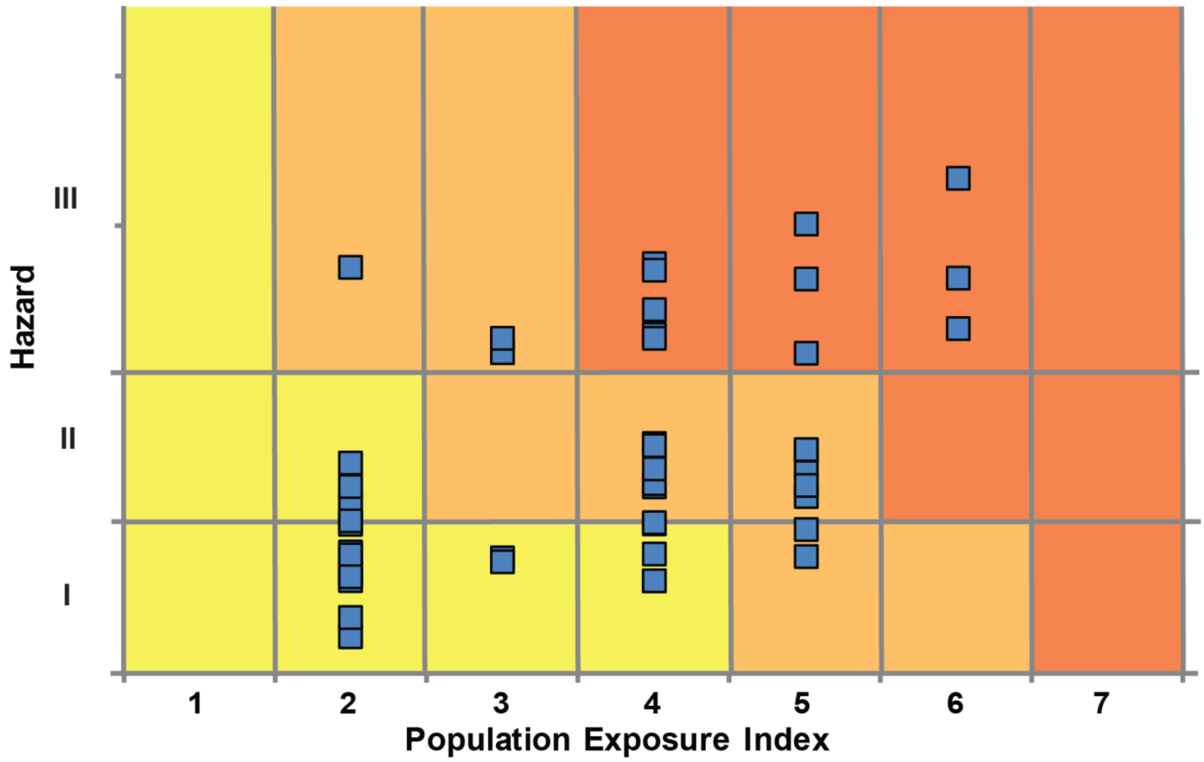

Figure 8.7 Distribution of volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Seventy-two volcanoes have historical records of activity. These volcanoes range across the risk spectrum, with most classed as Risk Level II. Several research and monitoring institutions are active in Japan, though the JMA is the principal monitoring body. The level of monitoring varies volcano to volcano, however there is an overall trend in increased monitoring at the higher risk volcanoes. Forty-one of these volcanoes are continuously monitored by the JMA using dedicated seismic and deformation networks. A further seven volcanoes have monitoring networks located within 20 km or networks with discontinuous monitoring. JMA also continuously monitor a number of volcanoes which have a Holocene record of activity prior to 1500 AD.

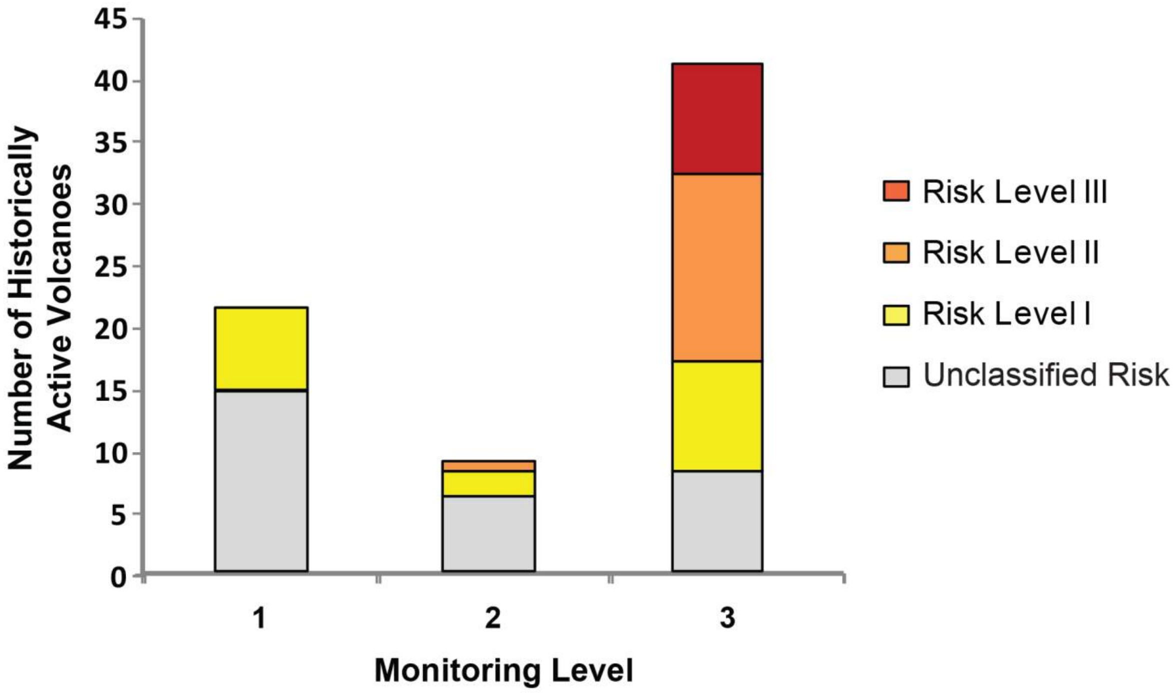

Figure 8.8 The monitoring and risk levels of the historically active volcanoes in Japan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

N.B. The volcanoes on the Kunashir and Iturup Islands are also discussed in the separate Region 9: Kuril Islands profile.

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Taiwan

Description

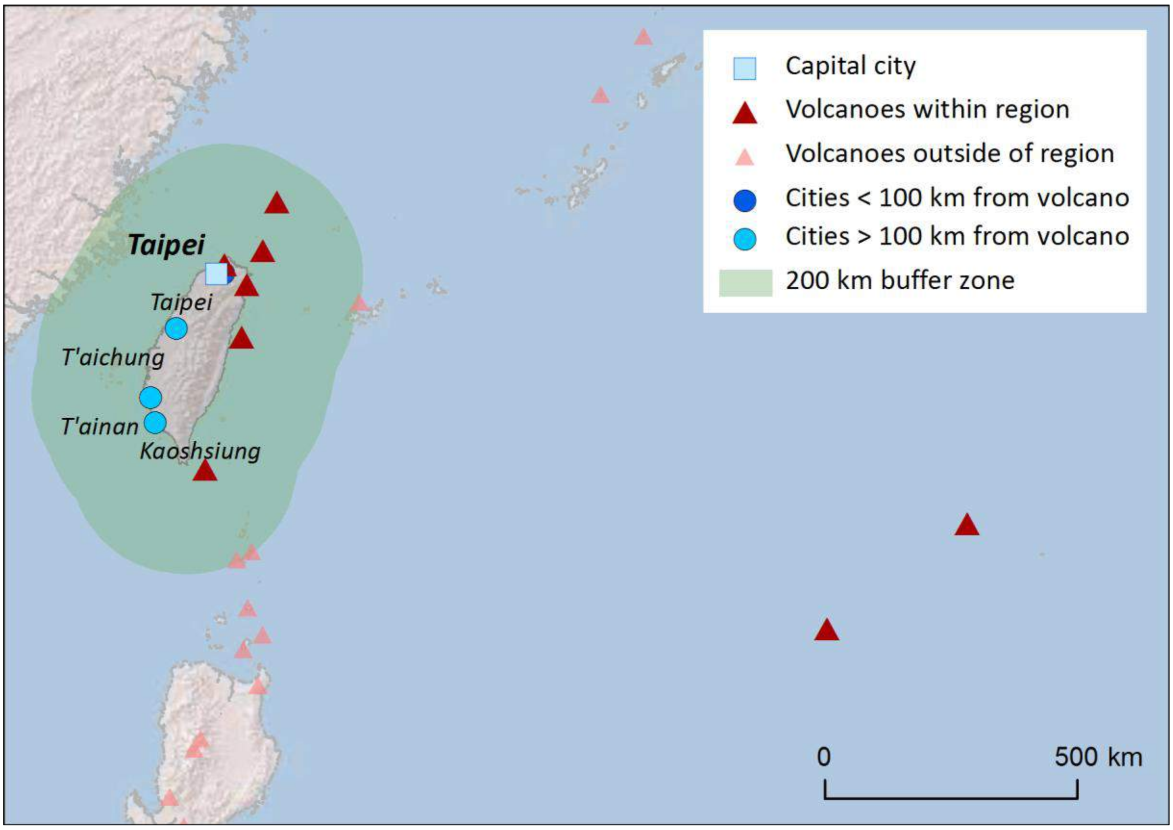

Figure 8.9 Location of Taiwan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Taiwan.

Eight Holocene volcanoes are located in Taiwan: the Tatun Group volcano on mainland Taiwan; Kueishantao and another three volcanoes near the north-east coast; and one volcano off the south-east coast. Volcanism here is due to the subduction of the Philippine Plate under the Eurasian Plate.

The Tatun Group is a complex of dominantly andesitic lava domes. Kueishantao is also dominantly andesitic, and is the only stratovolcano in Taiwan. The other six Holocene volcanoes are submarine of unknown composition.

Of the eight Holocene volcanoes, only three have confirmed Holocene records of eruptions, the remaining are suspected of having Holocene age activity. Tatun Group has a dated VEI 1 eruption of 4100 BC, whilst Kueishantao and an unnamed submarine volcano have historical records of eruptions in 1785 and 1853 respectively. The largest recorded eruption was the VEI 2 eruption in 1853.

Although most of Taiwan's volcanoes are located offshore, a considerable percentage of the population resides in areas proximal to Taiwan's Holocene volcanoes. This is due to the location of the Tatun Group, situated within 10 km of the capital, Taipei.

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The sparse Holocene eruption record in Taiwan means that assessment of hazard here is associated with large uncertainties, and focussed research is required to more fully understand the eruptive histories, particularly of the subaerial features. Indeed, in response to this need the Taiwan Volcano Observatory (TVO) was founded and became operational in October 2011. The TVO has primary responsibility for the Tatun Group volcano, where the observatory is situated, and Kueishantao. Monitoring is undertaken at both these volcanoes, with an extensive multi-system network of dedicated instrumentation and research at Tatun Group.

The TVO is supported by the Ministry of Science and Technology and is funded by the Taiwan government. At present risk assessments are being developed and the TVO participate in managing and mitigating the risks.

See also:

Taiwan Volcano Observatory – Tatun, tec.earth.sinica.edu.tw/TVO/free.php?link=sciedu/knowvol

Volcano Facts

Number of Holocene volcanoes	6 with 2 unconfirmed
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone (6), Rift zone (1)
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 2 eruption of an unnamed volcano in 1853.
Number of Holocene eruptions	3 confirmed eruptions. 5 uncertain eruptions, 1 discredited.
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historical eruptions	2

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
1	Lava dome(s)	Andesitic (1)
6	Submarine	Unknown (6)

Table 8.10 The number of volcanoes in Taiwan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2014) (National Statistics, Republic of China[1])	23,379,594
Gross Domestic Product (GDP) per capita (2013, CIA[2])	39,600
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2011[3])	0.882

Population Exposure

Capital city	Taipei
Distance from capital city to nearest Holocene volcano	<10 km
Total population (2011)	23,071,779
Number (percentage) of people living within 10 km of a Holocene volcano	612,157 (2.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	7,763,020 (33.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	10,878,326 (47.2%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	2,415

[1] eng.stat.gov.tw/mp.asp?mp=5
[2] www.cia.gov/library/publications/the-world-factbook/geos/tw.html
[3] 16124371.pdf

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Total length of railroads within 100 km of a volcano (km)	548

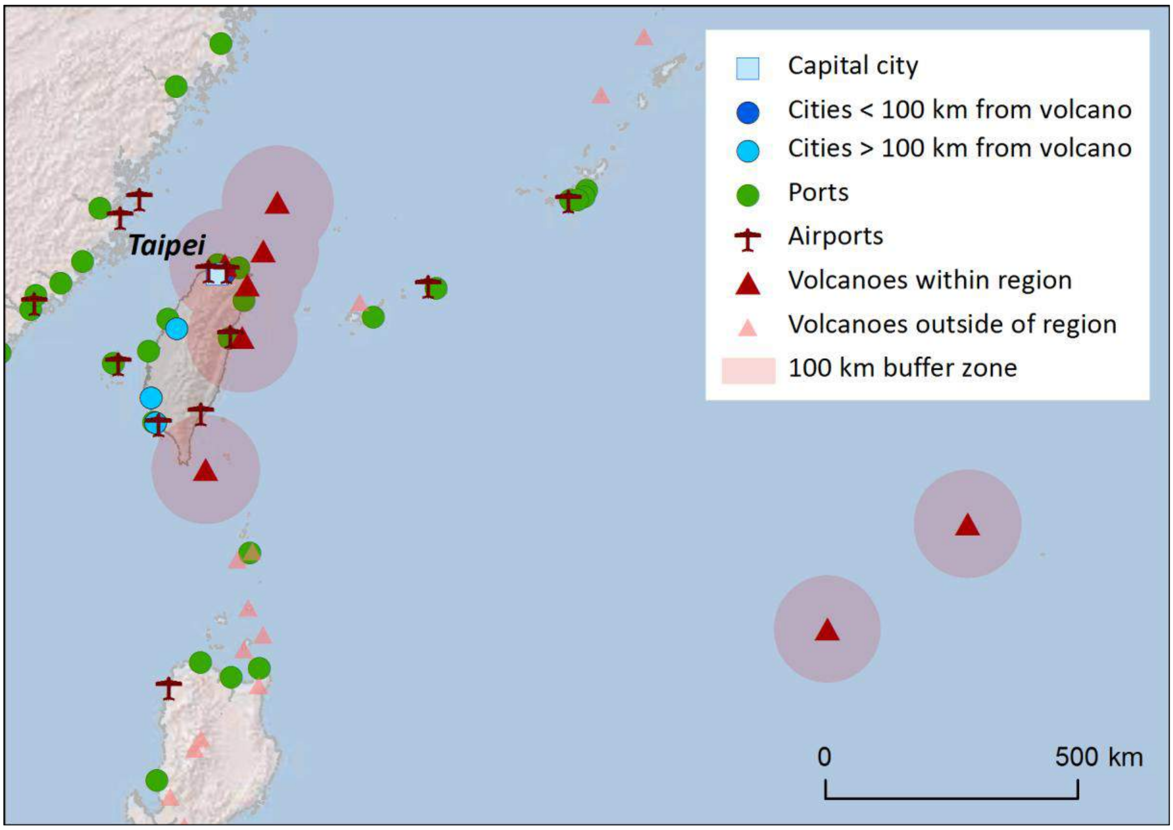

Figure 8.10 The location of Taiwan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes in Taiwan are concentrated in the north, where the capital Taipei lies within 100 km. Indeed it is less than 10 km from Taipei to the Tatun Group volcano. Other large cities and considerable infrastructure are exposed in the north, including airports and ports. Large cities in the south are also within 100 km of an unnamed volcano off the coast of Taiwan. An extensive road and rail network is exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in Taiwan are sparse and this prevents hazard assessment without significant associated uncertainties. The volcanoes here are therefore unclassified. Indeed, of the eight volcanoes, just three have a Holocene eruption record each with just one eruption. Both an unnamed volcano and Kueishantao have erupted historically, whilst the last recorded eruption of Tatun Group was in 4100 BC.

The PEI ranges from low to very high in Taiwan. No volcanoes are classified by risk level due to the absence of a hazard classification, however the high local population around the Tatun Group makes this a PEI 7 volcano, which indicates high risk.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR			Unnamed (281030)		Kueishantao		
	U- HR							Tatun Group
	U- NHHR	Unnamed (281010); Unnamed (281011); Zengyu	Unnamed (281020)		Unnamed (281040)			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 8.11 Identity of Taiwan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.National Capacity for Coping with Volcanic Risk*

Two volcanoes have historical activity: an unnamed submarine volcano and Kueishantao. The Taiwan Volcano Observatory principally monitors Tatun Group (active in the Holocene) and Kueishantao. The location of the Tatun Group volcano with a large proximal population and the dominance of monitoring activities here indicates that monitoring resources are focussed on volcanoes of highest risk.

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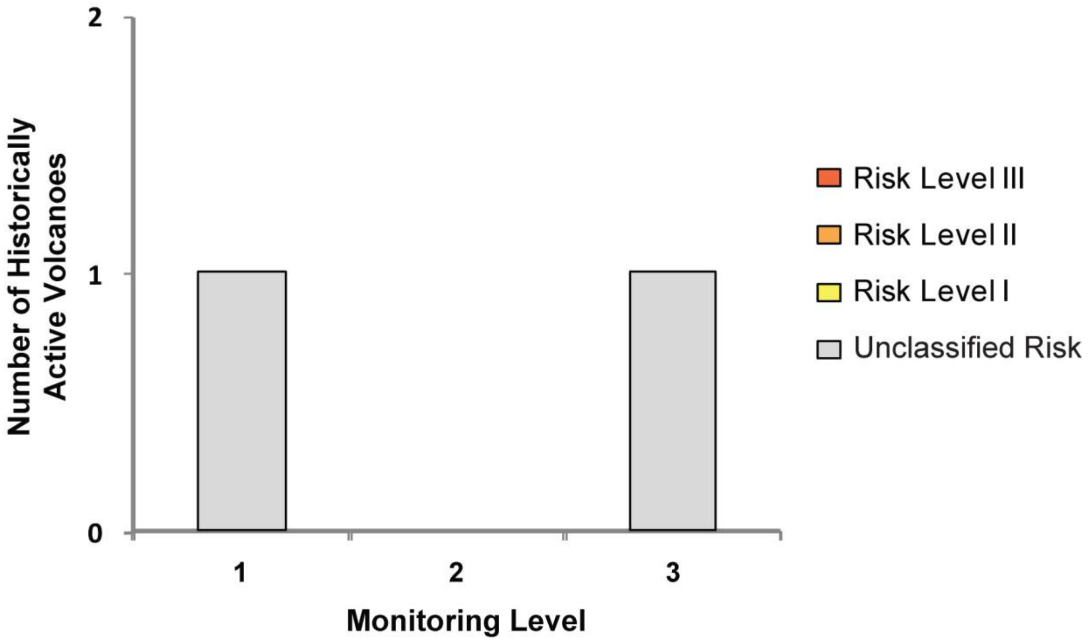

Figure 8.11 The monitoring and risk levels of the historically active volcanoes in Taiwan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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USA – Mariana Islands

For further USA profiles see Region 4 for American Samoa, Region 11 for Alaska, Region 12 for the contiguous states, Region 13 for Hawaii.

Description

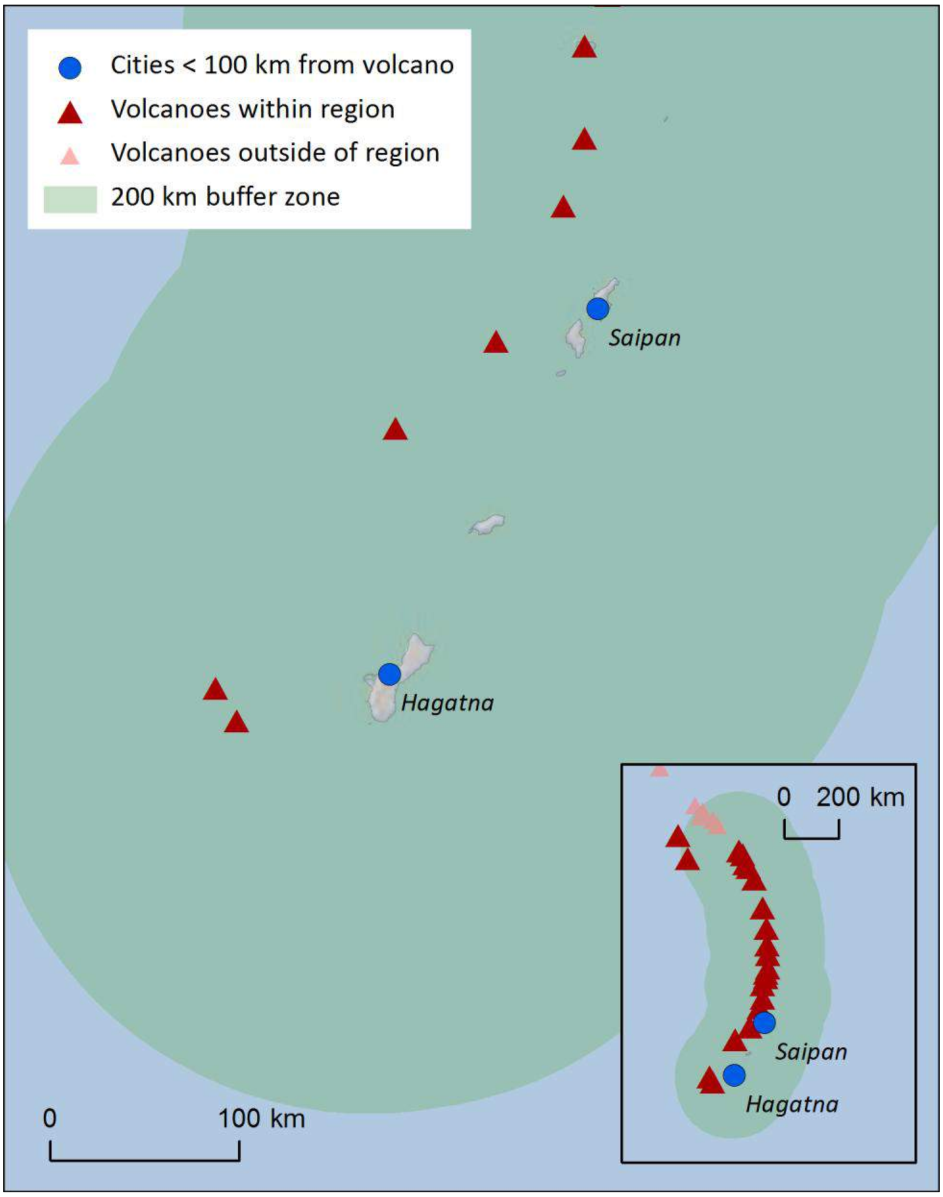

Figure 8.12 Location of the Marianas Island volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Marianas Islands.

Twenty-one Holocene volcanoes are located in the Marianas Islands, located at the southern end of the Izu-Marianas arc. Volcanism here is due to the subduction of the Pacific Plate beneath the Philippine plate, producing the ocean island arc. Eleven volcanoes are submarine, while all subaerial volcanoes are stratovolcanoes. Basaltic to dacitic rock types are present, with basalts and andesites being most common.

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Fifty-two confirmed Holocene eruptions are recorded in the Marianas, of VEI 0 to 4, indicating a range of activity from mild to large explosive events. Of these, forty-nine are recorded historically, all but one since 1800, demonstrating that the geological record is sparse and that activity here prior to this time is poorly understood. Pyroclastic flows are recorded in four historical eruptions (8% of events).

The population of the Marianas is sparse, with the biggest settlements being restricted to the largest islands to the east of the volcanic chain. The population within 30 km of the Holocene volcanoes is therefore just 1, however extending the radii to 100 km encompasses the whole population of the Marianas. Evacuations have been called during eruptions of Agrigan, Pagan and South Sarigan Seamount as recently as 2010. The 2010 eruption of South Sarigan Seamount produced an eruption column to 12km above the surface.

The CNMI (Commonwealth of the Northern Mariana Islands) Emergency Management Office, the Southern Methodist University and the Alaska and Hawaii Volcano observatories of the U.S. Geological Survey have been collaborating to establish monitoring networks in the Mariana Islands and to assess the volcanic hazards. Telemetered seismic stations are located on the historically active Anatahan and Pagan volcanoes and the Holocene Sarigan volcano, and infrasound arrays are used to detect explosive activity at the other Mariana Island volcanoes. Satellite monitoring is also undertaken.

See also:

Hawaii Volcano Observatory: hvo.wr.usgs.gov/volcanowatch/archive/2003/03_09_18.html

USGS Volcano Hazards Program: volcanoes.usgs.gov/vhp/observatories.php

USGS Northern Mariana Islands: volcanoes.usgs.gov/nmi/activity/

Volcano Facts

Number of Holocene volcanoes	21
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4.5 870 AD eruption of Alamagan.

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Number of Holocene eruptions	52 confirmed eruptions.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	11
Number of historical eruptions	49

Number of volcanoes	Primary volcano type	Dominant rock type
10	Large cone(s)	Andesitic (6), Basaltic (4)
11	Submarine	Andesitic (2), Basaltic (4), Dacitic (1) Unknown (4)

Table 8.12 The number of volcanoes in the Marianas Islands, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Saipan
Distance from capital city to nearest Holocene volcano	25.3 km
Total population (2011)	46,050
Number (percentage) of people living within 10 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	52,965 (>100%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	127
Total length of railroads within 100 km of a volcano (km)	0

The Northern Marianas Islands include many small settlements, with the biggest cities on the largest islands of Guam, Rota Island, Tinian and Saipan. Much of the infrastructure is also located on these islands, including four ports and two airports. These largest islands lie within 100 km of the volcanoes which are displaced to the west.

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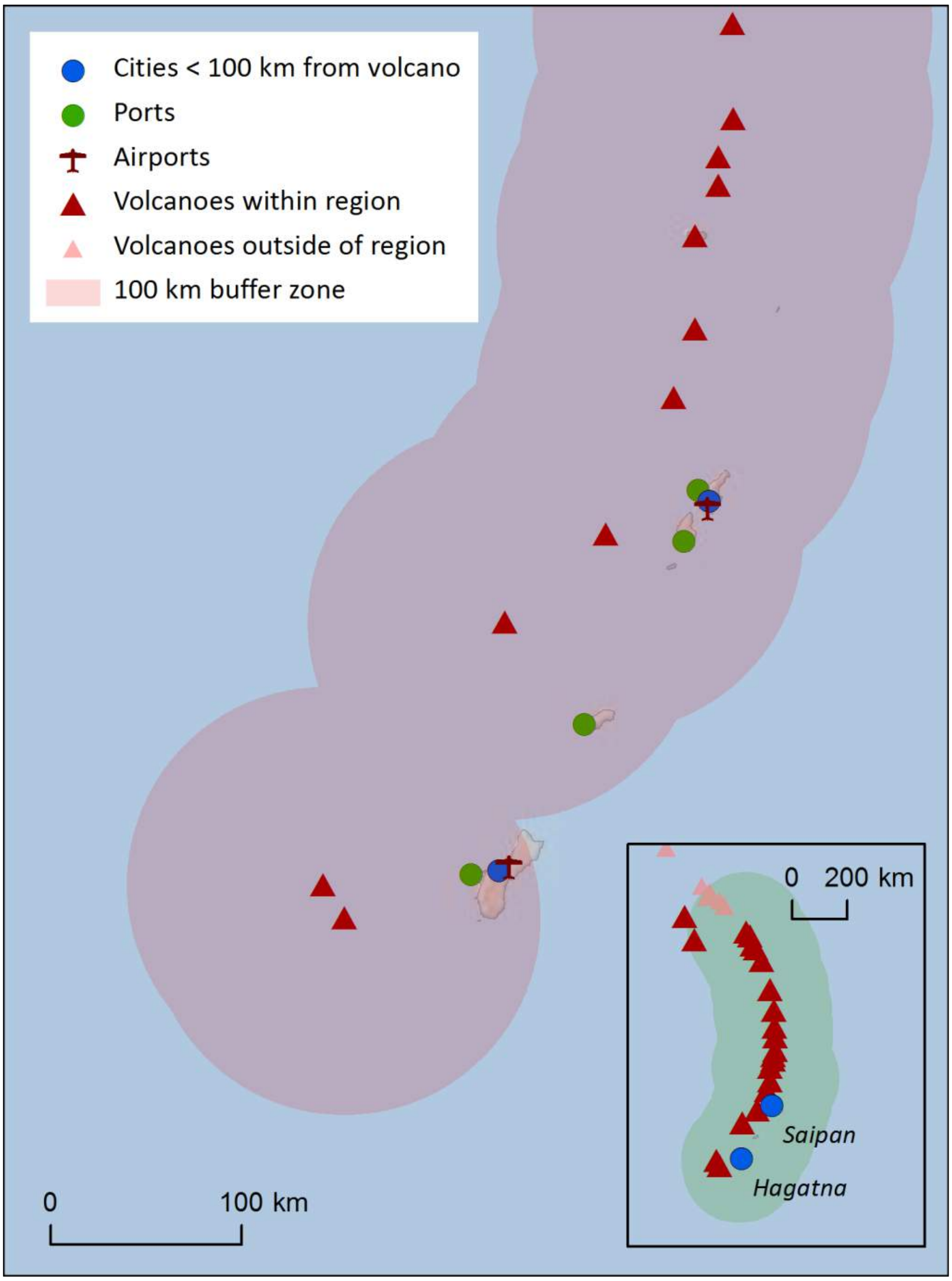

Figure 8.13 The location of CNMI's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption records of the volcanoes of the Marianas Islands. Indeed, out of 21 volcanoes, just three have sufficiently extensive and detailed records to have their hazard levels classified. These volcanoes, Pagan, Anatahan and Farallon de Pajaros, have records of 40 confirmed Holocene eruptions, most of which also have an attributed size. All but one of these eruptions occurred since the 1600s. With no eruptions over VEI 2, Farallon de Pajaros is

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classified at Hazard Level I, whilst Anatahan and Pagan, with records of VEI 3 and 4 eruptions respectively, are ranked at Hazard Level III. These three volcanoes are classified at Risk Level I, with no local populations.

With the exception of these three volcanoes, all others are unclassified. Nine volcanoes have no Holocene eruption record, though three, Zealandia Bank, Sarigan and Esmeralda Bank, have experienced unrest since 1900 AD. Eight unclassified volcanoes have records of historical eruptions, including eruptions since 1900 at seven volcanoes.

With low proximal populations in the Marianas, including no population within 30 km at any of the volcanoes, the PEI is low at 1 and 2.

CLASSIFIED	**Hazard III**	Pagan; Anatahan						
	Hazard II							
	Hazard I	Farallon de Pajaros						
UNCLASSIFIED	**U – HHR**	**Ahyi; Supply Reef; Asuncion; Agrigan;** Guguan; **South Sarigan Seamount**	**Ruby; NW Rota-1**					
	U- HR	Alamagan						
	U- NHHR	Unnamed (284138); Unnamed (284139); Maug Islands; **Zealandia Bank; Sarigan**	East Diamante; **Esmeralda Bank**; Forecast Seamount; Seamount X					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 8.13 Identity of the Marianas Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Anatahan	1	I
Farallon de Pajaros	1	I
Pagan	1	I

Table 8.14 Classified volcanoes of Mariana Islands ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 3 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

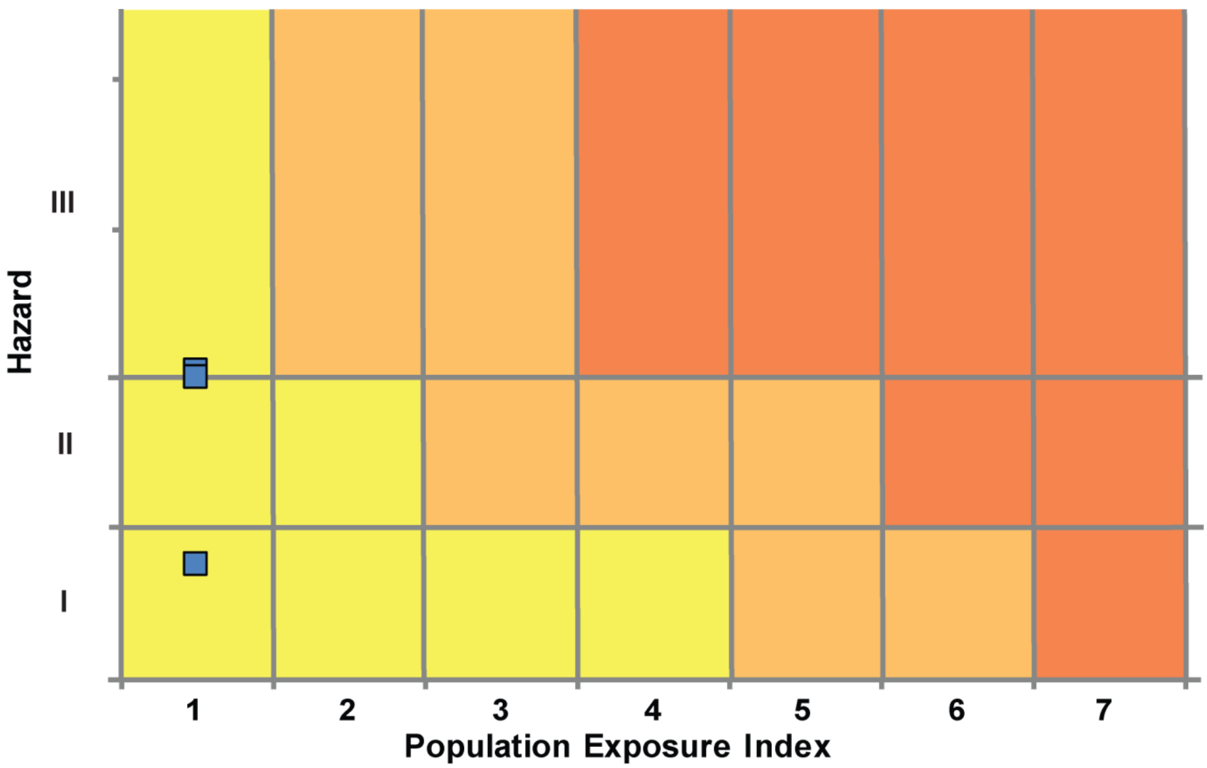

Figure 8.14 Distribution of the Marianas Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The monitoring of the Marianas Island volcanoes is the responsibility of the Alaska Volcano Observatory. The USGS Northern Marianas Duty Scientist is a position that rotates between the Alaska and Hawaii Volcano Observatories. The Risk Level I Anatahan and Pagan volcanoes have dedicated seismic monitoring in place, as does the Holocene age Sarigan. Infrasound arrays are used for detection of activity at other volcanoes here.

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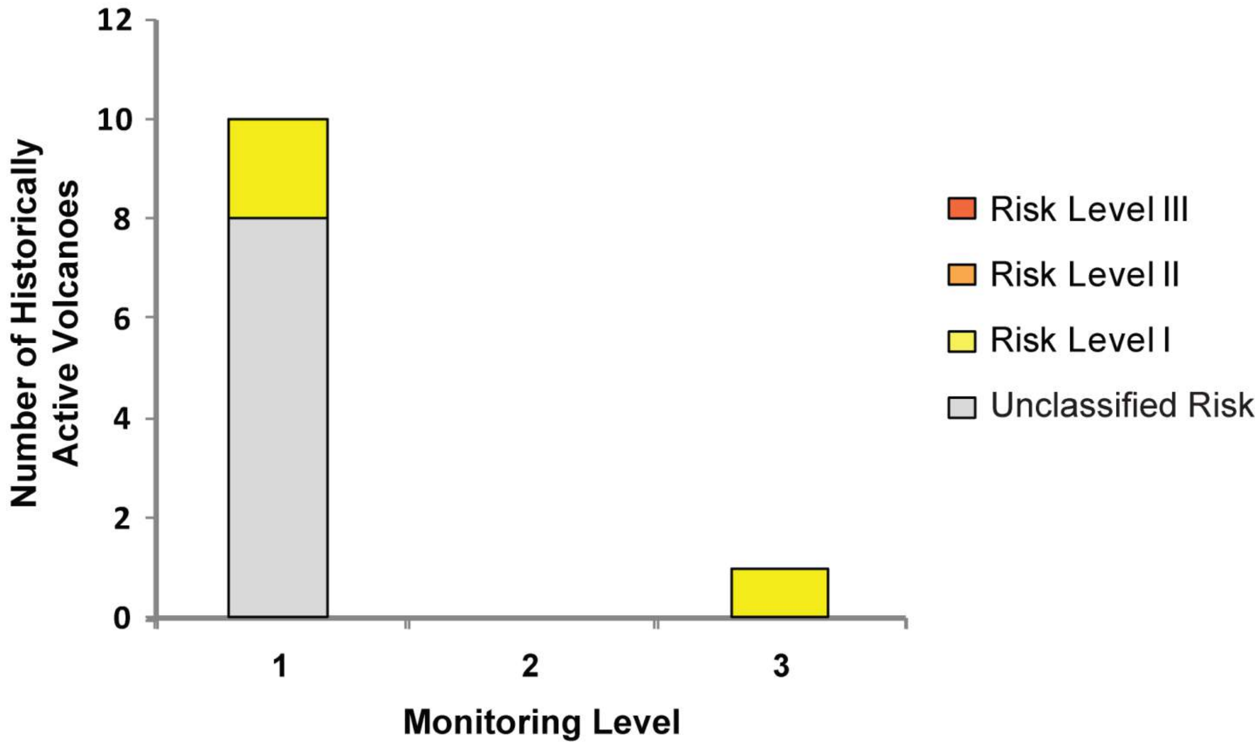

Figure 8.15 The monitoring and risk levels of the historically active volcanoes in the Marianas Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 9: Kuril Islands

Description

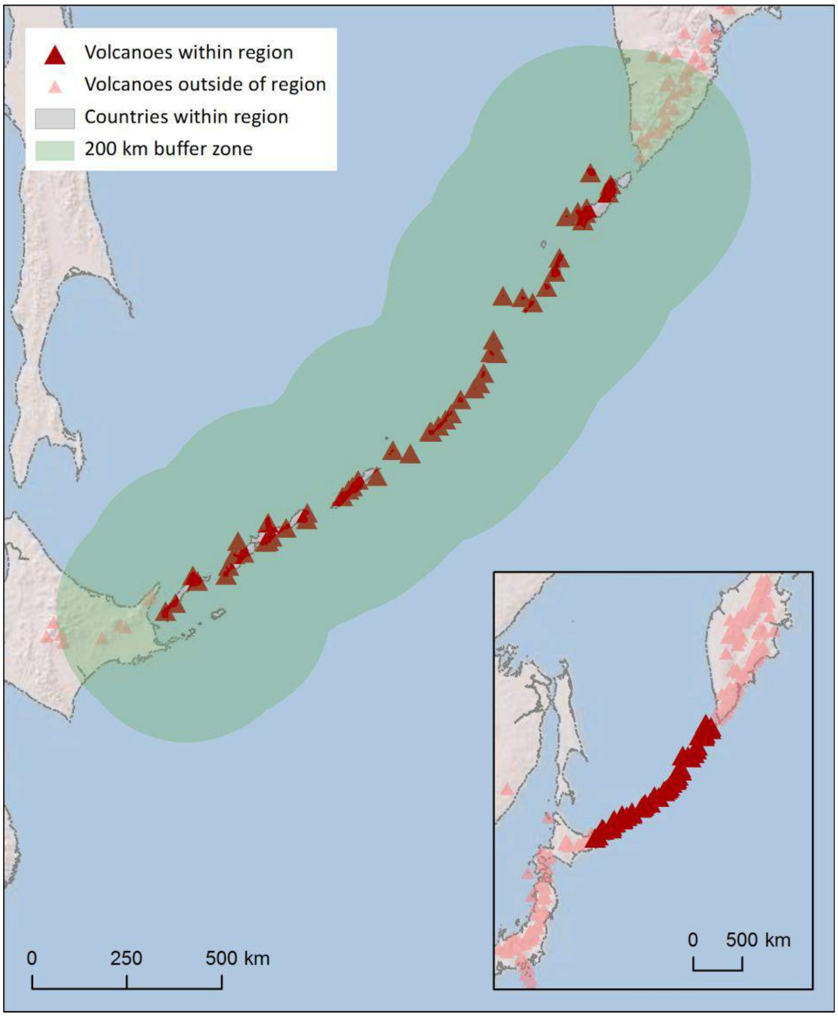

Figure 9.1 The distribution of Holocene volcanoes through the Kuril Islands region.

Forty-eight Holocene volcanoes are located in the Kuril Islands, stretching from Hokkaido, Japan in the south, to Kamchatka, Russia in the north. Volcanism in this arc is due to the subduction of the Pacific Plate beneath the Eurasian Plate. Most volcanoes here are of dominantly andesitic composition, and most are volcano types typically associated with explosive activity including stratovolcanoes and calderas.

Thirty-one of these volcanoes have Holocene records of 165 eruptions, of these, 148 of the eruptions are recorded post-1500 AD at thirty volcanoes, indicating the geological eruption record is sparse. Historical eruptions have ranged in size from VEI 0 to 5, indicating a range of eruption styles from mild events to large explosive eruptions. Two VEI 6 eruptions are recorded in the Holocene record and there are Pleistocene records of larger events, with the largest Quaternary eruption

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recorded in the Kuril Islands being the M7.3 eruption of Nemo Peak at 45 ka. Moderate eruptions dominate the record, however twelve large explosive historical eruptions of VEI ≥4 are recorded.

The size of a large number of eruptions in the Kuril Islands is unknown, and the dominance of the historical record indicates that further research is required to more fully understand the eruptive histories in this region and to better understand the hazard. However, the Kuril Islands are sparsely populated with only four volcanoes having over 10,000 people located within 100 km radii, reducing the risk substantially.

Both Japan and Russia are very familiar with responding to and monitoring eruptions and unrest (see Japan, region 8; and Russia, region 10). The northernmost volcanoes in the Kuril Islands are monitored by the Kamchatka Volcanic Eruption Response Team (KVERT) who primarily monitor these volcanoes by satellite observations with a few seismometers located on two historically active volcanoes.

Volcano facts

Number of Holocene volcanoes	48
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	8
Number of volcanoes generating lahars	6
Number of volcanoes generating lava flows	13
Number of eruptions with fatalities	3
Number of fatalities attributed to eruptions	32
Largest recorded Pleistocene eruption	The largest recorded Quaternary eruption occurred at Nemo Peak with the M7.3 K3 (Nemo 1) eruption at 45 ka.
Largest recorded Holocene eruption	The 8290 BP M7 caldera formation at Tao-Rusyr Caldera is the largest recorded Holocene eruption in LaMEVE in this region.
Number of Holocene eruptions	165 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	30
Number of historical eruptions	148

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Number of volcanoes	Primary volcano type	Dominant rock type
5	Caldera(s)	Andesitic (5)
34	Large Cone(s)	Andesitic (26), Basaltic (6), Unknown (2)
4	Small Cone(s)	Andesitic (3), Unknown (1)
5	Submarine	Unknown (5)

Table 9.1 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Note that the stratovolcano Chikurachki comprises the sub-features of the Lomonosov Group and stratovolcano Tatarinov.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	2
Large (> VEI 3)	30

Table 9.2 Average recurrence interval (years between eruptions) for small and large eruptions in the Kuril Islands.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 2 years, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded through the Kuril Islands of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with over 50% of all Holocene eruptions classed as such.

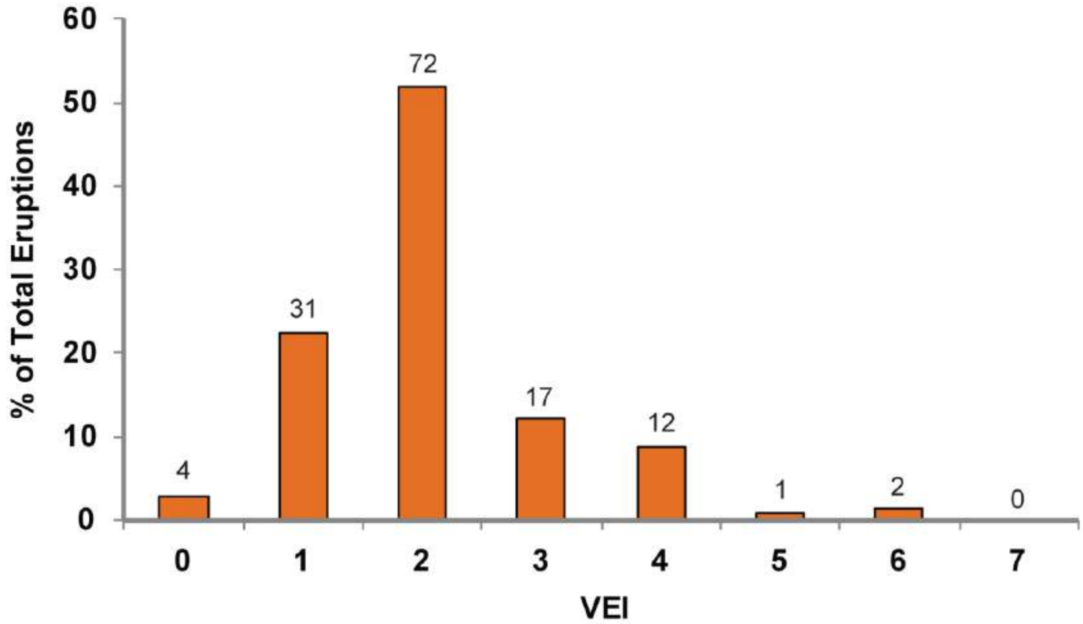

Figure 9.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 26 eruptions were recorded with unknown VEI.

Infrastructure Exposure

The volcanoes of the Kuril Islands are distributed between Hokkaido, Japan in the south and Kamchatka in the north. The entirety of the Kuril Island chain is volcanic and thus lies within 100 km of volcanoes, and the 100 km radii extend into Hokkaido and Kamchatka, exposing infrastructure here, including ports and airports. Whilst no infrastructure is described in the Kurile Islands here, there are settlements on some of the islands and all critical infrastructure is exposed.

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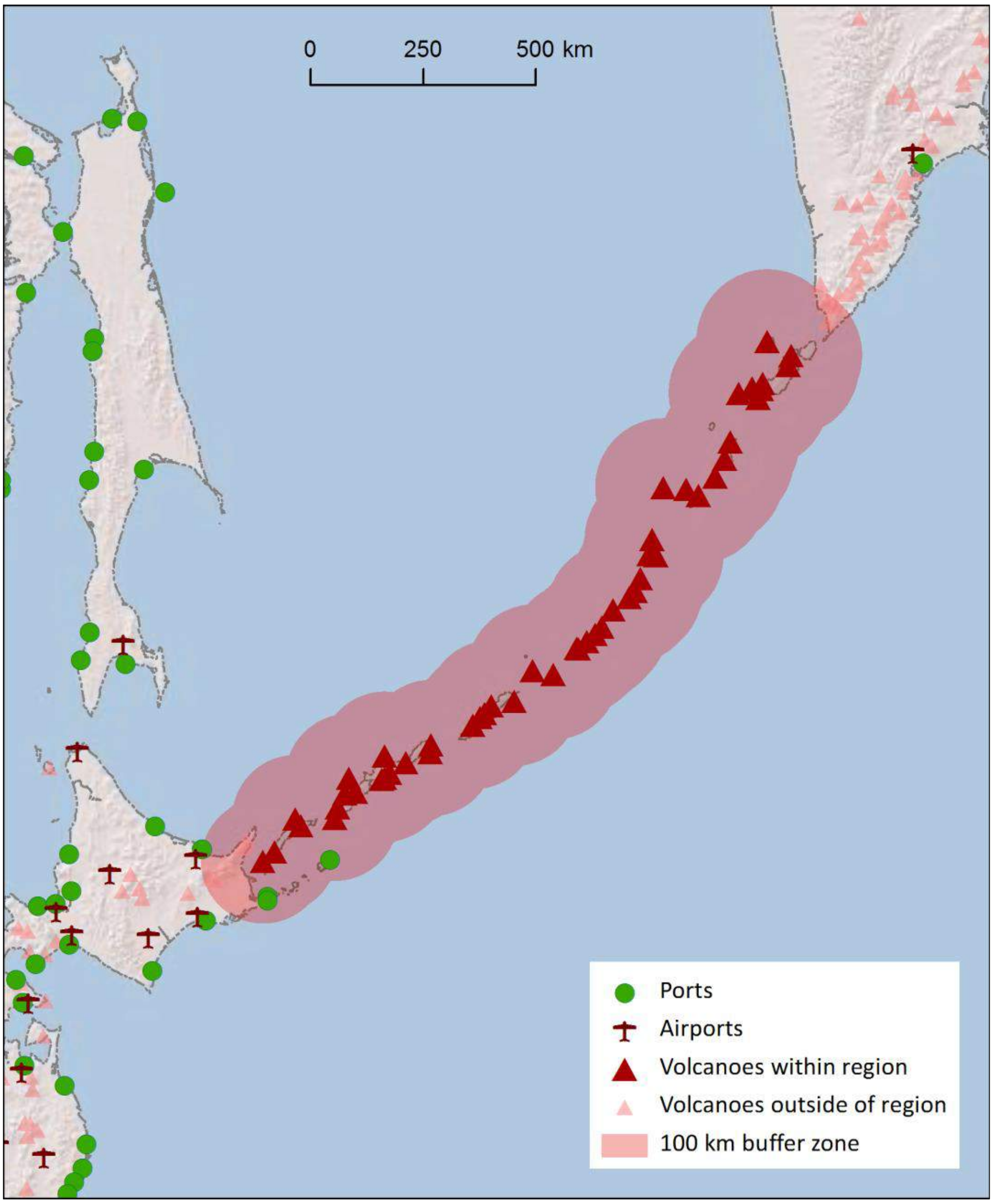

Figure 9.3 The location of the volcanoes in the Kuril Islands and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the 48 volcanoes in the Kuril Islands just 13 have a sufficient eruption record for hazard assessment. These volcanoes are classified into all three hazard levels, with Sarychev Peak, Sinarka and Kharimkotan being classed at the highest hazard here, Level III all with Holocene records of large explosive eruptions and pyroclastic flows recorded in more than 10% of their eruptions.

The 35 unclassified volcanoes have varying degrees of information in their records. 16 of these have no confirmed Holocene eruptions. One, Moekeshiwan [Lvinaya Past], has a Holocene record but no historical eruptions, and 18 have confirmed historical events including 12 with eruptions since 1900. Three volcanoes, Fuss Peak, Rasusan [Mendeleev] and Ushishur, have records of increased fumarolic emissions in the 1980s suggesting unrest above background levels.

The population in the Kuril Islands is low, and all volcanoes are classed with a low PEI of 1 and 2, with all but four volcanoes having fewer than 10,000 inhabitants located within 100 km (Tomariyama [Golovnin], Rasusan [Mendeleev], Ruruidake [Smirnov], and Chachadake [Tiatia]). This low PEI coupled with the dominant distribution of the volcanoes across Hazard Levels I and II makes the majority of the classified volcanoes of the Kuril Islands Risk Level I volcanoes. Just three volcanoes, Kharimkotan, Sarychev Peak and Sinarka, are classed at Risk Level II.

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CLASSIFIED	**Hazard III**		Sarychev Peak; Sinarka; Kharimkotan					
	Hazard II		Chachadake [Tiatia]; Etorofu-Yakeyama [Grozny Group]; Chirpoi; Chikurachki; Ebeko; Alaid					
	Hazard I	Chirinkotan	Moyorodake [Medvezhia]; Kolokol Group; Goriaschaia Sopka					
UNCLASSIFIED	**U – HHR**	**Ekarma**	Tomariyama [Golovnin]; **Rasusan [Mendeleev]; Etorofu-Atosanupuri [Atosanupuri]; Sashiusudake [Baransky];** Chirippusan [Chirip]; **Unnamed (290160); Zavaritzki Caldera**; Prevo Peak; **Ketoi**; **Ushishur**; **Rasshua**; **Unnamed (290230); Raikoke**; **Tao-Rusyr Caldera**; **Nemo Peak; Fuss Peak**; **Karpinsky Group**					
	U- HR		Moekeshiwan [Lvinaya Past]					
	U- NHHR	Odamoisan [Tebenkov]	Ruruidake [Smirnov]; Berutarubesan [Berutarube]; Nishihitokappuyama [Bogatyr Ridge]; Unnamed; Rucharuyama [Golets-Tornyi Group]; Rakkibetsudake [Demon]; Ivao Group; Rudakov; Tri Sestry; Unnamed; Milne; Urataman; Srednii; Shirinki; Vernadskii Ridge					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 9.3 Identity of the Kuril Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified (top). Those without sufficient data are Unclassified (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
45	2
3	1

Table 9.4 The number of volcanoes in the Kuril Islands classed in each PEI category.

Volcano	Population Exposure Index	Risk Level
Sarychev Peak	2	II
Sinarka	2	II
Kharimkotan	2	II
Chachadake [Tiatia]	2	I
Etorofu-Yakeyama[Grozny Group]	2	I
Moyorodake [Medvezhia]	2	I
Kolokol Group	2	I
Chirpoi	2	I
Goriaschaia Sopka	2	I
Chikurachki	2	I
Ebeko	2	I
Alaid	2	I
Chirinkotan	1	I

Table 9.5 Classified volcanoes of the Kuril Islands ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given.

Risk Levels

Number of Volcanoes	Risk Level
0	III
3	II
10	I
35	Unclassified

Table 9.6 The number of volcanoes in the Kuril Islands classified at each Risk Level.

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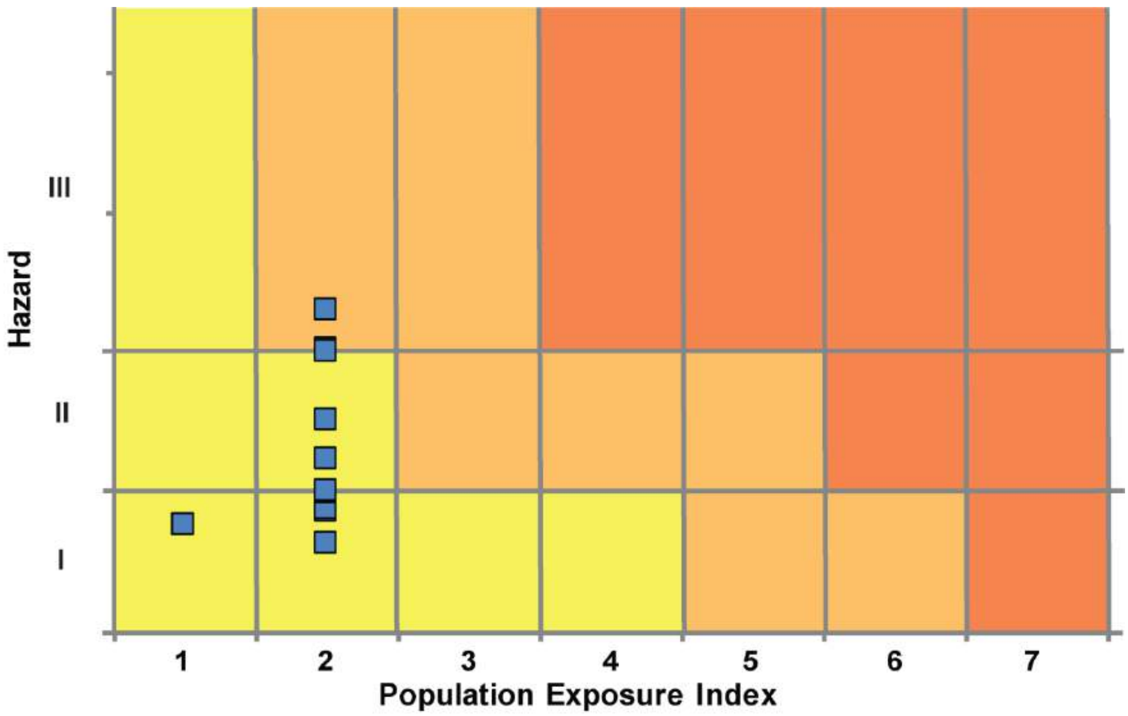

Figure 9.4 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Capacity for Coping with Volcanic Risk

Thirty-one volcanoes in the Kuril Islands have records of historical activity. The Kamchatka Volcanic Eruption Response Team (KVERT) monitors six volcanoes in the northern Kuriles, five of which have had historical activity. Of these, seismic stations are located at two volcanoes. At the time of the writing of this report, no information is available to suggest that there is dedicated ground-based monitoring throughout the remaining Kuril Island volcanoes.

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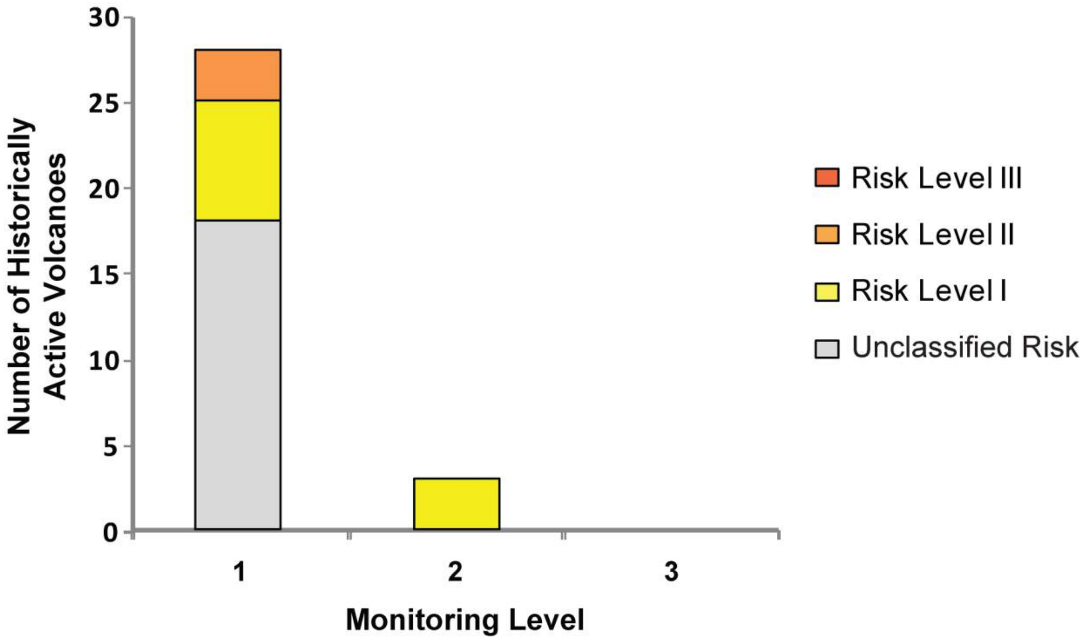

Figure 9.5 The monitoring and risk levels of the historically active volcanoes in the Kuril Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 10: Kamchatka and Mainland Asia

Region 10: Kamchatka and Mainland Asia comprises volcanoes from the China-Pakistan border in the west to Kamchatka in the east. Five countries are represented here. The country profiles for China and Russia include additional volcanoes from outside of this region (Table 10.1).

Country	Number of volcanoes
China	11 + 3 from Region 7
DPRK	3
Mongolia	5
Republic of Korea	3
Russia	120 + 1 from Region 1

Table 10.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

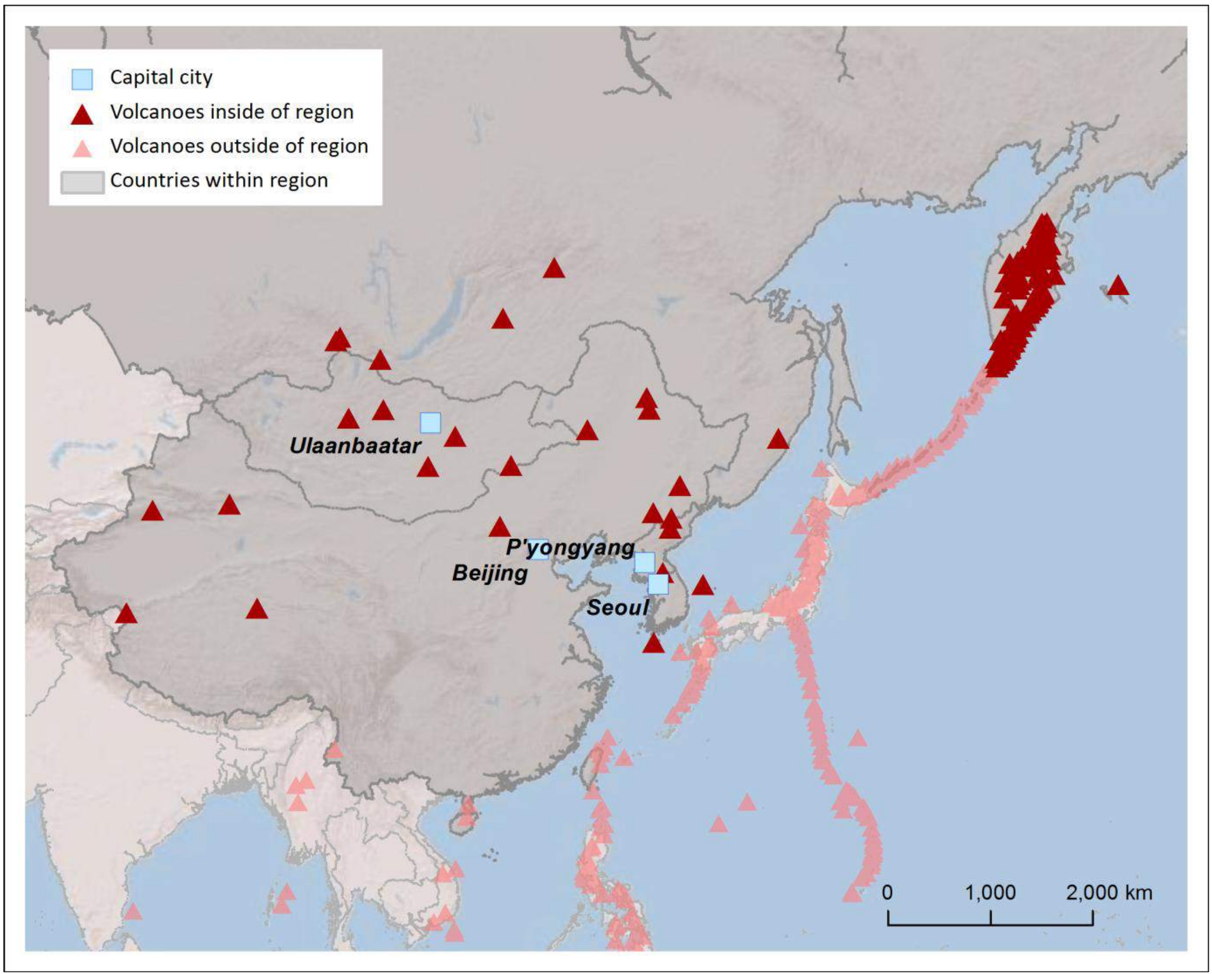

Figure 10.1 The distribution of Holocene volcanoes through the Kamchatka and Mainland Asia region. The capital cities of the constituent countries are shown.

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Description

140 Holocene volcanoes are located in Kamchatka (Russia) and Mainland Asia. Most of these volcanoes (120) are in Russia, dominantly on the Kamchatka Peninsula. Volcanism here is largely due to the subduction of the Pacific Plate beneath the Eurasian Plate, with volcanoes of the mainland being chiefly controlled through tensional processes.

A range of volcano morphologies are present in this region, though stratovolcanoes and other large cones dominate (74). Shield volcanoes, volcanic fields and cinder cones are also common features. Although a range of rock types are present, the composition is mostly mafic to intermediate with basaltic and andesitic compositions most common.

Along with volcano form and composition, a range of activity styles and eruption sizes are recorded throughout the Holocene, with eruptions of VEI 0 to 7. The most common eruption sizes are VEI 2 to 4, with about 80% of eruptions being designated as such, indicating that moderately explosive volcanism is a common feature of activity here. About 20% (107) of recorded sized eruptions have been large explosive VEI ≥4 events. These eruptions have been restricted to 22 volcanoes in Russia, Changbaishan on the China-DPRK border and Ulreung, Republic of Korea. The largest Holocene eruption in this region was the VEI 7 eruption of Changbaishan about 950 years ago. Large explosive eruptions are recorded from 22 volcanoes back into the Pleistocene.

Twenty-eight volcanoes have historical records of 337 eruptions, 95% of which were recorded through direct observations. 16% of historical events have involved the production of pyroclastic flows and 12% have resulted in lahars. 26% of historical eruptions have records of lava flows.

Just 1% of historical eruptions in this region have resulted in loss of life, largely due to the low population in this region. Most volcanoes (85%) have low proximal population, and as such are considered relatively low risk. However, the hazard (VHI) is not classified at 90% of the volcanoes here.

Of the historically active volcanoes, half have dedicated monitoring systems in place, with monitoring undertaken by the Institute of Volcanology and Seismology – KVERT in Russia, the China Seismological Bureau and Volcano Research Centre in China, and scientists in North Korea in collaboration with overseas research groups.

Volcano facts

Number of Holocene volcanoes	140
Number of Pleistocene volcanoes with M≥4 eruptions	22
Number of volcanoes generating pyroclastic flows	26 (136 eruptions)
Number of volcanoes generating lahars	13 (47 eruptions)
Number of volcanoes generating lava flows	46 (227 eruptions)
Number of eruptions with fatalities	5
Number of fatalities attributed to eruptions	20

Largest recorded Pleistocene eruption	The largest recorded Quaternary eruption occurred at Diky Greben in Kamchatka at 443 ka with the M7.6 eruption of the Golygin Ignimbrite.
Largest recorded Holocene eruption	The 950 BP M7.4 eruption of Changbaishan is the largest recorded Holocene eruption in this region in LaMEVE.
Number of Holocene eruptions	781 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	28
Number of historical eruptions	337

Number of volcanoes	Primary volcano type	Dominant rock type
10	Caldera(s)	Andesitic (5), Basaltic (4), Dacitic (1)
74	Large cone(s)	Andesitic (37), Basaltic (31), Dacitic (3), Trachytic/Andesitic (2), Unknown (1)
4	Lava dome(s)	Andesitic (1), Basaltic (2), Dacitic (1)
47	Shield(s)	Andesitic (2), Basaltic (45)
38	Small cone(s)	Andesitic (5), Basaltic (26), Phonolitic (1), Trachytic/Andesitic (1), Unknown (5)
5	Submarine	Dacitic (1), Unknown (4)
1	Unknown	Unknown (1)

Table 10.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	20

Table 10.3 Average recurrence interval (years between eruptions) for small and large eruptions in Kamchatka and West Asia.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 20 years.

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Eruption Size

Eruptions are recorded through the Kamchatka and Western Asia region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 50% of all Holocene eruptions classed as such, and about 80% of eruptions are VEI 2 to 4. 19% of eruptions here are explosive at VEI ≥4.

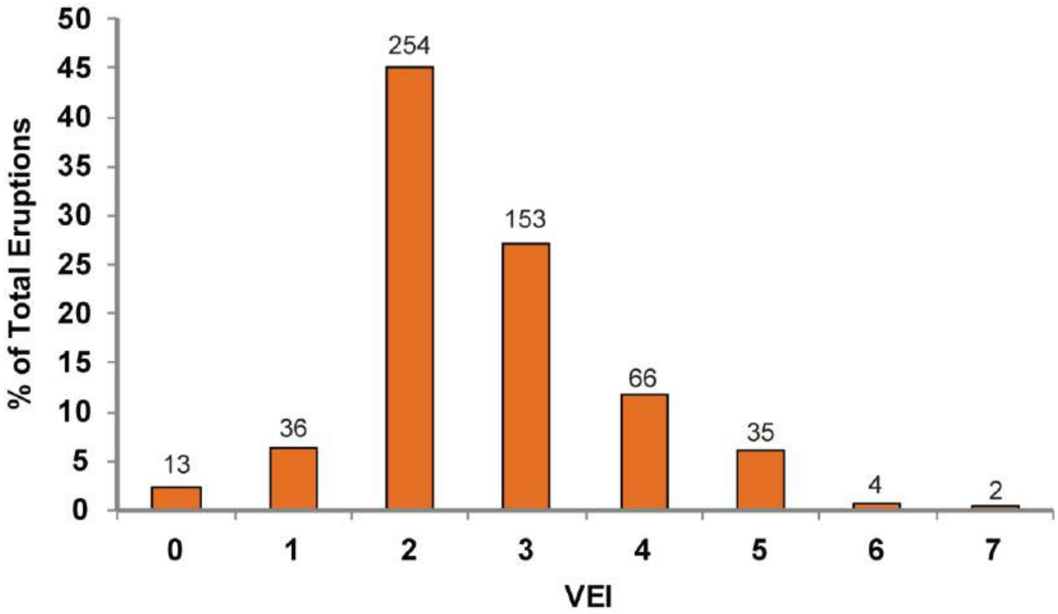

Figure 10.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 218 eruptions were recorded with unknown VEI.

Socio-Economic Facts (excluding North Korea)

Total population (2011)	1,551,803,374
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,178 – 27,541 (Mean 13,486)
Gross National Income (GNI) per capita (2005 PPP $)	4,245 – 28,231 (Mean 13,271)
Human Development Index (HDI) (2012)	0.675 – 0.909 (Medium to Very High, Mean 0.768 High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	415,094 (0.03 %)
Number (percentage) of people living within 30 km of a Holocene volcano	3,787,660 (0.24 %)
Number (percentage) of people living within 100 km of a Holocene volcano	32,410,044 (2.09 %)

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CLASSIFIED	**Hazard III**		Bezymianny; Shiveluch	Koryaksky; Avachinsky				
	Hazard II		Karymsky; Maly Semiachik; Kikhpinych; Krasheninnikov; Tolbachik; Kliuchevskoi					
	Hazard I		Mutnovsky; Gorely; Zhupanovsky; Kostakan					
UNCLASSIFIED	**U – HHR**		Koshelev; **Ilyinsky**; **Zheltovsky**; **Ksudach**; Opala; **Akademia Nauk**; **Kronotsky**; **Kizimen**; Ushkovsky; Khangar; **Ichinsky**; Alney-Chashakondzha; **Kunlun Volcanic Group**	**Changbaishan**		Wudalianchi		
	U- HR		Kambalny; Yavinsky; Diky Greben; Kurile Lake; Khodutka; Tolmachev Dol; Vilyuchik; Barkhatnaya Sopka; Veer; Bakening; Zavaritsky; Bolshoi Semiachik; Taunshits; **Uzon**; Gamchen; Komarov; Vysoky; Piip; Cherpuk Group; Bolshoi-Kekuknaysky; Shisheika; Terpuk; Sedankinsky; Gorny Institute; Kinenin; Bliznetsy; Titila; Elovsky; Nylgimelkin; Spokoiny; Ostry; Severny; Udokan Plateau; Tianshan Volcanic Group	Arshan; Taryatu-Chulutu; Ulreung	Halla	Turfan; Jingbo; Longgang Group		
	U- NHHR		Mashkovtsev; Kell; Belenkaya; Ozernoy; Olkoviy Volcanic Group; Plosky; Piratkovsky; Ostanets; Otdelniy; Golaya; **Asacha**; Visokiy; Unnamed; Bely; Bolshe-Bannaya; Dzenzursky; Schmidt; Unnamed; Udina; Zimina; Kamen; Maly Payalpan; Bolshoi Payalpan; Akhtang; Kozyrevsky; Romanovka; Uksichan; Kulkev; Geodesistoy; Anaun; Krainy; Kekurny; Eggella; Cherny; Unnamed; Verkhovoy; Pogranychny; Zaozerny; Bliznets; Kebeney; Uka; Fedotych; Leutongey; Tuzovsky; Mezhdusopochny; Shishel; Alngey; Kaileney; Plosky; Snezhniy; Iktunup; Snegovoy; Iettunup; Voyampolsky; Vitim Plateau; Tunkin Depression; Oka Plateau; Azas Plateau; Unnamed; Bus-Obo	Khanuy Gol; Middle Gobi	Keluo Group; Xianjindao; Dariganga Volcanic Field	Unnamed; Unnamed; Sikhote-Alin; Honggeertu; Ch'uga-ryong		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 10.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
9	5
4	4
8	3
119	2
0	1

Table 10.5 The number of volcanoes in Kamchatka and Mainland Asia classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
10	I
126	Unclassified

Table 10.6 The number of volcanoes in the Kamchatka and Mainland Asia region classified at each Risk Level.

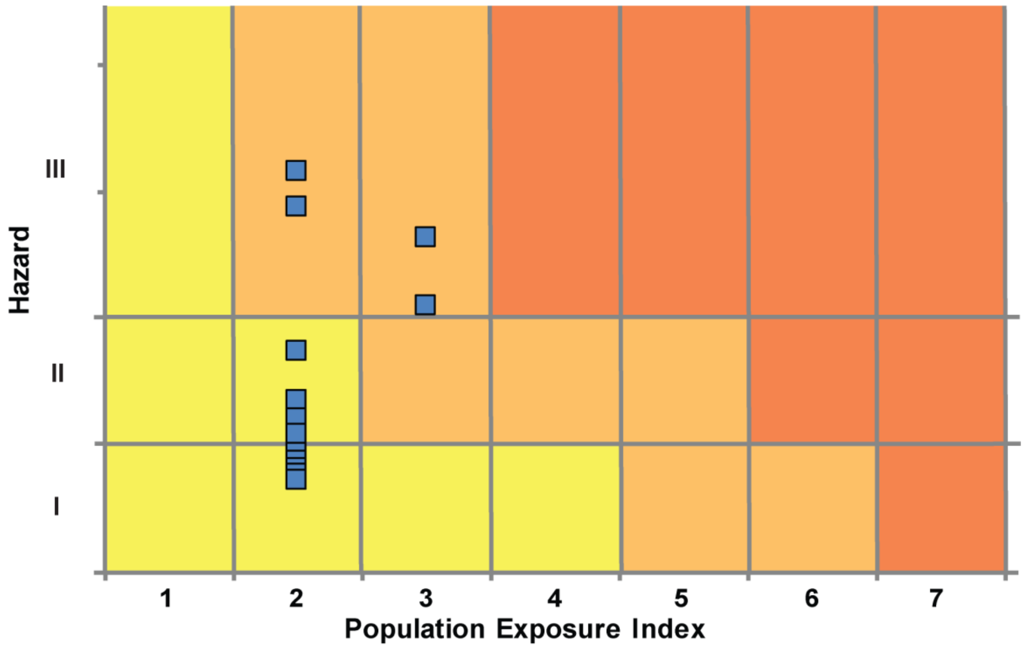

Figure 10.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional Monitoring Capacity

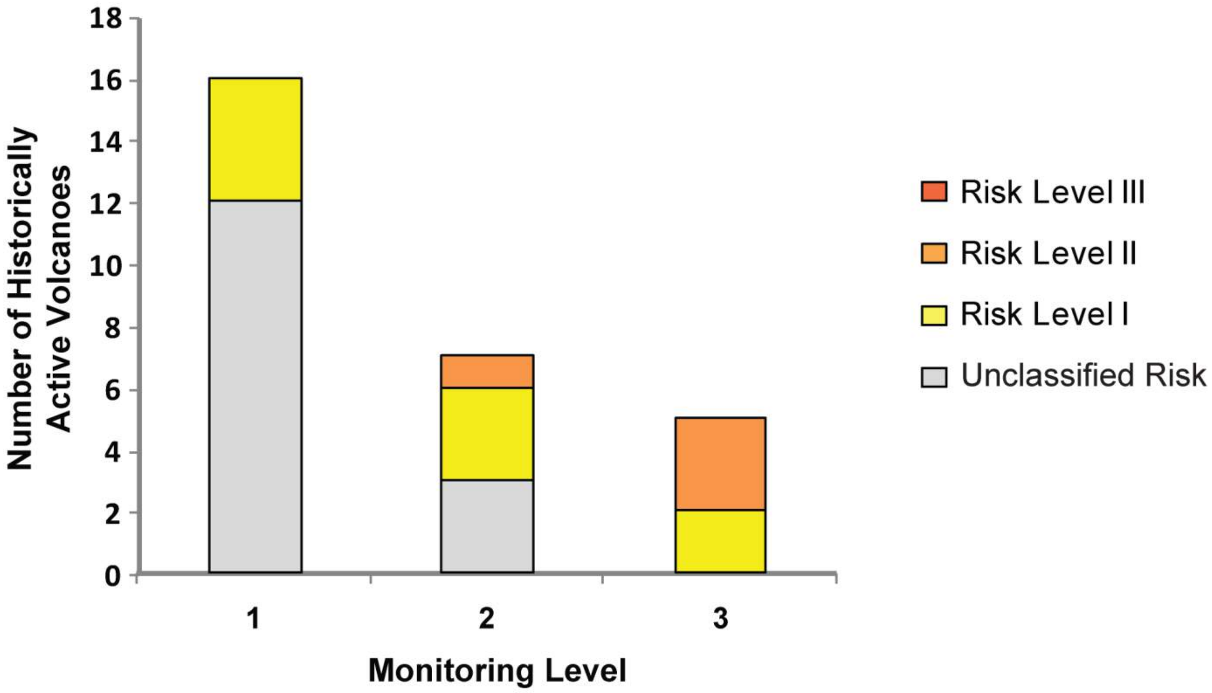

Figure 10.4 The monitoring and risk levels of the historically active volcanoes in the Kamchatka and Mainland Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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China

Note that we include Hainan Dao, Leizhou Dao and Tengchong from Region 7 in this profile.

Description

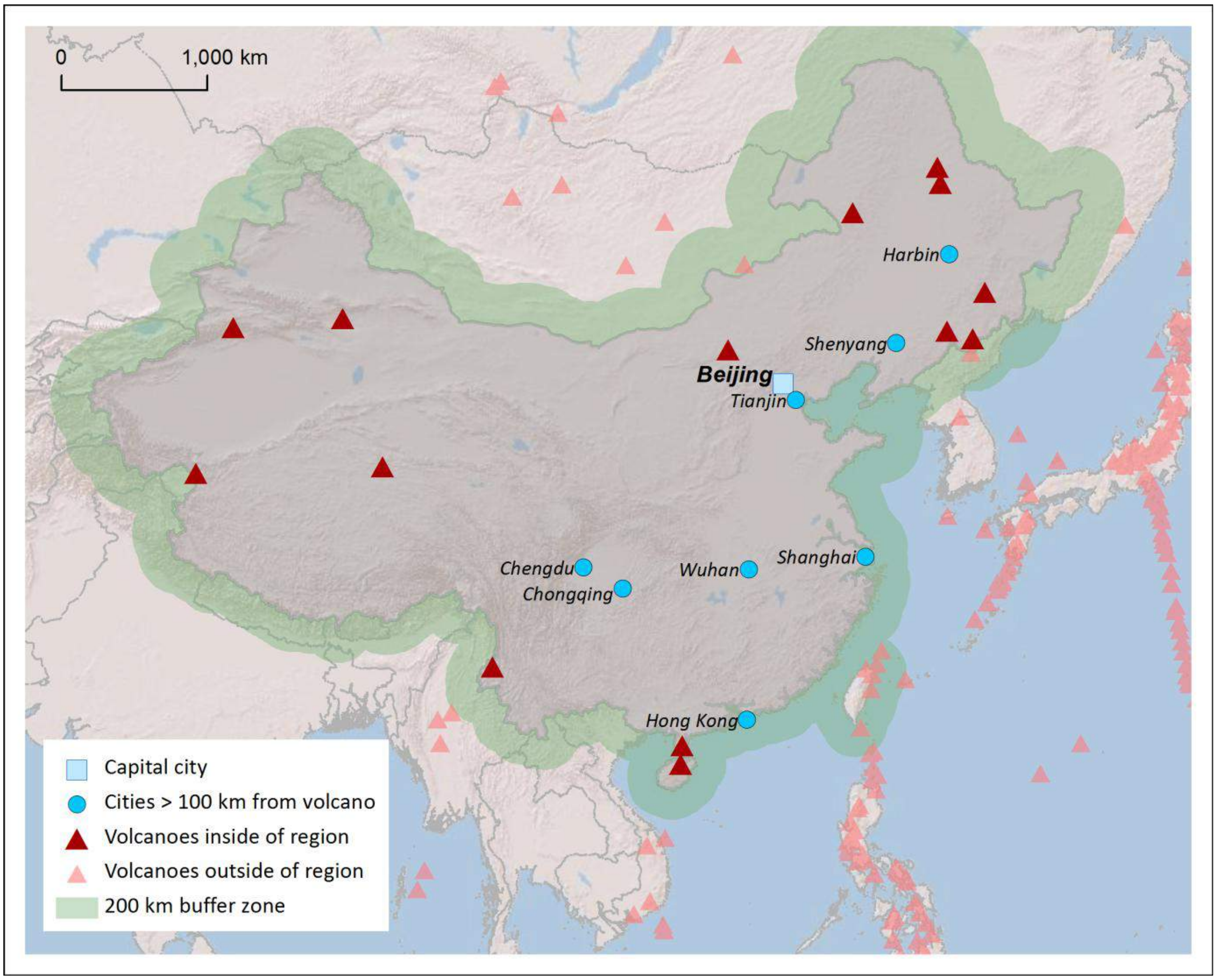

Figure 10.5 Location of China's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect China.

Fourteen Holocene volcanoes are located in China, in three broad groups – one in the south, one in the west and one in the north-east. These volcanoes are related to intra-plate processes. All but the stratovolcano Changbaishan, on the border with the Democratic People's Republic of Korea (DPRK), are volcanic fields, and small pyroclastic and cinder cones. Changbaishan is Trachytic/andesitic, whilst the small cones are largely much more mafic, with basaltic compositions.

Twenty-two confirmed eruptions are recorded in China during the Holocene, from ten volcanoes. These measured VEI 2 to 7, indicating a range of activity from mild to very large explosive events. The largest Holocene eruption was that of Changbaishan in 1000 AD, which deposited tephra as far as Japan. This volcano also has a Pleistocene record of VEI 7 activity.

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Four volcanoes have records of nine historical eruptions, measuring VEI 2 to 3 with over half of these being of unknown size. No historical eruptions are reported to have caused property damage or fatalities.

Throughout China about 380,000 people live within 10 km of a Holocene volcano, with over 23.4 million within 100 km of one or more volcanoes. As such, many of the volcanoes individually have very large local populations increasing the risk. Changbaishan has a moderate PEI, with about 30,000 within 30 km and over 1.6 million living within 100 km.

The China Seismological Bureau in the Institute of Geology monitor Changbaishan, Tenchong and Wudalianchi, the former two having experienced recent unrest. Due to the history of large explosive eruptions, monitoring is dominantly focussed at Changbaishan, where seismic, deformation and geochemical monitoring is undertaken. As this volcano borders the DPRK monitoring is undertaken separately across the border. The China Seismological Bureau is undertaking risk assessments, and currently grades Changbaishan at Risk Levels 3-4 (Potential risk to Conceivable threat), Tengchong as Risk level 3 (Potential risk) and Wudalianchi as Risk level 2 (no risk in the near future).

The Asian Disaster Reduction Center (ADRC) produced a report on Disaster Risk Reduction in China in 2012 however they do not consider volcanic hazards in this report. They describe the disaster management system in China, comprising a number of laws and the China National Committee for Disaster Reduction (NCDR) and the efforts of China to address the Hyogo Framework for Action. For full details of the disaster management system in China, see the ADRC report.

See also:

Hong, H. Et al., (2003) Volcano monitoring and risk assessing in China. IUGG 2013 abstract. www.jamstec.go.jp/jamstec-e/iugg/htm/abstract/abst/v11/016211-1.html

Institute of Geology, China Earthquake Administration: www.eq-igl.ac.cn/en/index.htm

ADRC China profile:
www.adrc.asia/nationinformation.php?NationCode=156&Lang=en&NationNum=22

Volcano Facts

Number of Holocene volcanoes	14, inclusive of one on the border with the DPRK
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	?15

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Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M7 Oga eruption of Changbaishan at 448 ka.
Largest recorded Holocene eruption	The 950 BP Baegdusan-Tomakomai tephra eruption from Changbaishan on the border with the DPRK at M7.4.
Number of Holocene eruptions	22 confirmed eruptions. 4 uncertain eruptions and 1 discredited eruption.
Recorded Holocene VEI range	2 – 7 and Unknown
Number of historically active volcanoes	4
Number of historical eruptions	9

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Large cone(s)	Trachytic / Andesitic (1)
13	Small cone(s)	Basaltic (9), Phonolitic (1), Trachytic / Andesitic (1), Unknown (2)

Table 10.7 The number of volcanoes in China, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	1,376,569,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	7,418
Gross National Income (GNI) per capita (2005 PPP $)	7,945
Human Development Index (HDI) (2012)	0.699 (Medium)

Population Exposure

Capital city	Beijing
Distance from capital city to nearest Holocene volcano	336.6 km
Total population (2011)	1,336,718,015
Number (percentage) of people living within 10 km of a Holocene volcano	381,848 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,745,202 (<1%)

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Number (percentage) of people living within 100 km of a Holocene volcano	23,492,100 (1.8%)

Ten largest cities, as measured by population and their population size:

Shanghai	14,608,512
Taipei	7,871,900
Beijing	7,480,601
Hong Kong	7,012,738
Wuhan	4,184,206
Chongqing	3,967,028
Chengdu	3,950,437
Tianjin	3,766,207
Shenyang	3,512,192
Harbin	3,229,883

Infrastructure Exposure

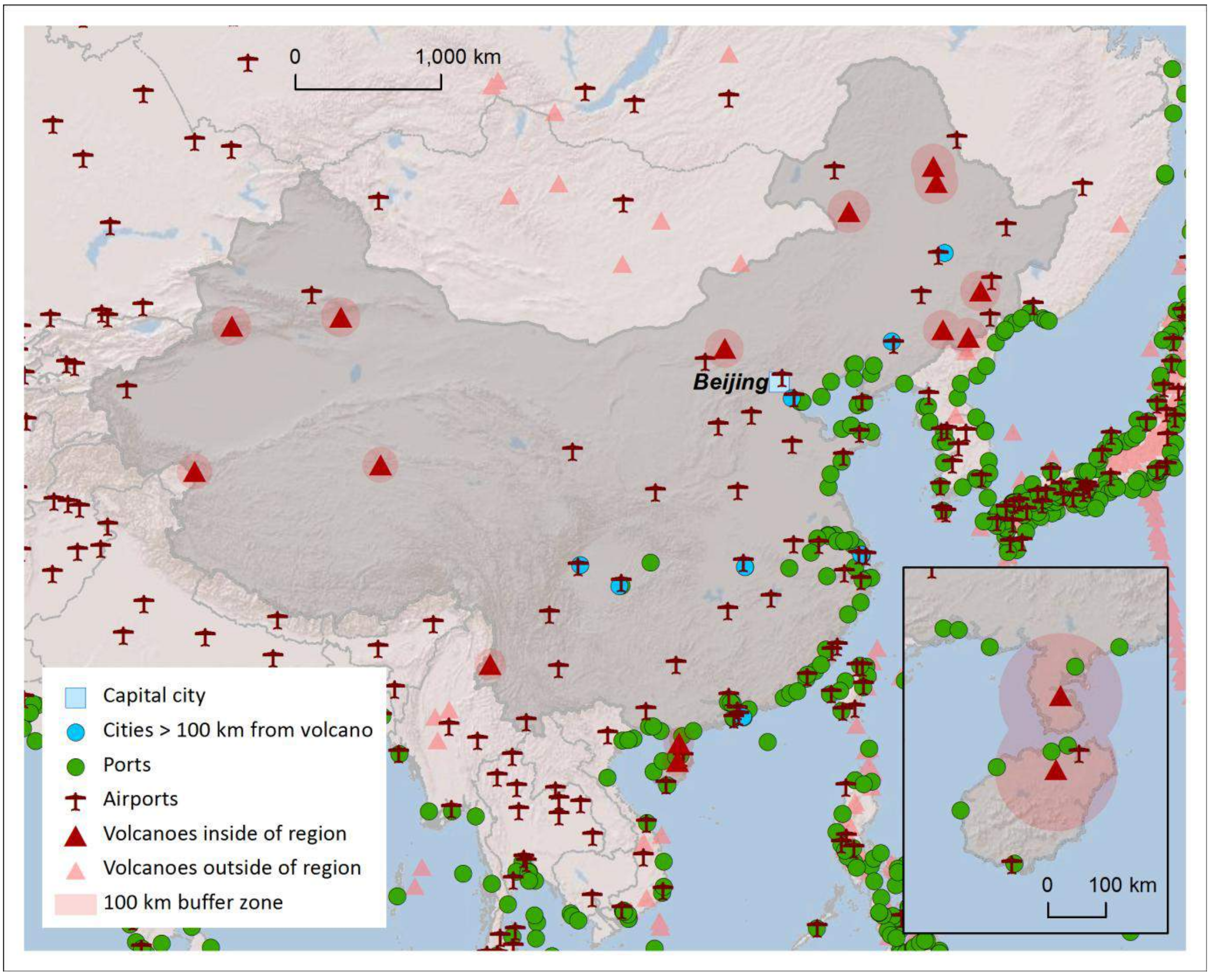

Figure 10.6 The location of China's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	12,059
Total length of railroads within 100 km of a volcano (km)	2,645

The volcanoes of China are widespread throughout the country. Those volcanoes in the west of the country are inland, away from the coast and ports, and distal to the largest cities in China which are concentrated in the east of the country. The Hainan Dao and Leizhou Bandao volcanoes in the south have ports and an airport within 100 km radius. Further airports are located in the radii of the northern volcanoes, though none of the ten largest cities are exposed. An extensive road and rail network falls within the radii. Some of the volcanoes here are located on the border with surrounding countries, with their 100 km radii extending into these countries including Myanmar, the DPRK, Mongolia and the Tibet Autonomous Region.

Hazard, Uncertainty and Exposure Assessments

The eruption record for the volcanoes in China are not sufficiently extensive or detailed to enable assessment of the hazard through the calculation of the VHI without large uncertainties, and these volcanoes are therefore unclassified. Out of the 22 confirmed Holocene eruptions here, only seven have a known VEI. Four volcanoes have a historical eruption record, two of which have erupted since 1900 AD – Kunlun Volcanic Group and Changbaishan. Changbaishan has a record of three Holocene eruptions of VEI ≥4, including a VEI 7 eruption in 1000 AD.

The PEI in China ranges from low to very high, with over half the volcanoes having PEI 5 – 7. The risk levels are unclassified as hazard is not known.

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CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Kunlun Volcanic Group**	**Changbaishan**		Wudalianchi		Hainan Dao
	U- HR		Tianshan Volcanic Group	Arshan		Turfan; Jingbo; Longgang Group	Tengchong	
	U- NHHR		Unnamed		Keluo Group	Honggeertu		Leizhou Bandao
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 10.8 Identity of China's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Four Chinese volcanoes have historical records of eruptions. At the time of the writing of this report no information is available to indicate the presence of dedicated ground-based monitoring at Hainan Dao or Kunlun Volcanic Field. However, the Institute of Geology, China Seismological Bureau monitor three: Changbaishan using at least one permanent seismic station, deformation and gas measurements; Wudalianchi using seismic stations; and the Holocene age Tenchong using an integrated monitoring network.

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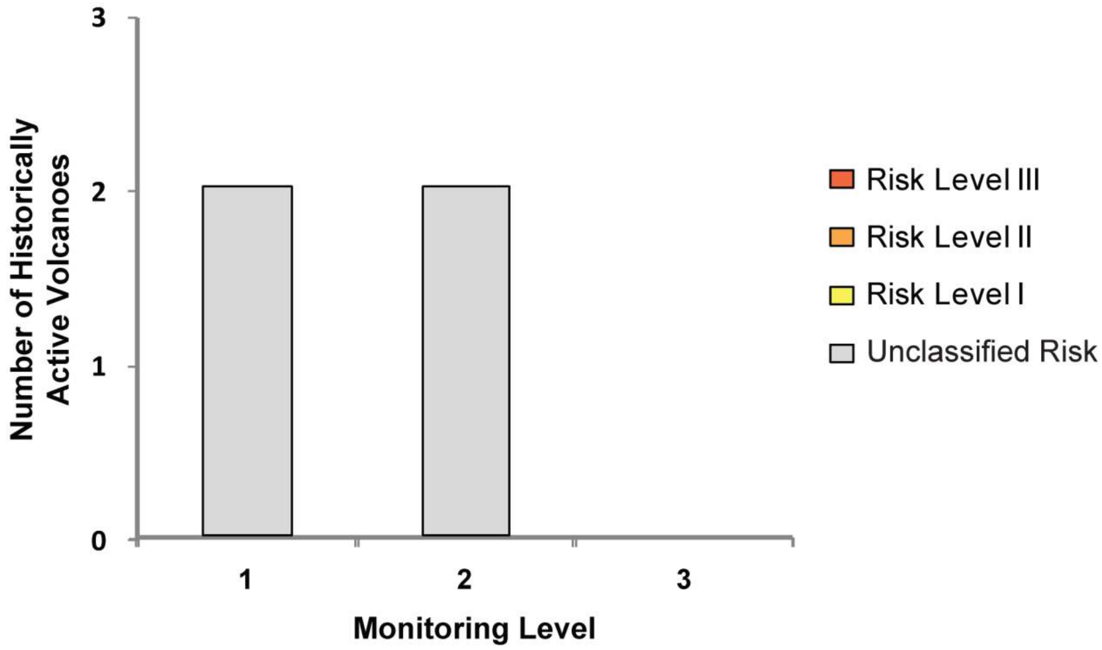

Figure 10.7 The monitoring and risk levels of the historically active volcanoes in China. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Democratic People's Republic of Korea (DPRK)

Description

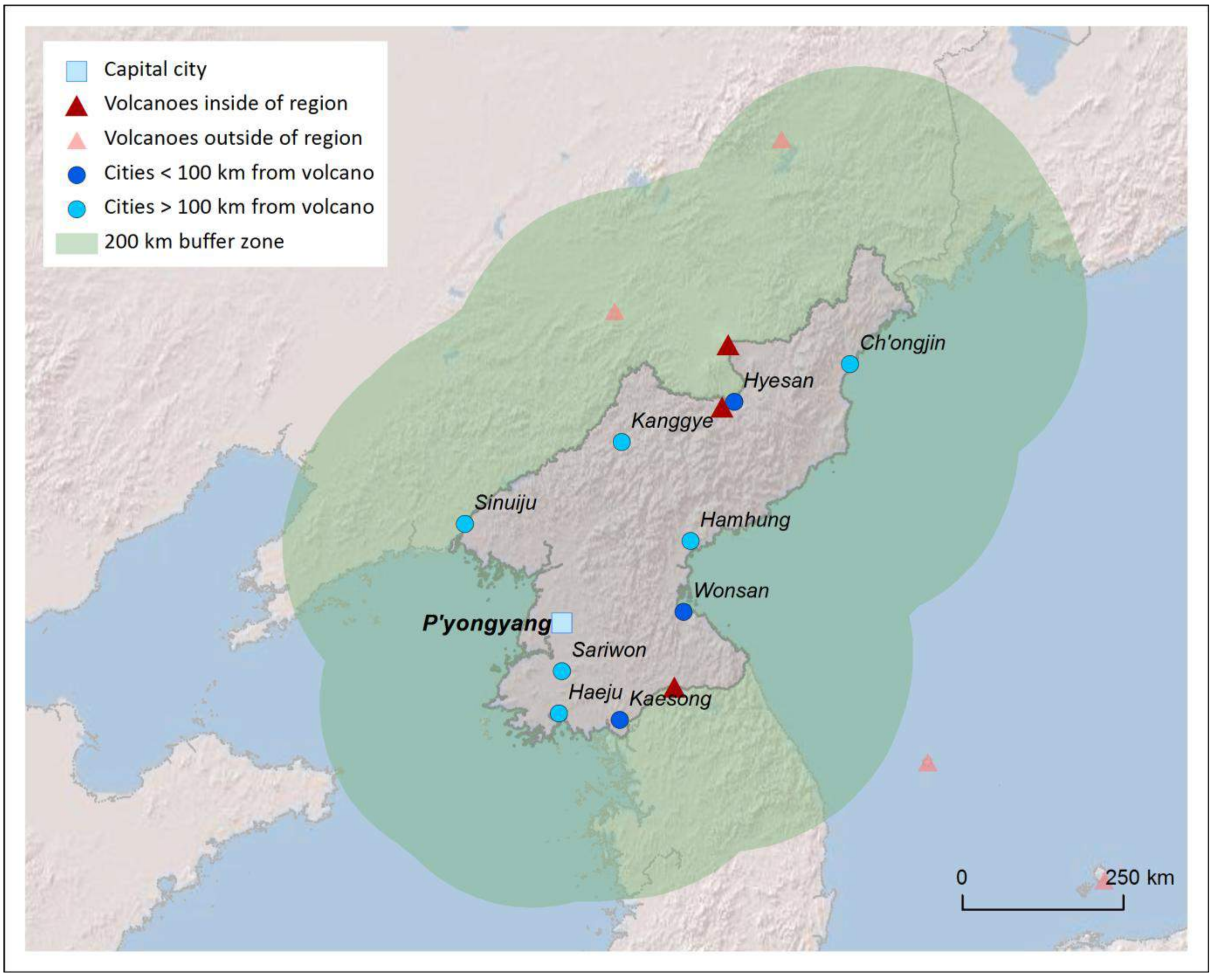

Figure 10.8 Location of the Democratic People's Republic of Korea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the DPRK.

Three Holocene volcanoes are recorded in the DPRK. One lies on the border with the Republic of Korea, whilst two others are located in the north of the country, on the border with China. These volcanoes are related to intra-plate processes, although this is not confirmed.

Changbaishan (the Chinese name for the volcano) is a large stratovolcano on the border with China. It is also known as Baektu, Paektu, Baegdu and Baitoushan, amongst other names. This is the only volcano in the DPRK to have a Holocene record of confirmed eruptions. The other two are suspected of having Holocene age activity.

Eight eruptions of VEI 2 to 7 are recorded at Changbaishan between 2160 BC and 1903. In 1000 AD the Millennium Eruption occurred. At VEI 7 this is one of the world's largest Holocene eruptions, depositing rhyolitic and trachytic tephra as far as northern Japan and forming the present caldera. This caldera, measuring 5 km wide and 850 m deep is now filled by Lake Tianchi.

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The eruptive histories of volcanoes in the DPRK are limited, and further research is required to better understand volcanism in this country and the hazards posed.

The China Seismological Bureau has installed monitoring equipment on the China side of Changbaishan. In 2002 - 2005 this began to show seismic activity and deformation of the flanks. Following this, scientists in the DPRK reached out for international collaboration to install monitoring equipment in the DPRK to more fully understand the workings of the volcano. A network of seismometers has been installed in collaboration with scientists from the UK and US. Ongoing collaboration with scientists in the DPRK should permit further understanding of the volcanic processes here and will hopefully expand the DPRK's ability to monitor and research volcanic activity using techniques and research not otherwise easily accessible to them.

See also:

Stone, R. (2013) Sizing up a slumbering giant, *Science*, 6 September 2013: 1060 – 1061.

Volcano Facts

Number of Holocene volcanoes	3, inclusive of one on the border with China and one on the border with the Republic of Korea
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M7 Oga eruption of Changbaishan at 448 ka.
Largest recorded Holocene eruption	The 950 BP Baegdusan-Tomakomai tephra eruption from Changbaishan on the border with China at M7.4.
Number of Holocene eruptions	8 confirmed eruptions. 5 uncertain eruptions.
Recorded Holocene VEI range	2 – 7 and unknown
Number of historically active volcanoes	1
Number of historical eruptions	4

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Trachytic / Andesitic (1)
1	Shield(s)	Basaltic (1)
1	Unknown	Unknown (1)

Table 10.9 The number of volcanoes in the DPRK, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	24,763,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Pyongyang
Distance from capital city to nearest Holocene volcano	157.2 km
Total population (2011)	24,457,492
Number (percentage) of people living within 10 km of a Holocene volcano	23,737 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	406,248 (1.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,430,099 (9.9%)

Ten largest cities, as measured by population and their population size:

P'yongyang	3,222,000
Hamhung	559,056
Kaesong	338,155
Wonsan	329,207
Ch'ongjin	327,000
Sinuiju	288,112
Haeju	222,396
Kanggye	209,530
Sariwon	154,942
Hyesan	97,794

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Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	4,147
Total length of railroads within 100 km of a volcano (km)	829

The volcanoes in the DPRK border China to the north and the Republic of Korea to the south, thus exposing parts of these countries to the volcanic hazard. Two of the largest cities in the DPRK are located within the 100 km radii – Kaesong and Hyesan, thus exposing an extensive road and rail network. Pyongyang lies at over 150 km from a Holocene volcano.

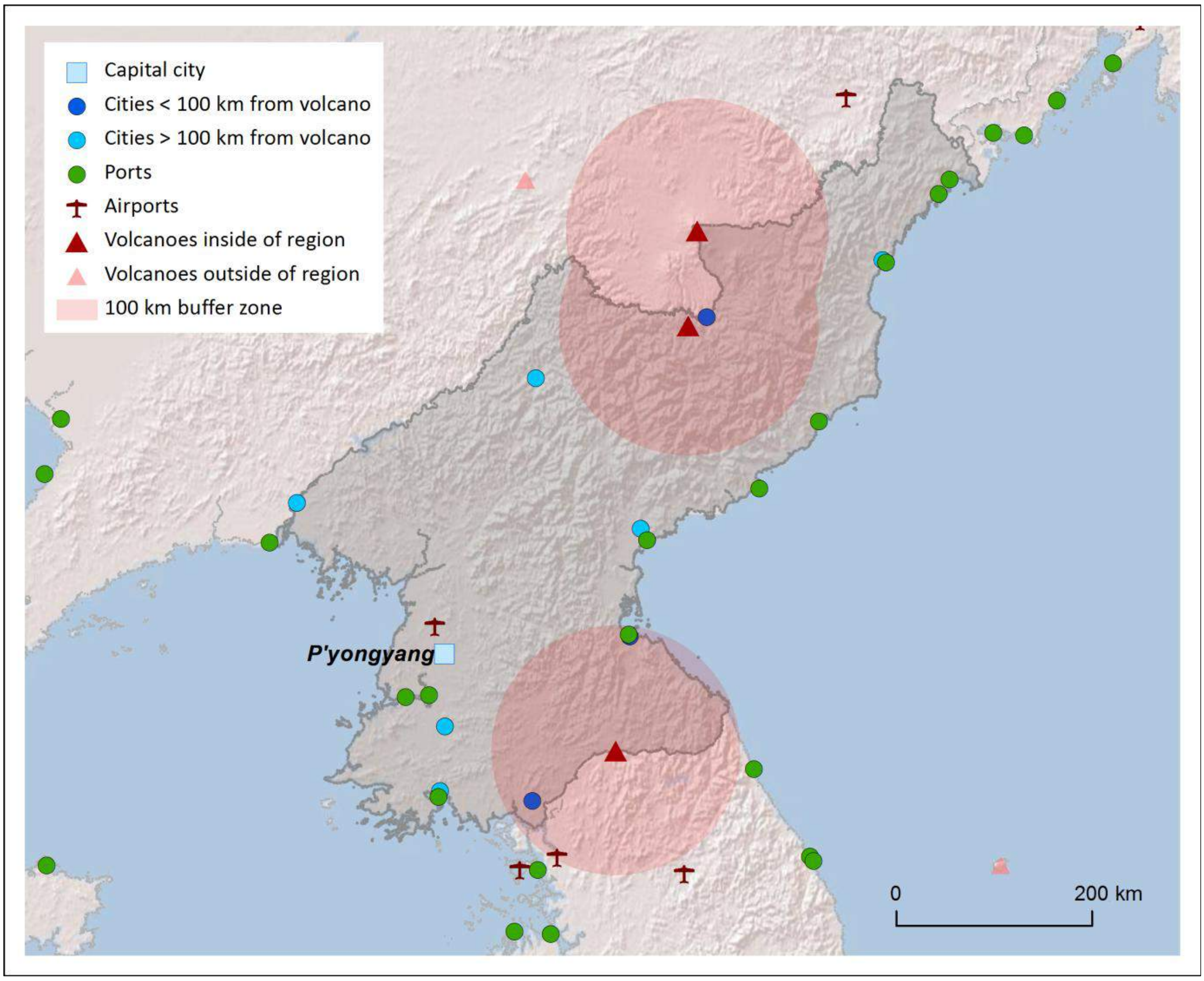

Figure 10.9 The location of the DPRK's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

Only Changbaishan on the border between the DPRK and China has a Holocene eruption record here; Xianjindao and Ch'uga-ryong have no confirmed Holocene eruptions. Without a detailed eruption record, inclusive of eruption sizes, hazard assessment through the calculation of the VHI is not viable without large uncertainties. These volcanoes are therefore unclassified. Changbaishan, though unclassified, is known to have a record of large explosive eruptions, including two Holocene VEI 4 events and one VEI 7 eruption in 1000 AD. This volcano also has erupted, on a smaller scale, since 1900 AD.

Changbaishan has the lowest PEI in the DPRK, at a PEI of 3. Xianjindao and Ch'uga-ryong both have larger local populations.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR			**Changbaishan**				
	U- HR							
	U- NHHR				Xianjindao	Ch'uga-ryong		
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 10.10 Identity of DPRK's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Only Changbaishan has a historical record of activity. This volcano is monitored on the China side of the border by the China Seismological Bureau using both permanent and mobile seismic stations and mobile deformation stations. In the DPRK, a seismic network comprising six seismic stations was installed and is monitored by scientists at Imperial College London and Cambridge University (UK) along with scientists in North Korea, in a collaborative effort that began in 2011.

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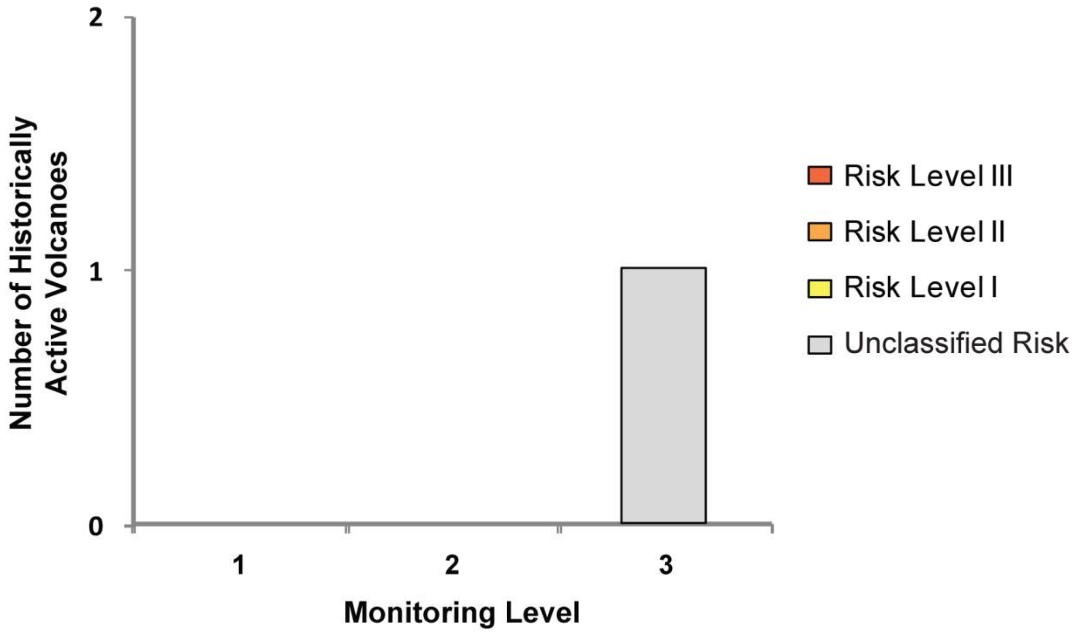

Figure 10.10 The monitoring and risk levels of the historically active volcanoes in the DPRK. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Mongolia

Description

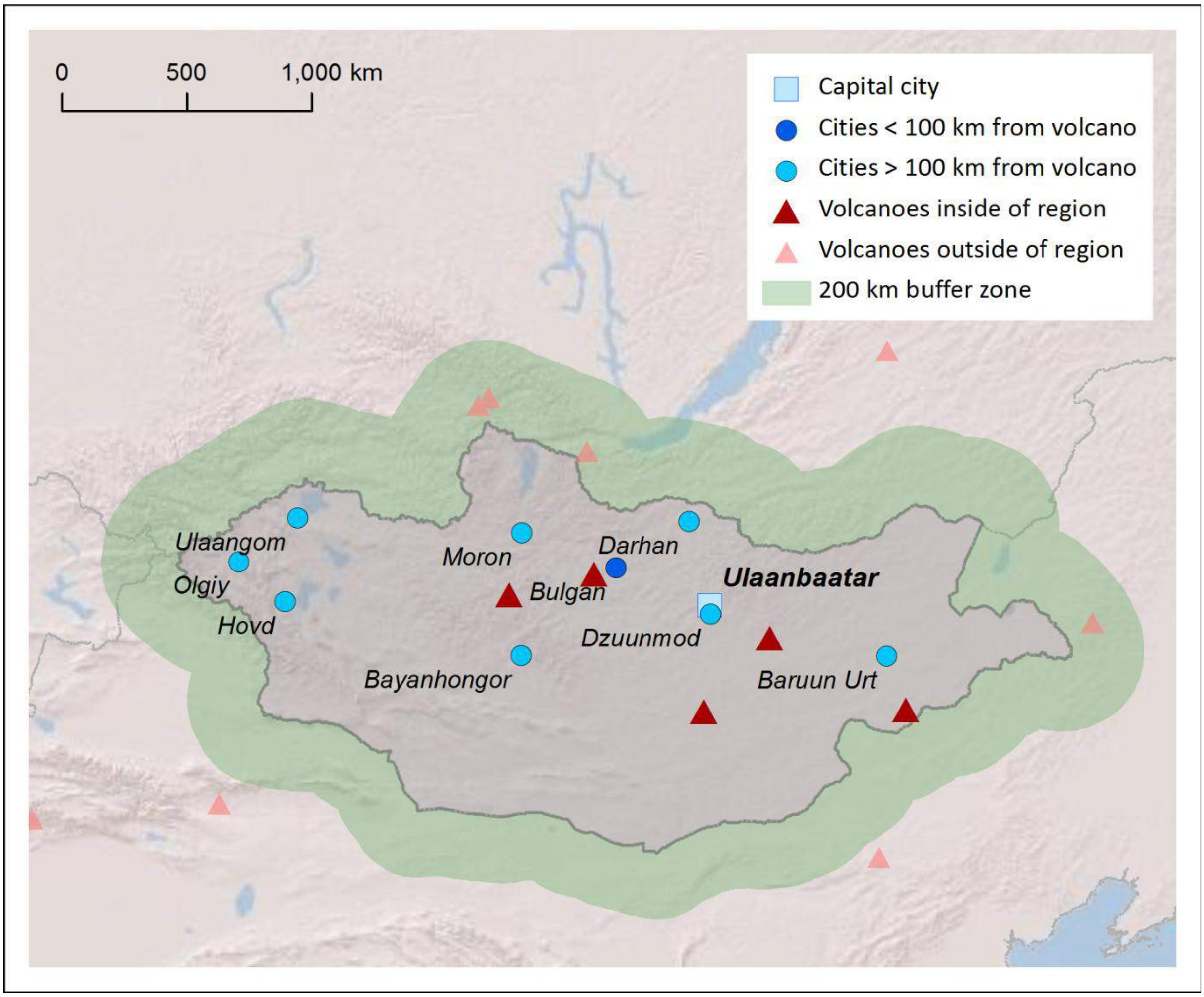

Figure 10.11 Location of Mongolia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mongolia.

Five Holocene volcanoes are distributed throughout central to eastern Mongolia. These volcanoes are related to intra-plate processes. All volcanoes here are volcanic fields and cinder cones and are dominantly basaltic in composition.

Only one volcano, Taryatu-Chulutu, has an eruption recorded in the Holocene, however Holocene activity is suspected at the others. The eruption of Taryatu-Chulutu occurred in 2980 BC. The eruption size is unknown, however lava flows were produced at this time.

The absence of detailed eruption histories at Mongolia's volcanoes makes assessment of hazard difficult and therefore associated with large uncertainties. Although one of the largest cities in Mongolia, Bulgan, lies about 60 km from Khanuy Gol volcano, all the other volcanoes have moderate proximal population sizes.

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The Asian Disaster Reduction Center (ADRC) have presented country reports on hazards in Mongolia since 1998. These do not consider volcanoes as it describes these as extinct. They describe the disaster management system in Mongolia and how the National Emergency Management Agency (NEMA) is "responsible for the implementation of the State disaster protection policy and legislation, as well as for the professional organization of nation wide activities". They also describe the structure of emergency response, numbers of emergency personnel and the activities within Mongolia towards addressing the Hyogo Framework for Action (HFA). See their report (given below) for full details.

See also:

NEMA: nema.gov.mn/

ADRC information on Disaster Risk Reduction of the Member Countries: Mongolia:
www.adrc.asia/nationinformation.php?NationCode=496&Lang=en&NationNum=18

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	
Largest recorded Holocene eruption	The eruption has no known VEI.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
5	Small cone(s)	Andesitic (1), Basaltic (4)

Table 10.11 The number of volcanoes in Mongolia, their volcano type classification and dominant rock type according to VOTW4.0.

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Socio-Economic Facts

Total population (2012)	2,793,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,178
Gross National Income (GNI) per capita (2005 PPP $)	4,245
Human Development Index (HDI) (2012)	0.675 (Medium)

Population Exposure

Capital city	Ulan Bator
Distance from capital city to nearest Holocene volcano	185 km
Total population (2011)	3,133,318
Number (percentage) of people living within 10 km of a Holocene volcano	1,391 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	13,413 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	120,899 (3.9%)

Ten largest cities, as measured by population and their population size:

Ulaanbaatar	844,818
Darhan	74,300
Olgiy	28,400
Ulaangom	28,085
Hovd	27,924
Moron	27,690
Bayanhongor	23,234
Dzuunmod	17,738
Bulgan	17,348
Baruun Urt	15,805

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,041
Total length of railroads within 100 km of a volcano (km)	191

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The Mongolian volcanoes are located through central Mongolia. The Dariganga Volcanic Field lies near the border with China, thus an area of China lies within the 100 km radius of this volcano. Part of eastern Mongolia lies within the radius of the Arshan volcano in north-western China. Being an inland country, no ports are exposed to the volcanic threat. One of the largest cities in Mongolia, Bulgan, lies within 100 km of the Khanuy Gol volcano, exposing the infrastructure here. However the capital, Ulaanbaatar, lies at nearly 200 km distance. A considerable road network is exposed in Mongolia.

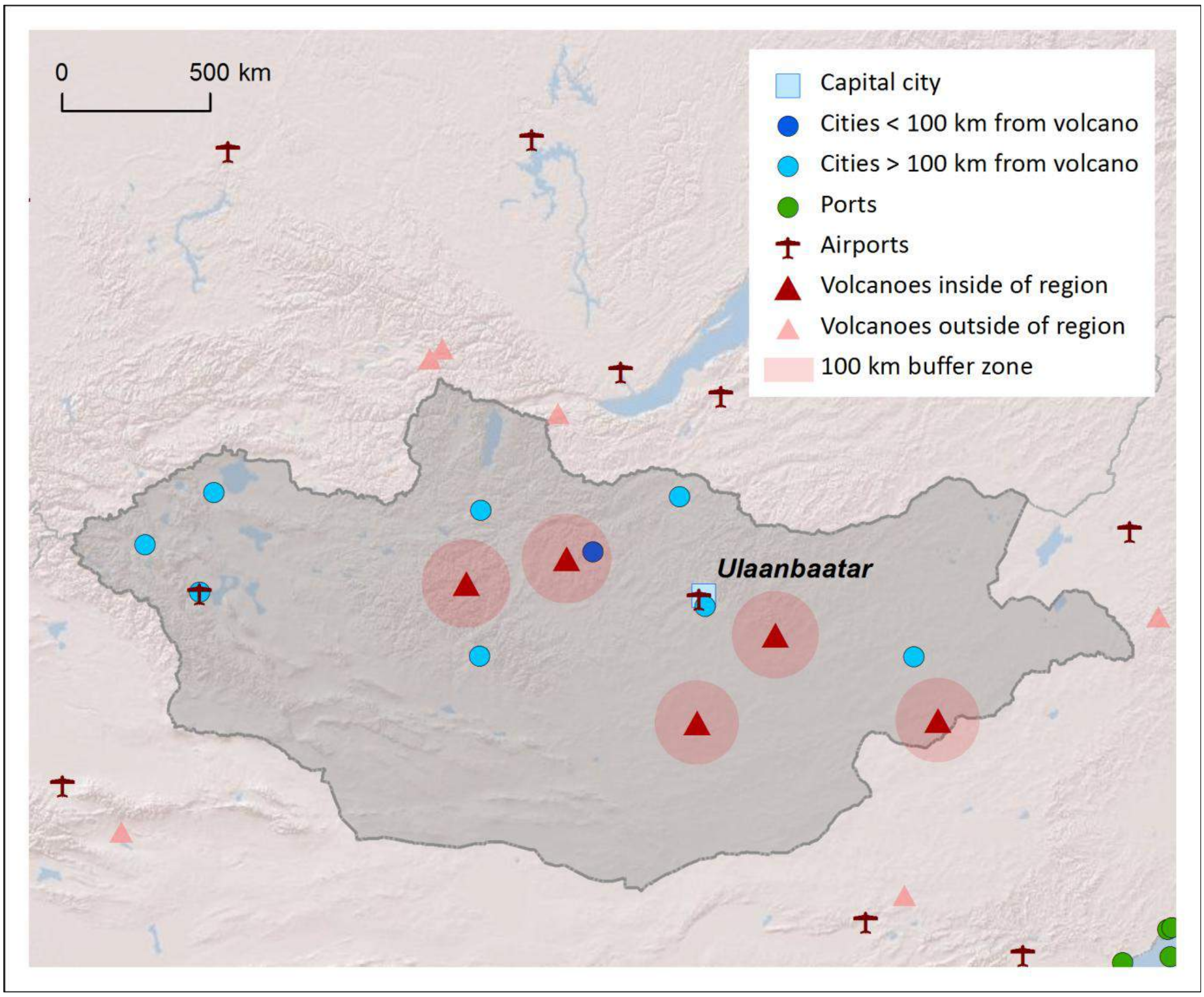

Figure 10.12 The location of Mongolia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of Mongolia's volcanoes, only Tayatu-Chulutu has a Holocene eruption record, and this comprises just one eruption of unknown size. The absence of extensive eruption histories prevents the assessment of hazard through the calculation of the VHI without large associated uncertainties. These volcanoes are therefore unclassified.

The PEI ranges from low to moderate, from PEI 2 – 4. The risk is unclassified with the absence of hazard information.

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CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			Taryatu-Chulutu				
	U- NHHR		Bus-Obo	Khanuy Gol; Middle Gobi	Dariganga Volcanic Field			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 10.12 Identity of Mongolia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Mongolia have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Mongolia.

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Republic of Korea

Description

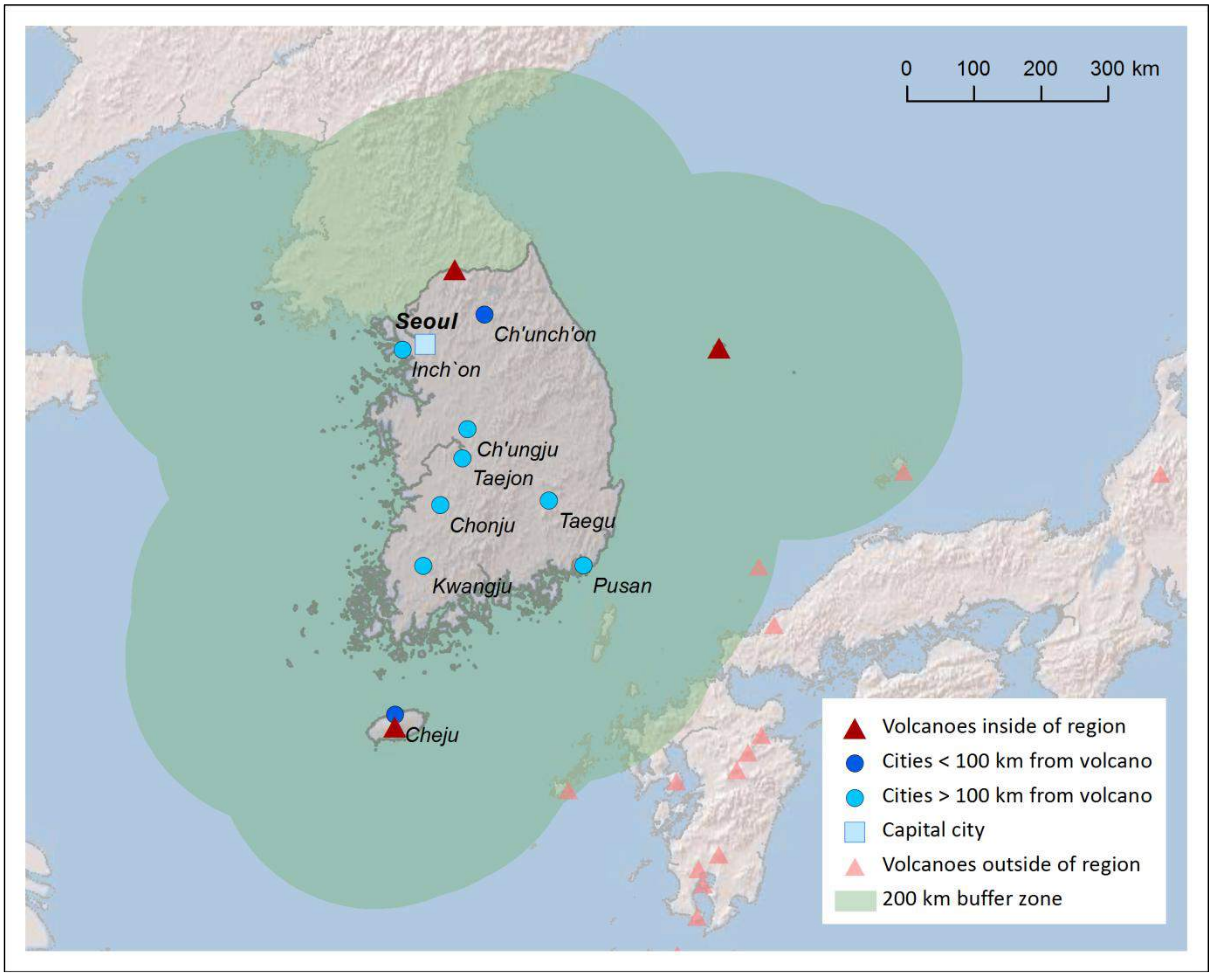

Figure 10.13 Location of the Republic of Korea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Republic of Korea.

Three Holocene volcanoes are located in the Republic of Korea – Ch'uga-ryong (now called Chugaryeong) on the border with the DPRK, Ulreung (now called Ulleung) off the east coast and Mt. Halla (also called Hallasan, Jeju Island) off the south coast. Volcanism here is attributed to intra-plate processes. We use the older names as currently used in VOTW4.0 for this report.

Ch'uga-ryong and Halla are basaltic shields. Ulreung is more felsic, being a dominantly trachy-andesitic stratovolcano.

Only Ulreung and Mt. Halla have confirmed eruptions recorded during the Holocene, with several eruptions recorded between about 9300 - 6300 BP and 2700 BP. Only one of these eruptions has an attributed size, with the 8750 BC eruption of Ulreung being a VEI 6 eruption which produced pyroclastic flows and deposited ash in central Japan. No historical activity has been recorded, with the most recent activity being the 1002 AD and 1007 AD eruptions of Mt. Halla.

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The absence of detailed eruptive histories for the volcanoes in the Republic of Korea, particularly with eruptions of unknown magnitudes, makes assessment of hazard difficult and associated with uncertainties. Both Ulreung and Halla form small populated islands, which are at particular risk due to the logistics of evacuating islands in a timely manner.

Monitoring of Mt. Halla is undertaken by the Jeju Volcanological Institute in collaboration with the Korea Institute of Geoscience and Mineral Resources (KIGAM) through the use of seismic and deformation instrumentation. This institute was founded in 2003 to undertake scientific research and monitoring. The personnel in this institute have some experience of responding to an eruption and have some resources and plans in place to respond to developing unrest and eruptions. Research into volcanic hazards is also ongoing focussed on the potential activity of Baekdusan (Mt. Baekdu, or Changbaishan in Chinese) in the neighbouring DPRK and the potential for the expansion of ash clouds from this volcano into the Republic of Korea.

The Asian Disaster Reduction Center (ADRC) produced a report on hazards in the Republic of Korea in 2008, with five previous versions dating back to 1998. In these they do not consider volcanic hazards. They describe the disaster management system in the country comprising the National Emergency Management Agency (NEMA), the National Disaster Management Institute and the National Institute for Disaster Prevention (NIDP). See the ADRC report for full details.

See also:

Jeju Island Geopark: geopark.jeju.go.kr/english/?mid=0101

Korea Institute of Geoscience and Mineral Resources: www.kigam.re.kr/english/index.asp

Asian Disaster Reduction Center: Republic of Korea:
www.adrc.asia/nationinformation.php?NationCode=410&Lang=en&NationNum=21

Volcano Facts

Number of Holocene volcanoes	3, inclusive of one on the border with the DPRK
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M6.7 Ulreung eruption of 10.7 ka would be the largest Pleistocene eruption recorded here, however as this is also

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	included in the Holocene dataset, the M6 Yamato eruption of Ulreung at 42 ka will be considered the largest Pleistocene event.
Largest recorded Holocene eruption	The M6.7 eruption of Ulreung at 10.7 ka producing the Oki tephra is just outside of the Holocene but is included in the Holocene dataset of VOTW4.0.
Number of Holocene eruptions	7 confirmed eruptions.
Recorded Holocene VEI range	6 and Unknown
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
2	Shield(s)	Basaltic (2)

Table 10.13 The number of volcanoes in the Republic of Korea, their volcano type classification and dominant rock type according to VOTW4.0.

The shield volcano of Halla has more than 360 monogenetic cones, producing flank eruptions as recently as the 11th century.

Socio-Economic Facts

Total population (2012)	48,943,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	27,541
Gross National Income (GNI) per capita (2005 PPP $)	28,231
Human Development Index (HDI) (2012)	0.909 (Very High)

Population Exposure

Capital city	Seoul
Distance from capital city to nearest Holocene volcano	89.3 km
Total population (2011)	48,754,657

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Number (percentage) of people living within 10 km of a Holocene volcano	3,400 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	538,158 (1.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,997,131 (8.2%)

Ten largest cities, as measured by population and their population size:

Seoul	10,349,312
Busan (Pusan)	3,678,555
Incheon (Inch`on)	2,628,000
Daegu (Taegu)	2,566,540
Daejeon (Taejon)	1,475,221
Gwangju (Kwangju)	1,416,938
Jeonju (Chonju)	711,424
Cheongju (Ch'ungju)	634,596
Jeju (Cheju)	329,068
Chuncheon (Ch'unch'on)	209,746

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	3,953
Total length of railroads within 100 km of a volcano (km)	175

Ulreung lies more than 100 km off the east coast of the Republic of Korea and is about 12 km across and thus the small settlements on the island lie entirely within the 100 km radius. Mt. Halla volcano lies off the coast to the south, exposing the island of Jeju Do (Cheju Do) in its entirety, as well as small islands closer to the mainland, with the 100 km radius extending to the southern tip of the mainland. Two airports and a port are exposed here. In the north, Ch'uga-ryong borders the DPRK, and the 100 km radius encompasses much of the northern Republic of Korea and southern DPRK. Seoul, the capital of the Republic of Korea, lies less than 90 km from this volcano, therefore considerable critical infrastructure is exposed.

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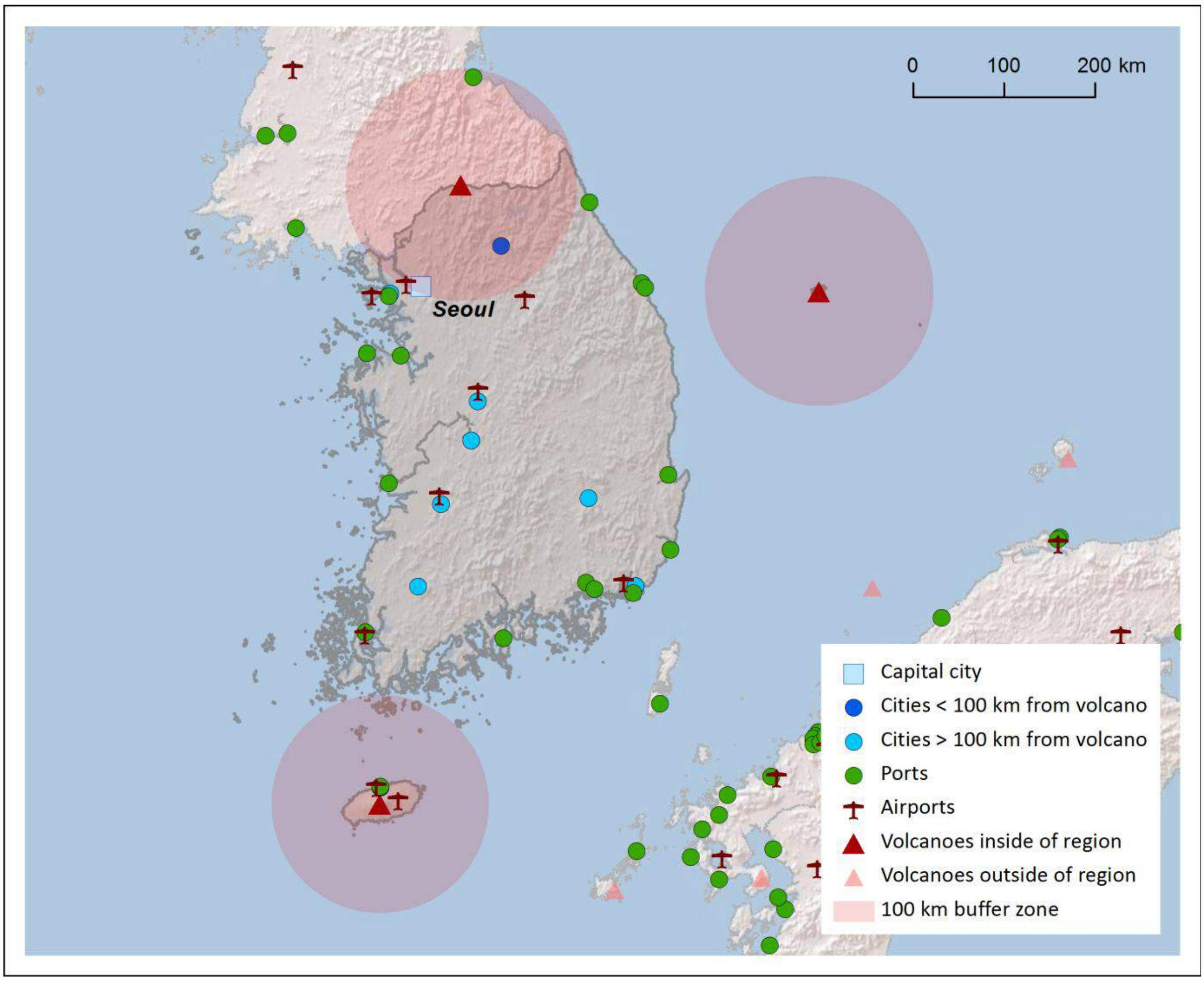

Figure 10.14 The location of the volcanoes in the Republic of Korea and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in the Republic of Korea are not sufficiently extensive for hazard assessment through the calculation of the VHI without large associated uncertainties, with just one eruption having an attributed VEI here. These volcanoes are therefore unclassified. Ulreung and Halla have seven Holocene eruptions between them, however Ch'uga-ryong has no confirmed Holocene events.

The PEI is moderate to high in the Republic of Korea, ranging from 3 to 5. Risk levels are not classified here due to the absence of hazard information.

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CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			Ulreung	Halla			
	U- NHHR					Ch'uga-ryong		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 10.14 Identity of the Republic of Korea's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in the Republic of Korea have recorded historical eruptions. However the Jeju Volcanological Institute operates two seismometers and deformation instrumentation at Mt. Halla volcano, which has a Holocene record of activity from the 11th Century.

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Russia

Note that we include Elbrus volcano from Region 1 here. See Region 9 for description of the Kuril Islands and Russian volcanoes here.

Description

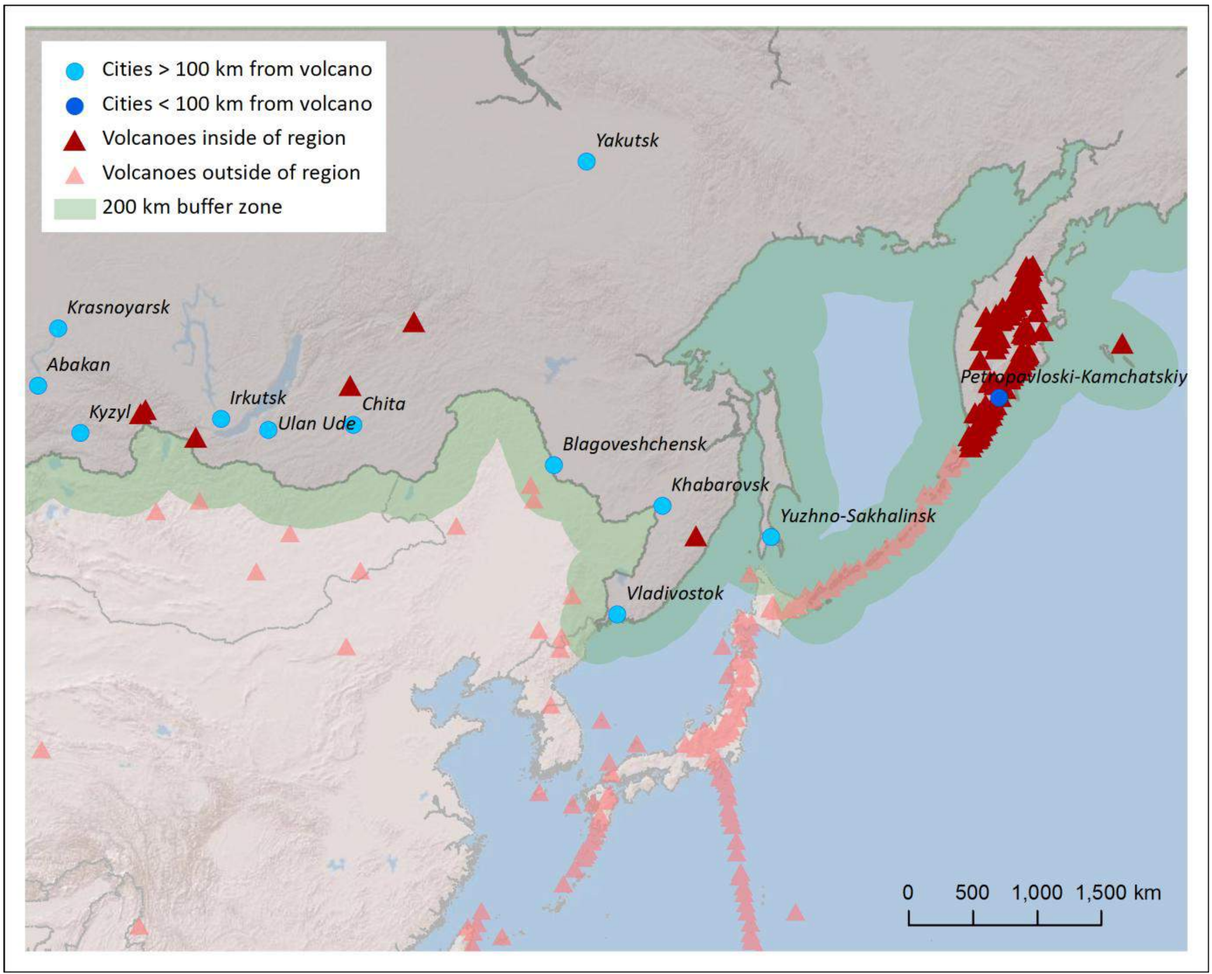

Figure 10.15 Location of Russia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Russia.

Volcanic activity in Russia is concentrated in the country's easternmost region on the Kamchatka peninsula and the Kurile island arc which stretches from Kamchatka in the north to Japan in the south. The activity arises due to the subduction of the Pacific Plate and forms part of the Pacific Ring of Fire. In addition, volcanism caused by tectonic rifting has occurred in the mainland part of Russia but is small and infrequent in comparison to the Kurile-Kamchatka volcanic arc. According to IVS volcano observatory, 3 to 5 volcanoes on the Kurile-Kamchatka arc are erupting on a daily basis.

Over half of the erupted material on the Kurile-Kamchatka volcanic arc is produced by the Central Kamchatka Depression on the Kamchatka peninsula. Here we find one of the largest volcanic centres in the world which includes the Klyuchevskoy volcano group and Sheveluch volcano. Frequent and

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vigorous volcanic activity continues SSE along the Eastern Volcanic Belt which is 850 km long and 50 - 100 km wide.

Highly active volcanism in Kamchatka has been ongoing for the past 2 to 2.5 million years. Holocene activity has been dominated by formation of large and spectacular stratovolcanoes. The largest of them, Klyuchevskoy, reaches 4750 m a.s.l. and is the tallest volcano in Eurasia. The number of active volcanoes is 29, where active is defined as having erupted since the 17th century, although several additional volcanoes are included based on other evidence of activity.

Kurile island arc has both on-land and submarine volcanoes. Volcanoes on land include 37 active and potentially active volcanoes. The number of submarine volcanoes is estimated to be around 100. The largest recent eruption in the Kuriles was in 2009 at Sarychev volcano (VEI 4).

The volcanoes in this region are capable of producing large explosive eruptions with ash-rich plumes, pyroclastic flows, direct blasts and deposits of ballistic material. Long-duration effusive eruptions can produce extensive lava flows, such as demonstrated by the eruption of Plosky Tolbachik 2012 - 2013. However, due to the sparse population of the region, the greatest volcanic hazard is ash on aviation routes. The tectonic nature of the region may also cause large earthquakes.

In Kamchatka, populated centres are located at over 30 km distance from volcanic centres. There have been 3 casualties in 3 separate eruptions of Klyuchevskoy since 1960 where scientists were killed near the summit. The largest eruptions over the last century, such as Bezymianny in 1956 (eruption column of 40 km a.s.l. and directed blast of 25 - 30 km, VEI 5) have not caused casualties or significant damage to infrastructure.

Regular monitoring of Kamchatkan volcanoes began in 1935 when the Kamchatka Volcanological Station was founded in Kliuchi. This is now the Institute of Volcanology and Seismology (IVS). The Kamchatka Volcanic Eruption Response Team (KVERT) was established in 1993. KVERT is responsible for issuing alerts (including aviation colour codes) for Kamchatka and Northern Kurile volcanoes.

See also:

Kamchatka Volcanic Eruption Response Team (KVERT): www.kscnet.ru/ivs/kvert/index_eng.php

Institute of Volcanology and Seismology: www.kscnet.ru/ivs/eng/

Volcano Facts

Number of Holocene volcanoes	154
Number of Pleistocene volcanoes with M≥4 eruptions	20
Number of volcanoes generating pyroclastic flows	28
Number of volcanoes generating lahars	17
Number of volcanoes generating lava flows	54

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Number of fatalities caused by volcanic eruptions	6
Tectonic setting	147 subduction zone, 2 intra-plate, 4 rift-zone, 1 unknown.
Largest recorded Pleistocene eruption	The M7.6 eruption of the Golygin Ignimbrite from Diky Greben at 443 ka.
Largest recorded Holocene eruption	The KO eruption of Kurile Lake, at M7.2 in 8387 BP.
Number of Holocene eruptions	891 confirmed eruptions. 32 uncertain eruptions and 8 discredited eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	25
Number of historical eruptions	330

Number of volcanoes	Primary volcano type	Dominant rock type
10	Caldera(s)	Andesitic (5), Basaltic (4), Dacitic (1)
71	Large cone(s)	Andesitic (36), Basaltic (31), Dacitic (3), Unknown (1)
4	Lava dome(s)	Andesitic (1), Basaltic (2), Dacitic (1)
44	Shield(s)	Andesitic (2), Basaltic (42)
20	Small cone(s)	Andesitic (4), Basaltic (13), Unknown (3)
5	Submarine	Dacitic (1), Unknown (4)

Table 10.15 The number of volcanoes in Russia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	143,021,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	14,808
Gross National Income (GNI) per capita (2005 PPP $)	14,461
Human Development Index (HDI) (2012)	0.788 (High)

Population Exposure

Capital city	Moscow

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Distance from capital city to nearest Holocene volcano	1423.5 km
Total population (2011)	138,739,892
Number (percentage) of people living within 10 km of a Holocene volcano	4,718 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	84,639 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,369,815 (1.7%)

Ten largest cities, as measured by population and their population size:

Moscow	10,381,222
Novosibirsk	1,419,007
Ekaterinburg	1,287,573
Nizny Novgorod	1,284,164
Samara	1,134,730
Omsk	1,129,281
Kazan'	1,104,738
Rostov-on-Don	1,074,482
Chelyabinsk	1,062,919
Ufa	1,033,338

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	3,042
Total length of railroads within 100 km of a volcano (km)	863

Volcanoes in Russia are distributed between two main groups: those on the Kamchatka Peninsula and those inland, north of Mongolia. Volcanoes in the Kuril Islands are discussed in the separate Kuril Island profile. The concentration of volcanoes in the Kamchatka Peninsula means this is exposed in its entirety, however being sparsely populated the exposed population is small. This does however mean that all critical infrastructure here is exposed, including that in the largest city, Petropavlovsk-Kamchatsky.

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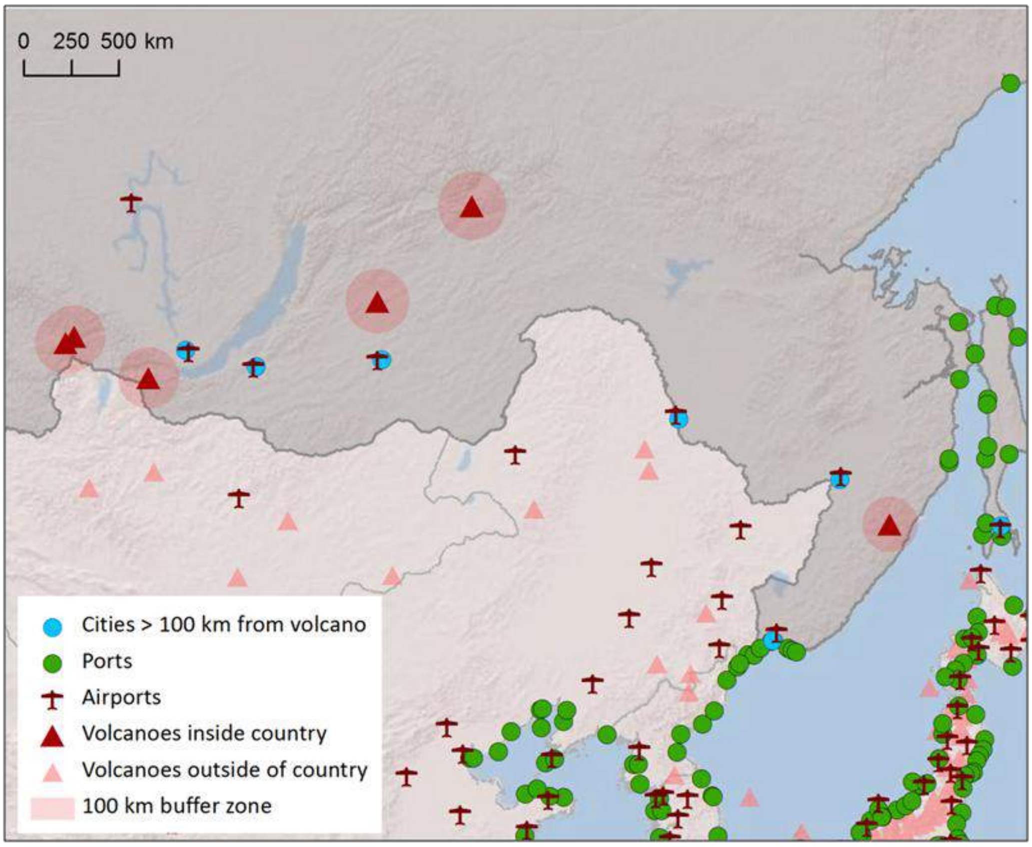

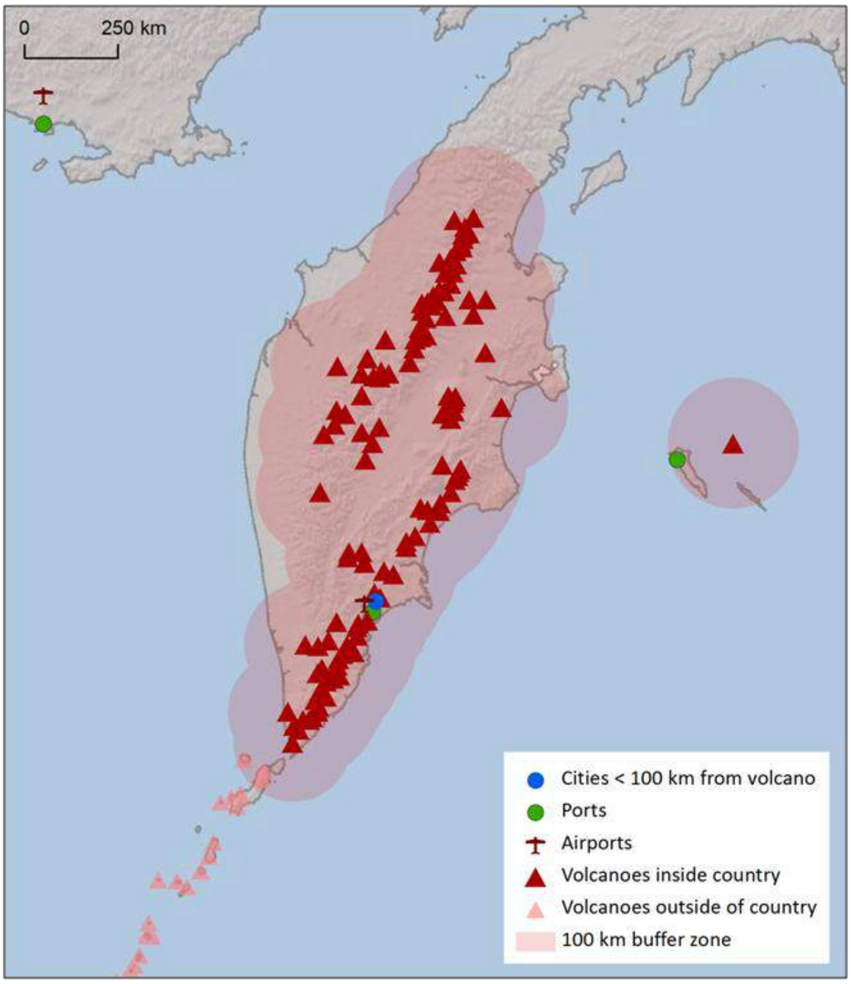

Figure 10.16 The location of Russia's volcanoes and the extent of the 100 km zone surrounding them. (Top) the eastern section of Mainland Russia; (Left) the Kamchatka Peninsula. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

The volcanoes of Russia have varying levels of data available in the eruption record. Just 12% of volcanoes have appropriate eruptive histories to define the hazard. These volcanoes are classified across all three hazard levels, and all but three have erupted since 1900 AD. Of the classified volcanoes, just Kostakan has no historical record.

Most volcanoes in Russia lack a sufficiently extensive eruption record to determine the hazard through calculation of the VHI without large associated uncertainties, and these are therefore unclassified. Indeed, 61 of these volcanoes have no confirmed eruptions during the Holocene. Of these, one, Asacha, has experienced unrest since 1900 AD. Of the remaining unclassified volcanoes with Holocene eruptions, 12 have records of historical activity, including eruptions since 1900 AD at six volcanoes. Thirteen of the unclassified volcanoes have Holocene records of large explosive VEI ≥4 eruptions.

Most volcanoes in Russia have a low local population, categorising these as PEI 2 volcanoes. In combination with the hazard levels this makes most classified volcanoes Risk Level I with just four classed at Risk Level II.

Volcano	Population Exposure Index	Risk Level
Avachinsky	3	II
Koryaksky	3	II
Bezymianny	2	II
Shiveluch	2	II
Gorely	2	I
Karymsky	2	I
Kikhpinych	2	I
Kliuchevskoi	2	I
Kostakan	2	I
Krasheninnikov	2	I
Maly Semiachik	2	I
Mutnovsky	2	I
Tolbachik	2	I
Zhupanovsky	2	I

Table 10.16 Classified volcanoes of Russia ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 10 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

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CLASSIFIED	**Hazard III**		Bezymianny; Shiveluch	Koryaksky; Avachinsky				
	Hazard II		Karymsky; Maly Semiachik; Kikhpinych; Krasheninnikov; Tolbachik; Kliuchevskoi					
	Hazard I		Mutnovsky; Gorely; Zhupanovsky; Kostakan					
UNCLASSIFIED	**U – HHR**		Koshelev; **Ilyinsky**; **Zheltovsky**; **Ksudach**; Opala; **Akademia Nauk**; **Kronotsky**; **Kizimen**; Ushkovsky; Khangar; **Ichinsky**; Alney-Chashakondzha					
	U- HR		Kambalny; Yavinsky; Diky Greben; Kurile Lake; Khodutka; Tolmachev Dol; Vilyuchik; Barkhatnaya Sopka; Veer; Bakening; Zavaritsky; Bolshoi Semiachik; Taunshits; **Uzon**; Gamchen; Komarov; Vysoky; Piip; Cherpuk Group; Bolshoi-Kekuknaysky; Shisheika; Terpuk; Sedankinsky; Gorny Institute; Kinenin; Bliznetsy; Titila; Elovsky; Nylgimelkin; Spokoiny; Ostry; Severny; Udokan Plateau					
	U- NHHR		Mashkovtsev; Kell; Belenkaya; Ozernoy; Olkoviy Volcanic Group; Plosky; Piratkovsky; Ostanets; Otdelniy; Golaya; **Asacha**; Visokiy; Unnamed; Bely; Bolshe-Bannaya; Dzenzursky; Schmidt; Unnamed; Udina; Zimina; Kamen; Maly Payalpan; Bolshoi Payalpan; Akhtang; Kozyrevsky; Romanovka; Uksichan; Kulkev; Geodesistoy; Anaun; Krainy; Kekurny; Eggella; Cherny; Unnamed; Verkhovoy; Pogranychny; Zaozerny; Bliznets; Kebeney; Uka; Fedotych; Leutongey; Tuzovsky; Mezhdusopochny; Shishel; Alngey; Kaileney; Plosky; Snezhniy; Iktunup; Snegovoy; Iettunup; Voyampolsky; Vitim Plateau; Tunkin Depression; Oka Plateau; Azas Plateau			Unnamed; Unnamed; Sikhote-Alin		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 10.17 Identity of Russia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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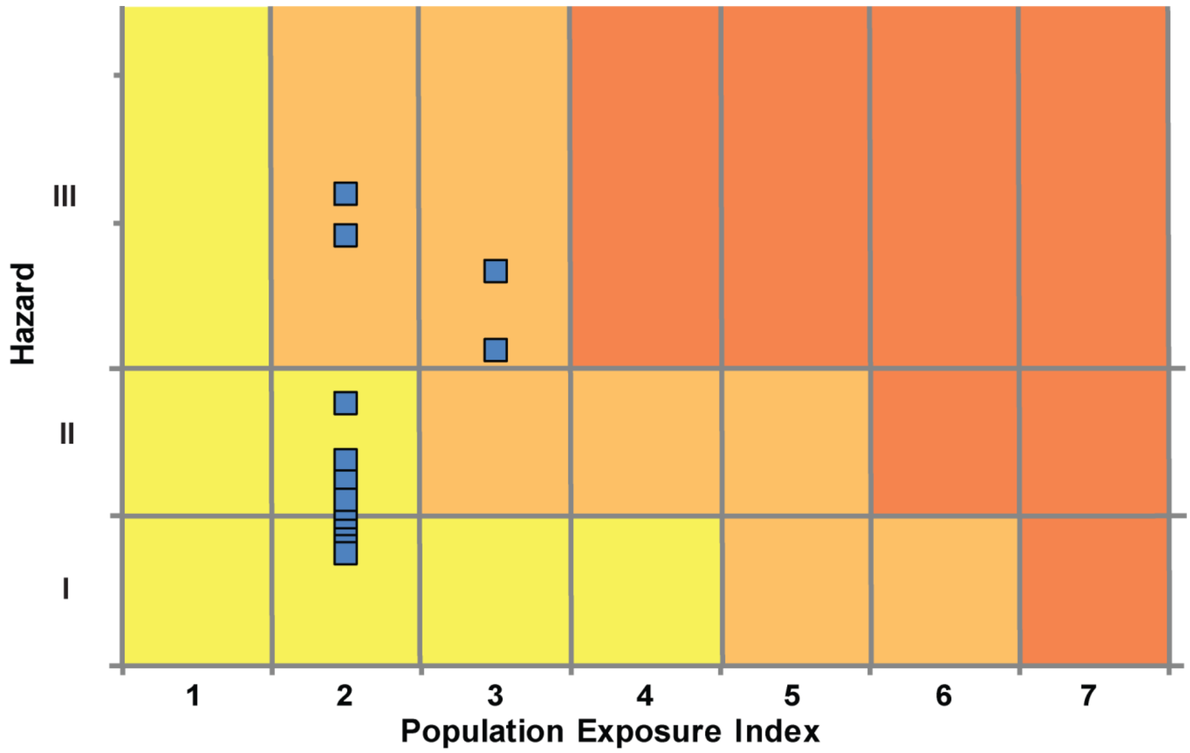

Figure 10.17 Distribution of Russia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Institute of Volcanology and Seismology (IVS FEB RAS) and Kamchatka Volcanic Eruption Response Team (KVERT) are responsible for monitoring volcanoes and providing aviation alerts. Twenty-five Russian volcanoes are recorded as having historical activity. Of these fourteen have no continuous monitoring. The remaining have dedicated seismic monitoring, from three or fewer stations at five volcanoes, to networks of seven or more stations. At least three volcanoes have additional deformation monitoring (Karymsky, Kliuchevskoi and Bezymianny).

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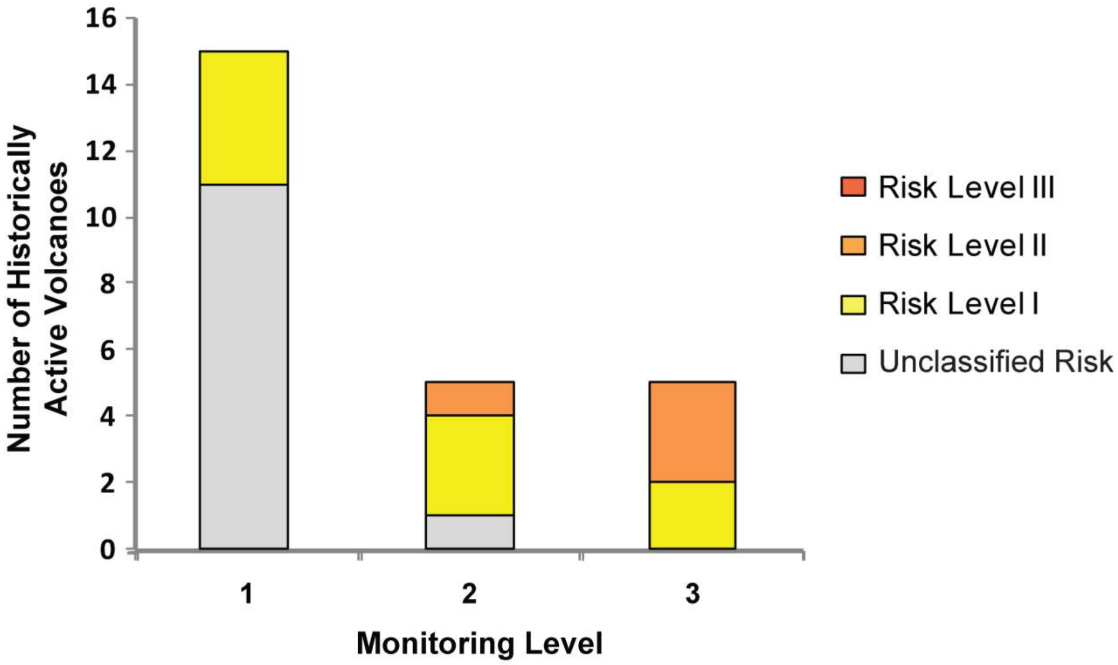

Figure 10.18 The monitoring and risk levels of the historically active volcanoes in Russia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 11: Alaska

Here volcanism in the U.S. state of Alaska is discussed. See Region 4 for American Samoa, Region 8 for the U.S. Marianas Islands, Region 12 for the contiguous states of the U.S.A. and Region 13 for Hawaii.

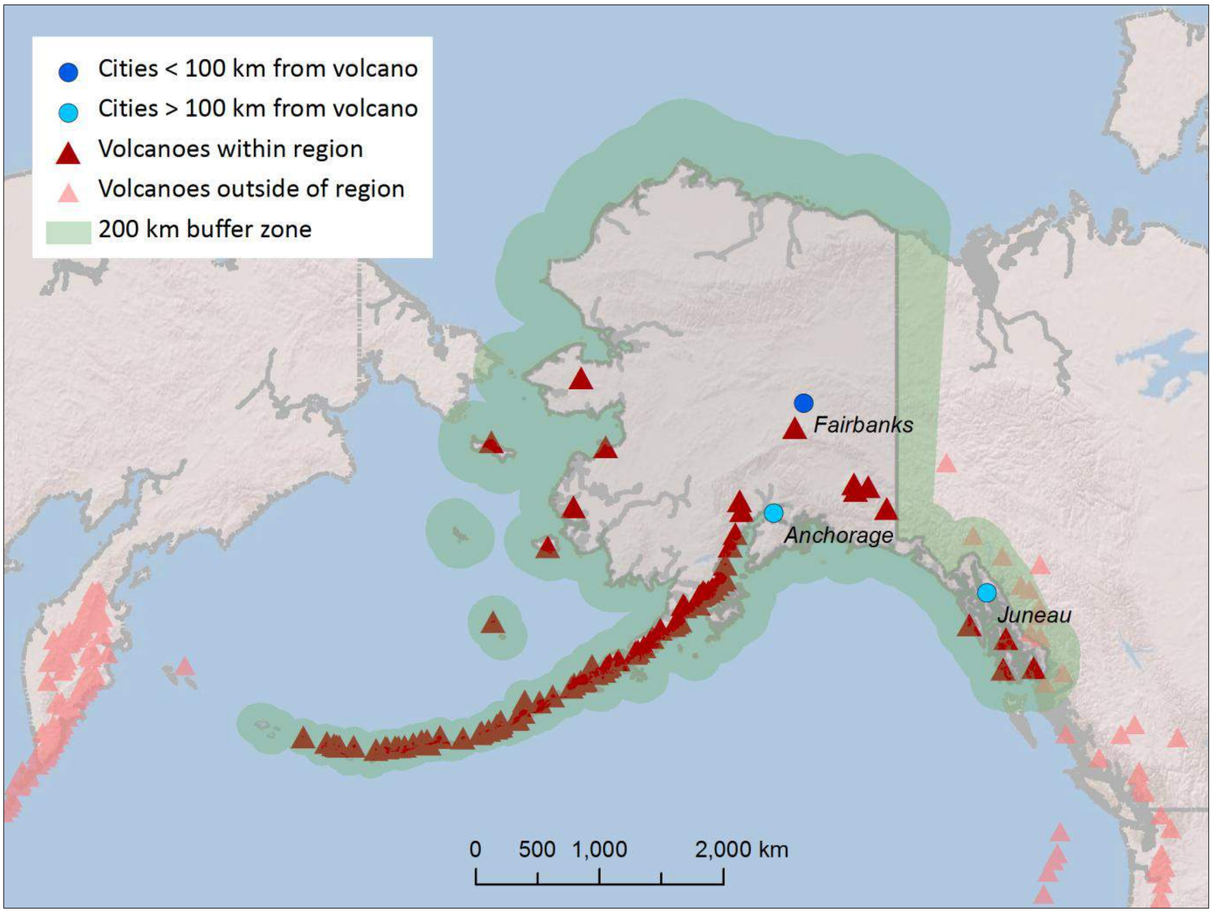

Figure 11.1 Location of Alaska's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Alaska

Description

This region comprises the American state of Alaska and the Aleutian Islands. Ninety-two Holocene volcanoes are located here, dominantly through the 2,500 km Aleutian Arc, which extends towards Kamchatka forming the northern section of the Ring of Fire. Further volcanoes are situated in the interior of Alaska, south on the border with Canada and to the most northerly of Alaska's volcanoes – Imuruk Lake on the Seward Peninsula. Volcanism in Alaska and the Aleutians is dominantly due to the subduction of the Pacific Plate beneath the North American Plate, however eleven volcanoes are due to intra-plate processes. Volcanoes of Alaska are dominantly andesitic in composition and most are stratovolcanoes.

During the Holocene 526 eruptions of VEI 0 – 6 are recorded in Alaska from 59 volcanoes. The remaining volcanoes are suspected of having eruptions of Holocene age. 44 of these volcanoes have records of 333 historical eruptions, of which 13 were large explosive eruptions of VEI 4 to 6. The

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VEI 6 1912 eruption of Katmai/Novarupta was the largest in the 20th Century anywhere in the world, producing voluminous air fall and ash flow. With a record of such explosive events, many have produced pyroclastic flows and lahars, yet due to the sparse population in Alaska only three eruptions have resulted in fatalities. Indeed, fewer than 20,000 people live within 30 km of volcanoes throughout the state.

The Alaska Volcano Observatory (AVO) list Akutan, Pavlof and Shishaldin as the most frequently active volcanoes historically, though emphasise that even today, there may not be a complete catalogue of activity as many of Alaska's volcanoes are remote and visual observations may be hampered by inclement weather. The historic records indicate about 2 eruptions per year here.

The AVO monitors volcanoes throughout Alaska and is a partnership of the U.S. Geological Survey, the Geophysical Institute of the University of Alaska Fairbanks and the Alaska Division of Geological and Geophysical Surveys. The AVO was set up in 1988 to monitor and study volcanism in Alaska. The AVO relies on federal, state and university resources.

The volcanoes in Alaska are potentially hazardous to aircraft, with more than 80,000 large aircraft per year over and possibly downwind of volcanoes here (Schaefer and Nye, 2008). A passenger aircraft with 231 people on board lost all power after encountering the ash cloud from Redoubt Volcano in 1989. Fortunately, the engines restarted after free-falling about 3,000 metres (Casadevall, 1994 in Schaefer and Nye, 2008). Schaefer and Nye (2008) describe eruptions here during 1989 to 1990 as the second-most costly eruptions in the history of the United States, having impacted on the aviation and oil industries. The AVO notifies the public and Volcanic Ash Advisory Centres (VAAC's) of Volcano Alert Levels (Normal, Advisory, Watch, and Warning), and separate Aviation Color Codes are issued – Green to Red. See Chapter 14.

The AVO conducts monitoring activities and scientific research, produces hazard assessments and is involved in hazard mitigation. Monitoring activities are widespread, with networks of seismometers and deformation instrumentation, in addition to satellite observations and deployment of other monitoring systems. About 30 volcanoes are monitored in Alaska and the Aleutians, including eighteen historically active volcanoes which have regular dedicated ground-based monitoring systems in place.

In the event of unrest or eruption, the AVO informs the public and emergency managers. The AVO communicates activity information to the Federal Aviation Administration, the National Weather Service, local military, civil authorities and the Alaska Department of Emergency Services and the Governor's Office of the State of Alaska. Information is released in line with the NVEWS method: VAN (Volcano Activity Notice) are important announcements of volcanic activity, change in activity, aviation colour code or alert levels; VONA (Volcano Observatory Notice for Aviation) focuses on ash cloud hazards; Daily Status Reports provide short statements on the activity of volcanoes at an elevated alert level; Weekly Summaries describe the week's activity and activity status of monitored volcanoes; and Information Statements provide further information on a variety of background topics.

See also:

Shaefer, J. and Nye, C. (2008) Monitoring the Active Volcanoes of Alaska, Alaska GeoSurvey News, Vol. II., No. 1. www.avo.alaska.edu/pdfs/cit4443.pdf

Alaska Volcano Observatory website: www.avo.alaska.edu/volcanoes/about.php

Volcano facts

Number of Holocene volcanoes	92
Number of Pleistocene volcanoes with M≥4 eruptions	7
Number of volcanoes generating pyroclastic flows	40
Number of volcanoes generating lahars	41
Number of volcanoes generating lava flows	90
Number of eruptions with fatalities	3
Number of fatalities attributed to eruptions	4
Tectonic setting	81 subduction zone, 11 intra-plate
Largest recorded Pleistocene eruption	The Old Crow Tephra eruption of Emmons Lake in Alaska is the largest Quaternary eruption recorded at M7.5. This eruption occurred at 96 ka.
Largest recorded Holocene eruption	Nine VEI 6 eruptions are recorded during the Holocene, with the most recent at Novarupta in 1912 AD.
Number of Holocene eruptions	526 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	44
Number of historical eruptions	333

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Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Andesitic (2), Rhyolitic (1)
67	Large cone(s)	Andesitic (43), Basaltic (13), Dacitic (3), Rhyolitic (2), Unknown (6)
3	Lava dome(s)	Andesitic (1), Dacitic (1), Unknown (1)
9	Shield(s)	Andesitic (3), Basaltic (6)
9	Small cone(s)	Andesitic (2), Basaltic (7)
1	Submarine	Andesitic (1)

Table 11.1 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	30

Table 11.2 Average recurrence interval (years between eruptions) for small and large eruptions in Alaska.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded throughout Alaska and the Aleutian Islands of VEI 0 to 6, representing a range of eruption styles from mild events to large explosive eruptions. VEI 2 events dominate the record, with about 45% of all Holocene eruptions of a known size classed as such, and nearly 90% are small to moderate at VEI 0 to 3. Over 11% of eruptions are large explosive events at VEI ≥4.

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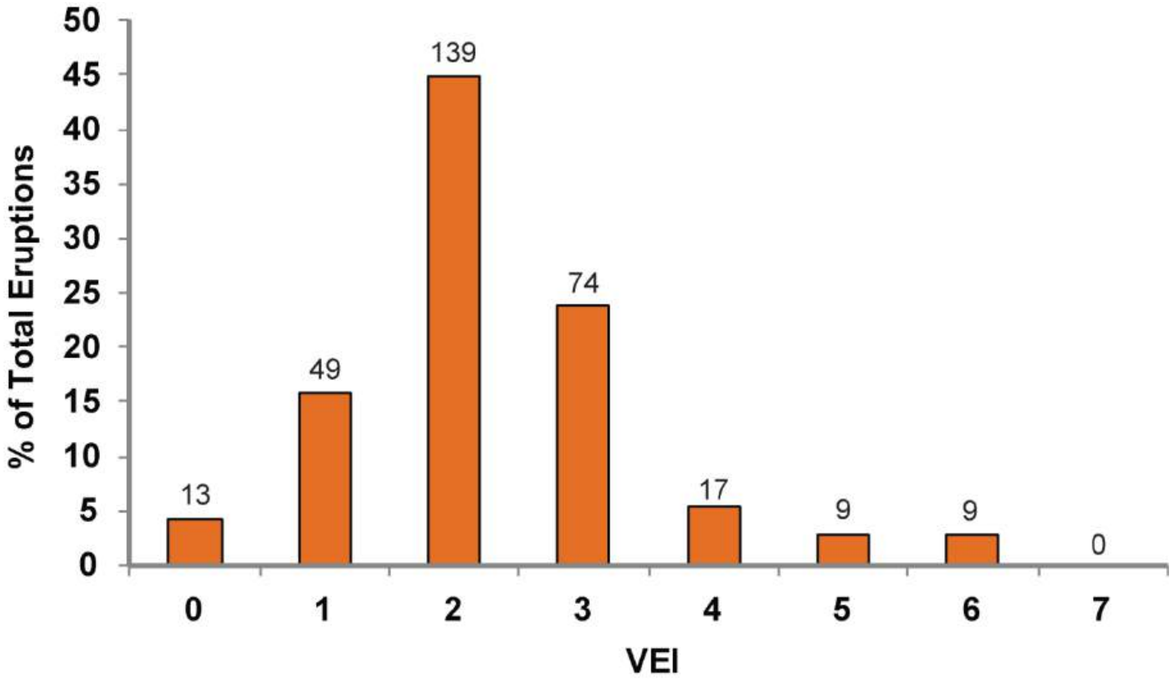

Figure 11.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI (310 events). A further 216 eruptions were recorded with unknown VEI.

Population Exposure

Capital city (of the State)	Juneau
Distance from capital city to nearest Holocene volcano	161 km
Total Population (2013)	735,132 (US Census Bureau)
Number (percentage) of people living within 10 km of a Holocene volcano	<2,000
Number (percentage of people living within 30 km of a Holocene volcano	<20,000
Number (percentage of people living within 100 km of a Holocene volcano	<230,000

Largest cities as measured by population and their population size (from 2010 United States Census):

Anchorage	291,826
Fairbanks	31,535
Juneau	30,711

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Infrastructure exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	80
Total length of roads within 100 km of a volcano (km)	6,431
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Alaska and the Aleutian Islands are concentrated in the south and west of Alaska. Of the largest cities, only Fairbanks lies within 100 km of a volcano (Buzzard Creek), while the capital, Juneau, lies over 160 km away from a Holocene volcano. With the volcanoes primarily located on islands and along the coastline of southern Alaska, 80 ports are situated within 100 km of these. Six airports and an extensive road network also lie within 100 km of Alaskan volcanoes, and numerous small settlements, with no towns besides the three largest described here having a population higher than 10,000.

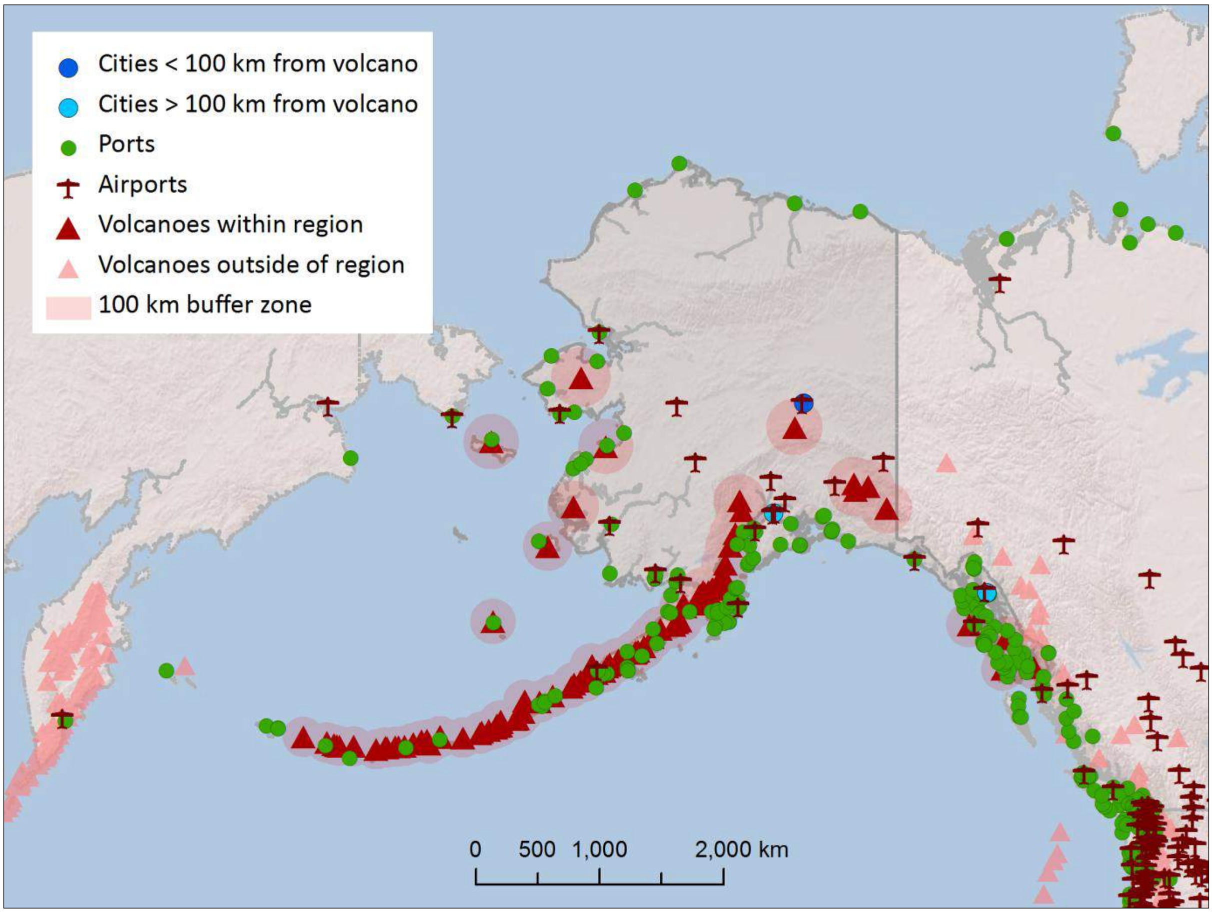

Figure 11.3 The location of Alaska's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

Of the 92 volcanoes in Alaska, just 22 have an assigned hazard level based on their eruptive history. These volcanoes classify across all three hazard levels, with most at Hazard Level II. Just four volcanoes are classed at Hazard Level III – Fisher, Augustine, Iliamna and Redoubt. These four volcanoes all have records of explosive, pyroclastic flow producing eruptions.

Of the unclassified volcanoes, 33 have no confirmed eruptions during the Holocene, though Kukak, Douglas, Dutton and Emmons Lake all have periods of unrest above background levels since 1900. 22 unclassified volcanoes have confirmed historical (post-1500 AD) eruptions, and of these 15 have erupted since 1900 AD. Eleven unclassified volcanoes have Holocene records of large explosive (VEI ≥4) eruptions.

The small population in Alaska, particularly in proximity to the volcanoes, is evidenced by the classification of all volcanoes here at PEI 1 and 2. Of the classified volcanoes, all but the three Hazard Level III volcanoes are classed at Risk Level I.

CLASSIFIED	**Hazard III**	Fisher	Augustine; Iliamna; Redoubt					
	Hazard II	Seguam; Cleveland; Okmok; Trident	Bogoslof; Akutan; Westdahl; Shishaldin; Pavlof; Veniaminof					
	Hazard I	Kiska; Gareloi; Kanaga; Great Sitkin; Amukta	Korovin; Makushin; Wrangell					
UNCLASSIFIED	**U – HHR**	**Little Sitkin**; **Semisopochnoi**; **Tanaga**; Takawangha; **Yunaska**; Carlisle; **Kagamil**; Vsevidof; **Chiginagak**; Ugashik-Peulik; **Katmai**; **Fourpeaked**	**Kasatochi**; **Atka**; Amak; **Kupreanof**; **Aniakchak**; **Ukinrek Maars**; **Martin**; **Novarupta**; Snowy Mountain; **Spurr**					
	U- HR	Moffett; Koniuji; Yantarni; Kaguyak; Hayes; Imuruk Lake; Churchill	Roundtop; Dana; Black Peak; Mageik; Griggs; St. Paul Island; Buzzard Creek; Edgecumbe					
	U- NHHR	Buldir; Segula; Davidof; Bobrof; Chagulak; Herbert; Tana; Uliaga; Recheschnoi; Kialagvik; Unnamed; Denison; Steller; **Kukak**; **Douglas**	Sergief; Isanotski; Frosty; **Dutton**; **Emmons Lake**; Pavlof Sister; Stepovak Bay 2; Stepovak Bay 3; Stepovak Bay 4; Nunivak Island; Ingakslugwat Hills; St. Michael; Kookooligit Mountains; Sanford; Gordon; Duncan Canal; Tlevak Strait-Suemez Is.; Behm Canal-Rudyerd Bay					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 11.3 Identity of Alaska's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
48	2
44	1

Table 11.4 The number of volcanoes in Alaska classed in each PEI category.

Risk Levels

Volcano	Population Exposure Index	Risk Level
Augustine	2	II
Fisher	1	I
Iliamna	2	II
Redoubt	2	II
Akutan	2	I
Bogoslof	2	I
Cleveland	1	I
Korovin	2	I
Makushin	2	I
Okmok	1	I
Pavlof	2	I
Shishaldin	2	I
Trident	1	I
Veniaminof	2	I
Westdahl	2	I
Wrangell	2	I
Amukta	1	I
Gareloi	1	I
Great Sitkin	1	I
Kanaga	1	I
Kiska	1	I
Seguam	1	I

Table 11.5 Classified volcanoes of Alaska ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given.

Number of Volcanoes	Risk Level
0	III
3	II
19	I
70	Unclassified

Table 11.6 The number of volcanoes in the Alaska region classified at each Risk Level.

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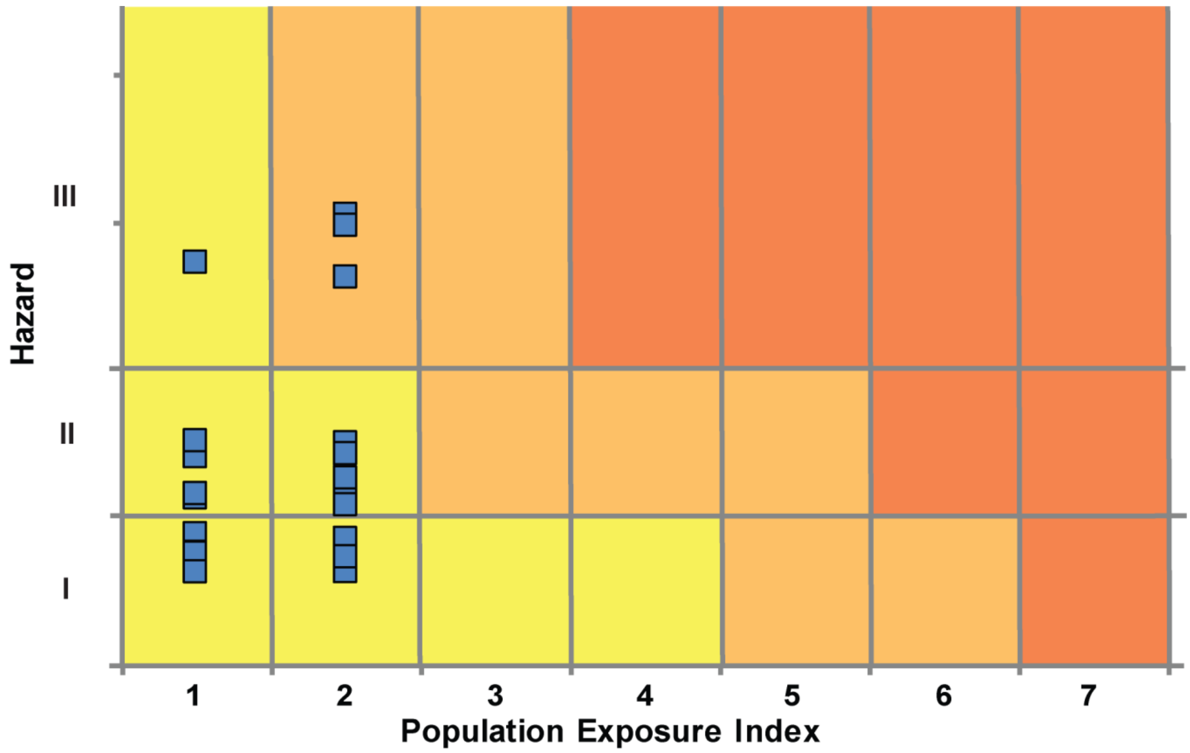

Figure 11.4 Distribution of the classified volcanoes of Alaska across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Forty-four volcanoes in Alaska have records of historical activity in VOTW4.22. These volcanoes are mainly Unclassified and Risk Level I, with just three at Risk Level II – Augustine, Ilimna and Redoubt. The AVO classes at least another six volcanoes as having historical activity. The AVO provides a list of volcanoes which have dedicated seismic monitoring. Twenty-one historically active volcanoes in Alaska do not have dedicated seismic monitoring, however, five of these have 3 or more seismometers located within 20 km according to the AVO map of monitoring stations. Eighteen volcanoes (10 Risk Level I, 3 Risk Level II, 5 unclassified) are monitored by the AVO with dedicated seismic networks and some with additional deformation networks.

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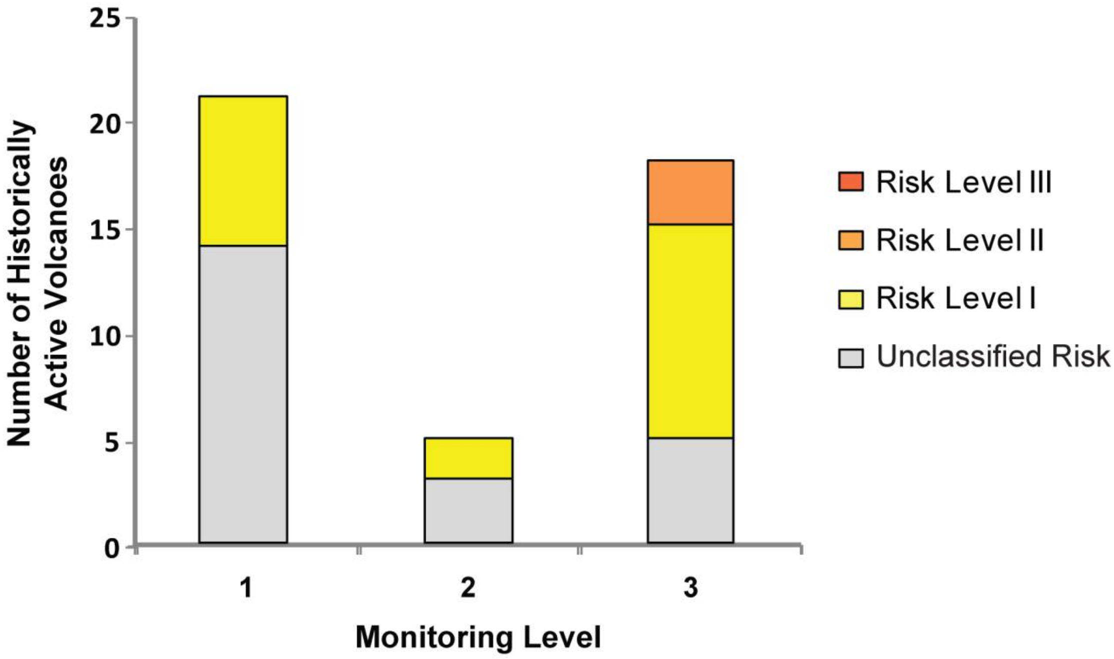

Figure 11.5 The monitoring and risk levels of the historically active volcanoes in Alaska. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 12: Canada and Western USA

Description

Region 12: Canada and Western USA comprises volcanoes throughout Canada and the contiguous states of the USA.

Country	Number of volcanoes
Canada	22
USA	48

Table 12.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

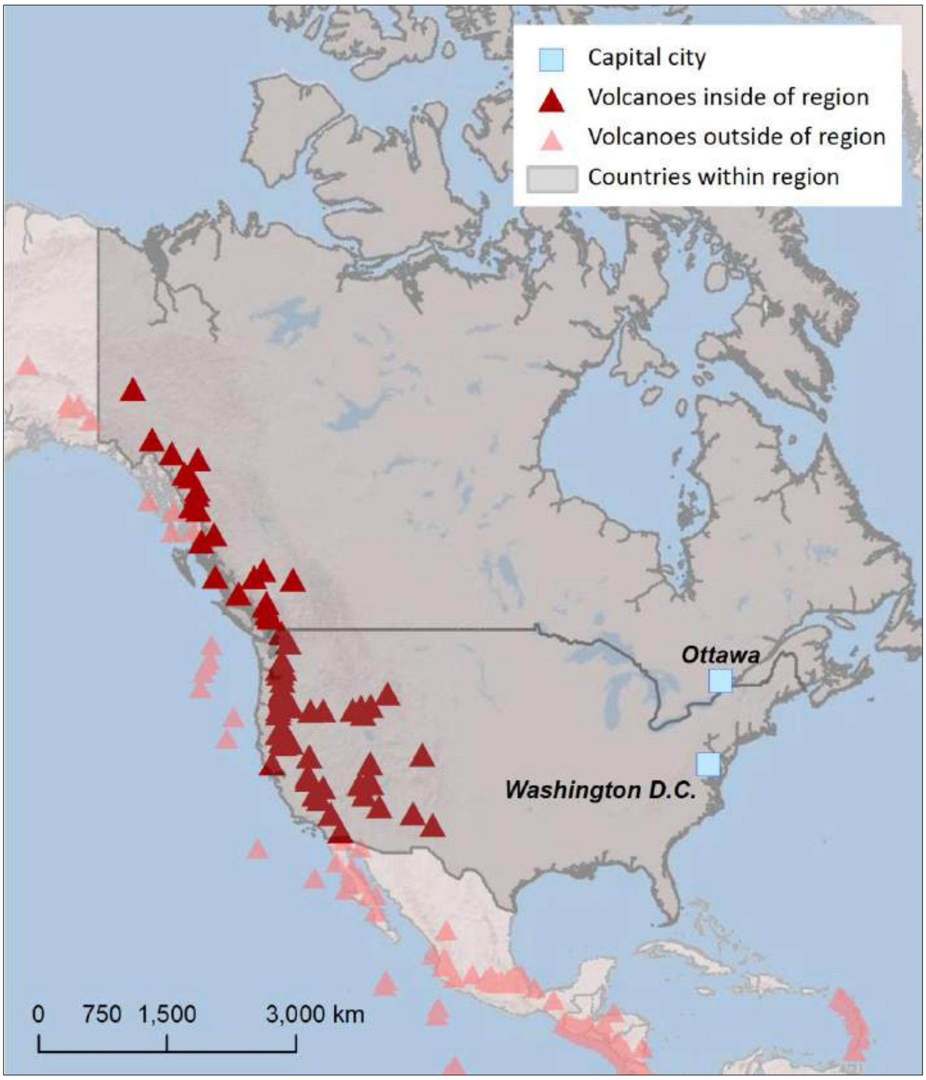

Figure 12.1 The distribution of Holocene volcanoes through the Canada and Western USA region. The capital cities of the constituent countries are shown.

Seventy Holocene volcanoes are located in Canada and the Western USA. Most of these volcanoes are in Washington, Oregon and California in the USA. Volcanism here is largely related to the

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subduction of the Juan de Fuca Plate beneath the North American Plate. Further north a range of tectonic environments give rise to volcanism, including subduction, rifting and intra-plate processes. Much of the volcanism of the western interior is due to extensional tectonics.

Volcanoes in this region adopt a variety of forms, with volcanic fields and cinder cones being most common (41 such volcanoes). Large cones are also common, with 16 stratovolcanoes and complex volcanoes, primarily found in the USA. Shields, lava domes, calderas and subglacial volcanoes are also located here. The rock type through this region is dominantly basaltic and andesitic, though a range of compositions is present, including silicic rhyolites, chiefly restricted to the western interior of the USA.

Along with volcano morphology and composition, a range of activity styles and eruption magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 7. About 66% of eruptions here have been small, at VEI 0 to 2, however 23 eruptions (about 18%) have been large explosive VEI ≥4 events. All but one of these VEI ≥4 eruptions are recorded from volcanoes in the USA. The largest Holocene eruption recorded in this region was the VEI 7 eruption of Crater Lake in about 5677 BC, which produced ash fall into Canada and pyroclastic flows that travelled 40 km.

Eleven volcanoes have historical records of 40 eruptions, about 70% of which were recorded through direct observations. The record of over 200 eruptions before 1500 AD indicates a reasonable geological record, reflecting geological studies here. 23% of historical eruptions have records of producing pyroclastic flows, one of the highest proportions in any region. Similarly, about 30% resulted in lahars. Lava flows are also recorded in 23% of eruptions, though many regions have a greater proportion.

8% of historical eruptions resulted in loss of life. Most volcanoes here have low proximal populations, and as such are considered relatively low risk. However, the hazard is unclassified at about 85% of volcanoes.

In the USA the U.S. Geological Survey runs a series of Volcano Observatories monitoring the activity here, undertaking scientific research and providing advice and alerts. In Canada, Natural Resources Canada is responsible for the volcanic hazard, however no volcanoes here have dedicated monitoring systems, though plans and resources are available if unrest occurs.

Volcano Facts

Number of Holocene volcanoes	70
Number of Pleistocene volcanoes with M≥4 eruptions	14
Number of volcanoes generating pyroclastic flows	14 (65 eruptions)
Number of volcanoes generating lahars	12 (59 eruptions)
Number of volcanoes generating lava flows	45 (117 eruptions)
Number of eruptions with fatalities	4

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Number of fatalities attributed to eruptions	84
Largest recorded Pleistocene eruption	The largest Quaternary eruption recorded was the M8.4 Lava Creek Tephra eruption at Yellowstone at 639 ka.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in LaMEVE in this region is the O (Caldera) formation at Crater Lake, at M6.8 in 7627 BP.
Number of Holocene eruptions	245 confirmed Holocene eruptions
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	11
Number of historical eruptions	40

Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Andesitic (1), Dacitic (1), Rhyolitic (1)
15	Large cone(s)	Andesitic (10), Dacitic (4), Trachytic / Andesitic (1)
5	Lava dome(s)	Rhyolitic (4), Trachytic / Andesitic (1)
10	Shield(s)	Andesitic (2), Basaltic (6), Rhyolitic (1), Trachytic / Andesitic (1)
36	Small cone(s)	Andesitic (3), Basaltic (31), Dacitic (2)
1	Subglacial	Phonolitic (1)

Table 12.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	10
Large (> VEI 3)	170

Table 12.3 Average recurrence interval (years between eruptions) for small and large eruptions in Canada and Western USA.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 years, whilst the ARI for large eruptions is longer, at about 170 years.

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Eruption Size

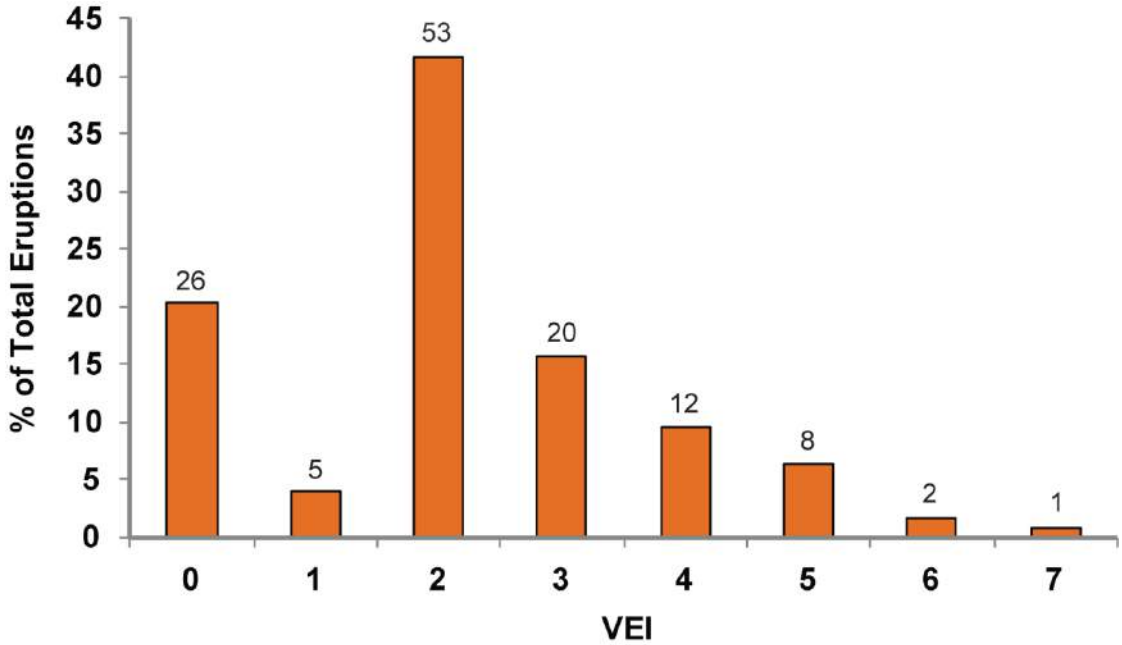

Figure 12.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 118 eruptions were recorded with unknown VEI.

Eruptions are recorded through the Canada and Western USA region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 45% of all Holocene eruptions classed as such. Over 18% of eruptions here are explosive at VEI ≥4.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	35,716 – 42,486
	(Mean 39,101)
Gross National Income (GNI) per capita (2005 PPP $)	35,369 – 43,480
	(Mean 39,425)
Human Development Index (HDI) (2012)	0.911 – 0.937 (Very High)

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Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	24,610 (0.01 %)
Number (percentage) of people living within 30 km of a Holocene volcano	375,305 (0.11 %)
Number (percentage) of people living within 100 km of a Holocene volcano	4,187,725 (1.22 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	102
Number of ports within 100 km of a volcano	49
Total length of roads within 100 km of a volcano (km)	29,259
Total length of railroads within 100 km of a volcano (km)	8,443

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CLASSIFIED	Hazard III		Shasta	Rainier; St. Helens				
	Hazard II			Baker				
	Hazard I		Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon					
UNCLASSIFIED	U – HHR		**Lassen Volcanic Center;** Mono Lake Volcanic Field; Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater	Glacier Peak; **Hood**				
	U- HR		Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field; Edziza; Hoodoo Mountain; Nazko; Meager	West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero; Garibaldi	San Francisco Volcanic Field			
	U- NHHR	**Cayley Volcanic Field**	Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field;** Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones	Lavic Lake	Soda Lakes; Garibaldi Lake	Clear Lake		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 12.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
1	5
3	4
14	3
51	2
1	1

Table 12.5 The number of volcanoes in Canada and Western USA classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
6	I
60	Unclassified

Table 12.6 The number of volcanoes in the Canada and Western USA region classified at each Risk Level.

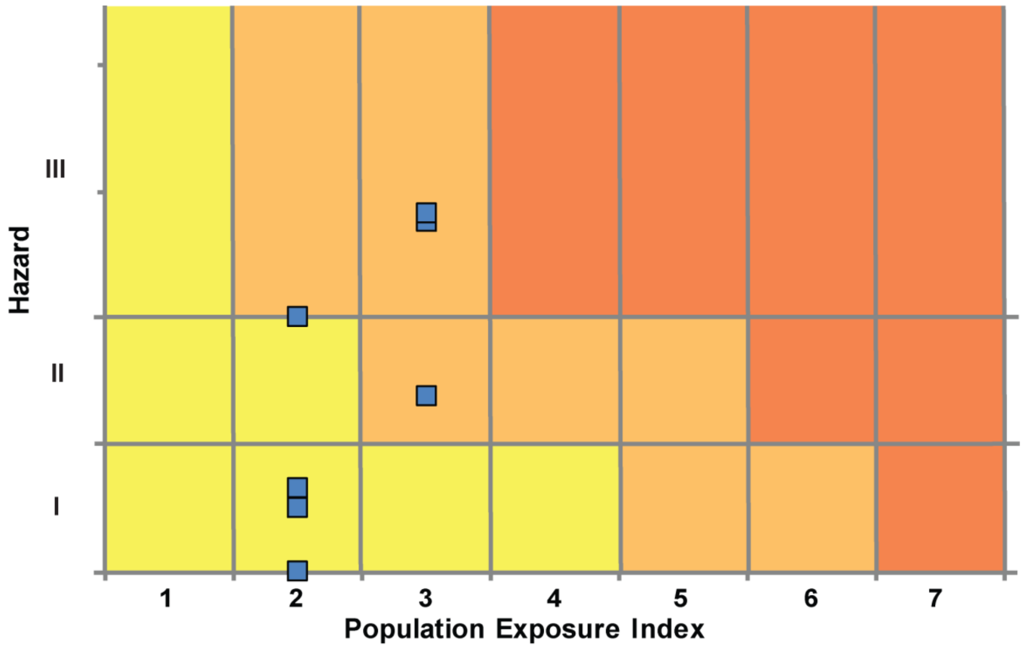

Figure 12.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional monitoring capacity

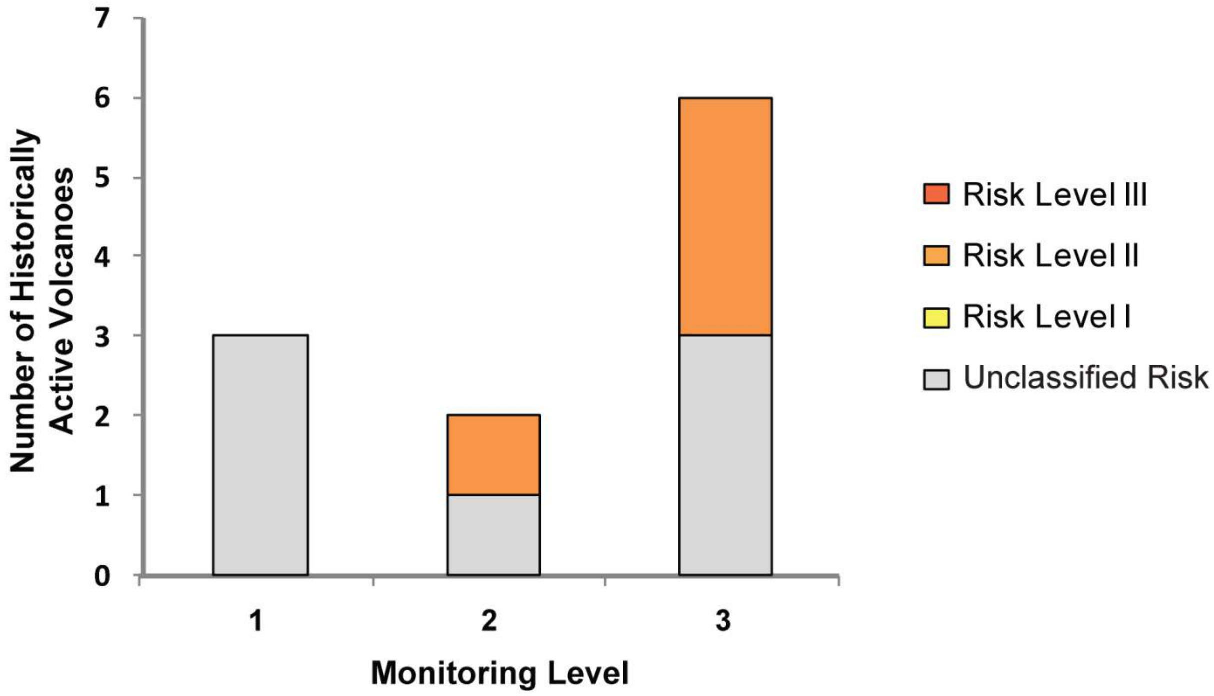

Figure 12.4 The monitoring and risk levels of the historically active volcanoes in Canada and the Western USA. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Canada

Description

Twenty-two volcanoes of Holocene age are listed by the GVP in western Canada, all in British Columbia and the Yukon Territory, from the border with Washington State (USA) in the south to Alaska (USA) in the north. Many of these volcanoes are volcanic fields comprising dozens of vents over thousands of square kilometres. Volcanism in Canada arises through compressional, subduction zone processes between the North American Plate and the Juan de Fuca Plate, and crustal extension within the North American Plate; intra-plate hotspot volcanism may also play a role. The range of origins for volcanism here results in a correspondingly large range of volcano morphologies and magma compositions. Although a number of stratovolcanoes are located in Canada, volcanic fields comprising many small discrete centres are the most common form of volcanism in Canada.

During the Holocene nineteen eruptions are recorded from eight volcanoes in VOTW4.22, however if eruptions from individual vents are considered then this number is far greater. It is highly probable that many more Canadian volcanoes have had Holocene activity, but this has not been confirmed quantitatively. Recorded activity ranges from VEI 0 to 5, indicating a range from small effusive activity to large explosive activity, however the size of most eruptions is unknown.

The largest Holocene eruption of VEI 5 occurred at the stratovolcano Mount Meager in 410 BC. This large explosive eruption generated pyroclastic flows, lahars, and lava domes, and the formation and failure of a dam made of welded pyroclastic material, with an accompanying flood. Ash was distributed across British Columbia and neighbouring Alberta. Hot springs are active at Mount Meager, indicative of an ongoing heat source. A debris avalanche, not of volcanic origin, occurred at this volcano in 2010, with debris extending to nearly 13 km, damming rivers and leading to the evacuation of 1500 residents, resulting in about costs of about \$10m CAD (Guthrie et al., 2011).

Historical activity has occurred at only one volcano, Tseax Cone, and is recorded in the oral histories of the Nisga'a people. The ~ AD 1700 eruption of Tseax River cone produced lavas which inundated a village. Evacuations, property damage, and fatalities occurred. Several other eruptions have occurred in the last few centuries and are documented geologically but not historically, probably due to the isolation of the volcanoes.

Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure, concentrated in the south of Canada, towards the border with the United States. Much of the Greater Vancouver Regional District lies within 100 km of Mount Baker (Washington State, USA) and the southernmost Canadian volcano, Garibaldi, however most volcanoes in Canada have a very low proximal population within 30 km. No detailed risk assessments have been undertaken for any Canadian volcanoes by the Geological Survey of Canada. All Canadian volcanoes have considerable uncertainty associated with the assessment of hazard, and research is needed to better understand the eruptive history.

Natural Resources Canada (NRCan) is the agency responsible for the provision of technical and scientific information regarding volcanic unrest, hazard and eruptions affecting Canada. The Geological Survey of Canada (GSC) is part of NRCan, and is funded by the federal government. There

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is currently no dedicated ground-based monitoring at any of the Canadian volcanoes, however a national seismic network is in place, monitored by NRCan. A seismologist is always on-call, and would be alerted to earthquakes of M≥3 detected through the continuous and automatic monitoring network. Small earthquakes and swarms near volcanoes might not be noticed by the seismologist on-call until the visual inspection of all data the next working day. Should seismic unrest be detected via this network, NRCan would respond by augmenting monitoring, as the resources are available to respond to developing situtations.

The most recent eruption in Canada took place around 1800 at the Lava Fork volcano in the Iskut-Unuk River cones. As such, no current employees at NRCan have experience in responding to an eruption. However, in 2007 an earthquake swarm occurred in the Nazko region, near Nazko cone. NRCan responded with additional monitoring and provided advice regarding the probable activity styles were an eruption to occur, and a preliminary volcanic hazard map was produced from existing data. Many of the personnel involved in the response to this swarm are still at NRCan.

NRCan has set protocols and plans in place to respond to increasing unrest and eruptions. The Interagency Volcanic Event Notification Plan (IVENP) would be activated at the onset of an eruption in Canada. IVENP is a short-term communications plan that outlines the rapid notification procedures among the key Canadian agencies that would be involved in the response to a volcanic eruption within or near Canada; it is a communications plan, not a response plan. IVENP's primary objective is to ensure that volcanic ash information for Canada is rapidly and appropriately communicated to aviation agencies. Natural Resources Canada's Standard Operating Procedure: Volcanic Situations details the NRCan protocols for volcanic unrest and eruptions. During volcanic unrest or eruption, Natural Resources Canada would communicate with numerous agencies involved in public safety and scientific research. This would include (but would not be limited to) the agencies involved in Canada's Interagency Volcanic Event Notification Plan (IVENP): Environment Canada (which includes the Volcanic Ash Advisory Centre in Montréal), Public Safety Canada, Emergency Management British Columbia, the Airline Pilots Association, Nav Canada, the Royal Canadian Mounted Police (RCMP), Transport Canada, and the Yukon Emergency Measures Organization. There would also likely be extensive communications with specific organizations or stakeholders in the region of unrest.

No specific Alert Level system has been developed for use in Canada due to the absence of recent activity. NRCan plans to use the U.S. Geological Survey's Volcano Alert Levels and Aviation Colour Codes in the event of unrest.

The public is exposed to hazard education in volcanic regions provided by Public Safety Canada, Emergency Preparedness British Columbia, and the Yukon Emergency Measures Organization, who work closely with NRCan in dealing with potential volcanic hazards. NRCan provides hazard information to the public through research publications, fact sheets, books, maps, brochures, etc. In addition, NRCan engages with the public through school visits, meetings, and conferences, and the Geological Survey of Canada includes publicly-accessible libraries and bookstores.

See also:

Guthrie, R.H., Friele, P., Allstadt, K., Roberts, N., Evans, S.G., Delaney, K.B., Roche, D., Clague, J.J., and Jakob, M. (2011). The 6 August 2010 Mount Meager rock slide-debris flow, Coast Mountains, British

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Columbia: characteristics, dynamics, and implications for hazard and risk assessment. *Natural Hazards and Earth System Sciences*, 12, 1277-1294.

Natural Resources Canada website: www.nrcan.gc.ca/home

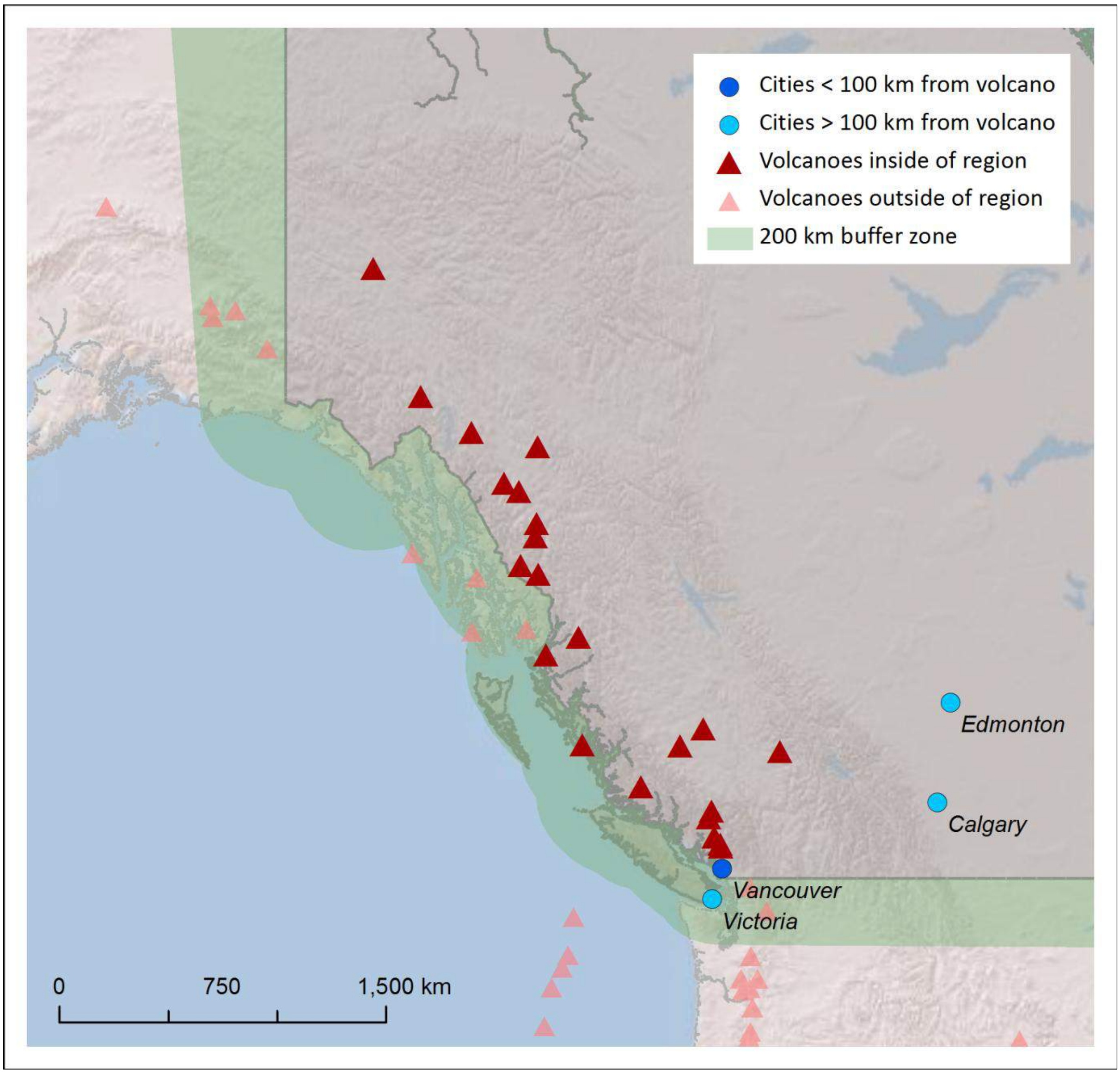

Figure 12.5Location of Canada's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Canada.

Volcano Facts

Number of Holocene volcanoes	22
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	8, with many monogenetic vents

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Number of fatalities caused by volcanic eruptions	Oral histories suggest ~2000 people, however the precise number is unknown.
Tectonic setting	16 intra-plate, 6 Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M5.0 Bridge River Tephra/Pebble Creek Formation of Mount Meager in 2360 BP.
Number of Holocene eruptions	19 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 – 5 and unknown
Number of historically active volcanoes	3
Number of historical eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)
4	Large cone(s)	Andesitic (1), Dacitic (2), Trachytic / Andesitic (1)
3	Shield(s)	Basaltic (1), Rhyolitic (1), Trachytic / Andesitic (1)
13	Small cone(s)	Andesitic (1), Basaltic (12)
1	Subglacial	Phonolitic (1)

Table 12.7 The number of volcanoes in Canada, their volcano type classification and dominant rock type according to VOTW4.0.

Silverthrone is the only caldera listed in Canada, however the age of the most recent activity at this volcano is uncertain as although the textures and degree of dissection suggests the lavas here are less than 10,000 years old this has not been confirmed with radiometric dating.

Hoodoo Mountain is classed in VOTW4.0 as a subglacial volcano. This is a complex, long-lived centre with both subaerial and subglacial deposits, and volcano-ice interaction has played a large role in its history. Many more volcanic centres in Canada have evidence for subglacial or ice-contact eruptions. Three monogenetic basaltic centres of Edziza are subglacial, and numerous further vents of Edziza could be classed as small cones, however Edziza itself is classed as a stratovolcano.

The age of the shield volcano Level Mountain is uncertain.

Socio-Economic Facts

Total population (2012)	34,828,000

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Gross Domestic Product (GDP) per capita (2005 PPP $)	35,716
Gross National Income (GNI) per capita (2005 PPP $)	35,369
Human Development Index (HDI) (2012)	0.911 (Very High)

Population Exposure

Capital city	Ottawa
Distance from capital city to nearest Holocene volcano	3299.6 km
Total population (2011)	34,030,589
Number (percentage) of people living within 10 km of a Holocene volcano	14 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,703 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	>2 million (<10%)

Ten largest cities, as measured by population and their population size:

Toronto	4,612,191
Montreal	3,268,513
Vancouver	1,837,969
Calgary	1,019,942
Ottawa	812,129
Edmonton	712,391
Winnipeg	632,063
Quebec	528,595
Victoria	289,625
Saskatoon	198,958

Infrastructure Exposure

Number of airports within 100 km of a volcano	7
Number of ports within 100 km of a volcano	21
Total length of roads within 100 km of a volcano (km)	8,634
Total length of railroads within 100 km of a volcano (km)	1,127

The volcanoes in Canada are located in the west through the provinces of British Colombia and the Yukon. Many of these volcanoes are located near the coast, and as such 21 ports are situated within

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100 km. Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure concentrated in the south of Canada, towards the border with the United States. The southernmost volcano in Canada, Garibaldi, lies just within 100 km of the USA, meaning the 100 km radius for this volcano extends into the US. And indeed, Mt Baker in the USA lies within 100 km of Canada, placing much of the Greater Vancouver Regional District within the 100 km radius of this Holocene volcano. Seven airports lie within 100 km of a volcano in Canada, as does an extensive road and rail network.

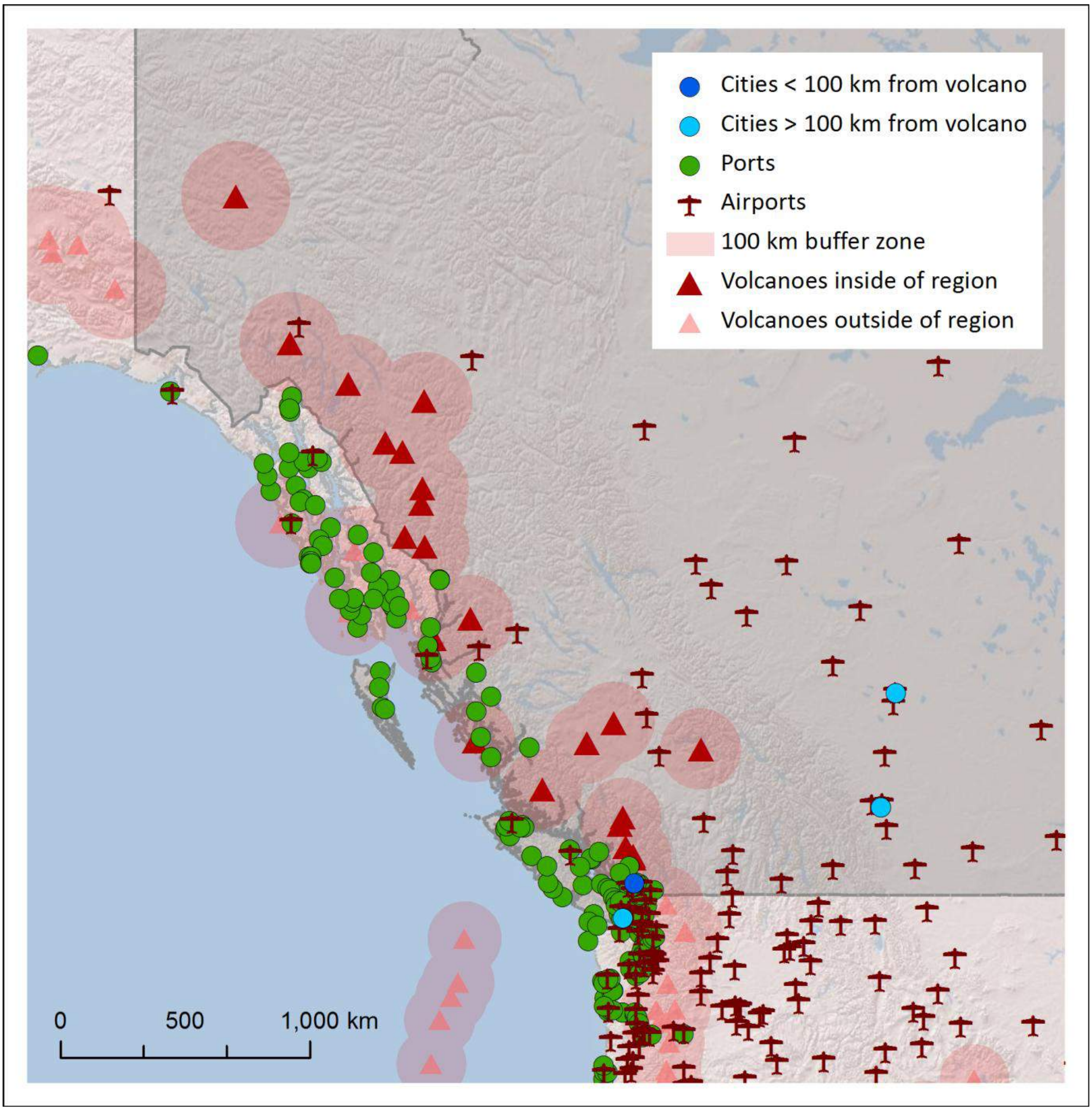

Figure 12.6 The location of Canada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in Canada are not sufficiently extensive or detailed for determination of the hazard through the calculation of the VHI without large associated uncertainties. All volcanoes here are therefore unclassified. Nineteen Holocene eruptions are confirmed from eight volcanoes or volcanic fields, with the remaining volcanoes having no confirmed Holocene eruptions. The most recent eruption was the 1800 AD eruption of Iskut-Unuk River Cones. Small earthquakes have been recorded in the vicinity of a number of Canada's volcanoes, however these have not been confirmed as volcanogenic.

Most Canadian volcanoes have very small proximal populations within 30 km, increasing substantially at 100 km radius, categorising these with low to moderate PEI of 2 – 4.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater					
	U- HR		Edziza; Hoodoo Mountain; Nazko; Meager	Garibaldi				
	U- NHHR		Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones;	Cayley Volcanic Field	Garibaldi Lake			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 12.8 Identity of Canada's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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National Capacity for Coping with Volcanic Risk

The volcanoes of Canada do not currently have dedicated ground-based monitoring systems in place. Only three Canadian volcanoes have been active since AD 1500, and these are unclassified for risk with a low PEI. Natural Resources Canada monitors a regional network of seismometers, which may provide indication of unrest at these volcanoes.

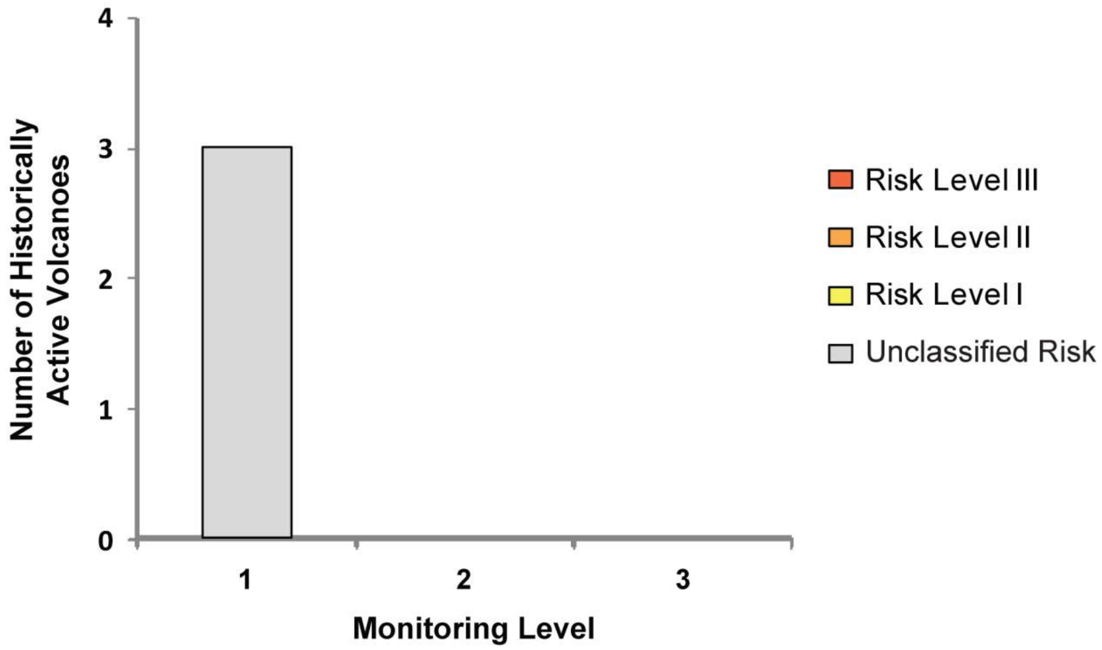

Figure 12.7 The monitoring and risk levels of the historically active (with eruptions since 1500 AD) volcanoes in Canada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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U.S.A. (contiguous states)

See Region 4 for American Samoa, Region 8 for the Marianas, Region 11 for Alaska, Region 13 for Hawaii.

Description

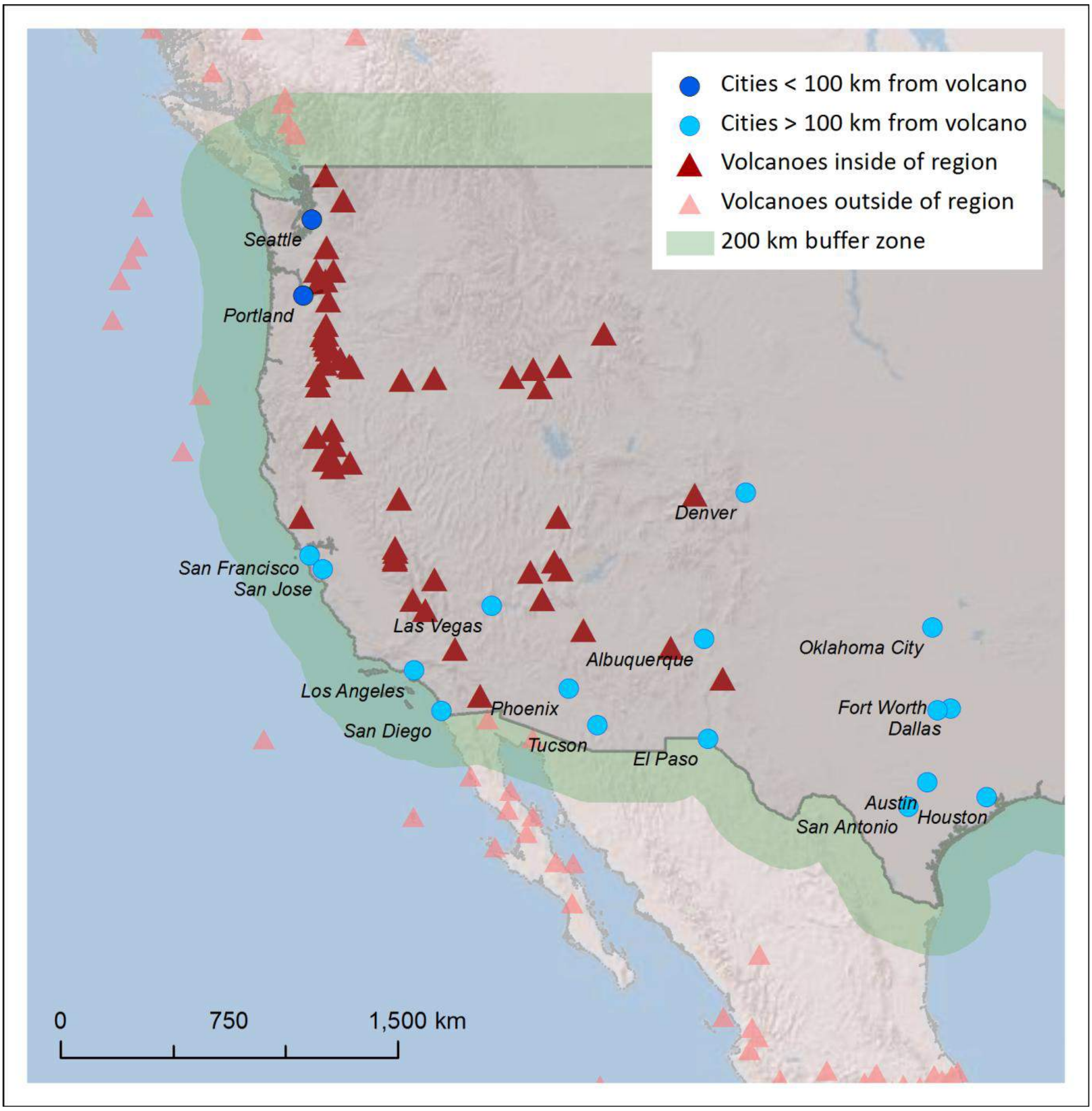

Figure 12.8 Location of the volcanoes in the contiguous United States, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect these states.

Forty-eight Holocene volcanoes are located in the contiguous 48 States of the U.S.A. (referred to from here as the U.S., excluding Alaska, Hawaii, Samoa and Marianas). Volcanism here is largely due to the subduction of the Pacific and Juan de Fuca Plates beneath the North American Plate and

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extensional tectonics inland. This has given rise to the formation of dominantly andesitic volcanic centres dominated by volcanic fields, cinder cones and stratovolcanoes.

The U.S. has an extensive Pleistocene record of large explosive eruptions, with 14 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M8.4 eruption of Yellowstone about 639,000 years ago, which ejected the 1000 cubic kilometre Lava Creek Tuff and formed the 45 x 85 km caldera.

Forty-two volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. 226 Holocene eruptions are recorded here, from VEI 0 to 7. This size range demonstrates the range in activity in the U.S., from small events to very large explosive eruptions. About 10% of eruptions here are recorded at VEI ≥4. Pyroclastic flows are recorded in about 28% of Holocene eruptions. The largest Holocene eruption was that of Mt. Mazama, about 7700 years ago, at the present day site of Crater Lake in Oregon. This VEI 7 eruption is one of the World's largest known Holocene eruptions, producing pyroclastic flows that extended to about 40 km, extensive ash fall into Canada and the 8 - 10 km caldera. Most commonly small eruptions of VEI 0 - 2 are recorded.

Of the Holocene record, about 16% of the eruptions have been recorded since 1500 AD, with 36 historic eruptions of VEI 1 to 5 from 8 volcanoes. Just 2 eruptions of VEI ≥4 (VEI 5) are recorded in 1800 and 1980 at Mt. St. Helens. The latter eruption produced a debris avalanche, lahars, pyroclastic flows and resulted in evacuations and loss of life.

In total, throughout the United States, less than 2% of the population live within 100 km of one or more Holocene volcano. The size of the local population varies at each volcano, however over 60% are classed here with a low PEI on the basis of a small local population.

The U.S. Geological Survey (USGS) Volcano Hazards Program (VHP) runs monitoring and research institutions with five volcano observatories, three of which are active in the contiguous U.S. The California Volcano Observatory (CalVO) monitors volcanoes in California and Nevada. The volcanoes of Washington, Oregon and Idaho are monitored by the Cascades Volcano Observatory (CVO). The Yellowstone Volcano Observatory (YVO) monitors the Yellowstone volcano.

Dedicated ground-based monitoring is operated at many volcanoes in the U.S. The USGS VHP and the Consortium of U.S. Volcano Observatories (CUSVO) have developed the National Volcano Early Warning System (NVEWS). This is designed to ensure that all volcanoes of the U.S.A. are monitored at appropriate levels based on their relative threat. This relative threat is determined using hazard and exposure indicators. Scores are assigned for these factors (including, but not limited to: volcano type, maximum eruption size, recurrence rates, occurrence of various hazardous phenomena, population size and infrastructure location). The hazard and exposure scores are multiplied to give an overall threat score. These scores are divided into five categories: Very High, High, Moderate, Low and Very Low.

Those volcanoes currently classed by the USGS with a High to Very High Threat potential are:

CalVO	Clear Lake
	Lassen Volcanic Center
	Long Valley Caldera

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	Medicine Lake
	Mono-Inyo Chain
	Shasta
	Salton Buttes
CVO	Crater Lake
	Glacier Peak
	Mount Adams
	Mount Baker
	Mount Hood
	Mount Rainier
	Mount St. Helens
	Newberry
	Three Sisters
YVO	Yellowstone

Many volcanoes, particularly those that have not had historical activity, are insufficiently monitored for detection of early volcanic unrest. NVEWS would ensure that the most hazardous volcanoes are properly monitored to allow forecasts of activity to be made and risk reduced.

See also:

Ewert, J.W., Guffanti, M., and Murray, T.L. (2005) An assessment of volcanic threat and monitoring capabilities in the United States: framework for a National Volcano Early Warning System. USGS Open-File Report, 2005-1164. pubs.usgs.gov/of/2005/1164/

Ewert, J.W. (2007) System for ranking relative threats of U.S. volcanoes, Natural Hazards Review, v8, no.4, p 112-124; dx.doi.org/10.1061/(ASCE)1527-6988(2007)8:4(112)

Guffanti, M., Diefenbach, A.K., Ewert, J.W., Ramsey, D.W., Cervelli, P.F., Schiling, S.P. (2009) Volcano-monitoring instrumentation in the United States, 2008, USGS Open-File Report 2009-1165. pubs.usgs.gov/of/2009/1165/

NVEWS: National Volcano Early Warning System: volcanoes.usgs.gov/publications/2009/nvews.php

USGS Volcanic Hazards Program: volcanoes.usgs.gov/index.php

Volcano Facts

Number of Holocene volcanoes	48
Number of Pleistocene volcanoes with M≥4 eruptions	14
Number of volcanoes generating pyroclastic flows	13
Number of volcanoes generating lahars	11
Number of volcanoes generating lava flows	37
Number of fatalities caused by volcanic eruptions	?79

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Tectonic setting	27 Subduction zone, 28 Rift zone
Largest recorded Pleistocene eruption	The Yellowstone eruptions of the Lava Creek Tuff 639,000 years ago and the Huckleberry Ridge Tuff about 2,133,000 years ago were both over magnitude 8.
Largest recorded Holocene eruption	The M6.8 Crater Lake eruption of Mt. Mazama, Oregon, in about 7627 BP.
Number of Holocene eruptions	226 confirmed eruptions.
Recorded Holocene VEI rang	0 – 7 and unknown
Number of historically active volcanoes	8
Number of historical eruptions	36

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
11	Large cone(s)	Andesitic (9), Dacitic (2)
5	Lava dome(s)	Rhyolitic (4), Trachytic / Andesitic (1)
7	Shield(s)	Andesitic (2), Basaltic (5)
23	Small cone(s)	Andesitic (2), Basaltic (19), Dacitic (2)

Table 12.9 The number of Holocene volcanoes in the contiguous states of the USA, their volcano type classification and dominant rock type according to VOTW4.0.

Note that the calderas here are Yellowstone (rhyolitic) and Crater Lake (dacitic). Long Valley caldera itself is not included as this is Pleistocene in age, however features within the area of Long Valley Caldera, considered distinct from the caldera, are included: Mammoth Mountain is a trachytic lava dome complex; Mono and Inyo Craters are rhyolitic lava domes and explosion craters; and Mono Lake Volcanic Field comprises cinder cones and lava domes.

Socio-Economic Facts

Total population (2012)	317,806,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	42,486
Gross National Income (GNI) per capita (2005 PPP $)	43,480
Human Development Index (HDI) (2012)	0.937 (Very High)

Population Exposure

Capital city	Washington D.C.
Distance from capital city to nearest Holocene volcano	2709.4 km
Total population (USA) (2011)	311,591,917
Number (percentage) of people living within 10 km of a Holocene volcano	26,309 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	388,808 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,196,889 (1.4%)

Ten largest cities, as measured by population and their population size:

New York	8,008,278
Los Angeles	3,694,820
Chicago	2,841,952
Houston	2,027,712
Philadelphia	1,517,550
Phoenix	1,321,045
San Antonio	1,256,810
San Diego	1,223,400
Detroit	951,270
San Jose	894,943

Infrastructure Exposure

Number of airports within 100 km of a volcano	95
Number of ports within 100 km of a volcano	28
Total length of roads within 100 km of a volcano (km)	20,625
Total length of railroads within 100 km of a volcano (km)	7,316

The volcanoes of the contiguous States are located in the western states, with most forming a chain north to south from Mexico to Canada in California, Oregon and Washington. Most volcanoes here are located far enough inland that ports are not located within their 100 km radius, however 28 ports are within this distance. Two of the largest cities in the USA, Seattle and Portland, are located within 100 km of volcanoes in the northern Cascade Range and nearly 100 airports are affected, along with numerous towns and cities. An extensive road and rail network falls within this distance of the volcanoes. The 100 km radius of volcanoes in the north and south extends into Canada and Mexico respectively, and indeed volcanoes in these countries also have 100 km radii extending into the USA.

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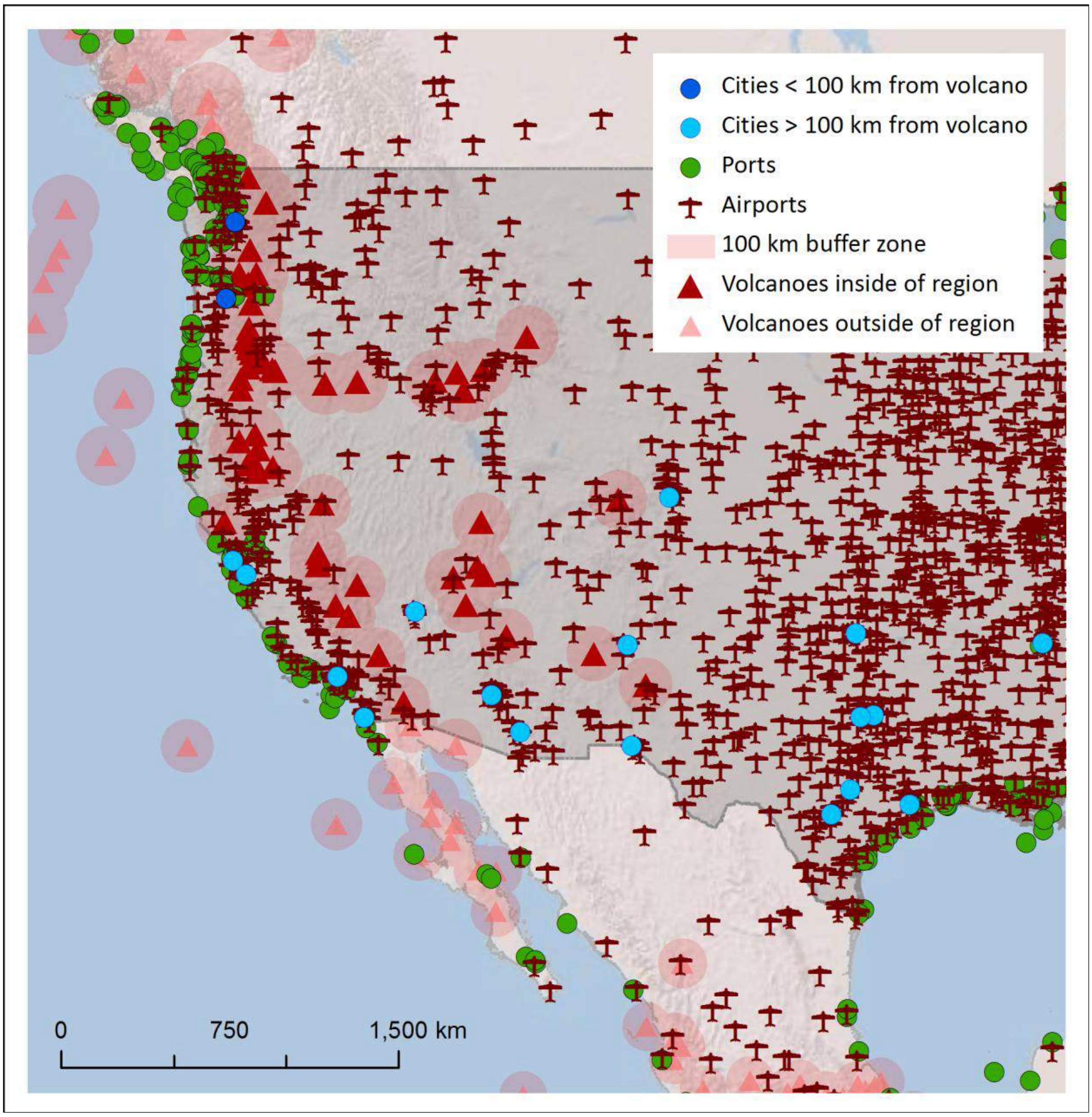

Figure 12.9 The location of the volcanoes in the contiguous United States and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of the contiguous states of the USA have varying levels of data available in their eruption record. About 20% of volcanoes have appropriate eruptive histories to determine a hazard level through calculation of the VHI. These classified volcanoes span all three hazard levels, though most are classed at Hazard Level I. With eruption histories including large explosive events and eruptions commonly producing pyroclastic flows, Shasta, Rainier and St. Helens all are classed at Hazard Level III.

Of the unclassified volcanoes, seven have no confirmed Holocene eruptions. The remaining unclassified volcanoes have a Holocene eruption record, including historic (post-1500 AD) events at four volcanoes. Only Lassen Volcanic Centre has erupted since 1900 AD, though unrest in this time has been recorded at Hood, Mammoth Mountain, Yellowstone and Coso Volcanic Field. Six unclassified volcanoes have Holocene records of large VEI ≥4 eruptions.

The PEI at these volcanoes ranges from low to high, at PEI 2 to 5. At most volcanoes the proximal population is relatively small, and all classified volcanoes are classed at Risk Levels of I and II.

CLASSIFIED	**Hazard III**		Shasta	Rainier; St. Helens				
	Hazard II			Baker				
	Hazard I		Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon					
UNCLASSIFIED	**U – HHR**		**Lassen Volcanic Center;** Mono Lake Volcanic Field	Glacier Peak; **Hood**				
	U- HR		Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field	West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero	San Francisco Volcanic Field			
	U- NHHR		Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field**	Lavic Lake	Soda Lakes	Clear Lake		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 12.10 Identity of the volcanoes in the contiguous States in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed

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*eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Baker	3	II
Rainier	3	II
St. Helens	3	II
Shasta	2	II
Adams	2	I
Craters of the Moon	2	I
Medicine Lake	2	I
Newberry	2	I
Three Sisters	2	I
Sand Mountain Field	2	I

Table 12.11 Classified volcanoes of the contiguous states of the U.S. ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 6 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

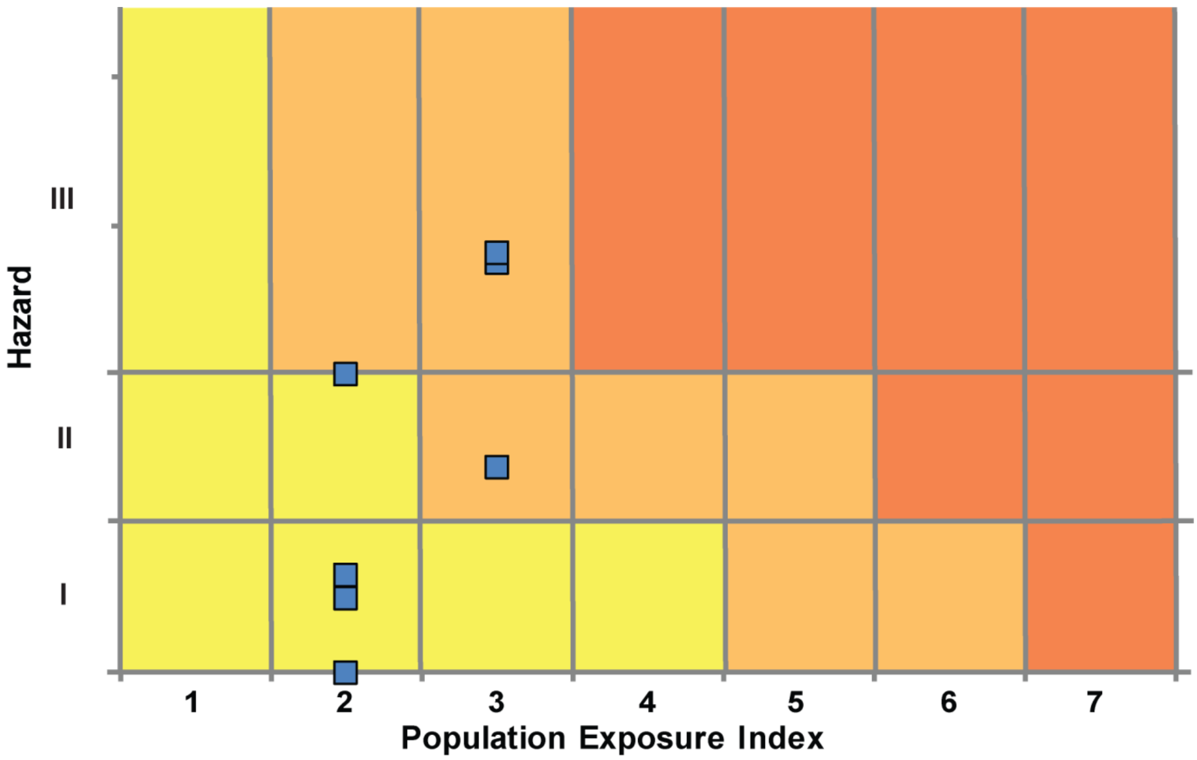

Figure 12.10 Distribution of the classified volcanoes in the contiguous states of the U.S. across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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National Capacity for Coping with Volcanic Risk

Eight volcanoes have records of historical activity in the U.S. Baker, Rainier, St. Helens and Shasta are classed at Risk Level II, while Glacier Peak, Hood, Lassen Volcanic Center and Mono Lake Volcanic Field are unclassified. These historically active volcanoes are monitored by the California Volcano Observatory (CalVO) and the Cascades Volcano Observatory (CVO) through seismic and deformation networks.

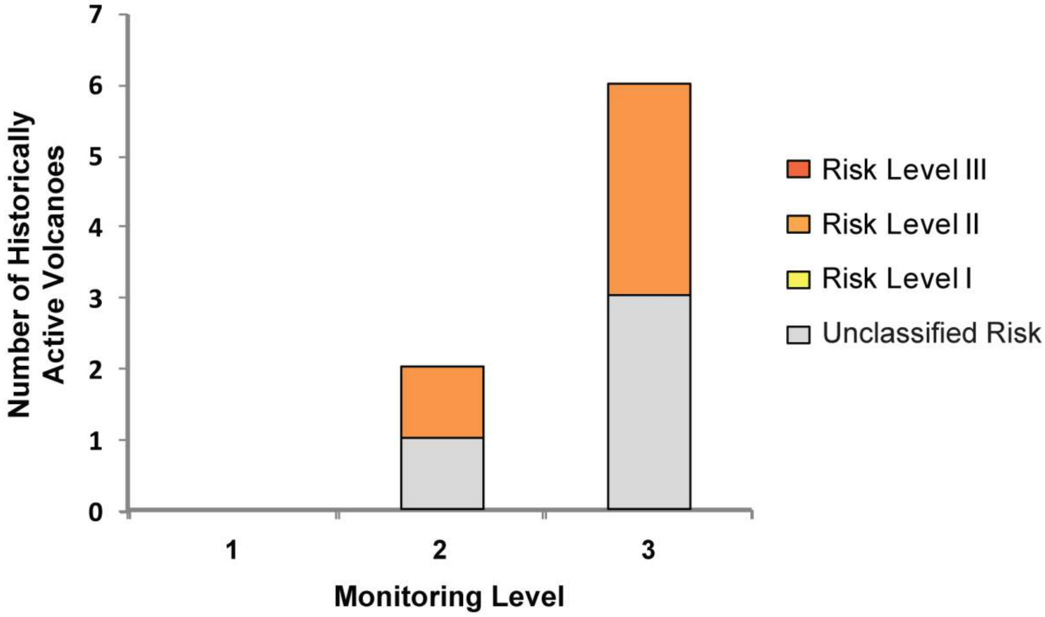

Figure 12.11 The monitoring and risk levels of the historically active volcanoes in the contiguous states of the U.S. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 13: Hawaii and Pacific Ocean

Region 13: Hawaii and the Pacific Ocean comprises volcanoes throughout the central Pacific, from the region's westernmost volcano of the Antipodes Island south of New Zealand to multiple volcanoes off the coast of the Americas. All are included in this regional discussion, and individual country profiles are provided. See Region 4 for the New Zealand profile.

Country	Number of volcanoes
France	4 + 4 from Regions 4 and 5
New Zealand (see Region 4)	1
USA	11

Table 13.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

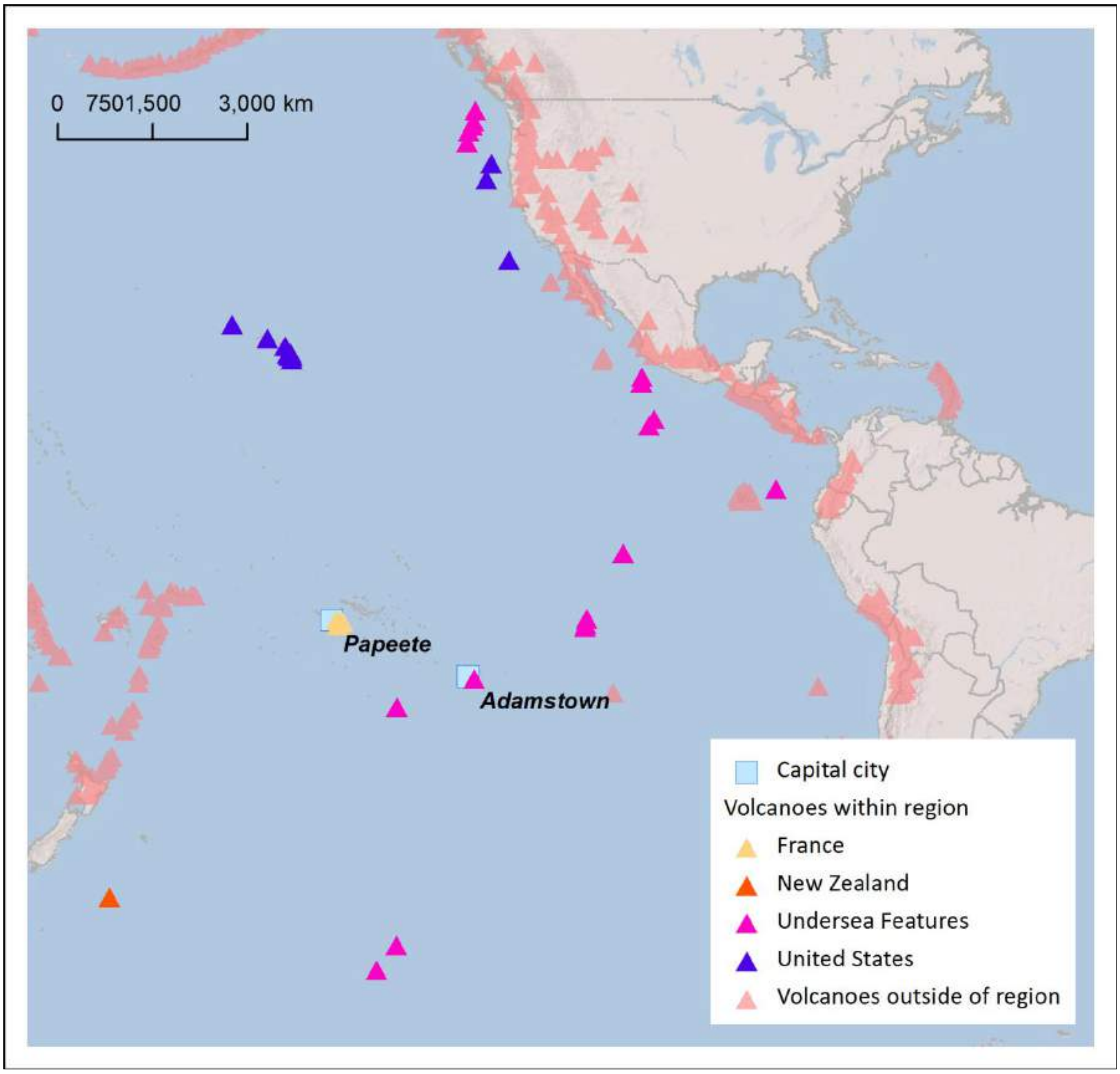

Figure 13.1 The distribution of Holocene volcanoes through the Hawaii and Pacific Ocean region. The capital cities of the constituent countries are shown.

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Description

Thirty-four Holocene volcanoes are located in Hawaii and the Pacific Ocean. Most of these volcanoes are undersea features of no specific nationality. Volcanism here is largely due to intra-plate, hotspot activity.

Most volcanoes in this region are submarine, and indeed this region has the highest proportion of submarine volcanoes. Most subaerial volcanoes are shields, with five located in Hawaii. One stratovolcano, Mehetia, is located in French Polynesia while the Antipodes Island of New Zealand is a group of pyroclastic cones. The composition of these volcanoes and their products is dominantly basaltic.

348 Holocene eruptions are confirmed throughout this region of VEI 0 to 4. Despite this range of activity the record is dominated by VEI 0 events, with nearly 90% of all eruptions classed as such demonstrating the prevalence of effusive eruptions of lavas. Just one eruption is recorded of VEI ≥ 3. Lava flows are recorded in 300 eruptions in this region, whilst just one eruption with a pyroclastic flow is recorded at Kilauea.

Twenty-one volcanoes have historical records of 172 eruptions, indicating that the geological record for this region is reasonably well populated. About 81% of historical eruptions have associated records of lava flows.

Just 3% of historical eruptions have resulted in loss of life, largely due to the low proximal populations at most volcanoes (91%) and the number of submarine volcanoes. This low population coupled with the dominantly effusive nature of eruptions here means that all but one classified volcano are classed as Risk Level I. Hualalai in Hawaii is classed at Risk Level II with the largest proximal population in the region.

Away from the subaerial volcanoes of Hawaii dedicated ground-based monitoring is largely absent. Within Hawaii, the Hawaiian Volcano Observatory monitor the volcanoes and provide hazard data and advice.

Volcano facts

Number of Holocene volcanoes	34
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1 (1 eruption)
Number of volcanoes generating lahars	0
Number of volcanoes generating lava flows	23 (300 eruptions)
Number of eruptions with fatalities	6
Number of fatalities attributed to eruptions	5,497?

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Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The 2560 and 2079 BP eruptions of the Older and Younger Uwekahuna Ash at Kilauea, Hawaii, are the largest recorded Holocene eruptions in this region at M4.2. No larger events are recorded in the Pleistocene in the LaMEVE database.
Number of Holocene eruptions	348 confirmed Holocene eruptions
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	21
Number of historical eruptions	172

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
5	Shield(s)	Basaltic (5)
1	Small cone(s)	Basaltic (1)
27	Submarine	Basaltic (21), Trachytic/Andesitic (1), Unknown (5)

Table 13.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	-

Table 13.3 Average recurrence interval (years between eruptions) for small and large eruptions in Hawaii and the Pacific.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year.

Eruption Size

Eruptions are recorded through the Hawaii and Pacific Ocean region of VEI 0 to 4, representing a range of eruption styles from gentle effusive events to explosive eruptions. VEI 0 events dominate the record, with nearly 90% of all Holocene eruptions classed as such. Just 0.3% of eruptions here are explosive at VEI ≥4.

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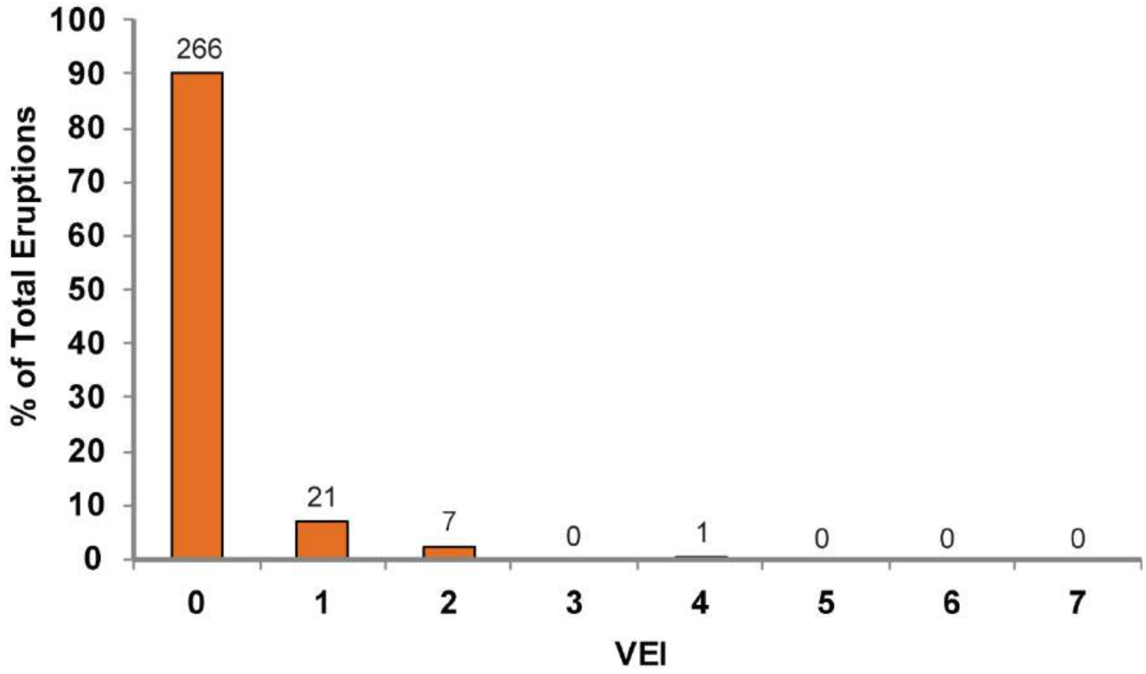

Figure 13.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 53 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	1,390,090
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2012)	

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	65,387 (4.70 %)
Number (percentage) of people living within 30 km of a Holocene volcano	132,822 (9.55 %)
Number (percentage) of people living within 100 km of a Holocene volcano	1,691,007 (>100 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	23
Total length of roads within 100 km of a volcano (km)	865
Total length of railroads within 100 km of a volcano (km)	0

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I	Adams Seamount; Macdonald; Unnamed; Southern EPR-Segment K	Mauna Loa; Teahitia	Kilauea		Hualalai		
UNCLASSIFIED	**U – HHR**	**CoAxial Segment**; **Axial Seamount**; **Cleft Segment**; **North Gorda Ridge**; **Unnamed (332090); Unnamed (334040); Galápagos Rift; Unnamed (334100);** Southern EPR-Segment J; **Southern EPR-Segment I**	**Loihi**; **Rocard**; **Moua Pihaa**		Haleakala			
	U- HR	**Endeavour Ridge**; Cobb Segment; Escanaba Segment; Northern EPR-Segment RO2; Northern EPR-Segment RO3	Mauna Kea					
	U- NHHR	Unnamed; Antipodes Island; Unnamed; Unnamed	Unnamed; **Mehetia**					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 13.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
1	5
1	4
1	3
8	2
23	1

Table 13.5 The number of volcanoes in Hawaii and the Pacific classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
1	II
7	I
26	Unclassified

Table 13.6 The number of volcanoes in the Hawaii and Pacific Ocean region classified at each Risk Level.

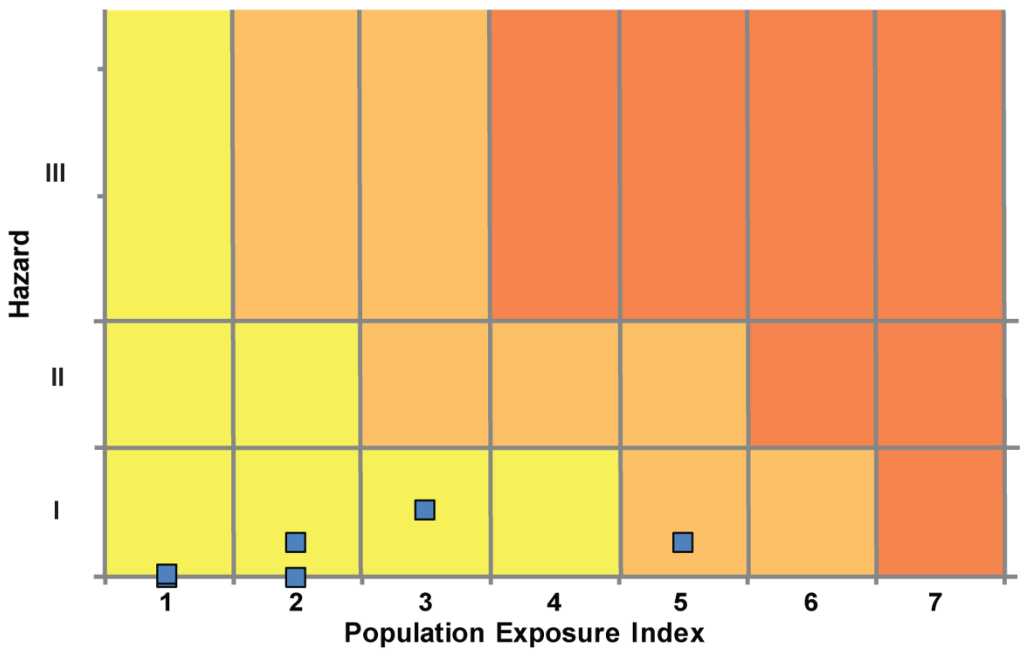

Figure 13.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional monitoring capacity

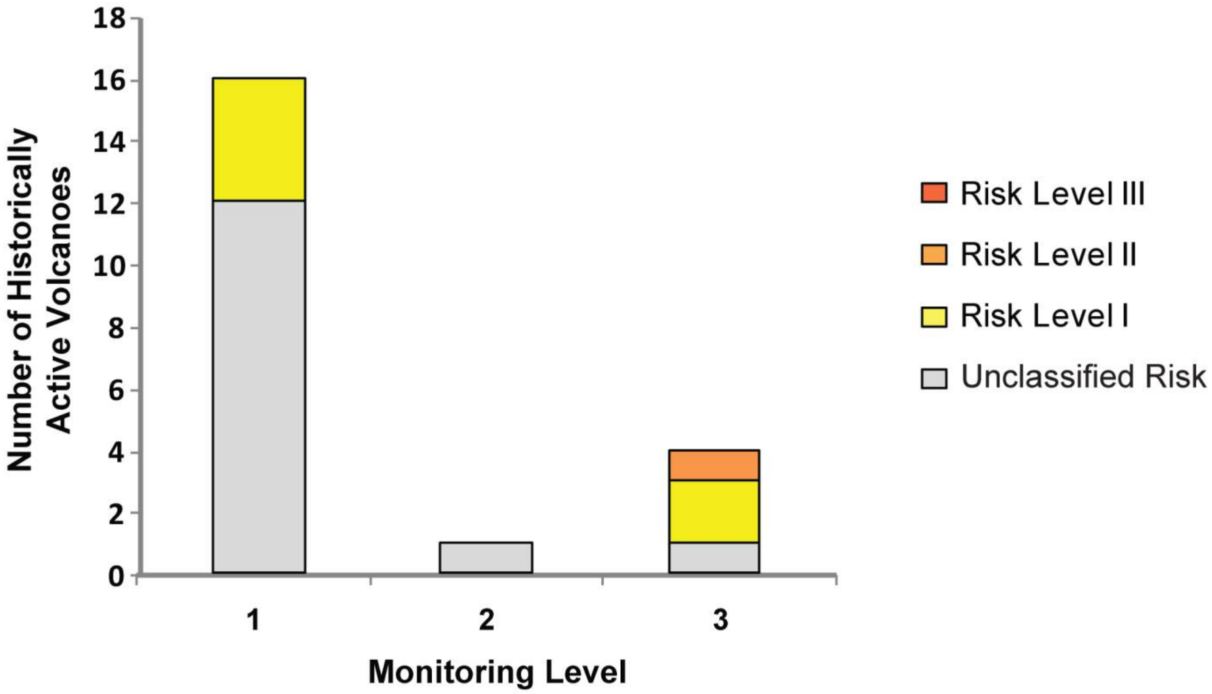

Figure 13.4 The monitoring and risk levels of the historically active volcanoes in Hawaii and the Pacific Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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France – Multiple Pacific Ocean islands

See Region 1 for mainland France, Region 3 for the French territories in the Indian Ocean. Note that here we include Region 13's Teahitia, Rocard, Moua Pihaa and Mehetia of French Polynesia, Wallis Islands from Region 4 and Eastern Gemini Seamount, Matthew Island and Hunter Island from Region 5 in discussion.

Description

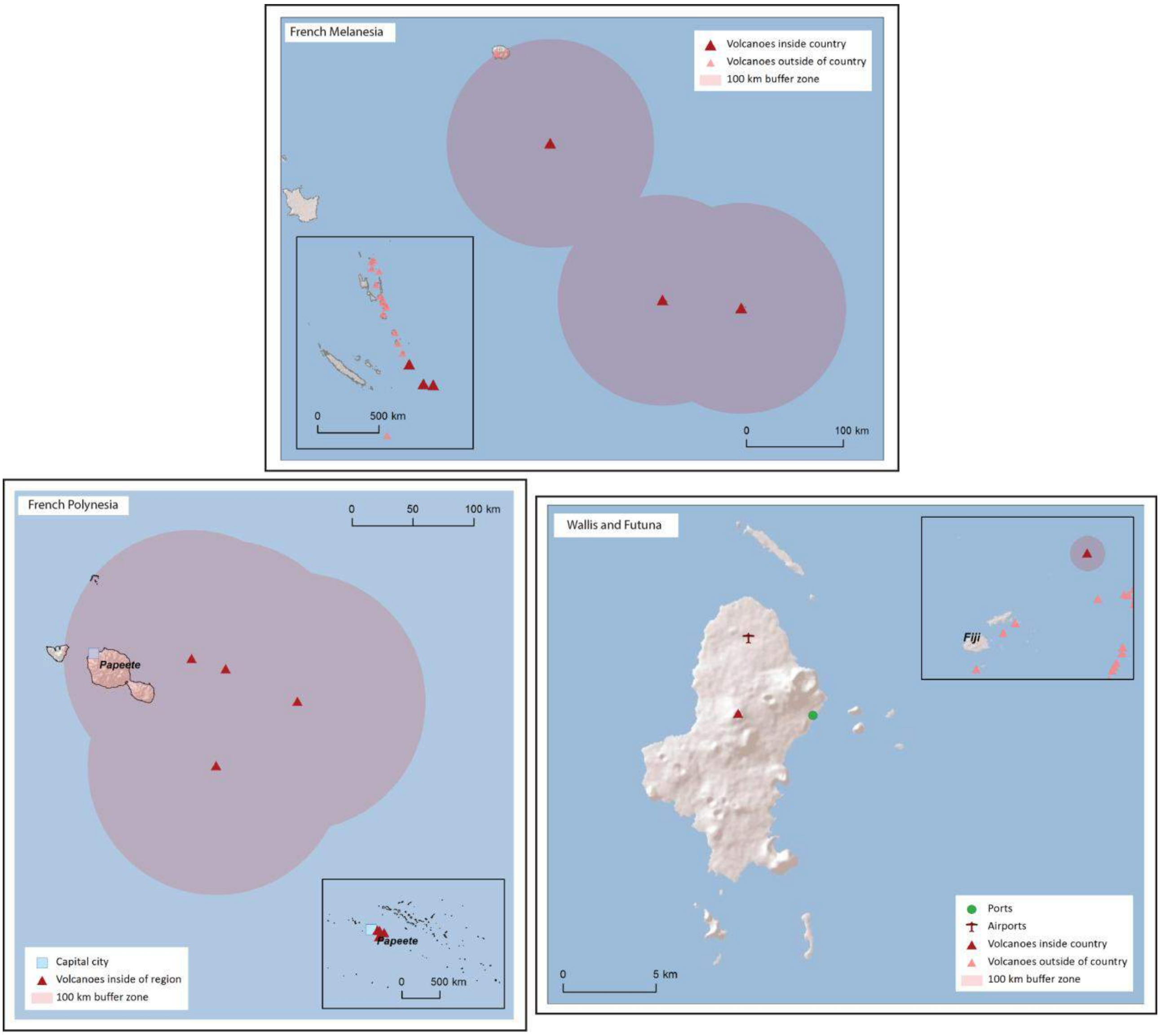

Figure 13.5 Location of the Pacific Ocean French volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Pacific Ocean French volcanoes.

A number of islands in the Pacific are French overseas territories. Eight Holocene volcanoes are located on these islands, with three located between Fiji and New Caledonia (Matthew Island, Hunter Island and the Eastern Gemini Seamount, these being located in a rift setting); the Wallis Islands located to the north-east of Fiji (in a subduction zone), and four located in French Polynesia

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(due to intra-plate hotspot processes). Four of these volcanoes are submarine, whilst the subaerial volcanoes comprise three stratovolcanoes and one shield volcano.

Seventeen Holocene eruptions of VEI 0 to 2 are recorded here, indicating predominantly mild activity and indeed lava flows are recorded in four events. All seventeen eruptions are recorded historically, with no geological record available for these volcanoes. All are recorded post-1835.

Only three of these volcanoes – Wallis Islands, Matthew Island and Mehetia have a population within 10 km. Assessment of hazard at these volcanoes is complicated by the sparse eruption history, but the risk here is considered relatively low. However, large eruptions cannot be ruled out.

Volcano Facts

Number of Holocene volcanoes	4 in Region 13, 1 in Region 4, 3 in Region 5
Number of Pleistocene volcanoes with M≥4 eruptions	
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	
Tectonic setting	Region 13: Intra-plate, Region 4: Subduction zone, Region 5: Rift zone
Largest recorded Pleistocene eruption	
Largest recorded Holocene eruption	
Number of Holocene eruptions	17
Recorded Holocene VEI range	0 – 2 and unknown
Number of historically active volcanoes	6
Number of historic eruptions	17

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large Cone(s)	Andesitic (2), Basaltic (1)
1	Shield(s)	Basaltic (1)
4	Submarine	Basaltic (3), Trachytic/Andesitic (1)

Table 13.7 The number of the Pacific Ocean French volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

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Population Exposure

Number (percentage) of people living within 30 km of a Holocene volcano	115
Total population	295,587 (280,026 in French Polynesia and 15,561 in Wallis and Futuna in 2014, https://www.cia.gov/library/publications/the-world-factbook/)

Largest cities, as measured by population and their population size:

Papeete (French Polynesia)	26,357

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	-

The volcanoes of French Polynesia are located to the east of the main island of Tahiti, with all but Mehetia lying within 100 km of this island. The 100 km radii of these volcanoes extend to fully encompass Tahiti, and much of the islands of Moorea and Tetiaroa. The capital, Papeete lies within these radii and all critical infrastructure is exposed.

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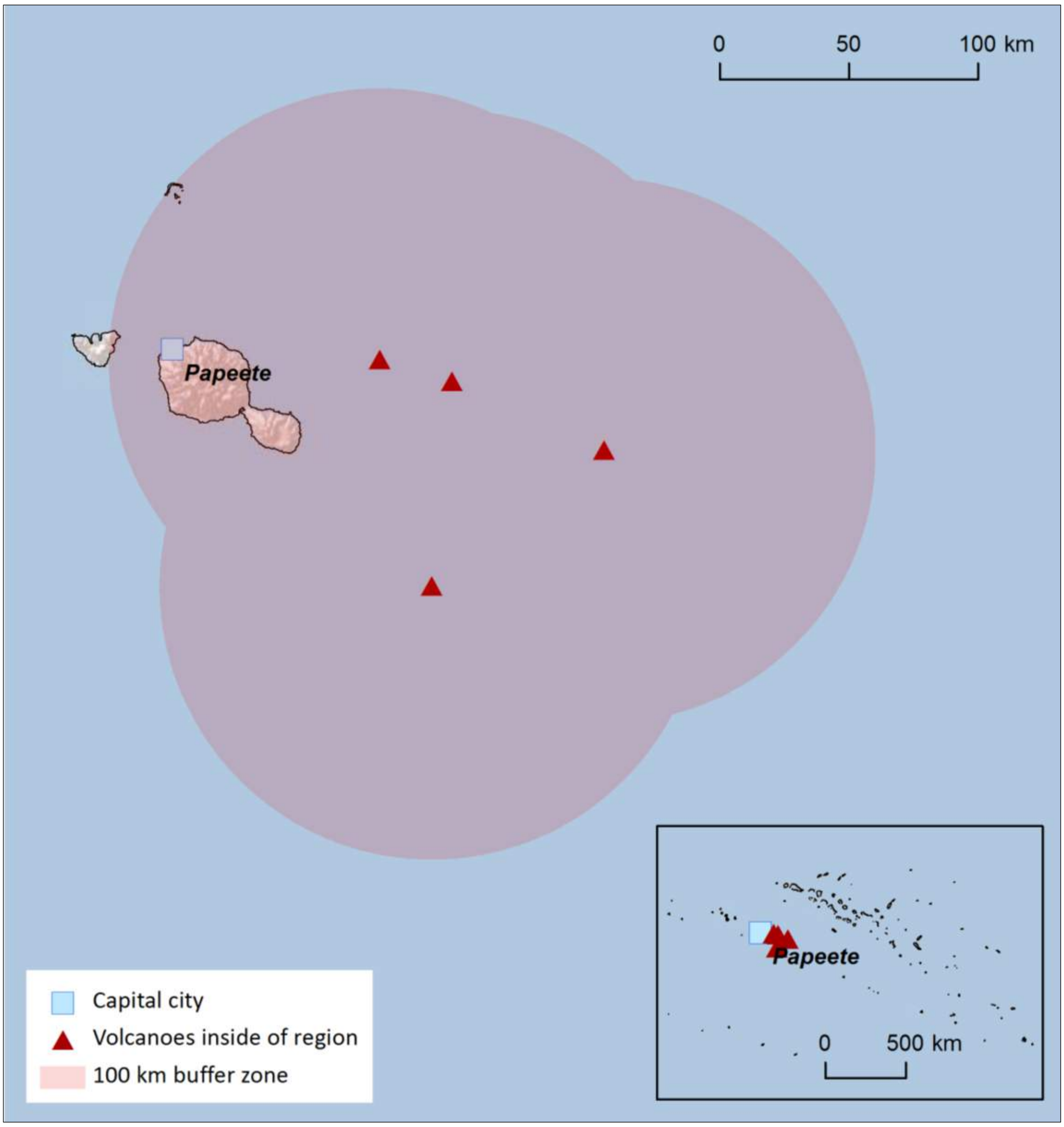

Figure 13.6 The volcanoes of French Melanesia, Matthew Island, Hunter Island and Eastern Gemini Seamount lie beyond 100 km to the south of Vanuatu.

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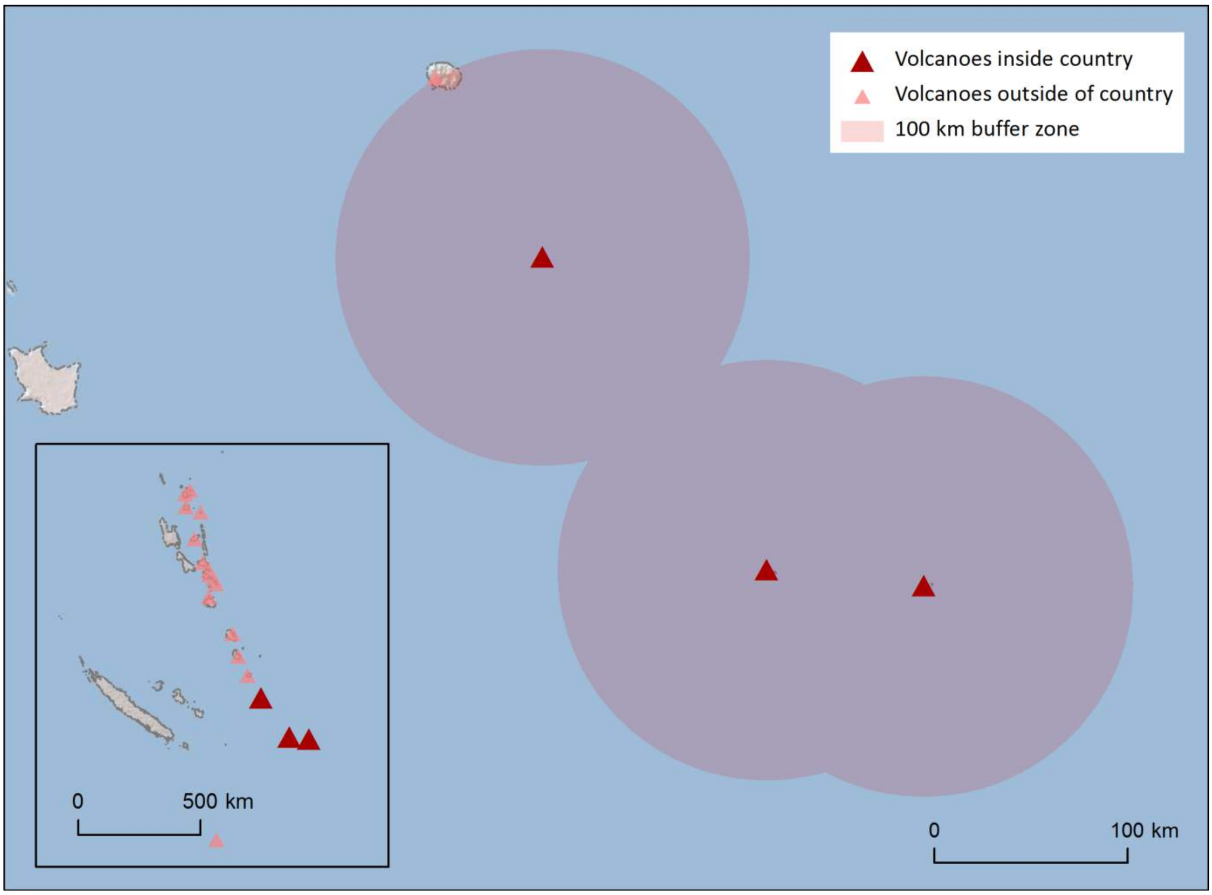

Figure 13.7 The location of French Melanesia and the volcanoes here and the extent of the 100 km zone surrounding them.

The Wallis Islands volcano is located on Wallis and Futuna, over 300 km from Samoa. The island measures no more than 30 km across and therefore all infrastructure here is exposed to volcanic hazards, lying within the 100 km radius of Wallis Islands volcano. This includes the capital, Mata-utu.

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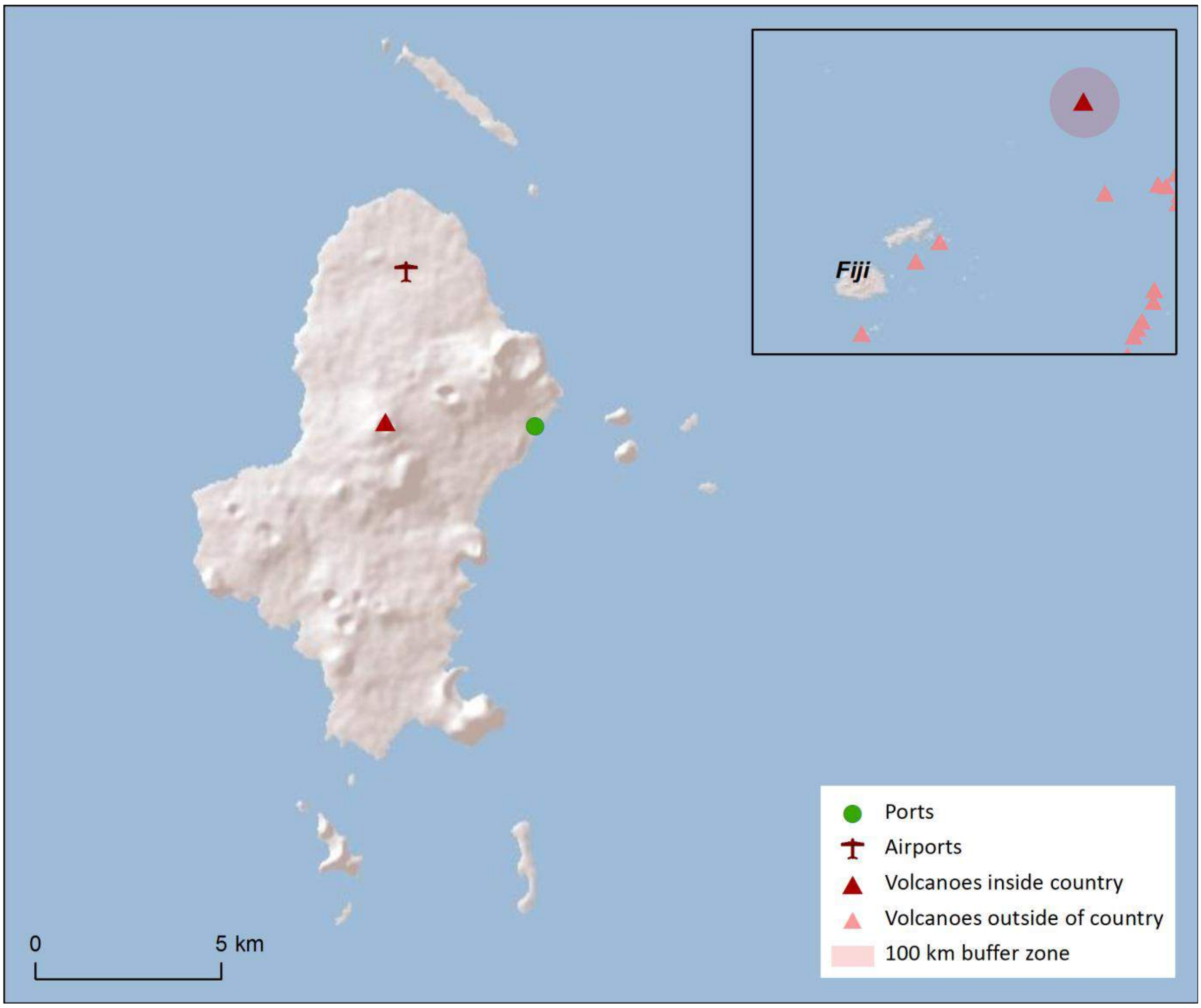

Figure 13.8 The location of Wallis and Futuna and the volcanoes here and the extent of the 100 km zone surrounding them.

Hazard, Uncertainty and Exposure Assessments

With the exception of Teahitia, the eruptive histories at all volcanoes here are insufficiently detailed to permit the determination of hazard through the calculation of the VHI without large associated uncertainties. Teahitia is classified at Hazard Level I, from historical VEI 0 eruptions. Of the unclassified volcanoes, two have no confirmed Holocene eruptions. The remaining unclassified volcanoes all have historical records only of eruptions of VEI 0 – 2.

The proximal population to these volcanoes is small, with only Wallis Islands, Matthew Island and Mehetia having a population within 10 km. For the latter two volcanoes, this doesn't increase within 100km. Whilst the islands of French Polynesia have a larger population within 100 km, all but Wallis Islands are classed with a low PEI of 2. With the population within 10 km at Wallis Islands, the PEI here is moderate at 4.

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CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I		Teahitia					
UNCLASSIFIED	**U – HHR**	**Eastern Gemini Seamount; Hunter Island**	**Rocard; Moua Pihaa; Matthew Island**					
	U- HR							
	U- NHHR		**Mehetia**		Wallis Islands			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 13.8 Identity of the volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Teahitia	2	I

Table 13.9 The classified Pacific Ocean French volcanoes ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

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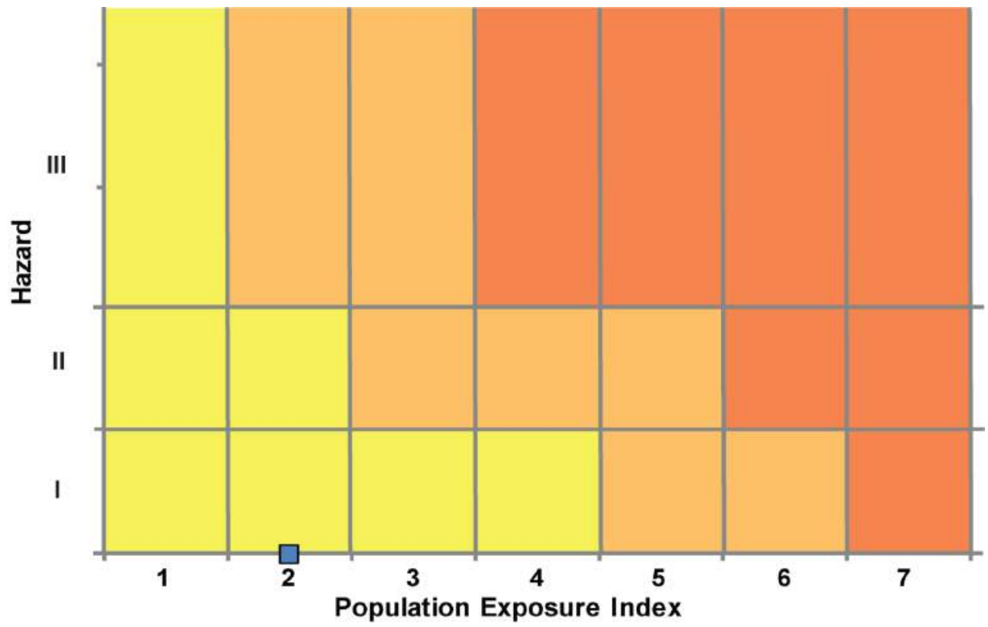

Figure 13.9 Distribution of the Pacific Ocean French classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in the French islands of the Pacific. At the time of the writing of this report there is no information available to indicate the presence of dedicated ground-based monitoring systems on these volcanoes.

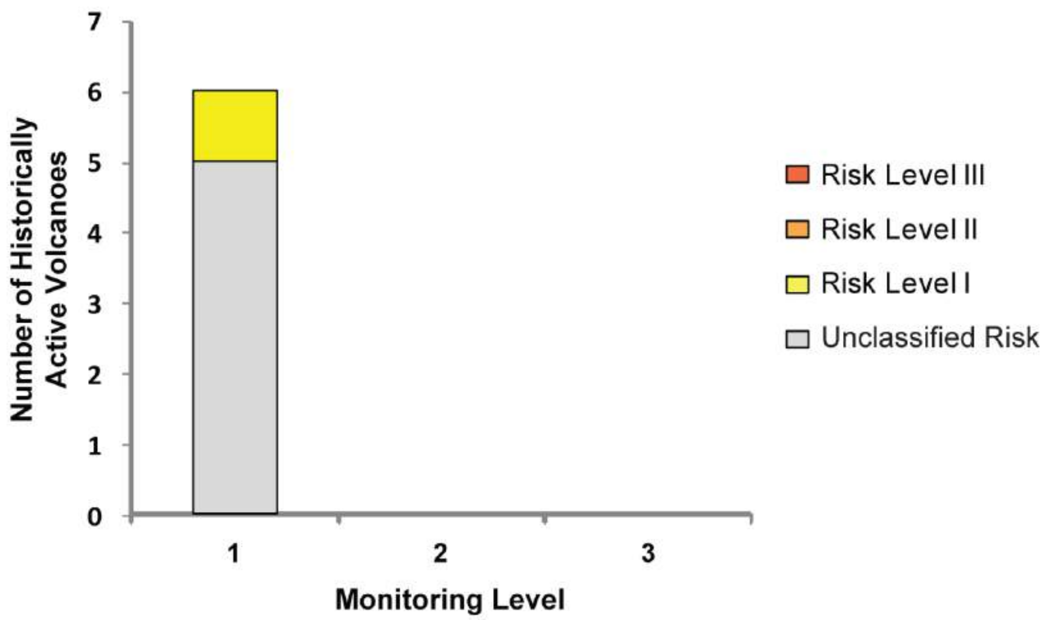

Figure 13.10 The monitoring and risk levels of the historically active volcanoes in the Pacific Ocean French volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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USA – Hawaii and Pacific

See Region 4 for American Samoa, Region 8 for the Marianas, Region 11 for Alaska, Region 12 for the contiguous states.

Here we discuss the volcanism in the US-Pacific. The profile focuses on the subaerial volcanism in Hawaii, then goes on to provide analysis of the submarine volcanoes located in the northern Pacific – the North Gorda Ridge, Escanaba Segment and an Unnamed volcano.

Description

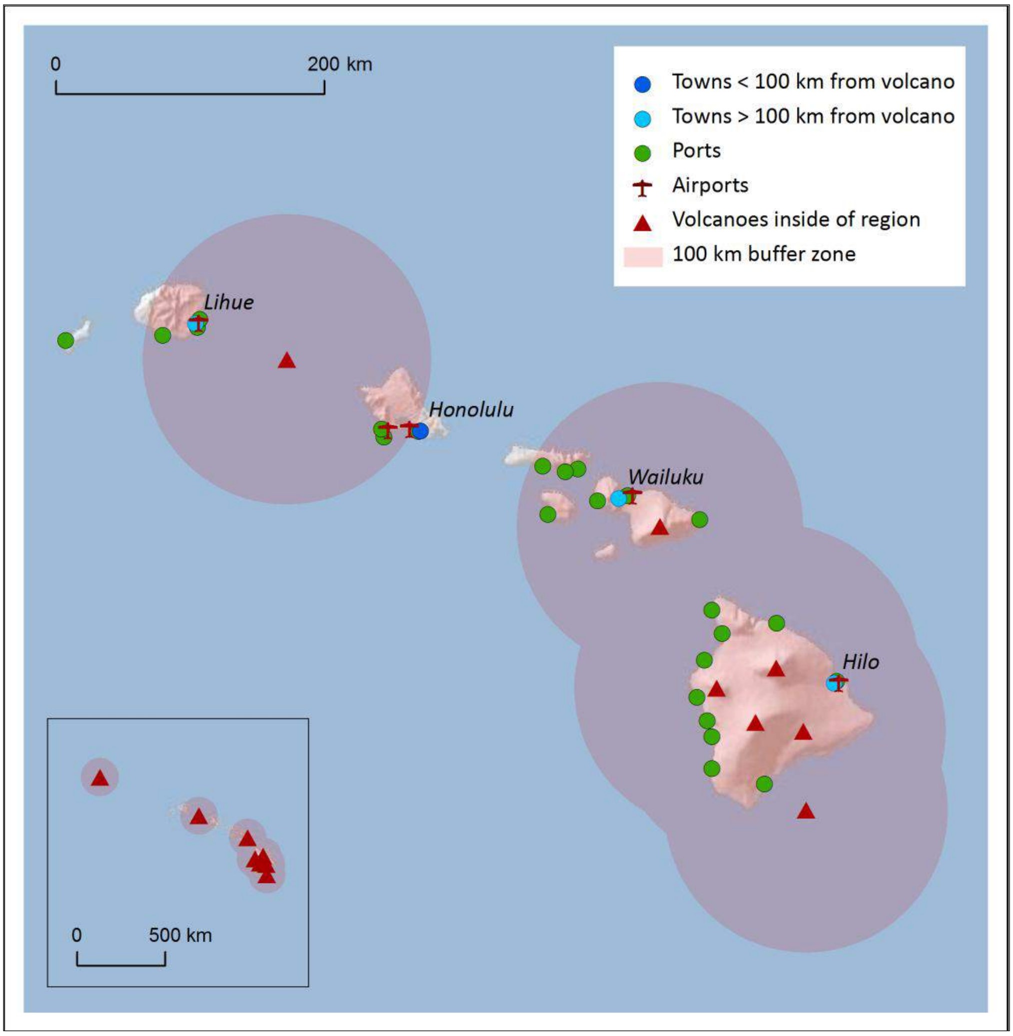

Figure 13.11 The location of Hawaii's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Eight Holocene volcanoes are located in Hawaii. Three submarine volcanoes are located off the southern coast of the Big Island (Hawaii), between Oahu and Kauai and beyond Kauai into the northwestern leeward islands. The remaining volcanoes are subaerial shields located on Hawaii and Maui. These volcanoes are dominantly basaltic in composition and result from intra-plate hotspot processes.

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VOTW4.22 records 277 confirmed Holocene in Hawaii. These ranged from VEI 0 to 4. Of these, 123 eruptions are recorded historically, post-1500 AD.

The nature of the volcanoes in Hawaii are such that eruptions are not restricted to the summit, as rift zones are active across Hawaiian volcanoes including Hualalai, Mauna Loa and Kilauea. These rift zones are areas of weakness which are exploited by magma bodies. Eruptions therefore commonly occur along these rifts, some of which are over 100 km long. Indeed, the East Rift Zone of Haleakala is about 150 km long and extends into the ocean. Basaltic rift zones such as in Hawaii are typically associated with effusive events, producing extensive basaltic lava flows. These lavas can extend from many points along the rift zone, propagating downhill, and much of the surface of Mauna Loa and Kilauea comprises lava flows younger than 1000 years old. The population at risk cannot therefore be thought of in relation to a summit point, but is in fact more widespread along the lengths of the rifts and downhill from these features. With development of land expanding towards rift systems, the threat to life and property increases. Several eruptions of Kilauea, Mauna Loa have lead to property damage and several have resulted in loss of life.

Just one historical eruption of VEI 4 is recorded at Kilauea in 1790 in VOTW4.22. This explosive eruption produced pyroclastic flows and ballistics killing hundreds. Ongoing work investigating this eruption suggests that it was in fact a VEI 3 event (J.Kauahikaua, pers. comm., 2014). Indeed, explosive activity is rare here.

The U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) was founded in 1912. Here scientific research and monitoring of the active volcanoes is undertaken, with a large monitoring network focussed on the island of Hawaii. Hazard assessment reports have been produced for Kilauea and Mauna Loa. The HVO provide Volcanic Activity Notices (VAN) for changes in alert levels and aviation colour codes. Regular updates are also released. See the profile for the U.S. contiguous states for description of the U.S. Geological Survey's NVEWS approach to monitoring.

See also:

Guffanti, M., Diefenbach, A.K., Ewert, J.W., Ramsey, D.W., Cervelli, P.F., and Schilling, S.P., 2009, Volcano-monitoring instrumentation in the United States, 2008: U.S. Geological Survey Open-file Report 2009-1165, 32 p. pubs.usgs.gov/of/2009/1165/

Hawaiian Volcano Observatory: hvo.wr.usgs.gov/observatory/

Volcano Facts

Number of Holocene volcanoes	8
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	0
Number of volcanoes generating lava flows	8

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Number of fatalities caused by volcanic eruptions	Hundreds
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three VEI 4 eruptions during the Holocene (VOTW4.22), however currently ongoing unpublished work indicates that these eruptions were no more than VEI 3 in size.
Number of Holocene eruptions	277 confirmed eruptions
Number of historically active volcanoes	6
Number of historical eruptions	123

Number of volcanoes	Primary volcano type	Dominant rock type
5	Shield(s)	Basaltic (5)
3	Submarine	Basaltic (1), Unknown (2)

Table 13.10 The number of volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Honolulu
Distance from capital city to nearest Holocene volcano	100 km
Total population (2010) (US Census Bureau[1])	1,360,301

Ten largest cities, as defined by population size, and populations (2010 US Census):

Honolulu	337,256
East Honolulu	49,914
Pearl City	47,698
Hilo	43,263
Kailua	38,635
Waipahu	38,635
Waipahu	38,216
Kaneohe	34,597
Mililani Town	27,629
Kahului	26,337

[1] factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

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Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	22
Total length of roads within 100 km of a volcano (km)	865
Total length of railroads within 100 km of a volcano (km)	0

With the exception of the island Ni'ihau, almost the entirety of the main islands of the Hawaiian island chain fall within 100 km of a Holocene volcano, therefore including much of the critical infrastructure and the largest cities, including the capital, Honolulu. Being volcanic islands, a large number of ports lie within the 100 km radii, 5 airports and a substantial road network is also affected.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information in the eruption records of Hawaii's volcanoes. Mauna Loa, Kilauea and Hualalai have sufficient detail to determine hazard through the calculation of the VHI and all are classified at Hazard Level I due to a largely effusive eruptive history.

There is insufficient data to calculate the VHI at the remaining volcanoes without large associated uncertainties. With the exception of an unnamed volcano, all unclassified volcanoes have a Holocene record of activity, with historical eruptions at Haleakala, Loihi and another unnamed volcano.

The PEI ranges from low to high in Hawaii, and with a Hazard Level of I, the classified volcanoes are classed at Risk Levels I and II. Just Hualalai is classed as Risk Level II, with the largest population within 10 km of all Hawaiian volcanoes.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I		Mauna Loa	Kilauea		Hualalai		
UNCLASSIFIED	**U – HHR**	**Unnamed (332090)**	**Loihi**		Haleakala			
	U- HR		Mauna Kea					
	U- NHHR		Unnamed (332080)					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 13.11 Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified

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*No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Hualalai	5	II
Kilauea	3	I
Mauna Loa	2	I

Table 13.12 Classified volcanoes ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

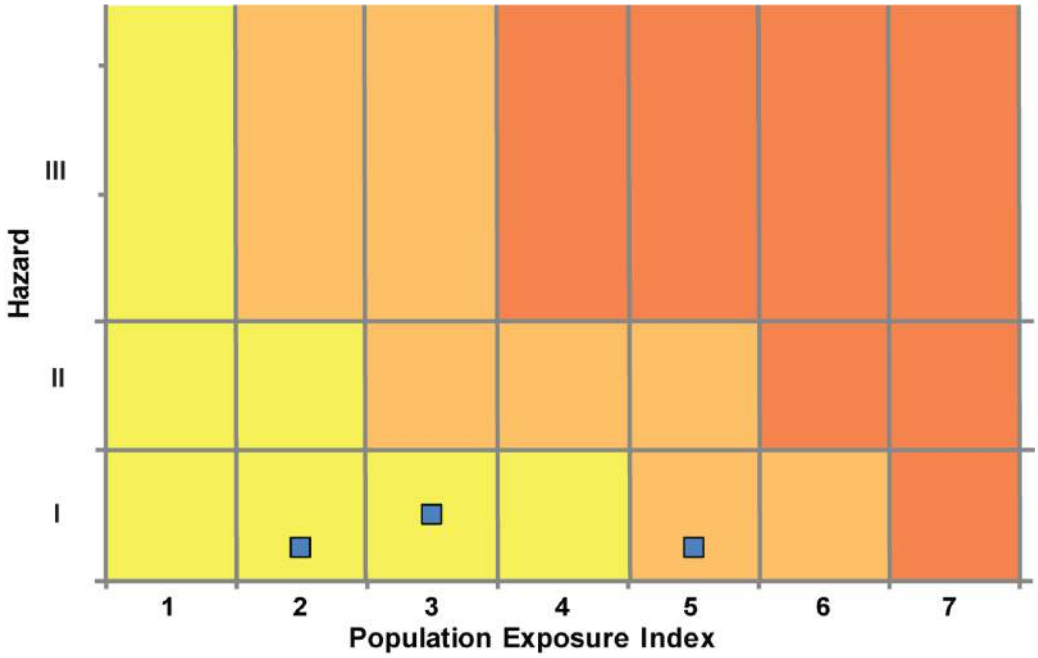

Figure 13.12Distribution of classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Seven volcanoes in Hawaii have historical records of activity. The unnamed submarine volcano does not have dedicated ground-based monitoring. The volcanoes on the Big Island, Loihi, Kilauea, Mauna Loa and Hualalai are monitored through an extensive seismic network, with additional deformation and gas monitoring at Kilauea and Mauna Loa. Numerous seismic stations are also located near Haleakala on Maui.

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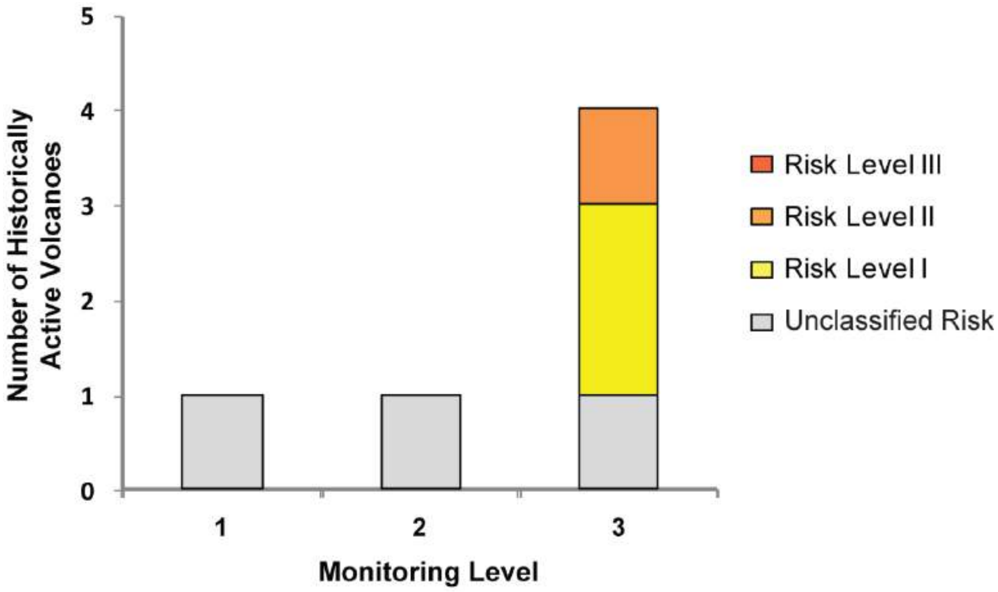

Figure 13.13 The monitoring and risk levels of the historically active volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

USA –Pacific-Other

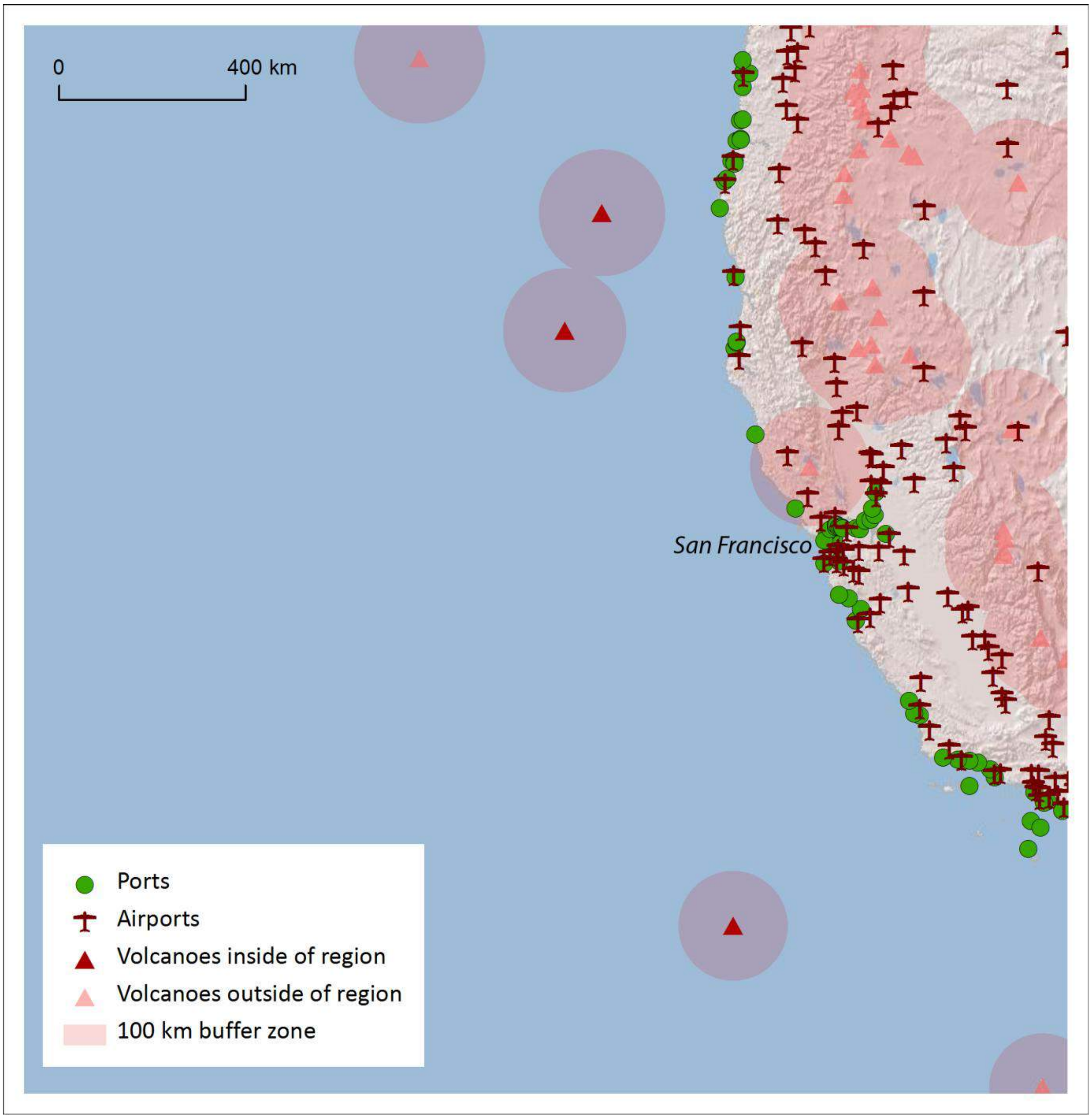

Figure 13.14 The location of the Pacific US volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Three submarine volcanoes are located beyond about 200 km off the coast of Oregon and California. These volcanoes – the North Gorda Ridge, Escanaba Segment and an unnamed volcano, are submarine features.

North Gorda Ridge formed on a spreading centre south of the Juan de Fuca ridge. An eruption occurred here in 1996, forming a submarine lava flow.

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Being remote submarine features there is no population living within 100 km of any of these volcanoes. The hazard is considered low to the nature of lava effusions at spreading ridges and with no permanent population the risk is therefore low.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate, rift-zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	All eruptions of VEI 0
Number of Holocene eruptions	4 confirmed eruptions
Number of historically active volcanoes	1
Number of historical eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
3	Submarine	Basaltic (2), Unknown (1)

Table 13.13 The number of volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

Hazard, Uncertainty and Exposure Assessments

The eruptive record for these volcanoes prevents the determination of hazard through calculation of the VHI without large uncertainties. These volcanoes are therefore unclassified. Just Escanaba Segment and North Gorda Ridge have a Holocene eruption record, most recently with a 1996 VEI 0 eruption of North Gorda Ridge. Despite the hazard being unclassified, the absence of a local population means the risk here is low.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR	**North Gorda Ridge**						
	U- HR	Escanaba Segment						
	U- NHHR	Unnamed (331050)						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 13.14 Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

One volcano has historical records of activity. This volcano, the submarine North Gorda Ridge volcano, does not have dedicated ground-based monitoring.

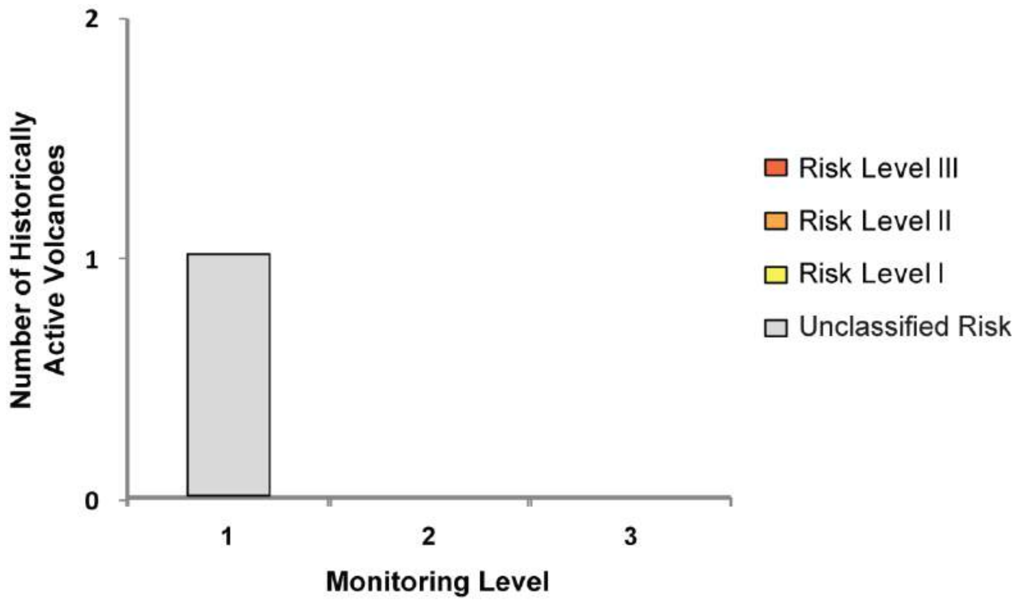

Figure 13.15 The monitoring and risk levels of the historically active volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 14: Mexico and Central America

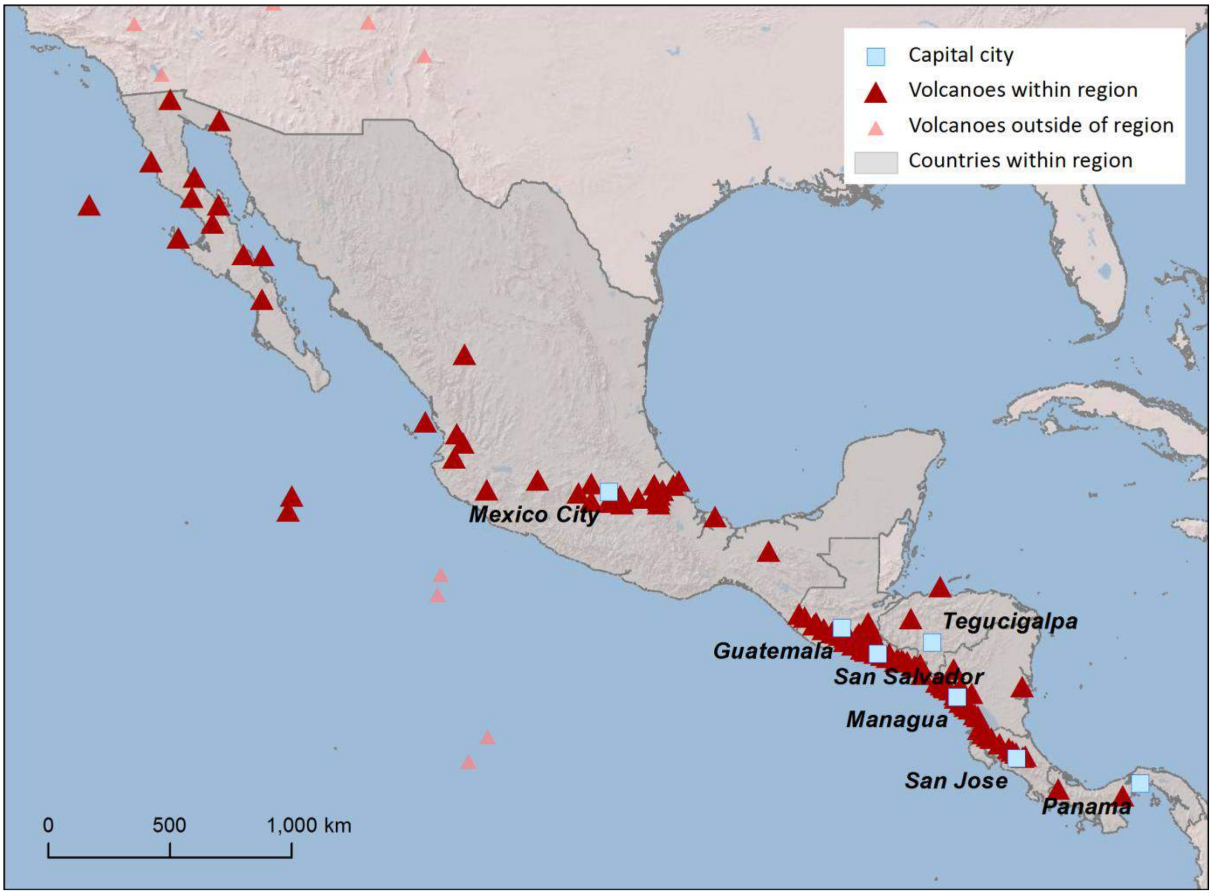

Figure 14.1 The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 14: Mexico and Central America comprises volcanoes from Panama in the south to the Mexico-US border in the north. Seven countries are represented here.

Country	Number of volcanoes
Costa Rica	10
El Salvador	22
Guatemala	23
Honduras	4
Mexico	40
Nicaragua	19
Panama	2

Table 14.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

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There are 118 Holocene volcanoes located in Mexico and Central America with most of these volcanoes located in Mexico. Volcanism here is largely related to the subduction of the Cocos Plate beneath the Caribbean and North American Plates.

A range of volcano types are present in this region, though most (about 60%) are stratovolcanoes. The rock type through this region is dominantly andesitic, but ranges from basaltic to rhyolitic.

A range of activity styles and eruption sizes are recorded through the Holocene, with eruptions of VEI 0 to 6. About 73% of eruptions have been small, at VEI 0 – 2, however about 11% (70) of eruptions have been large explosive VEI ≥4 events. The only countries in this region with no Holocene record of producing such eruptions are Honduras and Panama, though pyroclastic flows are recorded in Panama. The largest Holocene eruption in this region was the VEI 6 Terra Blanca Joven (TBJ) eruption of Ilopango in El Salvdor in about 450 AD. This eruption produced widespread pyroclastic flows and devastated Mayan cities. The capital of El Salvador lies within 20 km of this volcano.

Thirty-seven volcanoes have historical records of 578 eruptions, 98% of which were recorded through direct observations. Just 203 eruptions were recorded before 1500 AD. 12% of historical events produced pyroclastic flows, and 7% generated lahars. 23% of eruptions produced lava flows.

Lives were lost in 4% of historical eruptions, accounting for over 40,000 fatalities. This region has a high population, with most volcanoes (64%) having high proximal populations and as such many are considered relatively high risk. However the hazard (VHI) is poorly constrained at many volcanoes here so about 80% of volcanoes are unclassified in hazard and risk.

Thirty-one of thirty-seven historically active volcanoes in this region are monitored using at least one dedicated seismometer, with active monitoring groups in many of this region's countries.

Volcano Facts

Number of Holocene volcanoes	118
Number of Pleistocene volcanoes with M≥4 eruptions	39
Number of volcanoes generating pyroclastic flows	35 (171 eruptions)
Number of volcanoes generating lahars	22 (52 eruptions)
Number of volcanoes generating lava flows	31 (162 eruptions)
Number of eruptions with fatalities	26
Number of fatalities attributed to eruptions	46,317
Largest recorded Pleistocene eruption	The largest eruption in this region during the Quaternary is recorded at 84 ka with the M7.8 eruption of Los Chocoyos Ash (H) from Atitlán in Guatemala.

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Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region is the 1500 BP M6.7 TBJ eruption of Ilopango.
Number of Holocene eruptions	781 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	37
Number of historical eruptions	578

Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Basaltic (1), Dacitic (3), Rhyolitic (2)
68	Large cone(s)	Andesitic (44), Basaltic (18), Dacitic (5), Unknown (1)
4	Lava dome(s)	Andesitic (1), Dacitic (2), Rhyolitic (1)
8	Shield(s)	Andesitic (3), Basaltic (4), Trachytic / Andesitic (1)
33	Small cone(s)	Andesitic (7), Basaltic (20), Dacitic (1), Rhyolitic (2), Trachytic / Andesitic (1), Unknown (2)
1	Submarine	Unknown (1)

Table 14.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	50

Table 14.3 Average recurrence interval (years between eruptions) for small and large eruptions in Mexico and Central America.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 50 years.

Eruption Size

Eruptions are recorded through Mexico and Central America of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with about 50% of all Holocene eruptions classed as such. Nearly 11% of eruptions here are explosive at VEI ≥4.

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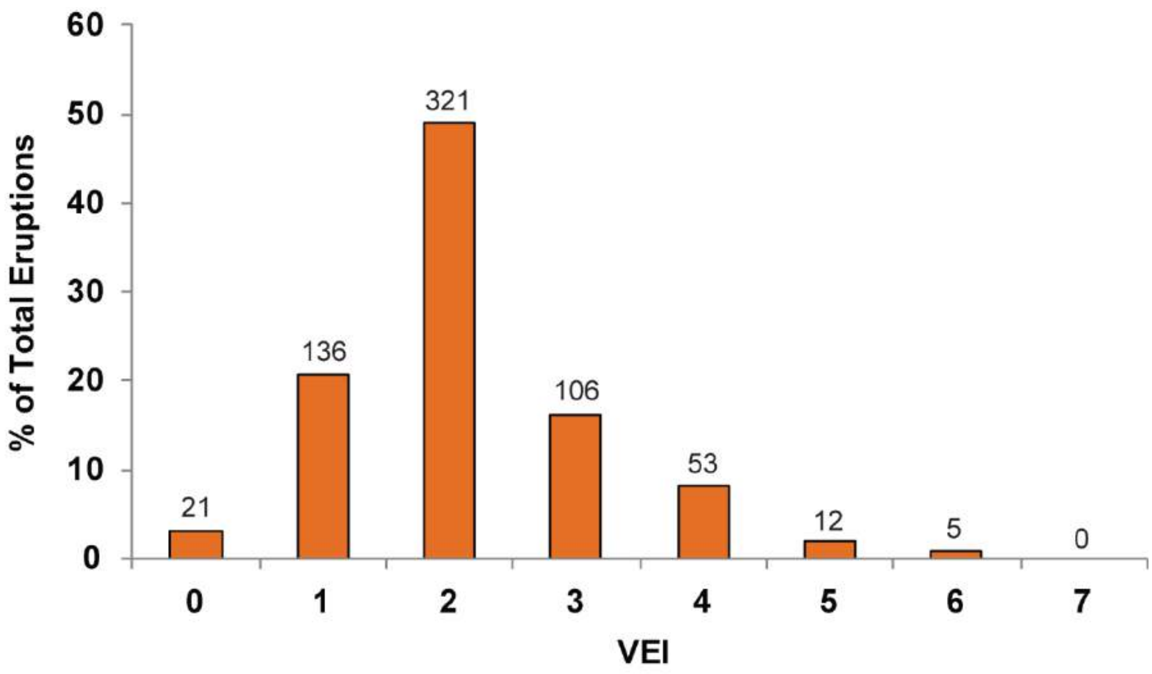

Figure 14.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 127 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	155,467,352
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579 – 13,766 (Mean 7,686)
Gross National Income (GNI) per capita (2005 PPP $)	2,551 – 13,519 (Mean 7,649)
Human Development Index (HDI) (2012)	0.581 – 0.78 (Medium to High, Mean 0.689 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	5,647,382 (3.63 %)
Number (percentage) of people living within 30 km of a Holocene volcano	36,638,320 (23.57 %)
Number (percentage) of people living within 100 km of a Holocene volcano	96,977,702 (62.38 %)

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Infrastructure Exposure

Number of airports within 100 km of a volcano	29
Number of ports within 100 km of a volcano	43
Total length of roads within 100 km of a volcano (km)	34,152
Total length of railroads within 100 km of a volcano (km)	2,308

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CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de; Fuego; Irazú; Turrialba	Santa María; Pacaya; Apoyeque	
	Hazard II			Rincón de la Vieja	San Cristóbal; Momotombo	Popocatépetl; Santa Ana; Telica; Concepción	Atitlán	Chichinautzin; Masaya
	Hazard I				Negro, Cerro; Arenal	San Miguel; Poás	Izalco	
UNCLASSIFIED	**U – HHR**	**Bárcena**; **Socorro**		**Cosigüina**	San Martín; **Chichón, El;** Conchagüita; **Pilas, Las**; **Miravalles**; Barú	Ceboruco; **Tacaná**	**Acatenango**	**Michoacán-Guanajuato;** Almolonga; **San Salvador;** Ilopango
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote; Tecuamburro; Barva	Zitácuaro-Valle de Bravo; Jocotitlán; Toluca, Nevado de; Naolinco Volcanic Field	**Nejapa-Miraflores**
	U- NHHR	Guadalupe; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado; San Borja Volcanic Field; Unnamed; Tres Vírgenes; Tortuga, Isla; Comondú-La Purísima	Utila Island; Maderas; Azul, Volcán; Orosí	San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los; Tigre, Isla el; Zacate Grande, Isla; Zapatera; Ciguatepe, Cerro el; Lajas, Las; Tenorio; Valle, El	Prieto, Cerro; Iztaccíhuatl; Humeros, Los; Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque; Cinotepeque, Cerro; Taburete; Conchagua; **Rota**; **Mombacho**; **Platanar**	Papayo; Serdán-Oriental; Gloria, La; Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego; Singüil, Cerro; **Apaneca Range**; Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna; Yojoa, Lake; Granada; Estelí	Durango Volcanic Field; Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
11	7
35	6
30	5
23	4
6	3
9	2
4	1

Table 14.5 The number of volcanoes in Mexico and Central America classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
11	III
10	II
2	I
95	Unclassified

Table 14.6 The number of volcanoes in the Mexico and Central America region classified at each Risk Level.

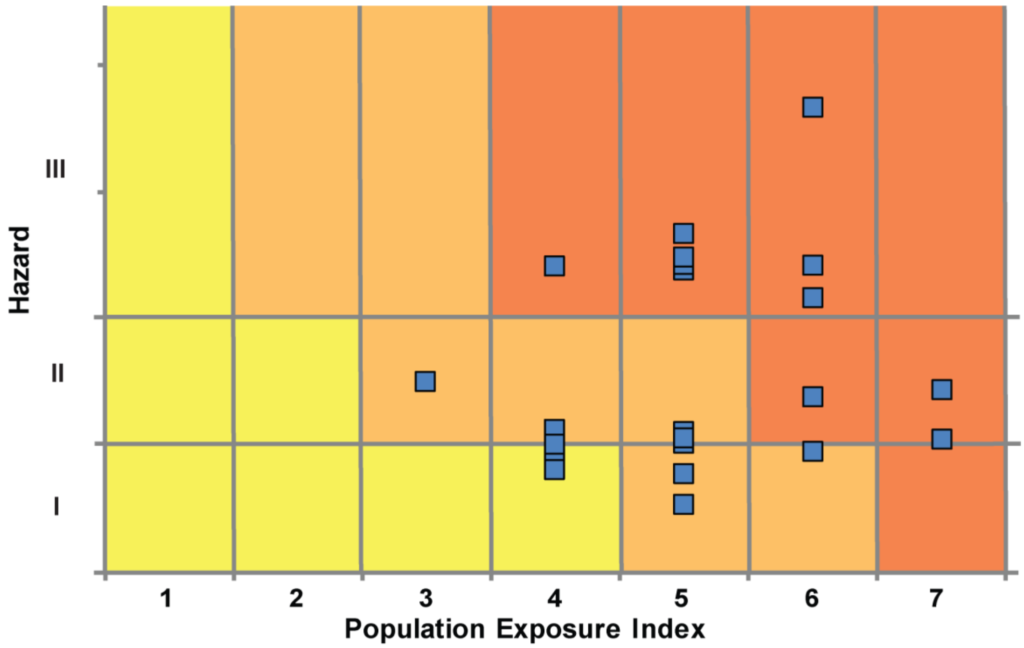

Figure 14.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional monitoring capacity

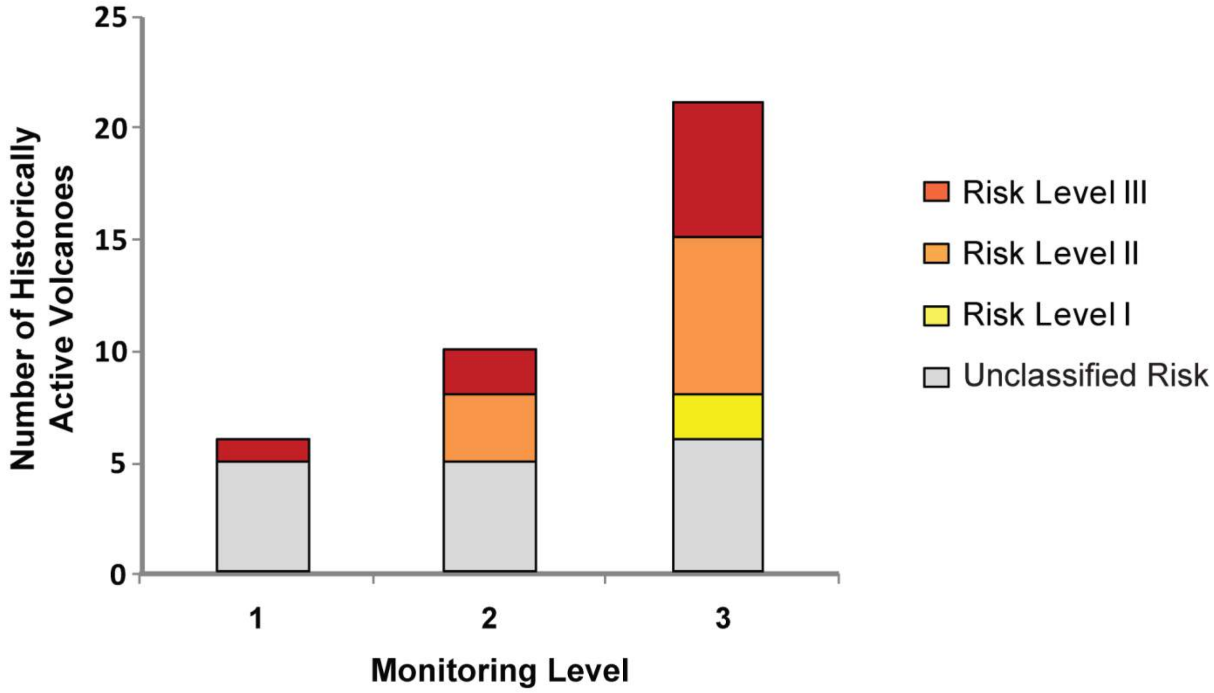

Figure 14.4 The monitoring and risk levels of the historically active volcanoes in Mexico and Central America. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Costa Rica

Description

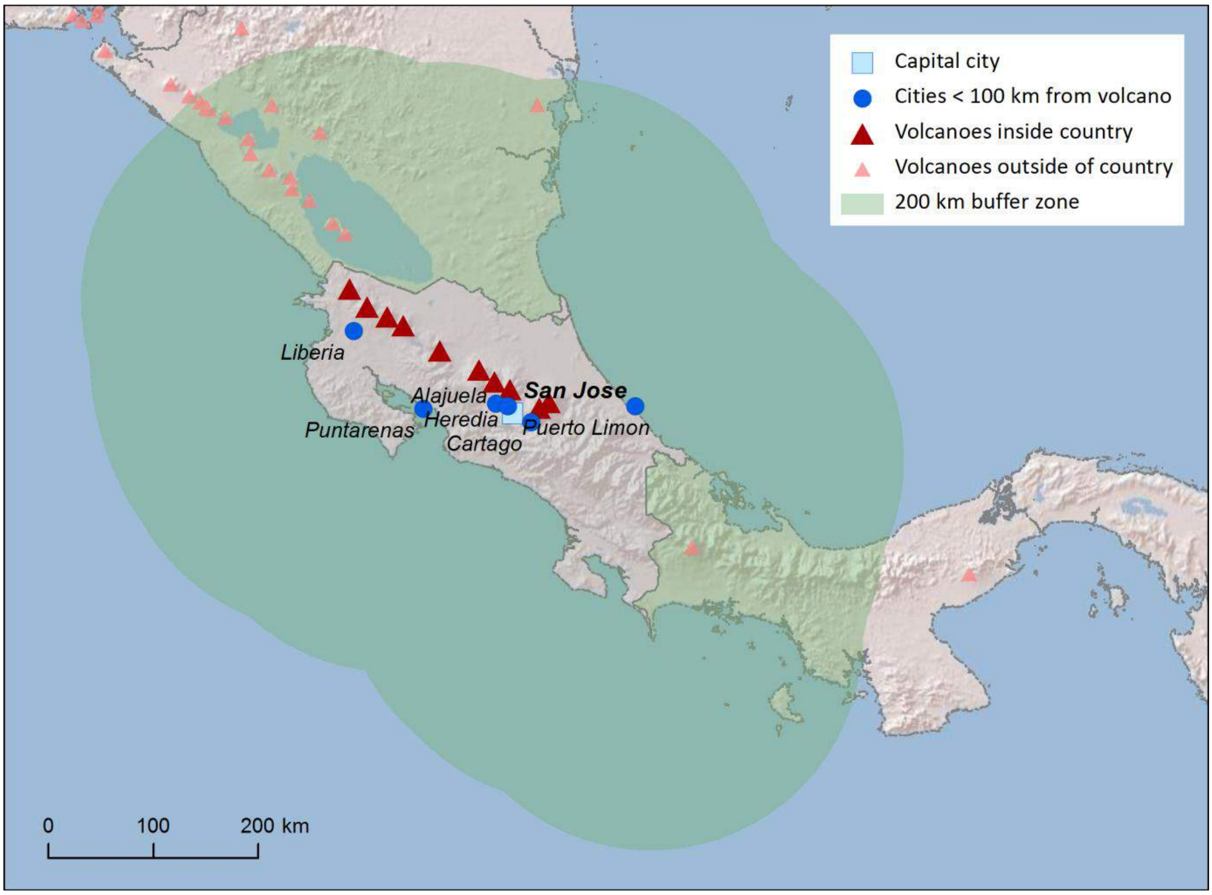

Figure 14.5 Location of Costa Rica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Costa Rica.

Ten Holocene volcanoes are located in northern Costa Rica. Volcanism here is the result of the subduction of the Cocos Plate beneath the Caribbean Plate, forming a chain of andesitic stratovolcanoes and complex volcanoes about 60 km inland, stretching from central Costa Rica to the border with Nicaragua.

VOTW4.22 records 151 confirmed eruptions during the Holocene from eight volcanoes until 2013. The remaining two volcanoes have suspected activity of Holocene age. Most eruptions were recorded historically: 103 eruptions are recorded since 1500 AD at seven volcanoes. These historical eruptions are listed at VEI 0 to 3, indicating moderate explosive activity. Twenty-two VEI 4 eruptions have been recorded during the Holocene, and larger events exist in the Pleistocene record. Pyroclastic flows and lahars are recorded in 10 and 12 historical eruptions, respectively. Lahars are a frequent feature in volcanism in the tropics due to rainfall, and secondary lahars can continue for years after the eruption.

The distribution of volcanoes throughout Costa Rica and neighbouring Panama and Nicaragua means that almost the entirety of the country and population lie within 100 km of one or more Holocene volcanoes.

The assessment of Hazard at the Holocene volcanoes of Costa Rica is associated with large uncertainties. However, almost all of the historically active volcanoes here are more fully understood and so have better constrained, and high, hazard levels. With moderate to large proximal populations at Costa Rican volcanoes the volcanic risk must be considered.

Irazú is one of Costa Rica's most active volcanoes, with frequent historical (post-1500 AD) explosive eruptions documented. An eruption in 1963 – 1965, one of Irazú's largest at VEI 3, caused ash fall that led to significant disruption of San José and surrounding areas. Indeed, it was estimated that 49% of Costa Rica's population was affected by ash fall from this eruption (GCROP, 1964 in Aguilar & Alvarado, 2014). Five major explosive eruptions have occurred at Turrialba during the past 3,500 years, and Turriable has had six eruptions between 2010 and March 2015.

In terms of fatalities, the most destructive eruption in Costa Rica's history is that of Arenal in July 1968. Situated towards the middle of Costa Rica's southeast to northwest trending line of volcanoes and roughly 70 km from the border with Nicaragua, Arenal is one of Costa Rica's most active volcanoes. The 1968 eruption initiated persistent activity which continued until 2010; 78 people were killed in the first three days, mostly by pyroclastic flows but also by ballistic bombs (Alvarado et al., 2006). The village of Tabacon, 3.5 km northwest of the volcano, was almost totally obliterated. Other destructive eruptions include the 1963 – 1965 eruption of Irazú, which led to approximately twenty fatalities (Aguiler & Alvarado, 2014).

The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Costa Rican Institute of Electricity (ICE), is responsible for the monitoring of Costa Rica's volcanoes. They maintain networks of seismometers at all historically active volcanoes, and have additional dedicated ground-based monitoring at three of the volcanoes.

OSIVAM, the Red Sismológica Nacional (RSN: UCR-ICE) have a Volcano Alert Level system, comprising seven levels over three colour-codes. Green, phases 1 to 3, are used for dormant volcanoes and those with active fumaroles and seismicity to minor eruptive activity limited to the vicinity of the crater. Yellow, phases 1 to 2 are used for increases in the volcanic activity, where seismic data exceeds baseline activity and magmatic movements are suspected, with phreatic eruptions and indications that a magmatic eruption will occur within a week. Red, phases 1 to 2, indicate magmatic eruptions, with chance of increased hazard affecting the local region and beyond. OSIVAM, RSN and OVSICORI (El Observatorio Vulcanológico y Sismológico de Costa Rica) release bulletins and reports describing activity, and all are available to the public.

The research and monitoring OSIVAM conduct help to understand activity in Costa Rica, to generate hazard maps and to present information for decision making purposes to the National Emergency Commission.

See also:

Observatorio Sismologico y Vulcanologico Arenal-Miravalles (OSIVAM) website:
www.rsn.ucr.ac.cr/index.php/es/vulcanologia/informacion-general

Aguilar, I. & Alvarado, G.E. (2014) Human and economic losses caused by the volcanism in Costa Rica from 1953 to 2005. *Revista Geológica de América Central*, 51: 93-128.

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Alvarado-Induni, G.E. (2005) *Costa Rica: Land of Volcanoes*. EUNED, Costa Rica, pp.306.

Alvarado, G.E., Soto, G.J., Schmincke, H-U., Bolge, L.L. and Sumita, M. (2006) The 1968 andesitic lateral blast eruption at Arenal volcano, Costa Rica. Journal of Volcanology and Geothermal Research, 157, 9 - 33.

Molina, F., Marti, J., Aguirre, G., Vega, E. & Chavarria, L. (2014) Stratigraphy and structure of the Canas Dulces caldera (Costa Rica). Geological Society of America Bulletin, 126: 1465-1480.

Volcano Facts

Number of Holocene volcanoes	10*
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	6
Number of volcanoes generating lahars	4+
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	103 (Aguilar & Alvarado, 2014)
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.7 eruption of the Liberia ignimbrite from Rincón de la Vieja at about 1.43 Ma (Molina et al., 2014)
Largest recorded Holocene eruption	19 eruptions of Arenal are recorded of VEI 4 during the Holocene.
Number of Holocene eruptions	151 confirmed eruptions. 18 uncertain and 8 discredited eruptions.
Recorded Holocene VEI range	0 – 4 and Unknown
Number of historically active volcanoes	6-
Number of historic eruptions	103

*Further volcanoes may have had Holocene age activity as suggested by a young appearance of their morphology, however detailed dating has not yet been undertaken. In some cases, what are considered sub-features of volcanoes in VOTW4.0 can be described as separate volcanoes. For example Chato is considered in VOTW4.0 as a stratovolcano of Arenal.

+Further volcanoes have had lahars in the Holocene, which are not specifically recorded in VOTW.4.22.

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-In VOTW4.22 Irazu, Poas, Arenal, Rincón de la Vieja, Turrialba and Miravalles have records of confirmed historical (post-1500 AD) eruptions. However, the 1946 eruption of Miravalles is described as a non-volcanic hydrothermal explosion by Alvardo-Induni (2005).

Number of volcanoes	Primary volcano type	Dominant rock type
10	Large cone(s)	Andesitic (10)

Table 14.7 The number of volcanoes in Costa Rica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	10,732
Gross National Income (GNI) per capita (2005 PPP $)	10,863
Human Development Index (HDI) (2012)	0.773 (High)

Population Exposure

Capital city	San José
Distance from capital city to nearest Holocene volcano	~25 km
Total population (2011)	4,576,562
Number (percentage) of people living within 10 km of a Holocene volcano	144,235 (3.2%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,424,754 (74.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,707,288 (>100%)

Ten largest cities, as measured by population and their population size (2011, data via data.un.org):

San José	284,054
Alajuela	254,886
Desamparados	208,411
San Carlos	163,745
Cartago	147,898
Perez Zeledón	134,534
Pococí	125,962
Heredia	123,616
Goicoechea	115,084
Puntarenas	115,019

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Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,031

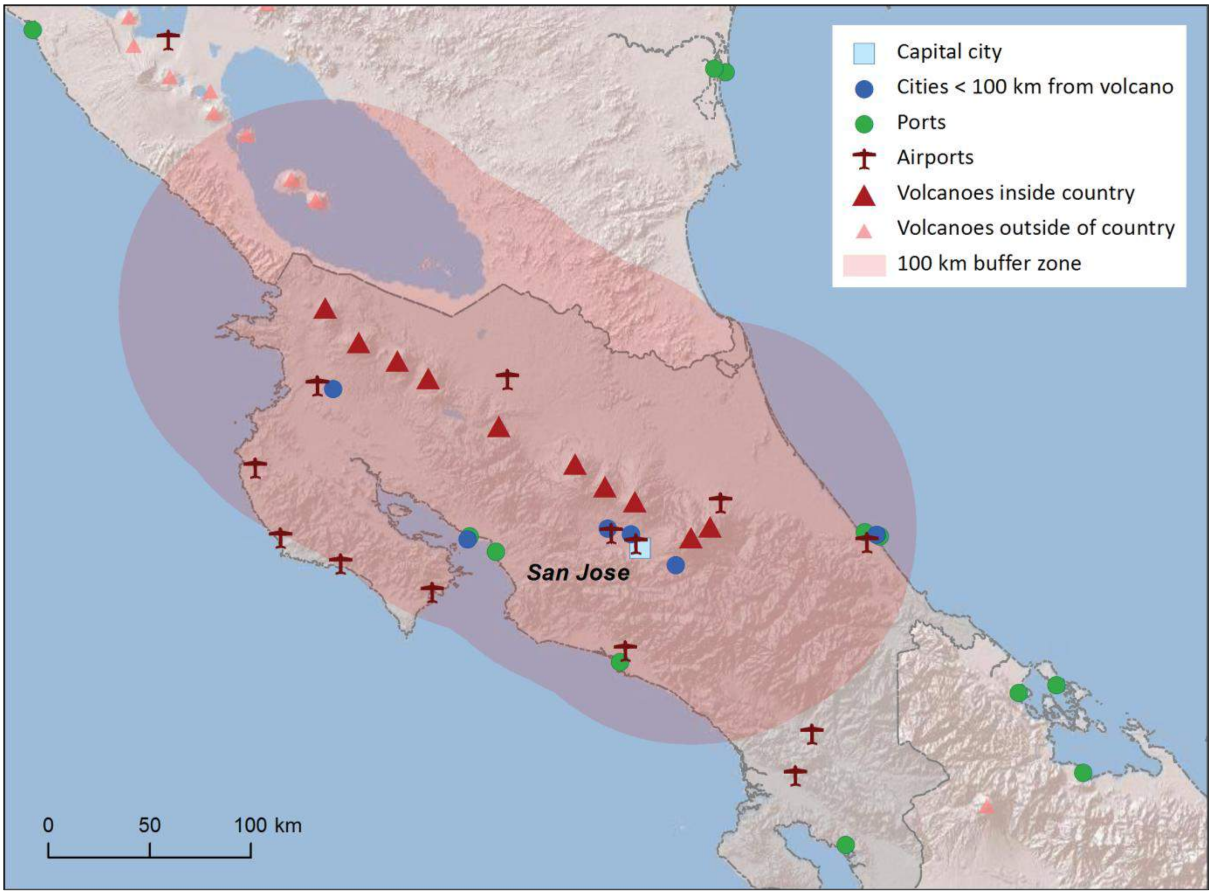

Figure 14.6 The location of Costa Rica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The Holocene volcanoes in Costa Rica form a chain through the centre to the north-west of the country. Being a relatively narrow country, the 100 km radii of these volcanoes forms a continuous band of exposure throughout much of the country, with only the southernmost region bordering Panama lying outside of this zone. The 100 km radii also extend beyond Costa Rica's borders and into Nicaragua, exposing a significant area here. Whilst the area around the Panama border lies outside of the radii of the Costa Rican volcanoes, it falls within the 100 km radius of Barú in Panama. Six of the largest cities in Costa Rica lie within 100 km of the country's Holocene volcanoes, including the capital, San José. San José lies within 100 km of five historically active volcanoes. Much of the critical infrastructure in the country is exposed to the volcanic hazard, including ports, airports and an extensive road network.

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Hazard, Uncertainty and Exposure Assessments

The data availability in the eruption records of Costa Rica's volcanoes is varied. Half of the volcanoes here have adequate data to allow the calculation of the VHI and the determination of a hazard level. These classified volcanoes are classed at Hazard Levels I, II and III. Irazú and Turrialba both have records of VEI 3 and 4 Holocene eruptions and explosive eruptions producing pyroclastic flows, and these are therefore scored most highly at Hazard Level III.

Five volcanoes here are unclassified as calculation of the VHI would be associated with large uncertainties due to the absence of sufficient information in the record. Indeed, three volcanoes have no confirmed Holocene eruptions. Barva and Miravalles both have a Holocene record. In 1980 and 1997 a seismic swarm and felt earthquakes occurred near Platanar, which may have been related to local faults. The 1946 steam explosion at Miravalles was described as non-volcanic. In 1997 there was a seismic swarm at Miravalles, which did not correlate with local faults.

The PEI in Costa Rica ranges from moderate to high at PEI 3 to 5. Coupled with the hazard levels, this categorises the volcanoes here at Risk Levels I to III. Irazú and Turialba are classed at Risk Level III, with over 3 million people living within 100 km and a hazard classification of Level III.

CLASSIFIED	**Hazard III**					Irazú; Turrialba		
	Hazard II			Rincón de la Vieja	Arenal			
	Hazard I					Poás		
UNCLASSIFIED	**U – HHR**				**Miravalles**			
	U- HR					Barva		
	U- NHHR			Orosí	Tenorio	**Platanar**		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.8 Identity of Costa Rica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Irazú	5	III
Turrialba	5	III
Poás	5	II
Arenal	4	II
Rincón de la Vieja	3	II

Table 14.9 Classified volcanoes of Costa Rica ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 2 volcanoes.

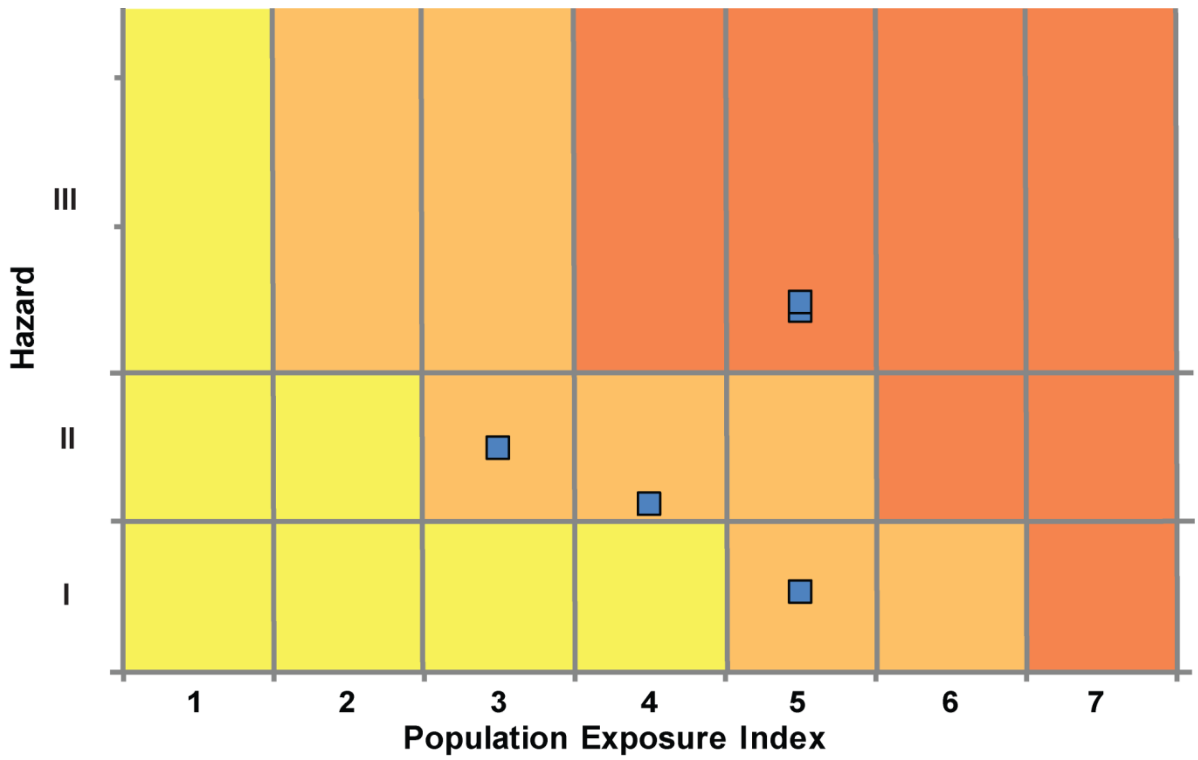

Figure 14.7 Distribution of Costa Rica's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes are recorded as having historical activity in Costa Rica. The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Red Sismológica Nacional and OVSICORI, is responsible for seismological and volcanological monitoring in northern Costa Rica. All historically active volcanoes have dedicated ground-based monitoring systems in place, all with seismic networks, and additional deformation and gas monitoring used at Arenal and Poás (Risk II), and Miravalles (Risk unclassified). The two Risk Level III volcanoes, Irazú and Turrialba, have regular visits by the observatory staff for further monitoring.

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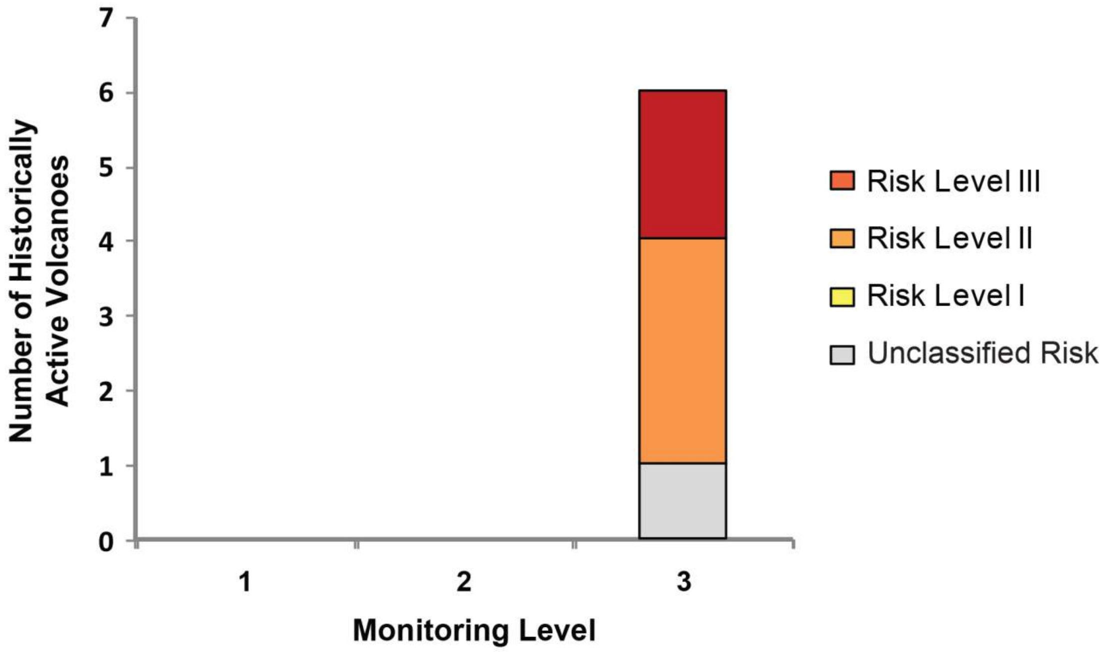

Figure 14.8 The monitoring and risk levels of the historically active volcanoes in Costa Rica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

El Salvador

Description

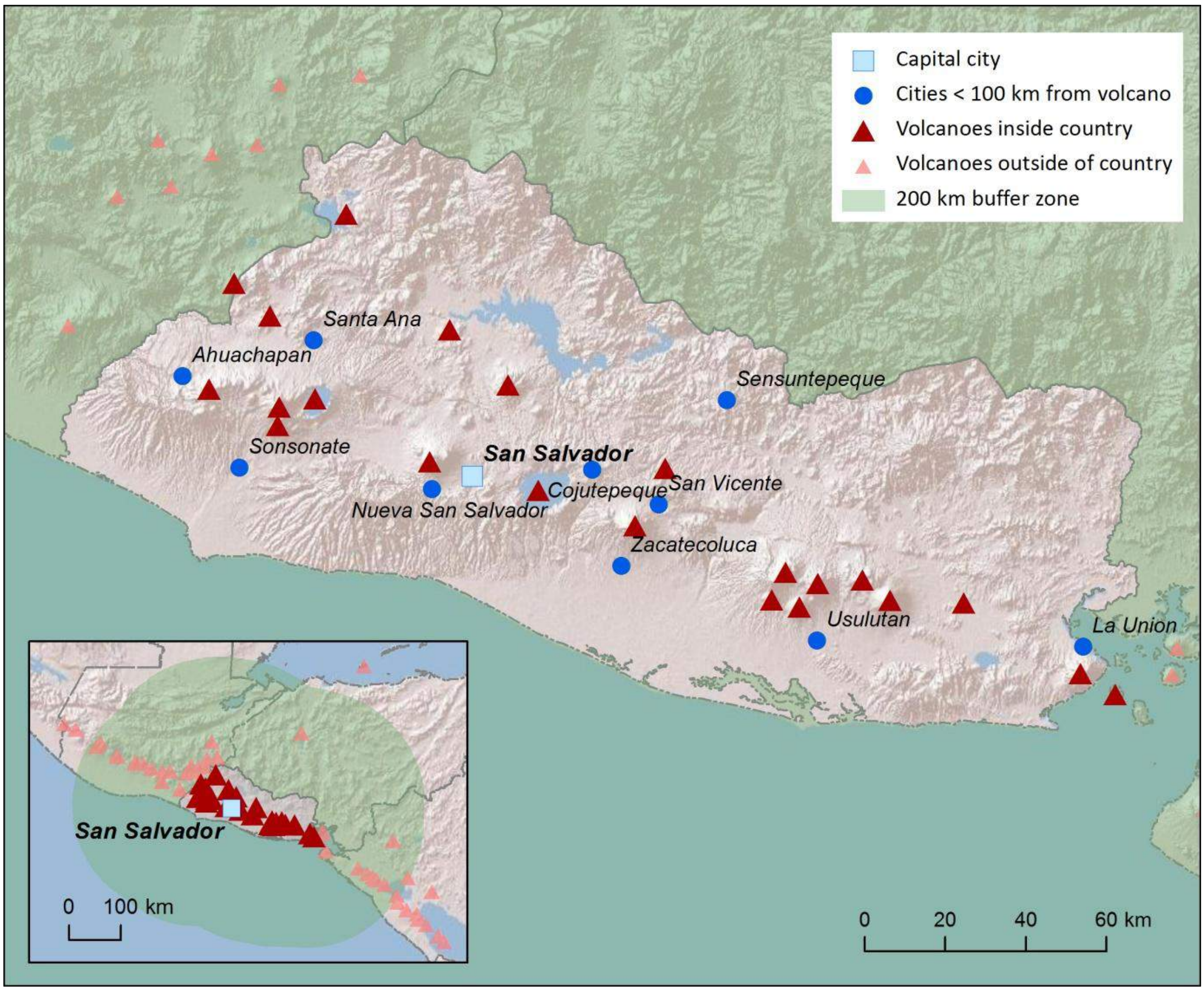

Figure 14.9 Location of El Salvador's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect El Salvador.

Twenty-two Holocene volcanoes are located throughout El Salvador, in a chain parallel to the coastline stretching from Guatemala in the north to the Gulf of Fonseca between El Salvador, Honduras and Nicaragua. Volcanism here is related to the subduction of the Cocos Plate beneath the Caribbean Plate.

The volcanoes of El Salvador are dominantly basaltic and andesitic stratovolcanoes, but there are also volcanic fields and more felsic calderas.

Six volcanoes have produced 102 eruptions during the Holocene, with the remaining volcanoes suspected of having activity of Holocene age. Eruptions have ranged in size from small VEI 0 events to large explosive VEI 6 events. Of these 102 eruptions, only three are recorded before 1500 AD, indicating that the eruption record is poorly known before historical times. All historical eruptions were small to moderate at VEI 0 – 3.

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The assessment of hazard at most of the volcanoes of El Salvador is complicated by poorly constrained eruptive histories, with hazard scores assigned here with large associated uncertainties. Further work is required to more fully understand the age and size of El Salvador's eruptions.

The distribution of the volcanoes through El Salvador means that the entirety of the country falls within 100 km of one or more Holocene volcano, thus all infrastructure and the total population fall in this zone. The capital, San Salvador, lies within 20 km of two historically active volcanoes – Ilopango and San Salvador, both of which have produced VEI 3 eruptions during historic times and VEI 4 - 6 eruptions pre-1500 AD. The most frequently active volcano in El Salvador, Izalco, lies within 50 km of the capital. Major et al. (2004) suggest that even short (>4 km) debris flows or lahars at San Salvador, San Vicente and San Miguel volcanoes could "put hundreds to thousands of lives, property and infrastructure at risk", with areas within 10 km of volcanoes being inundated within minutes to tens of minutes.

Over twenty eruptions have resulted in property damage in El Salvador and six eruptions of Santa Ana, Izalco, San Salvador, Ilopango and Apaneca Range have resulted in the loss of about 30,000 lives. The largest loss of life resulted from the 450 AD eruption of Ilopango, which produced widespread pyroclastic flows.

The Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales, DGOA-MARN is responsible for monitoring the volcanoes of El Salvador. DGOA-MARN monitor historically active volcanoes with dedicated instrumentation networks. Continuous monitoring is undertaken to establish baseline data, which allows for anomalous behaviour to be identified. Various techniques are used, with a network of telemetered seismic stations being the principal technique. Additional geochemical, gas and hydrogeochemical, deformation and visual monitoring is also undertaken. DGOA-MARN collaborate with the Volcanological Research Group at the National University of El Salvador in geochemical monitoring of gases.

About 10% of personnel at DGOA-MARN have experience of responding to an eruption, which can be expected to be beneficial in future responses to eruptions. Set procedures have been developed which will be followed in the event of unrest or eruption, with an activity ladder of forewarning – warning – alert – emergency. DGOA-MARN would inform civil defence as unrest and eruption occurs. Resources are currently not available to respond to and extend monitoring to developing situations at currently unmonitored or unrecognised volcanoes. Volcanic risk could be reduced through additional resources and increase in monitoring capacity.

See also:

DGOA-MARN website: www.snet.gob.sv/ver/vulcanologia

Major, J.J., Schiling, S.P., Pullinger, C.R., and Demetrio Escobar, C. (2004) Debris-flow hazards at San Salvador, San Vicente, and San Miguel volcanoes, El Salvador. *GSA Special Papers*, v.375, 89-108.

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Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	5
Number of volcanoes generating pyroclastic flows	4
Number of volcanoes generating lahars	1 eruption of Santa Ana in 2005 resulted in lahars according to VOTW4.22. However, lahars and secondary have also occurred at San Miguel, San Salvador and San Vicente.
Number of volcanoes generating lava flows	4 - 5
Number of fatalities caused by volcanic eruptions	?30,383
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.1 Conacaste (CCT) eruption of Coatepeque Caldera at 51 ka.
Largest recorded Holocene eruption	The M6.7 TBJ eruption of Ilopango at 1.5 ka.
Number of Holocene eruptions	102 confirmed eruptions. 13 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	6
Number of historic eruptions	99

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
14	Large cone(s)	Andesitic (7), Basaltic (7)
5	Small cone(s)	Basaltic (2), Dacitic (1), Unknown (2)

Table 14.10 The number of volcanoes in El Salvador, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,309,000

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Gross Domestic Product (GDP) per capita (2005 PPP $)	6,032
Gross National Income (GNI) per capita (2005 PPP $)	5,915
Human Development Index (HDI) (2012)	0.680 (Medium)

Population Exposure

Capital city	San Salvador
Distance from capital city to nearest Holocene volcano	12.3 km
Number (percentage) of people living within 10 km of a Holocene volcano	2,104,232 (34.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	5,810,384 (95.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,309,000 (100%)

Ten largest cities, as measured by population and their population size:

San Salvador	525,990
San Miguel	247,119
Santa Ana	176,661
Santa Tecla	124,694
Sonsonate	59,468
Usulutan	51,910
Cojutepeque	48,411
Zacatecoluca	39,613
San Vicente	37,326
Ahuachapan	34,102
La Union	26,807

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	2,019
Total length of railroads within 100 km of a volcano (km)	0

The numerous Holocene volcanoes in El Salvador are distributed throughout the country. Being a relatively small country, measuring no more than about 250 km across, the country in its entirety lies within the 100 km radii of the Holocene volcanoes. All infrastructure in the country is therefore

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exposed to the volcanic hazard. The capital, San Salvador, lies within 100 km of 15 Holocene volcanoes in El Salvador, including two historically active volcanoes within 20 km. The radii also extend beyond the country's border into Guatemala, Honduras and Nicaragua, and indeed volcanoes in these neighbouring countries have 100 km radii, which extend into El Salvador, including Cosiguina in Nicaragua and eleven volcanoes in Guatemala.

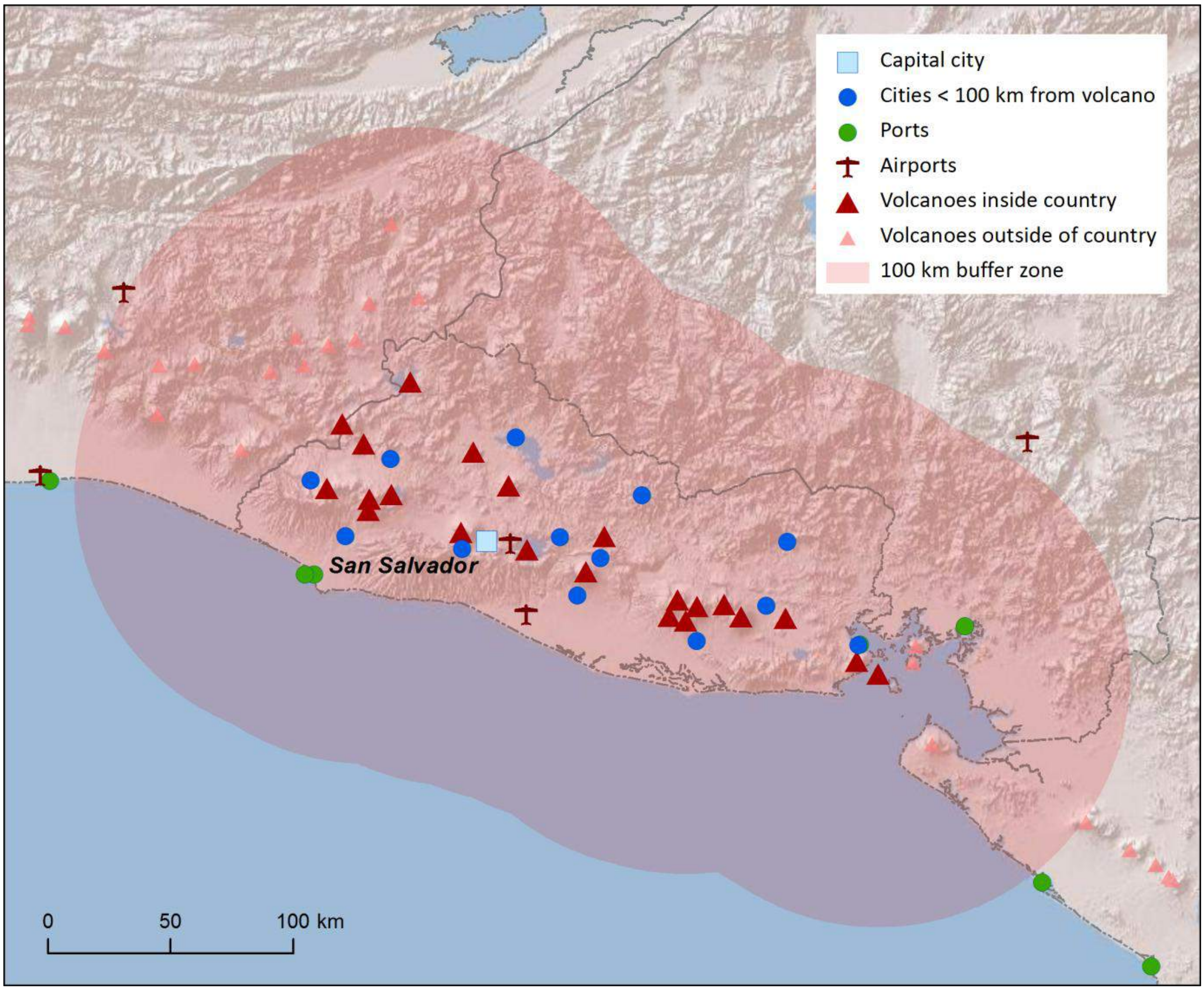

Figure 14.10 The location of El Salvador's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying amounts of information available in the eruption records of El Salvador's volcanoes. Just three volcanoes out of 22 have a detailed enough record to define hazard through the calculation of VHI, without large associated uncertainties. These three classified volcanoes are classed as Hazard Level I and II.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Three have historical records (post-1500 AD), including San Salvador and Ilopango which both have Holocene records of large VEI ≥4 eruptions.

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The PEI ranges from moderate to very high in El Salvador with large proximal populations. The classified volcanoes Izalco, Santa Ana and San Miguel are all classed at Risk Level II, with high local populations. Although unclassified for hazard, five volcanoes (San Salvador, Ilopango, Chingo, Coatepeque Caldera and Apastepeque Field) would be classed at Risk Level III given their PEI of 7.

CLASSIFIED	**Hazard III**							
	Hazard II					Santa Ana		
	Hazard I					San Miguel	Izalco	
UNCLASSIFIED	**U – HHR**				Conchagüita			**San Salvador;** Ilopango
	U- HR							
	U- NHHR					Cinotepeque, Cerro; Taburete; Conchagua	San Diego; Singüil, Cerro; **Apaneca Range;** Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna	Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.11 Identity of El Salvador's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Izalco	6	II
Santa Ana	5	II
San Miguel	5	II

Table 14.12 Classified volcanoes of El Salvador ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 0 volcanoes.

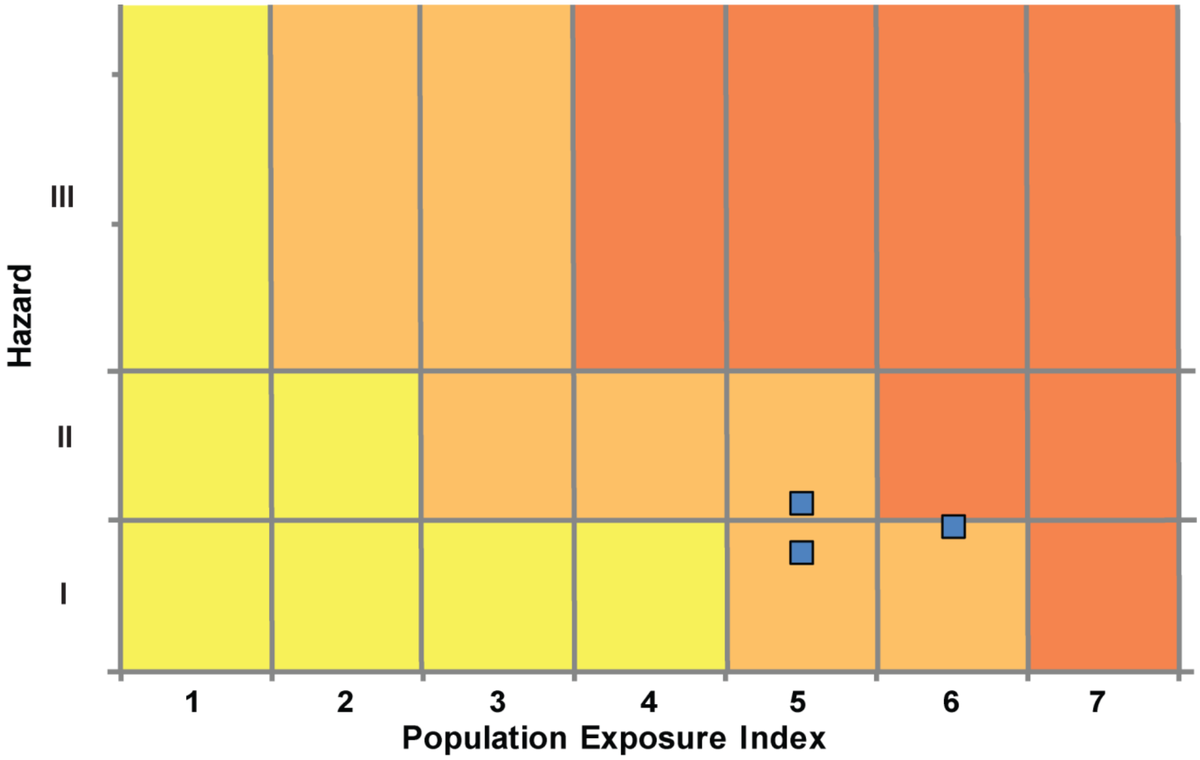

Figure 14.11 Distribution of El Salvador's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in El Salvador. The institution responsible for the monitoring of these volcanoes in DGOA-MARN the Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales. Seismic monitoring is undertaken at all volcanoes, with additional gas monitoring at San Miguel and San Salvador. Additional gas and deformation monitoring is undertaken at Santa Ana.

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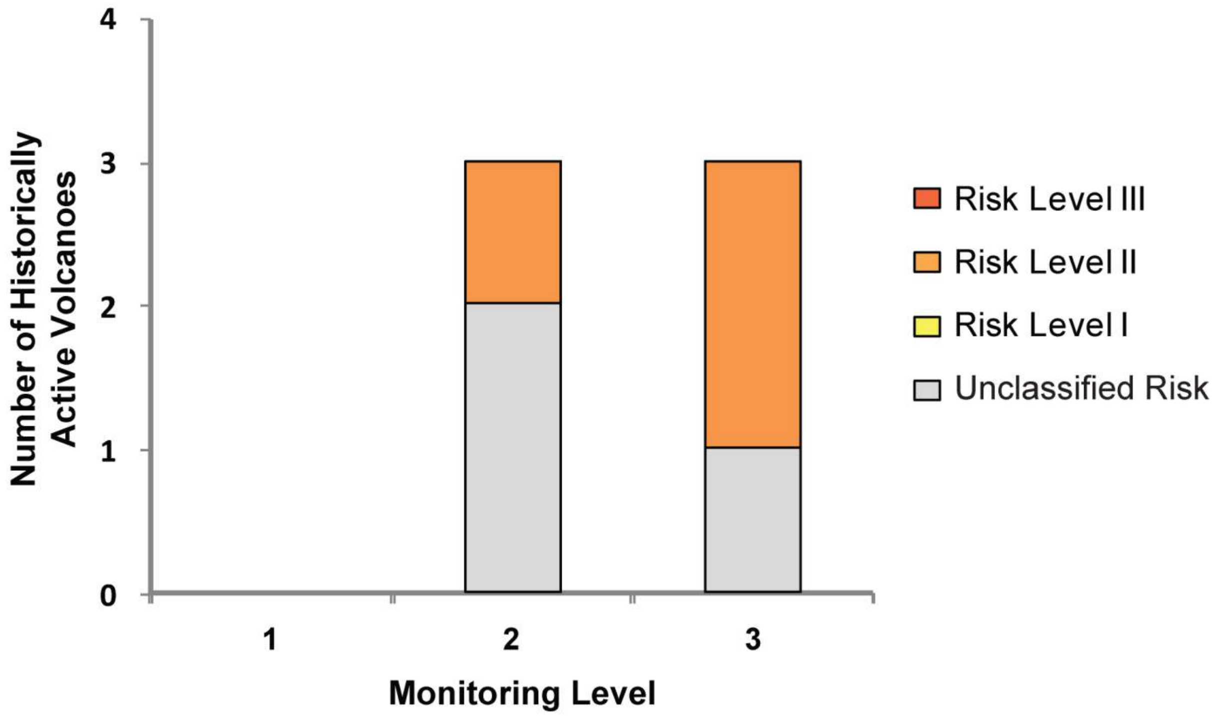

Figure 14.12 The monitoring and risk levels of the historically active volcanoes in El Salvador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Guatemala

Description

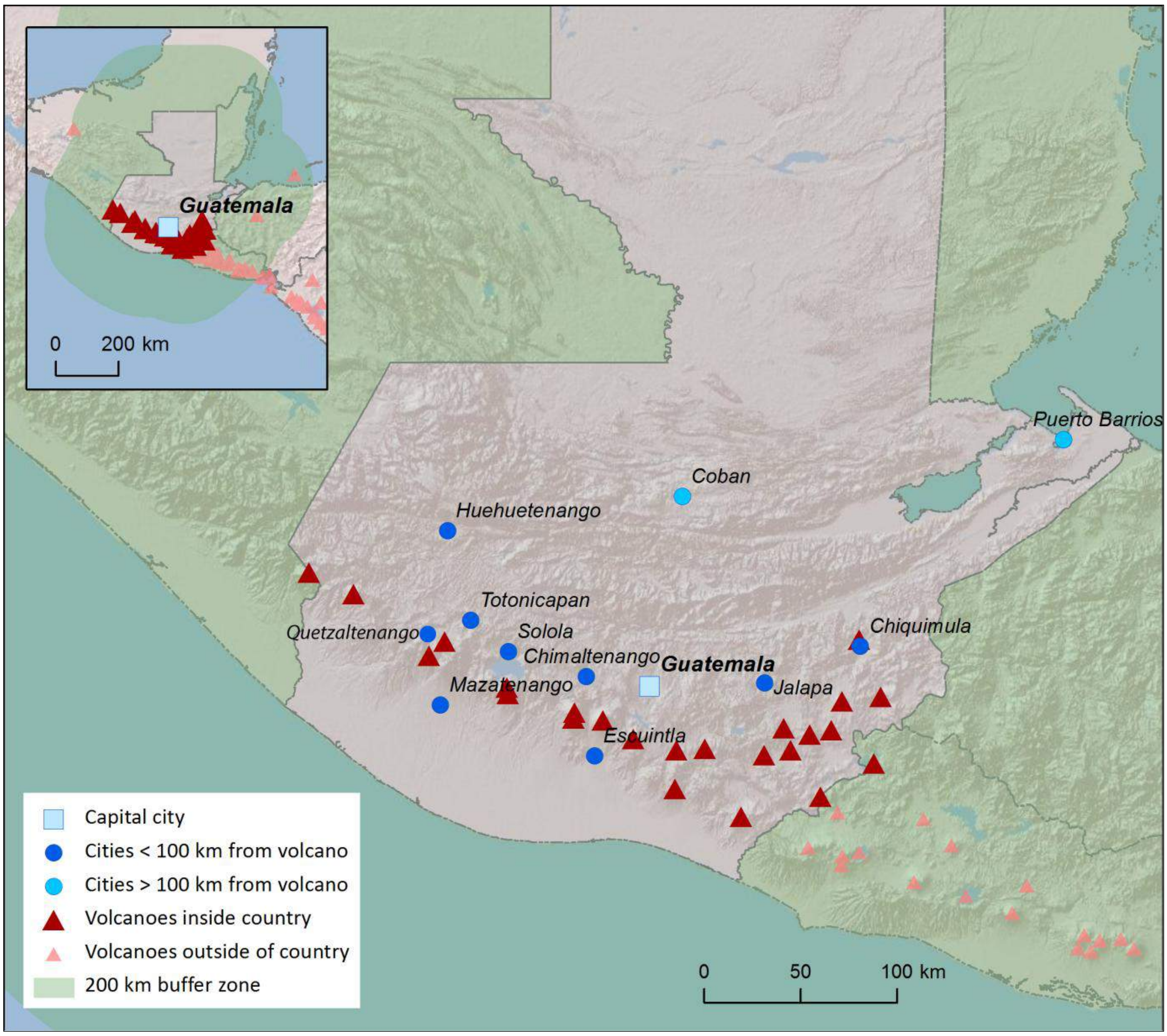

Figure 14.13 Location of Guatemala's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guatemala.

Twenty-four Holocene volcanoes are located in Guatemala, dominantly in a chain parallel to the country's Pacific coastline stretching from El Salvador in the south to Mexico in the north. Volcanism here is due to the subduction of the Cocos Plate beneath the Caribbean Plate.

Most of the volcanoes in Guatemala (17) are stratovolcanoes most frequently of basaltic to andesitic composition. A number of volcanic fields and cinder cones are present here, dominantly situated in the south-east towards the border with El Salvador. Counting individual cones and vents, INSIVUMEH, the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología states that 324 Quaternary volcanic vents are present throughout Guatemala from Bohnenberger (1969).

During the Holocene, 128 eruptions of VEI 1 - 6 are recorded at seven of Guatemala's volcanoes. The remaining volcanoes have suspected though unconfirmed eruptions. The Holocene VEI record indicates a range of eruption styles and sizes, from mild eruptions to large explosive events. Of these

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eruptions, 104 are historical (recorded since 1500 AD) suggesting the record is poorly known before historic times. Of the seven active volcanoes, all but Tecuamburro have records of producing pyroclastic flows, but only Santa Maria, Fuego and Tacana have a Holocene record of VEI ≥4 eruptions. An eruption of Cerro Quemada at Almolonga in 1150 BP is classed at VEI 3 in VOTW4.22, but has a volume which might indicate VEI4 (caldera volume of 0.1km^3, Conway et al., 1992) and numerous VEI 3 eruptions are recorded at Pacaya. The largest Holocene eruption occurred at Santa Maria in 1902, with a VEI 6 eruption, which devastated much of south-west Guatemala and resulted in about 10,000 fatalities through ash fall and secondary disease.

Eight eruptions at Santa Maria, Fuego and Pacaya have resulted in fatalities, and numerous evacuations have been ordered with a record of many eruptions resulting in property damage. Lahars in 1541 at Agua, during a non-eruptive phase, destroyed the then capital, Ciudad Vieja. The mobilisation of old tephra deposits during intense rainfall to form lahars can occur for years after eruptions, producing a long-term hazard.

A large population resides close to the volcanoes, with 95% of Guatemala's population living within 100 km of one or more Holocene volcanoes. Three large stratovolcanoes, Acatenango, Agua, and Fuego, overlook Guatemala's former capital, Antigua Guatemala, whilst much of the population of the present capital, Guatemala City, lives within 15 to 20 km of Pacaya. About 2 million live within the Pleistocene Amatitlan caldera, just north of Pacaya. The historically active Atitlán, Fuego and Acatenango are also located within about 70 km of the capital. Though with no recorded historical eruptions, but with a catastrophic historical lahar, Agua is also located within this distance. Further, Guatemala's second city and fourth largest population centre, Quetzaltenango, is situated approximately 10 km north-northeast of Santa María, and less than 5 km from the Cerro Quemado dome complex (part of the Almolonga caldera and volcanic field (Ewert and Harpel, 2004). Guatemala's volcanoes also threaten rural communities, as all have over 100,000 residents within 30 km of their summits.

INSIVUMEH, a government funded agency, which is part of the Communications, Infrastructure and Housing Ministry, is responsible for monitoring of Guatemala's volcanoes and the provision of advice to the government regarding volcanic activity. INSIVUMEH run four Volcano Observatories: Santiaguito Observatory (OVSAN), Fuego Observatory (OVFGO I) in Panimache I and Sangre de Cristo (OVFGO II), and the Pacaya Observatory (OVPAC). Visual monitoring is undertaken and continuous seismic monitoring is in place with real-time telemetry of the data to the INSIVUMEH headquarters. The seismic equipment used to monitor volcanoes is part of the national seismic network. The resources are not available to respond to developing situations at previously unknown/inactive or un-monitored volcanoes.

A colour-coded alert scheme is used to communicate volcanic activity. INSIVUMEH communicate with the civil protection agency CONRED to recommend alert levels. These alert levels are communicated to the public via bulletins. If unrest increases at a volcano, INSIVUMEH communicate this to CONRED. Protocols are in place for increasing unrest and eruption, including the issuing of regular bulletins and communication with the Civil Aviation Authority and regional VAAC. INSIVUMEH are primarily responsible for the hazard evaluation, while CONRED and other civil authorities undertake risk assessments.

See also:

Bohnenberger, O.H. (1969) Los focus eruptivos Cuaternarios de Guatemala. Publicaciones Geologicas del ICAITI, 23-24.

Conway, F.M., Vallance, J.W., Rose, W.I., Johns, G.W. and Paniagua, S. (1992) Cerro Quemado, Guatemala: the volcanic history and hazards of an exogenous volcanic dome complex. *Journal of Volcanology and Geothermal Research*, 52:4, 303 – 308, 311-323.

Ewert, J.W. and Harpel, C.J. (2004) In Harm's Way: Population and Volcanic Risk. *Geotimes*, April 2004.

INSIVUMEH: www.insivumeh.gob.gt/

CONRED: www.conred.gob.gt/www/index.php

Volcano Facts

Number of Holocene volcanoes	24, inclusive of two on the border with El Salvador and one on the border with Mexico
Number of Pleistocene volcanoes with M≥4 eruptions	3 currently listed in LaMEVE: Fuego, Pacaya and Ayarza. There is also evidence of M≥4 eruptions at Tacaná, Santa Maria, Siete Orejas, Sabana Grande, Atitlan, Amatitlan and Tecuamburro.
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5*
Number of volcanoes generating lava flows	6*
Number of fatalities caused by volcanic eruptions	?>11,555
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.8 Los Chocoyos Ash (H) eruption of Atitlán at 84 ka.
Largest recorded Holocene eruption	The M6.3 eruption of Santa María in 1902 AD.
Number of Holocene eruptions	128 confirmed eruptions. 28 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	1 – 6 and unknown

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Number of historically active volcanoes	7
Number of historic eruptions	104

*The number of volcanoes with Holocene age lahars and lava flows recorded in VOTW4.22 is thought to be an underestimate, with most Guatemala volcanoes suspected of producing lavas and lahars due to intense rainfall outside of eruptive activity.

Number of volcanoes	Primary volcano type	Dominant rock type
17	Large cone(s)	Andesitic (9), Basaltic (5), Dacitic (3)
1	Lava dome(s)	Rhyolitic (1)
6	Small cone(s)	Basaltic (6)

Table 14.13 The number of volcanoes in Guatemala, their volcano type classification and dominant rock type according to VOTW4.0.

The volcano types described here are the classifications in VOTW4.0. Lava domes are present at several volcanoes. For example Almolonga is listed as a stratovolcano, however much of the Holocene volcanism has been dominated by dome formation and destruction. The same applies to Santa Maria, which is listed as a stratovolcano, but has been dominated by dome forming activity for about a century and it is this lava dome activity which is the main cause of hazard.

Socio-Economic Facts

Total population (2012)	15,135,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,351
Gross National Income (GNI) per capita (2005 PPP $)	4,325
Human Development Index (HDI) (2012)	0.581 (Medium)

Population Exposure

Capital city	Guatemala City
Distance from capital city to nearest Holocene volcano	29.0 km*
Total population (2011)	13,824,463
Number (percentage) of people living within 10 km of a Holocene volcano	1,423,044 (10.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	7,922,171 (57.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	13,081,892 (94.6%)

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*Villa Nueva and southern parts of Guatemala City lie within 15 to 20 km of the nearest volcano, Pacaya.

Ten largest cities, as measured by population and their population size:

Guatemala City	1,022,001 (UNDP data, 2001)
Mixco	452,134 (UNDP data, 2001)
Villa Nueva	390,329 (UNDP data, 2001)
Quetzaltenango	152,223 (UNDP data, 2001)
Escuintla	114,626 (UNDP data, 2001)
Chimaltenango	82,370
Huehuetenango	79,426
Totonicapan	69,734
Puerto Barrios	56,605
Coban	53,375

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	2,921
Total length of railroads within 100 km of a volcano (km)	0

The numerous volcanoes in Guatemala are distributed through the south of the country, from the border with El Salvador to that with Mexico. With so many volcanoes in a relatively narrow stretch of land, the 100 km radii extends to encompass much of southern Guatemala, and also extend into El Salvador, Mexico and Honduras exposing infrastructure here. The 100 km radii of about 10 volcanoes in El Salvador also extend into Guatemala. Many of Guatemala's largest cities are located in the south of the country, and hence fall within 100 km of the Holocene volcanoes. Indeed eight of the most populous cities lie here in addition to the capital, Guatemala City. Much of the critical infrastructure in the country is therefore exposed to the volcanic hazard, including airports, ports and an extensive road network. Guatemala City lies within 70 km of several historically active volcanoes, including Atitlan, Acatenango, Fuego, Agua and Pacaya.

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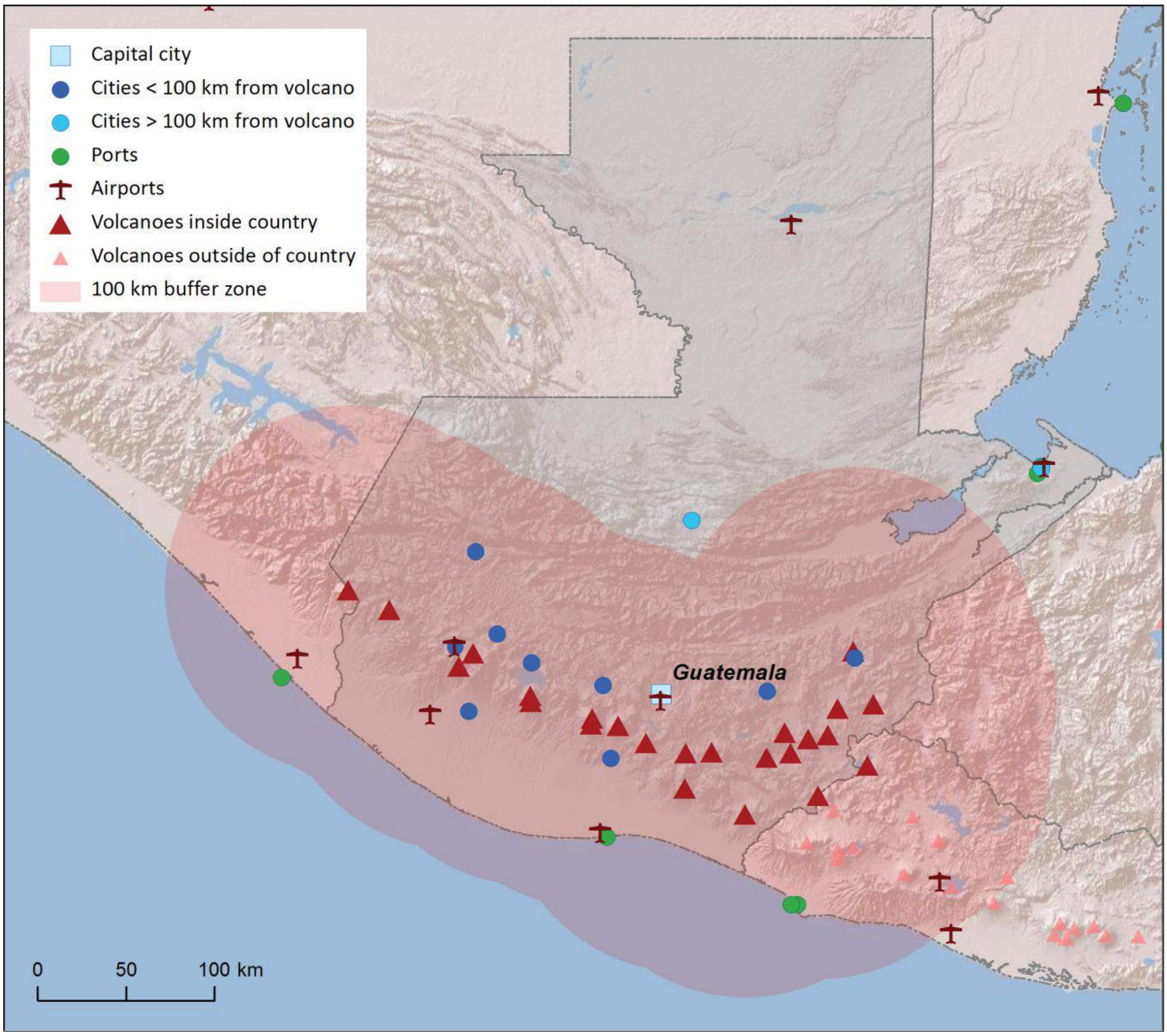

Figure 14.14 The location of Guatemala's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Guatemala's volcanoes. Just four volcanoes out of 24 have sufficient detail to define the hazard through the calculation of the VHI. Three of these, Fuego, Santa Maria and Pacaya are classified at Hazard Level III, with records of explosive activity and pyroclastic flows and Holocene records of VEI ≥3 eruptions. Atitlan is classified as Hazard Level II, with a smaller percentage of eruptions with pyroclastic flows. All four of these volcanoes have high proximal populations, and PEIs of 5 and 6. These are therefore classified at Risk Level III.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Four have Holocene records, including historical events at Tacana, Almolonga and Acatenango. Eruptions since 1900 AD are recorded at the latter. With no classification of hazard, the risk levels cannot be determined, however these all have large local populations, with PEIs of 5 – 7, suggesting risk levels of II to III.

CLASSIFIED	Hazard III					Fuego	Santa María; Pacaya	
	Hazard II						Atitlán	
	Hazard I							
UNCLASSIFIED	U – HHR					Tacaná	**Acatenango**	Almolonga
	U- HR					Tecuamburro		
	U- NHHR					Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque	Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego	Chingo
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.14 Identity of Guatemala's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Pacaya	6	III
Santa María	6	III
Atitlán	6	III
Fuego	5	III

Table 14.15 Classified volcanoes of Guatemala ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 4 volcanoes.

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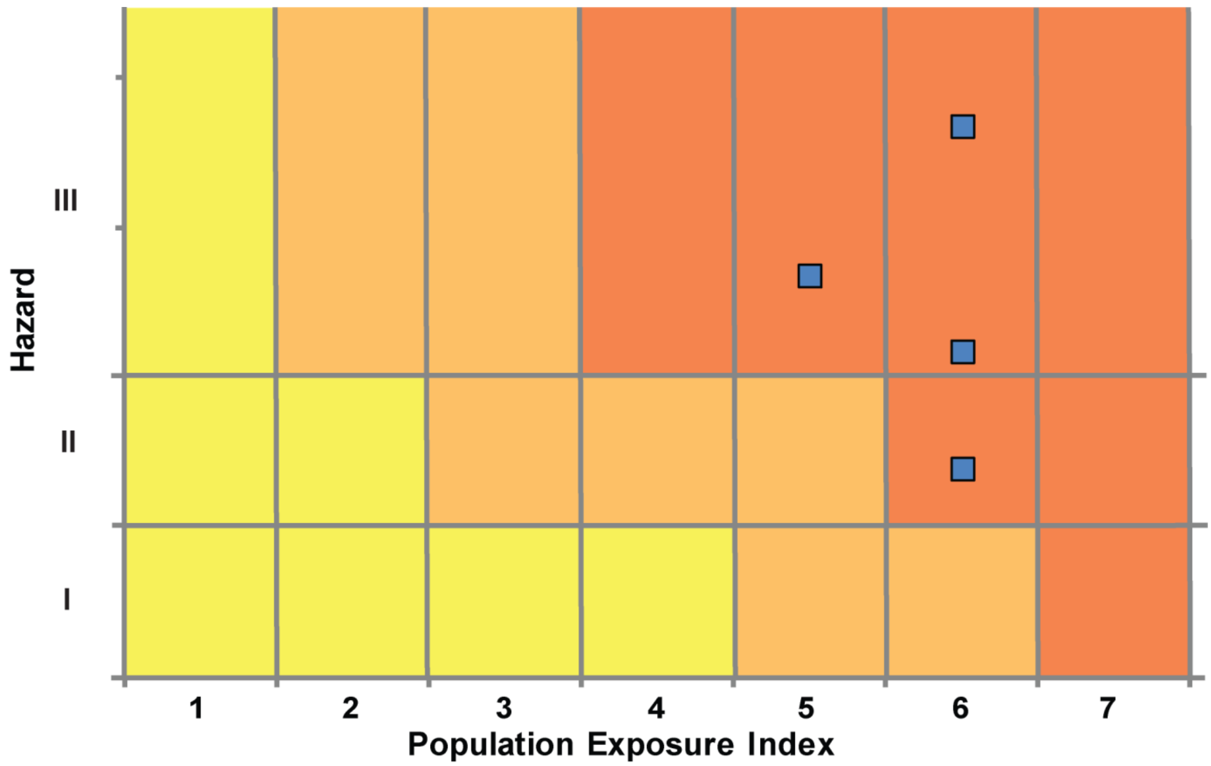

Figure 14.15 Distribution of Guatemala's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I – III.

National Capacity for Coping with Volcanic Risk

Seven volcanoes in Guatemala have recorded historical eruptions. These are classified as Risk Levels III (Atitlán, Fuego, Pacaya and Santa María) and Unclassified (Almolonga, Acatenango and Tacaná). The Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) is responsible for monitoring these volcanoes. Monitoring is focussed on the Risk Level III volcano Santa Maria where seismic networks and geochemical monitoring is undertaken. Seismic monitoring is also undertaken at Fuego and Pacaya. A national seismic network is in place which may detect seismic activity at those volcanoes with no dedicated systems, if the seismic activity is very strong.

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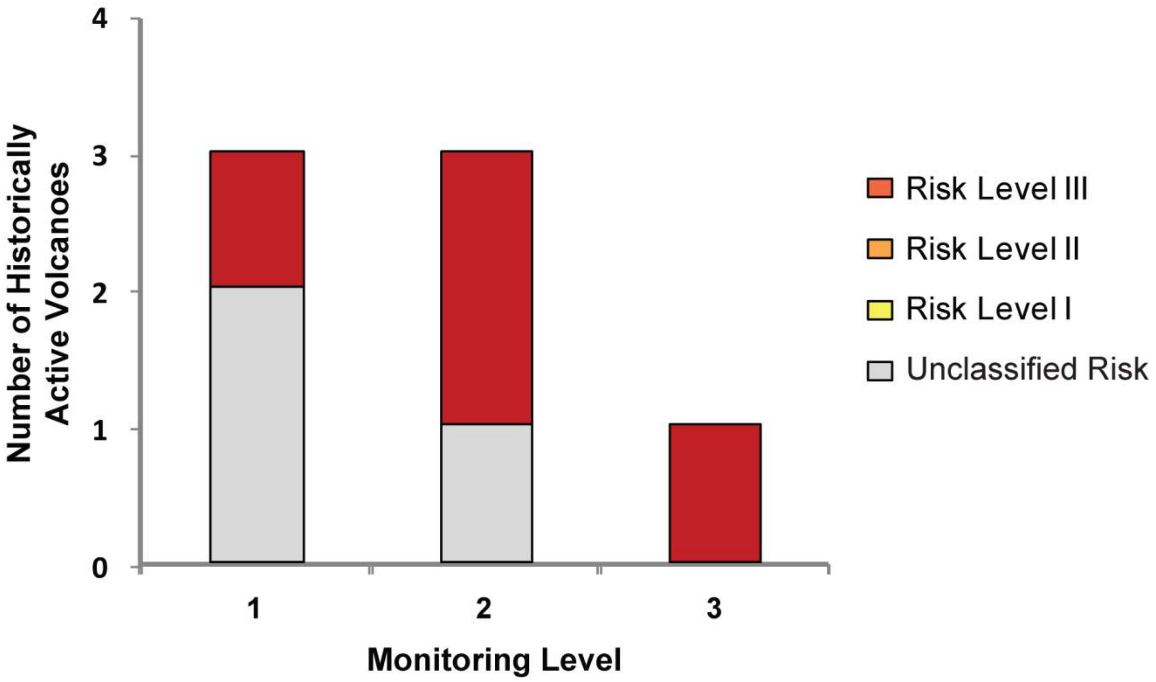

Figure 14.16 The monitoring and risk levels of the historically active volcanoes in Guatemala. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Honduras

Description

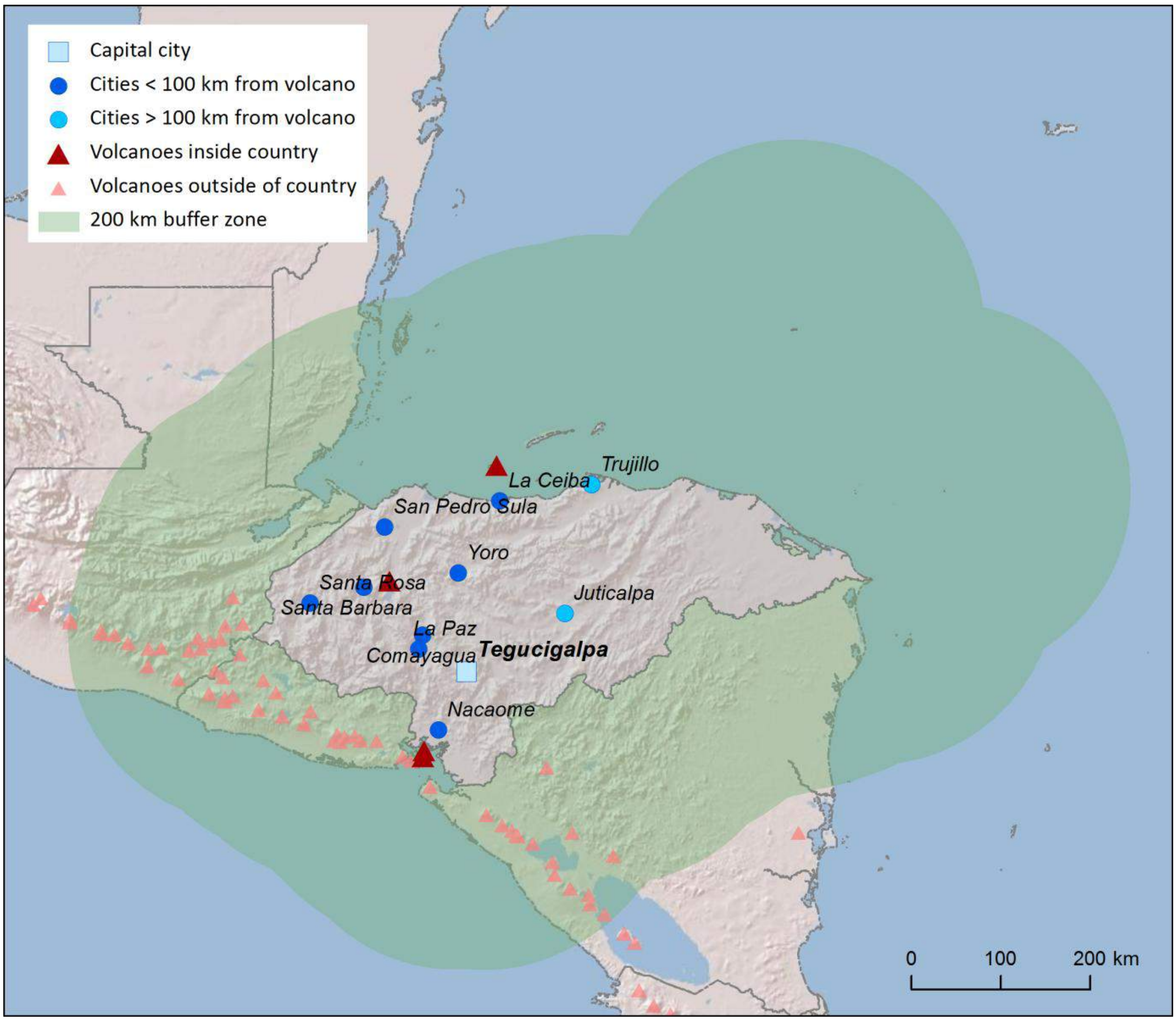

Figure 14.17 Location of Honduras' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Honduras.

Four Holocene volcanoes are located in Honduras, of these, only Lake Yojoa is situated on the mainland, in north-central Honduras. Utila Island volcano is situated in the Caribbean Sea of the northern coast of Honduras, whilst Isla el Tigre and Isla Zacate Grande lie off the southern coast in the Gulf of Fonseca. The country lies on the Caribbean plate, with the Cocos Plate subduction zone lying to the south.

No eruptions are recorded in the Holocene, however Holocene activity is suspected at Utila Island, Isla Zacate Grande and Isla el Tigre due to deposits of lavas and a satellite vent of this age. With deposits of suspected Holocene age, these volcanoes would benefit from further research to date the eruptions and develop an eruptive history. There is no Pleistocene record of large explosive eruptions or a historical record of unrest.

The volcanoes in Honduras are dominantly basaltic. Those in the Gulf of Fonseca are stratovolcanoes, whilst the more northerly volcanoes are small cones comprising a volcanic field and pyroclastic cones. Being basaltic centres, with suspected Holocene lavas, effusive and localised moderately explosive activity may be a feature of the volcanism here.

Despite the small number of the volcanoes, over 80% of the population in Honduras lives within 100 km of one or more Holocene volcanoes. This is due to the widespread distribution of the Honduran volcanoes and the proximity of volcanoes in neighbouring countries, with some southern Guatemalan and northern Nicaraguan volcanoes and many of the volcanoes in El Salvador having 100 km radii extending into Honduras. Similarly, the radii of the Honduran volcanoes extend into these countries. The extent of population exposure is also due to the location of many of the country's largest cities in these 100 km radii, including the capital, Tegucigalpa.

The Honduran volcanoes are unclassified in both hazard and risk due to the lack of a comprehensive eruptive history, meaning the understanding of the hazard at these volcanoes is limited and the Hazard Level assignment would be associated with considerable uncertainty.

At the time of the writing of this report there was no information available to suggest that ground-based monitoring is undertaken at the volcanoes in Honduras. With no historical activity or constrained Holocene activity, the hazard from neighbouring volcanoes may be greater than that within the borders of Honduras.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	0 confirmed. Suspected activity.
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

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Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (2)
2	Small cone(s)	Basaltic (2)

Table 14.16 The number of volcanoes in Honduras, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	7,960,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,566
Gross National Income (GNI) per capita (2005 PPP $)	3,426
Human Development Index (HDI) (2012)	0.632 (Medium)

Population Exposure

Capital city	Tegucigalpa
Distance from capital city to nearest Holocene volcano	96.4 km
Total population (2011)	8,143,564
Number (percentage) of people living within 10 km of a Holocene volcano	41,037 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	423,747 (5.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,650,766 (81.7%)

Ten largest cities, as measured by population and their population size:

Tegucigalpa	850,848
San Pedro Sula	489,466
La Ceiba	130,218
Comayagua	58,784
Juticalpa	33,686
Santa Rosa	27,753
La Paz	17,555
Yoro	15,774
Santa Barbara	15,119
Nacaome	13,929

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Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	7
Total length of roads within 100 km of a volcano (km)	3,924
Total length of railroads within 100 km of a volcano (km)	0

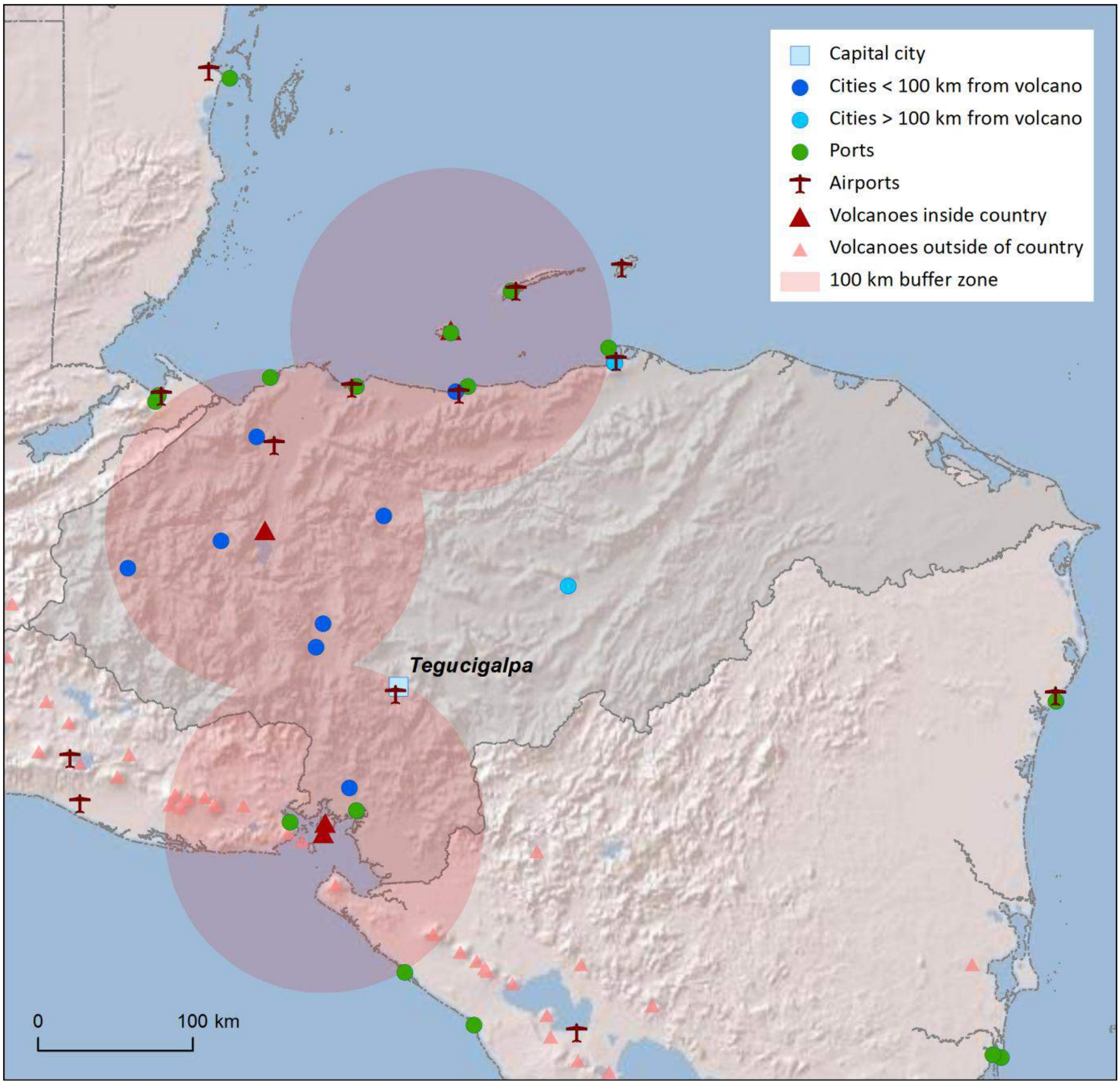

Figure 14.18 The location of Honduras' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes of Honduras are widely distributed, from the Gulf of Fonseca in the Pacific Ocean, to a volcano in central mainland Honduras, to Utila Island in the Caribbean Sea. The 100 km radii of these volcanoes cover an extensive section of Honduras and extend into Guatemala, El Salvador and Nicaragua. Eight of the largest cities in Honduras lie within the 100 km radii of the Holocene

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volcanoes, as does the capital, Tegucigalpa. Much of the country's critical infrastructure is therefore exposed, including ports on the Caribbean Sea and Pacific Ocean, airports and an extensive road network. Tegucigalpa is not situated within 100 km of any historically active volcanoes.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Honduras have a record of confirmed Holocene eruptions. The absence of an extensive eruption record prevents assessment of hazard through the calculation of the VHI, and as such these volcanoes are unclassified.

The PEI ranges from moderate to high in Honduras, with Lake Yojoa having the highest PEI with over 120,000 living with 10 km. Without a hazard classification, the risk levels for Honduran volcanoes cannot be determined.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR			Utila Island	Tigre, Isla el; Zacate Grande, Isla		Yojoa, Lake	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 14.17 Identity of Honduras' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Honduras have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Honduras.

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Mexico

Description

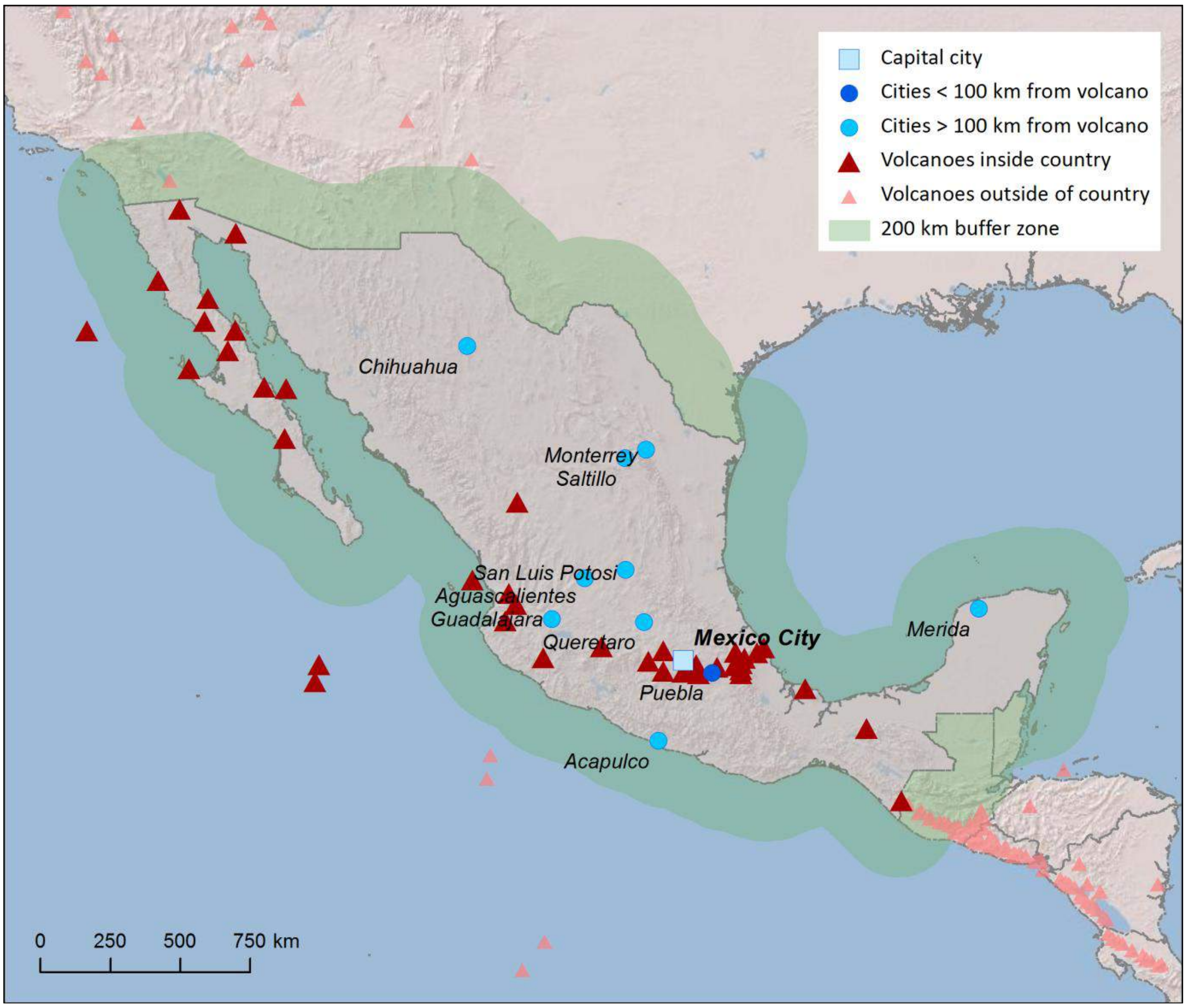

Figure 14.19 Location of Mexico's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mexico.

Forty Holocene volcanoes are located in Mexico, including one on the border with Guatemala. Volcanoes are concentrated on the Baja California peninsula and across central Mexico, around the capital, Mexico City. Volcanism here is primarily due to the subduction of the Pacific and Cocos Plates beneath the North American Plate. This has given rise to the formation of dominantly andesitic volcanic centres, primarily comprising groups of cinder or tuff cones and stratovolcanoes, though a range of volcano types are present.

Mexico has an extensive Pleistocene record of large explosive eruptions, with 20 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M7.4 Xáltipan Ignimbrite from Los Humeros about 460,000 years ago. This ignimbrite covered about 3,500 square kilometres and formed the 15 by 21 km caldera.

Eighteen volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. VOTW4.22 records 214 Holocene eruptions here,

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from VEI 0 to 6. This size range demonstrates the range in activity in Mexico, from small events to very large explosive eruptions. About 12% of eruptions here are recorded at VEI ≥4. About 46% of all eruptions have records of producing pyroclastic flows. The largest Holocene eruption was that of the Jala Pumice from Ceboruco in about 930 AD. This produced voluminous rhyolitic pumice and formed a 4 km wide caldera. Most commonly, small eruptions of VEI 0 – 2 are recorded, with about 35% of the Holocene record comprising such events. About 20% of Holocene eruptions were VEI 3, being moderately explosive.

Of the Holocene record, about 50% of the eruptions have been recorded post-1500 AD, with 103 historic eruptions of VEI 0 – 5 from 10 volcanoes. About 10% of these (10 eruptions) were of VEI ≥4. Two VEI 5 eruptions have occurred historically, at Colima in 1913 and El Chichón in 1982. Pyroclastic flows and surges during the 1982 eruption devastated an area extending about 8 km around the volcano.

In total, throughout Mexico, about 50% of the population live within 100 km of one or more Holocene volcanoes. The size of the local population varies at each volcano, with 13 volcanoes having a low PEI. However, 50% of the volcanoes have high local populations. Fatalities are recorded in about 8% of historical eruptions, with none recorded since 1996.

Monitoring of the historically active volcanoes in Mexico is undertaken by CENAPRED (National Center for Disaster Prevention), UNAM (Universidad Nacional Autónoma de México) and UCOL (Universidad de Colima).

CENAPRED creates, manages and evaluates public policies for risk reduction, coordinating risk information and early warning systems. CENAPRED and UNAM collaborate with joint research projects and shared expertise and also collaborate with the U.S. Geological Survey. CENAPRED and UNAM's main monitoring focus is on Popocatepetl, one of the most frequently active volcanoes in Mexico, located just 70 km from Mexico City. Popocatepetl has a complex monitoring system of visual, seismic, geodetic and geochemical instruments installed, with telemetered data CENAPRED for data processing. Upon detection of seismic unrest an alarm system is activated and duty staff are notified. The Scientific Technical Advisory Committee undertakes analysis of the data and makes recommendations based on the activity level. Government officials and civil protections are regularly updated and the public is informed. Hazard maps are available for flow and fall hazards.

Volcán de Colima, Mexico's most frequently active volcano, is monitored by the University of Colima. The University of Colima uses seismic, deformation, visual and geochemical, thermal and acoustic monitoring. All staff members have experience of responding to volcanic eruptions. Resources are limited with little current funding available to this institution. The Sub-committee for Geological Hazards of Colima informs civil protection about the level of volcanic activity, however no formal alert system is currently in use at Volcán de Colima. The Protección Civil de Jalisco (Jalisco state) control the alert system there and the State of Colima are currently developing an official alert system. Advice is provided to the public for what to do before, during and after eruptions, and hazard maps and evacuation routes are provided.

See also:

CENAPRED: www.cenapred.unam.mx/es/

University of Colima, Centro Universitario de Estudios e Investigaciones de Vulcanologia: portal.ucol.mx/cueiv/

Volcano Facts

Number of Holocene volcanoes	40, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	20
Number of volcanoes generating pyroclastic flows	12
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	13
Number of fatalities caused by volcanic eruptions	?>2,197
Tectonic setting	27 Subduction zone, 13 Rift zone
Largest recorded Pleistocene eruption	The M7.4 eruption of the Xáltipan Ignimbrite from Los Humeros at 460 ka.
Largest recorded Holocene eruption	The VEI 6 eruption of the Jala Pumice from Ceboruco in 930AD.
Number of Holocene eruptions	214 confirmed eruptions. 30 uncertain and 1 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	10
Number of historic eruptions	103

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
13	Large cone(s)	Andesitic (11), Dacitic (1), Unknown (1)
3	Lava dome(s)	Andesitic (1), Dacitic (2)
6	Shield(s)	Andesitic (2), Basaltic (3), Trachytic / Andesitic (1)
15	Small cone(s)	Andesitic (7), Basaltic (5), Rhyolitic (2), Trachytic / Andesitic (1)
1	Submarine	Unknown (1)

Table 14.18 The number of volcanoes in Mexico, their volcano type classification and dominant rock type according to VOTW4.0.

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Socio-Economic Facts

Total population (2012)	121,073,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	12,776
Gross National Income (GNI) per capita (2005 PPP $)	12,947
Human Development Index (HDI) (2012)	0.775 (High)

Population Exposure

Capital city	Mexico City
Distance from capital city to nearest Holocene volcano	46.7 km
Total population (2011)	113,724,226
Number (percentage) of people living within 10 km of a Holocene volcano	394,678 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	15,418,740 (13.6%)
Number (percentage) of people living within 100 km of a Holocene volcano	57,764,870 (50.8%)

Ten largest cities, as measured by population and their population size:

Mexico City	11,285,654
Guadalajara	1,640,589
Puebla	1,392,099
Monterrey	1,122,874
Merida	717,175
Chihuahua	708,267
San Luis Potosi	677,704
Aguascalientes	658,179
Acapulco	652,136
Saltillo	621,250

Infrastructure Exposure

Number of airports within 100 km of a volcano	13
Number of ports within 100 km of a volcano	10
Total length of roads within 100 km of a volcano (km)	17,530
Total length of railroads within 100 km of a volcano (km)	2,233

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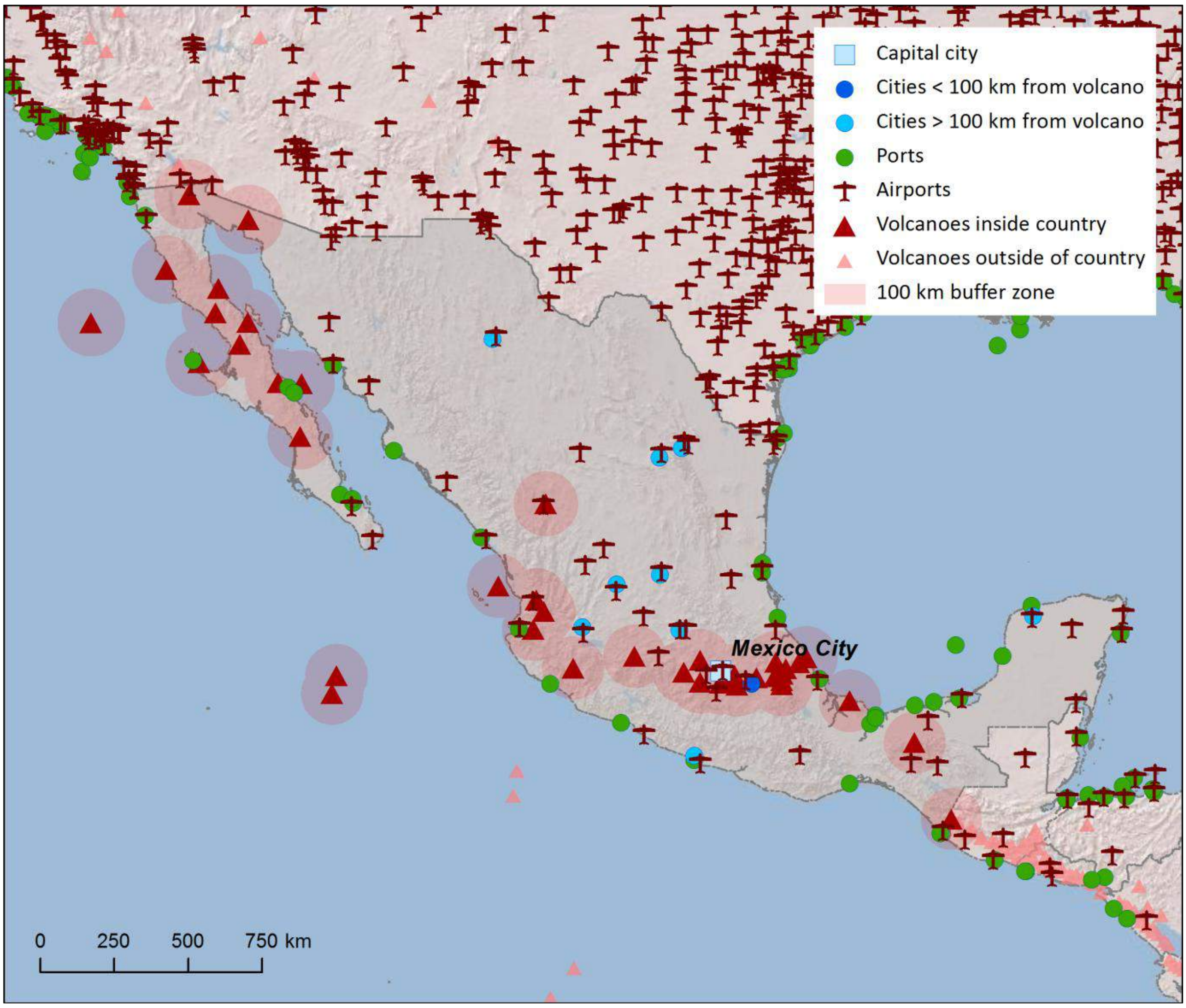

Figure 14.20 The location of Mexico's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes in Mexico are distributed throughout the Baja California peninsula, across central Mexico and to the border with Guatemala. The 100 km radius of Tacaná, on the Mexico-Guatemala border extends into both countries, while the radius surrounding Pinacate in the north extends into Arizona in the USA. Four volcanoes in Guatemala and Salton Buttes in California, USA have 100 km radii that extend into southern and northern Mexico respectively, exposing infrastructure here. Two of the largest cities in Mexico lie within 100 km of the Holocene volcanoes, including Puebla and the capital, Mexico City, hence exposing significant critical infrastructure here. Mexico City lies within 100 km of the historically and frequently active Popocatépetl volcano. The distribution of the volcanoes throughout the country places numerous ports and airports under threat as well as a very extensive road and rail network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data in the eruption records of Mexico's volcanoes. Out of 40, just four have sufficient detail to define the hazard through the calculation of the VHI. These volcanoes are classified at Hazard Level II and III, with Holocene records of large explosive eruptions of VEI ≥4 and a

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particularly strong record of explosive eruptions accompanied by pyroclastic flows at Colima and Pico de Orizaba.

Of the unclassified volcanoes, 22 have no records of confirmed Holocene age eruptions. The remaining have a Holocene record, including historical events at seven volcanoes, with eruptions recorded since 1900 AD at five of these volcanoes. Five unclassified volcanoes have records of Holocene age large explosive VEI ≥4 eruptions.

The PEI ranges from low to very high in Mexico. The classified volcanoes all have moderate to very high PEIs and these are therefore classed at Risk Levels II and III. The risk levels for the unclassified volcanoes cannot be determined due to the absence of hazard data.

CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de		
	Hazard II					Popocatépetl		Chichinautzin
	Hazard I							
UNCLASSIFIED	**U – HHR**	**Bárcena; Socorro**			San Martín; **El Chichón**	Ceboruco; **Tacaná**		**Michoacán-Guanajuato**
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote	Zitácuaro-Valle de Bravo; Jocotitlán; Toluca, Nevado de; Naolinco Volcanic Field	
	U- NHHR	Guadalupe; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado; San Borja Volcanic Field; Unnamed; Tres Vírgenes; Tortuga, Isla; Comondú-La Purísima		San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los	Prieto, Cerro; Iztaccíhuatl; Humeros, Los	Papayo; Serdán-Oriental; Gloria, La	Durango Volcanic Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 14.19 Identity of Mexico's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Chichinautzin	7	III
Orizaba, Pico de	5	III
Popocatépetl	5	II
Colima	4	III

Table 14.20 Classified volcanoes of Mexico ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 3 volcanoes.

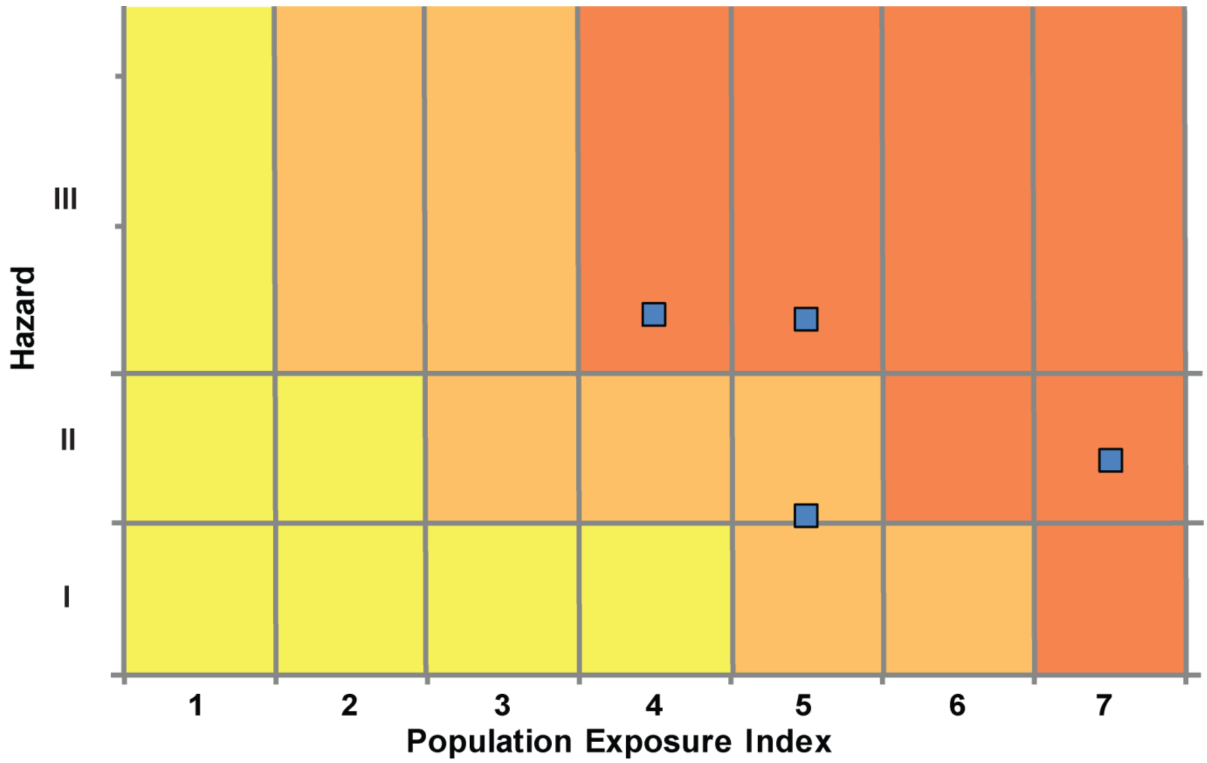

Figure 14.21 Distribution of Mexico's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes in Mexico have records of historical activity. Seven of these are unclassified whilst three are at Risk Levels II and III. At the time of the writing of this report, no information available indicated dedicated ground-based monitoring at three volcanoes here (Bárcena, Socorro, Michoacán-Guanajuato). However, a national seismic network is in place. At seven historically active volcanoes, dedicated seismic monitoring and additional deformation and sometimes gas monitoring is used.

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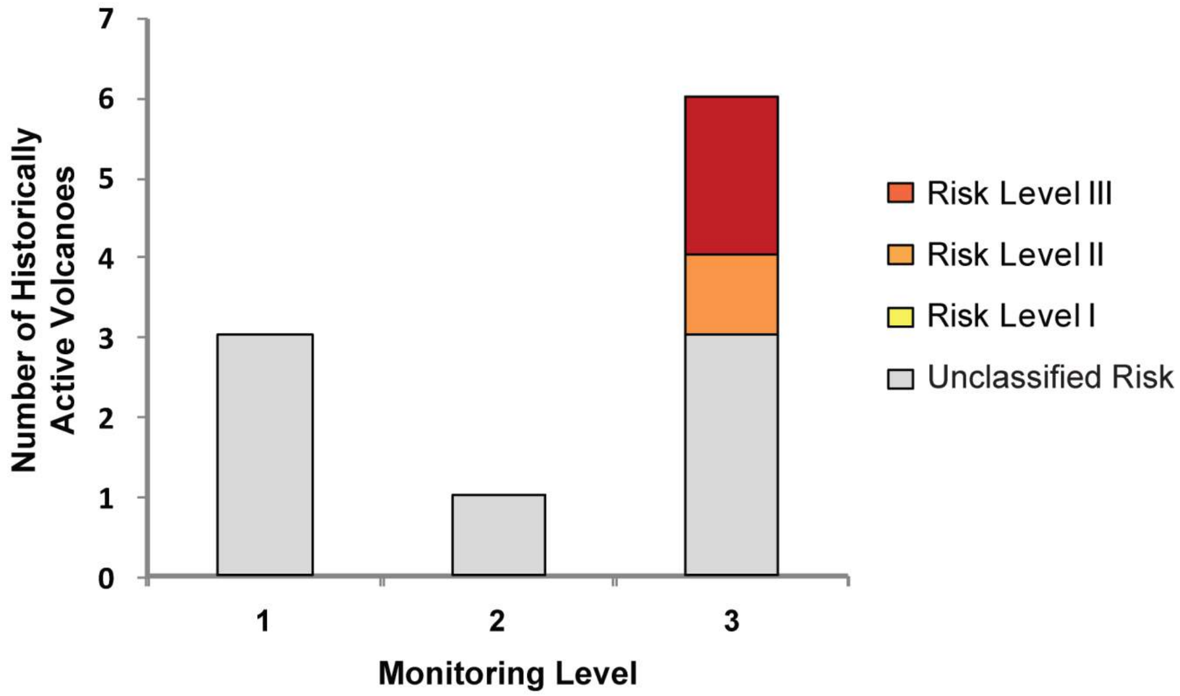

Figure 14.22 The monitoring and risk levels of the historically active volcanoes in Mexico. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Nicaragua

Description

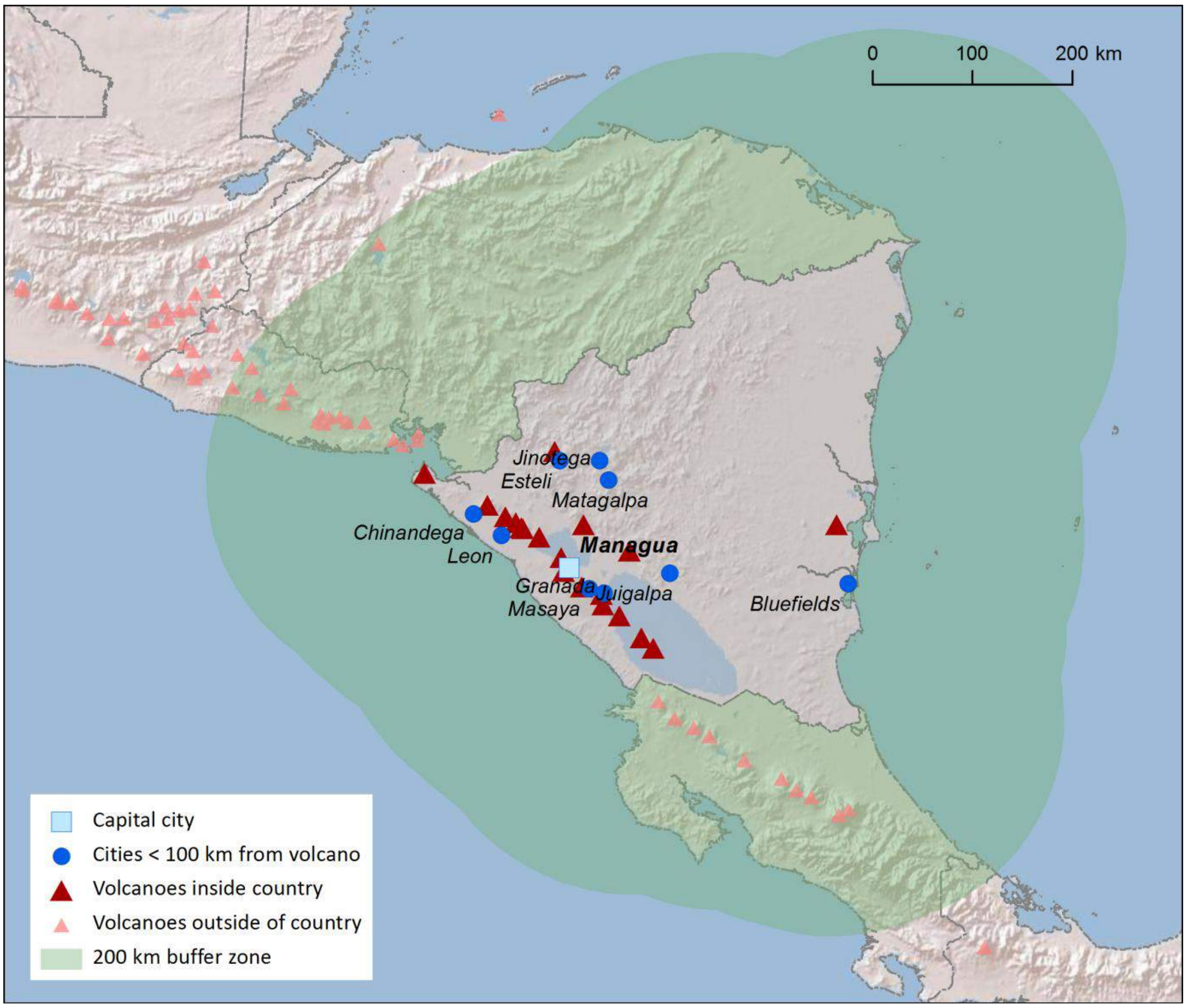

Figure 14.23 Location of Nicaragua's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Nicaragua.

Nineteen Holocene volcanoes are located in Nicaragua, dominantly in a chain near the west coast, from the border with Costa Rica in the south and the Gulf of Fonseca in the north. One, Volcán Azul (Blue volcano), lies near the Caribbean Sea coast. Volcanism in Nicaragua is due to the subduction of the Cocos Plate beneath the Caribbean Plate. A range of volcano types have developed throughout Nicaragua, though most volcanoes are dominantly basaltic and andesitic stratovolcanoes. A number of basaltic volcano fields comprising multiple cinder cones have also formed, and large calderas are also present.

VOTW4.22 records 191 confirmed eruptions here during the Holocene, ranging in size from VEI 0 – 6 indicating a range in activity styles from mild events to very large explosive eruptions. Seven volcanoes have records of producing pyroclastic flows. The largest recorded Holocene eruption was the VEI 6 eruption of Masaya at about 6,000 years ago. This basaltic Plinian eruption produced ash fall and pyroclastic flows. Masaya has been one of the most frequently active volcanoes in Nicaragua

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in the Holocene, with 34 recorded eruptions, but these have mainly been small to moderate events. The capital of Nicaragua, Managua, lies only about 20 km from this volcano and a large explosive eruption here could have devastating consequences.

Most of the eruptions recorded during the Holocene were recorded in historical times, since 1500 AD, with 172 eruptions recorded in this time from eight volcanoes. With a scarce eruption record prior to 1500 AD, the assessment of hazard at many of Nicaragua's volcanoes is difficult and associated with significant uncertainties. Further research documenting the Holocene eruption record would be beneficial in understanding volcanism here.

Despite high proximal populations surrounding most volcanoes in Nicaragua, with over 1.5 million people living within 10 km of one or more Holocene volcanoes throughout the country and most of the population living within 100 km of one or more Holocene volcanoes, just five eruptions have recorded about 2,000 fatalities. In 1992, a VEI 3 eruption of Cerro Negro produced widespread damage due to voluminous ash fall. Despite the evacuation of over 20,000 people, many roofs collapsed resulting in loss of life. In 1998 Volcán Casita, a cone of San Cristóbal, suffered a catastrophic landslide and lahar following Hurricane Mitch. Several villages were buried and several thousand lost their lives. Lahars in the tropics are relatively common-place with the high rainfall, and lahars can occur for many years after eruptions due to the remobilisation of ash.

The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring in Nicaragua. All historically active volcanoes are seismically monitored, with additional deformation monitoring at five volcanoes. INETER analyse the data in near real-time and release monthly bulletins of volcanic activity and status online. INETER is a member of WOVO.

See also:

Instituto Nicaragüense de Estudios Territriales (INETER): www.ineter.gob.ni/

Volcano Facts

Number of Holocene volcanoes	19
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5
Number of volcanoes generating lava flows	6-7
Number of fatalities caused by volcanic eruptions	?
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Upper Apoyo Tephra (UAT) from Apoyo at 29,468 BP.

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Largest recorded Holocene eruption	The M6.3 San Antonio Tephra eruption from Masaya at 6 ka.
Number of Holocene eruptions	191 confirmed eruptions. 23 uncertain.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	8
Number of historic eruptions	172

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (1), Dacitic (1)
10	Large cone(s)	Andesitic (6), Basaltic (4)
2	Shield(s)	Andesitic (1), Basaltic (1)
5	Small cone(s)	Basaltic (5)

Table 14.21 The number of volcanoes in Nicaragua, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,009,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579
Gross National Income (GNI) per capita (2005 PPP $)	2,551
Human Development Index (HDI) (2012)	0.599 (Medium)

Population Exposure

Capital city	Managua
Distance from capital city to nearest Holocene volcano	6.4 km
Total population (2011)	5,666,301
Number (percentage) of people living within 10 km of a Holocene volcano	1,521,967 (26.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,371,558 (59.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,314,523 (93.8%)

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Ten of the largest cities, as measured by population and their population size (2005 Census, www.inide.gob.ni/):

Managua	937,489
León	174,051
Masaya	138,582
Matagalpa	133,416
Chinandega	121,793
Esteli	112,084
Granada	105,171
Tipitapa	101,685
Jinotega	99,382
El Viejo	76,775

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,333
Total length of railroads within 100 km of a volcano (km)	0

With the exception of Volcán Azul in the east of the country, all volcanoes in Nicaragua are situated in the west, largely in a chain paralleling the coastline. With numerous volcanoes located here, a large expanse of the country lies within the 100 km radii of these volcanoes. These radii also extend into Costa Rica, Honduras and El Salvador. All ten of Nicaragua's largest cities, including the capital, Managua, lie within 100 km of Holocene volcanoes, and hence much of the country's critical infrastructure is exposed including ports, airports and an extensive road network. Managua lies within 100 km of seven historically active volcanoes.

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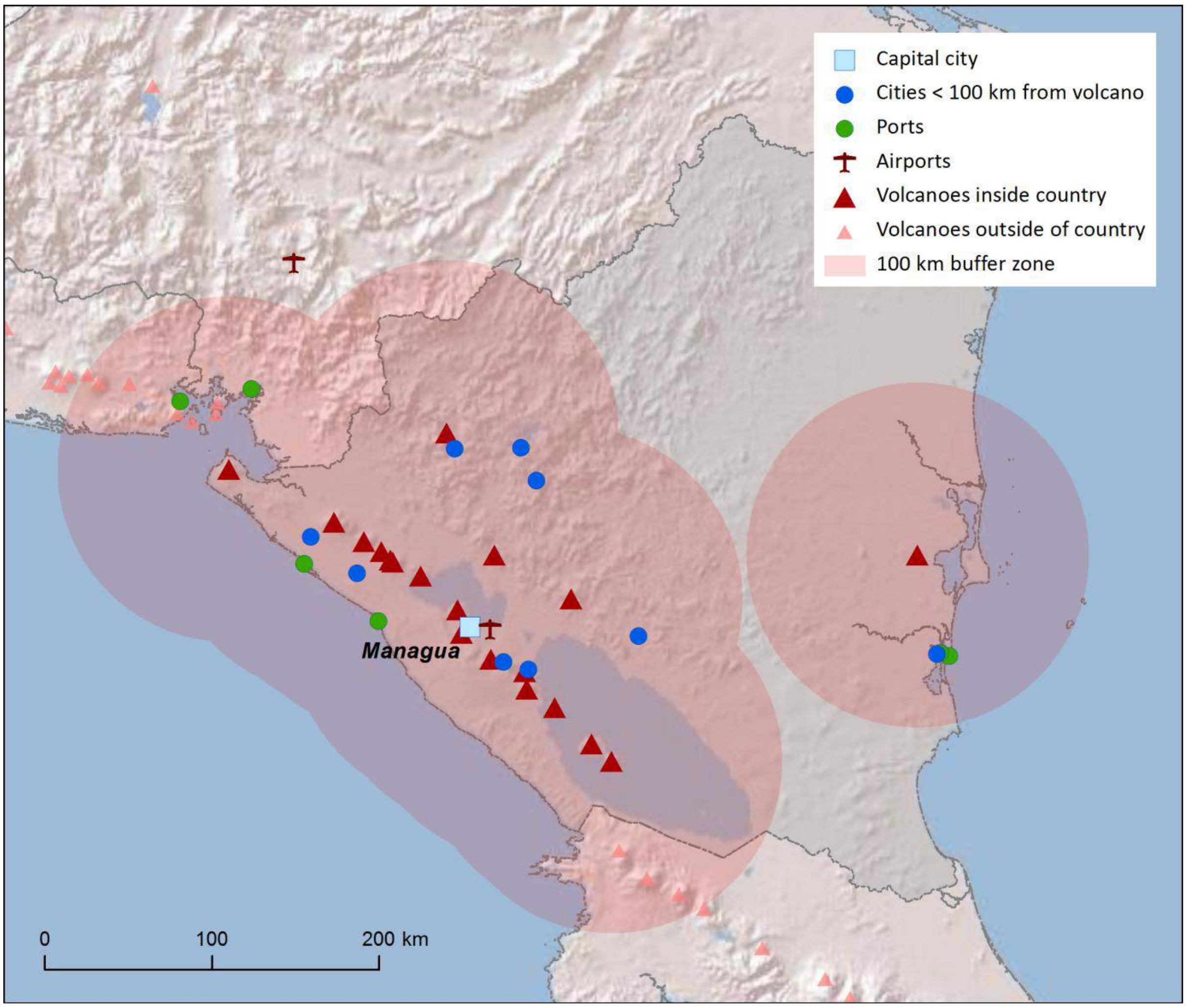

Figure 14.24 The location of Nicaragua's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Nicaragua's volcanoes. About 40% of volcanoes have sufficient detail to define the hazard through the calculation of the VHI. These are classified across the hazard levels, with just one at Hazard Level III: Apoyeque. This volcano has a Holocene record of a VEI 6 eruption and all Holocene eruptions recorded here are large, explosive VEI ≥4 events.

Of the unclassified volcanoes, nine have no recorded confirmed Holocene eruptions. Three have Holocene records, including historical events at Cosigüina and Las Pílas. Eruptions since 1900 AD are recorded at the latter, and seismic unrest has been detected at the former. Unrest is also described at Nejapa-Miraflores, Rota and Mombacho.

The PEI ranges from moderate to very high in Nicaragua, with over half of the volcanoes here classed with a high local population and PEI of 5 to 7. The classified volcanoes are classed across all three Risk levels, with just Apoyeque and Masaya being Risk Level III. Although unclassified in hazard, the very high PEI at Nejapa-Miraflores indicates that this would class as a Risk Level III.

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CLASSIFIED	**Hazard III**						Apoyeque	
	Hazard II				San Cristóbal; Momotombo	Telica; Concepción		Masaya
	Hazard I				Negro, Cerro			
UNCLASSIFIED	**U – HHR**			**Cosigüina**	**Las Pilas**			
	U- HR							**Nejapa-Miraflores**
	U- NHHR			Maderas; Azul, Volcán	Zapatera; Ciguatepe, Cerro el; Lajas, Las	**Rota; Mombacho**	Granada; Estelí	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 14.22 Identity of Nicaragua's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Masaya	7	III
Apoyeque	6	III
Concepción	5	II
Telica	5	II
Momotombo	4	II
San Cristóbal	4	II
Negro, Cerro	4	I

Table 14.23 Classified volcanoes of Nicaragua ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 4 volcanoes; Risk Level III – 2 volcanoes.

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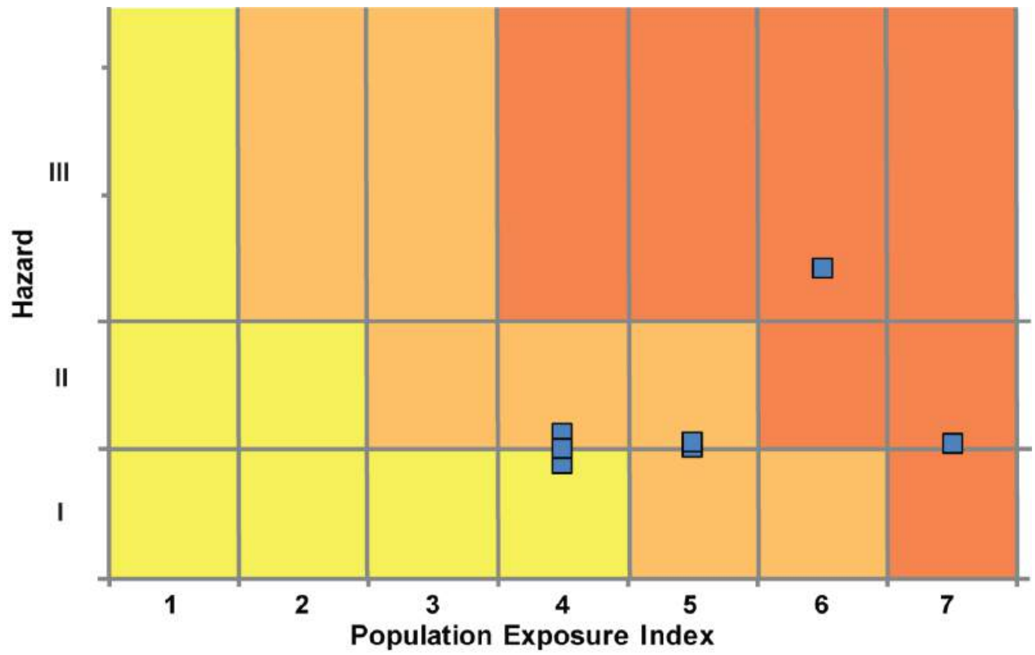

Figure 14.25 Distribution of Nicaragua's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes have recorded historical activity. The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring. All historically active volcanoes have continuous seismic monitoring, with near real-time analysis. In addition to this, deformation monitoring is undertaken at San Cristóbal, Cerro Negro, Concepción, Cosigüina and the Risk Level III Masaya.

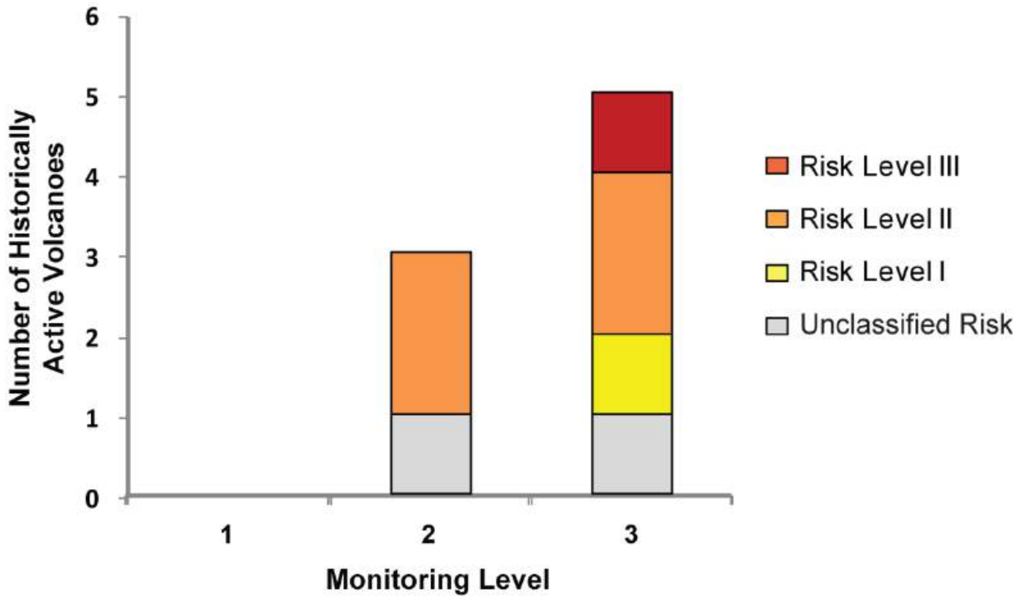

Figure 14.26 The monitoring and risk levels of the historically active volcanoes in Nicaragua. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Panama

Description

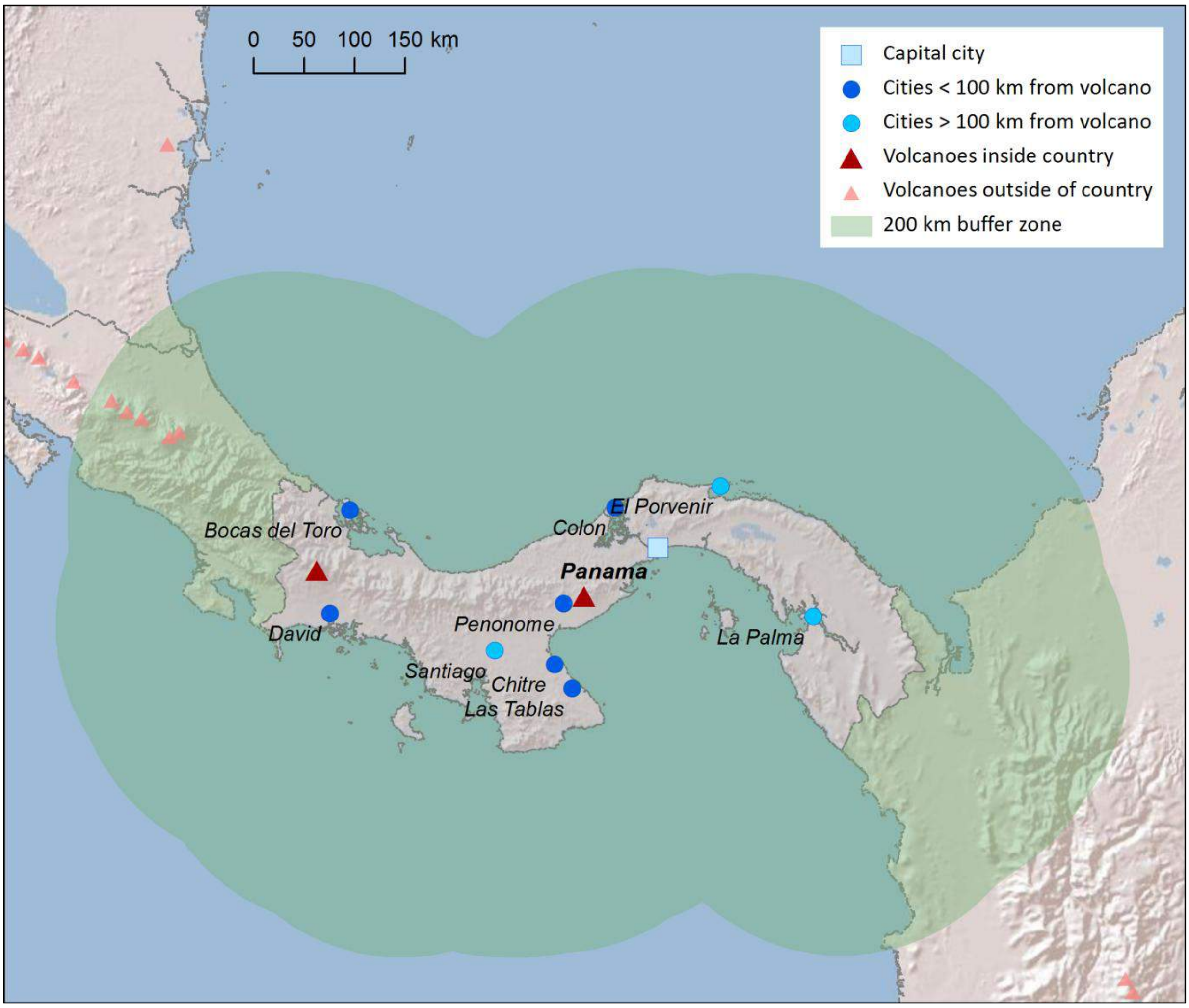

Figure 14.27 Location of Panama's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Panama.

Two Holocene volcanoes are situated in Panama. Barú lies in the west, close to the border with Costa Rica. El Valle lies in central Panama, around 80 km from the Panama Canal.

The volcanoes in Panama lie at the southern end of the Central American volcanic arc. Located on the Caribbean plate, several plates converge in this region with both the Caribbean and Nazca plates undergoing subduction.

Of the two Holocene volcanoes, neither has recorded historical activity, and only Barú has confirmed Holocene eruptions, with the most recent occurring in 710 AD. The size of the eruptions are unknown, however multiple pyroclastic surge deposits are identified suggesting a history of explosive eruptions at Barú. A record of Pleistocene activity at El Valle shows the occurrence of large magnitude explosive eruptions, with a magnitude 4 eruption here 56,000 years ago. Both volcanoes are large dominantly andesitic and dacitic Stratovolcanoes. This rock chemistry coupled with the explosive deposits suggests dominantly explosive activity in Panama with the potential for future eruptions of a similar style, producing pyroclastic density currents, ash fall and lahars.

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Nearly 93% of the population of Panama lives within 100 km of the Holocene volcanoes, as many of the largest cities in the country lie within this distance. Indeed, the capital, Panama City lies at around 80 km from El Valle. Despite the large proportion of the population being exposed, the population within 10 km is moderate, and the volcanoes here are classed at PEI 4. A Holocene record of property damage exists at Barú. Barú has the potential to affect neighbouring Costa Rica, whilst some of the southernmost volcanoes in Costa Rica lie within 200 km of Panama.

Ash fall has been deposited more than 100 km downwind in prehistoric eruptions of Barú and dome collapses and subsequent hot PDCs have been channelled westwards. The town of Volcán is built on the deposits of these flows. Sherrod et al. (2008) describes these flows as constrained to 15 km from the summit dome. Large lahar plains extend to the south, and the city of David, the second most populous in Panama is located on this plain.

Barú is monitored by a seismic network maintained by the Institute of Geosciences at the University of Panama.

See also:

Sherrod, D.R., Vallance, J.W., Tabia Espinosa, A., and McGeehin, J.P. (2008) Volcan Baru; eruptive history and volcano-hazards assessment: US Geological Survey Open-File Report 2007-1401. 33p pubs.usgs.gov/of/2007/1401/

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The 56 ka M4.0 El Hato Ignimbrite and El Valle de Antón caldera formation of El Valle.
Largest recorded Holocene eruption	All Holocene eruptions are of unknown VEI.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historic eruptions	-

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Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (1), Dacitic (1)

Table 14.24 The number of volcanoes in Panama, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	3,808,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,766
Gross National Income (GNI) per capita (2005 PPP $)	13,519
Human Development Index (HDI) (2012)	0.780 (High)

Population Exposure

Capital city	Panama City
Distance from capital city to nearest Holocene volcano	82.6 km
Total population (2011)	3,460,462
Number (percentage) of people living within 10 km of a Holocene volcano	18,189 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	266,966 (7.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,203,311 (92.6%)

Largest cities, as measured by population and their population size:

Panama	408,168
David	82,859
Colon	76,643
Santiago	45,355
Chitre	43,966
Penonome	12,394
Las Tablas	8,570
La Palma	1,845
Bocas del Toro	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	12

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Total length of roads within 100 km of a volcano (km) 1,394

Total length of railroads within 100 km of a volcano (km) 75

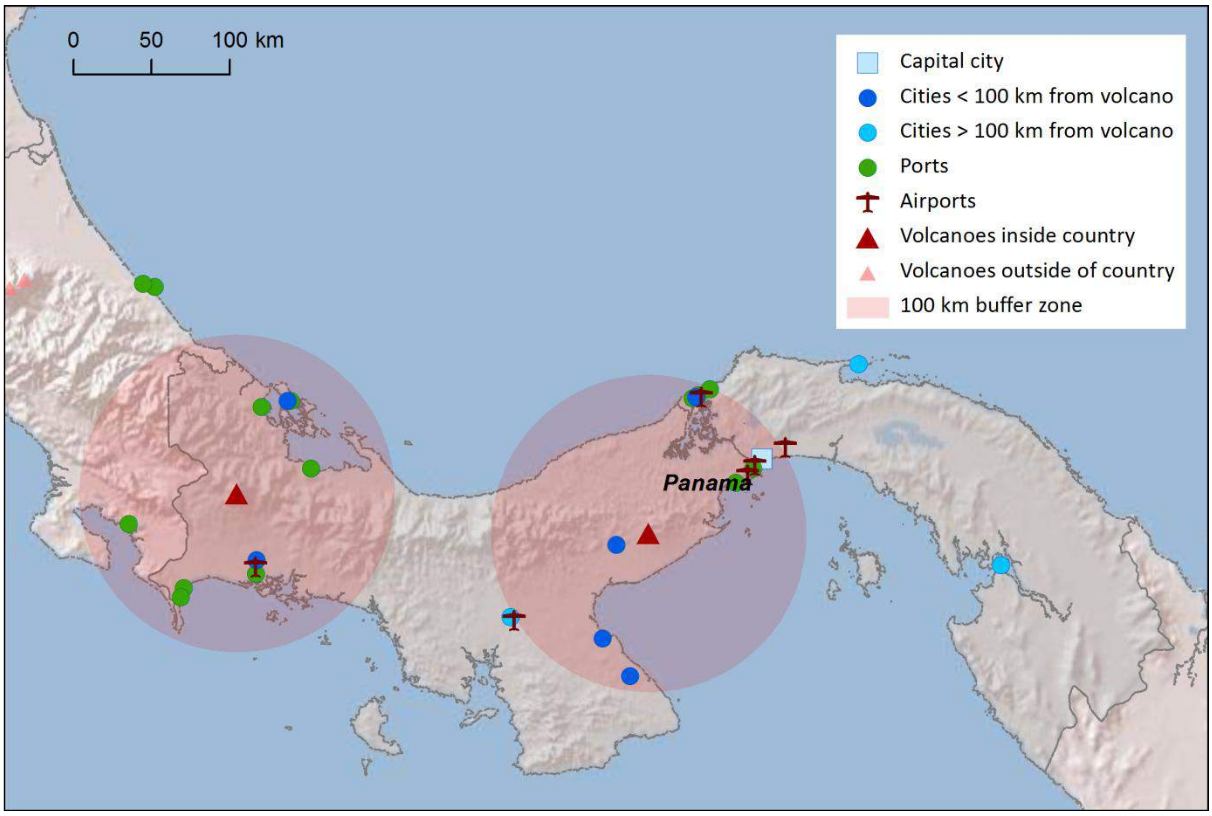

Figure 14.28 The location of Panama's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The two volcanoes in Panama are located in the centre and west of the country. The 100 km radius of the western volcano, Barú, extends across the border into Costa Rica, exposing infrastructure here as well as encompassing a number of ports and two of Panama's largest cities. The 100 km radius of El Valle volcano, encompasses several of Panama's largest cities, including the capital, Panama City, and crucially the Panama Canal, hence considerable critical infrastructure is exposed here.

Hazard, Uncertainty and Exposure Assessments

Neither volcano in Panama have a sufficiently extensive record for assessment of the hazard through the calculation of the VHI. Indeed, El Valle has no confirmed Holocene eruptions. Five Holocene eruptions are known at Barú, however the VEI is unknown. These volcanoes are therefore unclassified.

Both volcanoes in Panama have a moderate proximal population and are classed at PEI 4.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR				Barú			
	U- HR							
	U- NHHR				El Valle			
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

Table 14.25 Identity of Panama's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.National Capacity for Coping with Volcanic Risk*

A network of seismometers dedicated to the monitoring of Barú volcano has been installed and is managed by the University of Panama. El Valle has no historical eruption record and no dedicated ground-based monitoring.

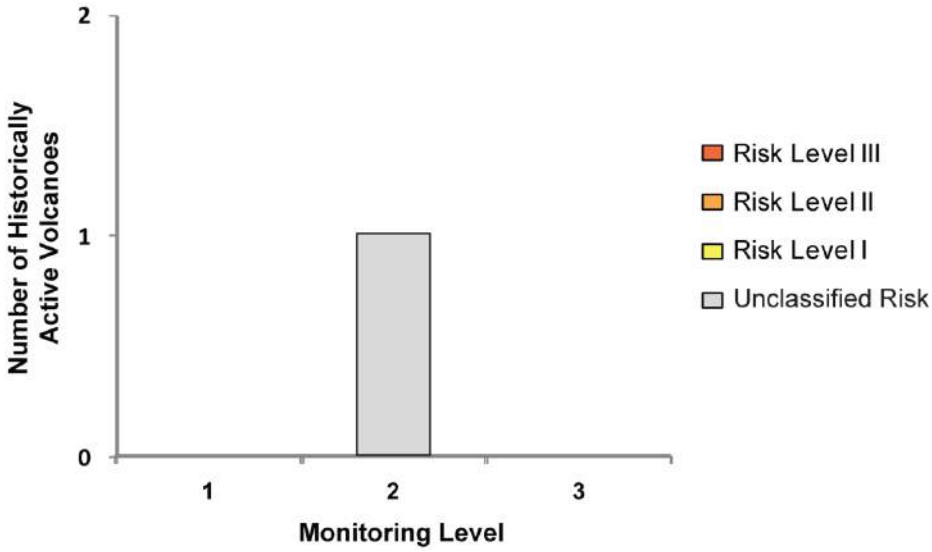

Figure 14.29 The monitoring and risk levels of the historically active volcanoes in Panama. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 15: South America

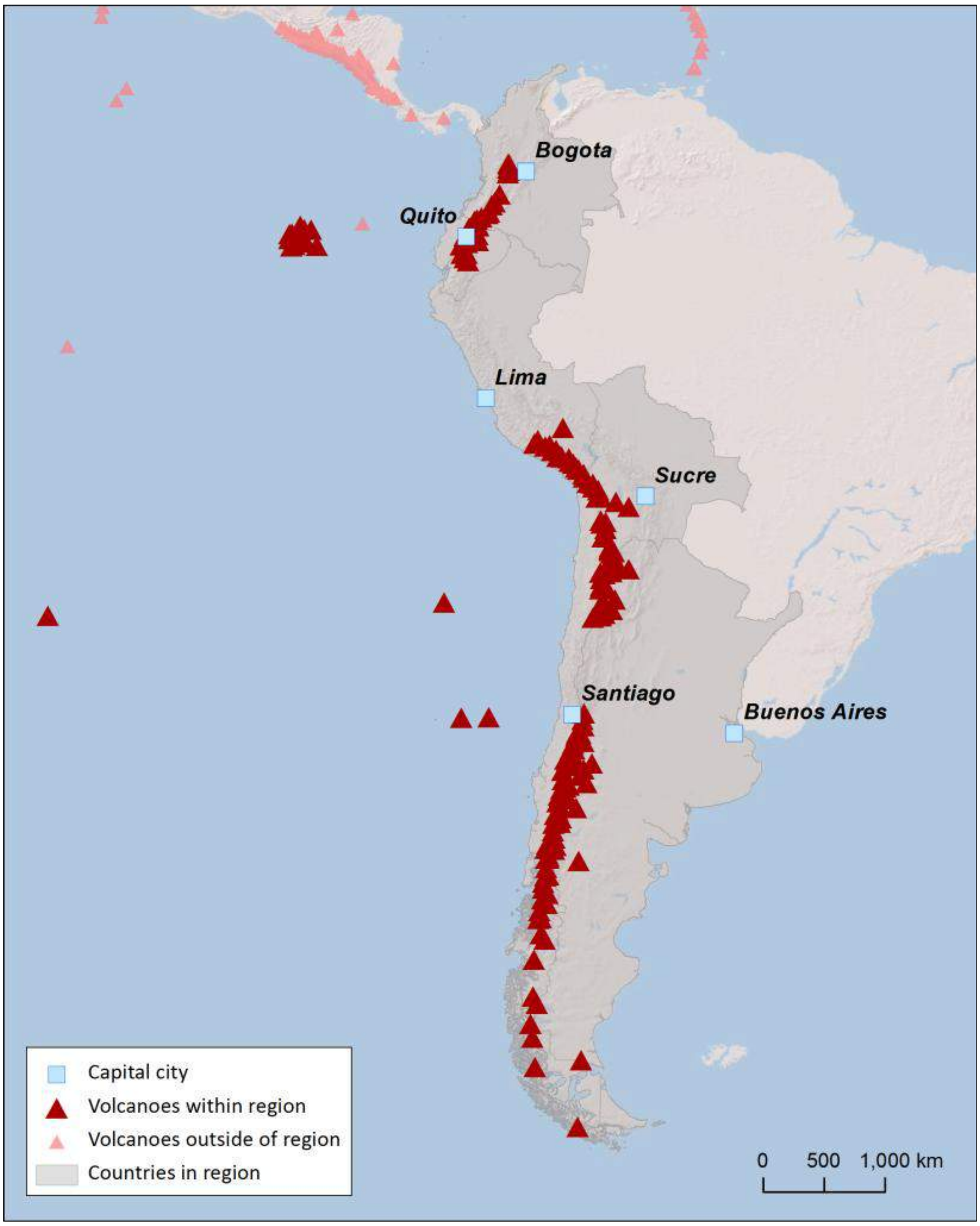

Figure 15.1 The distribution of Holocene volcanoes through the South America region. The capital cities of the constituent countries are shown.

Description

Region 15: South America comprises volcanoes throughout South America, from Colombia in the north to the tip of Chile in the south, and west to include the Galapagos Islands and Chilean islands in the Pacific Ocean. Six countries are represented here. All are included in this regional discussion, and individual profiles are provided.

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Country	Number of volcanoes
Argentina	41
Bolivia	12
Chile	105
Colombia	15
Ecuador	35
Peru	17

Table 15.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

197 Holocene volcanoes are located in South America. Most of these volcanoes are in Chile. Volcanism here is largely related to the subduction of the Nazca Plate beneath the South American Plate.

A range of volcano types are present, though most are stratovolcanoes. The rock composition varies from basaltic to rhyolitic, but is most commonly andesitic.

Along with ranges of volcano morphologies and rock types, a range of activity styles and eruption magnitudes are recorded throughout the Holocene, with eruptions ranging from VEI 0 to 6. About 72% of eruptions have been small, at VEI 0 to 2, however about 12% of eruptions have been large explosive VEI ≥4 events. The only countries in this region with no Holocene record of VEI ≥4 eruptions are Argentina and Bolivia, though pyroclastic flows are recorded in eruptions at volcanoes on the border of Chile-Argentina and Chile-Bolivia. Four VEI 6 eruptions are recorded here. The two most recent were the 1280 eruption of Quilotoa in Ecuador in which pyroclastic flows and lahars reached the Pacific, and the 1600 eruption of Huaynaputina, Peru, in which pyroclastic flows reached 13 km and lahars reached 120 km.

Seventy-six volcanoes have historical records of 672 eruptions, 95% of which were recorded through direct observations. Areas where the population is sparse have fewer observed events and therefore a less comprehensive record. Pyroclastic flows and lahars are recorded in 12 and 15% of historical eruptions respectively. Lava flows are recorded in 20% of historical eruptions. Many of South America's volcanoes are ice-capped, and as such lahars and explosive eruptions may be frequent.

Lives have been lost in 5% of historical eruptions. The eruption of Nevado del Ruiz in Colombia in 1985 resulted in the greatest loss of life, with over 20,000 fatalities due to lahars. These were produced during a moderate VEI 3 eruption, which led to the melting of the summit ice-cap. Most volcanoes (72%) have low proximal populations, and as such are considered relatively low risk. However, the hazard is poorly constrained at many volcanoes here, with no hazard and risk classification at about 80% of the region's volcanoes. Eight Risk Level III volcanoes are located in this region, all in Ecuador and Colombia.

Most historically active volcanoes are monitored in this region, with an apparent concentration of monitoring at the Risk Level II and III volcanoes. Chile, Colombia, Ecuador and Peru all have specific monitoring institutions.

Volcano facts

Number of Holocene volcanoes	197
Number of Pleistocene volcanoes with M≥4 eruptions	38
Number of volcanoes generating pyroclastic flows	45 (217 eruptions)
Number of volcanoes generating lahars	32 (126 eruptions)
Number of volcanoes generating lava flows	49 (194 eruptions)
Number of eruptions with fatalities	34
Number of fatalities attributed to eruptions	33,230
Largest recorded Pleistocene eruption	The 2.2 Ma M8 Cerro Galán Ignimbrite from Cerro Galán is the largest recorded Quaternary explosive eruption in this region.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in LaMEVE in this region in the 800 BP Quilotoa eruption at M6.4.
Number of Holocene eruptions	976 confirmed Holocene eruptions
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	76
Number of historical eruptions	672

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
13	Caldera(s)	Andesitic (5), Dacitic (5), Rhyolitic (3)
129	Large cone(s)	Andesitic (87), Basaltic (15), Dacitic (21), Trachytic/Andesitic (1), Unknown (5)
7	Lava dome(s)	Andesitic (1), Dacitic (4), Rhyolitic (1), Unknown (1)
18	Shield(s)	Andesitic (1), Basaltic (17)
28	Small cone(s)	Andesitic (13), Basaltic (11), Dacitic (1), Unknown (3)
1	Subglacial	Dacitic (1)
1	Submarine	Unknown (1)

Table 15.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

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Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	50

Table 15.3 Average recurrence interval (years between eruptions) for small and large eruptions in South America.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 50 years.

Eruption Size

Eruptions are recorded through South America of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with over 50% of all Holocene eruptions classed as such. 12% of eruptions here are explosive at VEI ≥4.

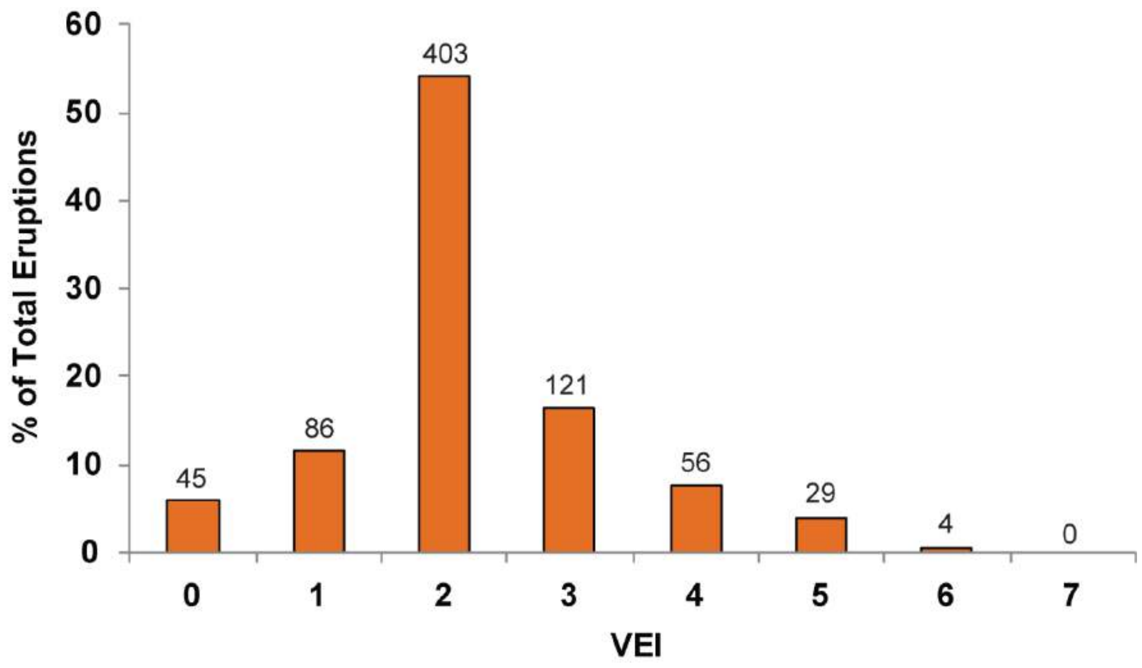

Figure 15.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 232 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	361,188,771
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,499 – 15,501
	(Mean 10,129)
Gross National Income (GNI) per capita (2005 PPP $)	4,444 – 15,347

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	(Mean 10,060)
Human Development Index (HDI) (2012)	0.675 – 0.819 (Medium to Very High, Mean 0.746 High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	1,252,806 (0.35 %)
Number (percentage) of people living within 30 km of a Holocene volcano	8,997,260 (2.49 %)
Number (percentage) of people living within 100 km of a Holocene volcano	35,346,223 (9.79 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	20
Number of ports within 100 km of a volcano	10
Total length of roads within 100 km of a volcano (km)	30,039
Total length of railroads within 100 km of a volcano (km)	3,118

*Table 15.4 (Next page): Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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CLASSIFIED	**Hazard III**		Azul, Cerro; Puyehue-Cordón Caulle; Osorno	Reventador; Sangay; Calbuco	Bravo, Cerro; Cayambe; Cotopaxi; Tungurahua	Nevado del Ruiz; Guagua Pichincha	Galeras; Atacazo	
	Hazard II		Fernandina; Yucamane; Láscar; Planchón-Peteroa; Chillán, Nevados de; Antuco; Copahue; Lonquimay; Llaima	Sabancaya; Ubinas; Villarrica	Tolima, Nevado del			
	Hazard I		Wolf; Negra, Sierra; Azul, Cerro; Guallatiri; Isluga; San Pedro; Huequi; Lautaro	Maipo	Puracé; Misti, El; Tupungatito; San José			
UNCLASSIFIED	**U – HHR**	Robinson Crusoe	Sumaco; Darwin; **Alcedo**; **Pinta**; **Marchena**; **Santiago**; Ticsani; **Irruputuncu**; Olca-Paruma; Putana; Llullaillaco; **Tinguiririca**; **Descabezado Grande**; Tromen; **Callaqui**; Quetrupillan; Huanquihue Group; **Mocho-Choshuenco**; Puntiagudo-Cordón Cenizos; Minchinmávida; Mentolat; **Hudson, Cerro**; **Arenales**; **Viedma**; **Reclus**; **Burney, Monte**; Fueguino	Huaynaputina; **Carrán-Los Venados**; **Chaitén**	**Huila, Nevado del**; **Doña Juana**; **Cumbal**; **Negro de Mayasquer, Cerro**; Antisana	Chacana		
	U- HR	Aliso	Ecuador; Taapaca; Parinacota; Socompa; **Ojos del Salado, Nevados**; Infiernillo; Longaví, Nevado de; Lanín; Antillanca Group; Cayutué-La Viguería; **Yanteles**; Corcovado; **Melimoyu**; Macá; Aguilera; Pali-Aike Volcanic Field	Soche; Huambo; Sollipulli; Caburgua-Huelemolle	Romeral; Chachimbiro; Chimborazo; Quimsachata; Andahua-Orcopampa	Santa Isabel; Machín; Azufral; Quilotoa	Cuicocha; Imbabura	Pululagua
	U- NHHR	San Félix; Unnamed; Blanca, Laguna	Genovesa; Auquihuato, Cerro; Sara Sara; Coropuna; Tutupaca; Casiri, Nevados; Tacora; Tambo Quemado; Tata Sabaya; Jayu Khota, Laguna; Nuevo Mundo; Pampa Luxsar; **Ollagüe**; Azufre, Cerro del; Sairecabur; Licancabur; Guayaques; Purico Complex; Colachi; Acamarachi; Overo, Cerro; **Chiliques**; Cordón de Puntas Negras; Miñiques; Tujle, Cerro; Caichinque; Tilocalar; Negrillar, El; Pular; Negrillar, La; Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Copiapó; Tuzgle; Aracar; Unnamed; Antofagasta; Cóndor, El; Peinado; **Robledo**; Tipas; Palomo; Atuel, Caldera del; Risco Plateado; Calabozos; Maule, Laguna del; San Pedro-Pellado; Blancas, Lomas; Resago; Payún Matru; Domuyo; Cochiquito Volcanic Group; Puesto Cortaderas; Trolon; Mariñaqui, Laguna; **Tolguaca**; Tralihue; Pantojo, Cerro; Tronador; **Cuernos del Diablo**; Yate; Hornopirén; Apagado; Crater Basalt Volcanic Field; Palena Volcanic Group; Puyuhuapi; Cay; Río Murta	Petacas; Santa Cruz; San Cristóbal; Easter Island	Sotará; Illiniza; Chachani, Nevado; Nicholson, Cerro	Mojanda	Licto	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
5	6
8	5
23	4
18	3
137	2
5	1

Table 15.5 The number of volcanoes in South America classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
8	III
10	II
22	I
157	Unclassified

Table 15.6 The number of volcanoes in the South America region classified at each Risk Level.

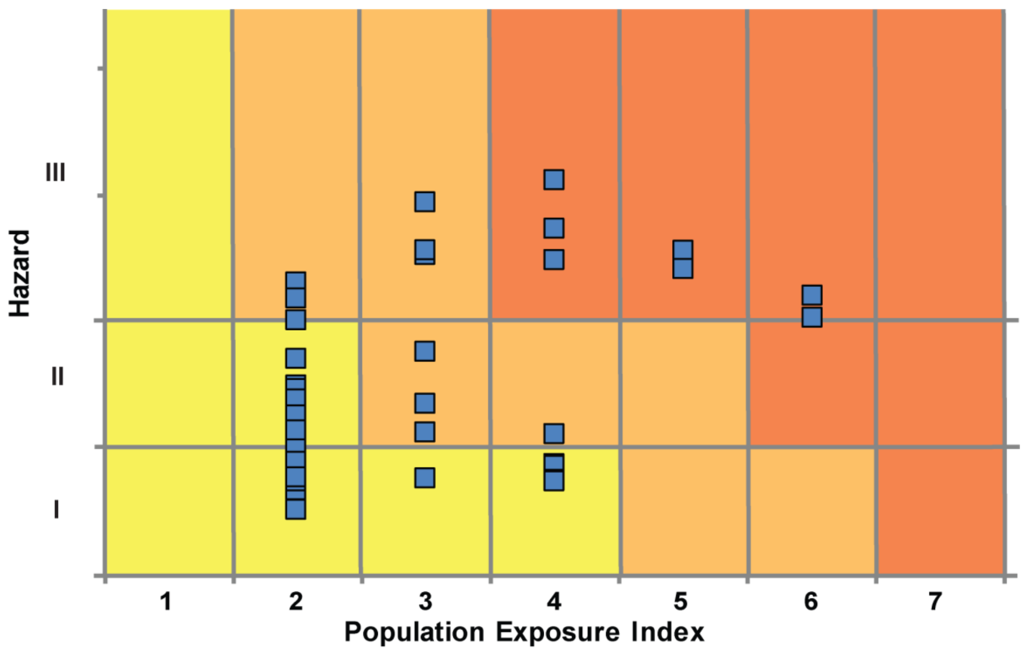

Figure 15.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional Monitoring Capacity

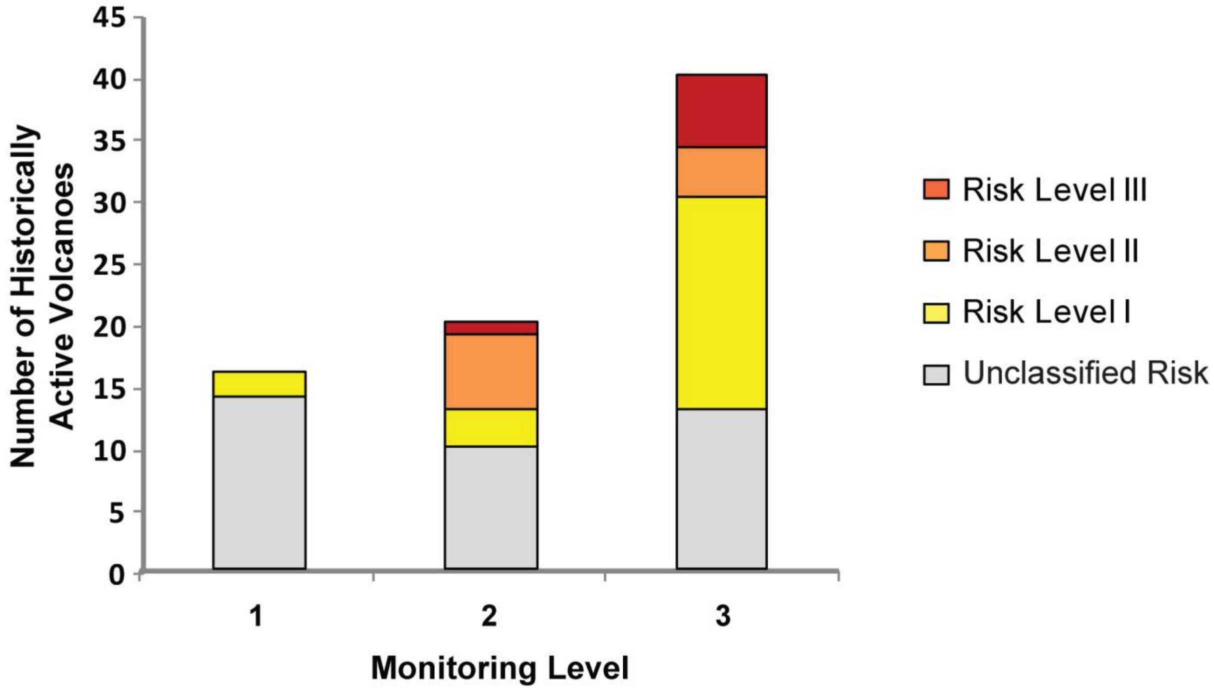

Figure 15.4 The monitoring and risk levels of the historically active volcanoes in South America. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers

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Argentina

Description

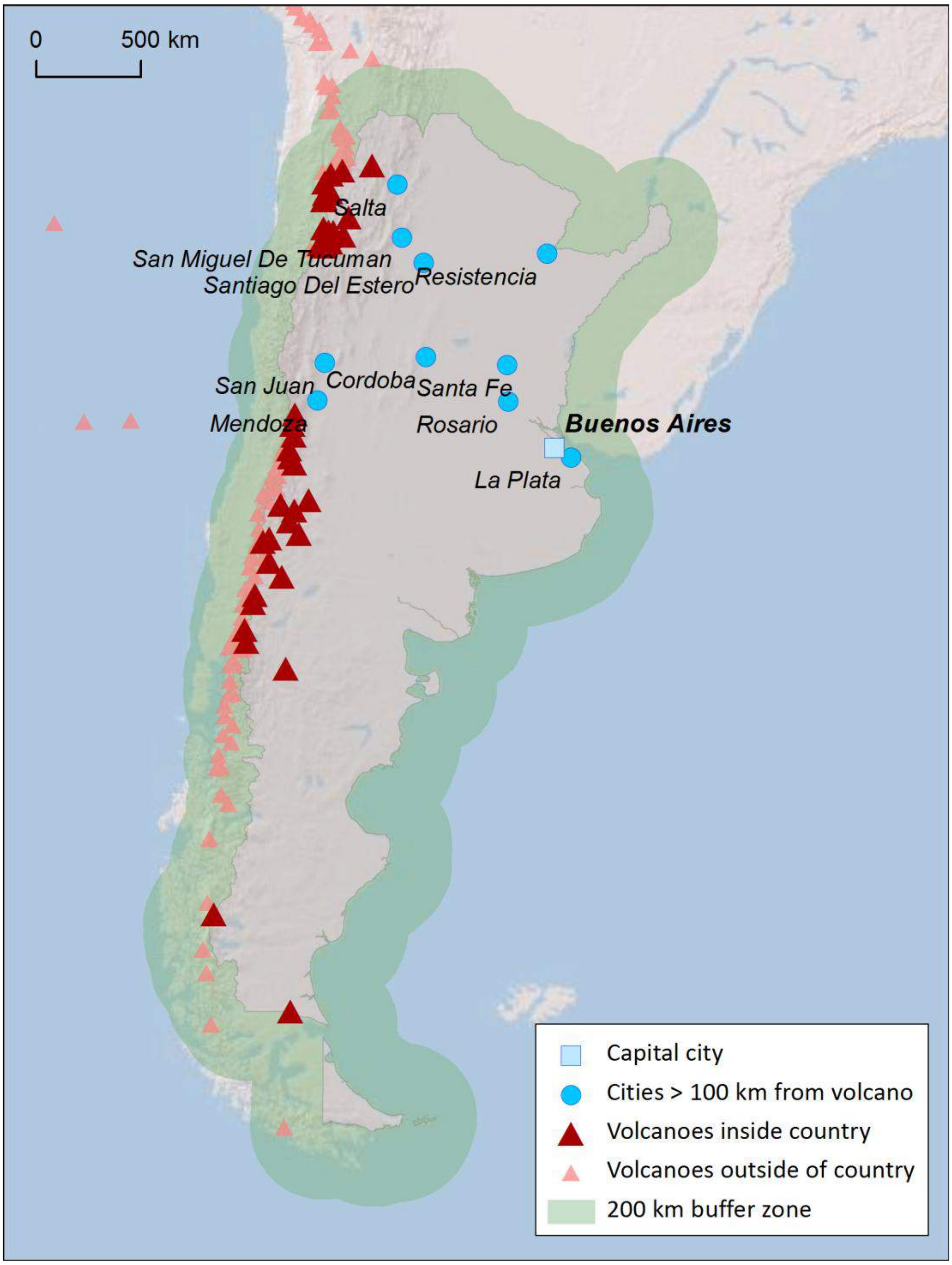

Figure 15.5 Location of Argentina's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Argentina.

Forty-one volcanoes are recorded in Argentina, including 19 on the border with Chile. Most of these volcanoes are located in the Andes, in western Argentina, dominantly in the centre and north of the country. Volcanism here is largely due to the subduction of the Nazca Plate beneath the South

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American Plate. A range of volcano types are present here, though most are stratovolcanoes of dominantly andesitic composition.

Large explosive Pleistocene activity is recorded in Argentina, and 61 eruptions of Holocene age are recorded from 13 volcanoes. The remaining Holocene volcanoes have activity that is suspected to have occurred in the last 10,000 years. Of these Holocene eruptions, 47 are of historical age, occurring at 8 volcanoes. VOTW4.22 records Holocene eruptions of VEI 0 to 3, indicating a prevalence of mild to moderate activity. However, recent studies have identified two Holocene VEI ≥6 eruptions from Cerro Blanco-Robledo volcanic complex, with the caldera forming eruption being one of the largest Holocene eruptions in the central Andes at approximately 4500 BP (Baez et al., 2015). Just one eruption, that of Copahue in 2000, has a recorded historical pyroclastic flow. During this event pyroclastic flows, scoria and ash fall occurred and evacuations were ordered with damage occurring to property.

Many of the most populous cities in Argentina are located far to the east of the volcanic chain, and the elevation of much of the Andes means that local populations are small. Indeed, less than 2,000 people live within 10 km of a Holocene volcano in the whole of Argentina, and less than 2% of the total population live within 100 km of one or more volcanoes (under 700,000). Although the hazard classification at many of Argentina's volcanoes is complicated by large uncertainties, the small local populations mean that these volcanoes are considered relatively low risk to proximal populations. However, the dominant wind direction is such that ash will commonly be distributed west to east across much of Argentina from eruptions in the far west of the country.

The Chilean volcanoes beyond the border are also very important to the hazard consideration in Argentina. Explosive eruptions of these volcanoes can produce ash clouds with ash dispersal throughout Argentina. Indeed, the dominant wind direction here is west to east, leading to ash fall in Argentina in most Chilean eruptions (Viramonte et al., 2001). There are many examples of this (Figure 15.6). For example, the 2008 eruption of Chaitén produced ash fall beyond the Argentine coast (Folch et al., 2008, Durant et al., 2012) and the 2011 eruption of Cordón Caulle resulted in significant ash fall across three Argentine provinces (Río Negro, Neuguén and Chubut) (Collini et al., 2012). Both eruptions had negative impacts on farming (livestock) and agriculture, water transportation networks and air and ground transportation networks (Collini et al., 2012). See the profile for Chile for further discussion of the Chilean volcanoes.

Ash remobilisation can occur for years after an eruption due to wind and rain, and this can cause issues even in times of inactivity at the volcanoes, therefore ash distribution throughout the country must be understood, both from Argentine and Chilean volcanoes.

Authorities in Argentina, especially SEGEMAR (Servicio Geologico y Minero Argentino), Comisión Nacional de Riesgos, Ministerio de Ciencia Tecnología e Innovación Productiva (MINCyT) and the Argentine Space Agency (CONAE) collaborate with the Servicio Nacional de Geologia y Mineria (SERNAGEOMIN) in Chile for monitoring of the border volcanoes. Seismic and deformation monitoring is in place as are cameras for visual observations. Universidad Nacional de Río Negro in collaboration with Firenze University, maintain temporary seismic array for volcanic monitoring in several potential dangerous volcanoes (Copahue, Domuyo, Tromen). Universidad Nacional de Salta in collaboration with Universidad de Cadiz maintains a high resolution GPS network in the Cerro

Blanco-Robledo caldera comnplex for deformation monitoring. Servicio Meteorológico Nacional, Universidad Nacional de Salta, CONICET and CONAE in cooperation with VAAC Buenos Aires work to give early alerts and ash-fall dispersion forecasts. Alerts are released and evacuations ordered as unrest and eruption occurs. SERNAGEOMIN also monitor most volcanoes within Chile, releasing alerts that can be used in ash forecasts for Argentina.

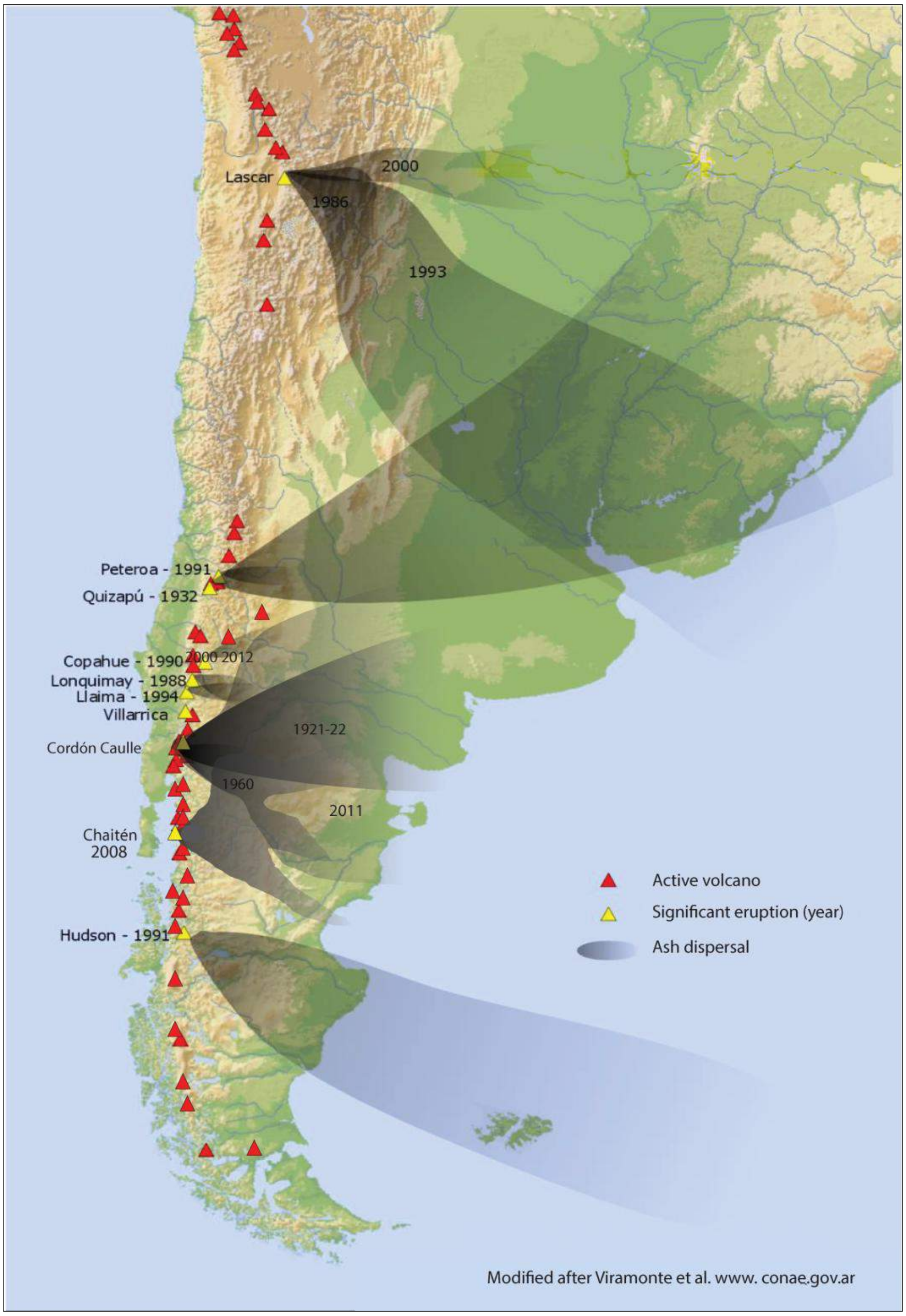

Figure 15.6 The active volcanoes of the central and southern Andes and ash dispersal across Argentina from recent eruptions of Chilean volcanoes. Modified after Viramonte et al. 2001.

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Volcano Facts

Number of Holocene volcanoes	41, inclusive of 19 on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	6, inclusive of 3 on the border with Chile
Number of volcanoes generating pyroclastic flows	4
Number of volcanoes generating lahars	2
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	37 subduction zone, 4 intra-plate
Largest recorded Pleistocene eruption	The M8 eruption of the Cerro Galán Ignimbrite from Cerro Galán at 2.08 Ma.
Largest recorded Holocene eruption	Recent studies reveal that Cerro Blanco – Robledo caldera has had the most powerful Holocene eruption in ~4,500 BP and at VEI ≥6 (Baez et al., 2015).

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Number of Holocene eruptions	61 confirmed eruptions. 14 uncertain and 2 discredited eruptions.
Recorded Holocene VEI range	0 – 3 in VOTW4.22, with VEI ≥6 indicated by recent studies (Baez et al., 2015).
Number of historically active volcanoes	8
Number of historic eruptions	47

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
3	Caldera(s)	Andesitic (2), Rhyolitic (1)
28	Large cone(s)	Andesitic (13), Basaltic (4), Dacitic (7), Unknown (4)
1	Lava dome(s)	Dacitic (1)
1	Shield(s)	Basaltic (1)
7	Small cone(s)	Andesitic (3), Basaltic (4)
1	Subglacial	Dacitic (1)

Table 15.7 The number of volcanoes in Argentina, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	41,117,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	15,501
Gross National Income (GNI) per capita (2005 PPP $)	15,347
Human Development Index (HDI) (2012)	0.811 (Very High)

Population Exposure

Capital city	Buenos Aires
Distance from capital city to nearest Holocene volcano	974.1 km
Total population (2011)	41,769,726
Number (percentage) of people living within 10 km of a Holocene volcano	1,809 (<1%)

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Number (percentage) of people living within 30 km of a Holocene volcano	26,905 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	618,387 (1.5%)

Ten largest cities, as measured by population and their population size:

Buenos Aires	13,076,300
Cordoba	1,428,214
Rosario	1,173,533
Mendoza	876,884
San Miguel De Tucuman	781,023
La Plata	694,167
Salta	512,686
Santa Fe	468,632
San Juan	447,048
Resistencia	387,158

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	4,638
Total length of railroads within 100 km of a volcano (km)	278

Volcanoes in Argentina occur along the western border of the country, on the border with Chile. Volcanoes here are located in three main groups, in the north, centre and south. Many of the border volcanoes here have 100 km radii that extend into Chile, and likewise the radii of Chilean volcanoes extend into western Argentina. The capital, Buenos Aires, lies in the east of the country at nearly 1000 km distance to the nearest Holocene volcano, and most of the largest cities in the country lie far east of the volcanic chain. Only the southernmost Palei-Aike volcano is located near the coast exposing ports and an airport here. An extensive road and rail network lies within the radii of the volcanoes throughout the country.

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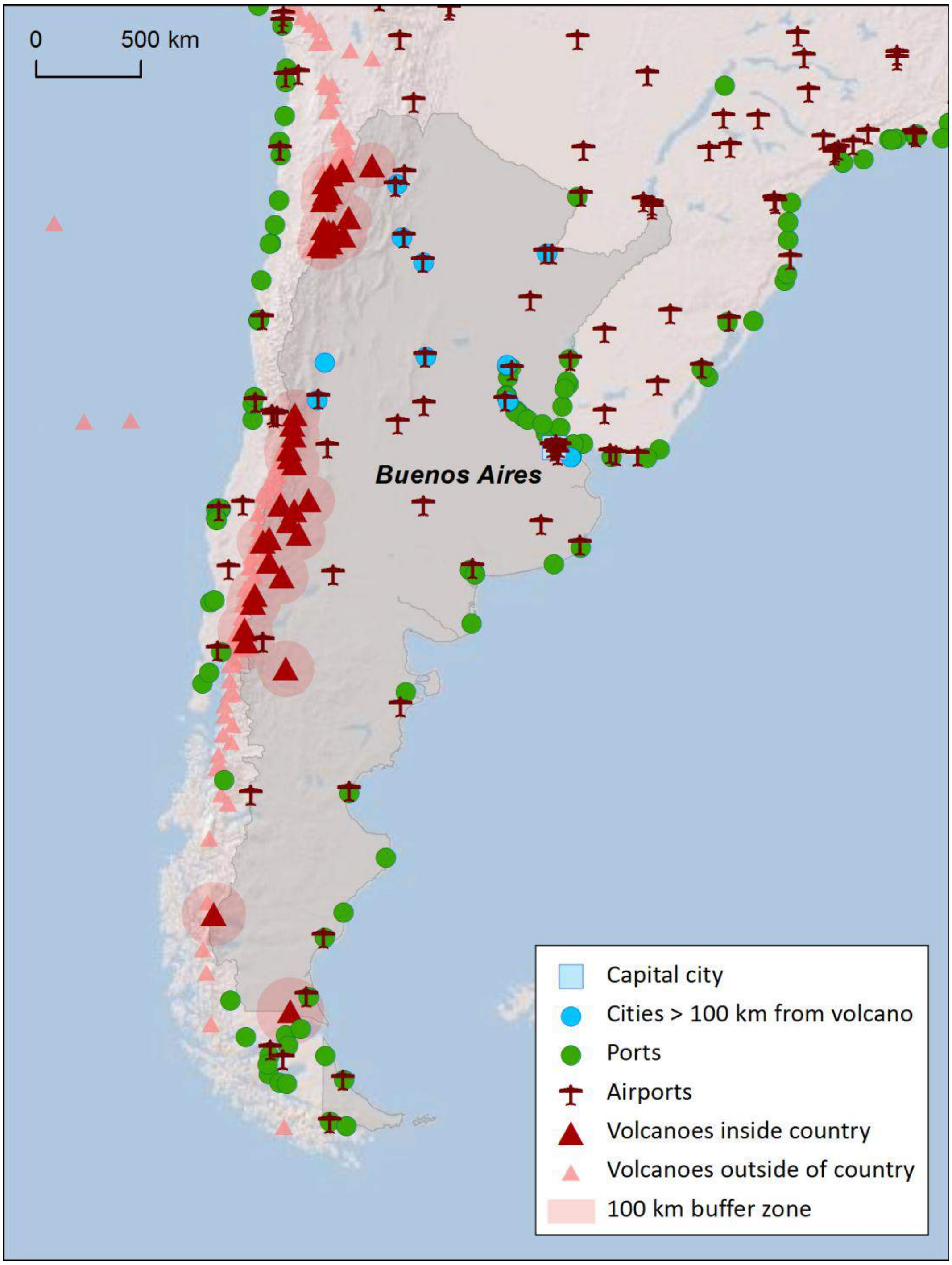

Figure 15.7 The location of Argentina's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Argentina's volcanoes. Just four out of 41 have sufficient detail to define the hazard through the calculation of the VHI. These are classified at Hazard Levels I and II.

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Of the unclassified volcanoes, 28 have no confirmed eruptions in the Holocene record. Nine have a Holocene record, including historical events at Llullaillaco, Tromen, Huanquihue Group and Viedma. The latter has recorded eruptions since 1900 AD. Unrest has been recorded at a further three unclassified volcanoes.

The PEI in Argentina is classed as low to moderate, with most volcanoes having a PEI of 2. All classified volcanoes here are classed at Risk Level I. Given the low population, all unclassified volcanoes would be classed at Risk Levels I and II, were the hazard known.

CLASSIFIED	Hazard III							
	Hazard II		Copahue					
	Hazard I			Maipo	Tupungatito; San José			
UNCLASSIFIED	U – HHR		Llullaillaco; Tromen; Huanquihue Group; **Viedma**					
	U- HR		Socompa; **Nevados Ojos del Salado**; Infiernillo; Lanín; Pali-Aike Volcanic Field; **Cerro Blanco-Robledo complex***					
	U- NHHR	Blanca, Laguna	Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Tuzgle; Aracar; Unnamed; Antofagasta; Cóndor, El; Peinado; Tipas; Atuel, Caldera del; Risco Plateado; Payún Matru; Domuyo; Cochiquito Volcanic Group; Puesto Cortaderas; Trolon; Tralihue; Pantojo, Cerro; Tronador; Crater Basalt Volcanic Field					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 15.8 Identity of Argentina's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

**Note that Robledo had no eruptions recorded in VOTW4.22, but recent studies have identified a large explosive Holocene at this volcano (Baez et al., 2015) and so its entry has been adjusted here from U-NHHR to U-HR.*

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Volcano	Population Exposure Index	Risk Level
San José	4	I
Tupungatito	4	I
Maipo	3	I
Copahue	2	I

Table 15.9 Classified volcanoes of Argentina ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 4 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

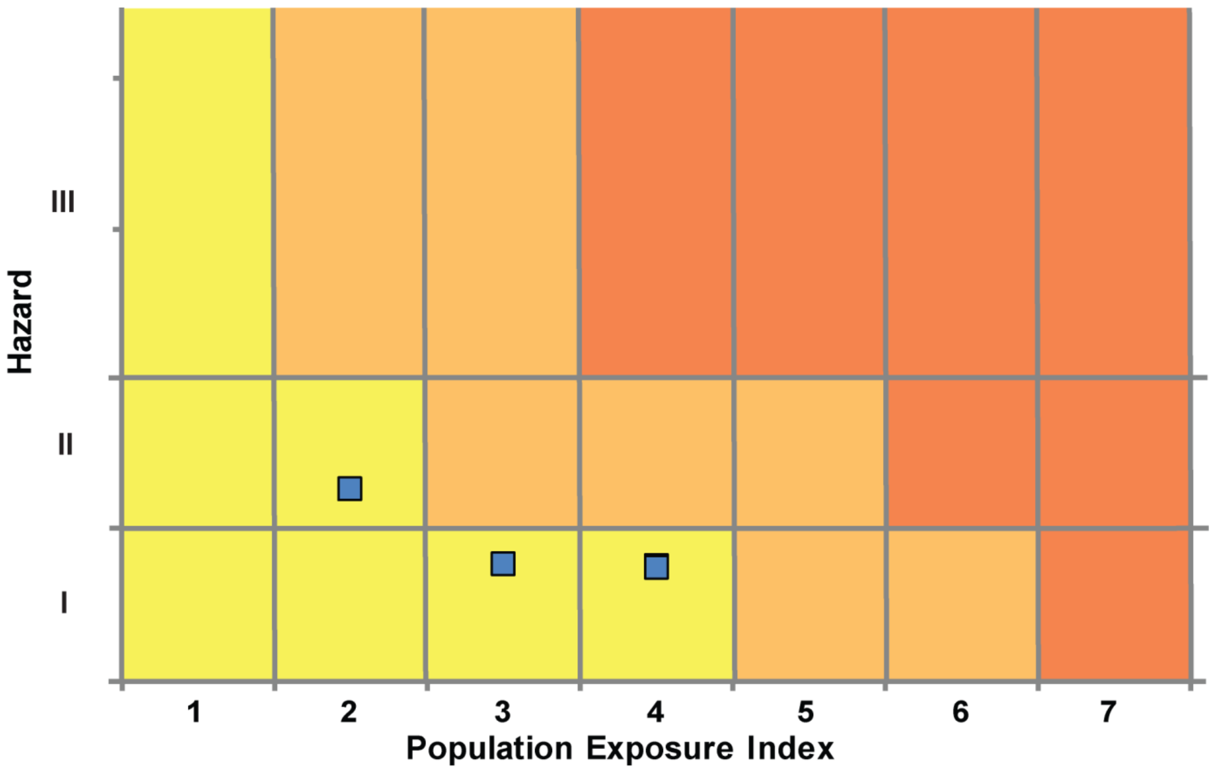

Figure 15.8 Distribution of Argentina's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes in Argentina, inclusive of those on the border with Chile, have records of historical activity. Four are classified at Risk Level I (Tupungatito, San José, Maipo, Copahue) and four are unclassified with a PEI of 2 (Llullaillaco, Tromen, Huanquihue Group and Viedma). At the time of the writing of this report, no information is available to indicate that dedicated ground-based monitoring is in place the four unclassified volcanoes. However, SERNAGEOMIN in Chile operate monitoring systems at four of the border volcanoes, with seismic and deformation monitoring at Copahue, Maipo, Tupungatito and San José.

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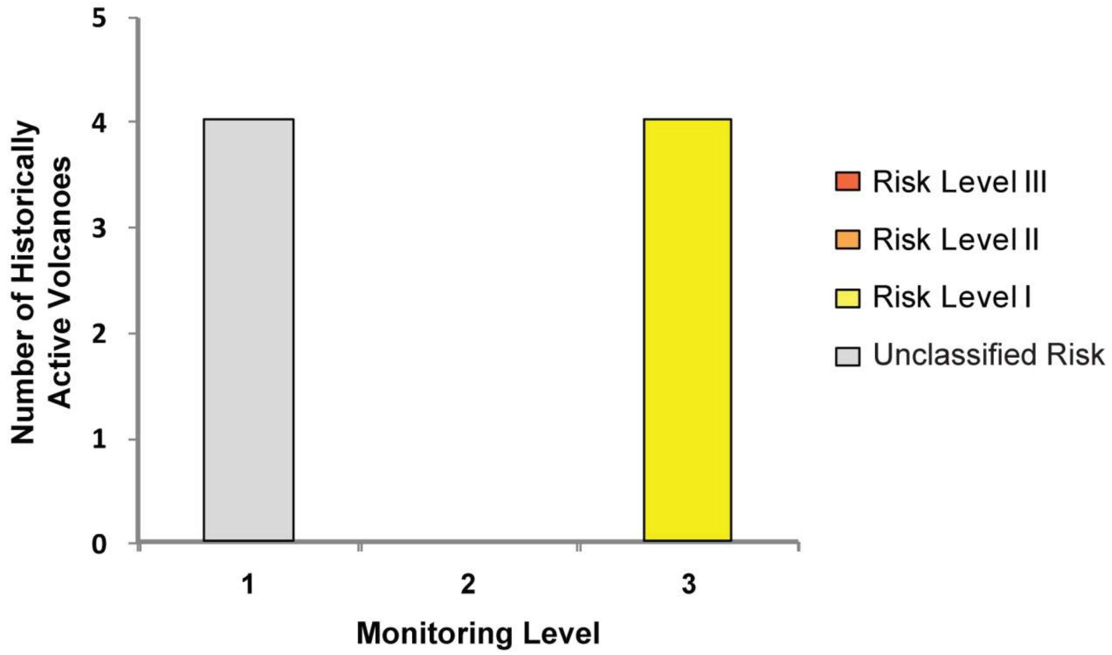

Figure 15.9 The monitoring and risk levels of the historically active volcanoes in Argentina. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Bolivia

Description

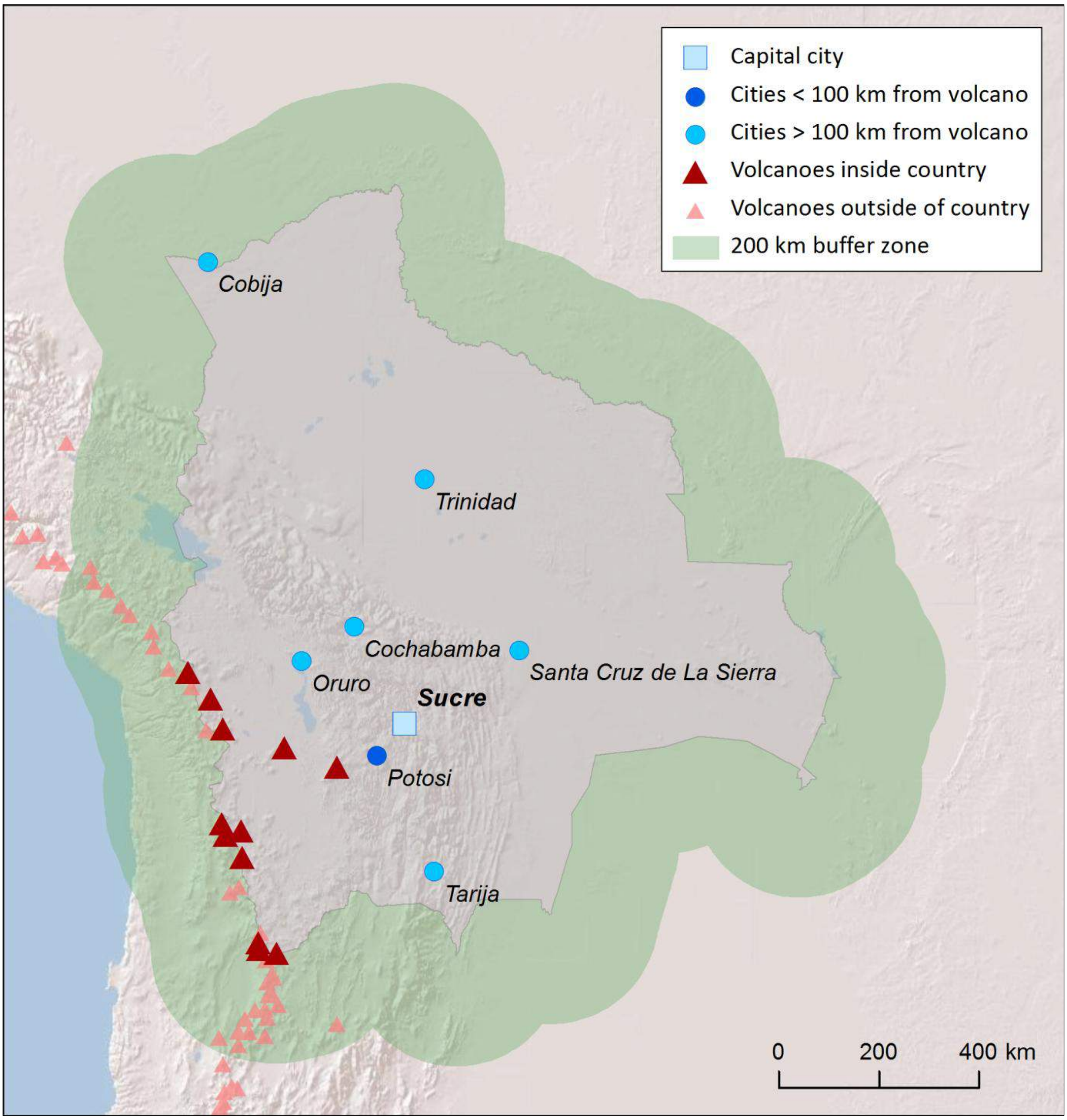

Figure 15.10 Location of Bolivia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Bolivia.

Twelve Holocene volcanoes are located in Bolivia, including seven on the border with Chile. Volcanism here is largely due to the subduction of the Nazca Plate beneath the South American Plate. A variety of volcano forms have developed here, with stratovolcanoes being the most common. The composition varies from basaltic to rhyolitic, though andesitic compositions are most common.

Very large explosive eruptions are recorded back into the Pleistocene, but the Holocene record is sparse, with just seven confirmed eruptions. Two of these were recorded historically, in 1865 at

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Olca-Paruma, and in 1995 at Irruputuncu. This latter eruption is the largest recorded in the Holocene, at just VEI 2.

The sparse nature of the eruptive record suggests that the hazard (the VHI) is poorly constrained however the volcanoes of Bolivia are remote, with the most populous cities located to the east. Only a small number of people live in close proximity to Holocene volcanoes in Bolivia, with about 3,000 in total within 10 km, and less than 500,000 within 100 km of these volcanoes. As such, current understanding suggests that these volcanoes are of relatively low risk.

There is no official monitoring institution in Bolivia, however SERNAGEOMIN in Chile monitors the border volcanoes. Two part-time scientists at the Universidad Mayor de San Andres undertaken volcanic research in Bolivia, and they advise that there are no current response protocols in place for developing unrest or eruption, largely due to the remote nature of the volcanoes. They suggest that infrastructure is at risk, with highways (the Oruro-Pisiga and Patacamaya-Tambo Quemado highway), railways (the Arica line) and an electricity generating station near Nuevo Mundo highlighted as being exposed.

Volcano Facts

Number of Holocene volcanoes	12, inclusive of 7 on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.2 eruption of Laguna Colorado, at 1.9 Ma.
Largest recorded Holocene eruption	The VEI 2 eruption of Irruputuncu in 1995 AD.
Number of Holocene eruptions	7 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Rhyolitic (1)
7	Large cone(s)	Andesitic (7)
2	Lava dome(s)	Dacitic (2)
2	Small cone(s)	Andesitic (1), Basaltic (1)

Table 15.10 The number of volcanoes in Bolivia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	10,523,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,499
Gross National Income (GNI) per capita (2005 PPP $)	4,444
Human Development Index (HDI) (2012)	0.675 (Medium)

Population Exposure

Capital city	Sucre
Distance from capital city to nearest Holocene volcano	152.1 km
Total population (2011)	10,118,683
Number (percentage) of people living within 10 km of a Holocene volcano	3,098 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	29,479 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	465,904 (4.6%)

Largest cities, as measured by population and their population size:

Santa Cruz de La Sierra	1,364,389
Cochabamba	900,414
La Paz	812,799
Sucre	224,838
Oruro	208,684
Tarija	159,269
Potosi	141,251
Trinidad	84,259
Cobija	26,585

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Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	908
Total length of railroads within 100 km of a volcano (km)	282

The volcanoes are situated in a chain along much of the western border of Bolivia and Chile. The 100 km radii of these volcanoes fully encompasses this border, and extends into Chile, Peru and Argentina. Similarly, the border volcanoes in these countries have 100 km radii that extend into Bolivia. The capital, Sucre, lies at over 150 km from the nearest Holocene volcano. The volcanoes in Bolivia are relatively remote, but with numerous small settlements and an extensive road network lying within their 100 km radii.

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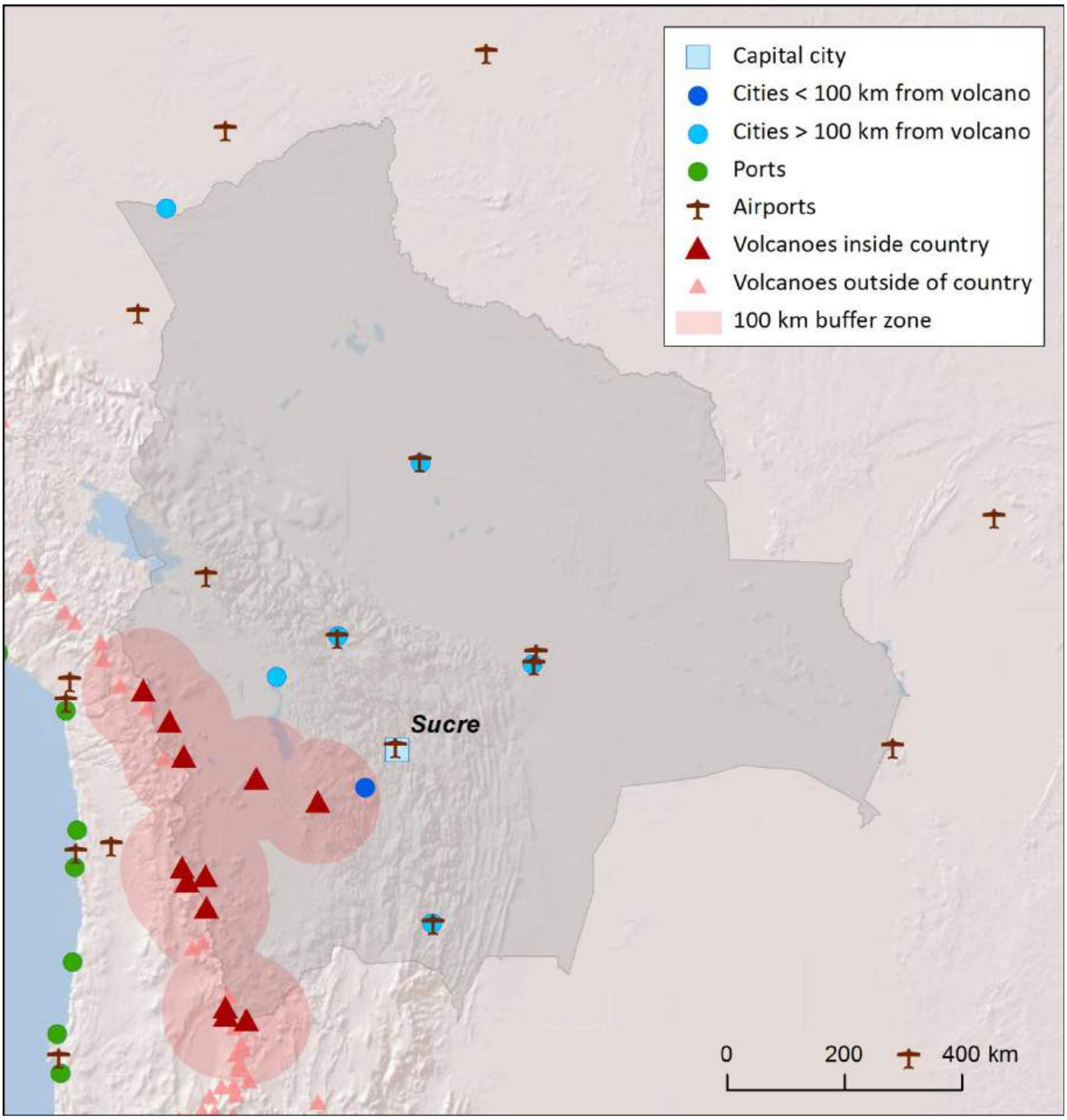

Figure 15.11 The location of Bolivia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for Bolivia's volcanoes lack sufficient detail to determine hazard levels through the calculation of the VHI. These volcanoes are therefore unclassified. Indeed, of the twelve volcanoes here, just three have a confirmed Holocene record of eruptions, including historical activity at Irruputuncu and Olca-Paruma. Eruptions and unrest have been recorded at these two volcanoes since 1900 AD, respectively.

The PEI at all Bolivian volcanoes is low at PEI 2. The absence of a hazard classification prevents determination of risk levels, however this low local populations suggests risk levels of I and II.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR		**Irruputuncu**; **Olca-Paruma**					
	U- HR		Parinacota					
	U-NHHR		Tambo Quemado; Tata Sabaya; Jayu Khota, Laguna; Nuevo Mundo; Pampa Luxsar; **Ollagüe**; Sairecabur; Licancabur; Guayaques					
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 15.11 Identity of Bolivia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Two volcanoes on the Bolivia-Chile border have historical records of activity. Monitoring undertaken by SERNAGEOMIN in Chile is described at both these volcanoes, however the details are unknown.

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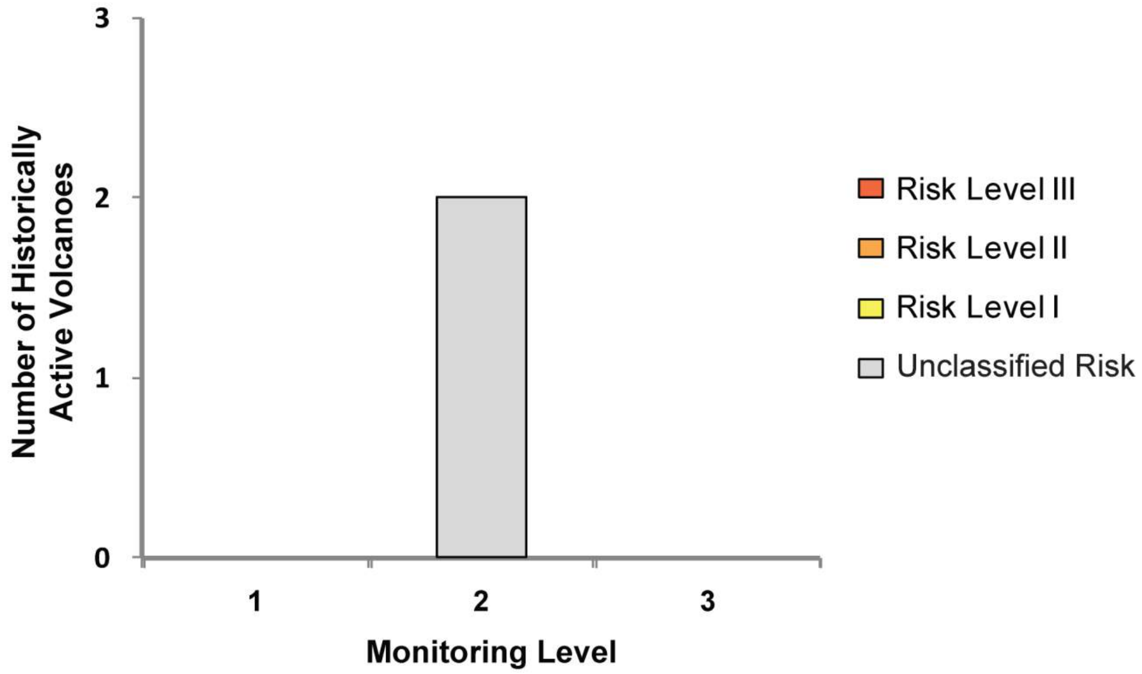

Figure 15.12 The monitoring and risk levels of the historically active volcanoes in Bolivia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Chile

Description

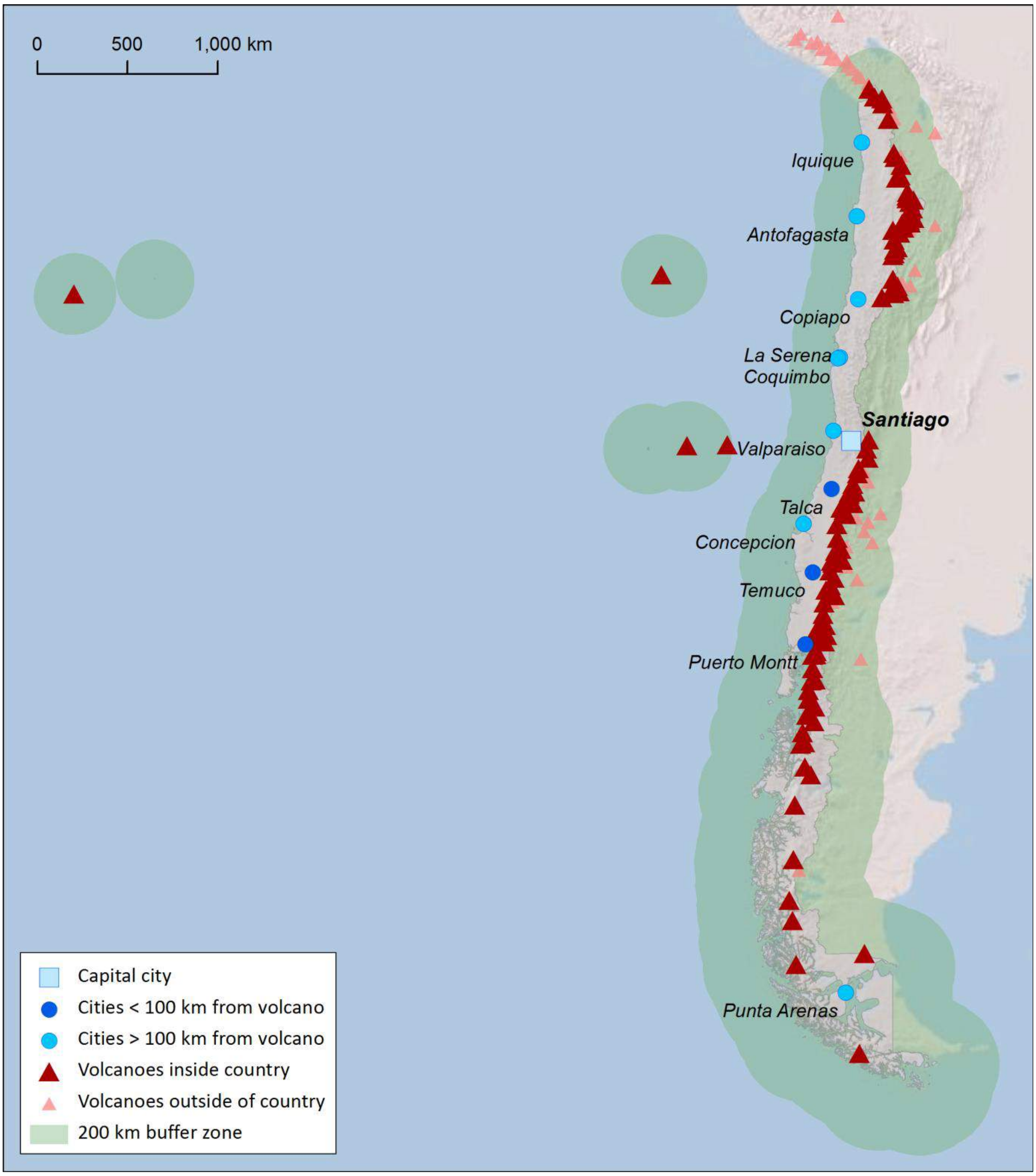

Figure 15.13 Location of Chile's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Chile.

There are 105 volcanoes in Chile, including nearly 30 on the borders within Argentina, Bolivia and Peru. Several groups of volcanoes are present, with scattered remote volcanoes in the very far south, a large concentration of volcanic centres south of Santiago and north of Copiapo, and Chilean islands in the Pacific Ocean. Volcanism through Chile is primarily due to the subduction of the Nazca Plate beneath the South American Plate and intra-plate processes in the Pacific.

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A range of volcano types are present throughout Chile, though stratovolcanoes are most common with about three quarters of volcanoes here being classified as such. The rock type also varies, from basaltic to rhyolitic, however andesitic compositions are most common.

Large explosive Pleistocene activity is recorded in Chile at 20 volcanoes. The largest Pleistocene eruptions were of magnitude 7.4, with three eruptions of this size at Calabozos caldera about 150,000, 300,000 and 800,000 years ago. Holocene activity has occurred here and hot springs are still active within the caldera.

Holocene activity in Chile has included 476 confirmed eruptions from 56 volcanoes. The remaining volcanoes have activity of suspected Holocene age. Holocene activity has comprised a range of activity styles and sizes, with eruptions from VEI 0 to 6, though only about 5% of these were VEI ≥4.

Historically, 40 volcanoes are recorded producing 357 eruptions. Of these, 8 were VEI ≥4, though pyroclastic flows are recorded in 16 eruptions. Lava flows have more commonly been recorded and 14% of eruptions have resulted in lahars. The largest historical eruption in Chile occurred at Cerro Azul in 1916. This VEI 5 eruption ejected 9.5 cubic kilometres of tephra and was one of the world's largest eruptions in the 20th century.

Only a small total population is situated within 10 km of one or more Holocene volcanoes in Chile, however this grows considerably at 30 km and to about 10.6 million at 100 km, accounting for about 63% of the population. Ten historic eruptions have resulted in loss of life, at Lonquimay, Llaima, Villarrica, Carran-Los Venados, Chaiten and Cerro Hudson.

The Red de Vigilancia Volcanic (Volcano monitoring network) and the Observatorio Volcanologico de Los Andes del Sur (OVDAS) are part of the Servicio Nacional de Geologia y Mineria (SERNAGEOMIN). This body is government funded, and was founded in 1996. The main objective of these groups is to establish monitoring systems and monitor the most dangerous volcanoes in Chile (based on the frequency of activity, proximity to population centres and vulnerability of public and private infrastructure) in order to provide information to the relevant authorities.

Monitoring is undertaken at many volcanoes using seismic networks, cameras, deformation and gas measurements. Success of the network has been proven in the eruption of Puyehue-Cordon Caulle and alerts at Hudson and Copahue. Resources and plans are available for responding to developing unrest and eruption at current un- or under-monitored volcanoes.

Scientific, technical and support staff are present at the monitoring institution, and about 20% of these have experience of responding to activity, however large amounts of data are gathered and further scientific experience and support is required for full analysis.

Regular technical meetings are held in the event of increased activity and an informal response protocol is followed, including alerting the regional VAAC. The Oficina Nacional de Emergencia del Ministerio del Interior y Seguridad Pública (ONEMI) coordinates emergency response. OVDAS communicates hazard assessments and alerts to ONEMI who use a civil protection alert system.

A relative threat ranking is produced by SERNAGEOMIN for the volcanoes of Chile. This is similar to the NVEWS method and VHI, using hazard indicators taken from the records and coupling these with exposure factors. The relative threat is the sum of the hazard × sum of exposure. This ranking system

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indicates that Villarrica and Llaima have the largest relative threat ranking, with these volcanoes being the most frequently active here with 126 historical eruptions between them coupled with large populations within 100 km.

A questionnaire was completed by SERNAGEOMIN as part of this study. This indicated that a number of volcano records in VOTW4.0 require updating, with some volcanoes considered Holocene age in VOTW4.0 but designated as Pleistocene age by SERNAGEOMIN. This highlights the value of close collaboration between the volcanological community to ensure up-to-date and sustainable data systems. Updates will be considered by the Smithsonian Institution.

See also:

SERNAGEOMIN: www.sernageomin.cl/volcan-observatorio.php

Volcano Facts

Number of Holocene volcanoes	105, inclusive of 19 on the border with Argentina, 7 on the border with Bolivia and 1 on the border with Peru
Number of Pleistocene volcanoes with M≥4 eruptions	20, inclusive of 3 on the border with Argentina
Number of volcanoes generating pyroclastic flows	19
Number of volcanoes generating lahars	13
Number of volcanoes generating lava flows	25
Number of fatalities caused by volcanic eruptions	?473
Tectonic setting	101 Subduction zone, 3 Intra-plate, 1 Rift zone
Largest recorded Pleistocene eruption	The Loma Seca Tuff, units S, V and L from Calabozos are all recorded at M7.4 at 150 ka, 300 ka and 800 ka respectively.
Largest recorded Holocene eruption	The M6.3 H1/T2 eruption from Cerro Hudson at 7710 BP.
Number of Holocene eruptions	476 confirmed eruptions. 74 uncertain and 9 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	40
Number of historic eruptions	357

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Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Andesitic (3), Dacitic (2), Rhyolitic (1)
78	Large cone(s)	Andesitic (51), Basaltic (12), Dacitic (12), Unknown (3)
2	Lava dome(s)	Andesitic (1), Dacitic (1)
3	Shield(s)	Basaltic (3)
15	Small cone(s)	Andesitic (5), Basaltic (7), Dacitic (1), Unknown (2)
1	Submarine	Unknown (1)

Table 15.12 The number of volcanoes in Chile, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	17,479,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	15,272
Gross National Income (GNI) per capita (2005 PPP $)	14,987
Human Development Index (HDI) (2012)	0.819 (Very High)

Population Exposure

Capital city	Santiago
Distance from capital city to nearest Holocene volcano	80.5 km
Total population (2011)	16,888,760
Number (percentage) of people living within 10 km of a Holocene volcano	21,030 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	208,768 (1.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	10,623,259 (62.9%)

Ten largest cities, as measured by population and their population size:

Santiago	4,837,295
Antofagasta	309,832
Valparaiso	282,448
Temuco	238,129
Iquique	227,499
Concepcion	215,413
Talca	197,479
Puerto Montt	160,054

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La Serena	154,521
Copiapo	129,280

Infrastructure Exposure

Number of airports within 100 km of a volcano	10
Number of ports within 100 km of a volcano	8
Total length of roads within 100 km of a volcano (km)	16,196
Total length of railroads within 100 km of a volcano (km)	2,139

The numerous volcanoes of Chile are located primarily along the country's eastern border with Argentina, Bolivia and Peru, and as such the 100 km radii of these volcanoes extend into these neighbouring countries. Similarly, volcanoes near the borders in these countries have radii extending into Chile, exposing the infrastructure here. Several volcanoes are situated in the Pacific off the coast of Chile. The capital, Santiago, lies within 100 km of the historically active Tupungatito and San José volcanoes, hence considerable critical infrastructure is exposed here. Being a relatively narrow stretch of land, much of southern Chile lies within 100 km of Holocene volcanoes, and many ports are exposed here. A very extensive road and rail network is exposed throughout the country, and many of the country's largest cities lie within 100 km.

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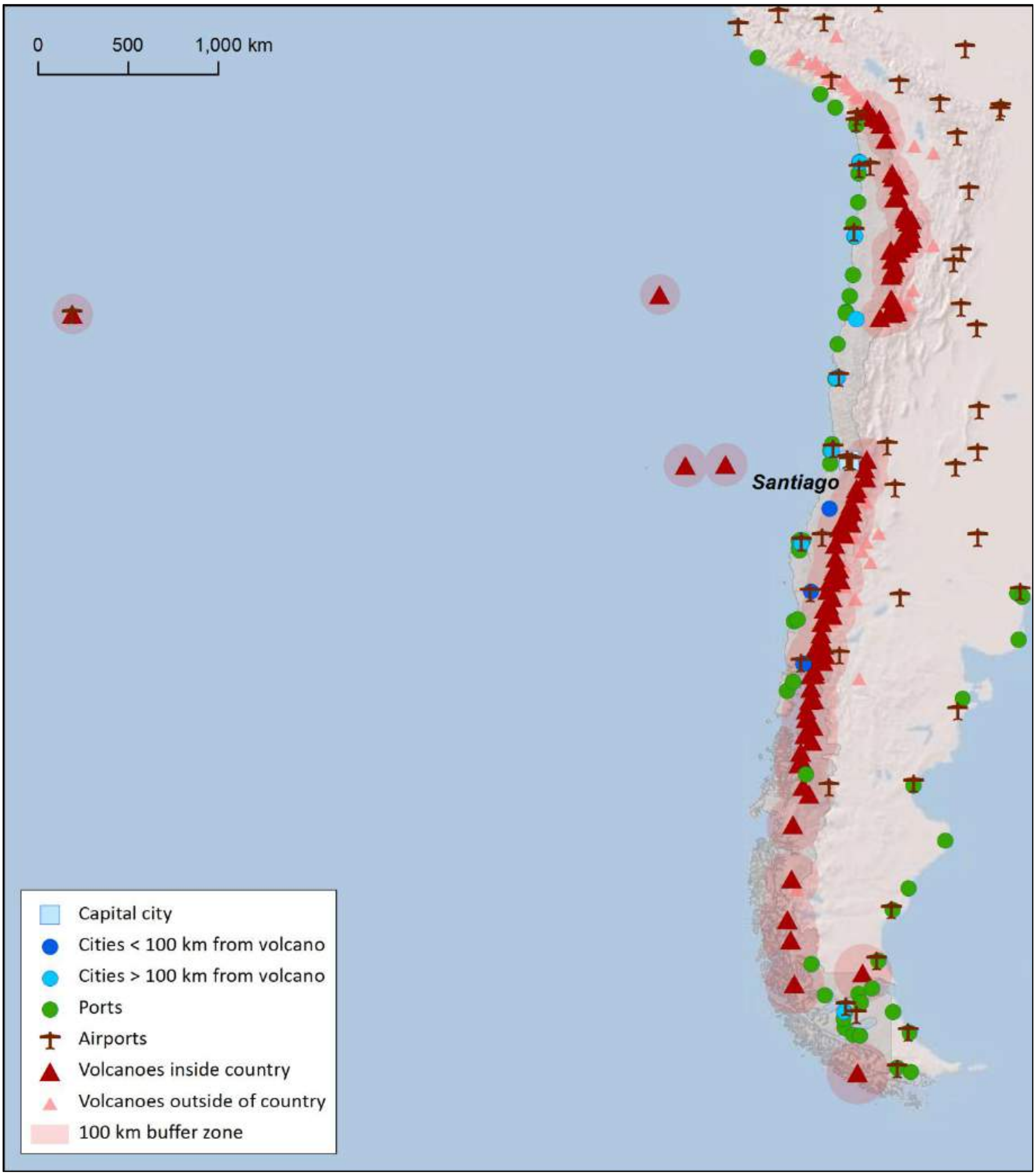

Figure 15.14 The location of Chile's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Chile's volcanoes. About 20% of the volcanoes here (20 out of 105) have sufficient detail to define the hazard through the calculation of the VHI. These are classified across all three hazard levels, with most being classed at Hazard Levels I and II. Four volcanoes are classed at Hazard Level III, all with Holocene records of eruptions of VEI 4 and 5 and all with records of explosive volcanism accompanied by the production of pyroclastic flows.

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Of the unclassified volcanoes, 49 have no records of confirmed Holocene age eruptions. 36 volcanoes have a Holocene eruption record, of which 20 have erupted historically (post-1500 AD) including eruptions since 1900 AD at 11 volcanoes. Unrest is described at nine unclassified volcanoes since 1900 AD. Seven unclassified volcanoes have Holocene records of large explosive VEI ≥4 eruptions.

The PEI ranges from 1 to 4, low to moderate, in Chile, with an overwhelming majority at PEI 2. The classified volcanoes are therefore Risk Levels of I and II. Although the risk levels cannot be defined for the unclassified volcanoes due to the absence of hazard details, these would all also be clased at Risk Level I and II.

CLASSIFIED	**Hazard III**		Cerro Azul; Puyehue-Cordón Caulle; Osorno	Calbuco				
	Hazard II		Láscar; Planchón-Peteroa; Chillán, Nevados de; Antuco; Copahue; Lonquimay; Llaima	Villarrica				
	Hazard I		Guallatiri; Isluga; San Pedro; Huequi; Lautaro	Maipo	Tupungatito; San José			
UNCLASSIFIED	**U – HHR**	Robinson Crusoe	**Irruputuncu**; **Olca-Paruma**; Putana; Llullaillaco; **Tinguiririca**; **Descabezado Grande**; **Callaqui**; Quetrupillan; **Mocho-Choshuenco**; Puntiagudo-Cordón Cenizos; Minchinmávida; Mentolat; **Cerro Hudson**; **Arenales**; **Reclus**; **Monte Burney**; Fueguino	**Carrán-Los Venados; Chaitén**				
	U- HR		Taapaca; Parinacota; Socompa; **Nevados Ojos del Salado**; Longaví, Nevado de; Lanín; Antillanca Group; Cayutué-La Viguería; **Yanteles**; Corcovado; **Melimoyu**; Macá; Aguilera; Pali-Aike Volcanic Field	Sollipulli; Caburgua-Huelemolle				
	U-NHHR	San Félix; Unnamed	Tacora; **Ollagüe**; Azufre, Cerro del; Sairecabur; Licancabur; Guayaques; Purico Complex; Colachi; Acamarachi; Overo, Cerro; **Chiliques**; Cordón de Puntas Negras; Miñiques; Tujle, Cerro; Caichinque; Tilocalar; Negrillar, El; Pular; Negrillar, La; Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Copiapó; Palomo; Calabozos; Maule, Laguna del; San Pedro-Pellado; Blancas, Lomas; Resago; Mariñaqui, Laguna; **Tolguaca**; Pantojo, Cerro; Tronador; **Cuernos del Diablo**; Yate; Hornopirén; Apagado; Palena Volcanic Group; Puyuhuapi; Cay; Río Murta	Easter Island				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 15.13 Identity of Chile's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Tupungatito	4	I
San José	4	I
Villarrica	3	II
Calbuco	3	II
Maipo	3	I
Azul, Cerro	2	II
Puyehue-Cordón Caulle	2	II
Osorno	2	II
Guallatiri	2	I
Isluga	2	I
San Pedro	2	I
Láscar	2	I
Planchón-Peteroa	2	I
Chillán, Nevados de	2	I
Antuco	2	I
Copahue	2	I
Lonquimay	2	I
Llaima	2	I
Huequi	2	I
Lautaro	2	I

Table 15.14 Classified volcanoes of Chile ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 15 volcanoes; Risk Level II – 5 volcanoes; Risk Level III – 0 volcanoes.

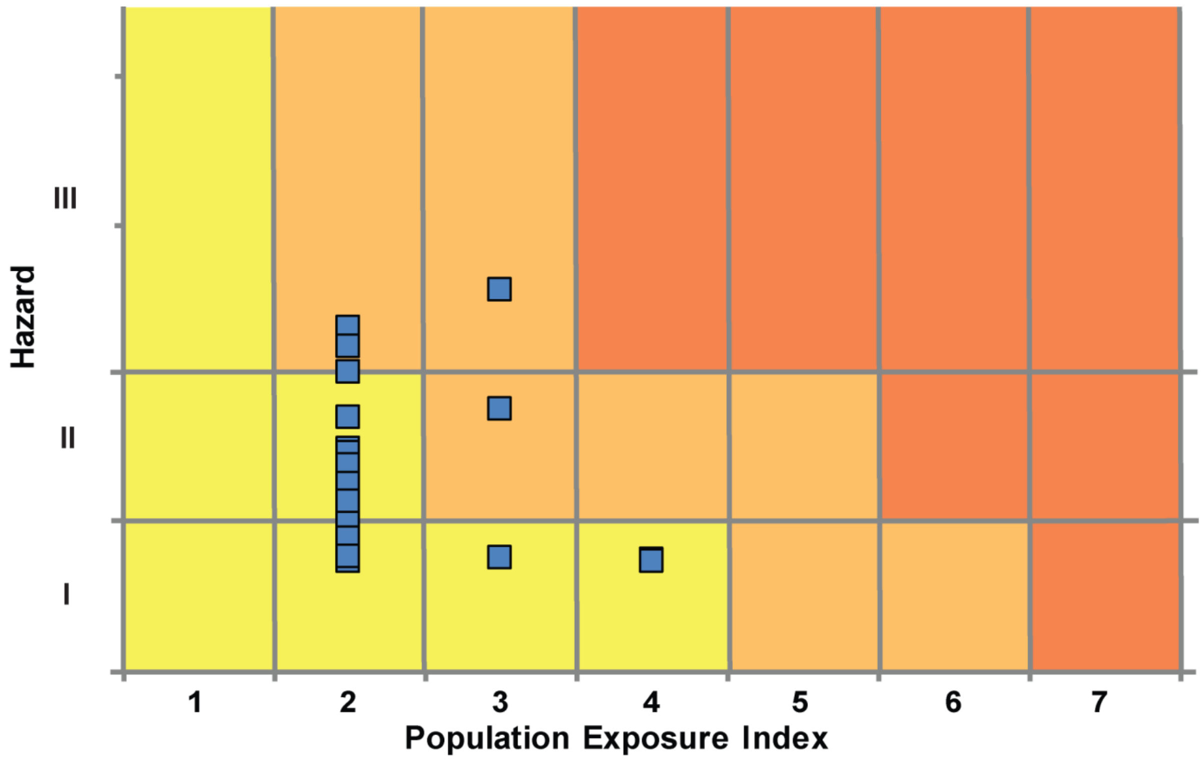

Figure 15.15 Distribution of Chile's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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National Capacity for Coping with Volcanic Risk

Forty volcanoes have records of historical activity in Chile. These volcanoes are primarily classed at Risk Level I. All Risk Level II historical volcanoes are monitored by SERNAGEOMIN using seismic stations as a minimum. Many volcanoes also have deformation monitoring.

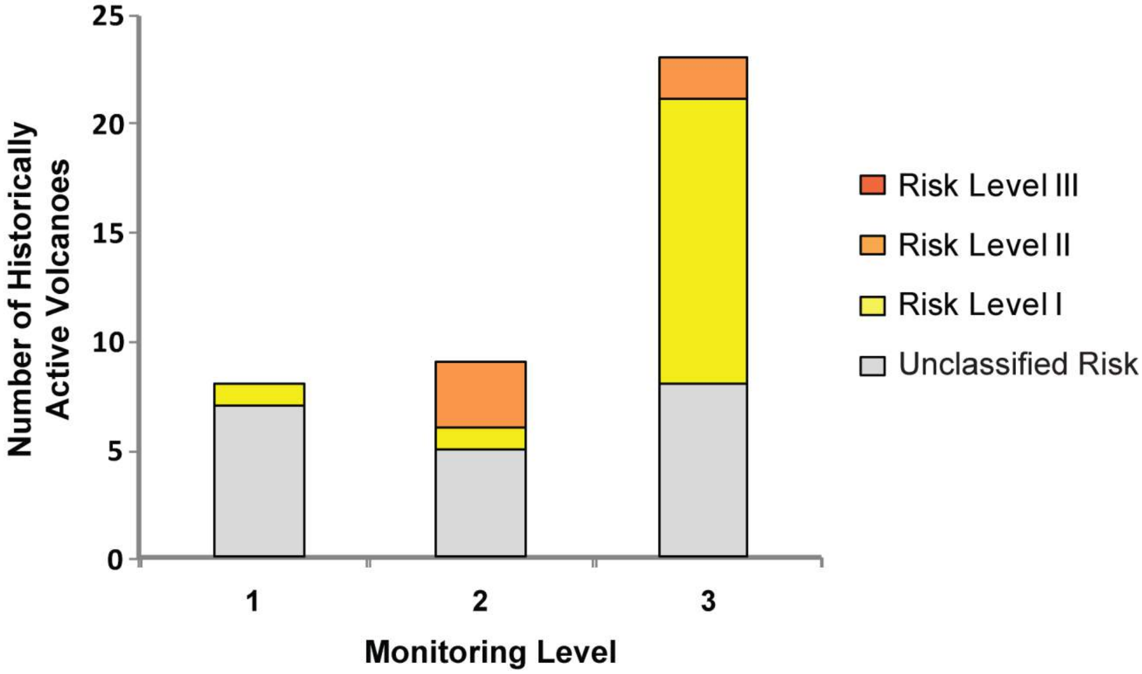

Figure 15.16 The monitoring and risk levels of the historically active volcanoes in Chile. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Colombia

Description

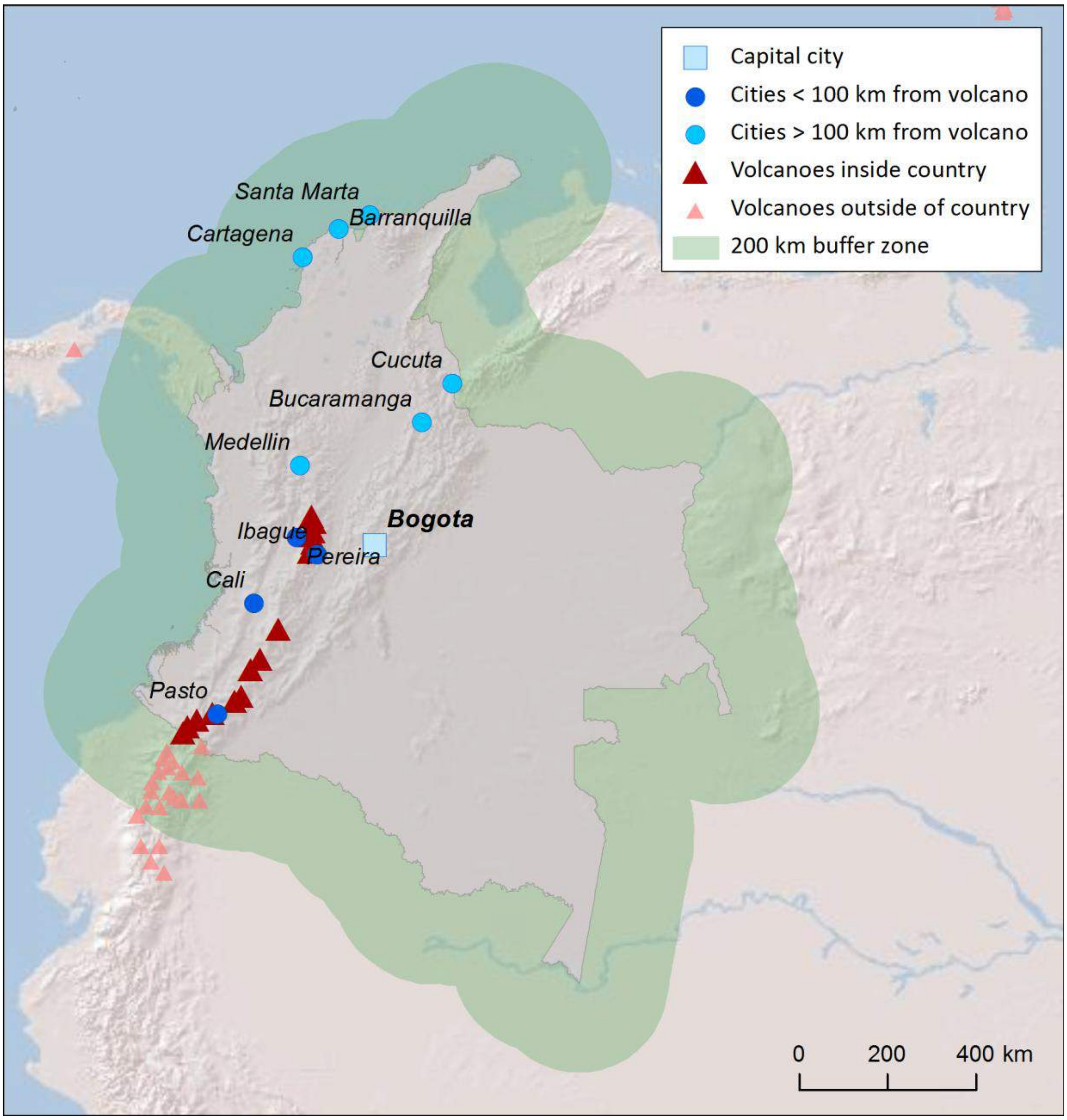

Figure 15.17 Location of Colombia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Colombia.

Fifteen Holocene volcanoes are distributed through the northern Andes in western Colombia to the Ecuador border, paralleling the Pacific coastline. These volcanoes are related to the subduction of the Nazca Plate beneath the South American Plate.

All Holocene volcanoes in Colombia form edifices typically associated with explosive-type activity, including stratovolcanoes and complex volcanoes, with the exception of the Petacas lava dome and Santa Isabel shield. The Colombian volcanoes are dominantly andesitic in composition. The explosive

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record continues into the Pleistocene, with three Colombian volcanoes hosting M/VEI ≥4 eruptions in this period.

There are 125 confirmed eruptions recorded in the Holocene, at VEI 1 to 5, indicating a range of activity from mild to strongly explosive. Eight volcanoes have a Holocene record of producing pyroclastic flows, and six are associated with lahars. Nine of the Colombian volcanoes have 79 eruptions recorded in historical times.

Many of Colombia's most populous cities are located on or towards the northern coast, away from volcanoes, however the cities of Cali, Ibague, Pasto and Pereira lie within 100 km of one or more Holocene volcanoes, with the latter three over-looked by Machin, Galeras and the Ruiz-Tolima chain. Numerous eruptions of Nevado del Ruiz, Nevado del Huila, Puracé and Galeras have resulted in evacuations and property damage. Fatalities are recorded in nine eruptions of these volcanoes and Doña Juana.

The assessment of hazard is complicated by sparse eruptive histories at over half of Colombia's volcanoes, resulting in hazard levels with large associated uncertainties hence just five volcanoes have a hazard level classified here. Nevado del Ruiz, Galeras and Cerro Bravo are classed with the highest hazard in Colombia based on detailed eruptive histories. Coupled with the high proximal population, these volcanoes are classed at Risk Level III.

Both Galeras and Nevado del Ruiz have caused loss of life. Machín has not caused any fatalities but has shown recent unrest, and its geological record indicates the potential for violent and destructive explosive eruptions. In 1993, a sudden intense but small magnitude explosive eruption of Galeras killed nine people, including six volcanologists who were in the inner crater or on its rim. A far larger disaster, the largest in South America's history, was the 1985 eruption of Nevado del Ruiz. Though only VEI 3, the eruption generated pyroclastic flows that melted the volcano's glacier cap and caused lahars. The mudflows descended the western flanks, flowing along the Río Lagunillas valley. The town of Armero, located on the banks of Río Lagunillas 48 km from the volcano, was completely buried. Though the death toll is uncertain, it is estimated that 21,000 of the 29,000 residents of Armero were killed, along with others elsewhere bringing the total loss of life to between 23,000 and 26,000.

Further eruptions with human impacts have occurred very recently at Galeras volcano. An eruption starting on 25th August 2010 spread ash as far as 30 km to the northwest; 7,000 people were advised to evacuate though few left their homes. Activity did not increase after this until January 2011.

Eruptions at a number of the northernmost volcanoes in Ecuador may directly affect Colombia as they lie within 100 km of the border. Similarly, Galeras, Cumbal and Azufral lie within 100 km of Ecuador.

Following the 1985 Nevado del Ruiz tragedy, the Colombian Government took steps to strengthen the monitoring and response mechanisms for Colombian volcanoes. These measures included making INGEOMINAS responsible for the monitoring of volcanoes and provision of scientific advice.

The Servicio Geologico Colombiano (INGEOMINAS) operate three volcano observatories in Colombia: Observatorio Pasto (responsible for Galeras, Cumbal, Chiles, Cerro Negro, Las Animas, Doňa Juana and Azufral); Observatorio Manizales (responsible for Nevado del Ruiz, Cerro Machin, Cerro Bravo, Nevado Santa Isabel, and Nevado Tolima); and Observatorio Popayan (responsible for Nevado del Huila, Sotará and Puracé). INGEOMINAS operate a monitoring network at Colombia's active volcanoes and the status of the volcanoes is communicated publically and is available online.

See also:

INGEOMINAS - www.sgc.gov.co/

Volcano Facts

Number of Holocene volcanoes	15, inclusive of one on the border with Ecuador
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	8
Number of volcanoes generating lahars	6
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	?25,567
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The El Boqueron Ancestral caldera collapse eruption of 580 ka at Nevado del Tolima and the 560 ka Coba Negra caldera forming eruption of Galeras are both recorded at M6.2.
Largest recorded Holocene eruption	The M5.5 R8 eruption of Nevado del Ruiz at 2.8 ka.
Number of Holocene eruptions	125 confirmed eruptions. 10 uncertain eruptions.
Recorded Holocene VEI range	1 – 5 and unknown
Number of historically active volcanoes	9
Number of historic eruptions	79

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Number of volcanoes	Primary volcano type	Dominant rock type
13	Large cone(s)	Andesitic (9), Dacitic (4)
1	Lava dome(s)	Unknown (1)
1	Shield(s)	Andesitic (1)

Table 15.15 The number of volcanoes in Colombia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	47,783,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,861
Gross National Income (GNI) per capita (2005 PPP $)	8,711
Human Development Index (HDI) (2012)	0.719 (High)

Population Exposure

Capital city	Bogatá
Distance from capital city to nearest Holocene volcano	138.6 km
Total population (2011)	44,725,543
Number (percentage) of people living within 10 km of a Holocene volcano	451,010 (1%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,236,251 (7.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	13,408,843 (30%)

Ten largest cities, as measured by population and their population size:

Bogota	7,102,602
Cali	2,392,877
Medellin	1,999,979
Barranquilla	1,380,425
Cartagena	952,024
Cucuta	721,398
Bucaramanga	571,820
Pereira	440,118
Santa Marta	431,781
Ibague	421,685

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Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	3,159
Total length of railroads within 100 km of a volcano (km)	420

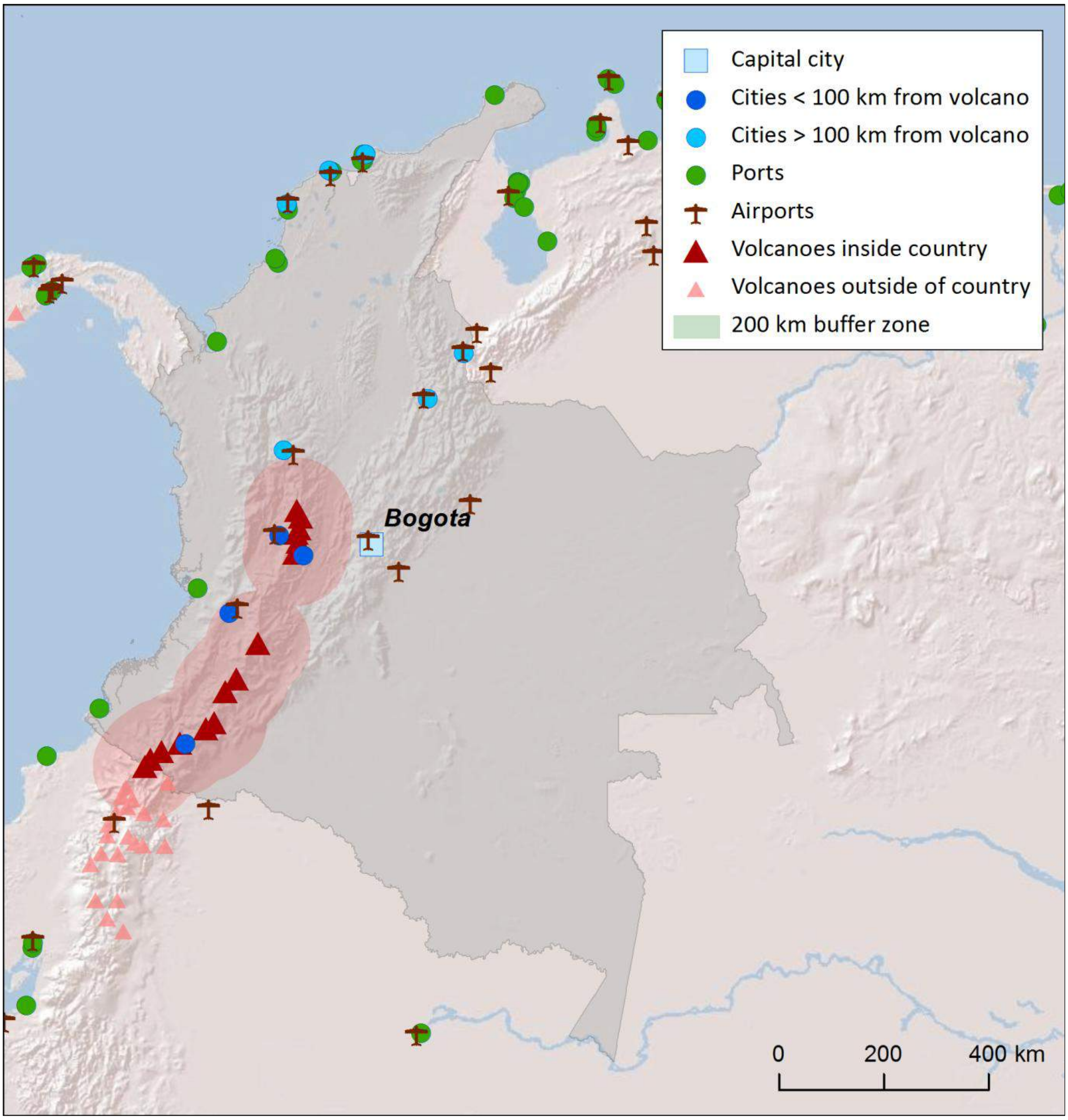

Figure 15.18 The location of Colombia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes in Colombia are located in the west of the country from the border with Ecuador to just north of the capital, Bogata. The southernmost volcanoes, Galeras, Cumbal and Azufral lie close to the Ecuador border, and their 100 km radii extend into Ecuador, exposing infrastructure here.

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Similarly, six of the northernmost of Ecuador's volcanoes have 100 km radii which extend into Colombia. Four of the largest cities in Colombia are situated within 100 km of Holocene volcanoes, including Pasto, Cali, Ibague and Pereira, exposing much of the critical infrastructure here. The capital, Bogata, lies within 140 km of several Holocene volcanoes, including the historically active Nevado del Ruiz and Nevado del Tolima.

Hazard, Uncertainty and Exposure Assessments

The volcanoes in Colombia are classed at Hazard Levels I to III. Ten of the 15 Colombian volcanoes have insufficient data available in their eruption records to adequately calculate a hazard score without very large uncertainties. The highest hazard levels are found at Nevado del Ruiz, Galeras and Cerro Bravo.

Of the unclassified volcanoes, three, Azufral, Machín and Sotará have had recorded periods of unrest above background levels since 1900. Both Azufral and Machín have Holocene eruption records but no historical eruptions. Four Colombian volcanoes: Nevado del Huila, Doña Juana, Cumbal and Cerro Negro de Mayasquer are unclassified, but have historical records of activity including post-1900 eruptions.

CLASSIFIED	**Hazard III**				Cerro Bravo	Nevado del Ruiz	Galeras	
	Hazard II				Nevado del Tolima			
	Hazard I				Puracé			
UNCLASSIFIED	**U – HHR**				Nevado del Huila, Doña Juana, Cumbal, Cerro Negro de Mayasquer			
	U- HR				Romeral	Santa Isabel, **Machín**, **Azufral**		
	U- NHHR			Petacas	**Sotará**			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 15.16 Identity of Colombia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Galeras	6	III
Ruiz, Nevado del	5	III
Bravo, Cerro	4	III
Tolima, Nevado del	4	II
Puracé	4	I

Table 15.17 Classified volcanoes of Colombia ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 1 volcano; Risk Level III – 3 volcanoes.

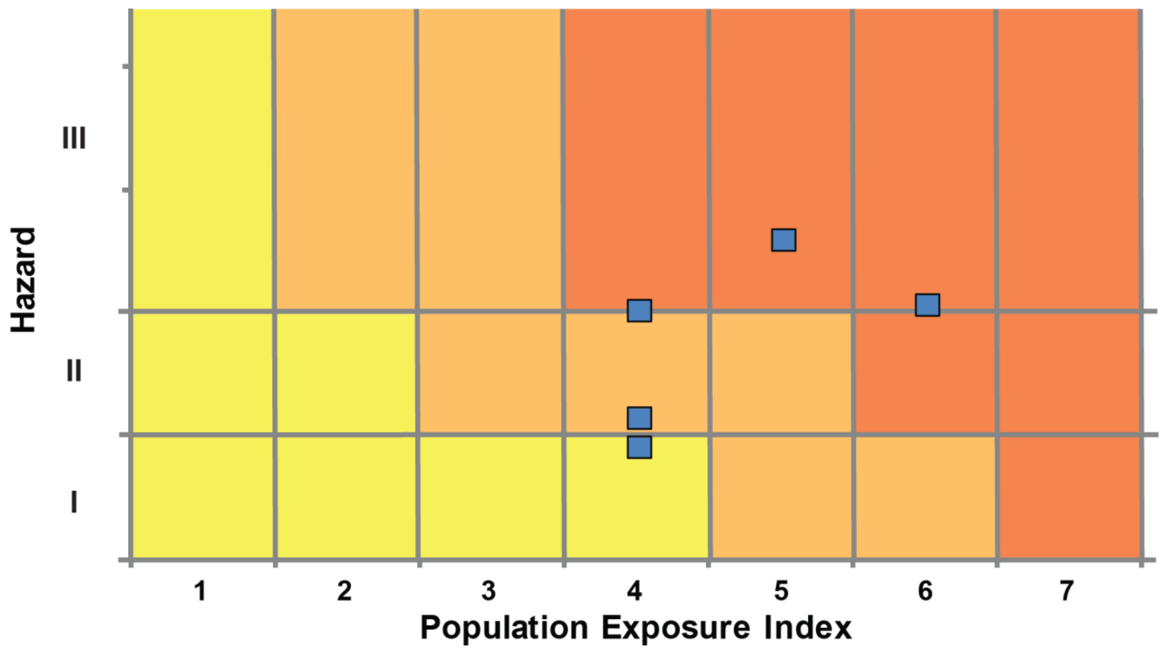

Figure 15.19 Distribution of Colombia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

All Colombian volcanoes have moderate to high PEI levels at PEI 3 to 6. The highest PEI is found at Galeras, which has over 120,000 living just within 10 km. Combined with a Hazard Level of III, Galeras is classed as a Risk Level III volcano. Of the classified volcanoes, just one volcano, Puracé is deemed Risk Level I, whilst one, Nevado del Tolima, is classed at Risk Level II.

National Capacity for Coping with Volcanic Risk

Nine volcanoes in Colombia have recorded historical activity. Of these, all have dedicated ground-based monitoring systems operated by INGEOMINAS. Seven volcanoes are classed here at Monitoring Level 3, with seismic networks in operation and additional deformation and or gas monitoring. The three volcanoes with the highest risk classification here are continuously monitored at this level.

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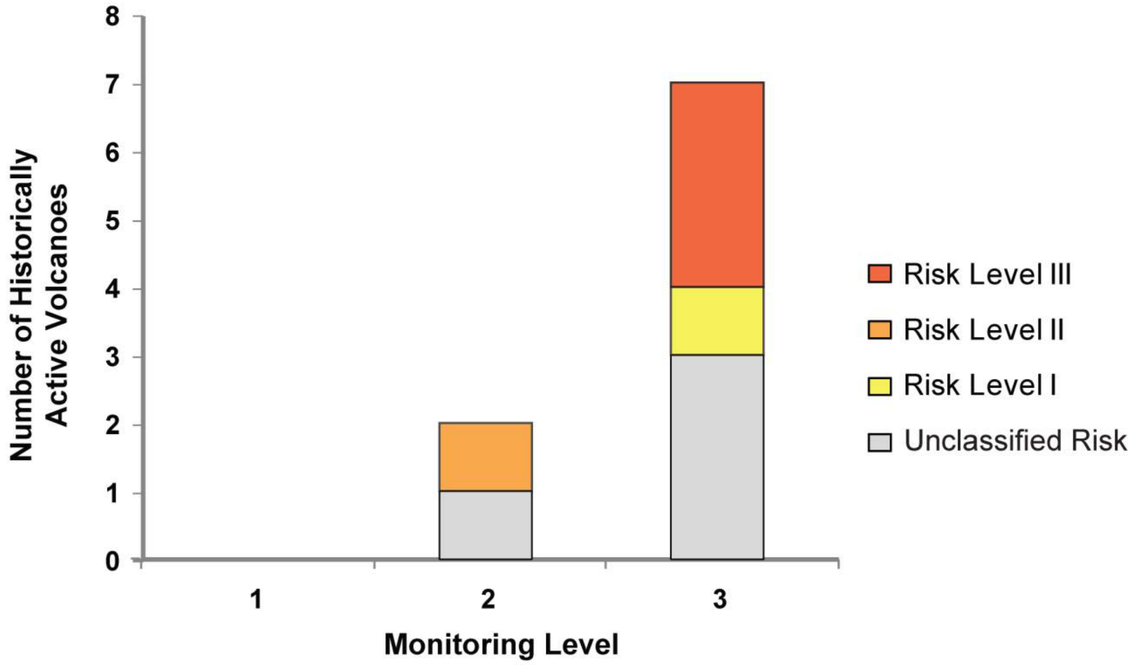

Figure 15.20 The monitoring and risk levels of the historically active volcanoes in Colombia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Ecuador and the Galapagos

Description

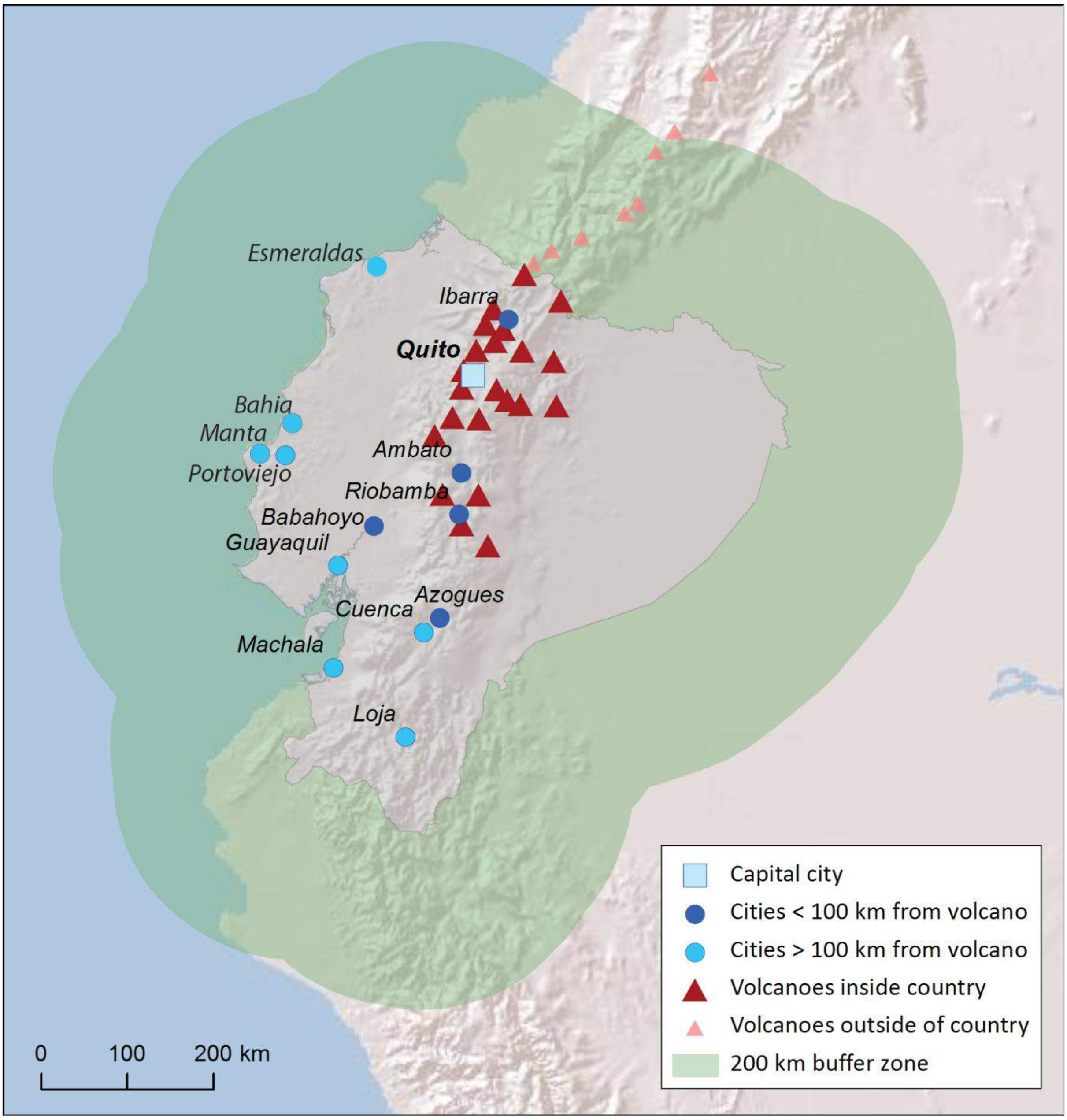

Figure 15.21 Location of Ecuador's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Ecuador.

Thirty-five volcanoes of Holocene age are identified in Ecuador. This includes volcanoes on mainland Ecuador and in the Galapagos Islands, nearly 1000 km to the west. Volcanism in mainland Ecuador is related to the subduction of the Nazca Plate beneath the South American Plate, whilst Galapagos volcanism is due to intra-plate hotspot volcanism and the Galapagos spreading centre. Volcanoes of the Galapagos are predominantly basaltic shields, while in mainland Ecuador the composition is more felsic and andesitic stratovolcanoes are most common.

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Twenty-eight of the volcanoes have 311 confirmed Holocene eruptions, the remaining volcanoes have suspected Holocene activity. With records of activity ranging in size from VEI 0 to 6, a range of activity styles is indicated, from mild effusions of lavas to large explosive events. The largest Holocene eruption on record is the ~1280 AD eruption of Quilotoa at VEI 6 / M6.4. This event generated extensive pyroclastic flows, ash fall and lahars. A larger eruption (M6.9) is recorded in the Pleistocene at 211 ka, with the Ash Flow of the Chalupas Caldera. Numerous Pleistocene eruptions of VEI/M ≥4 are recorded in Ecuador, and 43 large explosive eruptions of this size are recorded in the Holocene.

Since 1500 AD, 197 eruptions are recorded at nineteen volcanoes. Of these, 11 were VEI 4 indicating that large explosive eruptions are relatively frequent in Ecuador. The dominantly andesitic composition and stratovolcano morphology indicates typical explosive activity. The altitude of the volcanoes in Ecuador means that many of the volcanoes are capped with snow or glaciers. This increases the propensity to cause hazardous lahars as even small eruptions can result in the melting of ice caps. Indeed eight volcanoes in Ecuador have a Holocene record of lahar triggering.

The most frequently active volcanoes here are Cotopaxi, Reventador and Tungurahua, while Sangay is continuously active since 1628, but poses little threat since it is isolated from population centres.

The Galapagos Island volcanoes are exclusively shield volcanoes. With a small population of just over 20,000, the main hazard they pose is largely environmental, but also to wildlife, such as slow moving giant tortoises, as a result of lava flows and ash fall. One exception to this is Fernandina, which has erupted explosively on numerous occasions producing pyroclastic flows and debris avalanches. No fatalities are recorded as a result of eruptions of Fernandina.

Much of central and northern mainland Ecuador lies within 100 km of one or more Holocene volcanoes, and six of the most populous cities in the country fall in this zone. The capital, Quito, lies within 100 km of many volcanoes, and within about 12 km of the historically active Guagua Pichincha. This volcano had a VEI 4 eruption in 1660 resulting in extensive ash fall and ash accumulation in the capital. Pyroclastic flows and surges were channelled mainly to the west as the caldera is breached in this direction. This breach will still likely act to channel flows to the west, however surges in particular are not always constrained by topography and can reach small communities such as Lloa, but have never jumped the topographic barrier into the Quito basin.

The presence of many cities within 100 km of the Holocene volcanoes exposes a large proportion of the population to direct volcanic hazards, with 50% of Ecuador’s population residing within 100 km of one or more Holocene volcano.

The assessment of hazard at many of Ecuador’s volcanoes is complicated by incomplete or sparse eruption records and publication of this information in “grey literature” that is difficult to access, hence the assignment of hazard levels is associated with large degrees of uncertainty.

Fatalities have resulted from eruptions of Reventador, Guagua Pichincha, Cotopaxi, Tungurahua, Sangay and Cerro Azul. Greatest loss of life as a result of volcanism in Ecuadorian territories occurred in 1640, following an eruption of Tungurahua. Though some uncertainty surrounds the eruption record, it is believed an approximately VEI 3 eruption caused pyroclastic flows and a small sector collapse that destroyed a village and its 5,000 inhabitants. Eruptions of Cotopaxi in 1742, 1768, and

1877 have also significantly added to the death toll from volcanoes in Ecuador, with roughly 1,200 deaths as a result of lahars attributable to these three eruption periods.

The Instituto Geofisico of the Escuela Politécnica Nacional (IGEPN) is responsible for the study, monitoring and hazard assessment of Ecuador's volcanoes. Sixteen volcanoes are monitored with at least one broadband seismic instrument and one or more continuously operating GPS staton. Tungurahua, Cotopaxi, Guagua Pichincha, Reventador, Cuicocha and Antisana volcanoes are monitored with a broad suite of geophysical instruments and because of the completeness of their real-time networks are considered to b in an "A" category. Ten other volcanoes: Atacazo, Pululagua, Imbabura, Chachimburo, Cerro Negro, Cayambe, Soche, Sangay, Chimborazo and Quilotoa all have at least one or more broadband seismic and deformation-detecting stations. The IGEPN provides advice and information regarding volcanic activity and presents this information online, accessible to the public. Reports are regularly issued summarising volcanic activity and early warnings before a notable increase in eruptive activity is given on this web, via calls, over local radio stations and through social media. Close collaborations exist with the Secretariat for Risk Management. Before and during volcanic crises IGEPN scientists communicate and provide hazard assessments to local, regional and national authorities. At Tungurahua volcano, which has been erupting since 1999, a volunteer volcano observers group (Vigias) has been very successful in providing in situ observations of eruptive activity, via a radio system to the local observatory IGEPN scientists.

From here we provide the information for mainland Ecuador and the Galapagos Islands separately.

See also:

Servicio Nacional de Sismologia y Vulcanologia: www.igepn.edu.ec/

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Mainland Ecuador

Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Colombia
Number of Pleistocene volcanoes with M≥4 eruptions	7
Number of volcanoes generating pyroclastic flows	14
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	7
Number of fatalities caused by volcanic eruptions	?5,690
Tectonic setting	22 Subduction zone
Largest recorded Pleistocene eruption	The M6.9 Chalupas Ash Flow eruption of Chalupas at 211 ka.
Largest recorded Holocene eruption	The M6.4 eruption of Quilotoa about 700 years ago.
Number of Holocene eruptions	229 confirmed eruptions
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	10 according to VOTW4.22 (Cotopaxi, Reventador, Tungurahua, Guagua Pichincha, Cayambe, Sangay, Chacana, Antisana, Sumaco and Cerro Negro de Mayasquer). Activity at the latter three volcanoes is ambiguous.
Number of historic eruptions	131

Number of volcanoes	Primary volcano type	Dominant rock type
4	Caldera(s)	Dacitic (3), Rhyolitic (1)
17	Large cone(s)	Andesitic (13), Basaltic (1), Dacitic (3)
1	Small cone(s)	Andesitic (1)

Table 15.18 The number of volcanoes in Ecuador, their volcano type classification and dominant rock type according to VOTW4.0.

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Socio-Economic Facts

Total population (2012)	15,520,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	7,443
Gross National Income (GNI) per capita (2005 PPP $)	7,471
Human Development Index (HDI) (2012)	0.724 (High)

Population Exposure

Capital city	Quito
Distance from capital city to nearest Holocene volcano	12.2 km
Total population (2011)	15,007,343
Number (percentage) of people living within 10 km of a Holocene volcano	750,552 (5%)
Number (percentage) of people living within 30 km of a Holocene volcano	4,352,168 (29%)
Number (percentage) of people living within 100 km of a Holocene volcano	7,393,692 (49.3%)

Ten largest cities, as measured by population and their population size (2010, from UN data, data.un.org):

Guayaquil	2,278,691
Quito	1,607,734
Cuenca	329,928
Machala	231,260
Manta	217,553
Portoviejo	206,682
Loja	170,280
Ambato	165,185
Esmeraldas	154,035
Riobamba	146,324

Infrastructure Exposure

Number of airports within 100 km of a volcano	6 (Tulcan, Quito, Lago Agrio, Latacunga, Macas, Tena)
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	3,727
Total length of railroads within 100 km of a volcano (km)	0

In mainland Ecuador the 100 km radii of the volcanoes covers much of central and northern parts of the country, and the radii of six of the northernmost volcanoes extend into Colombia. Similarly, the three southernmost volcanoes of Colombia have 100 km radii which extend into Ecuador. Six of the largest cities in Ecuador are situated within 100 km of Holocene volcanoes, including the capital, Quito, hence much of the critical infrastructure of the country is exposed, including three airports and an extensive road network. Critical infrastructure such as two trans-Andean oil pipelines, four major hydroelectric installations, Quito's water supply from Antisana and Chacana volcanoes, as well as critical bridges are also exposed.

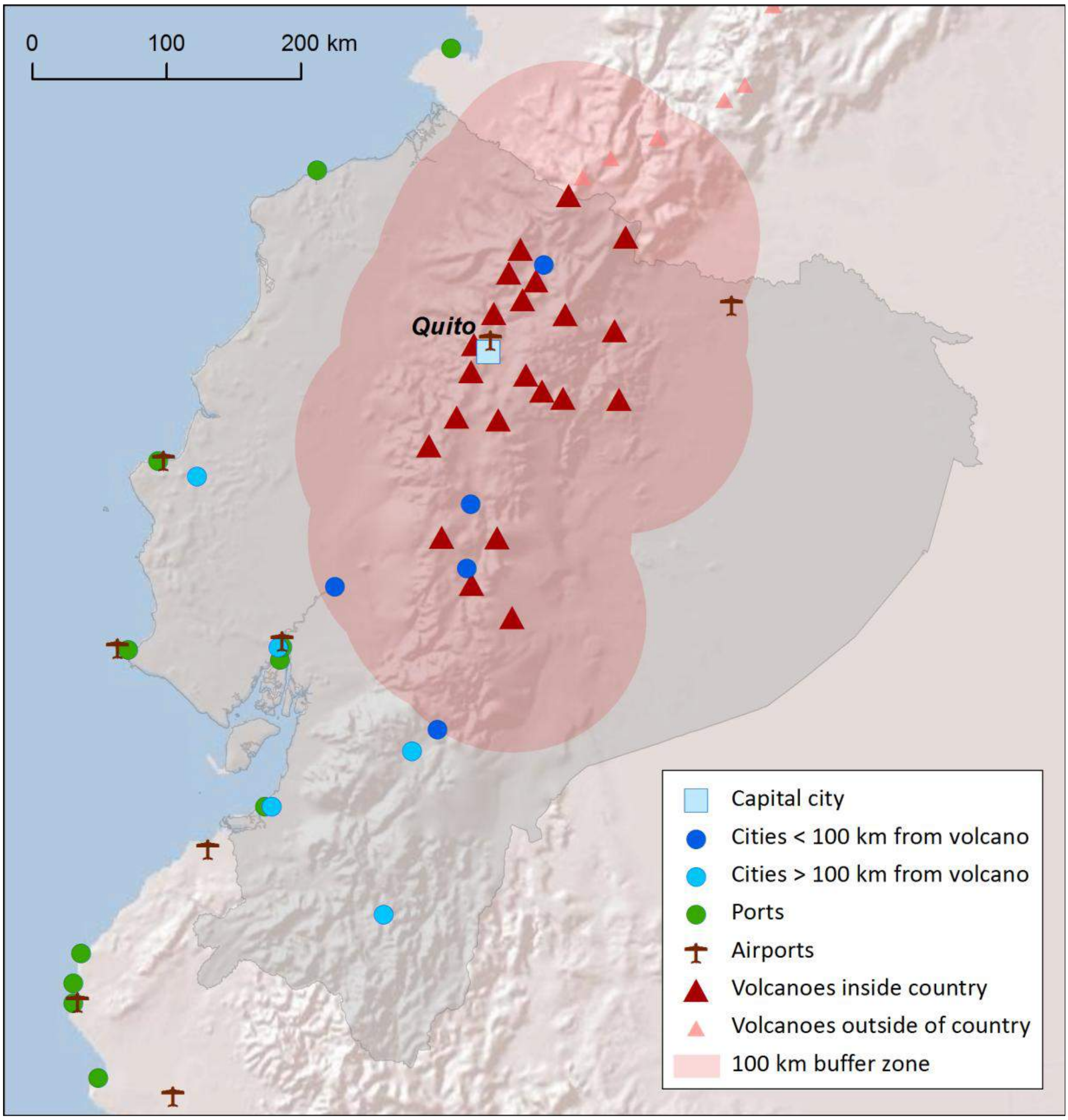

Figure 15.22 The location of Ecuador's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of mainland Ecuador's volcanoes. Seven volcanoes out of 23 have sufficient detail to define the hazard through the calculation of the VHI. All of these are classified at Hazard Level III, with Holocene records of VEI ≥3 eruptions and records of explosive eruptions with the production of pyroclastic flows.

Of the unclassified volcanoes, three have no confirmed Holocene eruptions on record. The remaining 12 volcanoes have a Holocene eruptive record, with historical events at four volcanoes including post-1900 AD eruptions at Cerro Negro de Mayasquer. Four unclassified volcanoes have a Holocene record of large VEI ≥4 eruptions.

The size of the proximal populations at Ecuador's volcanoes ranges from small to large, generating PEIs of 1 to 7. Moderate and high PEIs dominate. This range results in a range of risk levels when combined with the Hazard Levels, from II to III at the classified volcanoes. Although here we consider threat to life measured by population exposure, infrastructure exposure such as the water supply to Quito is also vital. This, for example, is supplied from the PEI4 Antisana volcano, which if it were to erupt would have grave consequences for Quito's water supply.

CLASSIFIED	**Hazard III**			Reventador; Sangay	Cayambe; Cotopaxi; Tungurahua	Guagua Pichincha	Atacazo	
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		Sumaco		**Cerro Negro de Mayasquer;** Antisana	Chacana		
	U- HR	Aliso		Soche	Chachimbiro; Chimborazo	Quilotoa	Cuicocha; **Imbabura**	Pululagua
	U- NHHR				Illiniza	Mojanda	Licto	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 15.19 Identity of Mainland Ecuador's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Atacazo	6	III
Guagua Pichincha	5	III
Tungurahua	4	III
Cotopaxi	4	III
Cayambe	4	III
Reventador	3	II
Sangay	3	II

Table 15.20 Classified volcanoes of Mainland Ecuador ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 5 volcanoes.

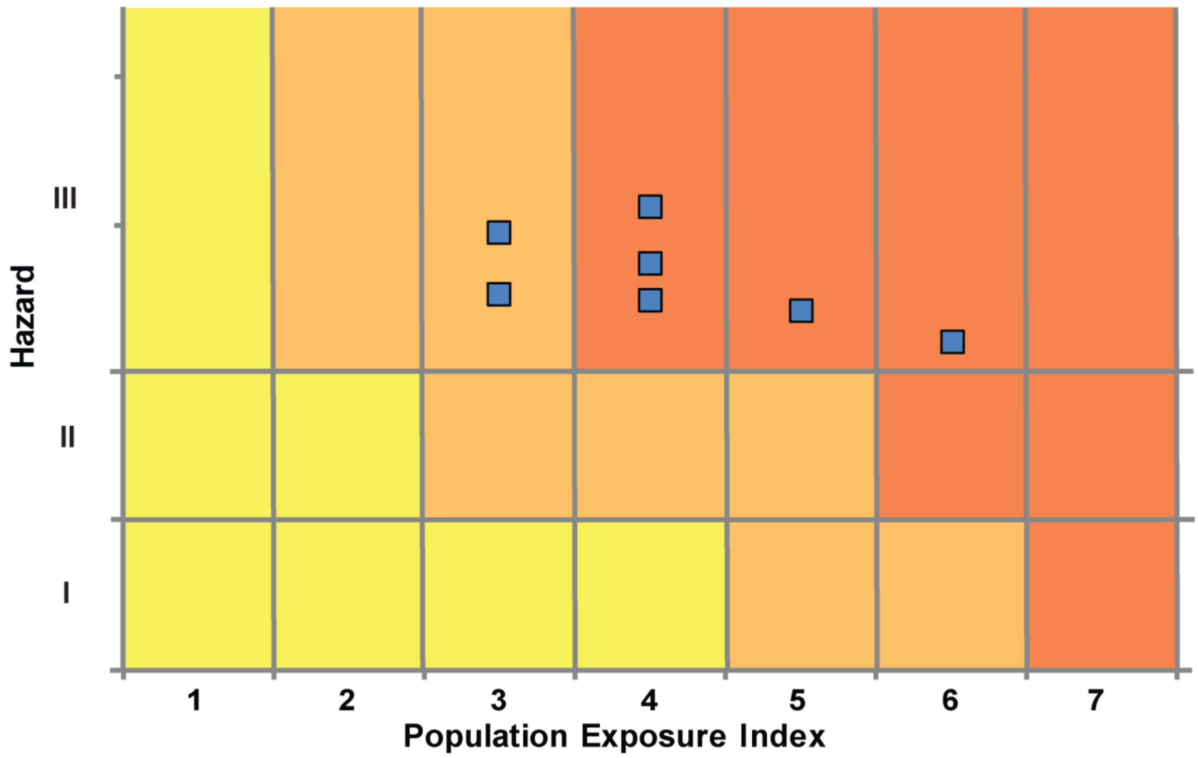

Figure 15.23 Distribution of mainland Ecuador's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes in mainland Ecuador have recorded historical activity. These volcanoes are distributed across all three monitoring levels with half of the volcanoes being classed at Monitoring Level 3. All Risk Level III volcanoes are monitored at Level 3, with the exception of Cayambe which also has both seismic and deformation monitoring. The Risk Level III volcanoes, Tungurahua, Guagua Pichincha and Cotopaxi all have multiple monitoring systems in place incldiing continuous seismic and deformation monitoring.

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Monitoring is undertaken by the Instituto Geofisico EPN. Note that this institute also uses Monitoring Levels 1 - 3 to describe levels of monitoring at Ecuador's volcanoes, but these are different levels to those used here.

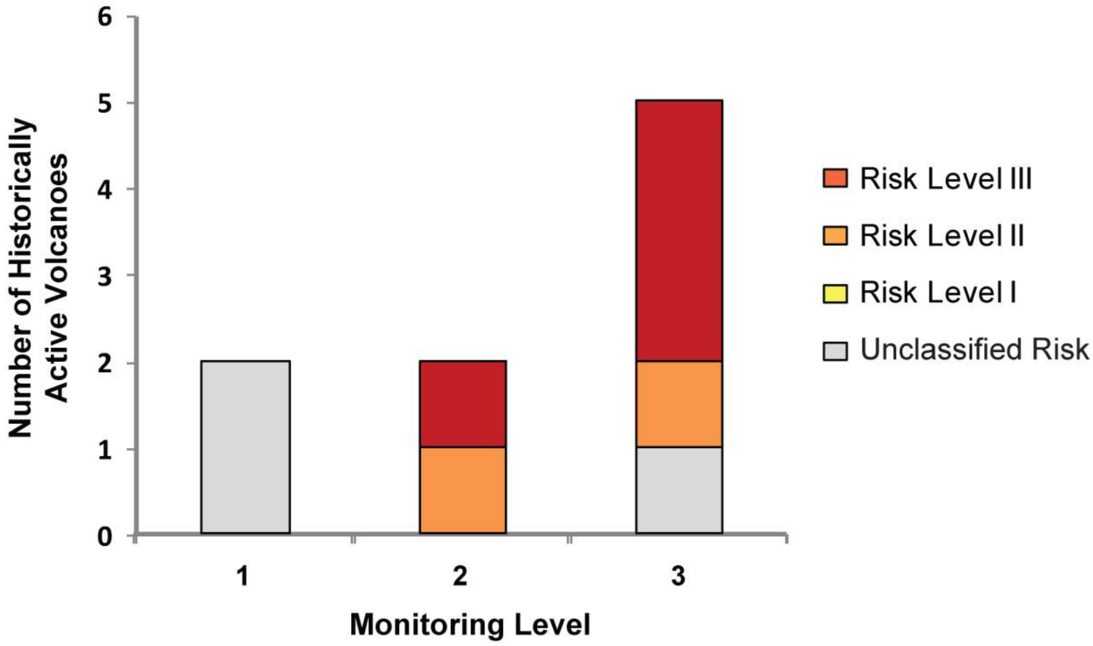

Figure 15.24 The monitoring and risk levels of the historically active volcanoes in mainland Ecuador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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<u>Galapagos Islands</u>

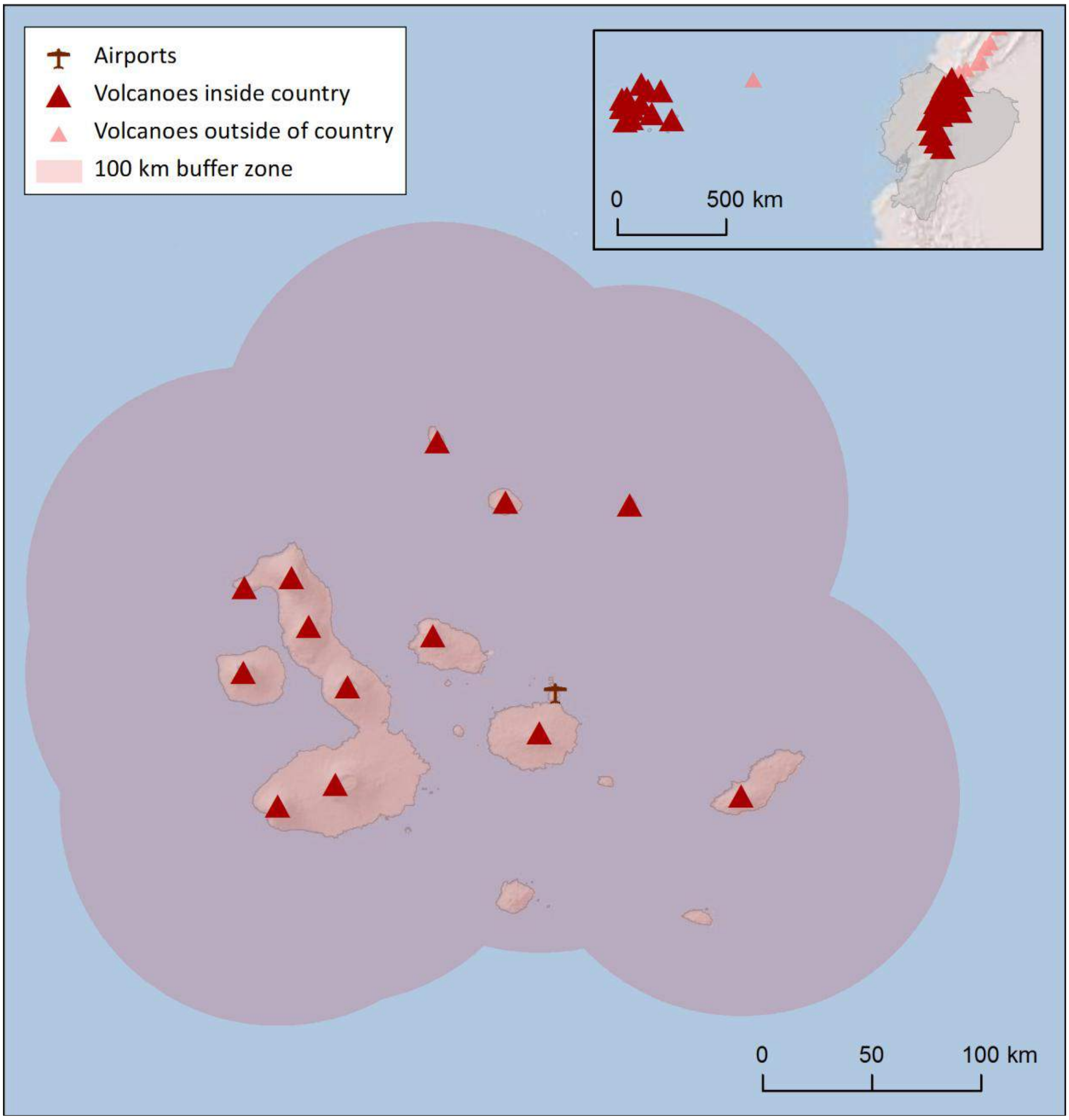

Figure 15.25 The volcanoes of the Galapagos Islands. Inset shows the location relative to mainland Ecuador.

Volcano Facts

Number of Holocene volcanoes	13
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	9

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Number of fatalities caused by volcanic eruptions	?1
Tectonic setting	13 Rift zone
Largest recorded Pleistocene eruption	The M5.2/VEI 5 Alcedo-A,B Tephra eruption of about 90,000 years ago.
Largest recorded Holocene eruption	The VEI 4 eruption of Fernandina in 1968.
Number of Holocene eruptions	82 confirmed eruptions
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	9
Number of historic eruptions	66

Number of volcanoes	Primary volcano type	Dominant rock type
13	Shield(s)	Basaltic (13)

Table 15.21 The number of volcanoes in Ecuador, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Puerto Baquerizo Moreno
Distance from capital city to nearest Holocene volcano	12.3 km
Total population (2010, www.inec.gob.ec/estadisticas/)	25,124
Percentage of people living within 100 km of a Holocene volcano	100%

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	-
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	0

In the Galapagos Islands, the 100 km radii extend to fully encompass the island group, exposing all infrastructure here.

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Hazard, Uncertainty and Exposure Assessments

Of the thirteen volcanoes in the Galapagos Islands, just four have a sufficiently detailed eruption record to determine hazard levels through the calculation of the VHI. These are classified at Hazard Levels I and II.

Of the unclassified volcanoes, three have no confirmed Holocene eruptions on record. Six have a record of Holocene eruptions, including historical age events and post-1900 AD eruptions.

The size of the proximal populations at the volcanoes of the Galapagos is typically small, generating PEIs of 2 to 3. All classified volcanoes here are classed at Risk Level I.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	Hazard III							
	Hazard II		Fernandina					
	Hazard I		Wolf; Negra, Sierra; Azul, Cerro					
UNCLASSIFIED	U – HHR		Darwin; **Alcedo**; **Pinta; Marchena; Santiago**					
	U- HR		Ecuador					
	U- NHHR		Genovesa	Santa Cruz; San Cristóbal				

*Table 15.22 Identity of the Galapagos Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Azul, Cerro	2	I
Fernandina	2	I
Negra, Sierra	2	I
Wolf	2	I

Table 15.23 Classified volcanoes of the Galapagos Islands ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 4 volcanoes; Risk Level II –0 volcanoes; Risk Level III – 0 volcanoes.

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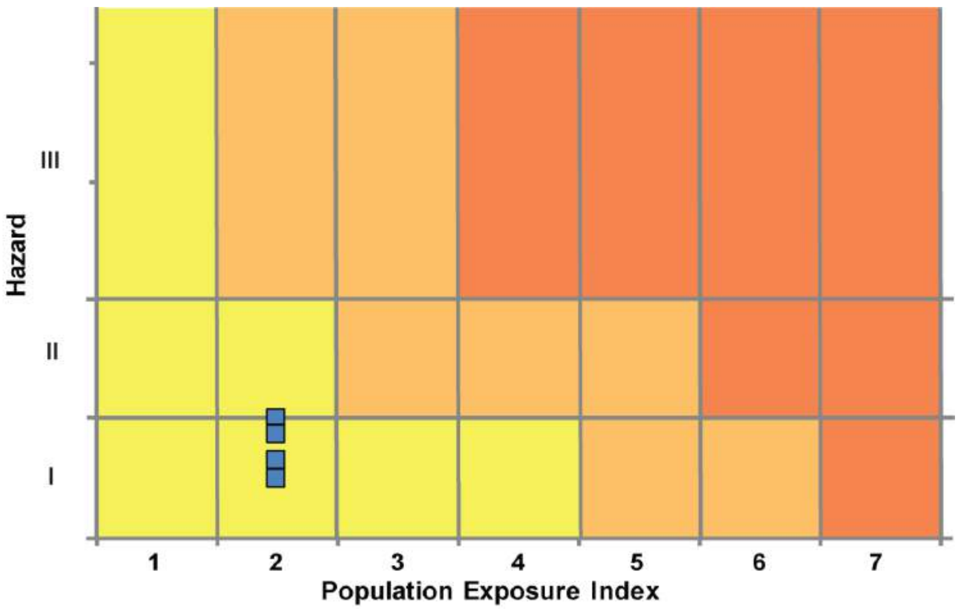

Figure 15.26 Distribution of the Galapagos Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Nine volcanoes in the Galapagos Islands have recorded historical activity. Monitoring is undertaken by the Instituto Geofisico EPN. Note that this institute also uses Monitoring Levels 1 - 3 to describe levels of monitoring at Ecuador's volcanoes, but these are different levels to those used here. A seismic monitoring network in the Galapagos Islands has been installed.

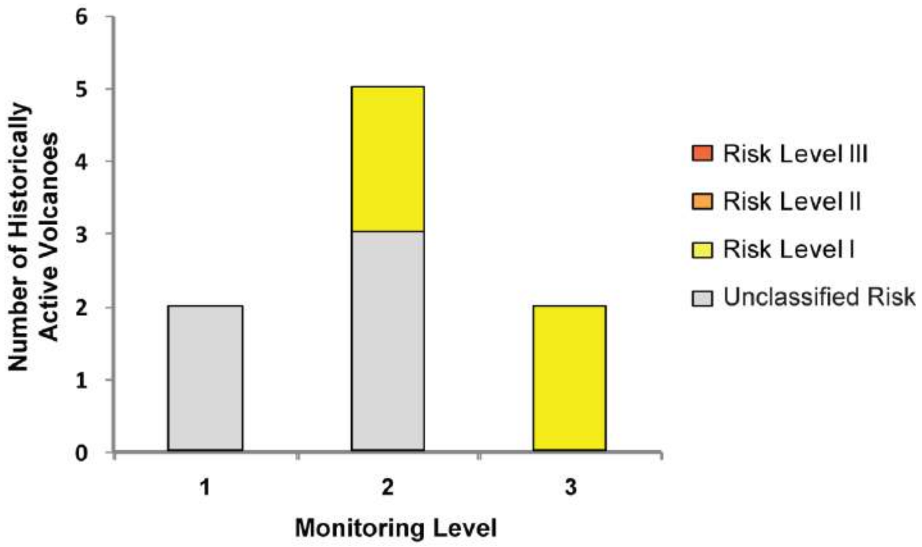

Figure 15.27 The monitoring and risk levels of the historically active volcanoes in the Galapagos Islands of Ecuador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Peru

Description

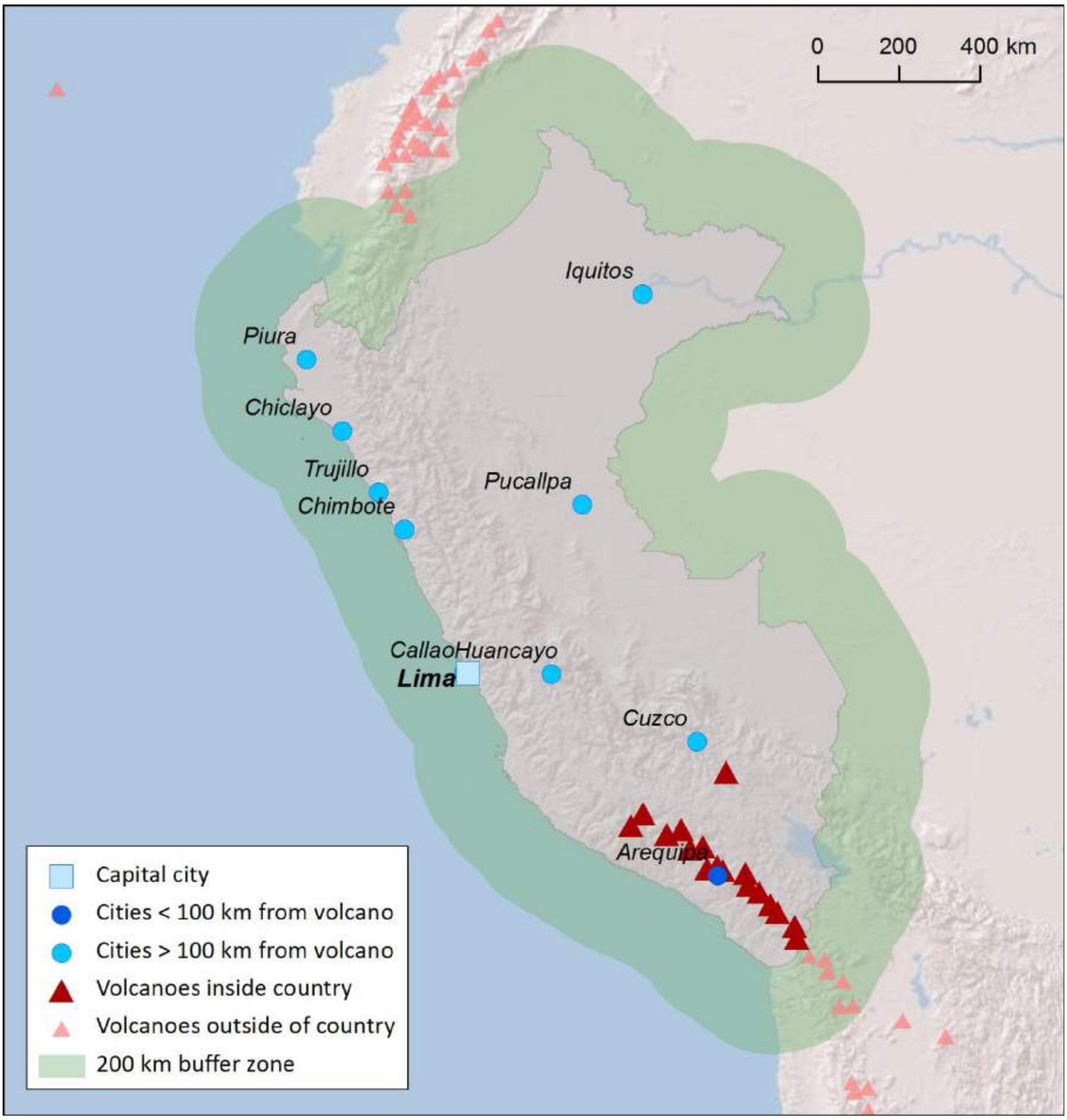

Figure 15.28 Location of Peru's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Peru.

Seventeen Holocene volcanoes are recorded in Peru. These volcanoes are located in the Andes in a chain through southern Peru to the border with Chile. Volcanism occurs here due to the subduction of the Nazca Plate beneath the South American Plate. Although subduction is also ongoing in northern Peru, the angle of the subducting slab has not led to recent volcanism. Although Peru's volcanoes are a variety of types, including cinder cones and lava domes, most are stratovolcanoes of dominantly andesitic composition.

Large explosive Pleistocene activity is recorded in Peru, and sixty eruptions of Holocene age are recorded here. Of these, thirty-six are of historical age. These historical eruptions occurred at six

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volcanoes, and covered a range of sizes, from small events of VEI 1 to very large explosive VEI 6 eruptions. Three volcanoes have Holocene records of producing pyroclastic flows and four with lahars. The largest historical eruption was the 1600 AD eruption of Huaynaputina. This eruption produced voluminous tephra falls, pyroclastic flows and surges which travelled 13 km and lahars that reached the Pacific Ocean, 120 km away. The cities of Arequipa and Moquengua suffered significant damage, and about 1500 lives were lost.

Arequipa, one of the most populous cities in Peru, lies at about 75 km from Huaynaputina, and within 100 km of five other Holocene volcanoes, including the historically active Sabancaya, El Misti and Ubinas, the most frequently active volcano in Peru in historic times.

The Instituto Geofisico del Peru (IGP) and the Instituto Geológico Minero y Metalúrgico (INGEMMET) are responsible for scientific research and the monitoring of the volcanoes in Peru, and indeed actively monitor five historically active volcanoes and three further Holocene volcanoes through a variety of dedicated ground-based instrumentation, including seismic stations, geochemical and gas monitoring and various deformation monitoring. Monitoring is undertaken regularly, with an alarm system and automated seismic system. A regional seismic network is operational in Peru, which can register seismicity throughout the volcanic chain. Some resources and plans are available for monitoring to be extended to currently un-monitored volcanoes in developing situations. About a quarter of the observatory staff have experience of responding to an eruption.

In addition to ground-based monitoring, VDAP – the Volcano Disaster Assistance Program of the U.S. Geological Survey provides satellite information during eruptions, and InSAR and MODIS images are provided by Cornell University and Torino University.

The IGP provide scientific and technical advice to the Instituo Nacional de Defensa Civil (INDECI) in the event of unrest and eruption. The director of the Observatorio Vulcanologico de Sur (OVS), Orlando Macedo, represents the IGP on the regional committee for crises (the Comite de Operaciones de Emergencia Regional, COER). The regional aviation authority, Corporacion Peruana de Aviacion Comercial (CORPAC) reports to the regional VAAC.

The IGP extend a programme of hazard education to the public, and the IGP and INGEMMET websites are publically accessible, distributing information about Peru's volcanic activity. The IGP do not provide risk assessments but advise on management and mitigation of volcanic risk. An alert level system is in place, and the IGP, INGEMMET and IGUNSA recommend declaration of alerts to the COER authority.

Large and growing cities are located near active volcanoes in Peru, and with the expansion of the cities, the risk increases as larger populations live ever-closer to the volcanoes. Educational programs about volcanic risk and restriction of building in proximal areas would greatly improve the volcanic risk situation in Peru.

See also:

Instituto Geofisico del Peru: www.igp.gob.pe/portal/#

Instituto Geológico Minero y Metalúrgico (INGEMMET):
www.ingemmet.gob.pe/form/Inicio.aspx#

Observatorio Vulcanologico Del Sur: ovs.igp.gob.pe/monitoreo

Thouret, J-C., Finizola, A., Fornari, M., Legeley-Padovani, A., Suni, J. and Frechen, M. (2001) Geology of El Misti volcano near the city of Arequipa, Peru. *Geological Society of America Bulletin*, 113: 1593-1610.

Volcano Facts

Number of Holocene volcanoes	17, inclusive of one on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	4
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	1,500?
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.7 Sillar of Arequipa Ignimbrite eruption of Nevado Chachani at 2.42 Ma.
Largest recorded Holocene eruption	The 1600 AD eruption of Huaynaputina at M6.1.
Number of Holocene eruptions	60 confirmed eruptions. 14 uncertain eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	6
Number of historic eruptions	36

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
11	Large cone(s)	Andesitic (9), Dacitic (1), Trachytic / Andesitic (1)
2	Lava dome(s)	Dacitic (1), Rhyolitic (1)
4	Small cone(s)	Andesitic (3), Unknown (1)

Table 15.24 The number of volcanoes in Peru, their volcano type classification and dominant rock type according to VOTW4.0.

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Socio-Economic Facts

Total population (2012)	30,041,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,049
Gross National Income (GNI) per capita (2005 PPP $)	9,306
Human Development Index (HDI) (2012)	0.741 (High)

Population Exposure

Capital city	Lima
Distance from capital city to nearest Holocene volcano	533.1 km
Total population (2011)	29,248,943
Number (percentage) of people living within 10 km of a Holocene volcano	25,307 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,143,689 (3.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,836,138 (9.7%)

Ten largest cities, as measured by population and their population size:

Lima	7,737,002
Arequipa	841,130
Callao	813,264
Trujillo	747,450
Chiclayo	577,375
Iquitos	437,620
Huancayo	376,657
Piura	325,466
Chimbote	316,966
Cuzco	312,140

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	1,410
Total length of railroads within 100 km of a volcano (km)	0

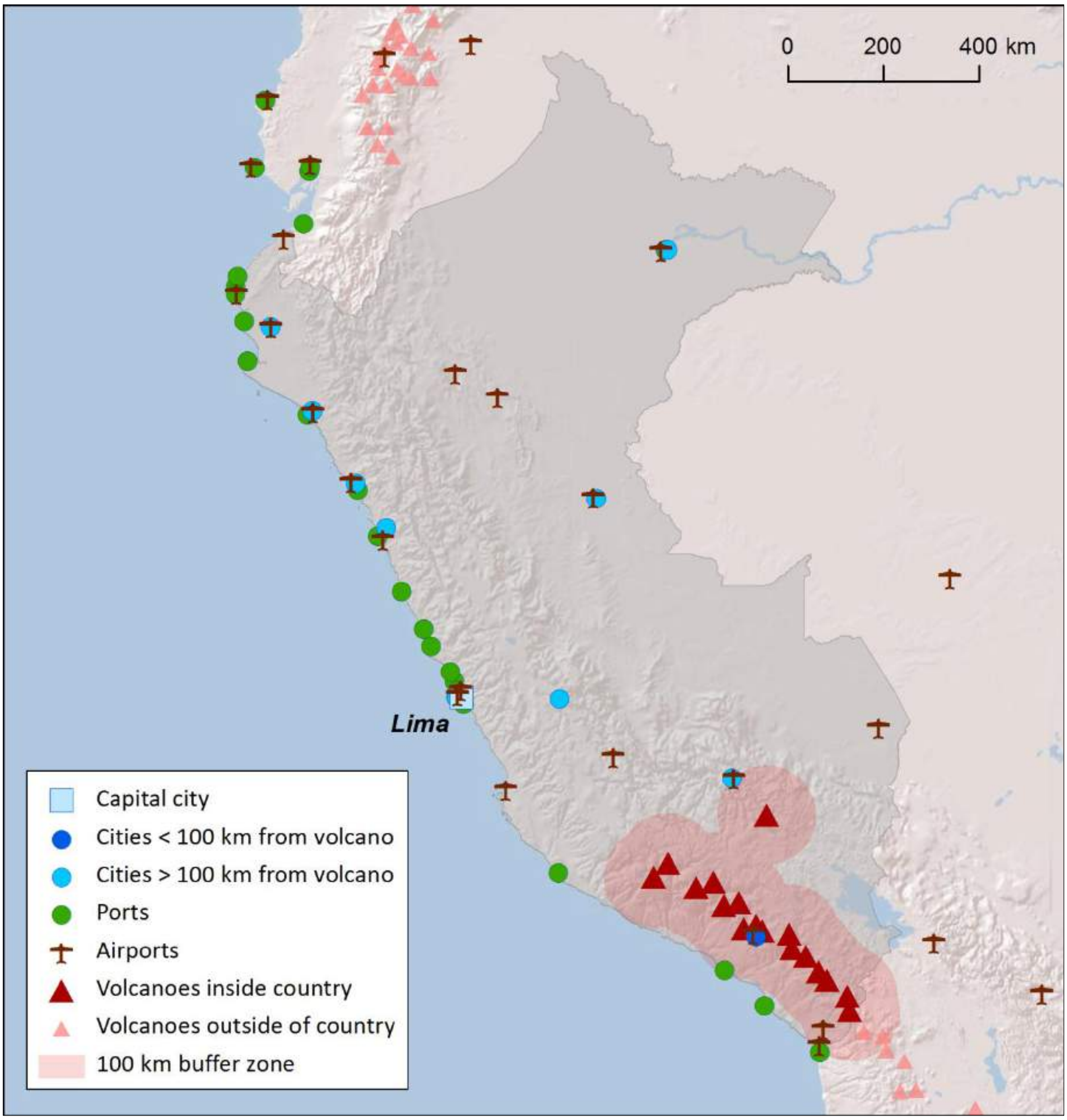

Figure 15.29 The location of Peru's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The Peruvian volcanoes are located in the south of the country bordering Chile, through the Andean chain. The southernmost two volcanoes in Peru have 100 km radii that extend into Chile, exposing the infrastructure here, and similarly, several of the northernmost volcanoes in Chile have 100 km radii which extend into southern Peru. The capital, Lima, is distal to the volcanoes, being located over 500 km north. However, one of the largest cities in Peru, Arequipa, is located with 100 km of six Holocene volcanoes, including the historically active Sabancaya, El Misti, Ubinas and Huaynaputina volcanoes, and hence considerable infrastructure is exposed here, including an extensive road network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Peru's volcanoes. The record is sufficient at just four volcanoes to define the hazard through the calculation of the VHI. These are classified across Hazard Levels I and II.

Despite a Holocene record including a VEI 4 eruption, El Misti's eruption record is dominated by historical VEI 1 and 2 eruptions and older eruptions of an undetermined size. This mildly explosive historical activity controls the determination of the VHI giving El Misti a Hazard Level of I. However, Thouret et al. (2001) identified "tens of pyroclastic flows" over the last 50,000 years from this volcano, including pyroclastic flows which reached about 12 km - a distance at which the outskirts of the city of Arequipa now lies. Thouret et al. (2001) determine recurrence intervals for ash falls of about 500 to 1500 years, and for pumice falls of 2,000 to 4,000 years. El Misti is assigned a Risk Level of I due to the hazard level classification, however the potential for larger eruptions than seen historically must be recognised, along with the potential for extensive pyroclastic flows. Indeed, areas of Arequipa are designated as high risk by IGP (http://ovs.igp.gob.pe/) and INGEMMET (http://ovi.ingemmet.gob.pe/).

Of the unclassified volcanoes, eight have no confirmed Holocene age eruptions on record. Five have a Holocene record, including historical (post-1500 AD) age activity at Ticsani and Huaynaputina. Just the latter has a record of large explosive VEI ≥4 Holocene eruptions.

The PEI ranges from low to high in Peru, at PEI 2 to 4. Of the classified volcanoes, two are classed as Risk Level II and two at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II		Yucamane	Sabancaya; Ubinas				
	Hazard I				Misti, El			
UNCLASSIFIED	**U – HHR**		Ticsani	Huaynaputina				
	U- HR			Huambo	Quimsachata; Andahua-Orcopampa			
	U-NHHR		Auquihuato, Cerro; Sara Sara; Coropuna; Tutupaca; Casiri, Nevados; Tacora		Chachani, Nevado; Nicholson, Cerro			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

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*Table 15.25 Identity of Peru's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Misti, El	4	I
Sabancaya	3	II
Ubinas	3	II
Yucamane	2	I

Table 15.26 Classified volcanoes of Peru ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

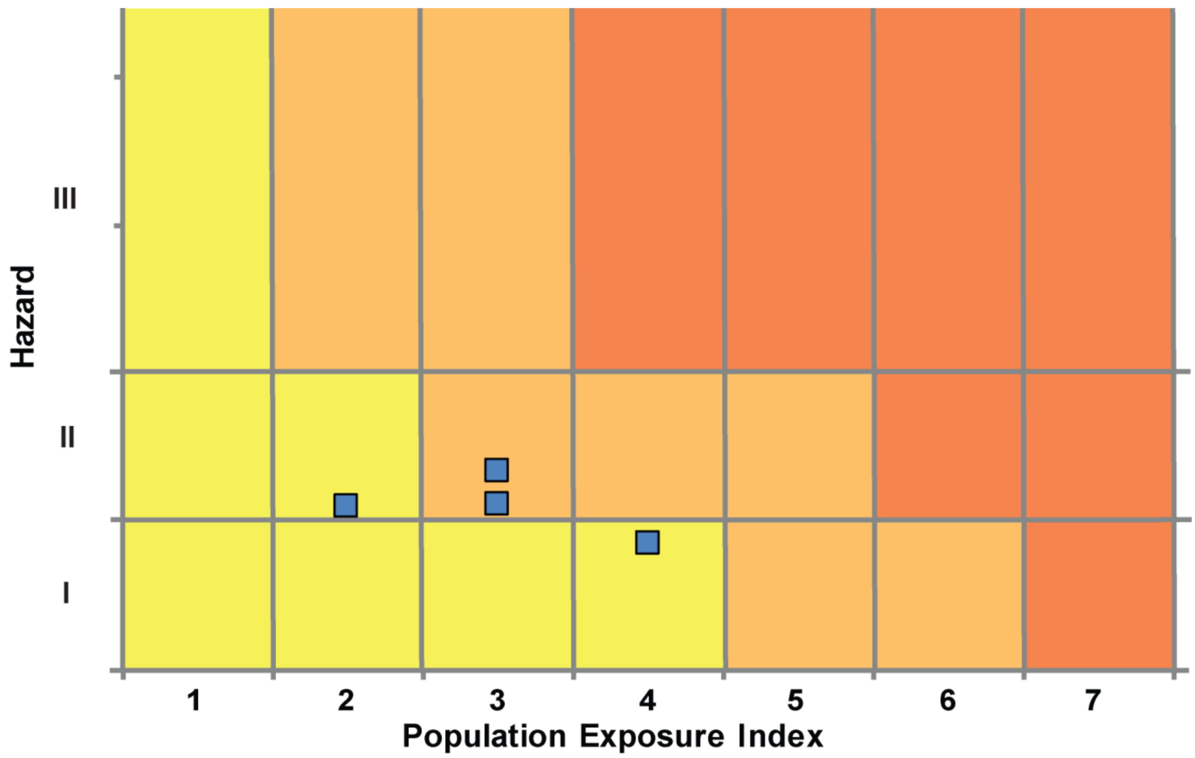

Figure 15.30 Distribution of Peru's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in Peru. Of these, five have regular monitoring. Just Yucamane, a Risk Level I volcano, currently has no dedicated regular ground-based monitoring. The five others, including El Misti (Risk Level I), Sabancaya and Ubinas (Risk Level II) and Huaynaputina and Ticsani (Unclassified), are monitored by the Instituto Geofisico del Peru and the Instituto Geológico Minero y Metalúrgico (INGEMMET). These institutes also monitor Tutupaca, Coropuna

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and Nevado Chachani. Seismic networks are used at Sabancaya and Huaynaputina. Seismic networks and additional deformation and gas monitoring is undertaken at Ticsani, El Misit and Ubinas.

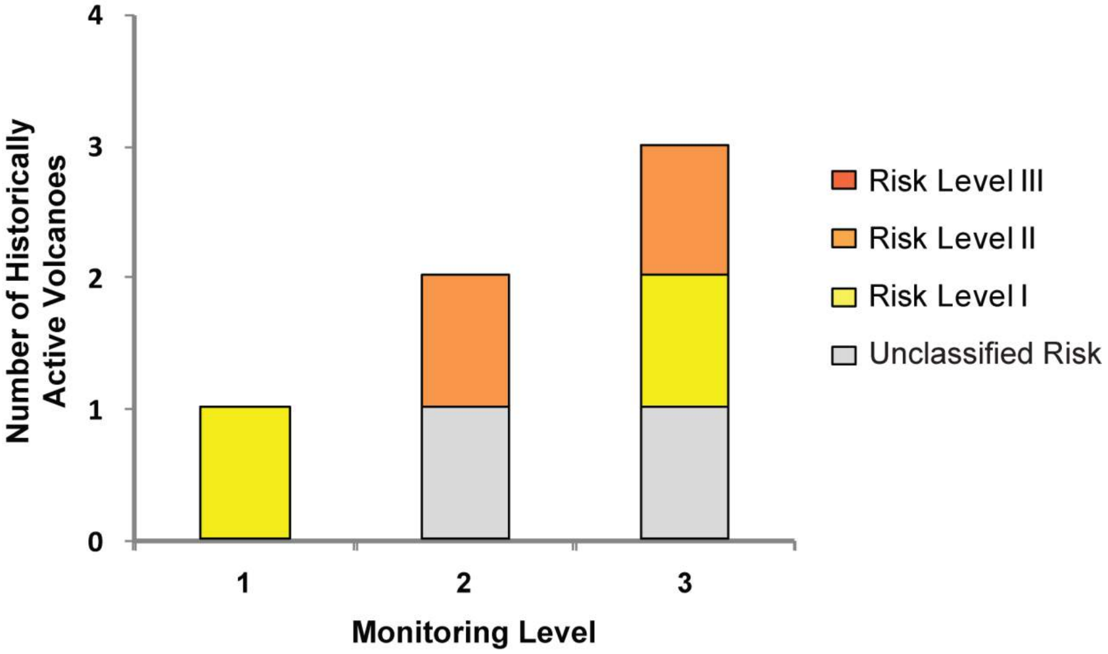

Figure 15.31 The monitoring and risk levels of the historically active volcanoes in Peru. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 16: West Indies

The West Indies region comprises the islands of the Lesser Antilles. Some of these islands are independent countries, whilst other retain ties to Europe.

Country	Number of volcanoes
Dominica	5
France	2
Grenada	2
Netherlands –Dutch Antilles	2
St. Kitts and Nevis	2
St. Lucia	1
St. Vincent and the Grenadines	1
UK - Montserrat	1

Table 16.1 The countries represented in this region and the number of Holocene volcanoes.

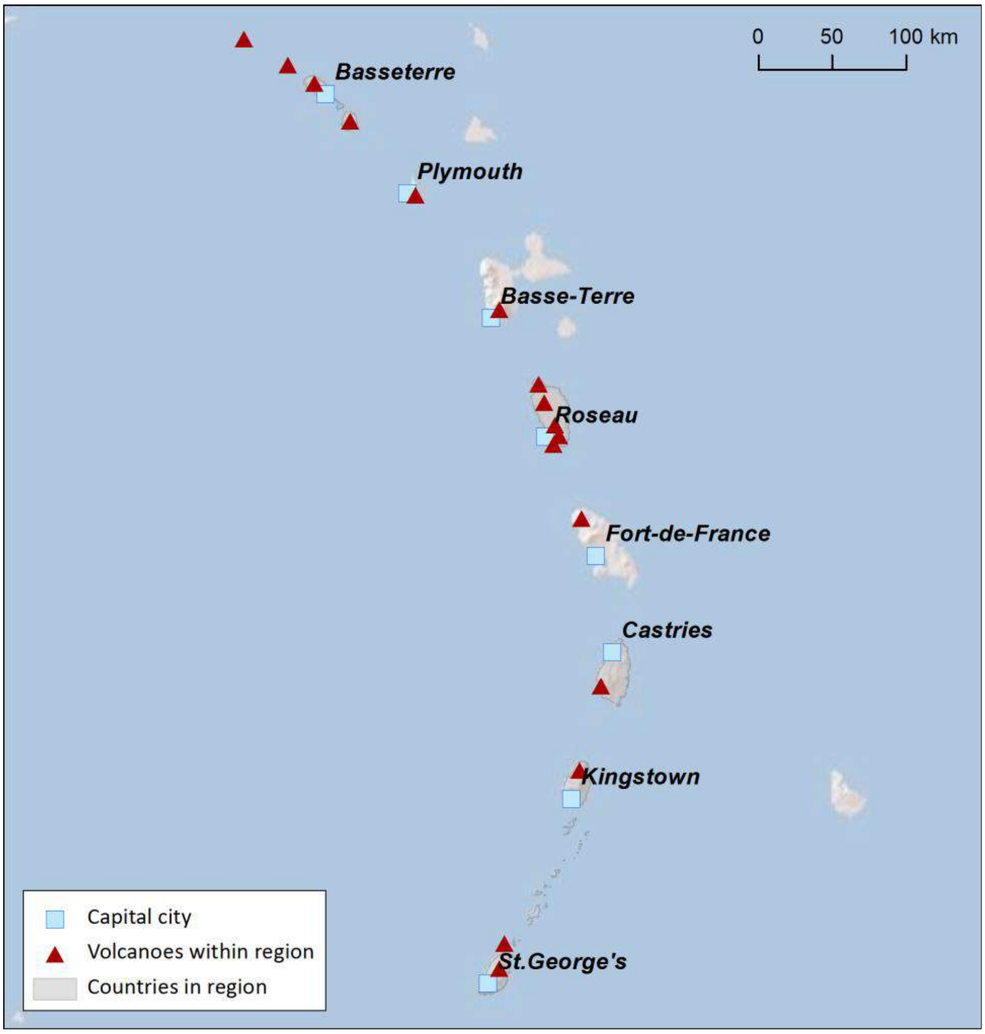

Figure 16.1 The distribution of Holocene volcanoes through the West Indies region. The capital cities of the constituent countries are shown.

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The Lesser Antilles arc forms along the eastern edge of the Caribbean Plate, with volcanism generated by the subduction of the Atlantic Ocean crust beneath this Caribbean Plate.

Sixteen Holocene volcanoes are located in the Lesser Antilles, from the southernmost island of Grenada to the northern island of Saba, of the Dutch Antilles. Of these, nearly 90% are andesitic stratovolcanoes.

Activity here is dominantly explosive with most eruptions recorded with explosive elements. Whereas the most common eruption size in most regions is VEI 2, here nearly half of all eruptions with a given size have been VEI 4. Nearly 70% of the volcanoes have Holocene records of producing pyroclastic flows, and about three quarters of all recorded eruptions here produced pyroclastic flows. Pyroclastic flows are recorded in about half of all historical eruptions, whilst only 2% of historical events have recorded lava flows. About a third of historical eruptions have resulted in lahars. Four historical eruptions have generated tsunamis.

Comprising multiple small islands, the population of much of the West Indies is located in close proximity to the volcanoes. Whilst population sizes of individual islands may be low, commonly 100% of the population live within 30 or 100 km of one or more Holocene volcano. Critically, the proximity of the islands to each other also means that eruptions on one island may impact on neighbouring islands. This is particularly relevant for tsunamis.

The assessment of hazard by the Volcanic Hazard Index is complicated by large uncertainties at many of the volcanoes of the West Indies. Further efforts in understanding the size of those eruptions with unknown magnitudes and confirming the occurrence of some uncertain events would help understanding here, however, individual focussed hazard assessments based on likely eruption scenarios have been undertaken at the volcanoes here with detailed integrated hazard maps and descriptions of probable activity (see Lindsay et al., 2005).

The volcanoes of the West Indies are very well monitored, with both observatories in Guadeloupe and Martinique run by the Institut de Physique du Globe Paris and the Seismic Research Centre (SRC) of the University of West Indies operating comprehensive monitoring systems throughout the island chain. Most monitoring is undertaken through seismic stations, with deformation and additional monitoring (gases, geochemical etc) at some volcanoes. Informal arrangements are in place for access to Earth Observation data as needed. Plans and resources are available for responding to developing situations at un- or under-monitored volcanoes, and in the event of significant unrest temporary observatories would be established staffed by members of the SRC and local equivalent groups where possible.

Monitoring equipment is not manned continuously, instead a monitoring alert system is in place. The SRC is funded by annual contributions from island governments and additional grant funding. About 60% of the staff members of the SRC have experience of responding to eruptions.

In the event of unrest or eruption, the SRC will provide regular updates to the National Emergency Operations Committee and will contact the regional VAAC. Response is guided by an Alert Level Table. This outlines actions to be taken by Scientific Staff and Civil Authorities. Generally response to unrest involves increased/intensification of monitoring with additional measurements and instruments deployed, increased site visits and provision of advice to civil authorities via regular

Scientific Advisories. Response will depend on the signals derived from monitoring sites. Communications with local authorities is normally via the National Disaster Coordinator but there is allocation for contacting the highest office on the island if thought necessary by the SRC monitoring team.

The SRC are not responsible for providing risk assessments, but are involved in risk management and mitigation through the provision of educational materials, hazard maps and public outreach.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano facts

Number of Holocene volcanoes	16
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	11+ (101 eruptions)
Number of volcanoes generating lahars	6 (26 eruptions)
Number of volcanoes generating lava flows	3-4 (6 eruptions)
Number of eruptions with fatalities	4
Number of fatalities attributed to eruptions	31,283
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons in Dominica, about 36,000 years ago.
Largest recorded Holocene eruption	The 1812 AD M4.7 eruption of Soufrière St. Vincent is the largest recorded Holocene eruption in this region in LaMEVE.
Number of Holocene eruptions	132 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	8
Number of historical eruptions	42

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)
14	Large cone(s)	Andesitic (13), Dacitic (1)
1	Submarine	Basaltic (1)

Table 16.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	10
Large (> VEI 3)	110

Table 16.3 Average recurrence interval (years between eruptions) for small and large eruptions in the West Indies.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 years, whilst the ARI for large eruptions is longer, at about 110 years.

Eruption Size

Eruptions are recorded through the West Indies of VEI 0 to 4, representing a range of eruption styles from effusive events to large explosive eruptions. VEI 4 events dominate the record, with nearly 45% of all Holocene eruptions classed as such.

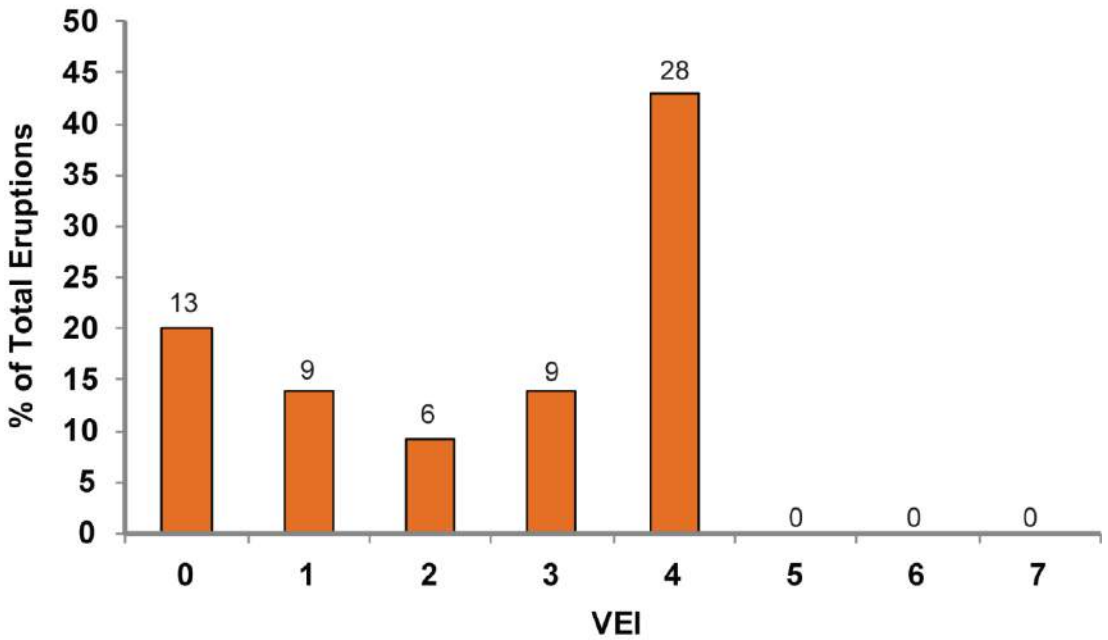

Figure 16.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 67 eruptions were recorded with unknown VEI.

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Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	309,233 (22.30 %)
Number (percentage) of people living within 30 km of a Holocene volcano	1,093,521 (78.87 %)
Number (percentage) of people living within 100 km of a Holocene volcano	1,388,737 (>100 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	14
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

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Hazard, Uncertainty and Exposure Assessments

CLASSIFIED	**Hazard III**				Soufrière Hills; Pelée; Soufrière St. Vincent	Soufrière Guadeloupe		
	Hazard II							
	Hazard I			Kick 'em Jenny				
UNCLASSIFIED	**U – HHR**		**Saba**			**Watt, Morne**; **Qualibou**		
	U- HR		Quill, The	**Liamuiga**		**Trois Pitons, Morne**; Plat Pays, Morne		
	U- NHHR				**Nevis Peak**; **Diables, Morne aux;** Diablotins, Morne	St. Catherine		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
6	5
6	4
2	3
2	2
0	1

Table 16.5 The number of volcanoes in the West Indies classed in each PEI category.

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Risk Levels

Number of Volcanoes	Risk Level
4	III
0	II
1	I
11	Unclassified

Table 16.6 The number of volcanoes in the West Indies region classified at each Risk Level.

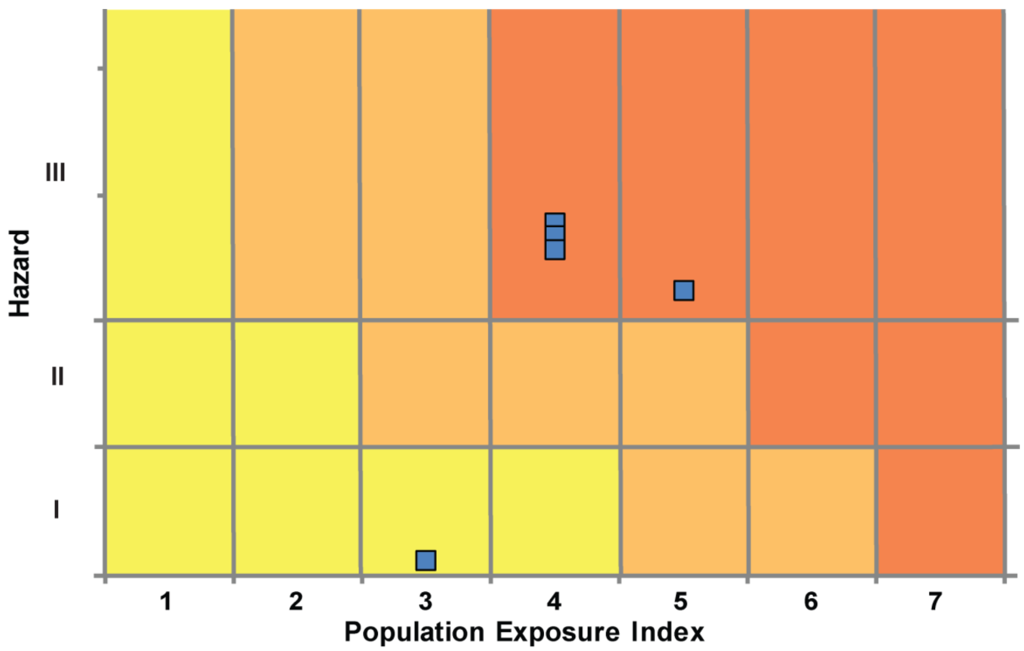

Figure 16.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional monitoring capacity

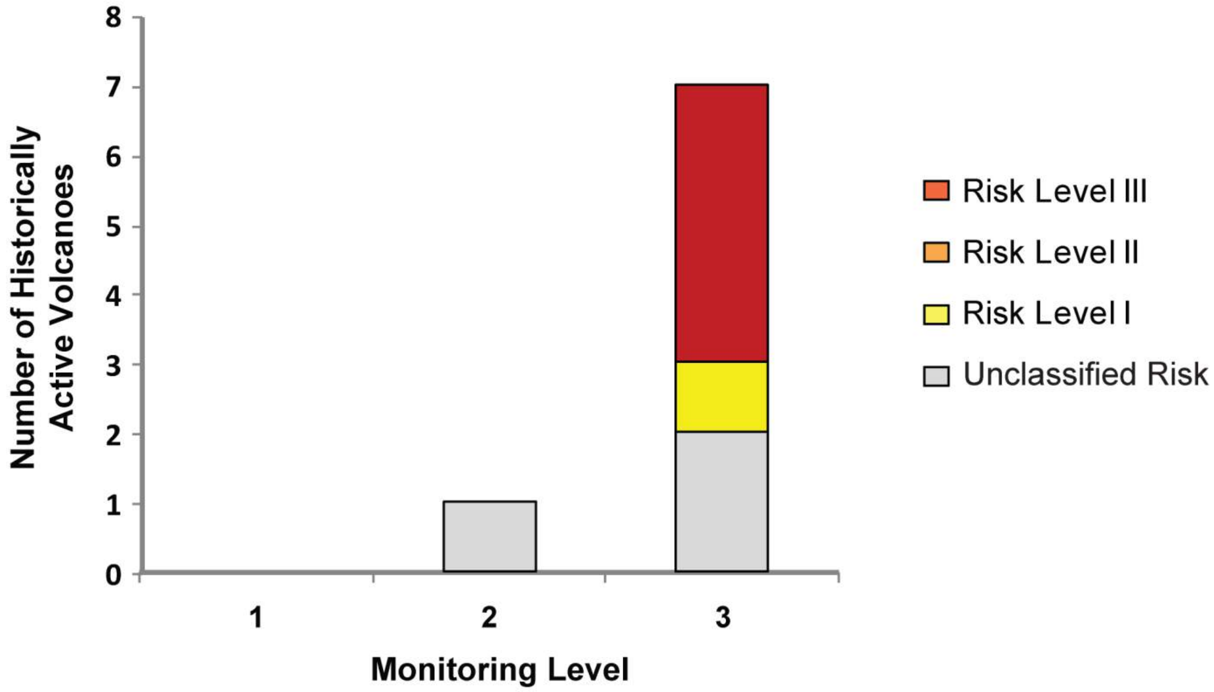

Figure 16.4 The monitoring and risk levels of the historically active volcanoes in the West Indies. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Dominica

Description

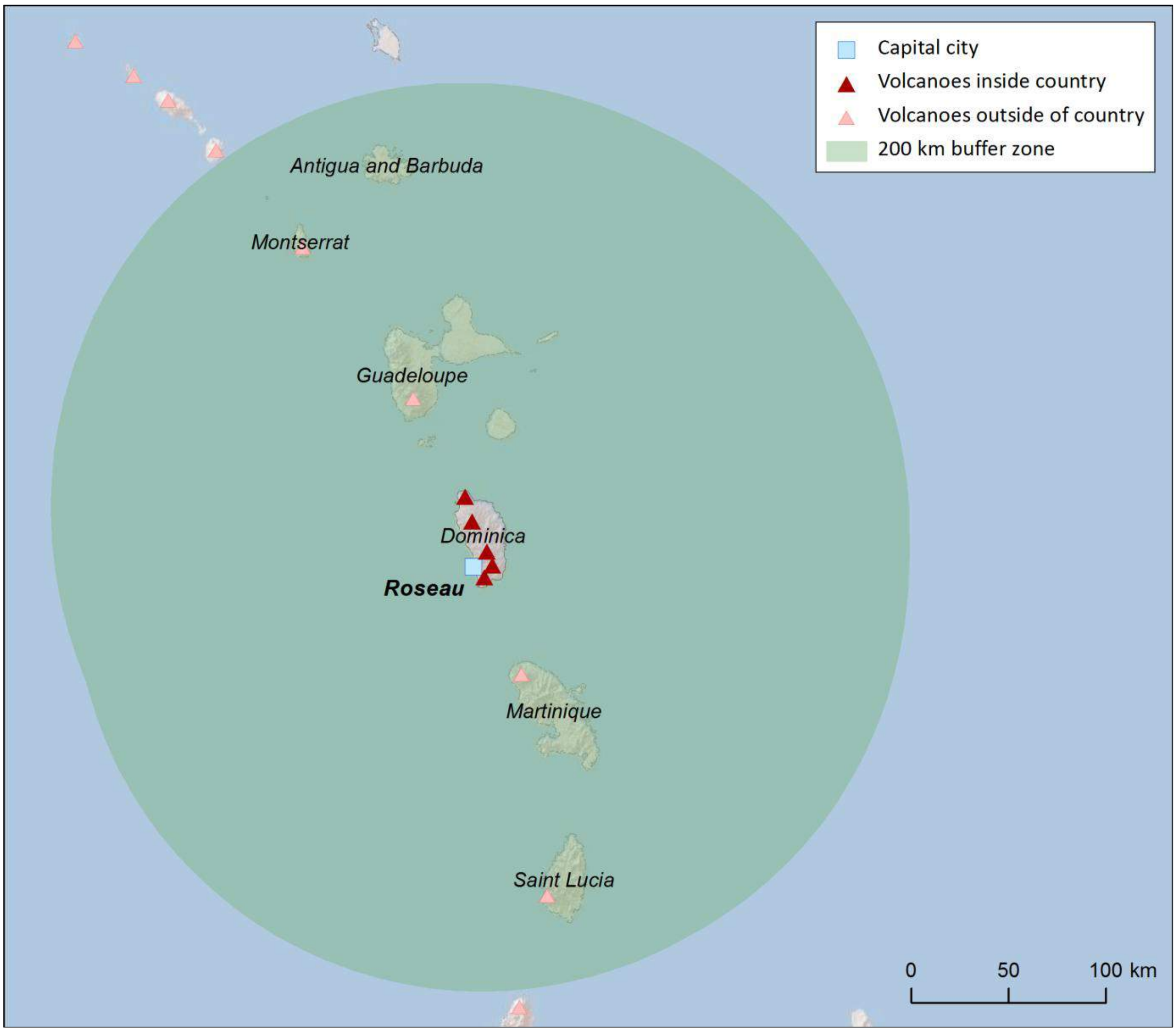

Figure 16.5 Location of Dominica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Dominica.

Five Holocene volcanoes are listed in Dominica, aligned roughly in a chain north-south through the centre of the island. Five volcanoes are listed in VOTW4.0, however separate features of these volcanoes including domes and stratovolcanoes are described as separate volcanoes by the University of the West Indies Seismic Research Centre, making a total of nine Holocene volcanoes on Dominica. Here we consider the record of five volcanoes. Volcanism here is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate. All volcanoes are stratovolcanoes and complex volcanoes, of dominantly andesitic composition.

Large explosive eruptions are recorded in Dominica from three volcanoes during the Pleistocene, including the M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at about 36,000 years ago. Only Morne Trois Pitons, Morne Watt and Morne Plat Pays have a record of confirmed eruptions

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during the Holocene, with 11 eruptions of VEI 1 to 2. The other two volcanoes, Morne aux Diables and Morne Diablotins in the north of the island have suspected but unconfirmed Holocene activity. The largest recorded Holocene eruption was that of Morne Watt in 1880, however the size of nine of eleven eruptions is unknown. Morne Watt is the only historically active volcano here, with, in addition to the VEI 2 eruption of 1880, a VEI 1 eruption in 1997.

Despite the absence of data regarding the size of eruptions here, seven out of eleven eruptions produced pyroclastic flows, indicating explosive activity has been commonplace.

Being a relatively small volcanic island, the whole population resides within 30 km of one or more Holocene volcanoes. Indeed, about 84% of the population live within 10 km. The highest proximal population is at Morne Plat Pays, where several towns lie in the valleys radiating from the volcano and the capital, Roseau, lies within 10 km.

Lindsay et al. (2005) present hazard maps for a number of hazard scenarios on the island and present an integrated hazard map of the most likely eruption scenarios. This divides the island into four colour-coded zones, from Green Zone 4 Low hazard to Red Zone 1 Very High Hazard. The southern tip of the island is designated as Very High Hazard, as it includes the immediate area around Morne Watt. Much of the south of the Island is Zone 2, High Hazard, including the capital, Roseau. See Lindsay et al. (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Dominica's volcanoes. Indeed, they monitor the historically active Morne Watt with multiple dedicated ground-based systems, and also monitor those volcanoes with known or suspected Holocene activity. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M., Smith, A.L., Roobol, M.J., and Stasiuk, M.V. (2005) Dominica, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition www.uwiseismic.com/Downloads/Dominica_VHA.pdf

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-

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Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at 36,385 BP.
Largest recorded Holocene eruption	The VEI 2 eruption of Morne Watt in 1880 AD.
Number of Holocene eruptions	11 confirmed eruptions.
Recorded Holocene VEI range	1 – 2 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
5	Large cone(s)	Andesitic (4), Dacitic (1)

Table 16.7 The number of volcanoes in Dominica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	72,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	11,120
Gross National Income (GNI) per capita (2005 PPP $)	10,977
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Roseau
Distance from capital city to nearest Holocene volcano	7.3 km
Total population (2011)	72,969
Number (percentage) of people living within 10 km of a Holocene volcano	61,224 (83.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	71,052 (97.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	71,052 (97.4%)

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Largest cities, as measured by population and their population size:

Roseau	16,571

Infrastructure Exposure

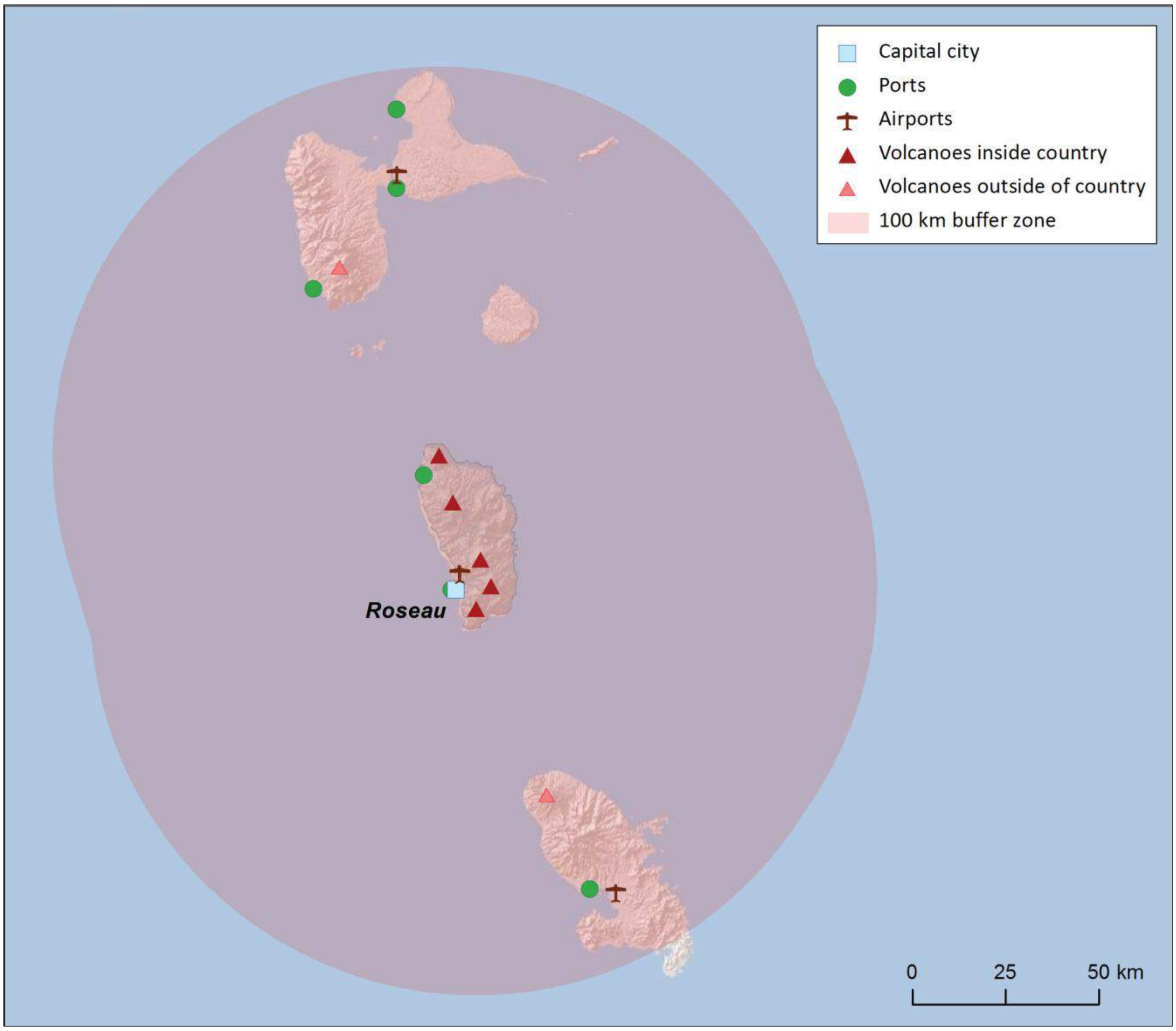

Figure 16.6 The location of Dominica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

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The volcanoes in Dominca form a chain across the island. Being only a small island, measuring no more than 50 km across the country in its entirety lies within a short distance from Holocene volcanoes. Indeed the 100 km radii of the Dominican volcanoes extends beyond Dominica to encompass Guadeloupe and much of Martinique, exposing much of the critical infrastructure on these islands. The volcanoes of Martinique and Guadeloupe likewise have 100 km radii extending to expose Dominica and the infrastructure here. The capital of Dominica, Roseau, lies less than 10 km from three Holocene volcanoes – Morne Plat Pays, Morne Trois Pitons and the historically active Morne Watt. All infrastructure in Dominica and the whole population lie within 50 km of a Holocene volcano.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Dominica have a sufficiently detailed eruption record to be able to define the hazard level through the calculation of the VHI. These volcanoes are therefore unclassified. Two volcanoes have no confirmed Holocene activity on record. Morne Trois Pitons, Morne Plat Pays and Morne Watt have a Holocene eruption record, including historical activity at the latter. Unrest has been described at Morne aux Diables and Morne Trois Pitons since 1900 AD.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**					**Morne Watt**		
	U- HR					**Morne Trois Pitons;** Morne Plat Pays		
	U- NHHR				**Morne aux Diables;** Morne Diablotins			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 16.8 Identity of Dominica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

The PEI ranges from 4 to 5 in Dominica, with moderate to high proximal populations. The risk levels cannot be determined here due to the absence of a hazard classification.

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National Capacity for Coping with Volcanic Risk

One volcano, Morne Watt, has a record of historical eruptions. This volcano and all Holocene volcanoes here are actively monitored by the Seismic Research Centre (University of the West Indies). At Morne Watt a seismic and deformation network is continuously in operation. Additional monitoring of gases and geochemistry of waters and fumaroles is also regularly undertaken.

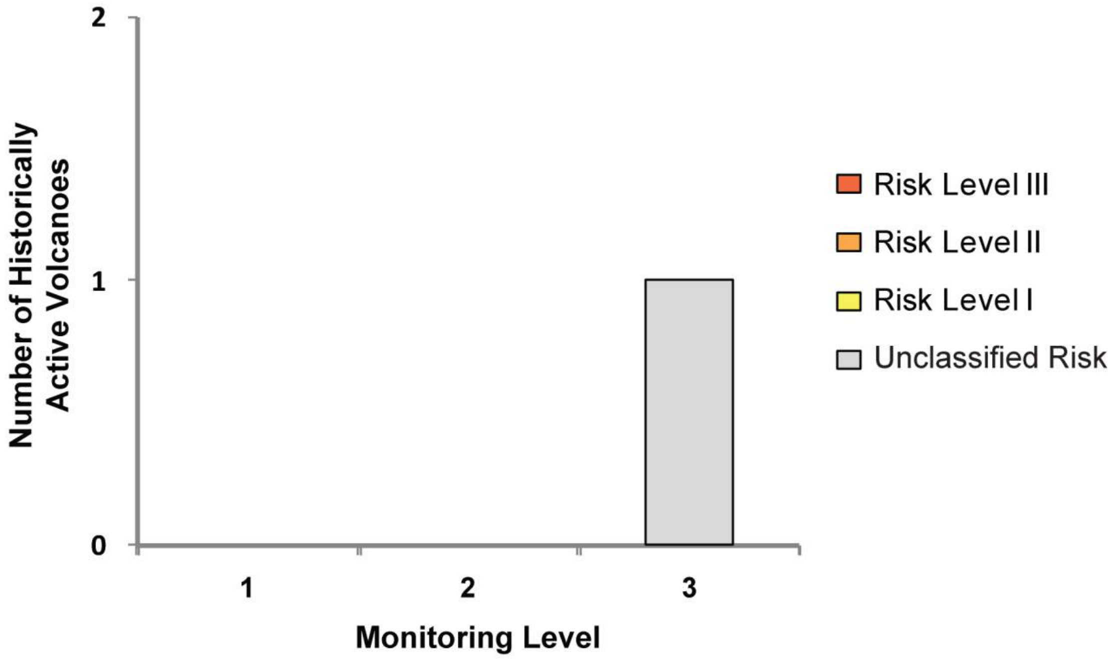

Figure 16.7 The monitoring and risk levels of the historically active volcanoes in Dominica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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France – Martinique, Guadeloupe

See Region 1 for mainland France, Region 3 for French territories in the Indian Ocean, Region 13 for French territories in the Pacific Ocean.

Description

Figure 16.8 Location of Guadeloupe and Martinique's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guadeloupe and Martinique.

Two islands in the Lesser Antilles are overseas territories of France: Martinique and Guadeloupe. Both of these islands have a Holocene volcano. On Guadeloupe, the La Soufrière Guadeloupe volcano sits in the southern tip of the island. On Martinique, Montagne Pelée is situated in the northern tip of the island. Both these volcanoes are andesitic stratovolcanoes, related to the subduction of the North American Plate beneath the Caribbean Plate.

Both La Soufrière Guadeloupe and Montagne Pelée have a record of Holocene and Pleistocene eruptions. The largest Pleistocene eruption was at La Soufrière of Guadeloupe at about 46,000 years ago, with the M5.3 Pintade eruption.

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During the Holocene a total of 74 eruptions are confirmed between the two volcanoes, with most, 54, being recorded at Pelée. These eruptions were of VEI 1 – 4, with large explosive eruptions of VEI 4 recorded at both volcanoes. Twenty-three events were of this size, demonstrating the prevalence of explosive activity on these French islands. Indeed, 86% of recorded eruptions have associated pyroclastic flows.

Eight historical eruptions are recorded at La Soufrière of Guadeloupe, and five at Montagne Pelée. These eruptions have ranged in size from VEI 1 to 4. The largest historical eruption was that of Montagne Pelée in 1902. This catastrophic VEI 4 eruption produced pyroclastic flows and destroyed the city of St. Pierre, resulting in nearly 30,000 fatalities.

Being small islands, relatively high proportions of the population live within 10 km of the volcanoes here, with about 5% of the population of Martinique and 17% of the population of Guadeloupe living within this distance. The whole population lives within 100 km of these volcanic centres.

Boudon et al. (2005) present possible future eruption scenarios for Martinique and suggest that the most probable activity is phreatic events, dome-forming eruptions or open-vent pumiceous eruptions. They also suggest that collapse of the south-western flank of the volcano is of low probability, but consider it due to the devastating effects it could have, including potential for directed blasts and tsunami generation. They present a hazard map for Martinique based on a quantitative assessment of volcanic hazard, showing hazard concentrated around Montagne Pelée and St. Pierre, with much of the southern half of the island being of low hazard.

Komorowski et al., (2005) suggest future eruption scenarios for Guadeloupe in order of decreasing probability of occurrence of: intense prolonged fumarolic activity, phreatic eruptions, edifice collapse eruptions, effusive and explosive dome-forming eruptions and large explosive eruptions. They present an integrated hazard map for these scenarios with the area of highest hazard being located around the summit of La Soufrière of Guadeloupe and to the south-west, with additional high hazard in the valleys radiating from the volcano.

Both La Soufrière of Guadeloupe and Montagne Pelée have dedicated volcano observatories. The Observatoire Volcanologique et Sismologique de la Guadeloupe and the Observatoire Volcanologique et Sismologique de la Martinique run by the Institut de Physique du Globe de Paris manage extensive seismic, deformation and geochemical monitoring networks that are complemented by other geophysical techniques and geological surveys. The monitoring equipment is also used for regional seismic monitoring and tsunami alerts. These monitoring institutions also conduct scientific research to better understand activity here. About 10% of the staff have experience of responding to an eruption. These monitoring institutions do not present risk assessments but are involved in management and mitigation of risks, through interactions with national responsible agencies as well as through a programme of hazard education for the public. Since 1999, the level of activity and main results of the monitoring of La Soufrière of Guadeloupe and Montagne Pelée as well as the regional seismic activity are communicated on a monthly basis widely to the authorities, population and stakeholders through a bulletin available on the internet and via email.

In the event of unrest and eruptions the institutions release alerts using an alert level system. Alert levels are also communicated regularly.

See also:

Observatoire Volcanologique et Sismologique de la Guadeloupe - www.ipgp.fr/pages/03030402.php

Observatoire Volcanologique et Sismologique de la Martinique - www.ipgp.fr/pages/03030302.php

Boudon, G., Le Friant, A., Villemant, B., and Viode, J-P. (2005) Martinique, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Komorowski, J-C., Boudon, G., Semet, M., Beauducel, F., Anenor-Habazac, C., Bazin, S., and Hammouya, G. (2005) Guadeloupe, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	Martinique: 1; Guadeloupe: 1
Number of Pleistocene volcanoes with M≥4 eruptions	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating pyroclastic flows	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lahars	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lava flows	Martinique: - Guadeloupe: 1
Number of fatalities caused by volcanic eruptions	Martinique:29,523
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption:	The M5.3 Pintade eruption of Soufrière Guadeloupe at 46,465 BP.
Largest recorded Holocene eruption	The P1, P2 and P3 eruptions of Pelée on Martinique are all recorded as M4.6 and occurred at 610, 1,600 and 1,940 BP.
Number of Holocene eruptions	Guadeloupe: 20 confirmed.

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	Martinique: 54 confirmed eruptions.
Recorded Holocene VEI range	1 – 4 and Unknown
Number of historically active volcanoes	Guadeloupe:1
	Martinique: 1
Number of historic eruptions	Guadeloupe: 8
	Martinique: 5

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)

Table 16.9 The number of volcanoes in the French West Indies, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	Martinique: 403,000;
	Guadeloupe: 464,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Martinique: Fort-de-France;
	Guadeloupe: Basse-Terre
Distance from capital city to nearest Holocene volcano	Martinique: 26.3 km Guadeloupe: 7.7 km
Total population (2011)	Martinique: 412,465
	Guadeloupe: 456,703
Number (percentage) of people living within 10 km of a Holocene volcano	Martinique: 20,924 (5.1%)
	Guadeloupe: 78,100 (17.1%)
Number (percentage) of people living within 30 km of a Holocene	Martinique: 281,424 (68.2%)

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volcano	Guadeloupe: 296,828 (65%)
Number (percentage) of people living within 100 km of a Holocene volcano	Martinique: 402,028 (97.5%) Guadeloupe: 460,883 (100%)

Largest cities, as measured by population and their population size (2011 census data from Institut National de la Statisique et des Études Économiques (INSEE, www.insee.fr):

Fort-De-France	88,182
Les Abymes	60,079
Pointe-à-Pitre	16,191
Basse-Terre	11,962

Infrastructure Exposure

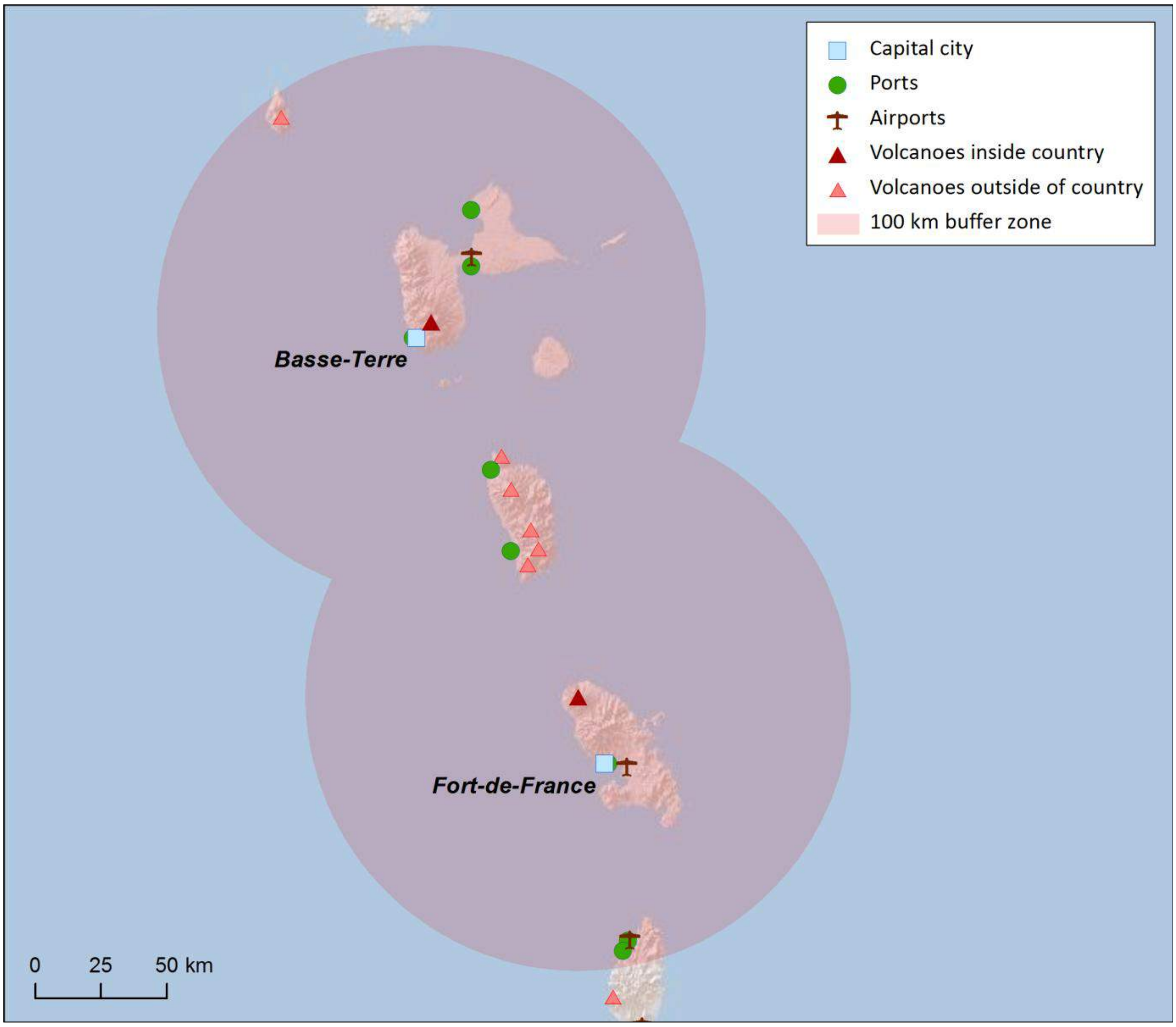

Figure 16.9 The location of Guadeloupe's and Martinique's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in the French West Indies are located on the southern tip of the island of Guadeloupe and the northern tip of the island of Martinique. Being small islands, measuring no more than 70 km across, these are in their entirety within the 100 km radii of these volcanoes, exposing all infrastructure and population on Guadeloupe and Martinique. The 100 km radii also extend to fully encompass Dominica, exposing all infrastructure here. The 100 km radius of Pelée on Martinique extends to encompass the northern tp of St. Lucia, whilst much of the island of Montserrat is exposed in the 100 km radius of La Soufrière of Guadeloupe. Likewise, the radii of Soufrière Hills Volcano extends to Guadeloupe.

Hazard, Uncertainty and Exposure Assessments

Both La Soufrière of Guadeloupe and Montagne Pelée have sufficient information in their eruption records to define a hazard level through calculation of the VHI. Both are classed as Hazard Level III, with VEI 4 Holocene eruptions and a history of explosive eruptions producing pyroclastic flows.

The PEI at La Soufrière of Guadeloupe and Montagne Pelée is 5 and 4 respectively, with moderate to large proximal populations, including over 70,000 living within 10 km at Soufrière Guadeloupe. With a Hazard Level of III, both volcanoes are classed at Risk Level III.

CLASSIFIED	**Hazard III**				Pelée	Soufrière Guadeloupe		
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 16.10 Identity of Martinique's and Guadeloupe's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed

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eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière Guadeloupe	5	III
Pelée	4	III

Table 16.11 Classified volcanoes of Guadeloupe and Martinique ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 2 volcanoes.

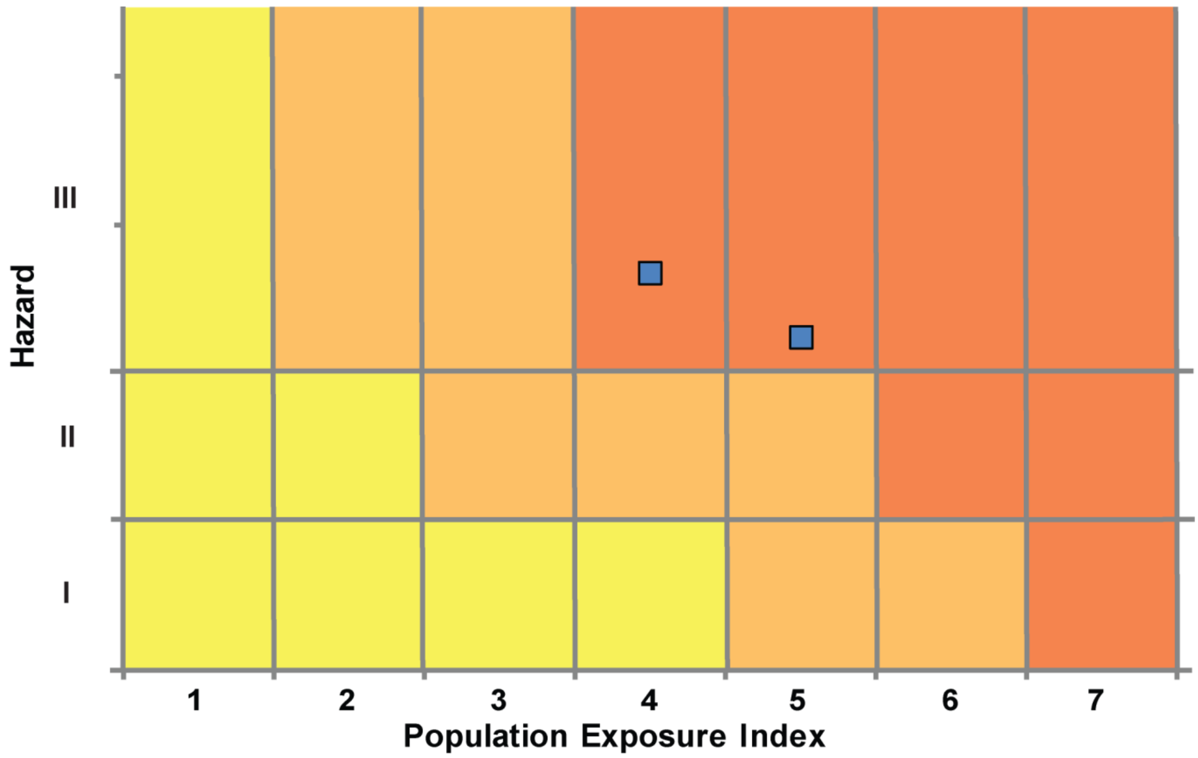

Figure 16.10 Distribution of Martinique and Guadeloupe's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Both Soufrière Guadeloupe and Pelée are monitored by the Observatoire Volcanologique et Sismologique de Guadeloupe (OVSG/IPGP) and Observatoire Volcanologique et Sismologique de Martinique (OVSM/IPGP) respectively. Extensive seismic, deformation and geochemical networks are in place at both volcanoes.

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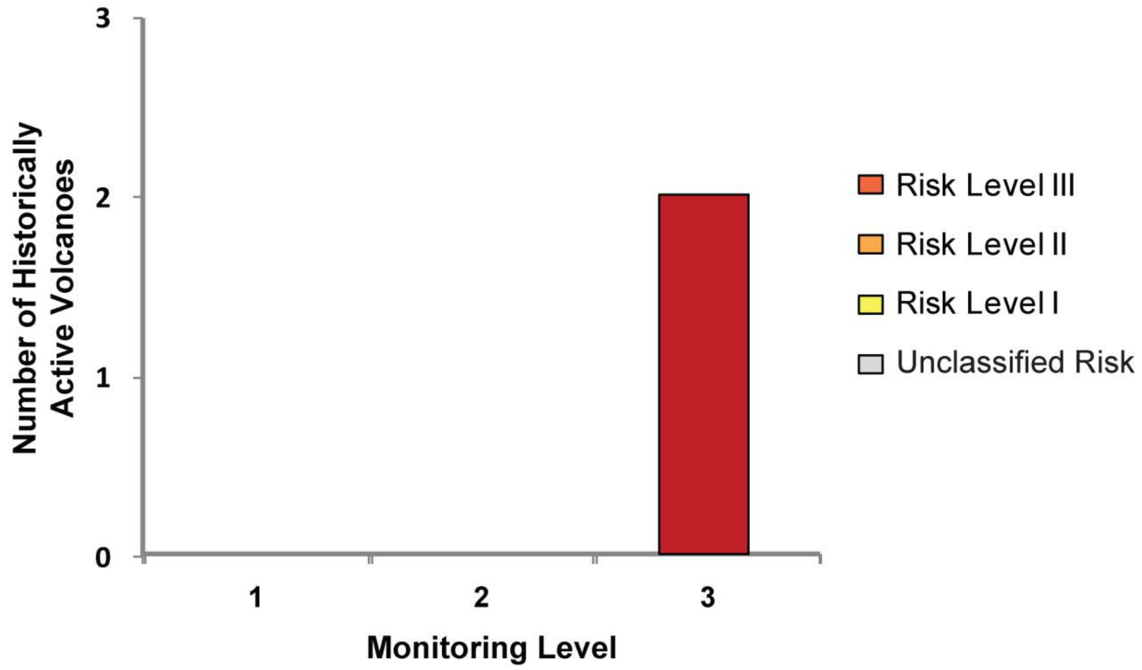

Figure 16.11 The monitoring and risk levels of the historically active volcanoes in Martinique and Guadeloupe. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Grenada

Description

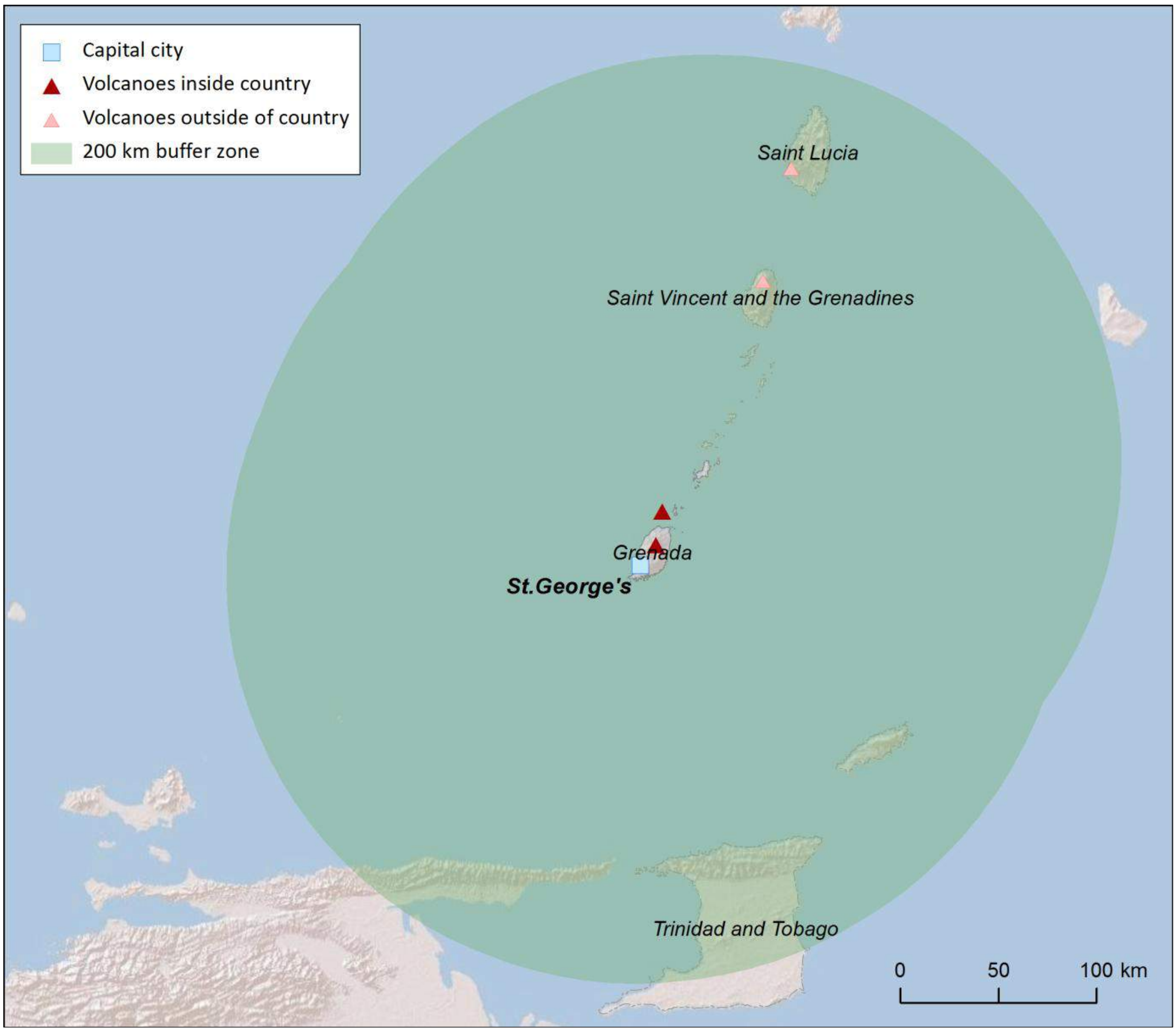

Figure 16.12 Location of Grenada volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Grenada.

Two Holocene volcanoes are present in Grenada: one, the andesitic stratovolcano St.Catherine is situated in the north of the island, and the second, the basaltic submarine Kick 'em Jenny located off the northern shore. Volcanism here is due to the subduction of the Atlantic Ocean beneath the Caribbean Plate.

Only Kick 'em Jenny has a Holocene record of confirmed eruptions, with 13 VEI 0 – 1 eruptions. St. Catherine is also suspected of having Holocene age activity. Activity at Kick 'em Jenny has involved both explosions and lava effusion. The largest eruption on record occurred in 1939 when an eruption cloud rose to nearly 300 m above the surface of the sea.

Being a small island group, the entire population lives close to the volcanoes. Being the only subaerial volcano here, the largest proximal population is located at St. Catherine.

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Submarine volcanoes can pose various hazards. Ballistics may breach the surface though these are unlikely to reach the main island of Grenada. Gas release from the volcanoes can lower the water density. Ships may lose buoyancy and sink due to this, and indeed it is suggested that Kick 'em Jenny may have caused the sinking of the Island Queen with over 60 people on board in 1944.

Robertson (2005) presents eruption scenarios for the island, comprising dome growth and explosive eruption. Integrated hazard maps are presented in which the highest hazard is concentrated in the north of the island around St. Catherine volcano. Also of note is the presence of explosion craters running approximately NNE-SSW through the island, which may suggest that further craters may develop.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Grenada's volcanoes. Indeed, they monitor the historically active Kick 'em Jenny with multiple seismic and deformation stations placed on islands close to this submarine volcano. They also monitor the Holocene volcano St. Catherine. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre: www.uwiseismic.com/

Robertson, R. (2005) Grenada, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 1 eruption of Kick 'em Jenny of 1939 AD.
Number of Holocene eruptions	13 confirmed eruptions.
Recorded Holocene VEI range	0 – 1 and unknown
Number of historically active volcanoes	1

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Number of historic eruptions	12

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
1	Submarine	Basaltic (1)

Table 16.12 The number of volcanoes in Grenada, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	106,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,806
Gross National Income (GNI) per capita (2005 PPP $)	9,257
Human Development Index (HDI) (2012)	0.770 (High)

Population Exposure

Capital city	St. George's
Distance from capital city to nearest Holocene volcano	12.6 km
Total population (2011)	108,419
Number (percentage) of people living within 10 km of a Holocene volcano	50,457 (46.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	103,820 (95.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	105,009 (96.9%)

Largest cities, as measured by population and their population size:

Saint George's	7,500

Infrastructure Exposure

Number of airports within 100 km of a volcano	1

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Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Grenada are located on the main island and about 8 km off the coast of the main island. Being a group of small islands, with Grenada itself measuring no more than 40 km across, the country in its entirety lies within 100 km of the Holocene volcanoes, exposing all infrastructure here. Indeed, the 100 km radii of the volcanoes here extends beyond Grenada to encompass much of the Grenadines.

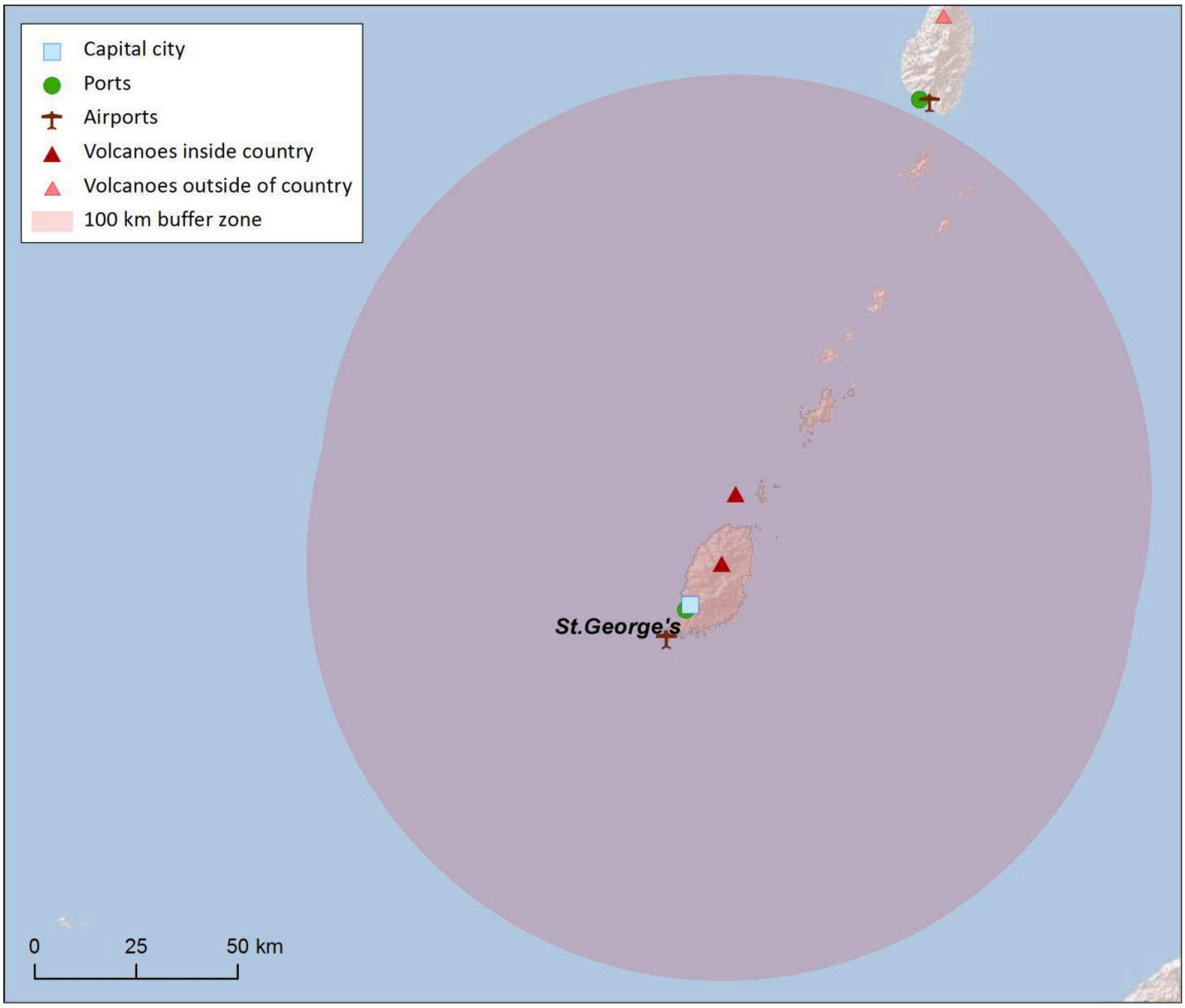

Figure 16.13 The location of Grenada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The two volcanoes of Grenada have very different eruption records. St. Catherine has no confirmed Holocene eruptions, and this volcano cannot therefore have a hazard level determined without large

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associated uncertainties. Kick 'em Jenny is sufficiently well known to classify this volcano as Hazard Level I. Kick'em Jenny has a moderate PEI and is classed at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I			Kick 'em Jenny				
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR					St. Catherine		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.13 Identity of Grenada's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Kick 'em Jenny	3	I

Table 16.14 Volcanoes of Grenada ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

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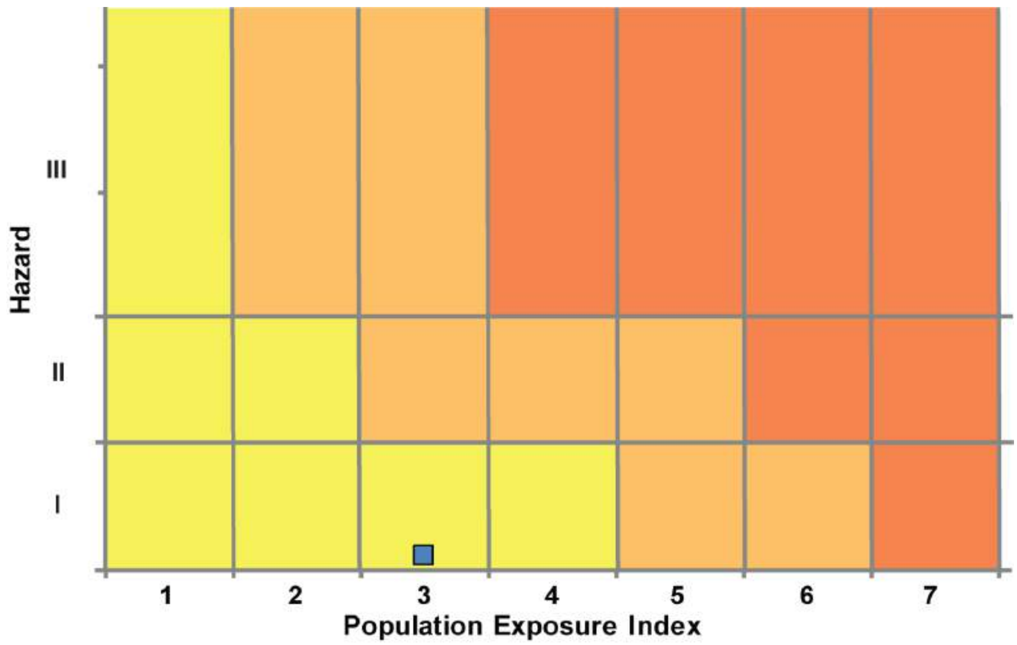

Figure 16.14 Distribution of Grenada's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Kick'em Jenny, the only historically active volcano in Grenada is monitored by the University of West Indies Seismic Research Centre. Being a submarine volcano, monitoring is undertaken using seismic and deformation stations on nearby islands. The SRC also monitor the Holocene volcano St. Catherine.

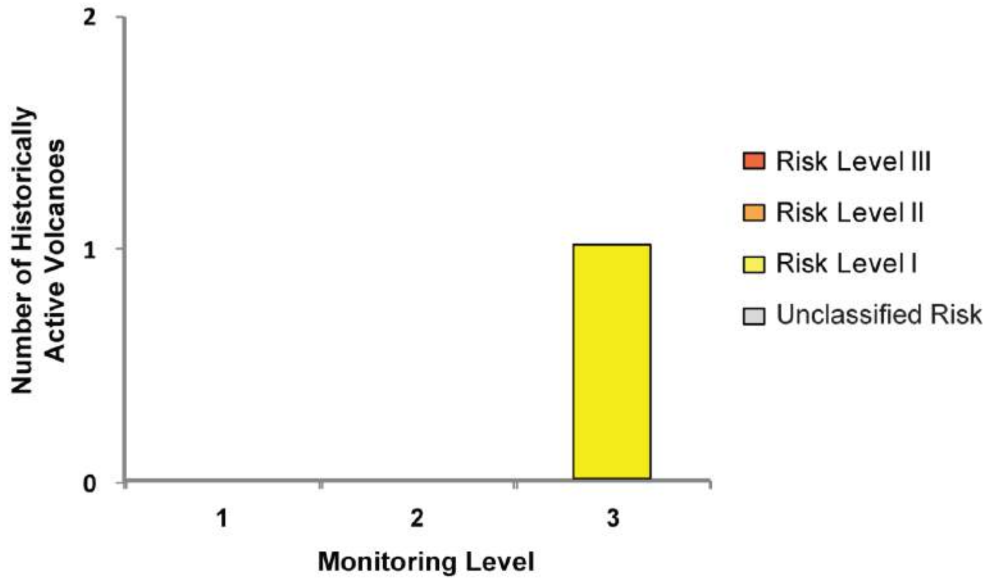

Figure 16.15 The monitoring and risk levels of the historically active volcanoes in Grenada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Netherlands (Dutch Antilles)

Description

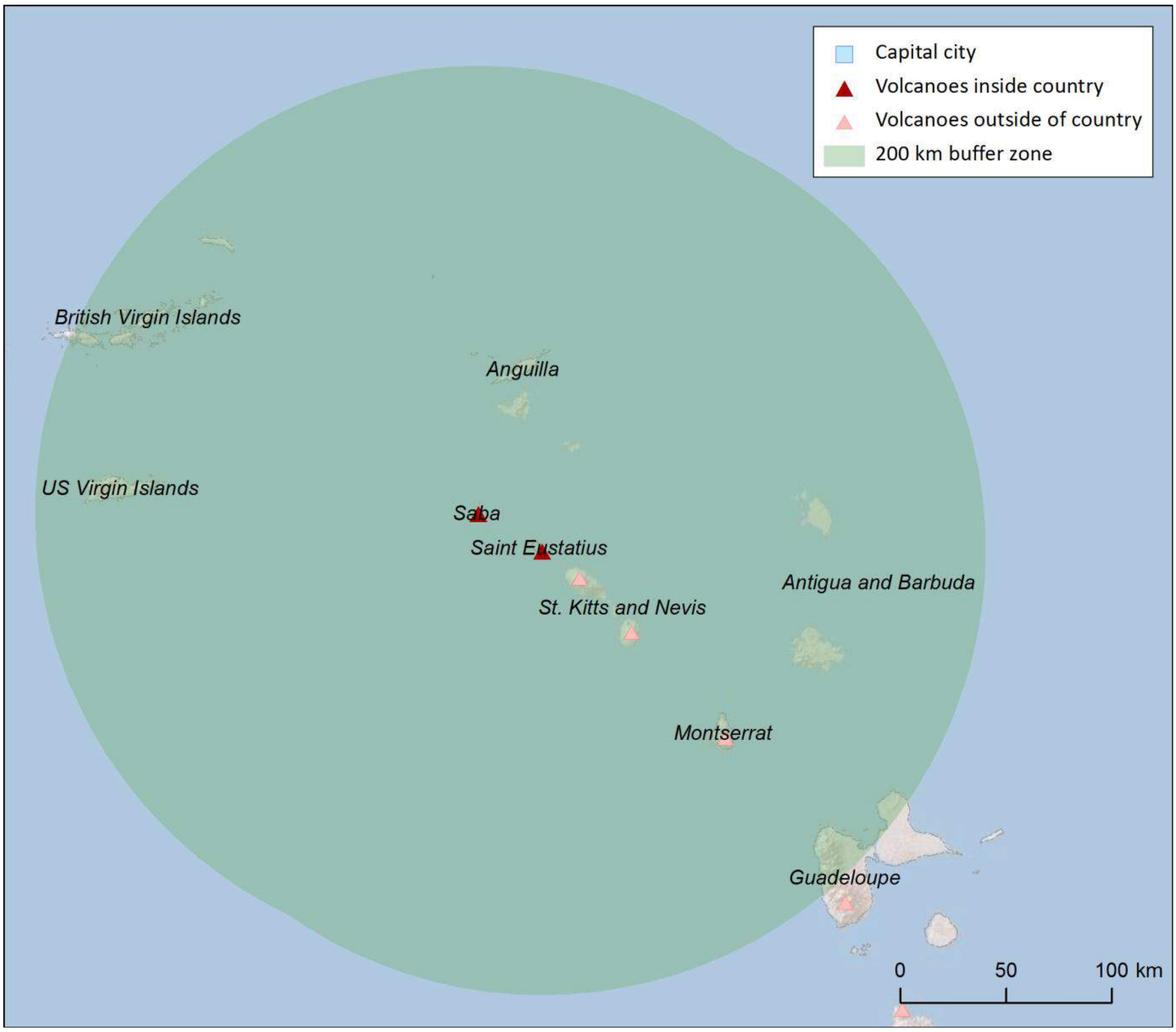

Figure 16.16 Location of the Dutch Antilles' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Dutch Antilles.

Two Holocene volcanoes are located in the Dutch Antilles, on the islands of Saba and Sint Eustatius in the northern Lesser Antilles. These andesitic stratovolcanoes result from the subduction of the Atlantic Ocean Crust beneath the Caribbean Plate.

Both Saba and The Quill volcanoes have confirmed Holocene eruptions on record, with just one historic eruption at Saba in 1640, and three Holocene eruptions at The Quill from 6140 BC to 250 AD. Only the 6140 BC eruption of The Quill has a known size, at VEI 4; the other eruptions are of unknown magnitude. Despite the absence of data regarding the size of eruptions, all four events produced pyroclastic flows, indicating explosive activity has been commonplace. Hot springs are located on these islands and recent unrest in the form of seismicity is recorded.

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Being small islands, the population of Saba and Sint Eustatius are situated in close proximity to the volcanoes. This accounts for about 25% of the population of the Dutch Antilles, with much of the population located in another island group off the Venezuela coast.

Smith and Roobol (2005) present eruption scenarios and suggest that the most likely style of future magmatic activity at Saba will involve the growth of a lava dome and associated block and ash flows and surges. They present volcanic hazard maps for Saba indicating that the entire island is considered Very High Hazard in the event of a dome-forming eruption. Smith and Roobol (2005) suggest that the most likely eruption scenario for future activity at The Quill is an explosive eruption producing pyroclastic flows, surges and ash fall. They indicate that only the north-west section of the island of Sint Eustatius lies outside of the High hazard zone for pyroclastic flows and surges (but still considered moderate), with much of the island being considered Very High Hazard and the whole island being High to Very High Hazard. See Smith and Roobol (2005) for full details.

The Koninklijk Nederlands Meteorologisch Instituut is responsible for the monitoring of the volcanoes of the Dutch Antilles. Indeed, they monitor the historically active Saba volcano with seismic and deformation stations, and also monitor The Quill. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

Smith, A.L., and Roobol, M.J. (2005) Saba, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Smith, A.L., and Roobol, M.J. (2005) St. Eustatius, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4 6140 BC eruption of The Quill.
Number of Holocene eruptions	4 confirmed eruptions.

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Recorded Holocene VEI range	4 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)

Table 16.15 The number of volcanoes in the Dutch Antilles, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	44,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2012)	

Population Exposure

Capital city	Willemstad
Distance from capital city to nearest Holocene volcano	789.3 km
Total population (2011)	15,021
Number (percentage) of people living within 10 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,797 (25.3%)

Largest cities, as measured by population and their population size:

Willemstad	125,000

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Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The islands of the Dutch Antilles form two groups in the Caribbean, one group off the coast of Venezuela and another in the northern Lesser Antilles. It is this northern group where the volcanoes are situated on the islands of Saba and Sint Eustatius. Being small islands, these are encompassed in their entirety within the 100 km radii of the volcanoes, as are the islands of St. Kitts and Nevis and north beyond Anguilla. Indeed, the 100 km radii of the volcanoes of St. Kitts and Nevis extend to encompass these northern islands of the Dutch Antilles exposing the infrastructure here. All infrastructure in this group of islands is exposed.

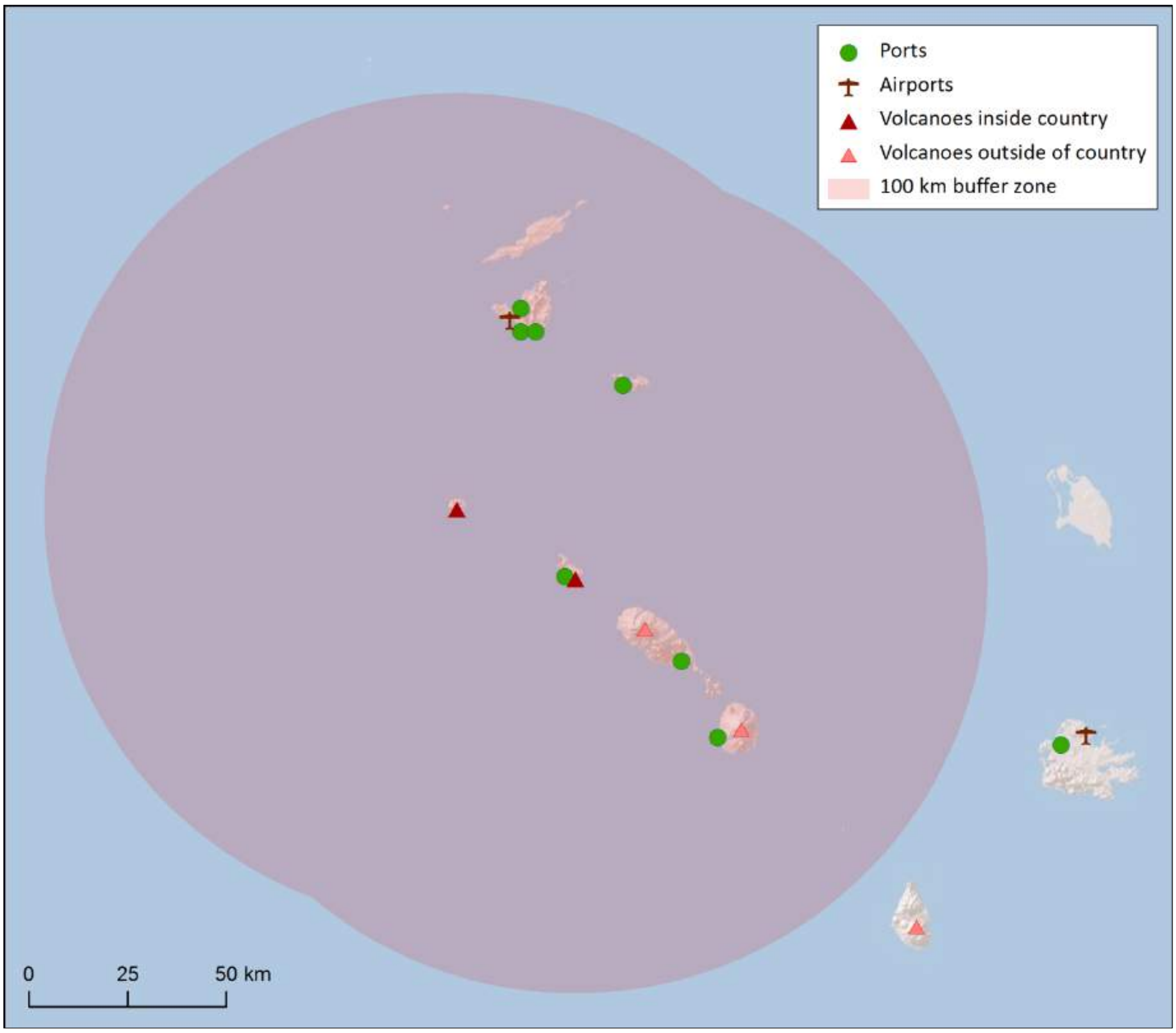

Figure 16.17 The location of the Dutch Antilles volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

Neither Saba nor The Quill have sufficiently detailed eruptive records to enable hazard classification through calculation of the VHI. Saba has a historical record of activity, along with unrest documented since 1900 AD. The Quill has three known Holocene eruptions, with one a VEI 4.

The PEI at Saba and The Quill is low at PEI 2.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Saba**					
	U- HR		The Quill					
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.16 Identity of the Dutch Antilles' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Seismometers are in place for monitoring of the Saba volcano, operated by the Koninklijk Nederlands Meteorologisch Instituut.

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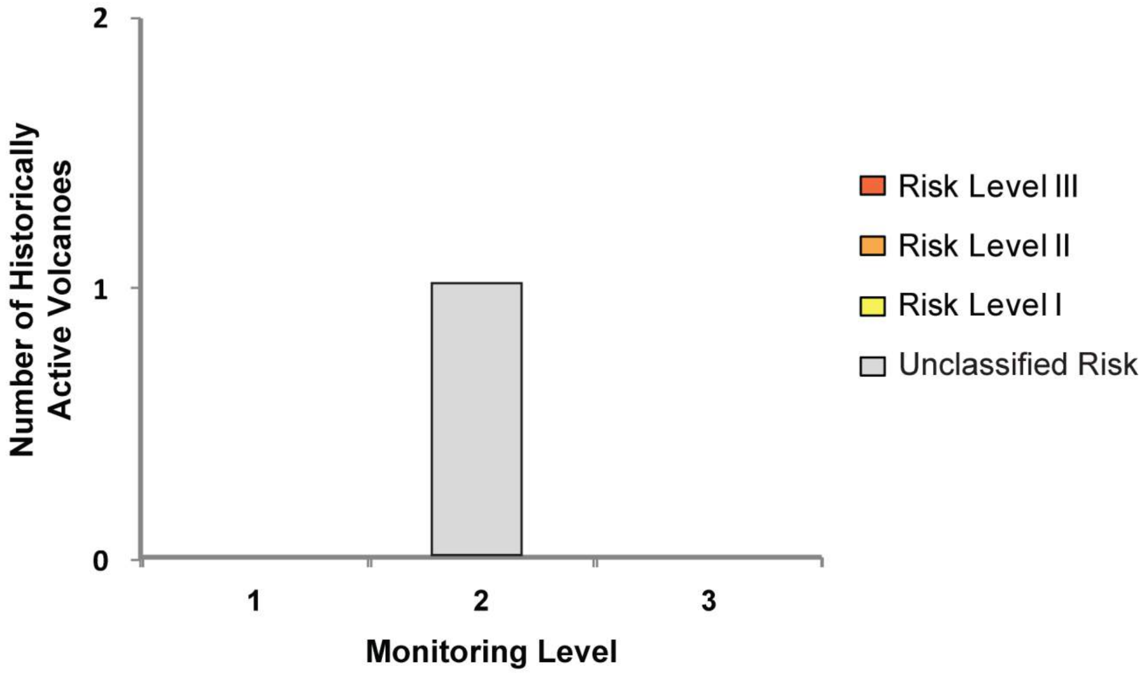

Figure 16.18 The monitoring and risk levels of the historically active volcanoes in the Dutch Antilles. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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St. Kitts and Nevis

Description

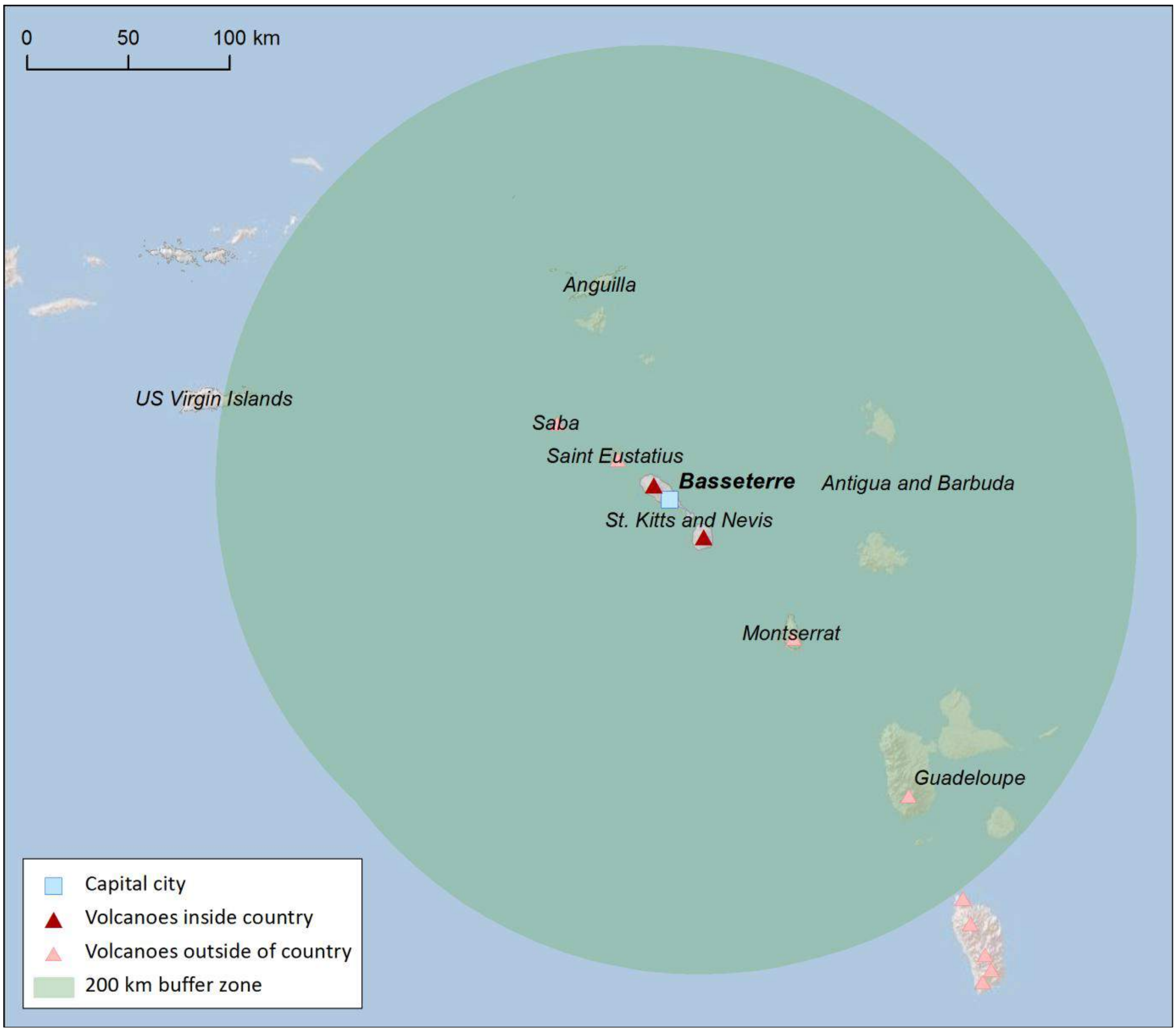

Figure 16.19 Location of St Kitts and Nevis' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St Kitts and Nevis.

Two Holocene volcanoes are located in St. Kitts and Nevis: Liamuiga on the island of St. Kitts and Nevis Peak central on Nevis. These two andesitic stratovolcanoes have formed due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Only Liamuiga has a confirmed Holocene record of eruptions, with two eruptions of VEI 4 and one of unknown magnitude recorded in 2010 BC, 160 AD and 60 AD, respectively. All three eruptions of Liamuiga reportedly produced pyroclastic flows, indicating that explosive activity is prevalent here. One of these events also resulted in a lahar and the deposits of this now underlie populated coastal regions on the island. The most recent dated eruption of Nevis Peak was about 100,000 years ago and the Holocene age of other activity here is questionable, however, active fumaroles and hot springs on Nevis Island and seismic swarms during the 20th century indicate unrest.

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With a sparse eruptive record, assessment of hazard at Nevis Peak is difficult and associated with large uncertainties. The record is better constrained at Liamuiga, however recent historical eruptions are uncertain. Robertson (2005) present hazard maps for a number of eruption scenarios at Liamuiga and present integrated hazard maps, where the north of the island of St. Kitts is considered the area of highest hazard. Simpson (2005) present hazard maps for effusive dome building eruptions from Nevis Peak and shows that the whole of Nevis Island is considered Very High Hazard or High Hazard with a large proportion of the island susceptible to inundation by pyroclastic flows.

Being relatively small islands, the whole country is situated close to these Holocene volcanoes, and about three quarters of the population live within 10 km of a Holocene volcano.

The University of the West Indies Seismic Research Centre (SRC) monitors the volcanoes of St. Kitts and Nevis using seismic and deformation networks and additional monitoring of springs and fumaroles when activity permits. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Robertson, R. (2005) St. Kitts, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Simpson, K. (2005) Nevis, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Both the D and F eruptions of Liamuiga, at 4470 and 1777 BP respectively, are recorded at M4.
Number of Holocene eruptions	3 confirmed eruptions. 2

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	uncertain eruptions.
Recorded Holocene VEI range	4 and unknown
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)

Table 16.17 The number of volcanoes in St. Kitts and Nevis, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	54,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,291
Gross National Income (GNI) per capita (2005 PPP $)	12,460
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Basseterre
Distance from capital city to nearest Holocene volcano	10 km
Total population (2011)	50,314
Number (percentage) of people living within 10 km of a Holocene volcano	37,080 (73.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	52,989 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	52,989 (>100%)

Largest cities, as measured by population and their population size:

Basseterre	12,920

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Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of St. Kitts and Nevis are located on both islands. Being small islands measuring no more than about 50 km across, this country in its entirety lies close to Holocene volcanoes. The 100 km radii of these volcanoes extend beyond the country's borders to encompass the northern islands of the Dutch Antilles, Montserrat, Antigua and Barbuda and much of Anguilla, exposing much of the infrastructure in the northern Lesser Antilles. Indeed the 100 km radii of the volcanoes of these other islands, including Soufriere Hills on Montserrat and Saba and The Quill of the Dutch Antilles encompasses and exposes St.Kitts and Nevis to the volcanic hazard.

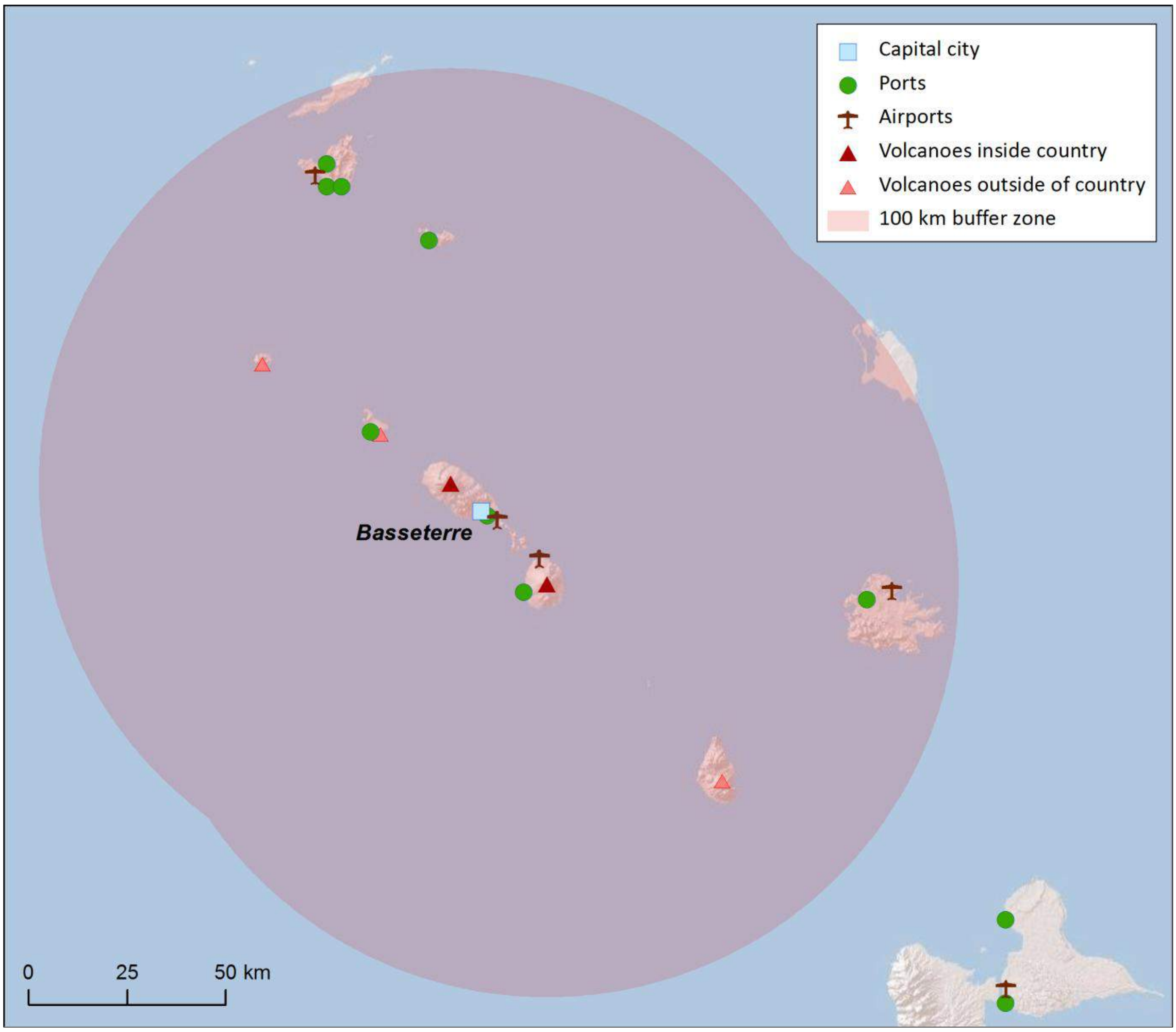

Figure 16.20 The location of St. Kitts and Nevis' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

Neither Liamuiga nor Nevis Peak have sufficient eruption records to determine the hazard level through calculation of the VHI. Indeed, there are no confirmed Holocene age eruptions at Nevis Peak. Three Holocene eruptions are recorded at Liamuiga, with two VEI 4 events. Both volcanoes have experienced unrest since 1900 AD suggesting active systems.

With moderate proximal populations in St. Kitts and Nevis, these volcanoes are classed at PEI 3 and 4. Risk levels cannot be determined due to lack of hazard data.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			**Liamuiga**				
	U- NHHR				**Nevis Peak**			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.18 Identity of St Kitts and Nevis' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in St. Kitts and Nevis have recorded historical eruptions, however seismic and deformation monitoring is undertaken here by the Seismic Research Centre.

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St. Lucia

Description

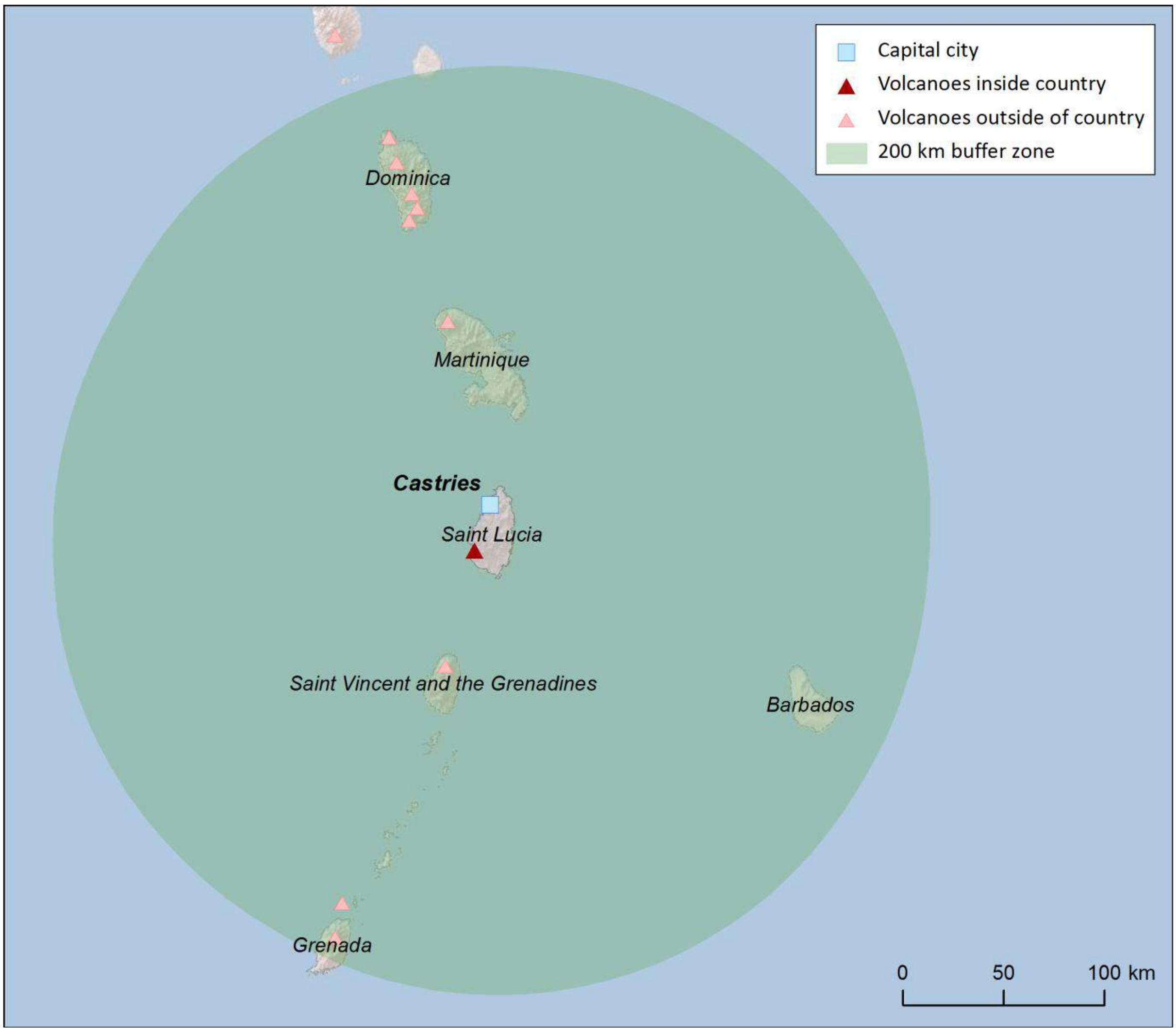

Figure 16.21 Location of St. Lucia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St. Lucia.

One Holocene volcano, Qualibou, is located in the south-east of the island of St. Lucia. This andesitic caldera is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Qualibou has a Pleistocene record of large explosive eruptions, with the M6.1 eruption of the Choiseul Tuff about 42,000 years ago forming the present caldera. Numerous post-caldera lava dome fill the crater floor. Only one Holocene eruption is confirmed, with a small VEI 1 phreatic eruption in 1766 that produced a thin layer of ash over an extensive area. The history of large explosive eruptions and andesitic composition suggests that future large explosive eruptions cannot be ruled out. However, Lindsay (2005) suggests that phreatic or hydrothermal eruptions or small explosive eruptions forming explosion craters are most likely. Unrest occurred in 1990 with a volcanic earthquake swarm.

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Lindsay (2005) presents eruption scenarios and hazard maps for dome forming eruptions and explosive Plinian eruptions at Qualibou. These show the hazard concentrated in the south-east of the island, around the volcanic centre, with High and Very High Hazard across much of the south and centre of St. Lucia in the event of an explosive Plinian eruption. See Lindsay (2005) for further detail.

Being a relatively small island, the whole population resides close to the volcano, with about 20% of the population living within 10 km.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Lucia's volcanoes. Indeed, they monitor Qualibou with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M. (2005) St. Lucia, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.1 eruption of the Choiseul Tuff from Qualibou at 42,264 BP.
Largest recorded Holocene eruption	The VEI 1 eruption of Qualibou in 1766 AD.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	1
Number of historically active volcanoes	1
Number of historic eruptions	1

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)

Table 16.19 The number of volcanoes in St. Lucia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	181,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,231
Gross National Income (GNI) per capita (2005 PPP $)	7,971
Human Development Index (HDI) (2012)	0.725 (High)

Population Exposure

Capital city	Castries
Distance from capital city to nearest Holocene volcano	23.5 km
Total population (2011)	161,557
Number (percentage) of people living within 10 km of a Holocene volcano	28,310 (17.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	178,196 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	179,005 (>100%)

Largest cities, as measured by population and their population size:

Cul De Sac	8,467
Castries	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

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Qualibou volcano is located in the south-east of the island of St. Lucia. Being only a small island, measuring no more than about 50 km across, this country in its entirety lies within the 100 km radius of this volcano and thus all infrastructure and population is exposed here. Indeed the 100 km radius extends beyond St. Lucia to fully encompass St. Vincent and extend into the Grenadines, and largely encompass Martinique, exposing the infrastruture and population on these islands. The 100 km radii of Pelée on Martinique and Soufrière St.Vincent on the island of St. Vincent also extend to encompass St. Lucia and thus expose the infrastructure here.

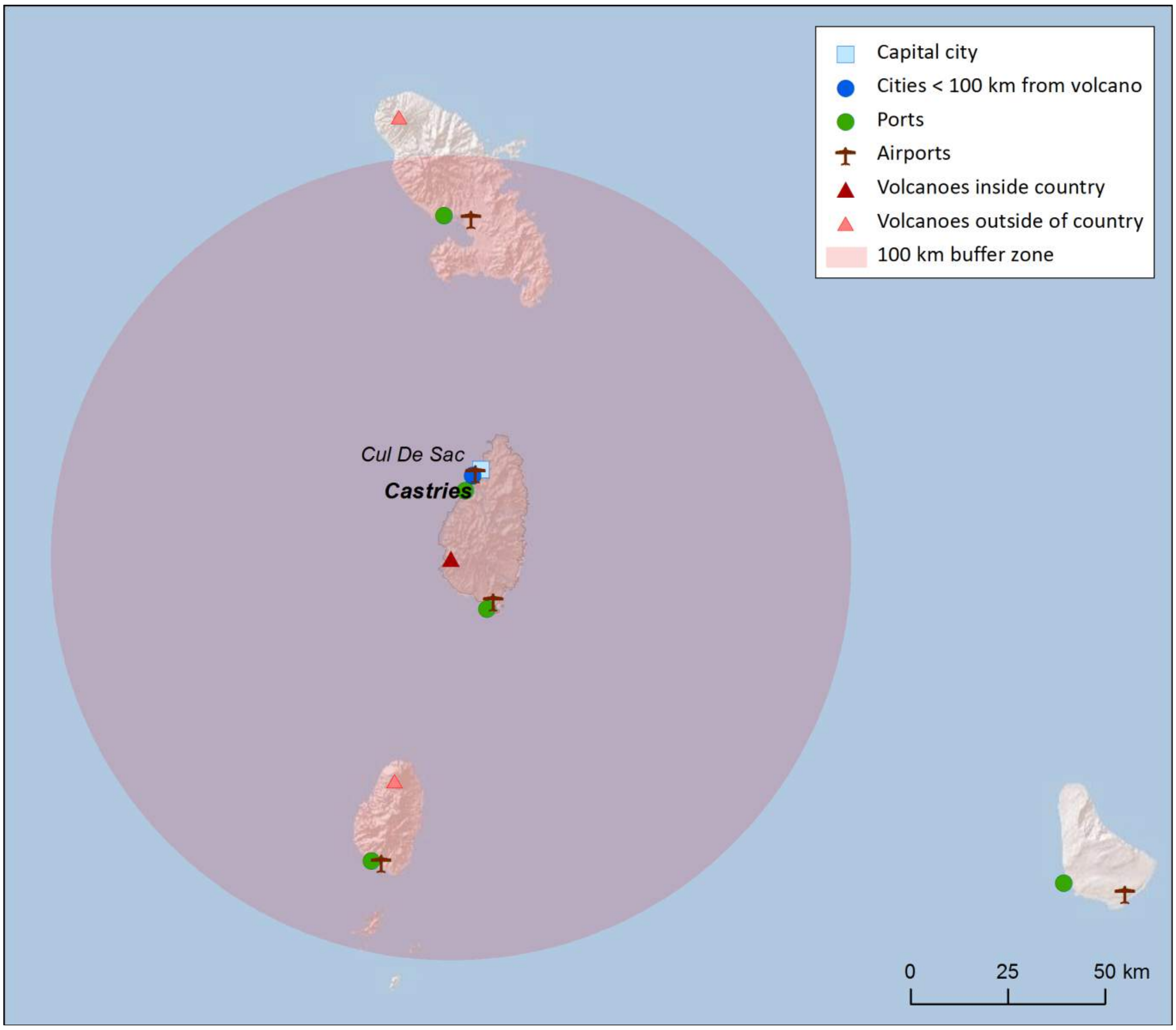

Figure 16.22 The location of St. Lucia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Qualibou in St. Lucia has just one confirmed eruption recorded during the Holocene, with a VEI 1 event in 1766. This is insufficient to calculate the VHI and therefore a hazard level is not determined here. Qualibou has a high local population, and is classed at PEI 5 suggestive of a risk level of II to III.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR					**Qualibou**		
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.20 Identity of St. Lucia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active volcano Qualibou through a seismic network and multiple deformation stations.

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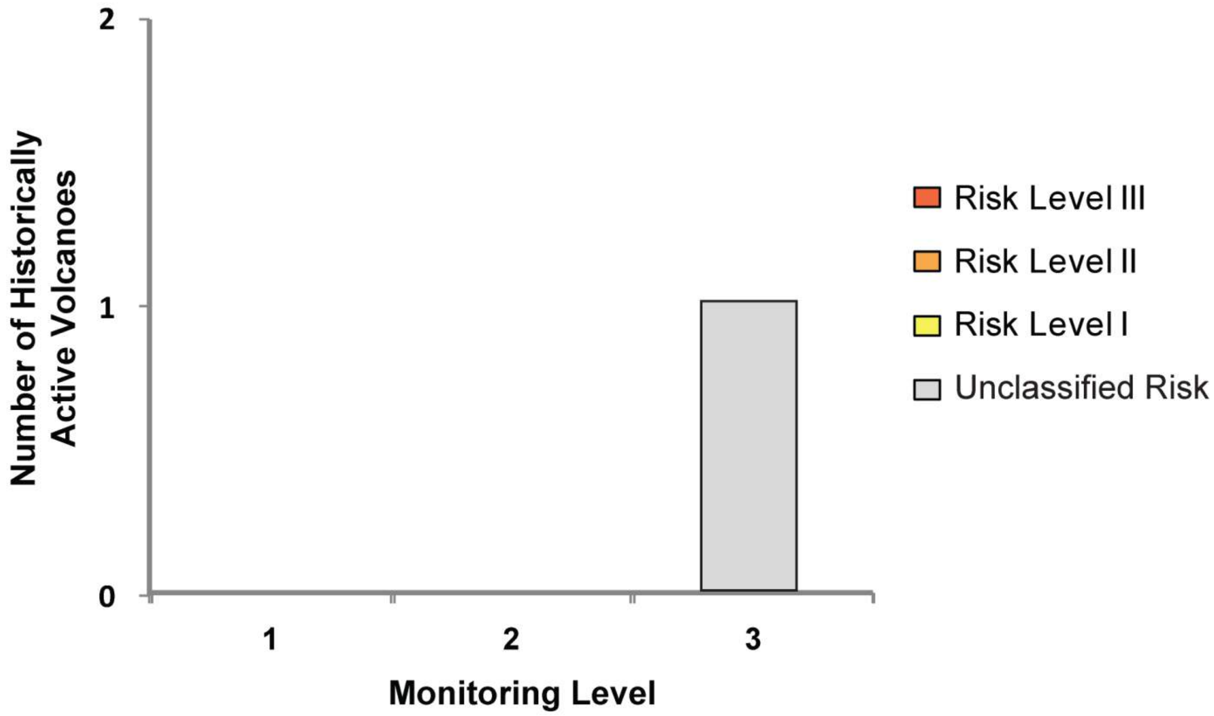

Figure 16.23 The monitoring and risk levels of the historically active volcanoes in St Lucia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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St. Vincent and the Grenadines

Description

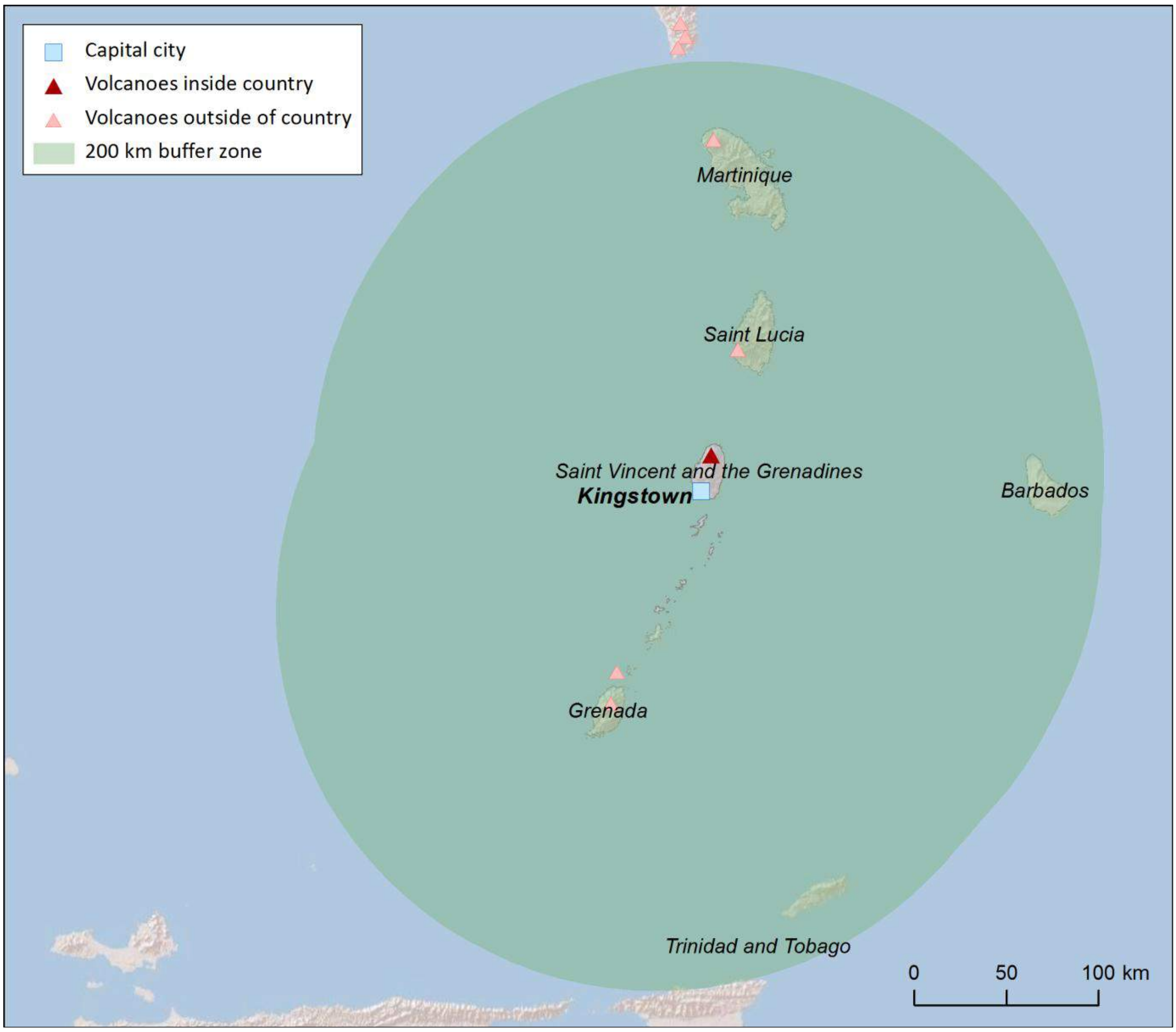

Figure 16.24 Location of St. Vincent and the Grenadines' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St. Vincent and the Grenadines.

One Holocene volcano, Soufrière St. Vincent, is located in the north of the main island of St. Vincent and the Grenadines. This andesitic stratovolcano has developed as a result of the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Twenty-one Holocene eruptions are confirmed at Soufrière St. Vincent, between 2380 BC and 1979 AD. These eruptions have varied in size from VEI 0 to 4, however all eruptions prior to the 1700s are of unknown magnitude. These eruptions however, all have records of producing explosive products including pyroclastic flows. Indeed 17 out of 21 eruptions recorded here have produced pyroclastic flows and much of the island is blanketed with deposits from these eruptions, indicating that explosive activity has been commonplace.

Two historical eruptions of VEI 4 are recorded here, including the VEI 4 eruption of 1902 which devastated much of the northern part of the island.

Being a relatively small island, the whole population is located close to the volcano, with about a quarter of the population living within 10 km alone. Four eruptions have resulted in fatalities with about 1,700 recorded, of which most occurred during the 1902 eruption.

Robertson (2005) described eruption scenarios at Soufrière St. Vincent and presents integrated hazard maps for effusive dome-forming and explosive eruptions, showing much of the north of the island as Very High Hazard, with decreasing hazard moving southwards. See Robertson (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Vincent and the Grenadines' volcanoes. Indeed, they monitor the Soufrière St. Vincent with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Robertson, R. (2005) St. Vincent, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?1,741
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4.7 eruption of Soufrière St. Vincent in 1812 AD.
Number of Holocene eruptions	21 confirmed eruptions. 1 uncertain eruption.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	1

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Number of historic eruptions	9

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)

Table 16.21 The number of volcanoes in St. Vincent and the Grenadines, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	110,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,482
Gross National Income (GNI) per capita (2005 PPP $)	9,367
Human Development Index (HDI) (2012)	0.733 (High)

Population Exposure

Capital city	Kingstown
Distance from capital city to nearest Holocene volcano	19.7 km
Total population (2011)	103,869
Number (percentage) of people living within 10 km of a Holocene volcano	24,415 (23.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	100,414 (96.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	108,973 (>100%)

Largest cities, as measured by population and their population size:

Kingstown	24,518

Infrastructure Exposure

Number of airports within 100 km of a volcano	8
Number of ports within 100 km of a volcano	1

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Total length of roads within 100 km of a volcano (km) 0

Total length of railroads within 100 km of a volcano (km) 0

Soufrière St. Vincent lies in the north of the main island of St. Vincent and the Grenadines. Being only a small island, the whole of St. Vincent lies within a short distance of this volcano, and the 100 km radius of this volcano extends to nearly fully encompass the islands of the Grenadines. This radius also extends to fully encompass and expose St. Lucia, and indeed, the 100 km radius of the Qualibou volcano on St. Lucia extends to encompass the whole of St. Vincent. All infrastructure is exposed here.

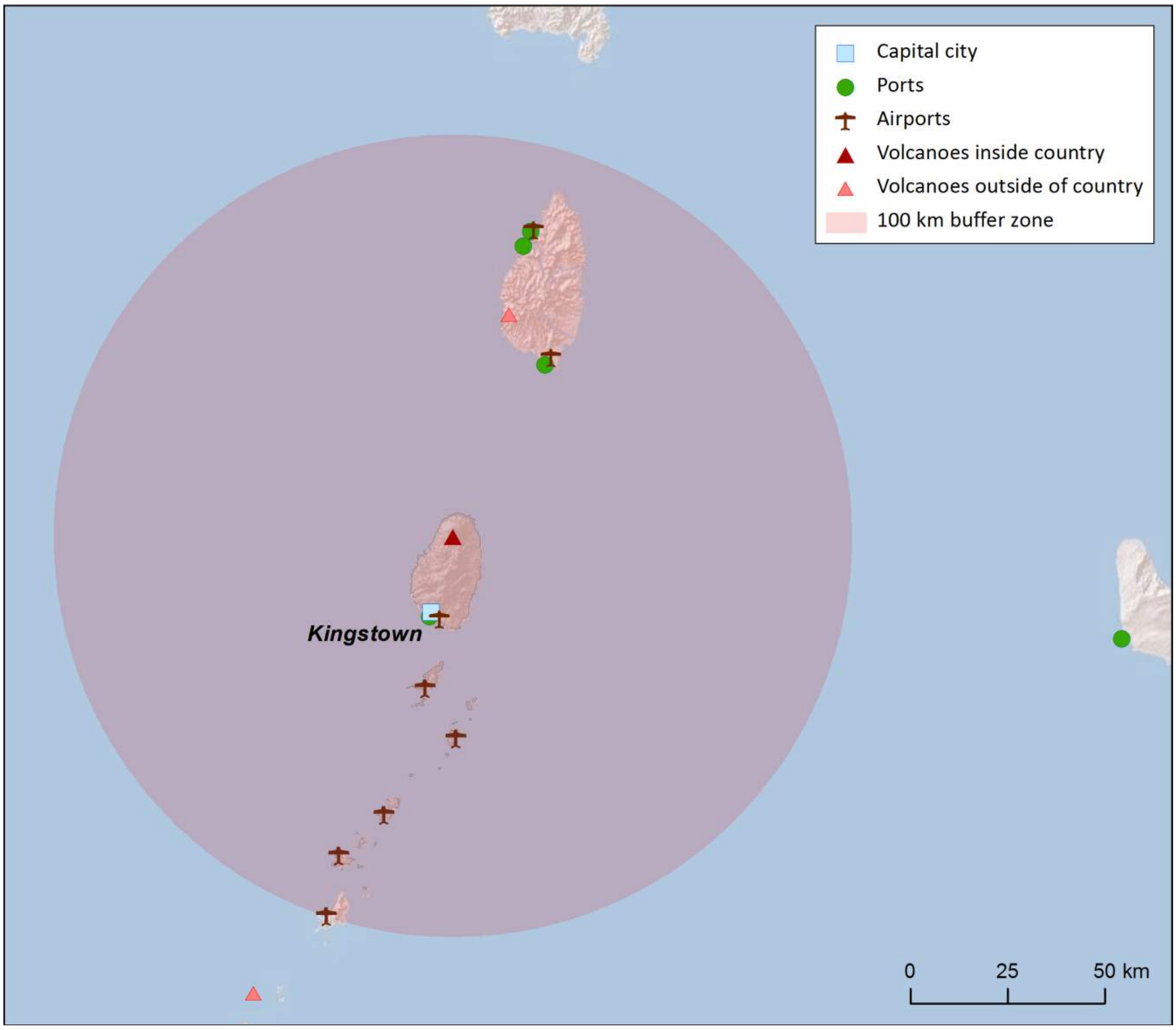

Figure 16.25 The location of St. Vincent and the Grenadines' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of 21 confirmed eruptions including seven with a known size, Soufrière St. Vincent has sufficient data available to determine the hazard level through the calculation of the

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VHI. With a record of VEI 4 eruptions and explosive events producing pyroclastic flows, this volcano is classified at Hazard Level III.

With a Hazard Level of III and a moderate PEI of 4, Soufrière St. Vincent is classed at Risk Level III.

CLASSIFIED	Hazard III				Soufrière St. Vincent			
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR							
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 16.22 Identity of the volcano of St. Vincent and the Grenadines and its Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière St. Vincent	4	III

Table 16.23 Classified volcanoes of St. Vincent and the Grenadines ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

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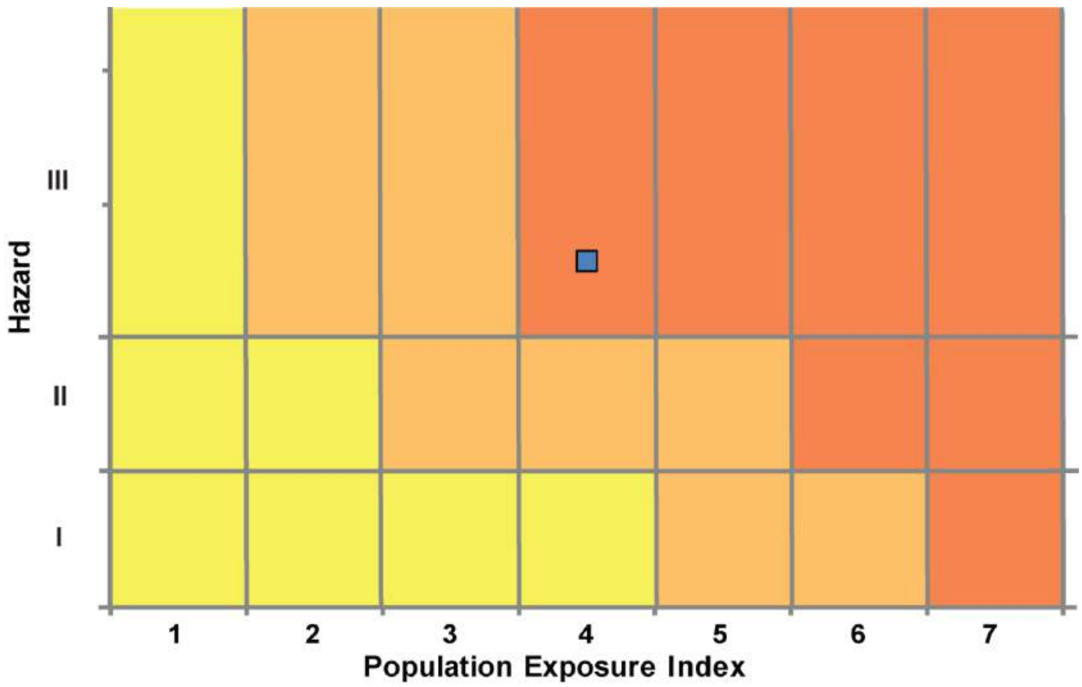

Figure 16.26 Distribution of St. Vincent and the Grenadines' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active Soufrière St. Vincent volcano through a seismic network and multiple deformation stations.

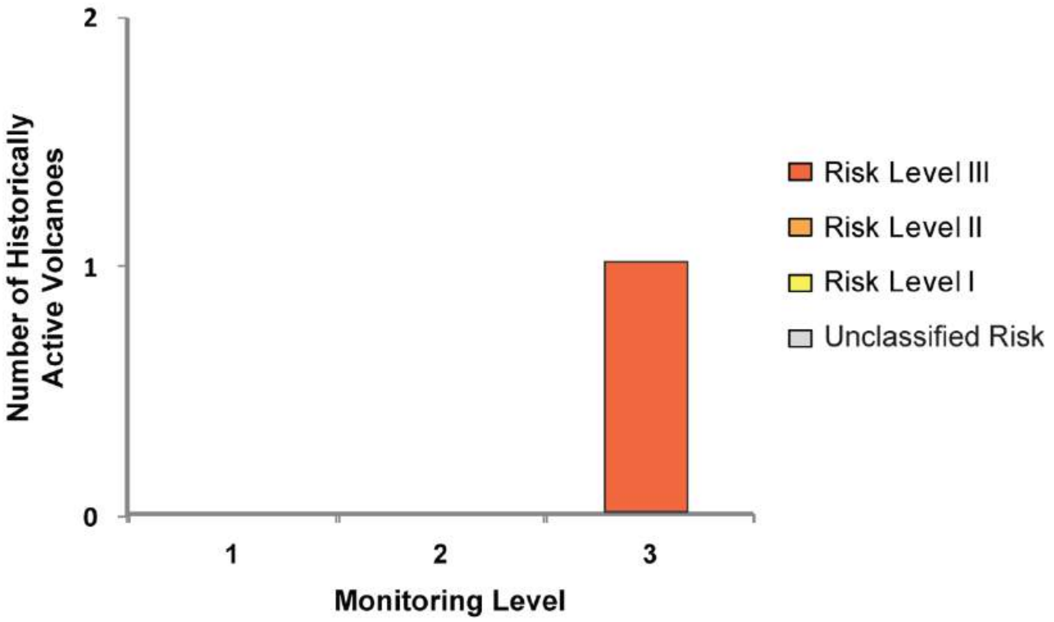

Figure 16.27 The monitoring and risk levels of the historically active volcanoes in St. Viincent and the Grenadines. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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UK – Montserrat

Description

Montserrat is a British Overseas Territory. There is one Holocene volcano on Montserrat, Soufrière Hills volcano, located in the southern half of the island. It is an andesitic stratovolcano related to the subduction of the Atlantic Ocean crust beneath the Caribbean Sea.

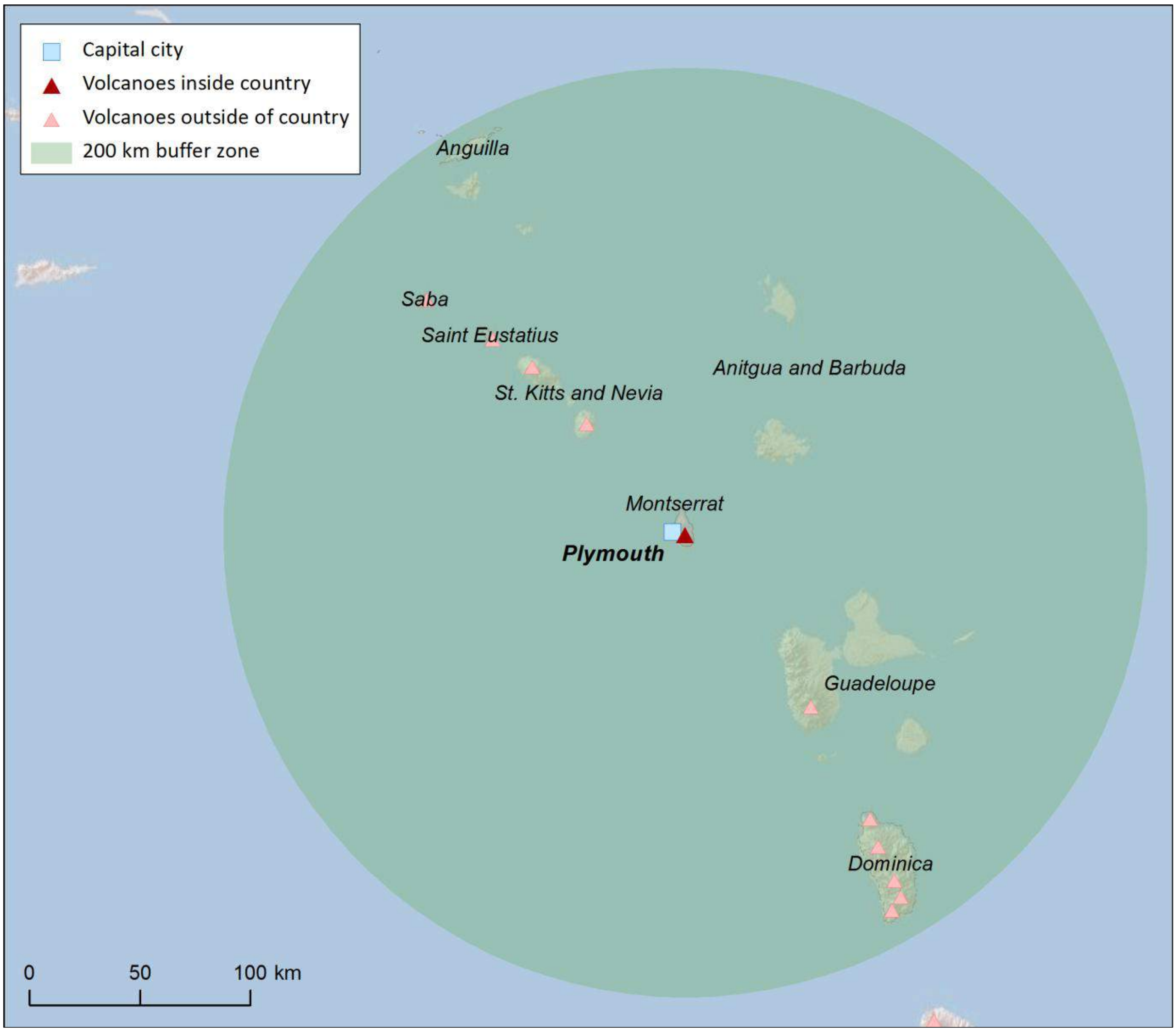

Figure 16.28 Location of Montserrat's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Montserrat.

Soufrière Hills volcano is currently active. Historic activity in the 17th Century produced the Castle Peak lava dome and seismic activity has occurred in swarms at 30 year intervals in the 20th Century. No other eruptions are recorded until the ongoing eruptions which started in August 1995. Eruptive activity is typified by lava dome growth followed by collapse resulting in pyroclastic density currents, lahars and ash plumes. Three VEI 3 eruptions were recorded in 1995, 2004 and 2005.

Parts of the southern half of the island were evacuated in 1995. In June 1997, 19 people were killed by pyroclastic density currents resulting from partial dome collapse. As a direct result of this, the

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entire southern half of the island was made an exclusion zone. Since then, several different exclusion zones have been imposed on Montserrat. At present, southern Montserrat is divided into several distinct zones and access to these is controlled depending on the level of volcanic activity.

By 1998, approximately 70% of the population had left the island (Kokelaar, 2002). The capital city of Plymouth has been destroyed by multiple ash fall and pyroclastic density current deposits. Montserrat is a small island with the whole population (c.5000) living within 12 km of the volcano.

Montserrat has a dedicated volcano observatory: Montserrat Volcano Observatory (MVO) run by the University of the West Indies Seismic Research Centre (SRC). MVO provides regular updates on alert levels and short-term hazard assessments. An international panel of scientists and practitioners, the Scientific Advisory Committee on Montserrat Volcanic Activity (SAC) provides hazard and risk assessments [Chapter 21].

See also:

Montserrat Volcano Observatory – www.mvo.ms

Kokelaar, B. P. (2002). Setting, chronology and consequences of the eruption of Soufrière Hills Volcano, Montserrat (1995-1999). *Geological Society, London, Memoirs*, *21*(1), 1-43.

Wadge, G., Robertson, R.E.A., and Voight, B. (eds) (2014). The Eruption of Soufriere Hills Volcano, Montserrat from 2000 to 2010. Geological Society Memoir No.39.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	19
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three VEI 3 eruptions are recorded at Soufrière Hills in 1995, 2004 and 2005.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	3 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	4

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)

Table 16.24 The number of volcanoes in Montserrat, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2011)	5,140
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city (Montserrat)	Plymouth (abandoned)
Distance from capital city to nearest Holocene volcano	5.4 km
Total population (2011)	5,140
Number (percentage) of people living within 10 km of a Holocene volcano	4,900 (~95 %)
Number (percentage) of people living within 30 km of a Holocene volcano	5,140 (100%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,140 (100%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	3 (1 on Montserrat)
Number of ports within 100 km of a volcano	7 (1 on Montserrat)
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	0

The Soufriere Hills volcano is situated to the south of central Montserrat. Being a small island, all infrastructure and population here lies within 20 km of the volcano. Indeed the 100 km radius of

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Soufriere Hills extends to encompass much of Guadeloupe, St. Kitts and Nevis and Antigua and Barbuda, exposing much of the infrastructure here. The 100 km radii of the volcanoes of Guadeloupe and St. Kitts and Nevis likewise extend to encompass the island of Montserrat.

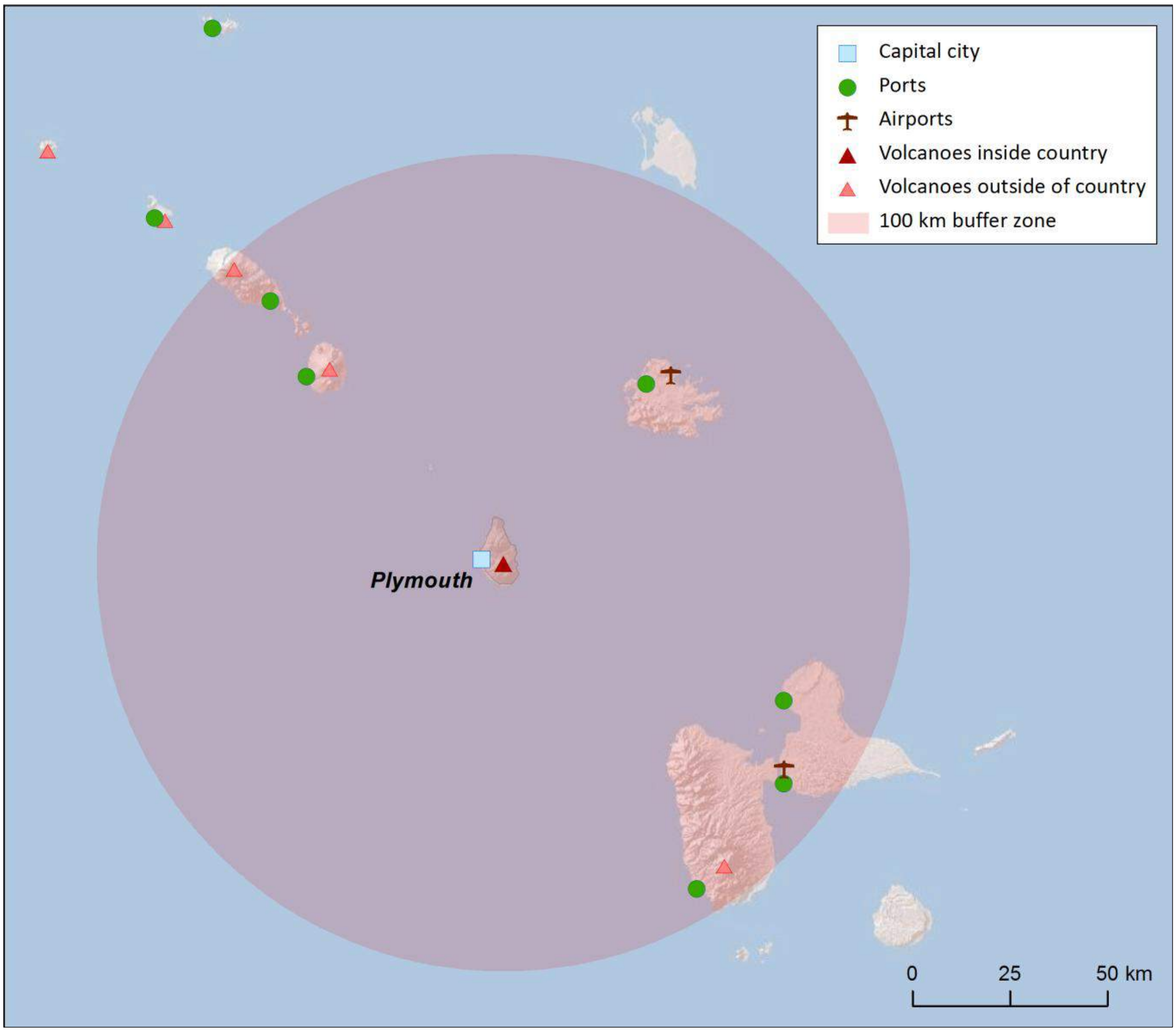

Figure 16.29 The location of Montserrat's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of five eruptions, three of which with a known size, the hazard level at Soufrière Hills volcano in Montserrat can be classified through the calculation of the VHI only when considering the recent long-duration activity as separate events. This is therefore classified at Hazard Level III with a history of VEI 3 eruptions accompanied by pyroclastic flows.

With the high Hazard Level and a moderate PEI of 4, Soufrière Hills Volcano is classed at Risk Level III.

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CLASSIFIED	Hazard III				Soufrière Hills			
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR							
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 16.25 Identity of Montserrat's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière Hills	4	III

Table 16.26 Classified volcanoes of Montserrat ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

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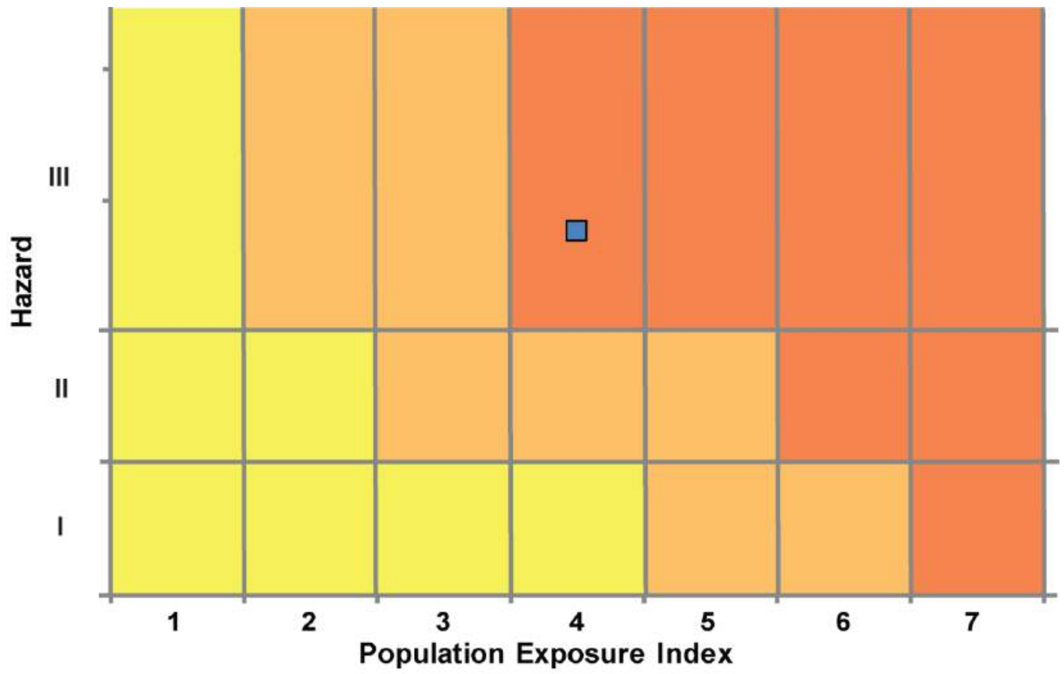

Figure 16.30 Distribution of Montserrat's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The historically active Risk Level III Soufrière Hills Volcano is monitored by the Montserrat Volcano Observatory. Dedicated seismic, deformation and gas monitoring networks are in place.

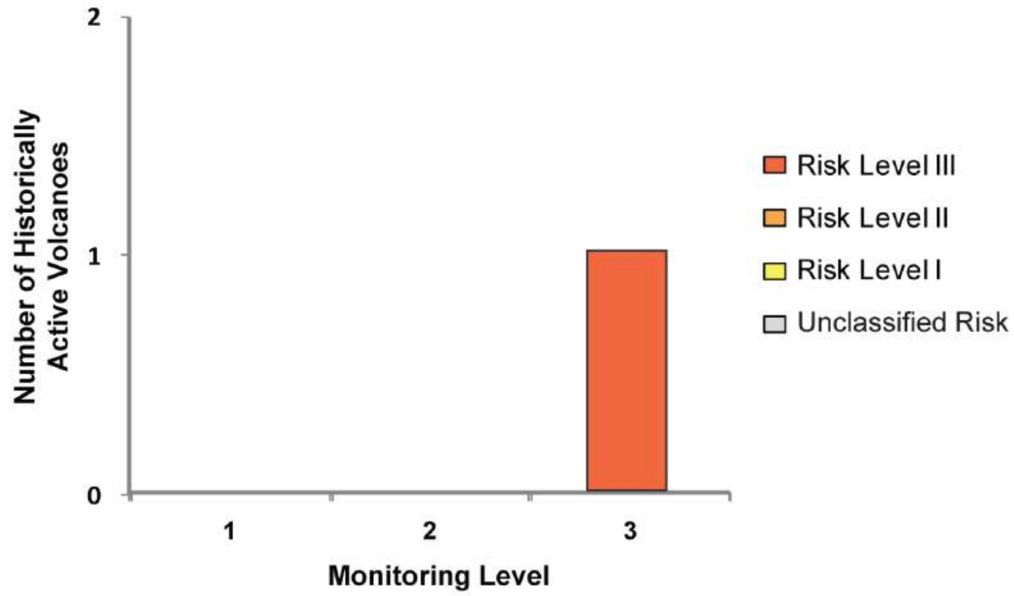

Figure 16.31 The monitoring and risk levels of the historically active volcanoes in Montserrat. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 17: Iceland and Arctic Ocean

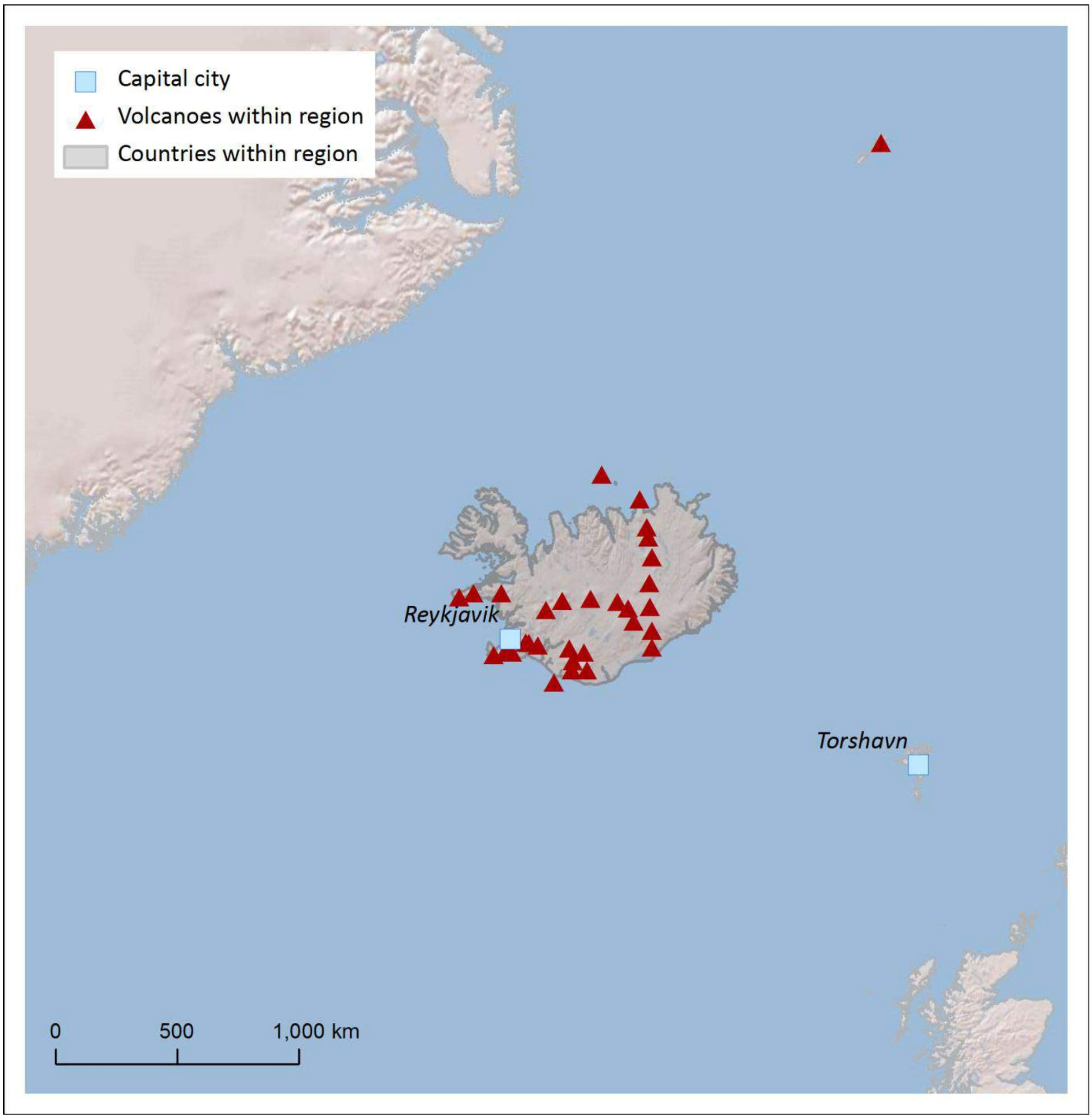

Figure 17.1 The distribution of Holocene volcanoes through the Iceland and Arctic region. The capital cities of the constituent countries are shown.

Description

Region 17: Iceland and Arctic Ocean comprises volcanoes in Iceland and Jan Mayen volcano in the northern Arctic, a volcano in Norwegian territories. Here we discuss all volcanoes of Region 17. The country profile for Norway includes Jan Mayen and two further Norwegian volcanoes in the southern Atlantic (Region 18).

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Country	Number of volcanoes
Iceland	30
Norway	1 + 2 from Region 18

Table 17.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Thirty-three Holocene volcanoes are located in Iceland and the Arctic Ocean, comprising 30 volcanoes in Iceland. These volcanoes are the result of intra-plate hotspot activity with a mid-ocean ridge.

A range of volcano types are present here, though most are stratovolcanoes. The composition of all but four volcanoes is dominantly basaltic. A range of activity styles and eruption magnitudes are recorded through the Holocene, with a range of eruptions from VEI 0 to 6, with about 10% of all eruptions being VEI ≥4.

Fourteen volcanoes have historical records of 146 eruptions, about 81% of which were recorded through direct observations. Just 4% of historical events have involved the production of pyroclastic flows and lahars, with lava flows recorded in 32% of historical eruptions.

VOTW4.22 records loss of life in 5% of eruptions. The population of this region is small, and as such most are considered relatively low risk. However, the hazard is unclassified at about half the volcanoes in this region.

Monitoring is undertaken at all historically active volcanoes in Iceland and the Arctic, with comprehensive monitoring at many of Iceland's volcanoes. See the Iceland country profile for details.

Volcano facts

Number of Holocene volcanoes	33
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	6 (16 eruptions)
Number of volcanoes generating lahars	1 (9 eruptions)
Number of volcanoes generating lava flows	22 (220 eruptions)
Number of eruptions with fatalities	12
Number of fatalities attributed to eruptions	10,315
Largest recorded Pleistocene eruption	The largest recorded Quaternary explosive eruption in this region is the Saksunarvatn eruption of Grímsvötn, Iceland in 10,180 BP.

	This eruption measured M6.6.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region in LaMEVE is the 3050 BP H3 M5.8 eruption of Hekla.
Number of Holocene eruptions	503 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	14
Number of historical eruptions	146

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (2)
14	Large cone(s)	Andesitic (1), Basaltic (11), Rhyolitic (1), Unknown (1)
2	Shield(s)	Basaltic (2)
7	Small cone(s)	Basaltic (7)
4	Subglacial	Basaltic (4)
4	Submarine	Basaltic (3), Unknown (1)

Table 17.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	2
Large (> VEI 3)	30

Table 17.3 Average recurrence interval (years between eruptions) for small and large eruptions in Iceland and the Arctic.

The eruption record indicates that on average small- to moderate-sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 2 years, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded through the Iceland and Arctic region of VEI 0 to 6, representing a range of eruption styles from gentle effusive events, to large explosive eruptions. There is a wide spread of eruption sizes, with the most populous group being VEI 2, with nearly 20% of all Holocene eruptions classed as such. Just over 10% of eruptions here are explosive at VEI ≥4.

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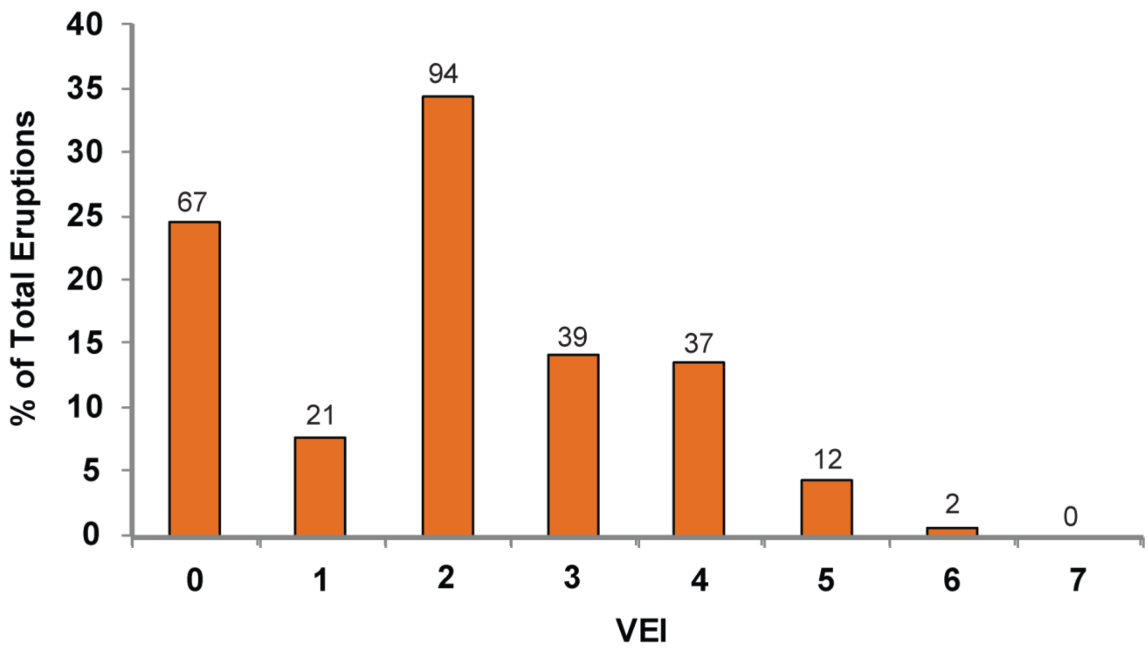

Figure 17.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 231 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	311,058
Gross Domestic Product (GDP) per capita (2005 PPP $)	33,618 (Iceland)
Gross National Income (GNI) per capita (2005 PPP $)	29,176 (Iceland)
Human Development Index (HDI) (2012)	0.906 (Very High, Iceland)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	7,255 (2.33 %)
Number (percentage) of people living within 30 km of a Holocene volcano	84,738 (27.24 %)
Number (percentage) of people living within 100 km of a Holocene volcano	286,832 (92.21 %)

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CLASSIFIED	**Hazard III**		Hekla					
	Hazard II	Jan Mayen	Katla; Grímsvötn; Bárdarbunga; Askja		Reykjanes			
	Hazard I		Snaefellsjökull; Ljósufjöll; Hveravellir; Kverkfjöll; Krafla	Hengill; Grímsnes		Krísuvík; Brennisteinsfjöll		
UNCLASSIFIED	**U – HHR**		**Vestmannaeyjar**; **Eyjafjallajökull**; Tjörnes Fracture Zone; Öraefajökull; Kolbeinsey Ridge					
	U- HR	Bouvet	Prestahnukur; Torfajökull; Fremrinamur; Theistareykjarbunga					
	U- NHHR	Thompson Island	Helgrindur; Hofsjökull; Tindfjallajökull; Tungnafellsjökull; **Esjufjöll**	**Hrómundartindur**				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 17.4 Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
2	5
1	4
3	3
24	2
3	1

Table 17.5 The number of volcanoes in Iceland and the Arctic Ocean classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
12	I
17	Unclassified

Table 17.6 The number of volcanoes in the Iceland and Arctic region classified at each Risk Level.

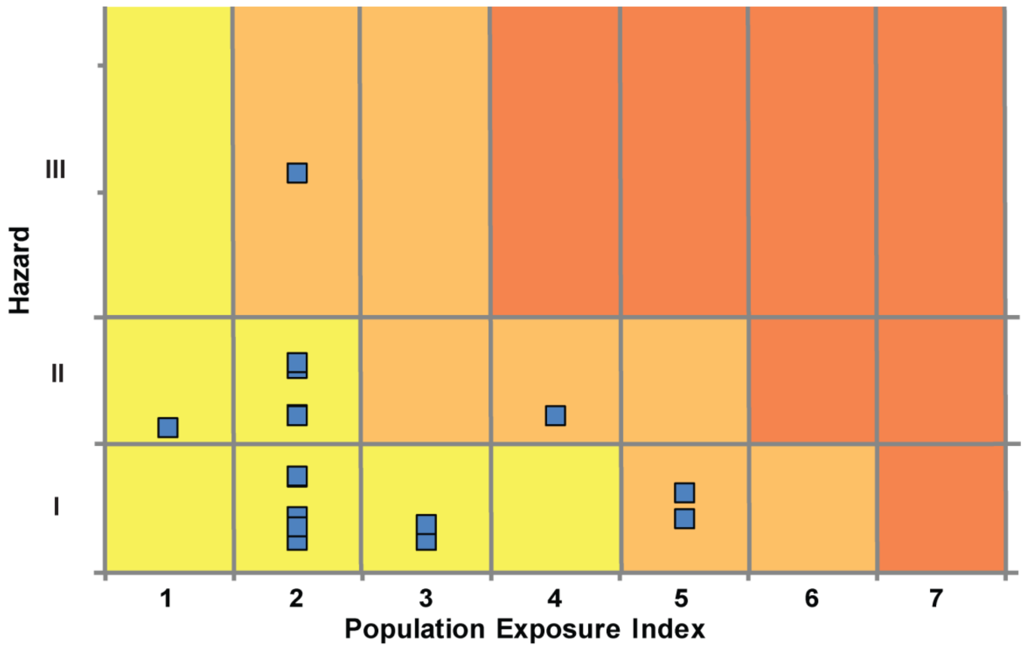

Figure 17.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional Monitoring Capacity

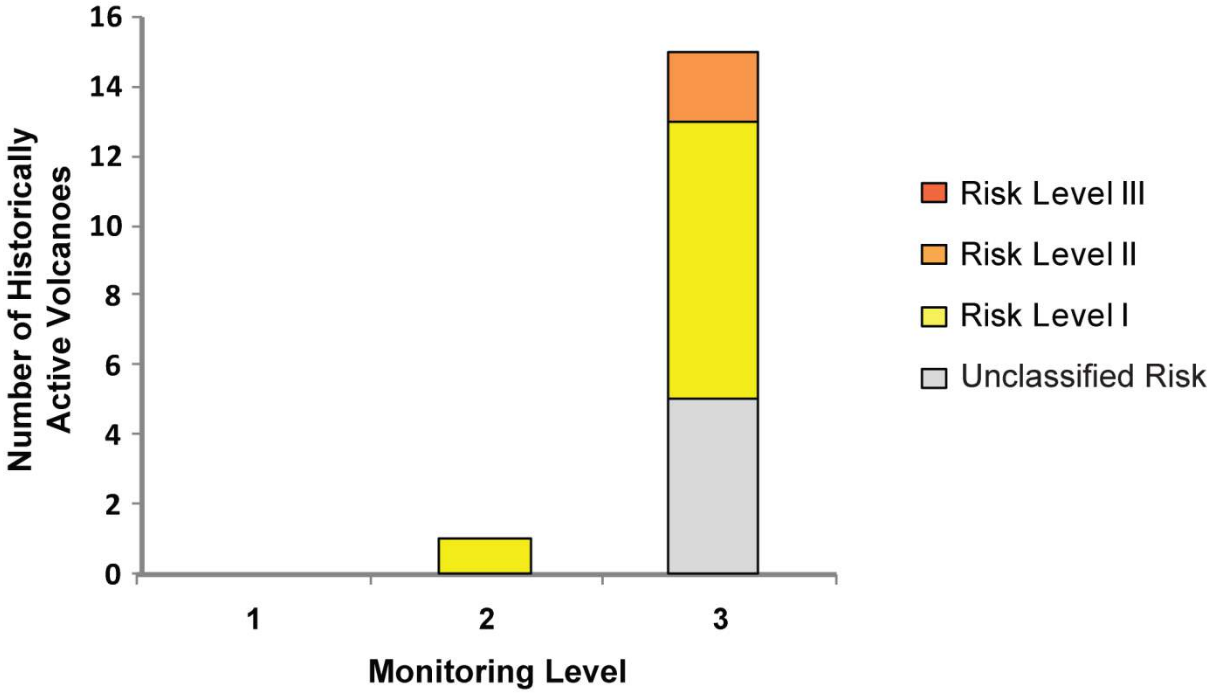

Figure 17.4 The monitoring and risk levels of the historically active volcanoes in Iceland. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Iceland

Description

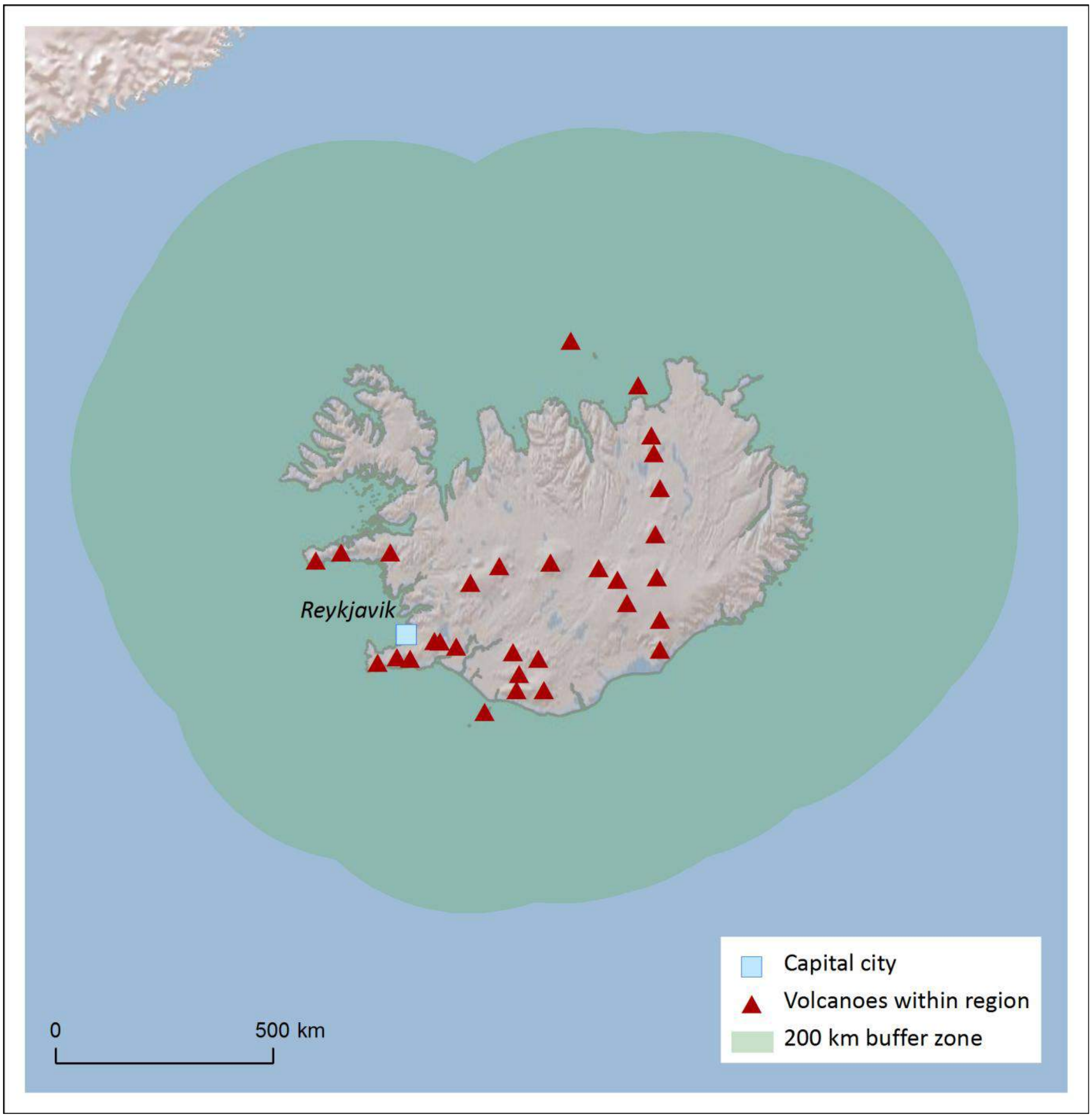

Figure 17.5 Location of Iceland's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Iceland.

Volcanism in Iceland is caused by divergence of two tectonic plates (European and North American), as well as a mantle-sourced 'hot-spot'. Active volcanic systems are located along the tectonic plate boundary, which cuts through Iceland roughly from south-west to north-east. The most frequently active volcanoes in recent decades have been Grimsvötn and Hekla.

In Iceland, volcanically active areas are subdivided into volcanic systems. This classification works well for Iceland due to its unique volcano-tectonic setting. One volcanic system may consist of one

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or more so-called central volcanoes, which may be linked through the sub-surface structure. The volcanic systems are 30-190 km long and 10-30 km wide. Some volcanic systems consist of a single central volcano (e.g. Öræfajökull), while others have a fissure swarm and no central volcano (e.g. Reykjanes). However, many volcanic systems have both (e.g. Hekla, Katla, Grimsvotn). Eruptions may take place in the central volcano and/or on the fissure swam. For example, the effusive Laki eruption in 1783-84 and the highly ash-rich 2011 Grimsvotn eruption were sourced from the same volcanic system but different parts.

Iceland has 28 Holocene volcanic systems listed in the GVP database. Several updates and new data on volcanic systems have been included in the Catalogue of Icelandic Volcanoes (CIV), which will be published by the Icelandic volcano observatory (IMO), University of Iceland, and Icelandic Civil Protection in the beginning of 2015. The CIV includes two additional Holocene volcanic systems, as well as one non-Holocene system that is nevertheless considered important for Icelandic volcanism.

Volcanic activity is highly varied and includes nearly all known types of eruption style, duration, products and composition. Eruptions are frequent with approximately three events per decade. It has been suggested that frequency of activity goes through cycles, and that we may be entering a more active interval. The majority of eruptions have been explosive due to the presence of glaciers on many volcanoes. Most of the frequently occurring eruptions are small (<0.1 km^3 DRE), while the largest flood-basalt eruptions (>10 km^3 DRE) have an approximately 500-1000 year repose interval. The largest explosive eruptions have reached VEI 6 (return period 1-2 per millennium), with the most recent one in 1362 CE.

The most frequent volcanic hazards include jökulhlaups (floods following an eruption under a glacier), tephra fall, and pollution of air and grazing pastures by ash, gases and aerosols. Damage due to lava flows is only likely if an eruption were to occur very close to inhabited areas, such as happened in the 1973 eruption in Vestmannaeyjar. Pyroclastic density currents and tsunamis are known to have occurred, but are relatively minor except in infrequent, large eruptions.

The most hazardous eruptions expected in Iceland are of two different types: (1) large effusive eruption, such as the Laki eruption 1783-84 AD, that lasts weeks or months. It would cause severe pollution by gas and aerosol in Iceland, and impact air quality in the Northern hemisphere; (2) VEI 6 explosive eruption close to inhabited areas, such as the 1362 eruption of Öræfajökull, producing pyroclastic density currents and heavy tephra fall. Additionally, smaller ash-rich eruptions (VEI 3-4) which last weeks to months can significantly damage agriculture in Iceland and cause prolonged air space closures (e.g. Eyjafjallajökull in 2010). In addition, even moderately sized eruptions may be extremely hazardous if they melt through a thick glacier and cause large jökulhlaups.

Loss of life directly caused by volcanic eruptions has fortunately been very modest (<15 people since 1500 CE). However, eruptions have caused a number of fatalities through indirect impact. The 1783-84 Laki eruption caused severe famine due to pollution of graze land and loss of livestock, and over 8,500 people are estimated to have died as a consequence. It is possible that this eruption also caused increased mortality in Europe due to air pollution, but exact scale of impact is not known. In modern times, risk to life remains low. This is a combination of a developed economy, advanced volcano monitoring systems, well-defined civil protection procedures and frequently low proximal populations, with most Icelandic volcanoes categorised at a low PEI of 2. Damage to infrastructure and economy (in particular roads and bridges) is however, considerable.

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Volcano Facts

Number of Holocene volcanoes	30
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	6
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	21
Number of fatalities caused by volcanic eruptions	?>10,315
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M6.6 Saksunarvatn eruption of Grímsvötn at 10,180 BP.
Largest recorded Holocene eruption	The M5.8 H3 eruption of Hekla at 3,050 BP.
Number of Holocene eruptions	496 confirmed eruptions. 27 uncertain and 7 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	13
Number of historic eruptions	140

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Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (2)
13	Large cone(s)	Andesitic (1), Basaltic (10), Rhyolitic (1), Unknown (1)
1	Shield(s)	Basaltic (1)
7	Small cone(s)	Basaltic (7)
4	Subglacial	Basaltic (4)
3	Submarine	Basaltic (3)

Table 17.7 The number of volcanoes in Iceland, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	326,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	33,618
Gross National Income (GNI) per capita (2005 PPP $)	29,176
Human Development Index (HDI) (2012)	0.906 (Very High)

Population Exposure

Capital city	Reykjavik
Distance from capital city to nearest Holocene volcano	24.9 km
Total population (2011)	311,058
Number (percentage) of people living within 10 km of a Holocene volcano	7,254 (2.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	84,737 (27.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	286,831 (92.2%)

Largest cities, as measured by population and their population size:

Reykjavik	113,906

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Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	17
Total length of roads within 100 km of a volcano (km)	8,930
Total length of railroads within 100 km of a volcano (km)	0

The Holocene volcanoes are widespread through Iceland and as such, almost the entirety of the country is located within the 100 km radii of these volcanoes. Just small areas to the east and north-west lie beyond 100 km. This places much of the critical infrastructure and main cities, including the capital Reykjavik, within the 100 km exposure radii. Numerous ports, airports and an extensive road network are affected.

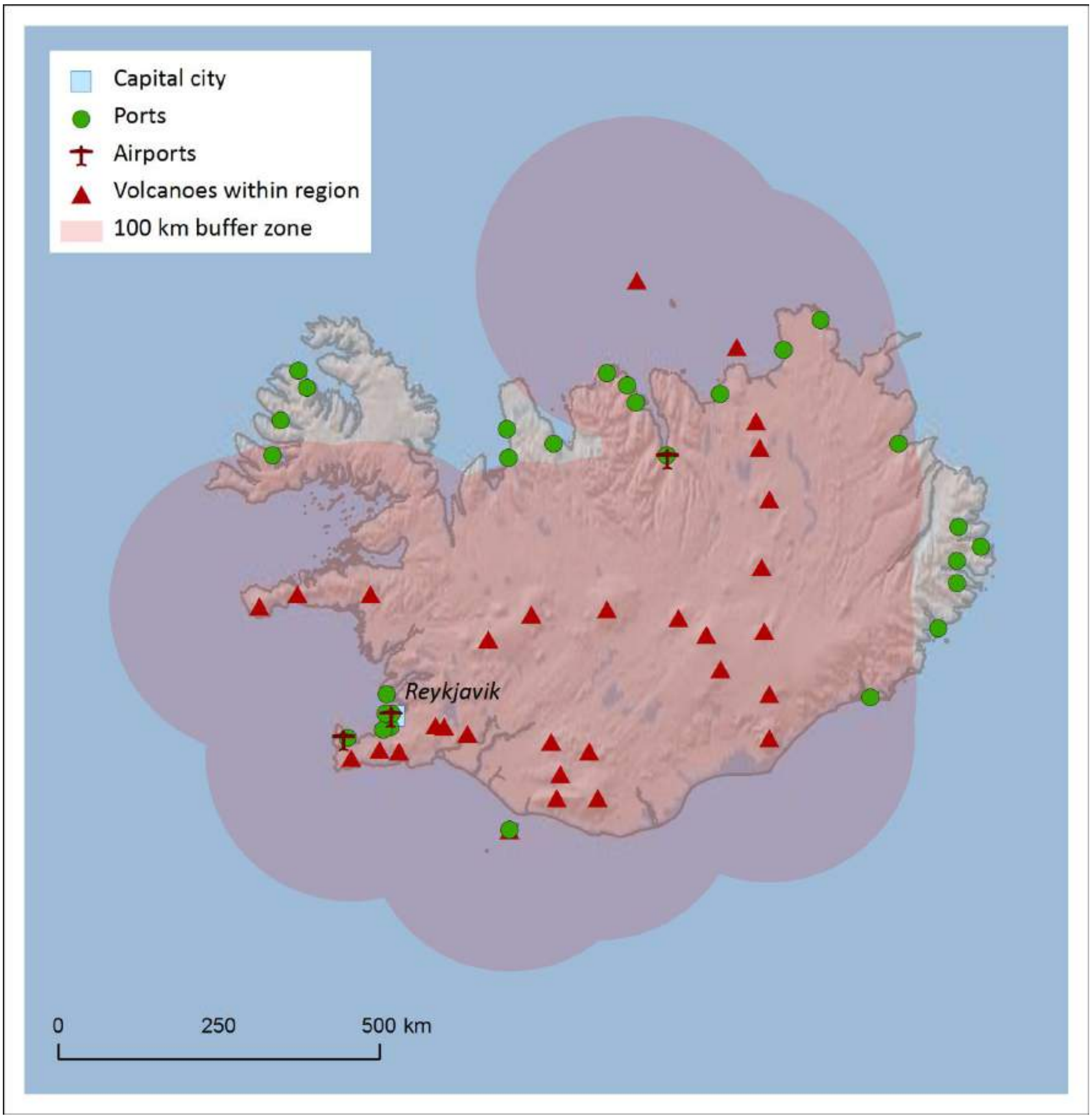

Figure 17.6 The location of Iceland's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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Hazard, Uncertainty and Exposure Assessments

The volcanoes of Iceland have varying levels of data available in the eruption record. 50% (15) of the volcanoes have appropriate eruptive histories to define the hazard. Eight of these have erupted since 1900. These volcanoes are classified across Hazard Levels I and II, with most at Level I.

Of the unclassified volcanoes, six have no confirmed Holocene age eruptions. The remaining volcanoes have a Holocene record, including five with historical activity.

In Iceland the PEI ranges from low to high, at PEI 2 to 5. With most volcanoes classed at PEI 2, the majority of Icelandic classified volcanoes are classed at Risk Level I, with just four being Risk Level II.

CLASSIFIED	**Hazard III**		Hekla					
	Hazard II		Katla; Grímsvötn; Bárdarbunga; Askja		Reykjanes			
	Hazard I		Snaefellsjökull; Ljósufjöll; Hveravellir; Kverkfjöll; Krafla	Hengill; Grímsnes		Krísuvík; Brennisteinsfjöll		
UNCLASSIFIED	**U – HHR**		**Vestmannaeyjar**; **Eyjafjallajökull**; Tjörnes Fracture Zone; Öraefajökull; Kolbeinsey Ridge					
	U- HR		Prestahnukur; Torfajökull; Fremrinamur; Theistareykjarbunga					
	U- NHHR		Helgrindur; Hofsjökull; Tindfjallajökull; Tungnafellsjökull; **Esjufjöll**	**Hrómundartindur**				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 17.8 Identity of Iceland's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Krísuvík	5	II
Brennisteinsfjöll	5	II
Reykjanes	4	II
Hengill	3	I
Grímsnes	3	I
Hekla	2	II
Snaefellsjökull	2	I
Ljósufjöll	2	I
Hveravellir	2	I
Katla	2	I
Grímsvötn	2	I
Bárdarbunga	2	I
Kverkfjöll	2	I
Askja	2	I
Krafla	2	I

Table 17.9 Classified volcanoes of Iceland ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 11 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

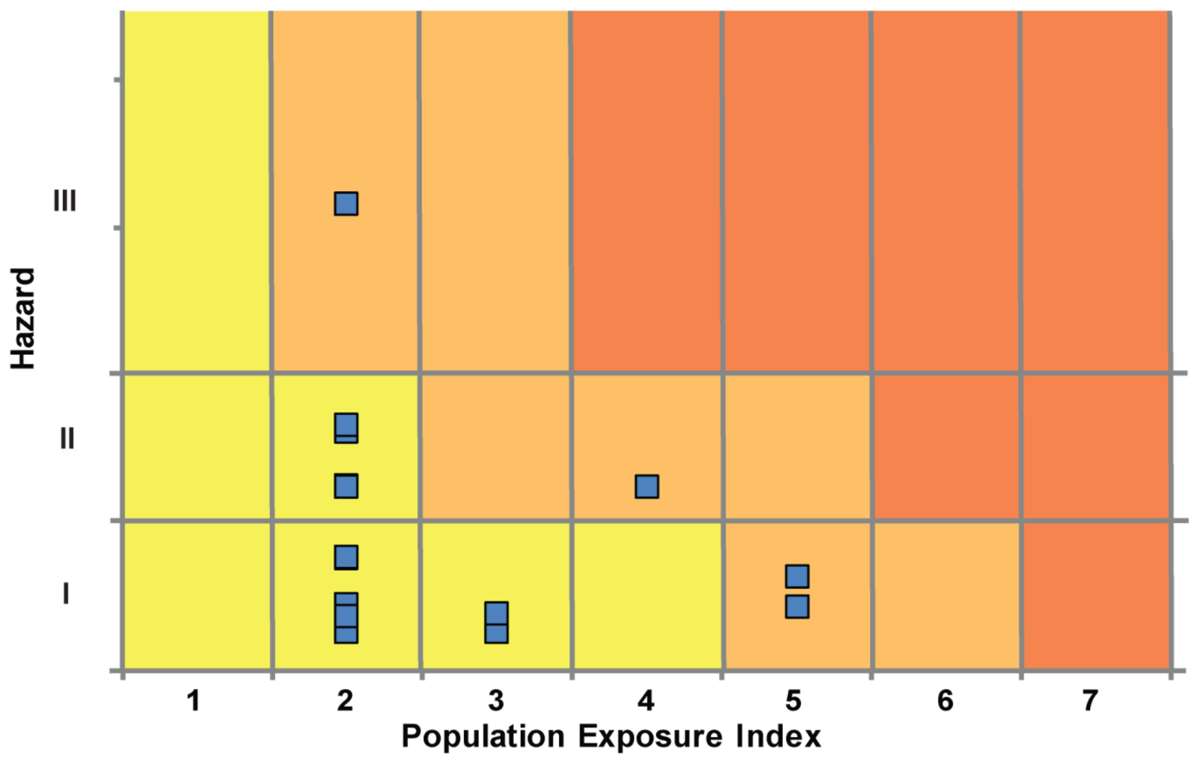

Figure 17.7 Distribution of Iceland's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Historical eruptions are recorded at 13 volcanoes in Iceland. All of these have dedicated ground-based monitoring systems in place, with monitoring conducted by the Iceland Meteorological Office

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(IMO). Multiple monitoring systems are used, including seismic analysis and deformation, categorising these volcanoes at Monitoring Level 3. Many of the Holocene volcanoes with activity prior to 1500 AD are also monitored by the IMO.

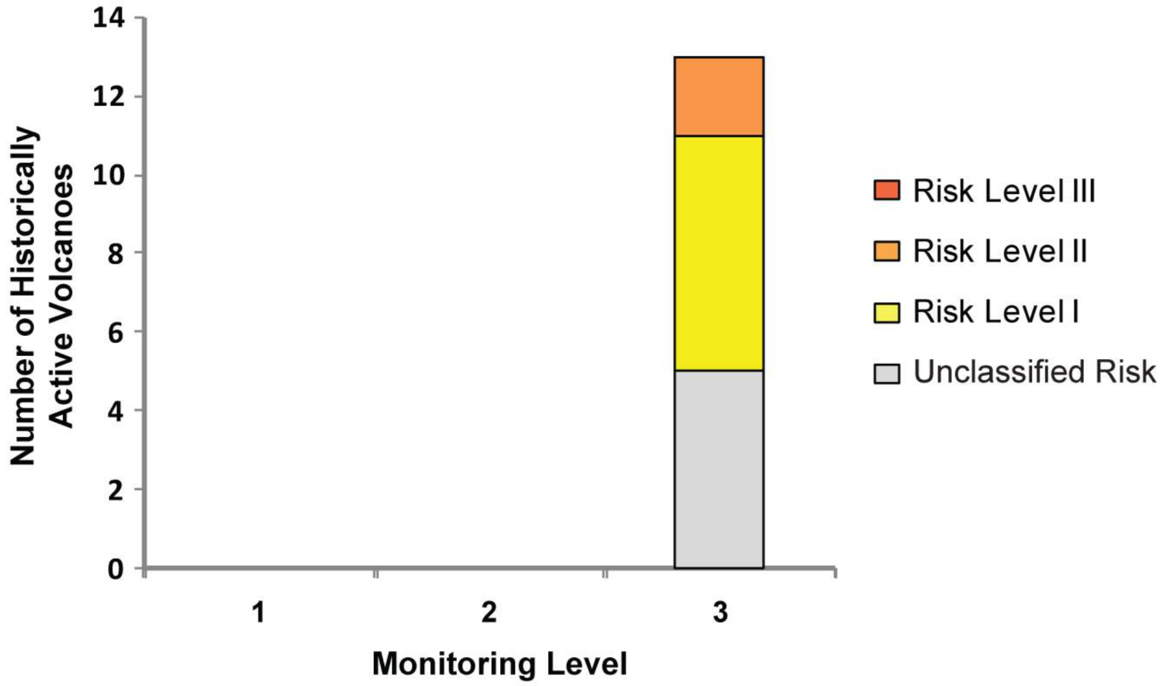

Figure 17.8 The monitoring and risk levels of the historically active volcanoes in Iceland. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Norway

Note that we include discussion of the remote Bouvet and Thompson Island volcanoes of the South Atlantic (Region 18) here.

Description

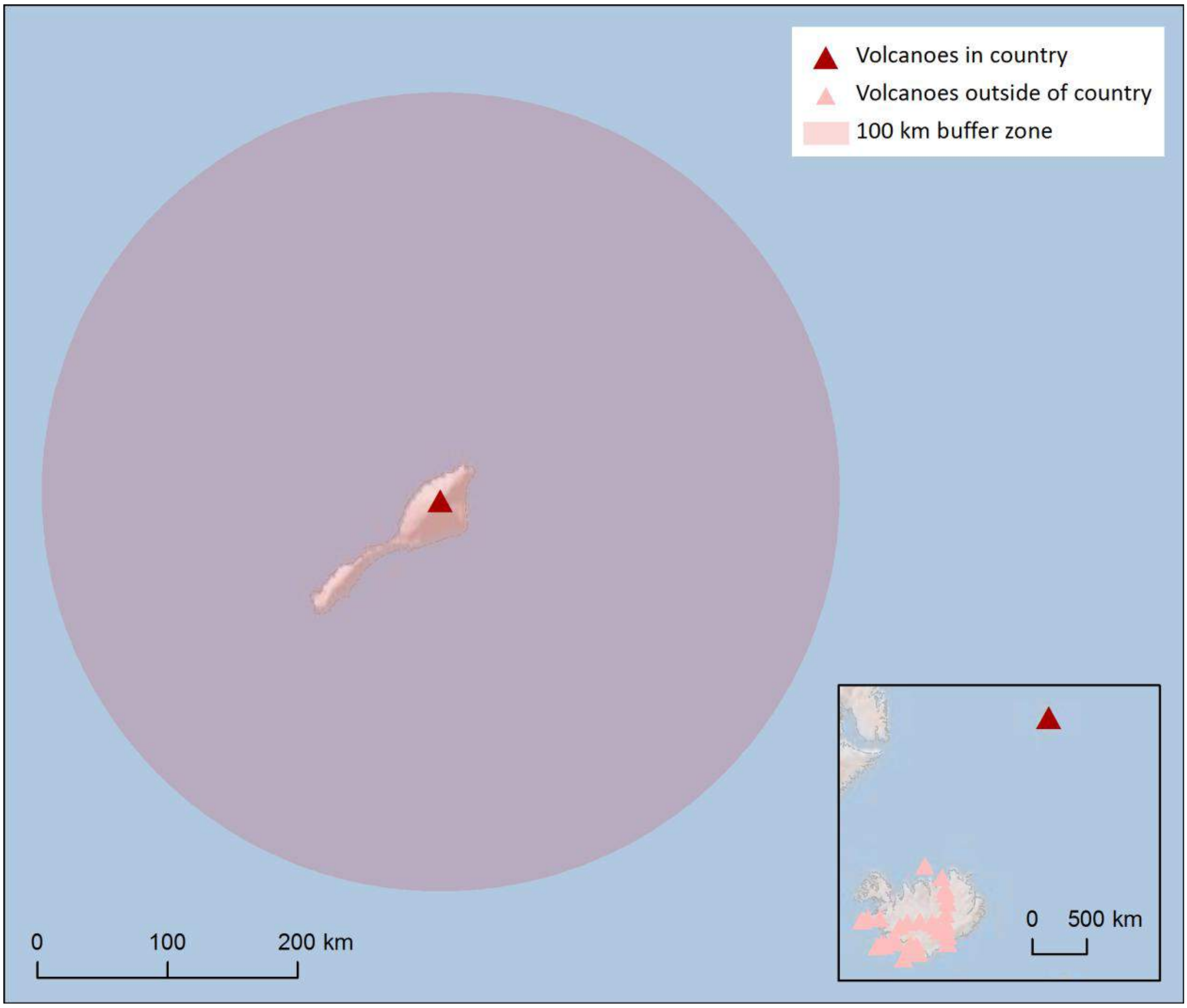

Figure 17.9 The location of Norway's volcano – Jan Mayen in the Iceland and Arctic Ocean region and the extent of the 100 km zone surrounding it.

There is no active volcanism on mainland Norway. An active volcano is found on a Norwegian island of Jan Mayen in the North Atlantic ocean. The small island (53 km long and 2-16 km wide) is situated approximately 550 km north of Iceland and 950 km west of Norway. The island has no residents other than temporary personnel working for the Norwegian Armed Forces or the Norwegian Meteorological Institute. Eighteen people spend the winter on the island, but the population may double (35) during the summer. Since 2010, the island has been closed to tourists.

The northern part of the island is dominated by a stratovolcano, Beerenberg, which is the northernmost active subaerial volcano on Earth. The upper part of Beerenberg is covered by an ice cap. The southern part of the island is a mountainous ridge made of scoria craters, scoria mounds, and lava domes.

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Volcanic activity is sourced in a fairly unusual tectonic setting near the intersection of the Jan Mayen Fracture Zone (a transform fault) and the Mohn's mid-ocean ridge. Six eruptions have occurred between 1732 and 1985. All of these eruptions were on flank vents and produced lava flows and scoria cones. The most recent eruptions were in 1970, 1973, and 1985.

The 1970 eruption began on September 18 and continued to January 1971. Intense storms hid the onset of the eruption. A commercial pilot spotted the eruption cloud on September 20. The personnel was evacuated, but returned shortly. The eruption was large, erupting at least 0.5 km^3 of basalt from a 6 km long fissure that ran from sea-level to an elevation of 1,000 m. There were at least five active craters.

The 1985 eruption began on January 6, 1985 and lasted only 35-40 hours. The volume of lava was two orders of magnitude smaller than in 1970-71. Earthquakes with magnitudes up to 5 occurred during the eruption. The eruption was thought to be from a leaky fracture zone not the Jan Mayen magma system proper. The vent was 35 km from the settlement. Personnel were not evacuated.

The Department of Earth Science, University of Bergen has operated seismic stations on Jan Mayen (as part of the National Seismic Network of Norway) since 1961. The three stations on Jan Mayen are used to make daily locations of the local seismicity as well as recording distal earthquakes. The 1985 eruption was the first one to be observed with the local seismic network. Volcanic tremors and low-frequency events were observed on 5 January at 2230 h and 10 hours later the first large earthquake occurred. No visual confirmation of the eruption was made until 6 January at 1630 h. The local network hence provides an efficient tool for monitoring and warning of volcanic activity. However, since there was no change in the local seismicity in the days or months before the 1985 eruption, it seems to be difficult to make long-term predictions of flank eruptions without introducing additional monitoring techniques.

Another volcanic area under Norwegian dependency is Bouvet Island in the South Atlantic Ocean. It is a small (49 km^2) and uninhabited sub-Antarctic island. It lies at the southern end of the Mid-Atlantic Ridge and is the most remote island in the world, approximately 2,200 kilometres south-southwest of the coast of South Africa. There have been no historical eruptions on the island, but the eruption history is not known. The existence of Thompson Island volcano about 70 km north-northeast of Bouvet was reported in 1893 but since this time there is no evidence of its existence.

References:

www.jan-mayen.no/

Havskov, J. and Atakan, K. (1991), Seismicity and volcanism of Jan Mayen Island. Terra Nova, 3: 517–526. doi: 10.1111/j.1365-3121.1991.tb00187.x

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-

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Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three eruptions of VEI 3 are recorded at Jan Mayen in 1732, 1818 and 1970.
Number of Holocene eruptions	8 confirmed eruptions. 2 uncertain and 1 discredited eruption.
Recorded Holocene VEI range	0 – 3 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	6

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
1	Shield(s)	Basaltic (1)
1	Submarine	Unknown (1)

Table 17.10 The number of volcanoes in Norway (Iceland and Arctic Ocean region and Atlantic Ocean region), their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2011)	4,691,849 (mainland Norway)
Gross Domestic Product (GDP) per capita (2005 PPP $)	47,626 (mainland Norway)
Gross National Income (GNI) per capita (2005 PPP $)	47,950 (mainland Norway)
Human Development Index (HDI) (2012)	0.955 (mainland Norway)

Population Exposure

Capital city	Oslo

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Distance from capital city to nearest Holocene volcano	1110.7 km
Number (percentage) of people living within 10 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	1 (<1%)

Infrastructure Exposure

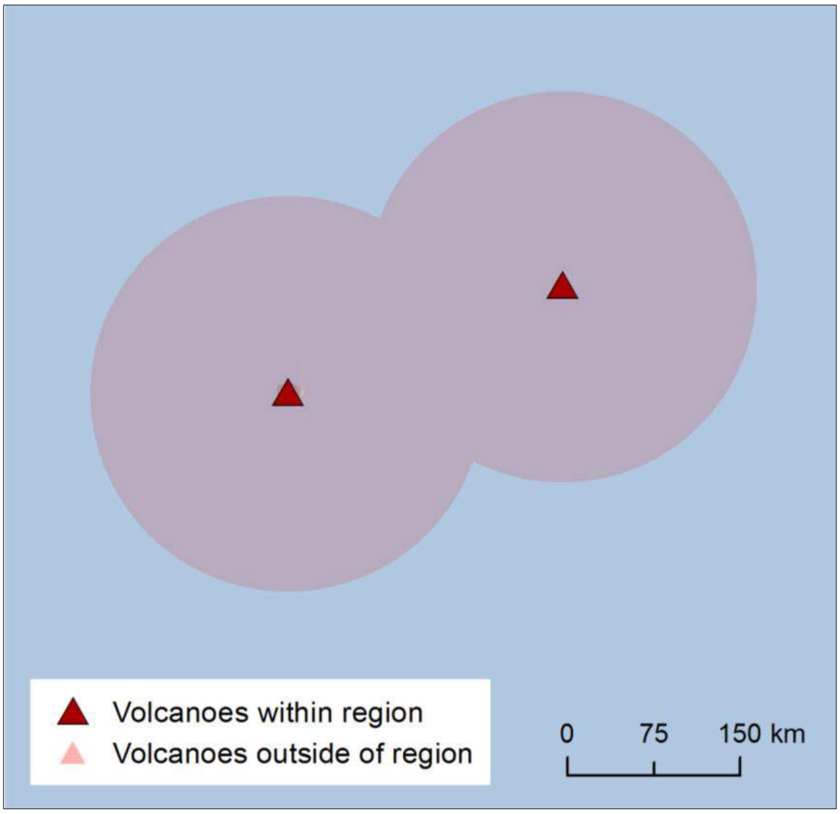

Figure 17.10 The Bouvet and Thompson Island volcanoes in the southern Atlantic Ocean, and the extent of the 100 km zone surrounding them.

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

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Hazard, Uncertainty and Exposure Assessments

Of the three Norwegian volcanoes, just Jan Mayen has a sufficient eruption record to determine hazard through calculation of the VHI. This volcano is classified as Hazard Level II. With just one recorded Holocene eruption, Bouvet is unclassified, as is Thompson Island which has no confirmed Holcoene activity.

With no population living within 100 km of the Norwegian volcanoes the PEI is classified at PEI 1. This makes these volcanoes Risk Level I, with no potential to increase in Risk level despite the uncertainty in the Hazard.

CLASSIFIED	**Hazard III**							
	Hazard II	Jan Mayen						
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR	Bouvet						
	U- NHHR	Thompson Island						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 17.11 Identity of Norway's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Jan Mayen	1	I

Table 17.12 Classified volcanoes of Norway ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

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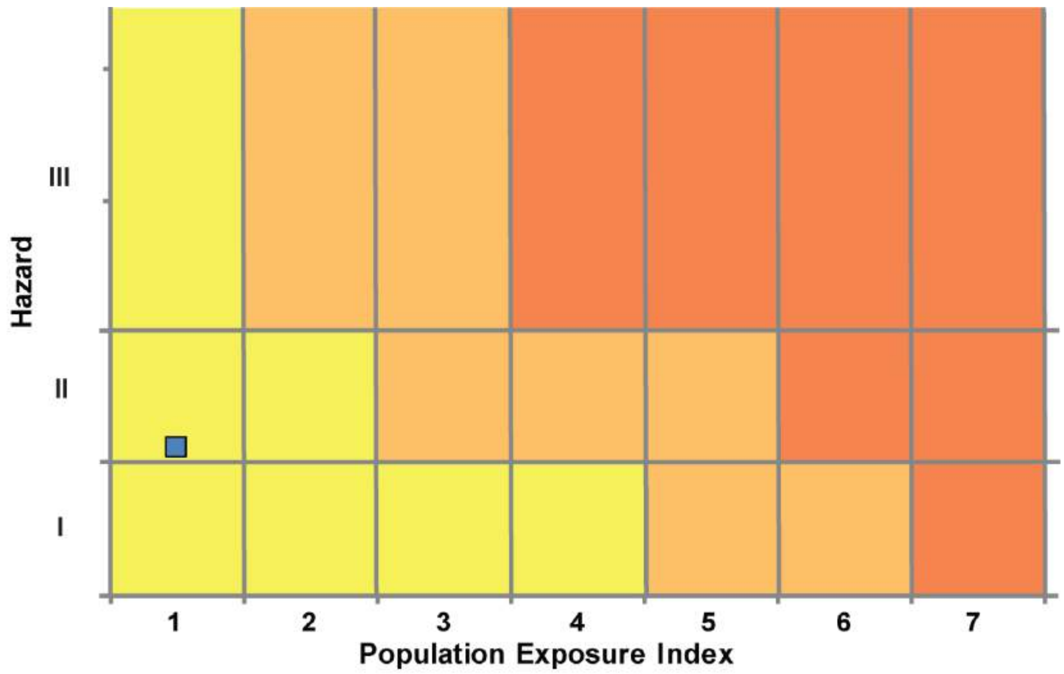

Figure 17.11 Distribution of Norway's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The University of Bergen operates a network of three seismometers on the island of Jan Mayen.

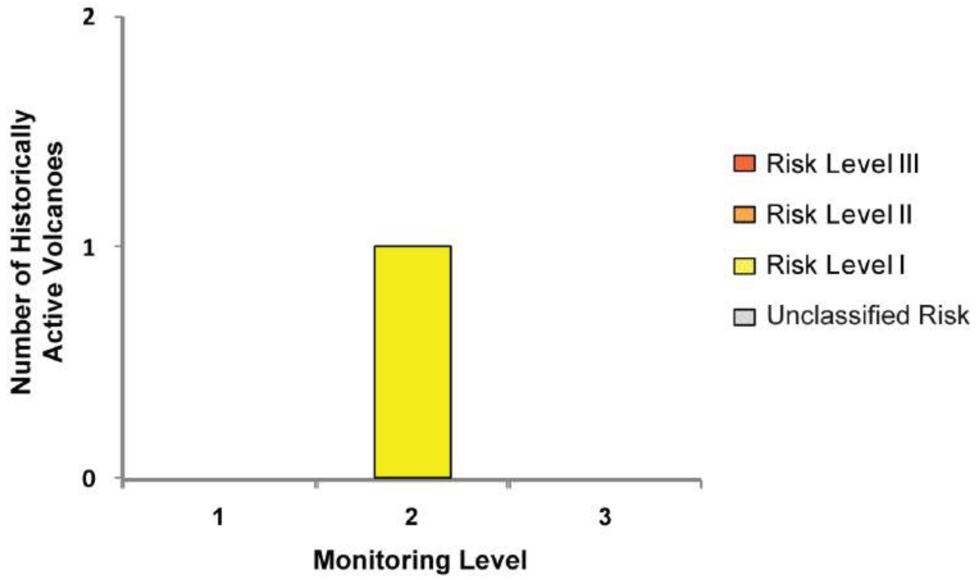

Figure 17.12 The monitoring and risk levels of the historically active volcanoes in Norway. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 18: Atlantic Ocean

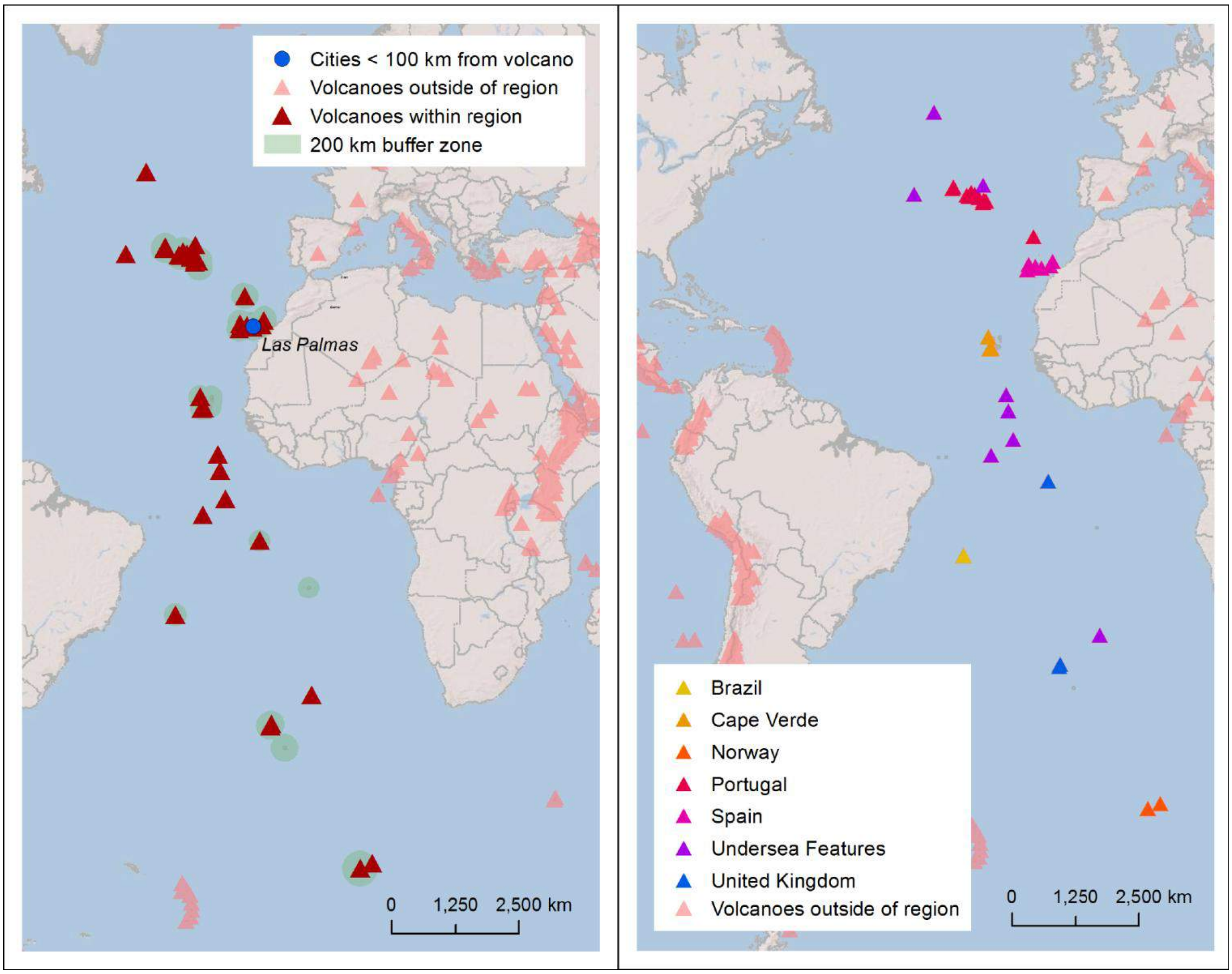

Figure 18.1 The distribution of Holocene volcanoes through the Atlantic Ocean region. The capital cities of the constituent countries are shown. The host countries are identified on the right.

Description

Region 18: the Atlantic Ocean comprises volcanoes throughout the Atlantic, from an unnamed seamount in the north to the Norwegian territory of Bouvet in the south. Six countries are represented here. All are included in this regional discussion, and individual country profiles are provided, however see Region 17 for the Norway profile.

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Country	Number of volcanoes
Brazil	1
Cape Verde	3
Norway (See Region 17)	2
Portugal – Azores	14
Spain – Canary Islands	6
UK	3

Table 18.1 The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Thirty-seven Holocene volcanoes are located in the Atlantic Ocean. Most of these are in the Azores. Volcanism here is largely related to intra-plate hotspot processes in the ocean crust, with several volcanoes on or near the mid-Atlantic Ridge. Considerable submarine volcanism occurs at the mid-Atlantic ridge, where rifting processes generate voluminous basalt flows.

Excluding the submarine volcanism of the Mid-Atlantic Ridge, eleven volcanoes in this region are classed as submarine. The dominant volcano types are stratovolcanoes, with numerous such volcanoes present through the Azores and Cape Verde in particular. Five volcanoes comprise fissure vents and or pyroclastic cones, and four shield volcanoes are found. The rock type through this region is dominantly basaltic, though ranges from basaltic to trachytic.

A range of activity styles and eruption sizes are recorded throughout the Holocene, with eruptions of VEI 0 to 5. About 70% of eruptions here have been small, at VEI 0 to 2, however over 18% of eruptions have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have largely been restricted to the Azores, with just one in the Canary Islands. Four VEI 5 eruptions are recorded at Agua de Pau and Furnas in the Azores, the most recent of which was the 1630 eruption of Furnas, which caused property damage and loss of life.

Twenty volcanoes have historical records of 58 eruptions, 95% of which were recorded through direct observations. Pyroclastic flows are recorded in 9% of historical events, whilst 57% produced lava flows.

Lives were lost in 16% of historical eruptions (9 events at 6 volcanoes – San Jorge, Furnas, Fayal, Pico in the Azores; La Palma in the Canary Islands and Fogo in Cape Verde). Most volcanoes have small to medium local populations, and as such most volcanoes in this region are classed at Risk Level II. However, the hazard is not classified at about 80% of the region's volcanoes.

Of twenty historically active volcanoes in this region, 14 have one or more dedicated seismometer for volcano monitoring.

Volcano facts

Number of Holocene volcanoes	37
Number of Pleistocene volcanoes with M≥4 eruptions	6

Number of volcanoes generating pyroclastic flows	8 (17 eruptions)
Number of volcanoes generating lahars	3 (4 eruptions)
Number of volcanoes generating lava flows	16 (111 eruptions)
Number of eruptions with fatalities	9
Number of fatalities attributed to eruptions	541
Largest recorded Pleistocene eruption	The largest recorded eruption in this region during the Quaternary is the DHF I: Fasnia Formation (Lower Grey Member) eruption of Tenerife, Canary Islands. This M6.5 event occurred at 289 ka.
Largest recorded Holocene eruption	There are four eruptions of VEI 5 recorded at Agua de Pau and Furnas.
Number of Holocene eruptions	166 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 5 and unknown
Number of historically active volcanoes	20
Number of historical eruptions	58

Number of volcanoes	Primary volcano type	Dominant rock type
17	Large cone(s)	Andesitic (1), Basaltic (8), Foiditic (3) Phonolitic (1), Trachytic /Andesitic (4)
4	Shield(s)	Basaltic (4)
5	Small cone(s)	Basaltic (5)
11	Submarine	Basaltic (1), Unknown (10)

Table 18.2 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	5
Large (> VEI 3)	230

Table 18.3 Average recurrence interval (years between eruptions) for small and large eruptions in the Atlantic Ocean.

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The eruption record indicates that on average small- to moderate- sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 5 years, whilst the ARI for large eruptions is longer, at about 230 years.

Eruption Size

Eruptions are recorded through the Atlantic Ocean region of VEI 0 to 5, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with nearly 50% of all Holocene eruptions classed as such. Over 18% of eruptions here are explosive at VEI ≥4.

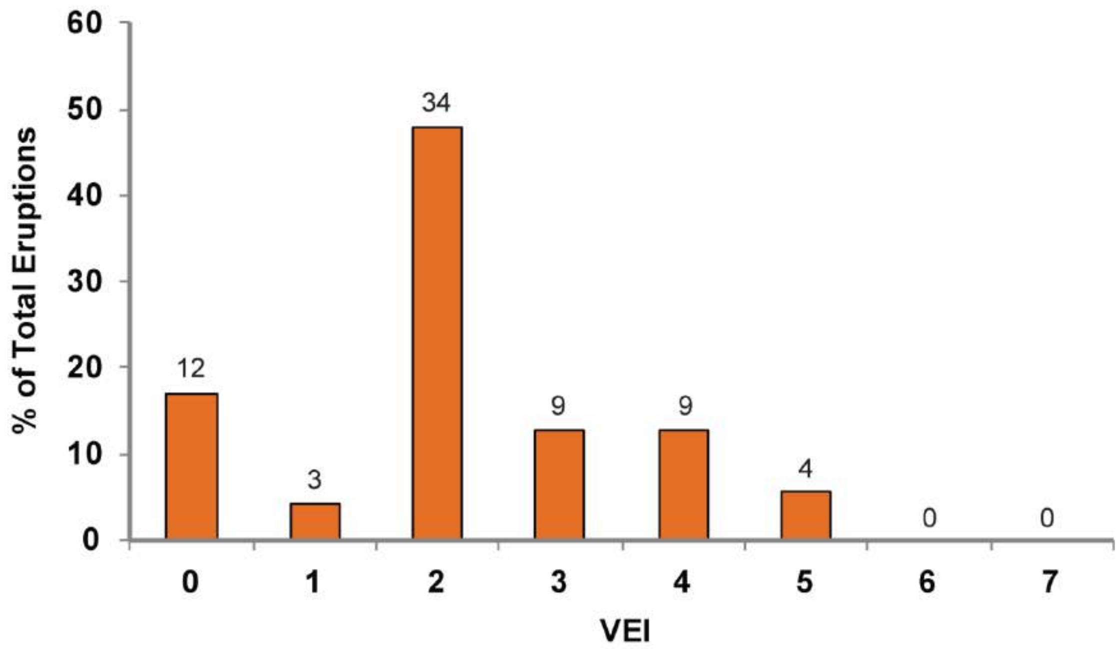

Figure 18.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 95 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	3,616 (Cape Verde)
Gross National Income (GNI) per capita (2005 PPP $)	3,609 (Cape Verde)
Human Development Index (HDI) (2012)	0.586 (Medium, Cape Verde)

Infrastructure Exposure

Number of airports within 100 km of a volcano	17
Number of ports within 100 km of a volcano	17
Total length of roads within 100 km of a volcano (km)	1,570
Total length of railroads within 100 km of a volcano (km)	0

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CLASSIFIED	**Hazard III**			Furnas	Agua de Pau			
	Hazard II			San Jorge	Sete Cidades; La Palma; Tenerife			
	Hazard I				Fogo			
UNCLASSIFIED	**U – HHR**	Unnamed (381020); Unnamed (381040); **Unnamed (385052)**	**Don Joao de Castro Bank**; **Monaco Bank; Tristan da Cunha; Nightingale Island**	Pico	**Fayal**; **Terceira; Hierro**	Lanzarote	Picos Volcanic System	
	U- HR	Bouvet		Flores	Gran Canaria		Madeira	
	U- NHHR	Unnamed (381030); Unnamed (385010); Unnamed (385020); Unnamed (385030); Unnamed (385040); Trindade; Thompson Island	Corvo; Ascensión	Graciosa; **Brava**	Fuerteventura	Sao Vicente		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 18.4 Identity of the volcanoesin this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
2	6
2	5
10	4
6	3
6	2
11	1

Table 18.5 The number of volcanoes in the Atlantic Ocean classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
1	III
5	II
1	I
30	Unclassified

Table 18.6 The number of volcanoes in the Atlantic Ocean region classified at each Risk Level.

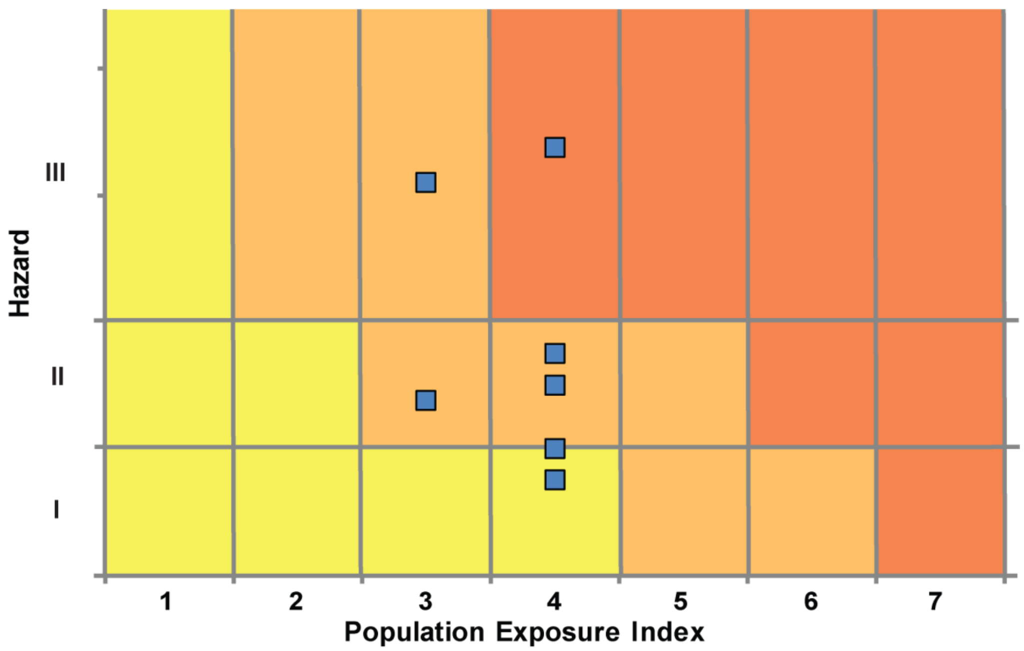

Figure 18.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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Regional Monitoring Capacity

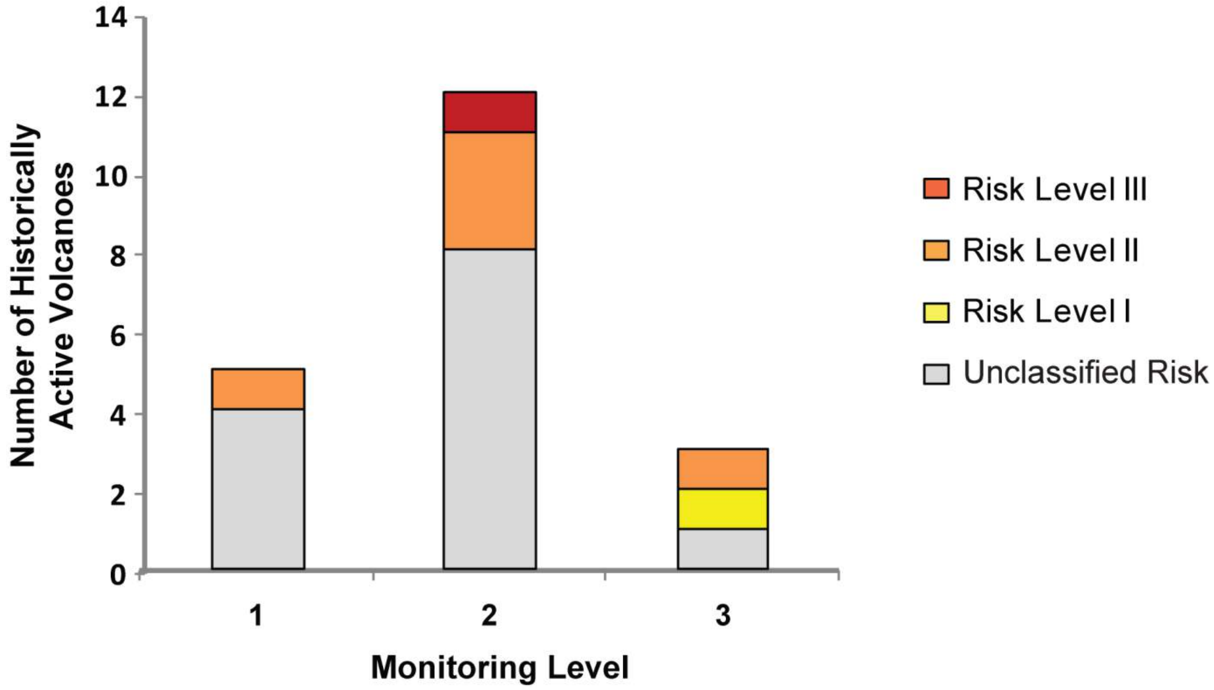

Figure 18.4 The monitoring and risk levels of the historically active volcanoes in the Atlantic Ocean. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Brazil

Description

One volcano, Trindade, forms an island of the same name lying about 1,100 km off the coast of Brazil. This volcano lies at the eastern end of a chain of submarine volcanoes extending from Brazil's coast and is related to intra-plate processes.

No Holocene eruptions are recorded at Trindade, however the youngest activity, which constructed a pyroclastic cone and extensive lava flows, is considered no older than Holocene (Almeida, 1961 in VOTW4.22). With no detailed eruptive history, the hazard level of this volcano cannot be determined.

Only a small contingent of the Brazilian Navy resides on the island of Trindade, with no permanent population located here or within 100 km of the volcano.

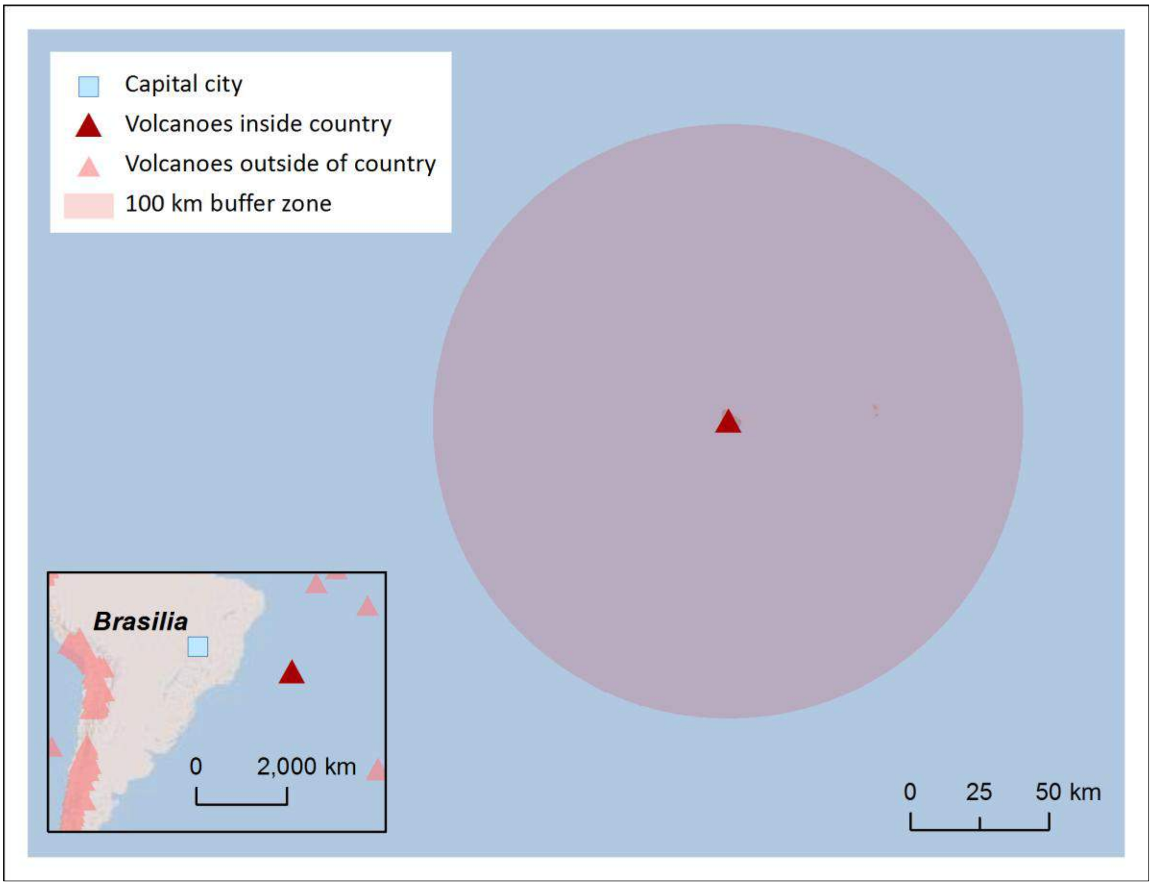

Figure 18.5 Location of Brazil's volcano, Trindade, and a 100 km radius surrounding it.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-

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Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Foiditic (1)

Table 18.7 The number of volcanoes in Brazil, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	198,833,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	10,278
Gross National Income (GNI) per capita (2005 PPP $)	10,152
Human Development Index (HDI) (2012)	0.730 (High)

Population Exposure

Capital city	Brasília
Distance from capital city to nearest Holocene volcano	2013.6 km
Total population (2011)	203,429,773
Number (percentage) of people living within 10 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)

Number (percentage) of people living within 100 km of a Holocene volcano	0 (0%)

Ten largest cities, as measured by population and their population size:

Sao Paulo	10,021,295
Rio de Janeiro	6,023,699
Salvador	2,711,840
Fortaleza	2,400,000
Belo Horizonte	2,373,224
Brasilia	2,207,718
Curitiba	1,718,421
Manaus	1,598,210
Recife	1,478,098
Porto Alegre	1,372,741

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The Trindade volcano is located at over 1000 km off the coast of Brazil, thus no areas of mainland Brazil lie within 100 km of a Holocene volcano. The Trindade and Martim Vaz islands are small and hence lie in their entirety within 100 km of the Trindade volcano, and as such all infrastructure here is exposed. No permanent settlements exist here, however a Brazilian Navy Base is located on Trinidade < 5 km from the volcano.

Hazard, Uncertainty and Exposure Assessments

With no confirmed Holocene eruptions recorded at Trindade volcano in Brazil hazard assessment through the calculation of the VHI cannot be undertaken and this volcano is therefore unclassified.

There is no permanent population living within 100 km of Trindade with the exception of a small contingent of the Brazilian Navy, hence a PEI of 1. Despite the absence of a hazard classification, this points to this volcano being ranked at Risk Level I.

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CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR	Trindade						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 18.8 Identity of Brazil's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Brazil have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Brazil.

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Cape Verde

Description

There are three Holocene volcanoes in Cape Verde as listed in VOTW4.0: Brava, Fogo and Sao Vicente. Fogo was most recently active in 2014-2015. Recent dating of rocks on Brava suggests that Holocene eruptions occurred here. Holocene lavas are described on Sao Vicente by Mitchell-Thomé, (1976) in VOTW4.0), however Holm et al. (2008) date activity here at 6.6 to 0.3 Ma. We include Sao Vicente in analysis here due to its inclusion in VOTW4.0. In their investigations of volcanic hazard in Cape Verde, Faria and Fonseca (2014) do not consider Sao Vicente as an active volcano, instead considering Santo Antão, north of Sao Vicente, as a potentially active centre, though the last dated activity here was about 90,000 years ago. Whilst Sao Vicente and Santo Antão are in the north, Brava and Fogo are in the south. All are stratovolcanoes related to a mantle hotspot.

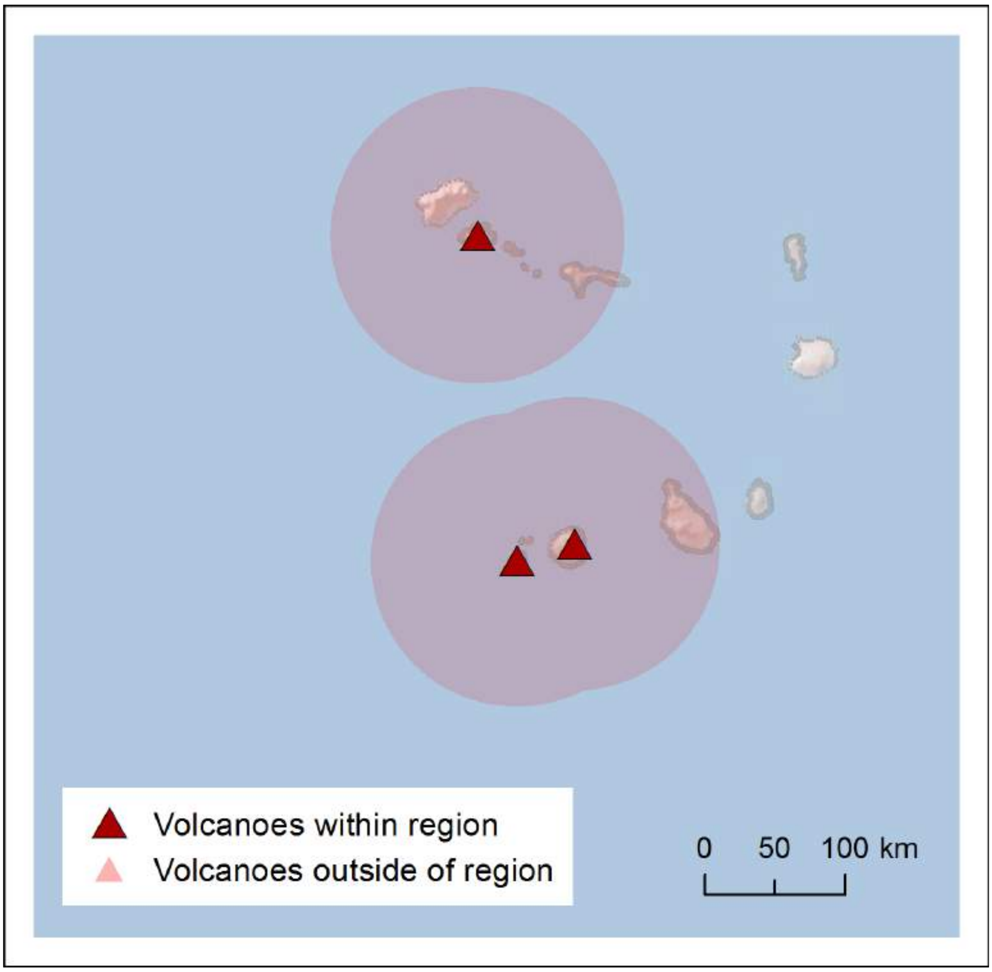

Figure 18.6 The location of the Cape Verde volcanoes and a 100 km buffer zone surounding them.

Brava is the westernmost island of the southern Cape Verde Islands. The age of the last eruption is unknown; however, frequent seismic swarms suggest the island is still active. Carbonantite lavas and pyroclastic deposits are also present on Brava, which are presumed to be Holocene to Pleistocene in age (Mourão et al., 2010).

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Fogo is the only historically active volcano in the Cape Verde Islands. Fogo is a stratovolcano with a 9 km wide collapse structure just NE of the centre of the island. The infilled collapse scar is open to the east and has a 1 km high horse-shoe shape wall. Within the collapse scar is a steep-sided cone, Pico, rising >1 km above the collapse floor. Pico had a period of very frequent eruptions from the time of Portuguese settlement in 1500 until about 1760, which are not listed individually in VOTW4.22, however the National Institute for Meteorology and Geophysics has identified separate sixteen separate events in this time, including a large eruption in 1680. Since then, ten historical eruptions have been recorded with lava flows sometimes reaching the eastern coast. Its last known eruption was the effusive eruption of November 2014 to February 2015.

Only Fogo has a record of historic eruptions, however, both Brava and Santa Antão have had historic felt seismicity and recorded seismic and geothermal activity. These latter volcanoes have a geological record of eruptions, including some explosive events. Faria and Fonseca (2014) consider the volcanic hazard levels to be highest on Fogo, Brava and Santa Antão and hence monitoring efforts are focussed here. They describe the lava flow hazard on Fogo as being particularly high along the eastern coast and within the collapse scar, and indeed during the 2014-2015 eruption numerous buildings were destroyed by lavas here. In Brava they describe the volcanic hazard awareness among the population and authorities as very low due to the absence of historical eruptions.

The National Institute for Meteorology and Geophysics (INMG) of the Cape Verde Government monitors the Fogo, Brava and Santa Antão volcanoes using networks of broadband seismometers (7 on Fogo, 2 on Brava, 4 on Santo Antão, 1 on Sao Vicente and 1 on Sal) and, on Fogo, three tiltmeters. Monitoring and civil protection were established on Fogo Volcano after the 1995 eruption. In 2010, it was recognised that Brava may pose a threat and monitoring was established.

Faria and Fonseca (2014) describe how a warning system is operational on Fogo, using an alert level system of five levels. If anomalous activity is detected, a warning is sent to the National Civil Protection Service, which is responsible for risk management in Cape Verde. Were unrest or activity to increase at the other volcanoes, as detected through the monitoring network, then warning systems would be established for these.

See also:

Faria, B., and Fonseca, J.F.B.D. (2014) Investigating volcanic hazard in Cape Verde Islands through geophysical monitoring: network description and first results. *Nat. Hazards Earth Syst. Sci*. 14, 485-499.

Heleno da Silva, S.I.N., Day, S.J., and Fonseca, J.F.B.D. (1999) Fogo Volcano, Cape Verde Islands: seismicity-derived constraints on the mechanism of the 1995 eruption. *Journal of Volcanology and Geothermal Research*, 94:219-231.

Holm, P.M., Grandvuinet, T., Friis, J., Wilson, J.R., Barker, A.K. and Plesner, S. (2008) An 40Ar-39Ar study of the Cape Verde hot spot: Temporal evolution in a semistationary plate environment. *Journal of Geophysical Research*, 113, B08201.

Mourão, C., Mata, J., Doucelance, R., Madeira, J., Silveira, A.B.D., Silva, L. C., & Moreira, M. (2010). Quaternary extrusive calciocarbonatite volcanism on Brava Island (Cape Verde): a nephelinite-carbonatite immiscibility product. *Journal of African Earth Sciences*, *56*(2), 59-74.

Ribeiro, O. (1960) A Ilha do Fogo e as sua Erupções. Justa de Investigação do Ultramar, Lisboa.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	No lahars are recorded in VOTW4.22 however lahar deposits are observed in Fogo (considered likely to be historical), Brava and Sao Antão.
Number of volcanoes generating lava flows	1
Tectonic setting	Intraplate
Largest recorded Pleistocene eruption	The M5.7 Cão Grande pumice of Santo Antão at 200 ka.
Largest recorded Holocene eruption	7 eruptions of VEI 2 are recorded at Fogo between 1785 AD and 1995 AD. An eruption identified in 1680 at Fogo does not have an attributed size and is not considered separately in VOTW4.22, however it is considered to have been a large explosive event.
Number of Holocene eruptions	11 according to VOTW4.22, with a further 15 identified by Ribeiro (1960).
Recorded Holocene VEI range	1 – 2 and unknown
Number of historically active volcanoes	1 (Fogo)
Number of historic eruptions	11 according to VOTW4.22, with a further 15 identified by Ribeiro (1960).

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large cone(s)	Basaltic (1), Foiditic (2)

Table 18.9 The number of volcanoes in Cape Verde, their volcano type classification and dominant rock type according to VOTW4.0.

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Socio-Economic Facts

Total population (2012)	496,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,616
Gross National Income (GNI) per capita (2005 PPP $)	3,609
Human Development Index (HDI) (2012)	0.586 (Medium)

*Population Exposure considering the location of Fogo, Brava and Sao Vicente**

Capital city	Praia
Distance from capital city to nearest Holocene volcano	87.1 km
Total population (2011)	516,100
Number (percentage) of people living within 10 km of a Holocene volcano	96,368 (18.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	144,129 (27.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	462,061 (89.5%)

*The exposed population is calculated based on the VOTW4.0 listing of Fogo, Brava and Sao Vicente as Holocene volcanoes. Of these, only Fogo has a confirmed Holocene eruption record. If the population exposure were calculated considering Fogo only, we would only include the islands of Brava, Fogo and Santiago within the 100 km radius, which account for a population of about 300,000; whilst within 30 km it is only the population of Fogo exposed (~33,000). Santo Antão is considered by Faria and Fonseca (2014) as a potentially active centre. This ~40 x 20 km island, home to about 44,000, comprises overlapping volcanic centres with the youngest activity being identified in the west.

Largest cities, as measured by population and their population size:

Praia	113,364

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	>100 km
Total length of railroads within 100 km of a volcano (km)	0

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The three Holocene volcanoes of the Cape Verde islands are located on separate small islands, which are fully within the 100 km radius of each volcano. Not all Cape Verde islands are within 100 km distance of these volcanoes, however, the main island Santiago and capital, Praia, lie within 100 km of the southernmost two volcanoes – Fogo and Brava. Although not described in the table here, an extensive road network is therefore affected and much of the critical infrastructure in the Cape Verde islands. The Pleistocene volcano of Santa Antão is home to about 44,000 people and hence significant infrastructure.

Hazard, Uncertainty and Exposure Assessments

Of Cape Verde's volcanoes, only Fogo has a sufficiently extensive eruption record to determine the hazard through the calculation of the VHI without significant associated uncertainties. This volcano is classified at Hazard Level I, with a historical record dominated by VEI 2 eruptions and the most recent activity (2014-2015) being VEI 0.

Neither Brava nor Sao Vicente have any confirmed Holocene eruptions on record, and as such these are unclassified. Brava has recorded unrest since 1900 AD, with the occurrence of minor seismicity.

The PEI in Cape Verde ranges from moderate to high. Despite the largest population within 100 km, with a PEI of 4 and Hazard Level I, Fogo is classed at Risk Level I. The risk is unclassified at Brava and Sao Vicente due to the absence of a hazard classification.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I				Fogo			
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR			**Brava**		Sao Vicente		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 18.10 Identity of Cape Verde's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Fogo	4	I

Table 18.11 Classified Volcanoes of Cape Verde ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

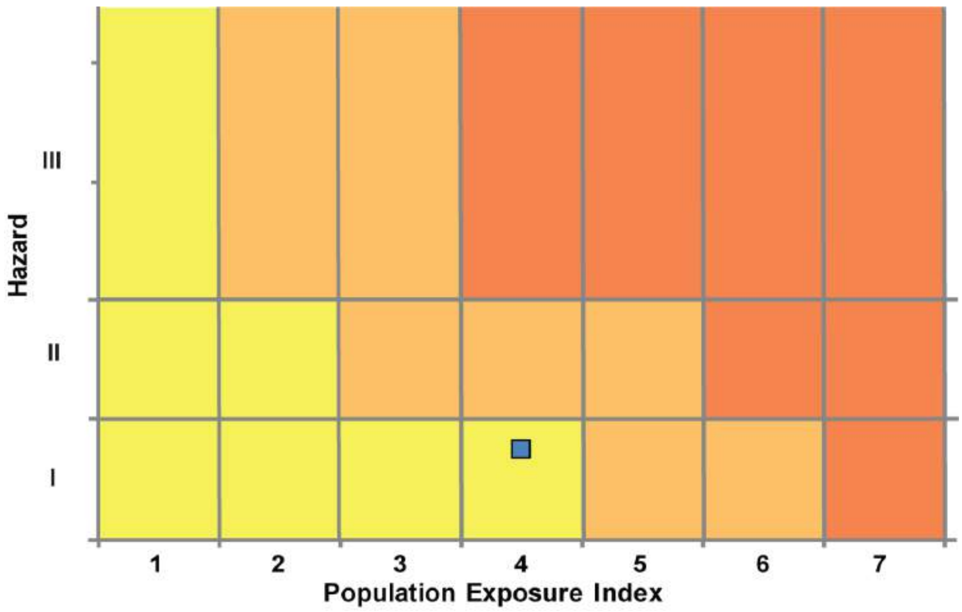

Figure 18.7 Distribution of Cape Verde's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The historically active Fogo is monitored by the Instituto Nacional de Meteorologia e Geofísica (National Institute for Meteorology and Geophysics) using a network of seismometers and tiltmeters. Fifteen seismometers are distributed throughout Cape Verde, focussed on the three largest islands Fogo, Santa Antão and Brava, considered with greatest Hazard by Faria and Fonseca (2014).

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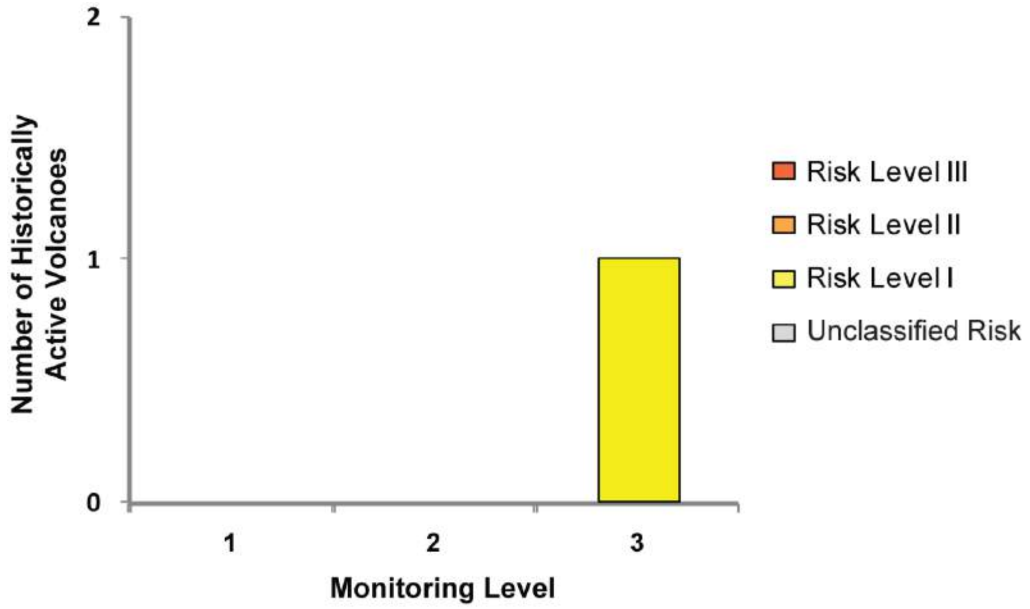

Figure 18.8 The monitoring and risk levels of the historically active volcanoes in Cape Verde. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Portugal - The Azores

Description

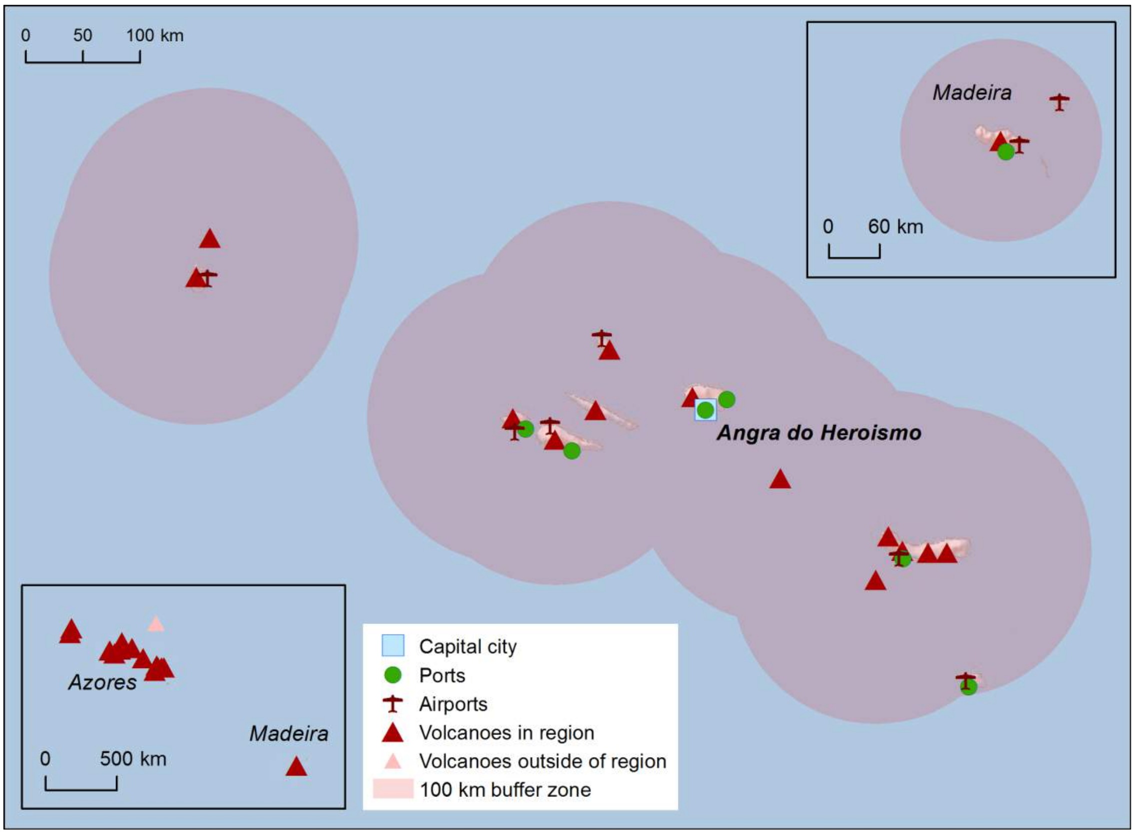

Figure 18.9 Location of the volcanoes in the Azores and a 100 km radius zone (pink) surrounding each volcano.

Fourteen Holocene volcanoes are located in the Azores. Volcanism here is due to the presence of a mantle plume intra-plate processes and tensional processes due to the presence of the Mid-Atlantic Ridge. Most volcanoes here are stratovolcanoes, and the composition of the rocks is most commonly basaltic.

Seventy-four eruptions of Holocene age are recorded, at VEI 0 to 5, indicating a range of activity from mild to large explosive events. Twenty-eight of these eruptions were recorded post-1500 AD.

One of the largest Holocene eruptions here was the VEI 5 eruption of Furnas in 1630. This produced pyroclastic flows and tephra fall, and resulted in significant damage and loss of life. Most activity has been dominated by Strombolian and Hawaiian eruption styles producing scoria and lava flows (Gaspar et al., 2011).

The size of the local population varies at each volcano, but throughout the Azores about 240,000 people live within 10 km of a Holocene volcano.

The Centre for Volcanology and Geological Risk Assessment (CVARG) of the Azores University advises the regional and local civil protection authorities on volcanic issues. The Observatório Vulcanológico

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e Sismológico da Univ. dos Açores (CIVISA) is responsible for monitoring of the volcanoes here, using geophysical, geodetic and geochemical monitoring networks.

A permanent seismic network is operational and additional mobile seismometers are available. Permanent and temporary geodetic stations are also available. If unrest or eruptions are detected, the CVARG Crisis cabinet is activated and data is transmitted to the regional and local civil protection authorities.

See also:

Gaspar, J.L., Queiroz, G., Ferreira, T., Amaral, P., Viveiros, F., Marques, R., Silva, C., and Wallenstein, N. (2011) Geological hazards and monitoring at the Azores (Portugal), Earthzine, www.earthzine.org/2011/04/12/geological-hazards-and-monitoring-at-the-azores-portugal/

Observatório Vulcanológico e Sismológico da Univ. dos Açores: www.cvarg.azores.gov.pt/Paginas/home-cvarg.aspx

Volcano Facts

Number of Holocene volcanoes	14
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	3
Number of volcanoes generating lava flows	8
Number of fatalities caused by volcanic eruptions	?>525
Tectonic setting	11 Rift zone, 3 intra-plate
Largest recorded Pleistocene eruption	The M6.1 Caldera forming eruption of 24,691 BP at Sete Cidades.
Largest recorded Holocene eruption	The M6 Seara Cerrado da Ladeira (A) eruption of Sete Cidades at 5 ka and the M6 eruptions of Units C and E at Furnas at 1,784 and 1,300 BP respectively.
Number of Holocene eruptions	74 confirmed eruptions. 3 uncertain eruptions.
Recorded Holocene VEI range	0 – 5 and unknown
Number of historically active volcanoes	10

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Number of historic eruptions	28

Number of volcanoes	Primary volcano type	Dominant rock type
9	Large cone(s)	Andesitic (1), Basaltic (5), Trachytic /Andesitic (3)
1	Shield(s)	Basaltic (1)
2	Small cone(s)	Basaltic (2)
2	Submarine	Basaltic (1), Unknown (1)

Table 18.12 The number of volcanoes in the Azores, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	21,317
Gross National Income (GNI) per capita (2005 PPP $)	20,557
Human Development Index (HDI) (2012)	0.816

Population Exposure

Capital city (Azores)	Ponta Delgada, Angra do Heroísmo, Horta
Distance from capital city to nearest Holocene volcano	<5 km
Total population (2011, source: Instituto Nacional de Estatistica, Statistics Portugal: censos.ine.pt)	514,557 (including the Azores and Madeira)
Number (percentage) of people living within 10 km of a Holocene volcano	240,349 (46.6%)
Number (percentage) of people living within 30 km of a Holocene volcano	487,994 (94.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	498,308 (96.8%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	8
Number of ports within 100 km of a volcano	7
Total length of roads within 100 km of a volcano (km)	1,270
Total length of railroads within 100 km of a volcano (km)	0

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The islands of the Azores are volcanic, meaning that the numerous towns and infrastructure of the Azores are located close to volcanic centres, including numerous ports and airports and an extensive road network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of the volcanoes in the Azores. Just four volcanoes, <30%, have a sufficiently detailed record to define the hazard. These volcanoes are classified across Hazard Levels II and III, all with Holocene eruptions of VEI ≥3. San Jorge is the only classified volcano with activity since 1900 AD.

The remaining ten volcanoes are unclassified. Of these two, Corvo and Graciosa, have no confirmed Holocene eruptions on record. All others have a Holocene record, including historical activity at Don Joao de Castro Bank, Pico, Picos Volcanic System, Fayal, Terceira and Monaco Bank, including eruptions since 1900 AD at the latter three volcanoes.

The PEI ranges from 2 to 6, low to high in the Azores, with the largest populations and highest PEI found at Picos Volcanic System and Madeira. At a PEI of 4, the Hazard Level III volcano Agua de Pau is classed with the highest Risk Level in the Azores at III. The remaining classified volcanoes are Risk Level II.

CLASSIFIED	**Hazard III**			Furnas	Agua de Pau			
	Hazard II			San Jorge	Sete Cidades			
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Don Joao de Castro Bank; Monaco Bank**	Pico	**Fayal; Terceira**		Picos Volcanic System	
	U- HR			Flores			Madeira	
	U- NHHR		Corvo	Graciosa				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 18.13 Identity of the Azores' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Volcano	Population Exposure Index	Risk Level
Agua de Pau	4	III
Sete Cidades	4	II
Furnas	3	II
San Jorge	3	II

Table 18.14 Classified volcanoes of the Azores ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III- 1 volcano.

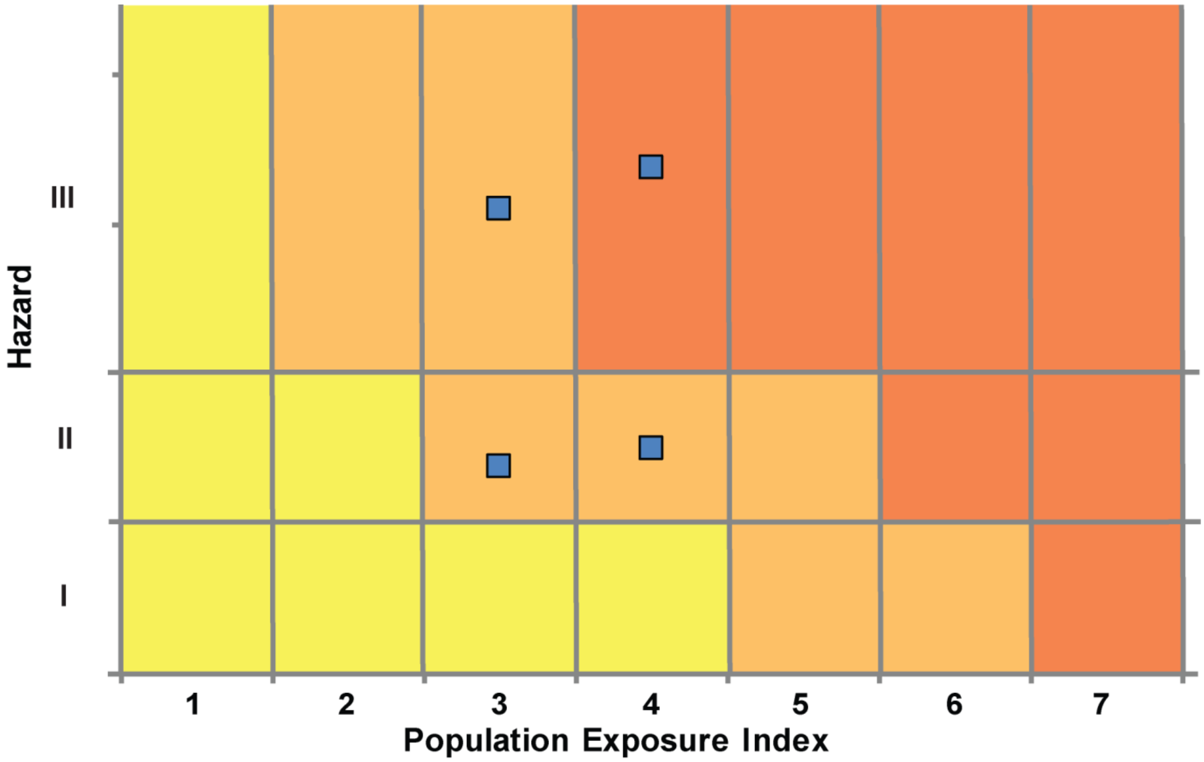

Figure 18.10 Distribution of the Azores' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes have records of historical activity in the Azores. The Observatório Vulcanológico e Sismológico da Univ. dos Açores (CIVISA) is responsible for monitoring of the volcanoes here, using seismic and deformation stations. At the time of the writing of this report the specifics of equipment at individual volcanoes are not known.

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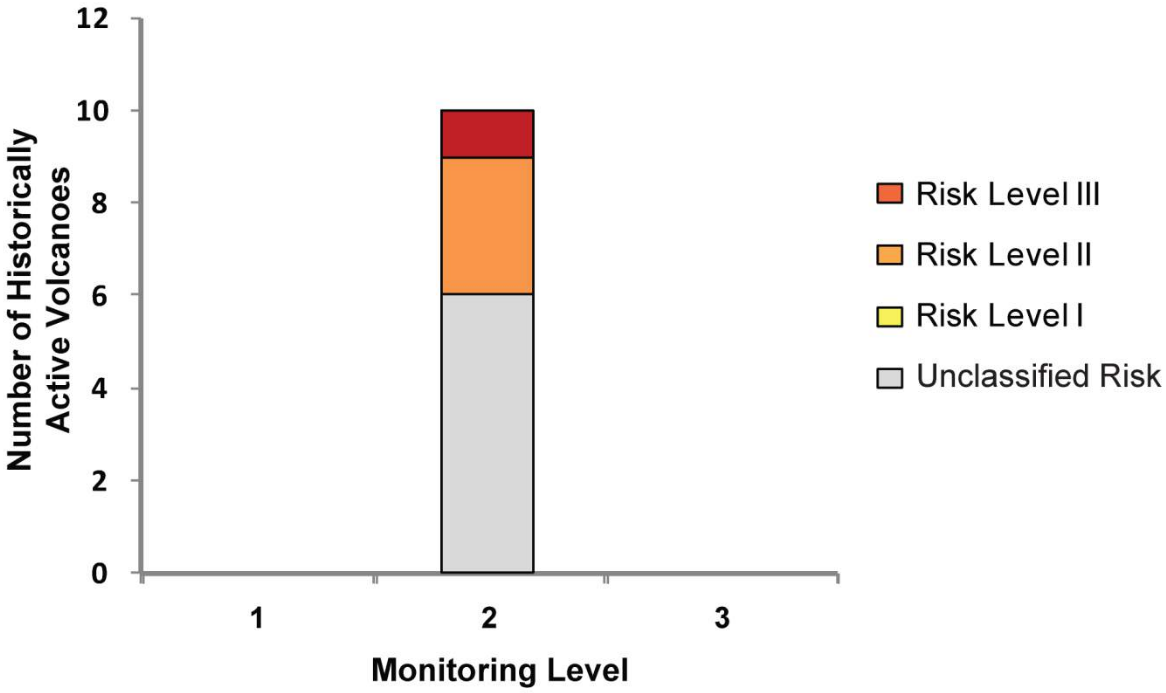

Figure 18.11 The monitoring and risk levels of the historically active volcanoes in the Azores. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Spain – Canary Islands

Description

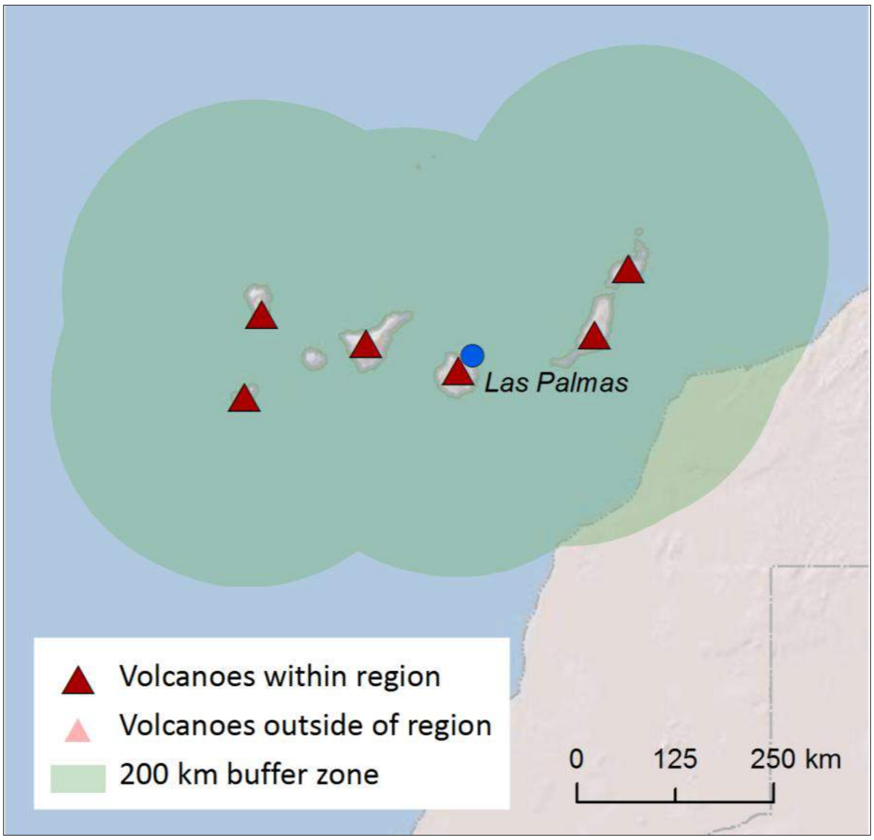

Figure 18.12 Location of volcanoes in the Canary Islands and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Canary Islands.

Six Holocene volcanoes are located in the Canary Islands. Volcanism here is due to intra-plate processes which have produced these basaltic centres. Volcano form varies, with two stratovolcanoes, a shield volcano and three fissure vents.

Seventy-four confirmed eruptions of Holocene age are recorded from five volcanoes. Fuerteventura has undated activity of suspected late Holocene age. These Holocene eruptions were of VEI 0 to 4, with mild to large explosive eruptions. The largest Holocene eruption was that of Tenerife about 2,000 years ago. The size of most Holocene eruptions (80%) is unknown.

In addition to a few unconfirmed eruptions, four volcanoes – La Palma, Tenerife, Lanzarote and El Hierro – have produced thirteen historical eruptions. These events are recorded as VEI 2, though violent Strombolian episodes are suspected. The submarine 2011 eruption of El Hierro is the exception, with no attributed size. This is the most recent eruption in the Canary Islands, and began with about three months of increased seismicity and deformation, prior to the submarine eruption.

The record is such that the hazard assessment for most of the Canary Island volcanoes is associated with considerable uncertainty and most volcanoes here are unclassified. Given the nature of volcanic islands, much of the population lives in close proximity to the volcanoes, and indeed Marrero et al.

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(2012) recommend that the Emergency Plan should include the possibility of evacuating more than 100,000 people in the event of an eruption warning in the Central Volcanic Complex of Tenerife.

The Instituto Geografico Nacional (IGN) is the official monitoring organisation in the Canary Islands, responsible for a national seismic network and volcano monitoring system. The IGN uses a monitoring alarm system that is triggered by earthquakes of magnitude 2.5 and above for regional seismicity. In the active volcanic islands the threshold magnitude is much lower, at <1.5. Additionally on El Hierro and Tenerife a dense deformation monitoring network of GPS monitors are in place, allowing daily and sub-daily velocity determinations with millimetre resolution. The IGN has been funded by the Spanish government for volcano monitoring since 2004.

In addition to the IGN, several research teams at different institutions and universities also conduct research and monitoring in the Canary Islands. The Consejo Superior de Investigaciones Cientificas (CSIC) and Laboratory of Astronomy and Geodesy (LAG-UCA; Cadiz University) maintain monitoring networks at El Hierro, Tenerife and Lanzarote. INVOLCAN is the National Centre for Volcanology, the Canary Islands Volcanological Institute, who aims to improve volcanic risk management in the Canary Islands.

Volcanic activity levels are determined by the monitoring and research teams and communicated to the decision-makers who decide on and communicate alert levels. The authorities are the Dirección General de Protección Civil del Gobierno de Canarias, at the regional level) and the Spanish Government (Dirección General de Protección Civil y Emergencias). The IGN is officially responsible for declaring alerts, but it is the Civil Defence and the decision makers whose publish the alerts and set the Emergency Response Levels and the colour of the Volcanic Traffic Light, according to the scientific information received. There is a non-official Volcanic Activity Level (VAL), developed and managed by IGEO-CSIC and LAG-UCA teams during the El Hierro volcanic process.

Several different systems are currently used in the Canary Islands and the Volcanic Emergency Plan is currently under revision. A clear set of protocols and response plans may be beneficial here.

See also:

IGN: www.ign.es/ign/main/index.do

INVOLCAN: www.involcan.org/

CSIC: www.csic.es/web/guest/historia

Marrero, J.M., Garcia, A., Llinares, A., Rodriguez-Losada, J.A., and Ortiz, R. (2012) A direct approach to estimating the number of potential fatalities from an eruption: Application to the Central Volcanic Complex of Tenerife Island. *Journal of Volcanology and Geothermal Research*, 219-220: 33-40.

Marti, J., Geyer, A., Andujar, J., Teixido, F., and Costa, F. (2009) Assessing the potential for future explosive activity from Teide-Pico Viejo stratovolcanoes (Tenerife, Canary Islands). *Journal of Volcanology and Geothermal Research*, 178: 529-542

Marti, J., Sobradelo, R., Felpeto, A., and Garcia, O. (2012) Eruptive scenarios of Phonolitic volcanism at Teide-Pico Viejo volcanic complex (Tenerife, Canary Islands). *Bull. Vulcanol*. 74:767-782

Volcano Facts

Number of Holocene volcanoes	6
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	5
Number of fatalities caused by volcanic eruptions	?16
Tectonic setting	Intraplate
Largest recorded Pleistocene eruption	The M6.5 eruption of the DHFI Fasnia Formation Lower Grey Member at Tenerife at 289 ka.
Largest recorded Holocene eruption	The M4.7 Montaña Blanca, Pico Viejo eruption of Tenerife at 2,030 BP.
Number of Holocene eruptions	74 confirmed eruptions. 6 uncertain eruptions, 1 discredited.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	4
Number of historic eruptions	13

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Large cone(s)	Basaltic (1), Phonolitic (1)
1	Shield(s)	Basaltic (1)
3	Small cone(s)	Basaltic (3)

Table 18.15 The number of volcanoes in the Canary Islands, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2013) (Instituto Nacional de Estadistica)[1]	2,092,826

Population Exposure

Capital city (Canary Islands)	Santa Cruz, Las Palmas

[1] www.ine.es/jaxi/tabla.do

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Distance from capital city to nearest Holocene volcano	<40 km
Number (percentage) of people living within 100 km of a Holocene volcano	2,092,826 (100%)

Largest cities, as measured by population and their population size:

Las Palmas	378,495

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	300
Total length of railroads within 100 km of a volcano (km)	0

The volcanic Canary Islands are small, each measuring no more than 100 km across, meaning that the 100 km radii around the volcanoes here covers this island group in its entirety. This therefore places all the towns, ports and critical infrastructure proximal to the volcanoes, inclusive of the capitals.

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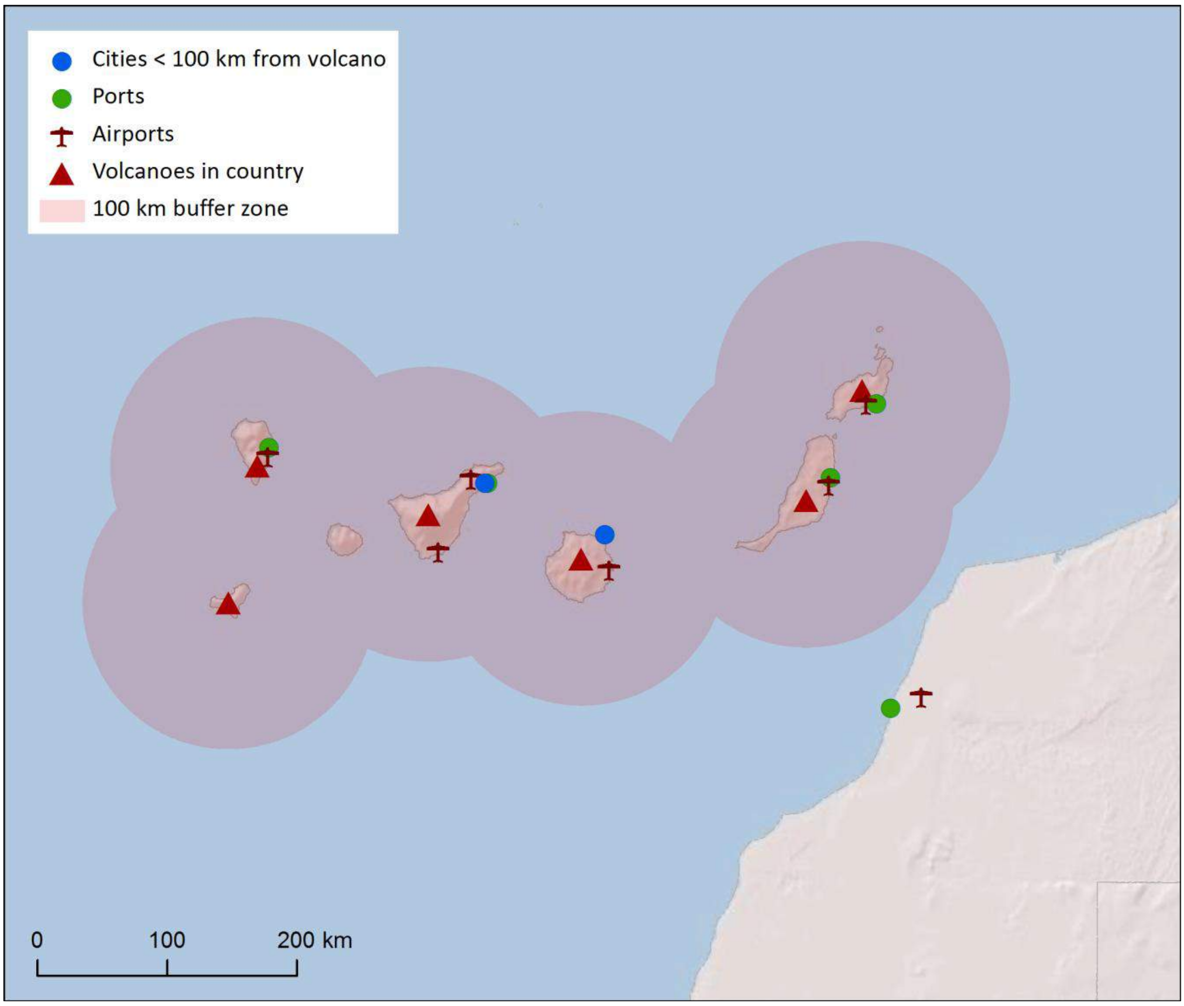

Figure 18.13 The location of the Canary Island volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The amount of data available in the eruption records of the Canary Island volcanoes is variable. La Palma and Tenerife have sufficient details to define the hazard through the calculation of the VHI without large associated uncertainties. The remaining five volcanoes cannot have a hazard level classified. These unclassified volcanoes include Fuertoventura, which has no confirmed Holocene activity, and Hierro and Lanzarote which both have historical eruptions, including the 2011 eruption of Hierro.

La Palma has a higher hazard score than Tenerife here due to more frequent historical eruptions, including one which produced a pyroclastic flow. However, no eruptions of greater than VEI 2 are recorded at La Palma, whilst Tenerife has a record of VEI 3 and VEI 4 events. Indeed, Marti et al. (2008) describe how explosive events have occurred at central and flank vents of Tenerife and Marti et al. (2012) calculate the volcanic threat at Tenerife using the NVEWS method, which designates

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this as a 'very high threat volcano', and calculate a probability of a large explosive eruption of magnitude 4 or above of 13.6% for the next 100 years using Extreme value theory.

The population of the Canaries is such that the volcanoes have moderate to high PEI levels at 4 and 5. The two classified volcanoes are classed at Risk Level II. Although here the population residing in the Canaries is considered, the tourist population must also be considered, with Marti et al. (2011) determining a mean daily hotel occupancy rate in 2009 of 52,000 on Tenerife alone. It must also be stressed that here the population is considered in concentric circles around the volcanoes, where as topographic features in particular are recognised for controlling the extent of the hazards and in Tenerife the hazard is recognised as particularly focussed on the northern side of the volcano, with the southern flank of Tenerife protected by the Cañadas caldera wall, which would act to restrain propagation of flows in this direction.

CLASSIFIED	**Hazard III**							
	Hazard II				La Palma; Tenerife			
	Hazard I							
UNCLASSIFIED	**U – HHR**				**Hierro**	Lanzarote		
	U- HR				Gran Canaria			
	U- NHHR				Fuerteventura			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 18.16 Identity of the Canary Island volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
La Palma	4	II
Tenerife	4	II

Table 18.17 Classified volcanoes of the Canaries ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

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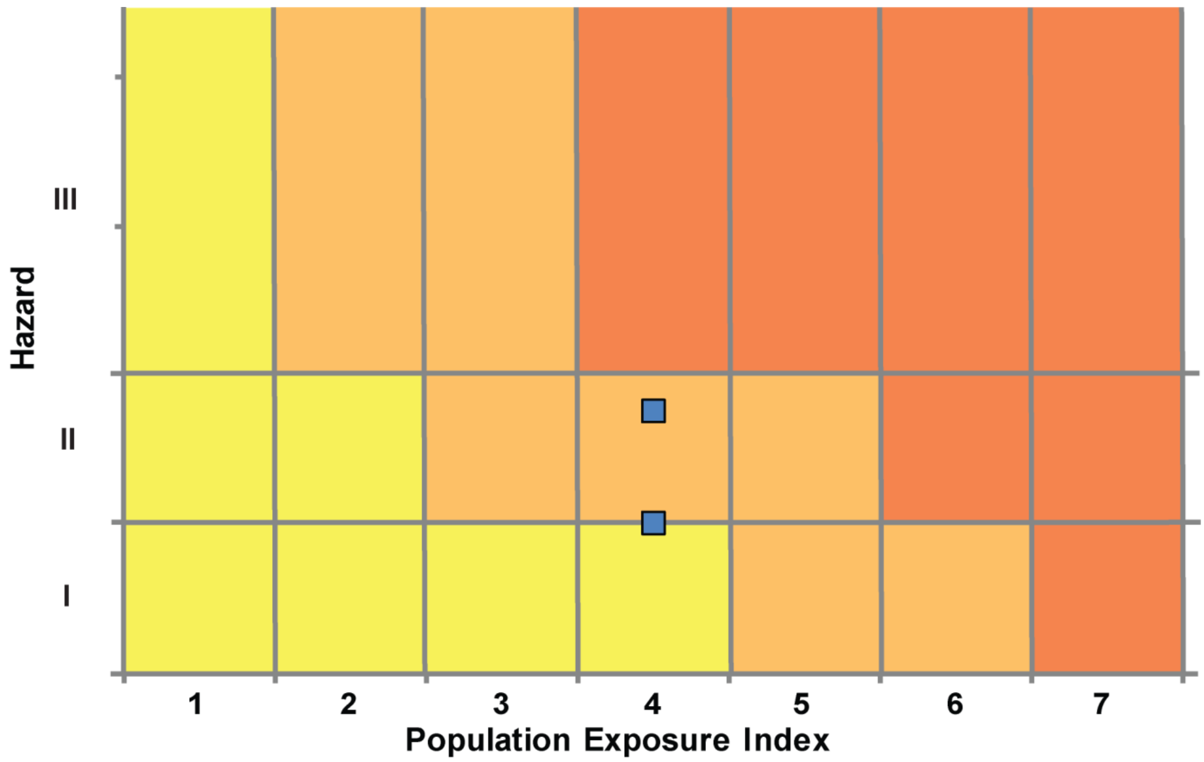

Figure 18.14 Distribution of the Canary Island classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Four volcanoes in the Canary Islands have records of historical activity. Monitoring is undertaken by a number of different groups in the Canaries. The official monitoring institution is the National Geographic Institute (Instituto Geografico Nacional, IGN) maintain permanent volcano monitoring networks comprising seismic and deformation stations on all of the islands, with dense monitoring networks on El Hierro and Tenerife. The other islands have seismic stations of the national seismic network. However, the Institute of Geosciences (IGEO-CSIC) in collaboration with the Laboratory of Astronomy and Geodesy (LAG-UCA, Cadiz University) manage networks at El Hierro and Tenerife (seismic and deformation) and seismic stations on Lanzarote. INVOLCAN and ITER (the Institute of Technology and Renewable Energies) operate a network of GPS stations throughout the Canary Islands as well as a geochemical network. INVOLCAN, ITER and the Andalusian Institute of Geophysics of the University of Grenada have plans for installation of a seismic network.

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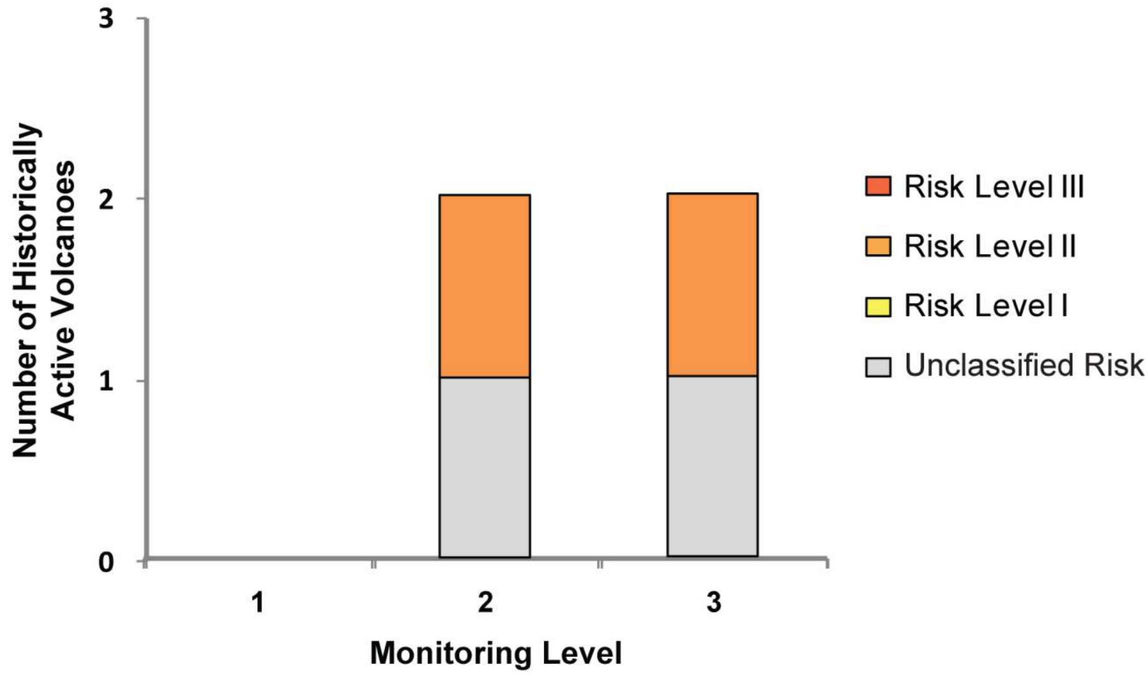

Figure 18.15 The monitoring and risk levels of the historically active volcanoes in the Canary Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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UK – Tristan da Cunha, Nightingale Island, Ascension

Description

Tristan da Cunha and Ascension are part of the British Overseas Territory of St Helena, Ascension and Tristan da Cunha. Tristan da Cunha comprises a group of islands: Tristan da Cunha Island, Nightingale Island, Inaccessible Island and Gough Island. The islands are the surface expression of volcanic edifices related to the Mid-Atlantic spreading Ridge.

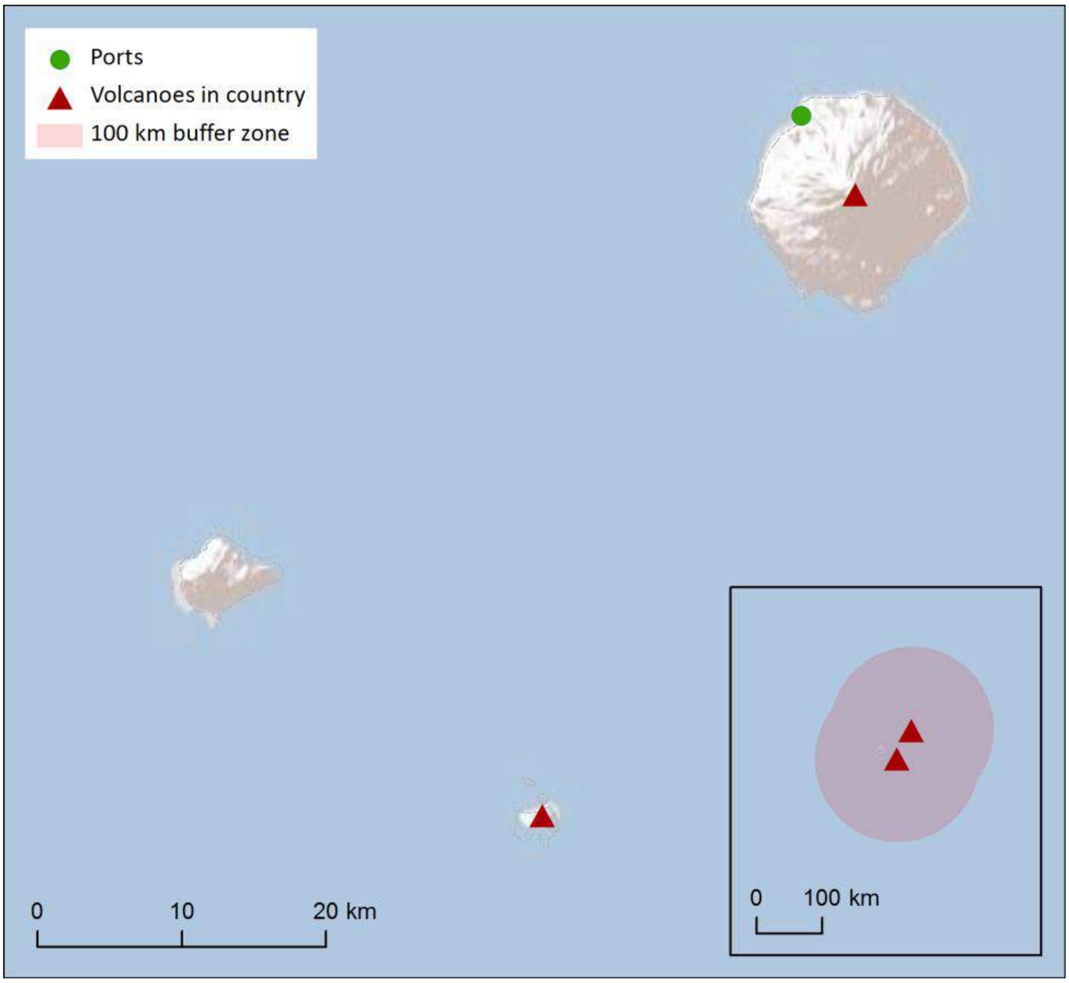

Figure 18.16 The location of the south Atlantic UK volcanoes of Tristan da Cunha and Nightingale Island. (Inset) A 100 km radius is seen around the volcanoes.

The overseas territory has three Holocene volcanoes: Tristan da Cunha, Nightingale and Ascension. Tristan da Cunha's last eruption occurred in 1961-62 with the formation of a lava dome and lava flow in the north-west of the island close to the settlement of Edinburgh-of-the-Seven-Seas. Tristan da Cunha is a trachy-balastic shield volcano with numerous parasitic cones on its flanks. The youngest summit lava has been dated at 5±1 ka and the youngest parasitic cone is 3±1 ka (Hicks et al., 2012).

Nightingale Island is part of the Tristan da Cunha archipelago and is located approximately 30 km to the southwest of Tristan da Cunha Island. Nightingale is a trachy-andesitic stratovolcano. In 2004 a seismic swarm was felt by islanders on Tristan da Cunha between the end of July and December. Pumice rafts were seen by fishermen and some eventually washed up on some of Tristan da Cunha's

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beaches. The events were located to a submarine eruption 37-55km south-southeast of Tristan da Cunha and is assumed to be a flank eruption of Nightingale volcano (O'Mongain et al., 2007).

Ascension Island is 3750 km north of Tristan da Cunha and lies just 90 km west of the Mid-Atlantic Ridge (MAR). Ascension is a basaltic stratovolcano predominantly comprising lava flows, pyroclastic deposits and scoria. A felsic complex in the centre and east of Ascension comprises a series of predominantly trachytic with some rhyolitic and basaltic lava flows and domes. The lower relief southern, western and northern parts of the island are dominated by mafic lava flows punctuated by numerous scoria cones. There has been no historical volcanic activity recorded on Ascension Island. The last eruption is unknown; however, it is proposed to have been late Holocene in age (Jicha et al., 2013).

Currently, the only monitoring stations on Tristan da Cunha are two CTBTO hydro-acoustic stations and an IRIS seismometer installed on Tristan to detect nuclear explosions and global tectonic earthquakes respectively. The British Geological Survey acts as a de facto remote volcano observatory for the South Atlantic but there is no contract or dedicated sustainable resource for this role beyond the BGS 'national capability' funding. As such, there is currently no dedicated volcano monitoring in the British Overseas Territory of St Helena, Ascension Island and Tristan da Cunha. The helicorder plots are checked daily by BGS staff for unusual activity. Should likely volcanic earthquakes be detected, BGS staff would communicate with FCO, CCS, the Islands' Administration Office and arrange to visit to check for evidence of volcanic activity on the island and potentially enhance monitoring capacity.

As the islands of Tristan da Cunha, Nightingale and Ascension are small, the entire populations live within 10 km of the volcanoes. Nightingale has no settlement; however, it is only c.40 km from the settlement on Tristan da Cunha, therefore an eruption on Nightingale would impact Tristan da Cunha islanders. The permanent population on Tristan da Cunha is 264. There is no permanent population on Ascension Island, with the majority of islanders (880 as of 2010) under a contract of employments to stay on the island.

See also:

O'Mongain, A., Ottemoller, L., Baptie, B., Galloway, D., and Booth, D., 2007, Seismic activity associated with a probable submarine eruption near Tristan da Cunha, July 2004-July 2006. *Seismological Research Letters*, 78, p. 375-382.

Hicks, A., Barclay, J., Mark, D.F., and Loughlin, S., 2012, Tristan da Cunha: Constraining eruptive behavior using the 40Ar/39Ar dating technique. *Geology*, 40, p. 723-726.

Jicha, B.R., Singer, B.S., and Valentine, M.J., 2013, 40Ar/39Ar Geochronology of Subaerial Ascension Island and a Re-evaluation of the Temporal Progression of Basaltic to Rhyolitic Volcanism. *Journal of Petrology*, 54, p. 2581-2596.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-

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Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The 1961 VEI 2 eruption of Tristan da Cunha.
Number of Holocene eruptions	3 confirmed eruptions
Recorded Holocene VEI range	0 – 2 and unknown
Number of historically active volcanoes	2
Number of historic eruptions	3

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (1), Trachytic/Andesitic (1)
1	Shield(s)	Basaltic (1)

Table 18.18 The number of volcanoes in the UK islands of the south Atlantic, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	?<300
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Edinburgh of the Seven Seas (settlement on Tristan da Cunha), Georgetown (Ascension)
Distance from capital city to nearest Holocene volcano	<10 km
Number (percentage) of people living within 10 km of a	100%

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Holocene volcano	
Number (percentage) of people living within 30 km of a Holocene volcano	100%
Number (percentage) of people living within 100 km of a Holocene volcano	100%

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

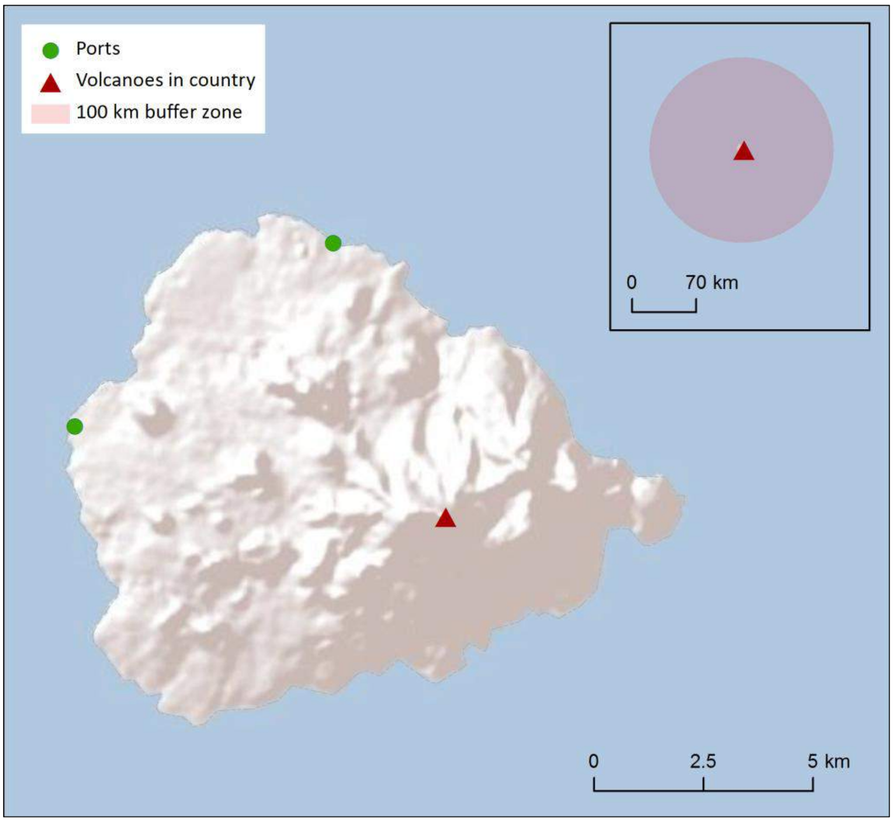

Figure 18.17 The location of Acension's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The islands of Tristan da Cunha, Nightingale Island and Ascension are remote outposts of the UK in the central and southern Atlantic. Settlements on Tristan da Cunha and Ascension lie within 10 km of the volcanoes, and hence all infrastructure on these islands is exposed within the 100 km radii of the volcanoes.

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Hazard, Uncertainty and Exposure Assessments

The eruption records for the UK volcanoes of the Atlantic Ocean are not sufficiently extensive to permit the calculation of the VHI and the determination of hazard levels. These volcanoes are therefore unclassified. Ascension has no confirmed Holocene activity, however both Tristan da Cunha and Nightingale Island have post-1900 AD eruptions.

The small population close to the three volcanoes here makes these PEI 2, a low population exposure index.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Tristan da Cunha; Nightingale Island**					
	U- HR							
	U- NHHR		Ascensión					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 18.19 Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Both Tristan da Cunha and Nightingale Island have records of historical activity. No information is available at the time of the writing of this report to indicate the presence of dedicated ground-based monitoring at Nightingale Island, however one British Geological Survey monitored seismometer is used at Tristan da Cunha.

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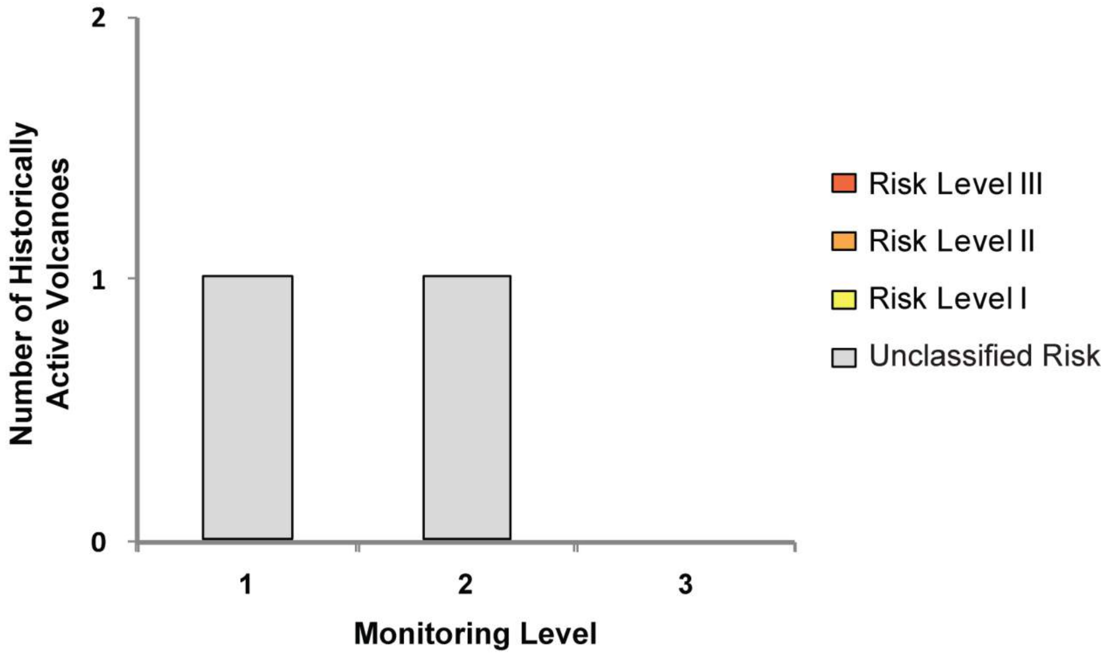

Figure 18.18 The monitoring and risk levels of the historically active volcanoes in Tristan da Cunha and Nightingale Island. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Region 19: Antarctica

Description

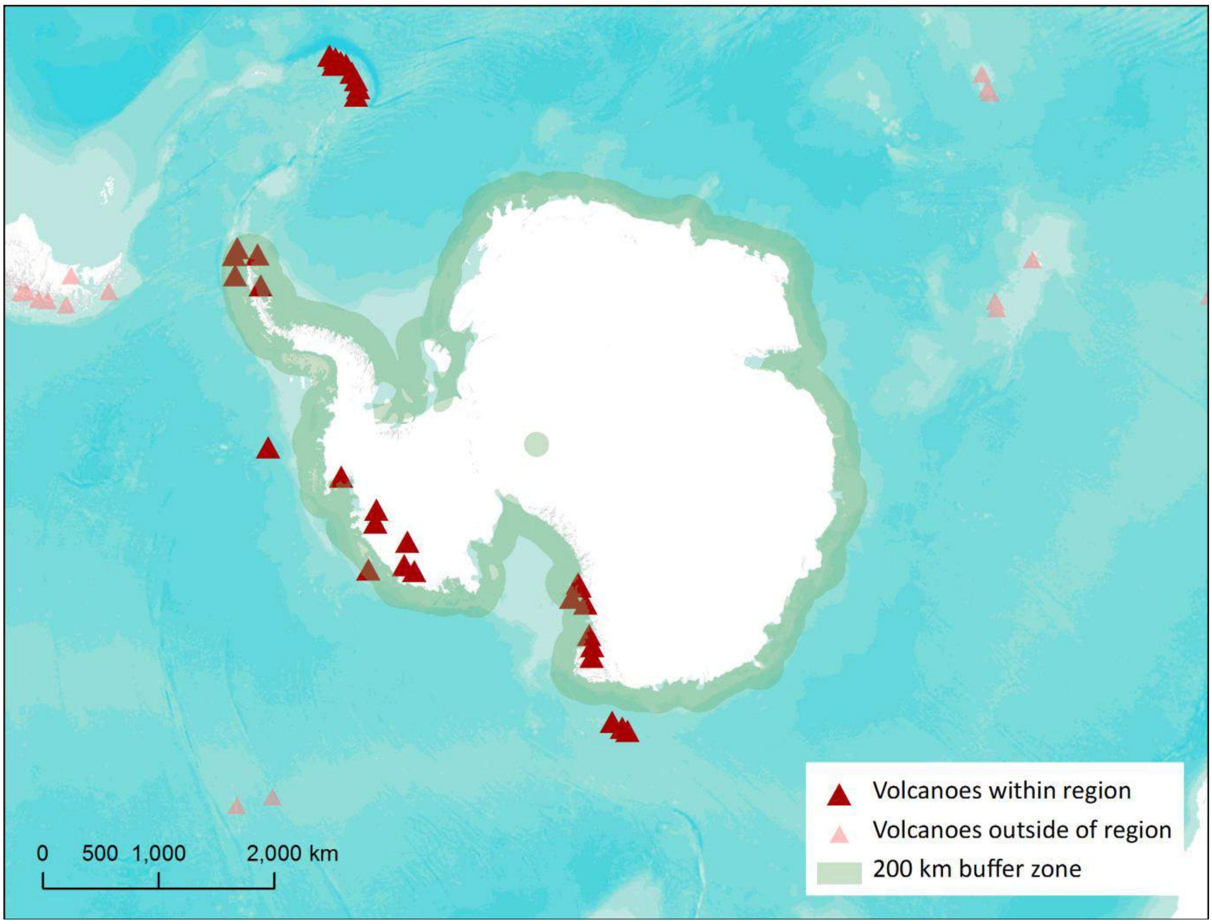

Figure 19.1 The distribution of Holocene volcanoes through the Antarctica region. A zone extending 200 km beyond the region's borders shows other volcanoes whose eruptions may directly affect Antarctica.

Thirty-two Holocene volcanoes are located in Antarctica. Half of these volcanoes have no confirmed eruptions recorded during the Holocene, and therefore the activity state is uncertain. A further volcano, Mount Rittmann, is not included in this count as the most recent activity here was dated in the Pleistocene, however this is geothermally active as discussed in Herbold et al. (2014). The region includes the South Sandwich Islands (a British Overseas Territory) and other island groups adjacent to Antarctica. Note that the volcanoes included and discussed here are described as country "Antarctica" and "UK" in VOTW4.0. Many of these volcanoes are related to rift and extension in the West Antarctic Rift System. Holocene volcanoes on the Antarctic continent except those on the northern tip of the Antarctic Peninsula are located in the West Antarctic Rift System. Those in the South Sandwich Islands are related to subduction processes. The range of tectonic settings here results in a range of compositions and volcano morphologies.

Eighty confirmed Holocene eruptions of VEI 0 - 4 are recorded in Antarctica, indicating mild activity to large explosive events, with small VEI 0 events with associated lava flows dominating the record. Although few large explosive eruptions are recorded in the Holocene, there is a record of VEI ≥4

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eruptions in the Pleistocene, with the largest recorded Quaternary eruption occurring at 1.7 Ma with the M7 Eltanin eruption of Young Island. This latter eruption is uncertain, having initially been identified through tephra studies by Huang et al., (1975) as a single large rhyolitic eruption from the Balleny Islands, then proposed as as product from the North Island, New Zealand by Kyle and Seward (1984) and later identified as several eruptive events from the Antarctica region by Shane and Froggatt (1992). Shane and Froggatt (1992) identified seven rhyolitic tephra zones between 2 and >0.06 Ma, and suggested stratovolcanoes in Marie Byrd Land as the likely sources. Fifty-two of these Holocene eruptions are recorded in historical times (since 1500 AD), however over 90% of these have in fact been recorded since 1800 AD, due to an increase in exploration and visual observations.

No permanent population resides in Antarctica, with only a transitory population of workers (mainly researchers), which grows to its maximum of a few thousand in the summer months. Due to this low population no eruptions have reported fatalities and the volcanoes are all low risk, however the hazard is still poorly understood at many of Antarctica's volcanoes.

Mount Erebus has long-term lava lake activity with occasional explosions and larger Strombolian activity. This activity, ongoing since at least 1972, has led to the establishment of the Mount Erebus Volcano Observatory (MEVO) with research undertaken primarily by the New Mexico Institute of Mining and Technology. Seismic and gas monitoring is undertaken and GPS and tiltmeters are used to investigate the deformation of the volcano. Although there is no permanent population here, the US base of McMurdo and the New Zealand Scott Base are located within 40 km of Erebus.

The Observatory Volcanologico Decepcion (OVD) was established by the Argentine Antarctic Institute, University of Buenos Aires and Higher Council for Scientific Research (CSIC), Spain, to study and monitor Deception volcano. Ground monitoring activities take place in the summer of each year, when seismic, gas, deformation and additional monitoring is undertaken. Monitoring and research is undertaken gain a better understanding of activity here and to provide forecasts of activity. No permanent population resides here, but significant numbers of scientists and tourists visit.

Mount Melbourne has been monitored by the Italian Antarctic Program in the past and the Korea Polar Research Institute plans to undertake monitoring here (P. Kyle, pers. comm. 2014).

See also:

Observatorio Volcanologico Decepcion: www.dna.gov.ar/CIENCIA/OVD/INDEX.HTM

Mount Erebus Volcano Observatory: erebus.nmt.edu/index.php/general-information

Herbold, C.W., McDonald, I.R., and Cary, S.C. (2014) Microbial Ecology of Geothermal Habitats in Antarctica. In: D.A. Cowan (ed*) Antarctic Terrestrial Microbiology*, Springer-Verlag, Berlin Heidelberg.

Huang, T.C., Watkins, N.D. and Shaw, D.M. (1975) Atmospherically transported volcanic glass in deep-sea sediments: volcanism in sub-Antarctic latitudes of the South Pacific during late Pliocene and Pleistocene time. *Geological Society of America Bulletin*, 86: 1305-1315.

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Kyle, P.R. and Seward, D. (1984) Dispersed rhyolitic tephra from New Zealand in deep-sea sediments of the Southern Ocean. *Geology*, 12: 487-490.

Shane, P.R. and Froggatt, P.C. (1992) Composition of widespread volcanic glass in deep-sea sediments of the Southern Pacific Ocean: an Antarctic source inferred. *Bulletin of Volcanology,* 54: 595-601.

Volcano facts

Number of Holocene volcanoes	32
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	0
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	4
Number of eruptions with fatalities	0
Number of fatalities attributed to eruptions	0
Tectonic settings	3 Rift zone, 20 Intra-plate, 9 Subduction zone
Largest recorded Pleistocene eruption	The M7 Eltanin eruption of Young Island at 1.7 Ma is the largest recorded Quaternary eruption in this region, however this event is uncertain with various authors attributing it to volcanic activity at other volcanoes and/or to multiple smaller eruptions: see Huang et al., (1975), Kyle and Seward (1984), and Shane and Froggatt (1992).
Largest recorded Holocene eruption	The largest Holocene eruption recorded in LaMEVE is the M4.7 eruption of the Hudson Mountains in 2160 BP.
Number of Holocene eruptions	80 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	12
Number of historical eruptions	52

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Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Basaltic (1)
16	Large cone(s)	Andesitic (4), Basaltic (10), Phonolitic (1), Trachytic/Andesitic (1)
9	Shield(s)	Basaltic (5), Phonolitic (1), Trachytic/Andesitic (3)
4	Small cone(s)	Andesitic (1), Basaltic (3)
2	Submarine	Rhyolitic (1), Unknown (1)

Table 19.1 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	3
Large (> VEI 3)	

Table 19.2 Average recurrence interval (years between eruptions) for small and large eruptions in Antarctica.

The eruption record indicates that on average small- to moderate- sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 3 years.

Eruption Size

Eruptions are recorded through Antarctica of VEI 0 to 4, representing a range of eruption styles from gentle effusive events, to explosive eruptions. VEI 0 and 2 events dominate the record, with about 80% of all Holocene eruptions classed as such. Fewer than 2% of eruptions here are explosive at VEI ≥4.

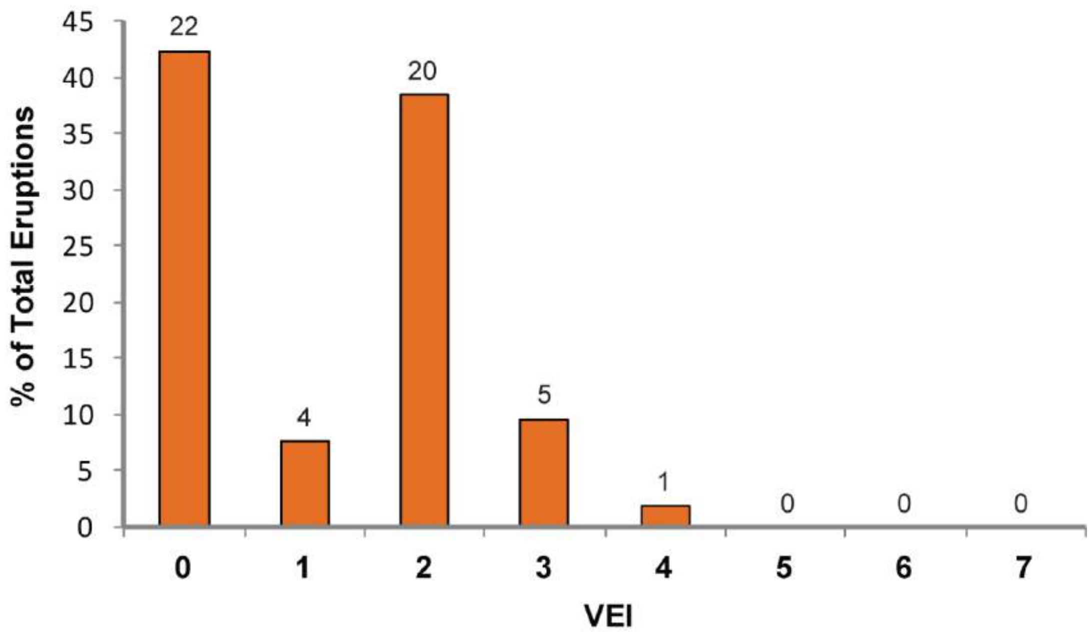

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Figure 19.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 28 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	No permanent residents. 1,100 staff in research stations during the winter, 4000 in the summer, 1000 additional offshore workers[2].
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 100 km of a Holocene volcano	0 (0%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Antarctica are widespread. Three ports are located within 100 km of the volcanoes here, but otherwise, with no permanent population living on Antarctica, there is little infrastructure exposed to the volcanic threat. McMurdo Station, which is situated between Erebus and Mt.

[2] www.cia.gov/library/publications/the-world-factbook/geos/ay.html

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Morning, has seasonal runways with significant air traffic from October to March which could be impacted by ash eruptions.

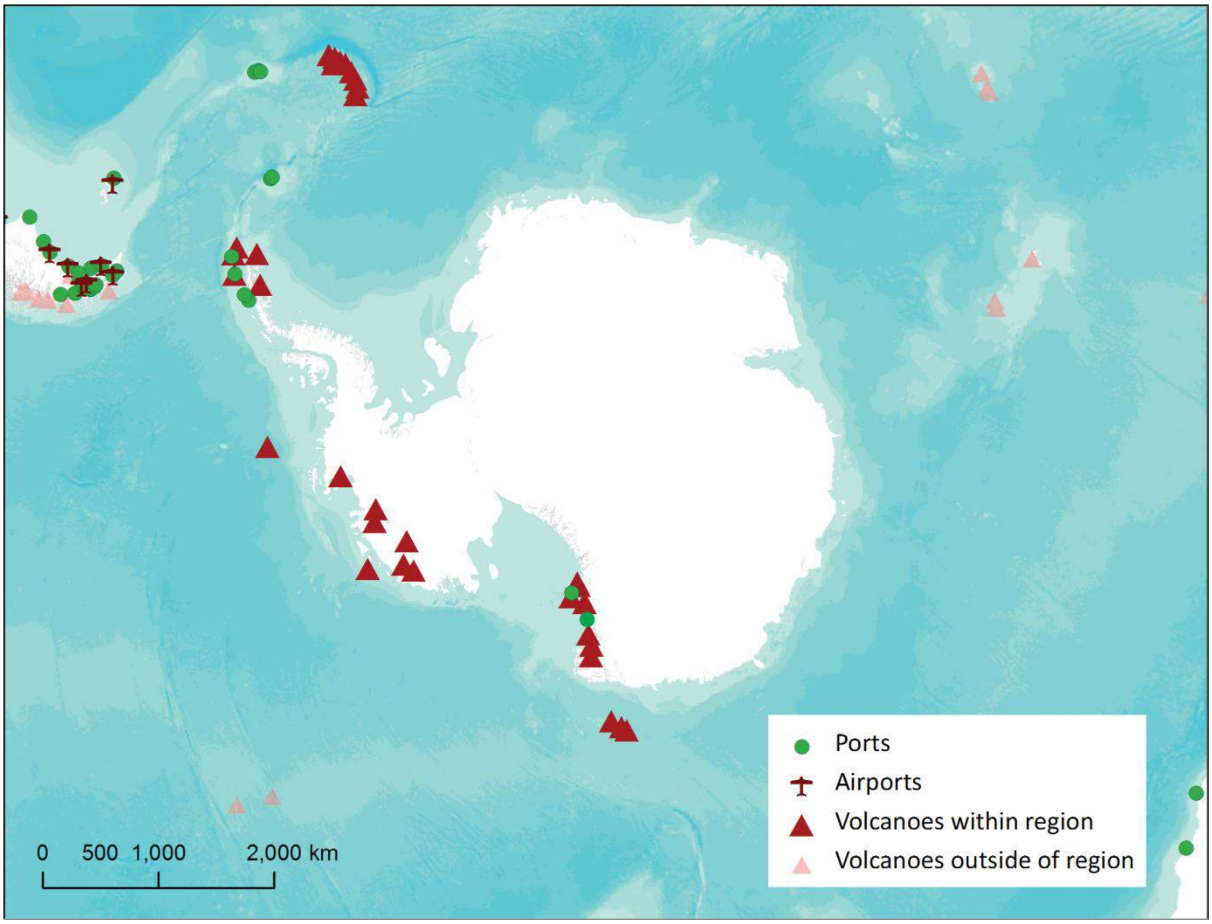

Figure 19.3 The location of Antarctica's volcanoes and ports.

Hazard, Uncertainty and Exposure Assessments

Of the 32 volcanoes in Antarctica, just four have assigned hazard levels: Deception Island, Erebus, Bristol Island and Michael. These volcanoes have a history of dominantly VEI 0 – 2 eruptions, frequently producing lava effusions and as such these are classed at Hazard Levels I and II.

The absence of extensive eruption records at the remaining volcanoes prevents hazard assessment without large uncertainties, and these are therefore unclassified. Of these, 16 have no confirmed Holocene eruptions. Eight unclassified volcanoes have records of historical eruptions, five of which have had eruptions since 1900: Penguin Island, Thule Islands, Montagu Island, Candlemas Island and Protector Shoal. Four unclassified volcanoes have experienced unrest above background levels since 1900.

With no permanent population in Antarctica, all volcanoes are classed as PEI 1, which therefore would categorise these as Risk Level I, regardless of the Hazard Level.

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CLASSIFIED	**Hazard III**							
	Hazard II	Deception Island						
	Hazard I	Erebus; Bristol Island; Michael						
UNCLASSIFIED	**U – HHR**	Buckle Island; **Melbourne**; **Penguin Island; Thule Islands**; **Montagu Island**; **Candlemas Island**; Zavodovski; **Protector Shoal**						
	U- HR	Pleiades, The; Berlin; Takahe; Hudson Mountains						
	U- NHHR	Young Island; Sturge Island; Unnamed; Unnamed; Morning, Mount; Royal Society Range; **Andrus**; Waesche; Siple; Toney Mountain; Peter I Island; Bridgeman Island; Paulet; **Seal Nunataks Group**; Hodson; **Leskov Island**						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 19.3 Identity of Antarctica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

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Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
0	2
32	1

Table 19.4 The number of volcanoes in Antarctica classed in each PEI category.

Volcano	Population Exposure Index	Risk Level
Bristol Island	1	I
Deception Island	1	I
Erebus	1	I
Michael	1	I

Table 19.5 Classified Volcanoes of Antarctica ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given.

Risk Levels for Classified volcanoes

Number of Volcanoes	Risk Level
0	III
0	II
4	I
28	Unclassified

Table 19.6 The number of volcanoes in the Antarctica region classified at each Risk Level.

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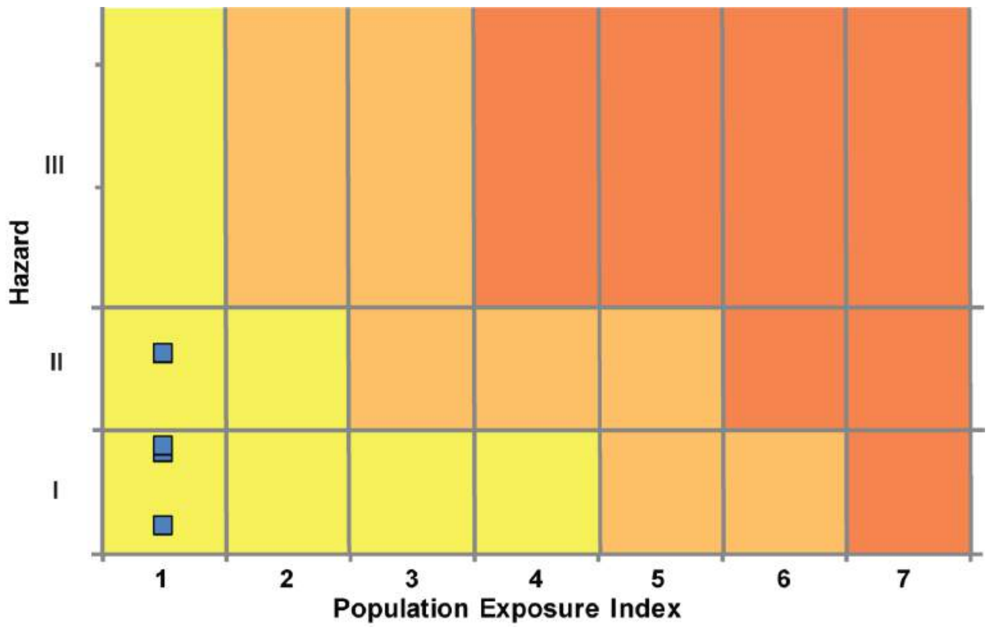

Figure 19.4 Distribution of the classified volcanoes of Antarctica across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Four Risk Level I volcanoes in Antarctica have records of historic activity. Of these Erebus and Deception have regular dedicated ground-based monitoring, including the use of seismic networks, gas and deformation monitoring. These systems are operated by the Mount Erebus Volcano Observatory and Observatory Volcanológico Deception. A further eight unclassified volcanoes (with no local populations) have historical records of activity but no current monitoring.

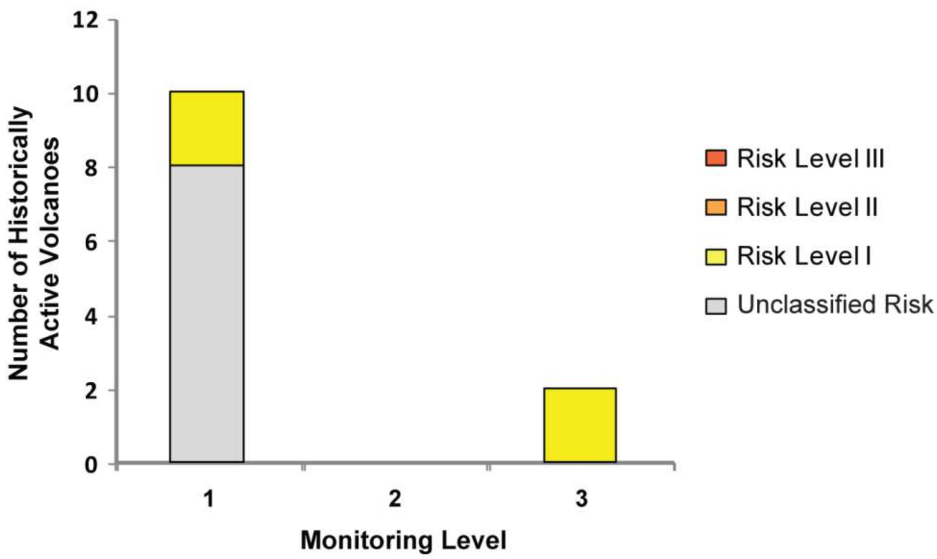

Figure 19.5 The monitoring and risk levels of the historically active volcanoes in Antarctica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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