2018 Update to the U.S. Geological Survey National Volcanic Threat Assessment

Scientific Investigations Report 2018–5140

U.S. Department of the Interior
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Cover. Lava fountains and channelized flow erupting from the Fissure 8 spatter cone along Kīlauea’s Lower East Rift Zone in the Leilani Estates subdivision, lower Puna, Hawai‘i, on June 25, 2018. Photograph by Ben Gaddis, U.S. Geological Survey.

Cover Background. Aerial view of the upper part of the May 18, 1980, eruption of Mount St. Helens. Photograph by U.S. Geological Survey.

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Contents

Figures

Tables

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Abstract

When erupting, all volcanoes pose a degree of risk to people and infrastructure, however, the risks are not equivalent from one volcano to another because of differences in eruptive style and geographic location. Assessing the relative threats posed by U.S. volcanoes identifies which volcanoes warrant the greatest risk-mitigation efforts by the U.S. Geological Survey and its partners. This update of the volcano threat assessment of Ewert and others (2005) considers new research in order to determine which volcanic systems should be added or removed from the list of potentially active volcanoes, updates the scoring of active volcanoes, and updates the 24-factor hazard and exposure matrix used to create the threat ranking. The threat assessment places volcanoes into five threat categories: very low, low, moderate, high, and very high. Within all five threat categories there are changes in relative rankings of volcanoes, and in a few cases, volcanoes moved between categories owing to changes in our understanding of their hazard, unrest, and exposure factors. Scorings of hazard factors were updated for some volcanoes where new research has identified Holocene eruptive activity or clarified our understanding of Holocene eruptive history and the occurrence of particular hazards such as tephra fall or pyroclastic density currents. The most numerous scoring changes made in the threat matrix since 2005 have been made among the hazard factors, particularly those accounting for observed eruptive activity or unrest.

The very low threat category underwent the greatest amount of change, dropping from 32 to 21 volcanoes, owing to better knowledge of the eruptive histories of those volcanoes. The list of 18 very high threat volcanoes determined by Ewert and others (2005) remains the same; 11 of the 18 volcanoes are located in Washington, Oregon, or California, where explosive and often snow- and ice-covered edifices can project hazards long distances to densely populated and highly developed areas. Five of the 18 very high threat volcanoes are in Alaska near important population centers, economic infrastructure, or below busy air traffic corridors. The remaining two very high threat volcanoes are on the Island of Hawai‘i, where densely populated and highly developed areas now exist on the flanks of highly active volcanoes. The high- and moderate-threat categories are dominated by Alaskan volcanoes. In these categories the generally more active and more explosive volcanoes in Alaska can have a substantial effect on national and international aviation, and large eruptions from any of the moderate- to very-high-threat volcanoes could cause regional or national-scale disasters. This revised threat assessment includes 18 very high threat, 39 high threat, 49 moderate threat, 34 low threat, and 21 very low threat volcanoes. The total of 161 volcanoes is a decrease of 8 from the total reported by Ewert and others (2005).

Introduction

Volcanoes produce many kinds of destructive phenomena. In the United States over the past 38 years, communities have been overrun by lava flows in Hawaii (fig. 1) and in Washington State, a powerful explosion has devastated huge tracts of forest and killed people tens of miles from the volcanic source (fig. 2), and debris avalanches and mudflows have choked major river ways, destroyed bridges, and swept people to their deaths (fig. 3). In California, noxious gas emissions have resulted in fatalities, and in Hawaii, given rise to widespread respiratory ailments. Airborne ash clouds have caused hundreds of millions of dollars of damage to aircraft and nearly brought down passenger jets in flight in U.S. and international airspace (fig. 4), and ash falls have caused agricultural losses and disrupted the lives and businesses of hundreds of thousands of people in Washington State and Alaska (fig. 5). The growing risk of such severe threats to communities, property, and infrastructure downstream and downwind of volcanoes drives the need to decipher past eruptive behavior, monitor the current activity, and mitigate damaging effects of these forces of nature (Munich RE, 2016).

The United States is one of Earth's most volcanically active countries, having within its territory more than 10 percent of the known active and potentially active volcanoes (Simkin and Siebert, 2000; Global Volcanism Program, 2013). The geographic footprint of U.S. volcanoes is large, extending from arctic Alaska in the north to tropical American Samoa south of the Equator, and from Colorado in the east to the Commonwealth of the Northern Mariana Islands in the western Pacific (fig. 6). Since 1980, there have been 120 eruptions and 52 episodes of notable volcanic unrest (increased

Figure 1. Lava flows erupted from fissures along Kīlauea's Lower East Rift Zone inundated communities in lower Puna, Hawai'i during the spring and summer of 2018. Photograph by Matt Patrick, U.S. Geological Survey.

Figure 2. Forest and logging truck destroyed by lateral blast from May 18, 1980, eruption of Mount St. Helens. Photograph by U.S. Geological Survey.

Figure 3. Washington State Highway 504 steel bridge structure carried about 0.5 kilometers (0.25 miles) downstream and partly buried by the May 18, 1980, mudflow from Mount St. Helens. Photograph by R.L. Schuster, U.S. Geological Survey.

Figure 4. Ascending eruption cloud from Redoubt Volcano as viewed to the west from the Kenai Peninsula on April 21, 1990. An encounter with an eruption cloud from Redoubt nearly brought down a passenger jetliner in 1989. Photograph by R. Clucas, U.S. Geological Survey.

Figure 5. Ash from the May 18, 1980, eruption of Mount St. Helens covering the ground and road at a farm in Connell, Washington, approximately 300 kilometers (180 miles) from the volcano. Photograph by Lyn Topinka, U.S. Geological Survey.

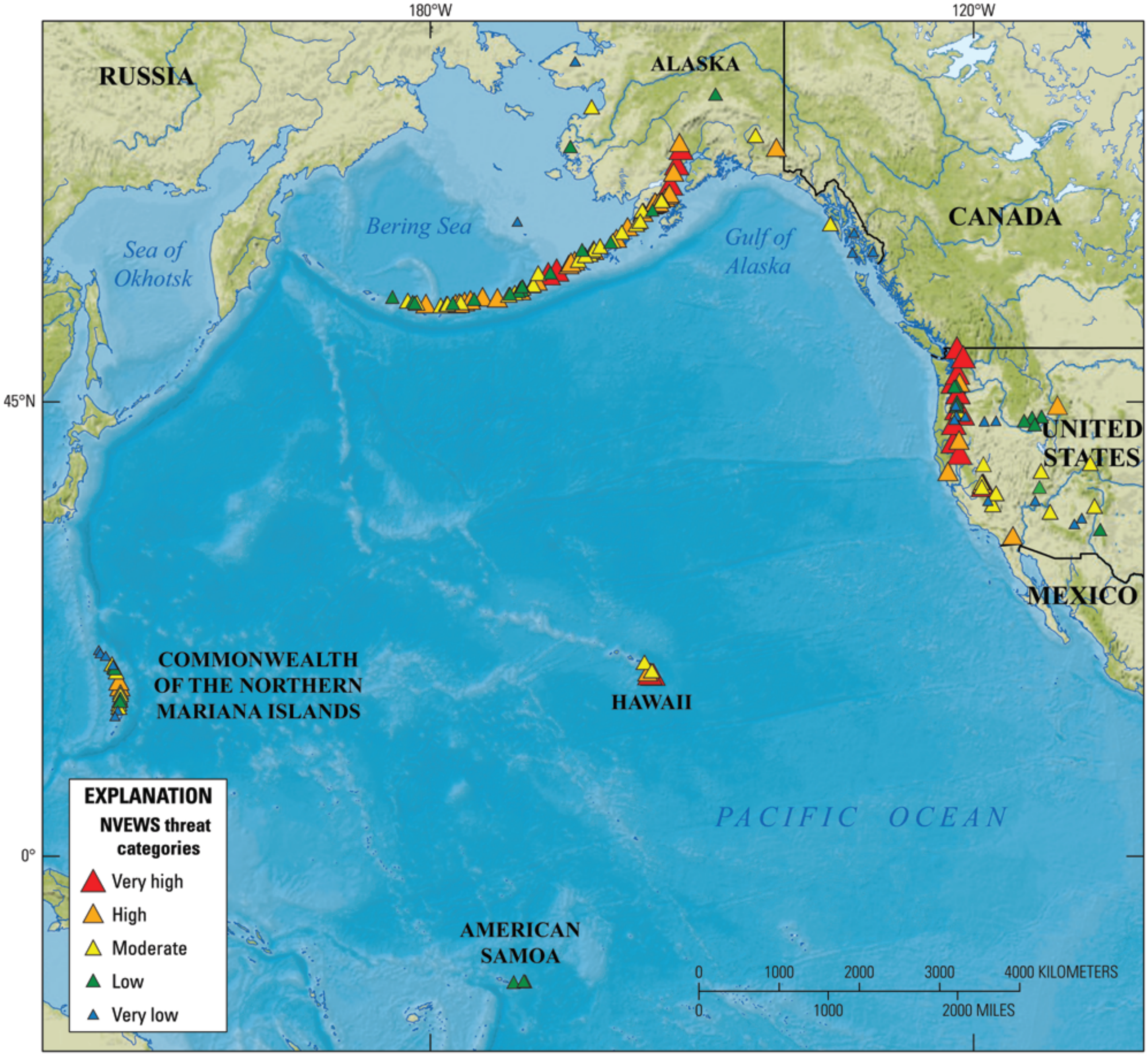

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Figure 6. Map showing locations of all U.S. volcanoes with threat category designated by color. NVEWS, National Volcano Early Warning System.

Table 1. Description and chronology of volcanic eruptions and unrest in the United States from 1980 through 2017, updated from Diefenbach and others (2009).

[GVP, Global Volcanism Program; VEI, volcanic explosivity index (eruption magnitude); *, approximate date; ?, unknown date; DD MMM YYYY, day month year]

GVP volcano number	Volcano	Eruption dates (DD MMM YYYY) and VEI (in parentheses)	Unrest episode (DD MMM YYYY)
		Hawai`i	
332000	Lōʻihi seamount	25 Feb 1996 - 09 Aug 1996[a] (0)	
332010	Kīlauea-Puʻu ʻŌʻō (East Rift Zone)	11 Mar 1980 - 11 Mar 1980 (0) 03 Jan 1983 - present (1)	
332010	Kīlauea-Halemaʻumaʻu (summit area)	30 Apr 1982 - 01 May 1982 (0) 25 Sep 1982 - 26 Sep 1982 (0) 12 Mar 2008 - present (1)	
332020	Mauna Loa	25 Mar 1984 - 15 Apr 1984 (0)	Inflation and deep seismicity: 24 Apr 2002 - 30 Mar 2010 Elevated seismicity and inflation: 17 Sep 2015 - present
		Conterminous United States	
321050	Mount St. Helens, Washington	27 Mar 1980 - 26 Oct 1986 (5) 07 Dec 1989 - 06 Jan 1990 (2) 05 Nov 1990 - 14 Feb 1991 (3[b]) 01 Oct 2004 - 27 Jan 2008 (2)	Elevated seismicity: 01 Jan 1995 - Oct 1995 Elevated seismicity and CO_2 detection: May 1998 - Jul 1998
322010	Mount Hood, Oregon		Earthquake swarm: 06 Jul 1980 - 05 Aug 1980 Earthquake swarm: 11 Jan 1999 - 14 Jan 1999 Earthquake swarm: 10 Jan 2001 - 19 Jan 2001 Earthquake swarm: 29 Jun 2002 - 29 Jun 2002
322070	South Sister, Oregon		Uplift began 1998* - continues at present (earthquake swarm: 23 Mar 2004 - 25 Mar 2004)
323020	Medicine Lake, California		Earthquake swarm: 29 Sep 1988 - 15 Nov 1988
323822	Long Valley Caldera, California		Recurrent earthquake swarms, changes in thermal springs and gas emissions, and uplift since 25 May 1980 and CO_2 emission from ground since 01 May 1989
325010	Yellowstone caldera, Wyoming		Recurrent earthquake swarms and ground deformation (uplift and subsidence), changes in hydrothermal features: 1980 - present
		Alaska	
311020	Kiska Volcano	01 Jun 1990 - 01 Jun 1990 (2)	
311050	Little Sitkin Island		Earthquake swarms: 29 Aug 2012 - 09 Jan 2013*
311060	Semisopochnoi Island	13 Apr 1987 - 26 May 1987 (2[c])	Earthquake swarm: 09 Jun 2014 - 04 Sep 2014* Earthquake swarm: ?? Jan 2015 - 28 May 2015*
311070	Mount Gareloi	07Aug 1980 - 17 Sep 1980 (3[b]) 15Jan 1982 - 15 Jan 1982 (3) 04 Sep 1987 - ? (1[b]) 17 Aug 1989 - ? (1)	
311080	Tanaga Volcano		Earthquake swarm: 01 Oct 2005 -25 Nov 2005

Table 1. Description and chronology of volcanic eruptions and unrest in the United States from 1980 through 2017, updated from Diefenbach and others (2009).—Continued

GVP volcano number	Volcano	Eruption dates (DD MMM YYYY) and VEI (in parentheses)	Unrest episode (DD MMM YYYY)
311110	Kanaga Volcano	05 Jan 1994 - 23 Jun 1995 (2) 18 Feb 2012 (2)	
311120	Great Sitkin Volcano		Earthquake swarms: ?? Feb 2001 - ?? Sep 2001 Earthquake swarms: 27 May 2002 - 28 May 2002 Earthquake swarms: ?? Jul 2013 - ?? Aug 2013 Earthquake swarms, vigorous steam plumes: 22 Nov 2017 - present
311130	Kasatochi Island	07 Aug 2008 - 08 Aug 2008 (4)	
311161	Korovin Volcano	04 Mar 1987 - 18 Mar 1987 (2) 30 Jun 1998 - 30 Jun 1998* (3)	Earthquake swarms, steam, and ash plumes: 23 Feb 2005 - 07 May 2005 Elevated seismicity and fumarolic activity: 16 Jan 2006 - ?? Sep 2007* Earthquake swarms: 29 Mar 2013 - 12 Apr 2013
311180	Seguam Island	27 Dec 1992 - 30 Dec 1992 (2) 28 May 1993 - 19 Aug 1993* (2)	
311190	Amukta Island	04 Sep 1987 - 04 Sep 1987* (1) ?? Jul 1996 - ?? Sep 1996 (1)	
311240	Mount Cleveland	12 Jul 1984 - 12 Jul 1984 (1) 28 Apr 1986 - 27 May 1986 (2) 19 Jun 1987 - 28 Aug 1987 (3) 25 May 1994 - 25 May 1994 (3) 05 May 1997 - 05 May 1997 (2) 02 Feb 2001 - 15 Apr 2001 (3) 27 Apr 2005 - 27 Sep 2005 (2) 06 Feb 2006 - 28 Oct 2006 (3) ?? Jun 2007 - 04 Sep 2008* (2) 02 Jan 2009 - 21 Jan 2009 (2) 25 Jun 2009 - 25 Jun 2009 (2) 02 Oct 2009 - 12 Dec 2009* (2) 30 May 2010 - 02 Jun 2010* (2) 16 Jul 2011 - 13 May 2013 (2) 28 Dec 2013 - 05 Jun 2014* (2) 14 Jun 2015 - 30 Sep 2015 (1) 16 Apr 2016 - 18 May 2016 (0) 24 Oct 2016 (1) 02 Mar 2017 - present (?)	Thermal anomalies: 26 Aug 2010 - 10 Sep 2010 Thermal anomalies, possible ash plume, and fumarolic activity: 12 Sep 2010 - 31 Mar 2011
311290	Mount Okmok	24 Mar 1981 - 24 Mar 1981 (3[b]) 08 Jul 1983 - 08 Jul 1983 (2) 18 Nov 1986 - 26 Feb 1988* (2) 13 Feb 1997 - 23 May 1997 (3) 12 Jul 2008 - 19 Aug 2008 (4)	Earthquake swarm: 11 May 2001 - 15 May 2001 Earthquake swarms and inflation: 17 Mar 2013 - 2014?
311300	Bogoslof Island	06 Jul 1992 - 24 Jul 1992 (3) 21 Dec 2016 - 30 Aug 2017 (3)	
311310	Makushin Volcano	?? May 1980 - ? (1) 30 Jan 1995 - 30 Jan 1995 (1)	Elevated seismicity: ?? Jul 2000 - ?? Jun 2001
311320	Akutan Island	08 Jul 1980 - 08 Aug 1980 (2) 07 Oct 1982 - ?? May 1983 (2) 03 Feb 1986 - 14 Jun 1986 (2) 31 Jan 1987 - 24 Jun 1987 (2) 26 Mar 1988 - 20 Jul 1988 (2) 27 Feb 1989 - 31 Mar 1989 (2) 22 Jan 1990 - 22 Jan 1990* (2) 06 Sep 1990 - 01 Oct 1990 (2) 15 Sep 1991 - 28 Nov 1991* (2) 08 Mar 1992 - 31 May 1992 (2) 18 Dec 1992 - ? (1)	Intense earthquake swarm and intrusion with ground cracks: 10 Mar 1996 - 18 Mar 1996

Table 1. Description and chronology of volcanic eruptions and unrest in the United States from 1980 through 2017, updated from Diefenbach and others (2009).—Continued

GVP volcano number	Volcano	Eruption dates (DD MMM YYYY) and VEI (in parentheses)	Unrest episode (DD MMM YYYY)
311340	Westdahl Peak	29 Nov 1991 - 15 Jan 1992* (3)	
311360	Shishaldin Volcano	19 Mar 1986 - ?? Mar 1987 (2) 23 Dec 1995 - 16 May 1996* (3) 02 Jun 1997 - 02 Jun 1997 (1) 09 Feb 1999 - 28 May 1999 (3) 17 Feb 2004 - 17 May 2004 (2) 28 Jan 2014 - 16 Oct 2015 (1)	Small phreatic explosions: 25 Sep 1999 - 04 Feb 2000 Increased seismicity: 15 May 2002 - 16 Aug 2002* Earthquakes, tremor, and thermal anomalies: 22 Feb 2005 - 22 Feb 2005 Elevated seismicity, low-level steam plumes, and thermal anomalies: 06 Jan 2009 - 11 Feb 2009 Increased thermal anomalies: ?? Jun 2009 - 16 Aug 2009 Increased seismicity and infrasound activity: 06 Dec 2017 - present
312011	Mount Dutton		Earthquake swarm: 10 Jul 1988 - 08 Aug 1988
312030	Pavlof Volcano	08 Nov 1980 - 13 Nov 1980 (3) 25 Sep 1981 - 27 Sep 1981 (3) 11 Jul 1983 - 18 Jul 1983 (2[b]) 14 Nov 1983-18 Dec 1983 (3) 16 Apr 1986 - 13 Aug 1988 (3) 05 Jan 1990 - 05 Mar 1990 (2) 16 Sep 1996 - 03 Jan 1997 (2) 15 Aug 2007 - 13 Sep 2007 (2) 13 May 2013 - 26 Jun 2013 (3) 31 May 2014 - 02 Jun 2014 (3) 12 Nov 2014 - 15 Nov 2014 (1) 27 Mar 2016 - 30 Jun 2016 (2)	Elevated seismicity: 07 Jun 2017 - 30 Aug 2017
312070	Mount Veniaminof	02 Jun 1983 - 17 Apr 1984 (3) 29 Nov 1984 - 09 Dec 1984 (2) 30 Jul 1993 - 28 Aug 1994* (2) 17 Apr 1995 - 30 Nov 1995 (1) 28 Sep 2002 - 23 Mar 2003 (1) 19 Feb 2004 - ?? Sep 2004 (2) 04 Jan 2005 - 25 Feb 2005* (2) 07 Sep 2005 - 04 Nov 2005 (1) 03 Mar 2006 - 07 Sep 2006 (1) 22 Feb 2008 - 27 Feb 2008* (1) 13 Jun 2013 - 12 Oct 2013* (3)	Elevated seismicity and steam plumes: 08 Jan 2009* - 19 Oct 2009 Elevated seismicity: 01 Oct 2015 - present
312110	Mount Chiginagak		Fumarolic activity and steam plumes: 22 Oct 1997 - 21 Aug 1998 Changes in hydrothermal features, gas emissions, and a lahar occurred: ?? Nov 2004 - ?? Jul 2005*
312140	Mount Martin		Strong seismic swarm: 08 Jan 2006 - 22 Jan 2006
312260	Fourpeaked Mountain	17 Sep 2006 - 17 Sep 2006 (2)	
313010	Augustine Volcano	27 Mar 1986 - 10 Sep 1986 (4) ?? Dec 2005 - 31 Mar 2006 (3)	
313020	Iliamna Volcano		Earthquake swarm and elevated gas emission: 10 May 1996 - ?? Feb 1997 Elevated seismicity and gas emissions: 22 Dec 2011 - 09 Jan 2013
313030	Redoubt Volcano	14 Dec 1989 - ?? Jun 1990 (3) 15 Mar 2009 - 01 Jul 2009* (3)	Repetitive earthquake swarm: 05 Apr 2010 - 12 Apr 2010
313040	Mount Spurr	27 Jun 1992 - 17 Sep 1992 (4)	Elevated seismicity, melt pit at summit, and increase in CO_2 and SO_2 emissions: ?? Jul 2004 - ?? Feb 2006
	Commonwealth of the Northern Mariana Islands		
284160	Agrigan Island		Increased fumarolic activity: 01 Aug 1990 - 06 Oct 1990

Table 1. Description and chronology of volcanic eruptions and unrest in the United States from 1980 through 2017, updated from Diefenbach and others (2009).—Continued

GVP volcano number	Volcano	Eruption dates (DD MMM YYYY) and VEI (in parentheses)	Unrest episode (DD MMM YYYY)
284170	Pagan Island	15 May 1981 - 01 May 1985* (4) 04 Sep 1987 - 04 Sep 1987 (1) 24 Aug 1988 - 12 Oct 1988 (2) 13 Apr 1992 - 13 Apr 1992 (1) 15 Jan 1993* - ?? Nov 1993 (2) 04 Dec 2006 - 08 Dec 2006 (1) 15 Apr 2009 - 28 Apr 2009* (?) 03 May 2010 - 11 Aug 2010 (1) 23 Apr 2011 - 01 Sep 2011*(2) 30 Oct 2012 - 11 Dec 2012*(2)	Intermittent, low level steam and gas plumes: 12 Aug 2010 - 22 Feb 2011 Elevated seismicity and vapor and gas plumes: ?? May 2014* - present
284200	Anatahan Island	10 May 2003 - 12 Jul 2003* (3) 12 Apr 2004 - 03 Sep 2005* (3) 20 Mar 2006 - 26 Jun 2006* (2) 27 Nov 2007* - 09 Aug 2008* (2)	Earthquake swarm, crater lake refills: 30 Mar 1990 - 31 Oct 1990 Earthquake swarm: 29 May 1993 - ?? Sep 1993
284141	Ahyi Seamount	24 Apr 2001 - 25 Apr 2001[a] (0) 24 Apr 2014 - 08 May 2014*[a] (0)	
284193	South Sarigan seamount	27 May 2010*- 29 May 2010*[a,c] (3)	Earthquake swarm: 09 Aug 2005 - 19 Aug 2005
284202	Ruby	11 Oct 1995 - 25 Oct 1995[a] (0)	
284211	NW Rota-1	2003*- 2010*[a] (0)	

[a]Submarine eruption.

[b]Inferred VEI assignment owing to difficulty of designation or based on anecdotal evidence.

[c]Vent source unknown, nearest volcano attributed with eruption.

seismicity, observed ground deformation, and (or) gas emission) at 44 U.S. volcanoes (table 1; Diefenbach and others, 2009).

In 2005 the U.S. Geological Survey (USGS) published a national volcanic threat assessment to help prioritize U.S. volcanoes for research, monitoring, and mitigation efforts based on objective measures of volcano hazards and exposure of people and infrastructure to those hazards (Ewert and others, 2005; Ewert, 2007). This report is an update of Ewert and others (2005), considering recent field and laboratory research on U.S. volcanoes, which has allowed us to add and remove volcanic systems on the list of potentially active volcanoes, to modify or combine nomenclature for several more volcanic systems, and to update the hazard and exposure factors used to determine threat level. In total, 40 volcanic systems had their inclusion status changed. The net result of this update is that we now include 161 volcanoes in the U.S. volcanic threat assessment, which is 8 fewer than in 2005. Within the five threat categories, there are some changes in the relative numeric rankings of volcanoes, and in a few cases, volcanoes moved between categories. Importantly, the 18 volcanoes assessed as very high threat did not change with respect to the original threat assessment by Ewert and others (2005) (table 2).

The original U.S. volcanic threat assessment was conducted simultaneously with an assessment of national volcano monitoring capabilities with the goal to establish a framework for a National Volcano Early Warning System (NVEWS; Ewert and others, 2005). This report is not an update on the NVEWS initiative, and we do not address monitoring improvements or status here, nor do we describe other measures which have been introduced to mitigate risk since 2005.

In updating the list of volcanoes to be considered in the U.S. volcanic threat assessment, we follow Ewert and others (2005) in using the Smithsonian Institution-Global Volcanism Program's (SI-GVP) Volcanoes of the World (VOTW) database of volcanoes that have been active in Holocene time as the basis for which volcanoes are assessed. Generally speaking, volcanoes that have erupted during the Holocene—defined by the International Commission on Stratigraphy as 11,650 calendar years before 1950 (Walker and others, 2009)—are considered by volcanologists to be active or potentially active (for example, Simkin and Siebert, 2000). However, volcanoes can have long life spans, sometimes lasting millions of years, with dormant intervals ranging to tens of thousands of years, which makes a precise definition of an active or potentially active volcano problematic. For the purposes of this threat assessment, we considered only those volcanoes that have erupted in the geologically recent past (in Holocene time) in addition to three notably large and long-lived caldera systems (Yellowstone, Wyoming; Valles, New Mexico; and Long Valley, California). We have coordinated

Table 2. Threat ranking for U.S. volcanoes. Threat groups are color coded: very high threat is red, high is orange, moderate is yellow, low is green, and very low is blue.

[AK, Alaska; AS, American Samoa; CA, California; CNMI, Commonwealth of the Northern Mariana Islands; HI, Hawaii; ID, Idaho; NM, New Mexico; OR, Oregon; UT, Utah; WA, Washington]

Rank	Volcano	State	Aviation threat score	Overall threat score	Latitude (in decimal degrees)	Longitude (in decimal degrees)
1	Kīlauea	HI	48	263	19.425	-155.292
2	Mount St. Helens	WA	59	235	46.2	-122.18
3	Mount Rainier	WA	37	203	46.87	-121.758
4	Redoubt Volcano	AK	48	201	60.485	-152.742
5	Mount Shasta	CA	39	178	41.42	-122.2
6	Mount Hood	OR	30	178	45.374	-121.694
7	Three Sisters	OR	30	165	44.133	-121.767
8	Akutan Island	AK	47	161	54.134	-165.986
9	Makushin Volcano	AK	47	161	53.891	-166.923
10	Mount Spurr	AK	48	160	61.299	-152.251
11	Lassen volcanic center	CA	32	153	40.492	-121.508
12	Augustine Volcano	AK	48	151	59.363	-153.43
13	Newberry Volcano	OR	30	146	43.722	-121.229
14	Mount Baker	WA	15	139	48.777	-121.813
15	Glacier Peak	WA	37	135	48.112	-121.113
16	Mauna Loa	HI	4	131	19.475	-155.608
17	Crater Lake	OR	37	129	42.93	-122.12
18	Long Valley Caldera	CA	29	129	37.7	-118.87
19	Mount Okmok	AK	47	117	53.43	-168.13
20	Iliamna Volcano	AK	34	115	60.032	-153.09
21	Yellowstone caldera	WY	27	115	44.43	-110.67
22	Aniakchak Crater	AK	41	112	56.88	-158.17
23	Hualālai	HI	27	109	19.692	-155.87
24	Mono-Inyo Craters	CA	29	106	37.88	-119
25	Mount Martin	AK	23	106	58.172	-155.361
26	Mount Mageik	AK	23	106	58.195	-155.253
27	Trident Volcano	AK	29	106	58.236	-155.1
28	Mount Katmai	AK	35	106	58.28	-154.963
29	Mount Veniaminof	AK	47	102	56.17	-159.38
30	Atka volcanic complex	AK	35	102	52.381	-174.154
31	Korovin Volcano	AK	35	102	52.381	-174.166
32	Shishaldin Volcano	AK	41	93	54.756	-163.97
33	Clear Lake volcanic field	CA	15	92	38.97	-122.77
34	Mount Adams	WA	15	92	46.206	-121.49
35	Hayes Volcano	AK	34	90	61.64	-152.411
36	Westdahl Peak	AK	47	89	54.518	-164.65
37	Novarupta	AK	35	88	58.27	-155.157
38	Mount Churchill	AK	29	82	61.38	-141.75
39	Kanaga Volcano	AK	41	81	51.923	-177.168
40	Ugashik-Peulik volcanic complex	AK	41	81	57.751	-156.368
41	Pavlof Volcano	AK	35	81	55.42	-161.887

Table 2. Threat ranking for U.S. volcanoes. Threat groups are color coded: very high threat is red, high is orange, moderate is yellow, low is green, and very low is blue.—Continued

Rank	Volcano	State	Aviation threat score	Overall threat score	Latitude (in decimal degrees)	Longitude (in decimal degrees)
42	Mount Griggs	AK	23	79	58.354	-155.092
43	Kaguyak Crater	AK	29	79	58.608	-154.028
44	Pagan Island	CNMI	28	79	18.13	145.8
45	Medicine Lake	CA	19	78	41.58	-121.57
46	Great Sitkin Volcano	AK	41	76	52.076	-176.13
47	Kasatochi Island	AK	35	75	52.177	-175.508
48	Mount Cleveland	AK	35	75	52.825	-169.944
49	Mount Moffett	AK	17	73	51.944	-176.747
50	Seguam Island	AK	47	73	52.315	-172.51
51	Fisher Caldera	AK	35	71	54.65	-164.43
52	Snowy Mountain	AK	12	71	58.336	-154.682
53	Fourpeaked Mountain	AK	12	71	58.77	-153.672
54	Mount Douglas	AK	12	71	58.855	-153.542
55	Semisopochnoi Island	AK	41	70	51.93	179.58
56	Salton Buttes	CA	14	68	33.2	-115.62
57	Agrigan Island	CNMI	24	67	18.77	145.67
58	Mount Edgecumbe	AK	23	65	57.05	-135.75
59	Mount Vsevidof	AK	29	65	53.13	-168.693
60	Mount Gareloi	AK	35	64	51.79	-178.794
61	Tanaga Volcano	AK	29	64	51.885	-178.146
62	Alamagan Island	CNMI	24	64	17.6	145.83
63	Anatahan Island	CNMI	18	64	16.35	145.67
64	Mount Dutton	AK	12	63	55.168	-162.272
65	Roundtop Mountain	AK	12	62	54.8	-163.589
66	Kukak Volcano	AK	12	62	58.453	-154.355
67	Mount Recheschnoi	AK	23	61	53.157	-168.539
68	Valles Caldera	NM	20	60	35.87	-106.57
69	Mono Lake volcanic field	CA	22	57	38	-119.03
70	Kiska Volcano	AK	34	55	52.103	177.602
71	Mount Chiginagak	AK	23	55	57.135	-156.99
72	Coso volcanic field	CA	15	55	36.03	-117.82
73	Emmons Lake	AK	23	54	55.341	-162.079
74	Pavlof Sister	AK	23	54	55.453	-161.843
75	Little Sitkin Island	AK	24	53	51.95	178.543
76	Bogoslof Island	AK	35	52	53.93	-168.03
77	Mount Dana	AK	29	52	55.641	-161.214
78	Soda Lakes	NV	13	51	39.53	-118.87
79	Mount Adagdak	AK	6	51	51.988	-176.592
80	San Francisco Volcanic Field	AZ	20	51	35.37	-111.5
81	Yantarni Volcano	AK	29	49	57.019	-157.185
82	Dotsero	CO	13	49	39.65	-107.03
83	Guguan Island	CNMI	24	48	17.32	145.85
84	Takawangha volcano	AK	17	47	51.873	-178.006

Table 2. Threat ranking for U.S. volcanoes. Threat groups are color coded: very high threat is red, high is orange, moderate is yellow, low is green, and very low is blue.—Continued

Rank	Volcano	State	Aviation threat score	Overall threat score	Latitude (in decimal degrees)	Longitude (in decimal degrees)
85	Frosty Peak	AK	12	46	55.082	-162.814
86	Haleakalā	HI	3	45	20.708	-156.25
87	Mount Denison	AK	12	44	58.418	-154.449
88	Mount Steller	AK	12	44	58.43	-154.4
89	Black Peak	AK	29	44	56.552	-158.785
90	Mammoth Mountain	CA	2	42	37.58	-119.05
91	Amukta Island	AK	29	41	52.5	-171.252
92	Ukinrek Maars	AK	17	41	57.832	-156.51
93	Mount Kupreanof	AK	12	40	56.011	-159.797
94	Mount Bachelor	OR	7	39	43.979	-121.688
95	Farallon de Pajaros	CNMI	20	37	20.53	144.9
96	Sarigan Island	CNMI	18	36	16.708	145.78
97	East Diamante	CNMI	18	36	15.93	145.67
98	Yunaska Island	AK	29	36	52.643	-170.629
99	Ubehebe Crater	CA	15	35	37.02	-117.45
100	Kagamil Volcano	AK	17	35	52.974	-169.72
101	Mount Wrangell	AK	3	35	62	-144.02
102	Black Rock Desert	UT	15	34	38.97	-112.5
103	Asuncion Island	CNMI	16	32	19.67	145.4
104	Mount Kialagvik	AK	12	32	57.203	-156.745
105	St. Michael Island	AK	12	31	63.45	-162.12
106	Mauna Kea	HI	2	30	19.82	-155.47
107	Carlisle Island	AK	12	29	52.894	-170.054
108	Tana	AK	12	29	52.83	-169.77
109	Zealandia Bank	CNMI	16	28	16.88	145.85
110	Segula Island	AK	10	27	52.015	178.136
111	Koniuji Island	AK	17	26	52.22	-175.13
112	Ingakslugwat Hills	AK	10	26	61.43	-164.47
113	Herbert Island	AK	12	23	52.742	-170.111
114	Uliaga Island	AK	12	23	53.065	-169.77
115	Chagulak Island	AK	10	22	52.577	-171.13
116	Bobrof Volcano	AK	6	20	51.91	-177.438
117	Amak Island	AK	12	20	55.424	-163.149
118	Supply Reef	CNMI	12	20	20.13	145.1
119	South Sarigan seamount	CNMI	12	20	16.58	145.78
120	Tutuila Island	AS	4	19	-14.295	-170.7
121	Unnamed	AK	12	17	57.87	-155.42
122	Maug Islands	CNMI	8	16	20.02	145.22
123	Hells Half Acre	ID	1	14	43.5	-112.45
124	Craters of the Moon	ID	0	14	43.42	-113.5
125	Mount Jefferson	OR	0	13	44.692	-121.8
126	Ta‘ū Island	AS	0	12	-14.23	-169.454
127	Ofu-Olosega	AS	0	12	-14.175	-169.618

Table 2. Threat ranking for U.S. volcanoes. Threat groups are color coded: very high threat is red, high is orange, moderate is yellow, low is green, and very low is blue.—Continued

Rank	Volcano	State	Aviation threat score	Overall threat score	Latitude (in decimal degrees)	Longitude (in decimal degrees)
128	Wide Bay cone	AK	1	12	53.968	-166.677
129	Buldir Volcano	AK	5	12	52.35	175.911
130	Davidof Island	AK	5	12	51.97	178.33
131	Indian Heaven	WA	0	12	45.93	-121.82
132	Belknap Crater	OR	2	12	44.285	-121.841
133	Markagunt Plateau	UT	8	11	37.58	-112.67
134	West Crater	WA	1	11	45.88	-122.08
135	Buzzard Creek	AK	2	10	64.07	-148.42
136	Black Butte Crater	ID	1	10	43.18	-114.35
137	Wapi Flow	ID	0	8	42.88	-113.22
138	Carrizozo Mountain	NM	0	6	33.78	-105.93
139	Stepovak Bay group	AK	2	6	55.93	-160
140	Blue Lake crater	OR	1	6	44.42	-121.77
141	Zuni-Bandera volcanic field	NM	0	5	34.8	-108
142	Sand Mountain volcanic field	OR	1	5	44.38	-121.93
143	Duncan Canal	AK	1	5	56.5	-133.1
144	Red Hill–Quemado volcanic field	NM	0	5	34.25	-108.83
145	Tlevak Strait-Suemez Island	AK	0	5	55.25	-133.3
146	Behm Canal-Rudyerd Bay	AK	1	5	55.32	-131.05
147	Davis Lake	OR	0	4	43.57	-121.82
148	Jordan Craters	OR	0	4	43.15	-117.47
149	St. Paul Island	AK	0	4	57.18	-170.3
150	Cinnamon Butte	OR	0	3	43.241	-122.108
151	Devils Garden	OR	0	3	43.512	-120.861
152	Diamond Craters	OR	0	3	43.1	-118.75
153	Uinkaret volcanic field	AZ	0	2	36.38	-113.13
154	Golden Trout Creek volcanic field	CA	0	2	36.358	-118.32
155	Fukujin seamount	CNMI	0	0	21.93	143.47
156	Kasuga 2	CNMI	0	0	21.6	143.637
157	Daikoku seamount	CNMI	0	0	21.324	144.194
158	Ahyi Seamount	CNMI	0	0	20.42	145.03
159	Ruby	CNMI	0	0	15.62	145.57
160	Esmeralda Bank	CNMI	0	0	15	145.25
161	Imuruk Lake	AK	0	0	65.6	-163.92

the list of volcanoes used in this threat assessment with the SI-GVP list of Holocene volcanoes to match as closely as possible; the few discrepancies that exist are mentioned in the following section.

Volcanic threat, as defined by Ewert (2007), is the combination of 24 factors describing a volcano's hazard potential and exposure of people and property to those hazards (independent of any mitigation efforts or actions). Prompted by the growing global recognition of airborne volcanic ash to enroute aviation, the 2005 U.S. threat assessment was the first time that hazards to aviation had been taken into account in any national-scale volcanic hazard or risk assessment and prioritization schema. The 24-factor threat assessment was designed to account for the highly variable knowledge of the eruptive histories of the more than 160 active U.S. volcanoes, and the diversity of eruptive styles and geographic settings of U.S. volcanoes, as well as to be easily understood by nonspecialists. Volcanoes were ranked by their threat scores and divided into five relative threat groupings: very low, low, moderate, high, and very high. These groupings have been used to develop a strategy for the USGS to prioritize where to focus volcanic risk mitigation through research, monitoring, hazard assessment, and community engagement (U.S. Geological Survey, 2007; Holmes and others, 2012). The results of the threat ranking are also an effective communication tool with which to engage stakeholders and the public in discussions of volcanic activity and hazards in the U.S. with the goal of developing effective emergency preparedness, coordination, and response plans.

Since 2005, the USGS volcanic threat assessment methodology has been adapted for use in Chile (Lara and others, 2006), New Zealand (Miller, 2011), Argentina (Elissondo and Villegas, 2011), the Caribbean region (Camejo and Robertson, 2013), and Peru (Macedo and others, 2016). It has also been included as part of the global assessment of volcanic hazards and risk prepared for the United Nations Office for Disaster Risk Reduction Global Assessment Report for Risk Reduction 2015 (GAR15 Report; Laughlin and others, 2015). The adaptation of the threat assessment methodology and ranking concept by so many groups demonstrates the utility of this kind of risk analysis.

Changes to the List of Active and Potentially Active U.S. Volcanoes Used for Threat Assessment

Conterminous United States

Published results from recent geologic field studies, most of which have employed increasingly sophisticated isotopic, paleomagnetic, and surface exposure dating techniques, allow us to add 3 volcanoes and remove 14 volcanoes from the original threat assessment list of Ewert and others (2005) and Ewert (2007) based upon their documented activity or inactivity in Holocene time. Our review of the active volcanic systems in the conterminous United States has been greatly facilitated by the ongoing geospatial cataloging effort by Ramsey and Siebert (2017). The net result of the new research and information is that we now include 48 volcanoes from the conterminous United States in this threat assessment, a decrease of 13 from those listed by Ewert and others (2005) and Ewert (2007) (figs. 7–9). Nearly all the volcanoes removed were originally classified as very low threat by Ewert and others (2005) and Ewert (2007). See table 3 for a listing of volcanoes in the conterminous United States

Volcanoes Added

Salton Buttes, California: The Salton Buttes are composed of five rhyolite lava domes found near the southern end of the Salton Sea in the Imperial Valley of southern California. Salton Buttes was not included in Ewert and others (2005) owing to uncertainty about the ages of the most recent eruptive activity. Research by Wright and others (2015) established Holocene ages for the domes by $^{40}Ar/^{39}Ar$, ^{238}U-^{230}Th zircon crystallization ages, and paleomagnetic dating. Accordingly, Salton Buttes has been added to the threat assessment as a high-threat volcano, and it now appears in the SI-GVP VOTW database of Holocene volcanoes.

Soda Lakes, Nevada: Soda Lake and Little Soda Lake are two maars located on the southwestern floor of the Carson Sink northwest of Fallon, Nevada. Soda Lakes was not included in Ewert and others (2005), nor was it included in the SI-GVP VOTW Holocene volcanoes database at the time. Soda Lakes deposits have not been radiometrically dated but based on the relation with Lake Lahontan sediments, the uppermost deposits are estimated to be younger than 6 ka (thousand years old; Cousens and others, 2012). Soda Lakes has been added to this assessment as a moderate-threat volcano and is now included in the SI-GVP VOTW Holocene database.

Red Hill-Quemado volcanic field, New Mexico: Variously referred to as the Red Hill volcanic field (Wood and Kienle, 1990), Quemado volcanic field (Dunbar, 2005), and most recently as the Red Hill-Quemado volcanic field (Onken and Forman, 2017), this feature was, until recently, included in the SI-GVP VOTW database of Pleistocene volcanoes. New accelerator mass spectrometer ^{14}C and optically stimulated luminescence dating of deposits by Onken and Forman (2017) from the Zuni Salt Lake vents of the Red Hill-Quemado volcanic field place the most recent eruptive activity between about 12.3 and 11.0 ka. The Red Hill-Quemado volcanic field has been added to this assessment as a very low threat volcano, and the SI-GVP has now moved this volcanic field to the Holocene VOTW database.

Volcanoes Dropped

Mount Washington, Oregon: Sherrod and others (2004) mapped Mount Washington as Pleistocene age, and on that basis Mount Washington has been removed from this threat assessment and it is now listed by the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Mount Washington as a very low threat volcano.

Lava Mountain, Oregon: Mackey and others (2014) employed cosmogenic ^{3}He dating to determine a most recent eruption age of 14 ka. On that basis Lava Mountain has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Lava Mountain as a very low threat volcano.

Four Craters Lava Field, Oregon: Mackey and others (2014) employed cosmogenic ^{3}He dating to determine a most recent eruption age of 14 ka, and on that basis Four Craters Lava Field has been removed from the threat assessment list. It is now listed by the SI-GVP VOTW database as Pleistocene

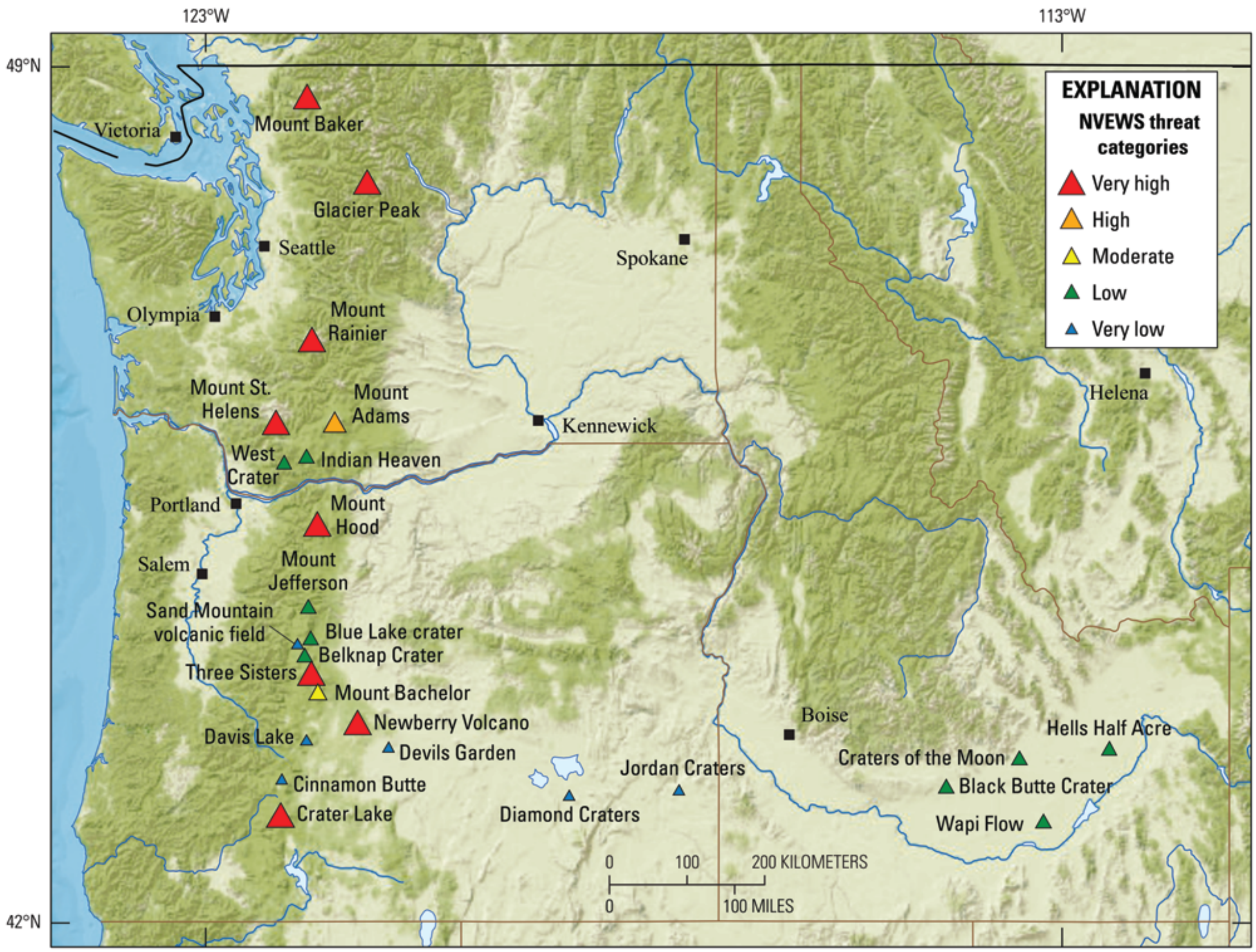

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Figure 7. Map showing volcano locations within the area of responsibility of the Cascades Volcano Observatory (Washington, Oregon, and Idaho). NVEWS, National Volcano Early Warning System.

age. Ewert and others (2005) and Ewert (2007) had classified Four Craters Lava Field as a very low threat volcano.

Jackies Butte, Oregon: The Jackies Butte volcanic field, which consists of two shields and two cinder cones, remains poorly studied. Owing to its morphologically older appearance than nearby Jordan Craters volcanic field, Jackies Butte is now classified as Pleistocene in the SI-GVP VOTW database. Jackies Butte has been removed from this threat assessment. Ewert and others (2005) and Ewert (2007) had classified Jackies Butte as a very low threat volcano.

Brushy Butte, California: Lavas of Brushy Butte are overlain by Giant Crater lava flow, which has been dated at 12.43 ka (Donnelly-Nolan, 2010). Brushy Butte has been removed from this threat assessment, and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Brushy Butte as a very low threat volcano.

Big Cave, California: The SI-GVP VOTW considers this volcano contemporaneous with Cinder Butte (38±7 ka). Big Cave has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Big Cave as a very low threat volcano.

Twin Buttes, California: Twin Buttes is not yet precisely dated, but based on field relations and morphology, Clynne and Muffler (2010) map this volcano as late Pleistocene age. Twin Buttes has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) had classified Twin Buttes as a very low threat volcano.

Tumble Buttes, California: Tumble Buttes is not yet precisely dated, but based on field relations and morphology, Clynne and Muffler (2010) map this volcano as late Pleistocene age. Tumble Buttes has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Tumble Buttes as a very low threat volcano.

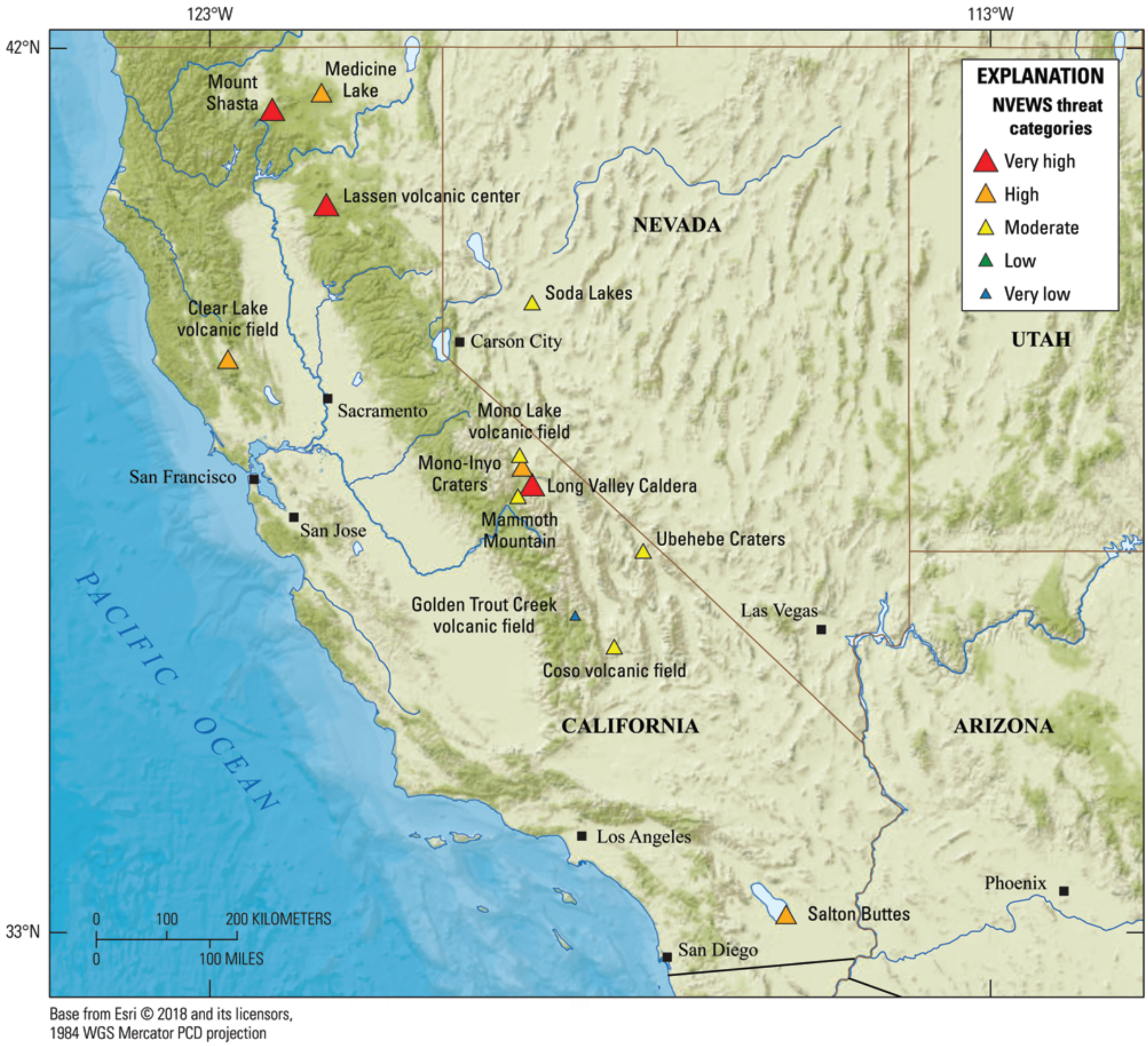

Figure 8. Map showing volcano locations within the area of responsibility of the California Volcano Observatory (California and Nevada). NVEWS, National Volcano Early Warning System.

Eagle Lake volcanic field, California: Recent geologic mapping and dating reported in Clynne and others (2017) indicate that the most recent lava flows erupted 130–123 ka. Ages were determined by paleomagnetic and $^{40}Ar/^{39}Ar$ dating techniques. The Eagle Lake volcanic field has been removed from this threat assessment and it is now listed by the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) and Ewert (2007) had classified Eagle Lake volcanic field as a very low threat volcano.

Lavic Lake volcanic field, California: Pisgah Crater, the most prominent and likely youngest vent in the Lavic Lake volcanic field, has been dated to about 22.5 ka using surface exposure ^{36}Cl cosmogenic isotope (Phillips, 2003) and rock varnish microstratigraphy (Liu, 2003) techniques. Nearby Sunshine Peak has not been dated but is likely contemporaneous with the other late Pleistocene vents of the Lavic Lake volcanic field. The SI-GVP VOTW database also mentions $^{40}Ar/^{39}Ar$ and paleomagnetic evidence for the Pleistocene age of the volcanic field, but as of this writing, the Lavic Lake field was still included in the Holocene VOTW database. Lavic Lake has been removed from this threat assessment because the available evidence indicates the most recent activity was in the late Pleistocene. Ewert and others (2005) had classified Lavic Lake as a very low threat volcano.

Amboy Crater, California: Phillips (2003) reports a surface exposure cosmogenic ^{36}Cl isotope age of about 80 ka that is in good agreement with a rock varnish microstratigraphy age of 85–74 ka (Liu, 2003). Amboy Crater has been removed from this threat assessment and it is now listed in the SI-GVP

Figure 9. Map showing volcano locations within the area of responsibility of the Yellowstone Volcano Observatory (Wyoming, Montana, Idaho, Utah, Colorado, New Mexico, and Arizona). NVEWS, National Volcano Early Warning System.

VOTW database as Pleistocene age. Ewert and others (2005) had classified Amboy Crater as a very low threat volcano.

Steamboat Springs, Nevada: Little recent volcanological work has been done at Steamboat Springs. Silberman and others (1979) provide age dates for the four small rhyolite lava domes of 1.52 –1.15-Ma and older. They also report that the hydrothermal system has been active for >2.5 Ma (million years). Arehart and others (2003) report trace element and gas geochemical data that are consistent with at least some of the heat source being of magmatic origin. Despite the magmatic gas components and the persistent nature of the geothermal system, the age and small volume of the most recent volcanic products lead us to conclude that Steamboat Springs should not be included among the potentially active U.S. volcanoes and it is removed from this threat assessment. Steamboat Springs is now listed in SI-GVP VOTW database as Pleistocene age, and had been classified by Ewert and others (2005) and Ewert (2007) as moderate threat.

Santa Clara volcanic field, Utah: The Santa Clara volcanic field has been ^{14}C dated at 32 ka (Willis and others, 2006; Biek and others, 2009). The Santa Clara volcanic field has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) had classified the Santa Clara volcanic field as a very low threat volcano.

Bald Knoll, Utah: No precise age of Bald Knoll is available. Doelling (2008) mapped the Bald Knoll and other nearby basalt flows as middle to late Pleistocene age. Bald Knoll has been removed from this threat assessment and it is now listed in the SI-GVP VOTW database as Pleistocene age. Ewert and others (2005) had classified Bald Knoll as a very low threat volcano.

Nomenclature Updates or Other Changes

Other changes to the list of volcanoes from the conterminous United States include changes in nomenclature as formerly separate volcanoes were grouped into single systems based on new research.

Mammoth Mountain, California: Mammoth Mountain is a silicic lava dome cluster surrounded by mafic vents that has been active since ~160 ka (Hildreth, 2004). The most recent silicic lava dome eruption is ~57 ka and mafic volcanism has continued on the periphery of Mammoth Mountain into the Holocene. One group of Holocene-age mafic vents, Red Cones, was used by the SI-GVP VOTW database and Ewert and others (2005) as the proxy name for the larger system. Following Hildreth (2004) and Hildreth and others (2014), we now use Mammoth Mountain as the named volcanic system that includes the silicic lava dome cluster and the peripheral mafic vents such as Red Cones. Mammoth Mountain is classified as a moderate threat volcano.

Mono-Inyo Craters, California: Mono Craters and Inyo domes were treated separately by the SI-GVP VOTW database of Holocene volcanoes and Ewert and others (2005). These are now combined into a single system, referred to as Mono-Inyo Craters. According to Hildreth (2004), “Continuity of the chain of virtually contiguous Holocene rhyolite vents demands that the Mono-Inyo chain represent in some sense a coherent magmatic system.” The SI-GVP VOTW database now lists Mono-Inyo Craters as the combined single volcanic system. Mono-Inyo Craters is classified as a high threat volcano.

Three Sisters, Oregon: The Three Sisters volcano complex is a grouping of stratovolcanoes (North Sister, Middle Sister, and South Sister), pyroclastic cones, fissure vents, and domes along the crest of the Cascade Range in central Oregon. South Sister volcano, which has Holocene flank vents, was used by the SI-GVP VOTW database and Ewert and others (2005) as the proxy for the larger complex of volcanoes. Following Hildreth and others (2012), both the SI-GVP VOTW database and this threat assessment now use Three Sisters as the named volcanic system, which encompasses the Three Sisters stratovolcanoes and their flank vents. In addition to including flank vents of South Sister, the Three Sisters volcano complex now includes the formerly separate North Sister volcanic field. The Three Sisters volcano complex is classified as very high threat.

San Francisco Volcanic Field, Arizona: Ewert and others (2005) followed the SI-GVP VOTW database convention in using Sunset Crater, the most recently active Holocene-age feature of the San Francisco Volcanic Field, as the proxy for the entire field. The SI-GVP and this assessment are now referring to the entire system as the San Francisco Volcanic Field. It is classified as moderate threat.

A note regarding Belknap Crater, Sand Mountain volcanic field, Blue Lake crater, and the North Sister volcanic field in Oregon. The area between Santiam and McKenzie Passes is one containing frequent Quaternary basaltic volcanism in a common tectonic framework (the High Cascades graben). Nomenclature for the area has been evolving through time as petrologic affinities among the various vent systems have become better defined and geochronology of the area has improved. For instance, Deligne and others (2016) show that the Sand Mountain volcanic field erupted in a short, perhaps decades-long, time period and tapped a heterogeneous magma source. They suggest it may not be appropriate to refer to the Sand Mountain vents as a volcanic field distinct from the other nearby Quaternary vents in the same tectonic setting. As more research is done in the Santiam Pass to McKenzie Pass area, it seems likely there will be changes in how volcano and volcanic field nomenclature is applied that may ultimately result in combining Belknap Crater, Sand Mountain volcanic field, Blue Lake crater and the formerly named North Sister volcanic field into a single Santiam-McKenzie volcanic field. The hazards presented by such a single field of basalt—basaltic andesite cinder cones, fissures, and small shields—are roughly equivalent to the current individually named volcanic systems that would compose it.

Table 3. U.S. volcanoes listed by state/territory and threat groups.

[CNMI, Commonwealth of the Northern Mariana Islands; St., saint]

State/ territory	Threat group				
	Very high	High	Moderate	Low	Very low
Alaska	Akutan Island, Augustine Volcano, Makushin, Redoubt Volcano, Mount Spurr	Aniakchak Crater, Atka volcanic complex, Mount Churchill, Mount Cleveland, Mount Douglas, Fisher Caldera, Fourpeaked Mountain, Great Sitkin Volcano, Mount Griggs, Hayes Volcano, Iliamna Volcano, Kaguyak Crater, Kanaga Volcano, Kasatochi Island, Mount Katmai, Korovin Volcano, Mount Mageik, Mount Martin, Mount Moffett, Novarupta, Mount Okmok, Pavlof Volcano, Seguam Island, Semisopochnoi Island, Shishaldin Volcano, Snowy Mountain, Trident Volcano, Ugashik-Peulik volcanic complex, Mount Veniaminof, Westdahl Peak	Mount Adagdak, Amukta Island, Black Peak, Bogoslof Island, Mount Chiginagak, Mount Dana, Mount Denison, Mount Dutton, Mount Edgecumbe, Emmons Lake, Mount Gareloi, Frosty Peak, Kiska Volcano, Kagamil Volcano, Kialigvik, Kukak Volcano, Mount Kupreanof, Little Sitkin Island, Pavlof Sister, Mount Recheschnoi, Roundtop Mountain, Mount Steller, St. Michael Island, Takawangha volcano, Tanaga Volcano, Ukinrek Maars, Mount Vsevidof, Mount Wrangell, Yantarni Volcano, Yunaska Island	Amak Island, Bobrof, Buldir Volcano, Buzzard Creek, Carlisle Island, Chagulak Island, Davidof Island, Herbert Island, Ingakslugwat Hills, Koniuji Island, Segula Island, Stepovak Bay group, Tana, Uliaga Island, Unnamed, Wide Bay cone	Behm Canal-Rudyerd Bay, Duncan Canal, Imuruk Lake, St. Paul Island, Tlevak Strait-Suemez Island
Washington	Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens	Mount Adams		Indian Heaven, West Crater	
Oregon	Crater Lake, Mount Hood, Newberry Volcano, Three Sisters		Mount Bachelor	Belknap Crater, Blue Lake crater, Mount Jefferson	Cinnamon Butte, Davis Lake, Devils Garden, Diamond Craters, Jordan Craters, Sand Mountain volcanic field
Idaho				Craters of the Moon, Hells Half Acre, Black Butte Crater, Wapi Flow	
California	Lassen volcanic center, Long Valley Caldera, Mount Shasta	Clear Lake volcanic field, Mono-Inyo Craters, Medicine Lake, Salton Buttes	Coso volcanic field, Mono Lake volcanic field, Mammoth Mountain, Ubehebe Crater		Golden Trout Creek volcanic field
Nevada			Soda Lakes		
Wyoming		Yellowstone caldera			
Colorado			Dotsero		
New Mexico			Valles Caldera	Carrizozo Mountain	Red Hill-Quemado volcanic field, Zuni-Bandera volcanic field
Utah			Black Rock Desert	Markagunt Plateau	
Arizona			San Francisco Volcanic Field		Uinkaret volcanic field
Hawaii	Kīlauea, Mauna Loa	Hualālai	Haleakalā, Mauna Kea		
CNMI		Agrigan Island, Pagan Island	Alamagan Island, Anatahan Island, Asuncion Island, East Diamante, Farallon de Pajaros, Guguan Island, Sarigan Island	Maug Islands, South Sarigan seamount, Supply Reef, Zealandia Bank	Ahyi Seamount, Daikoku seamount, Esmeralda Bank, Fukujin seamount, Kasuga 2, Ruby
American Samoa				Tutuila Island, Ofu-Olosega, Ta‘ū Island	

Alaska

A review of research conducted on Alaskan volcanoes since 2005 has resulted in additions, subtractions, and nomenclature changes to the list of volcanoes used in the national volcanic threat assessment. The net result of the new research and information is that we now include 86 Alaskan volcanoes in this threat assessment, a decrease of 4 from those listed by Ewert and others (2005) and Ewert (2007) (figs. 10–16). See table 3 for a listing of Alaskan volcanoes.

Volcanoes Added

Tana: Tana is located in the Islands of the Four Mountains, on the east half of Chuginadak Island; the west half of the island is occupied by Mount Cleveland. Tana is included in the current SI-GVP VOTW database based on youthful geomorphology and consultation with Alaska Division of Geological & Geophysical Surveys-Alaska Volcano Observatory (DGGS-AVO) volcanologist Chris Nye. Fieldwork in 2014–16 by an interdisciplinary team of scientists working with AVO discovered boiling-point fumaroles and deposits whose field relations and morphology indicate young age. These features are being isotopically dated, but results have not been reported as of this writing. Tana is classified as low threat.

Volcanoes Dropped

Mount Sergief: Based on morphology and location with respect to nearby active volcanoes, AVO geologists don't think Mount Sergief has been active in the Holocene (Michelle Coombs, U.S. Geological Survey, written commun., 2017). We have removed Mount Sergief from this threat assessment, and it is now listed in AVO and SI-GVP VOTW databases as Pleistocene in age. Ewert and others (2005) had classified Mount Sergief as a low threat volcano.

Isanotski Volcano: During the course of multiple low-level overflights, AVO volcanologist Chris Nye observed "nothing in the way of plausible postglacial flank vents and the summit is highly eroded" (Cheryl Cameron, Alaska Division of Geological & Geophysical Surveys, written commun., 2017). Isanotski Volcano has been removed from this threat assessment and is now listed in the AVO database as Pleistocene in age, but is still listed in the SI-GVP VOTW as Holocene with unknown Holocene activity. Ewert and others (2005) had classified Isanotski Volcano as a low threat volcano.

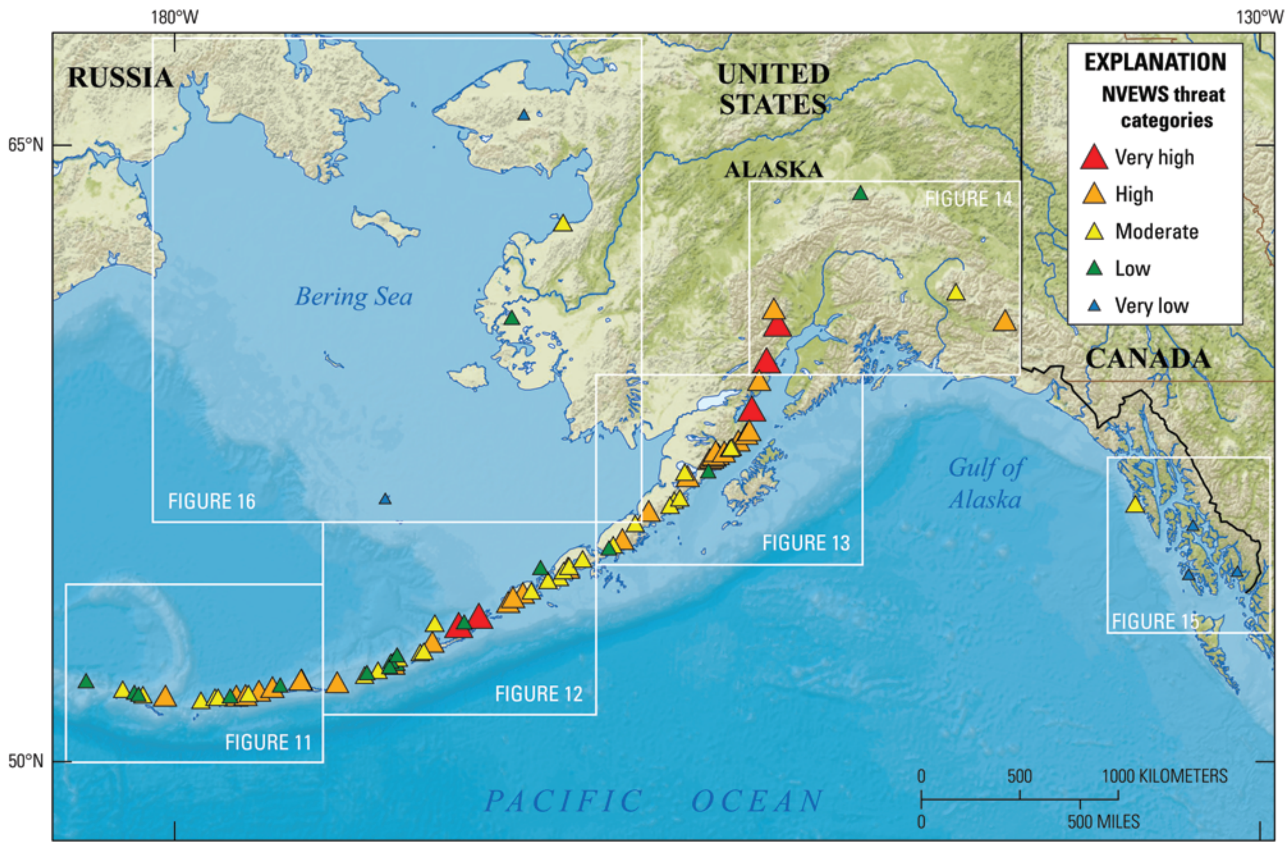

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Figure 10. Map showing volcano locations and threat categories within the State of Alaska, which is in the area of responsibility of the Alaska Volcano Observatory (Alaska and the Commonwealth of the Northern Mariana Islands). Boxes are outlines of areas depicted in figures 11–16, which show Alaskan volcanoes in greater detail. NVEWS, National Volcano Early Warning System.

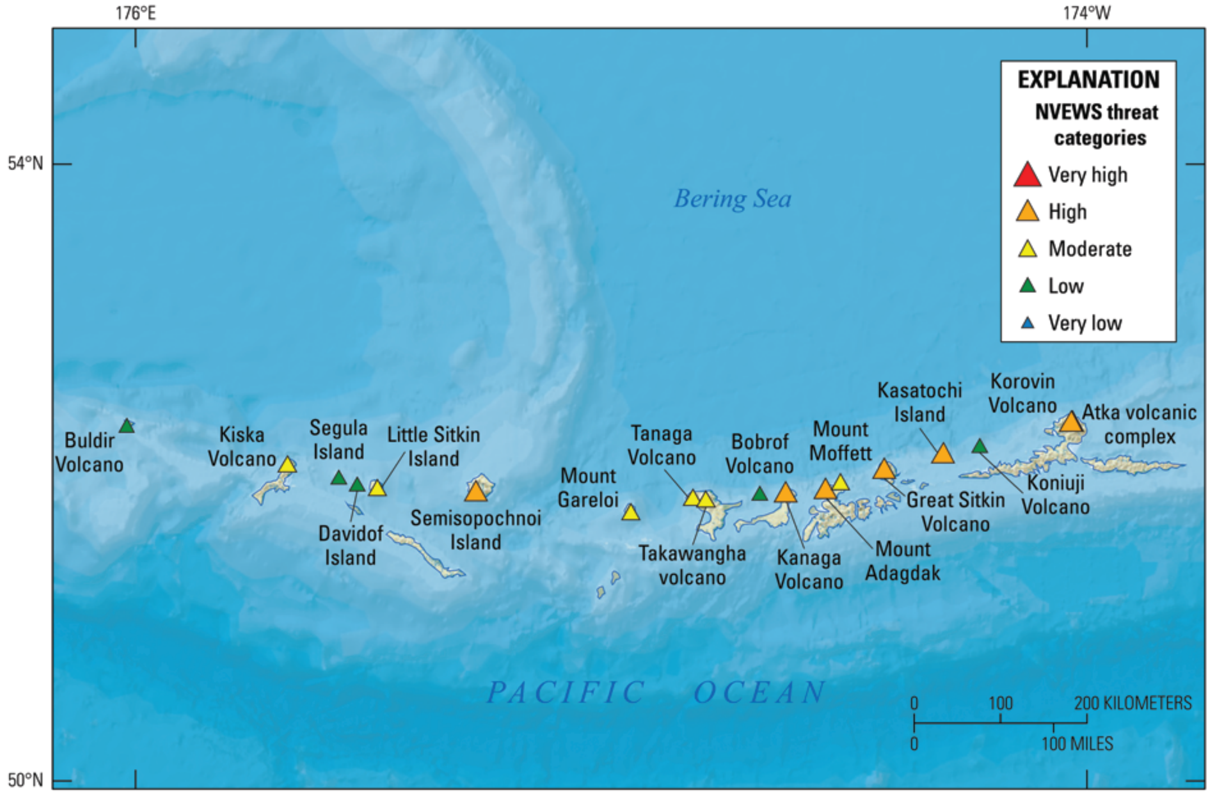

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Figure 11. Map showing volcano locations in the western Aleutian Islands. NVEWS, National Volcano Early Warning System.

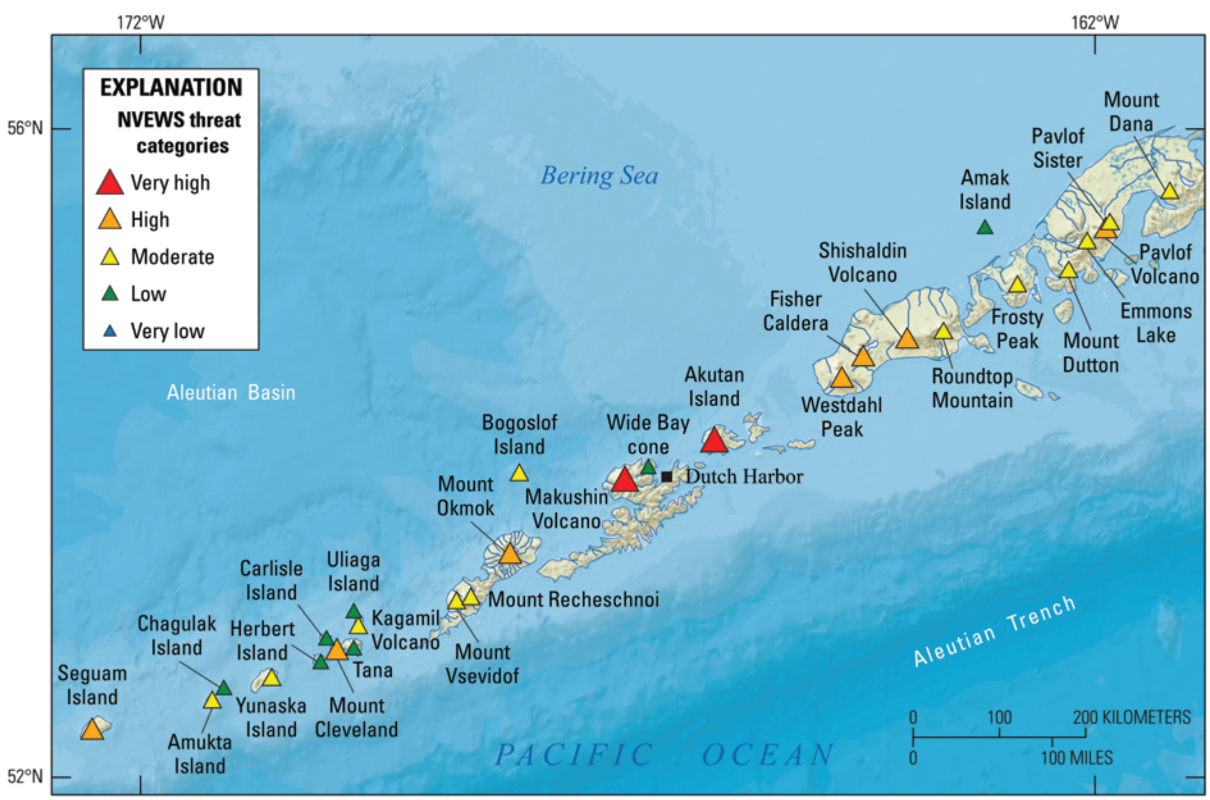

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Figure 12. Map showing volcano locations in the eastern Aleutian Islands and lower Alaska Peninsula. NVEWS, National Volcano Early Warning System.

Figure 13. Map showing volcano locations in the upper Alaska Peninsula and southern Cook Inlet. NVEWS, National Volcano Early Warning System.

Nunivak Island: Volcanism on Nunivak Island ranges in age from about 6 Ma to 0.15 Ma, with the youngest ages in the eastern part of the field (Wood and Kienle, 1990; Mukasa and others, 2007). Based on the reported ages we have removed Nunivak from this threat assessment. Nunivak Island is now listed in AVO and SI-GVP VOTW databases as Pleistocene in age. Ewert and others (2005) had classified Nunivak as a low threat volcano.

Kookooligit Mountains: Patton and Csejtey (1980) published five K-Ar age dates for Kookooligit lava flows, ranging from 1.46 Ma to 0.24 Ma. Mukasa and others (2007) report a single $^{40}Ar/^{39}Ar$ age date of 1.22±0.02 Ma to better constrain the maximum age of this volcanic system. Based on these reported ages we have removed the Kookooligit Mountains from this threat assessment and this system is now listed in AVO and SI-GVP VOTW databases as Pleistocene in age. Ewert and others (2005) had classified Kookooligit Mountains as a very low threat volcano.

Mount Sanford: Richter and others (2006) place eruptive activity at Mount Sanford squarely in the Pleistocene, 0.9–0.5 Ma. Based on their reported ages we have removed Mount Sanford from this assessment, and it is now listed in AVO and SI-GVP VOTW databases as Pleistocene in age. Ewert and others (2005) had classified Mount Sanford as a moderate threat volcano.

Mount Gordon: Richter and others (2006) map Mount Gordon as a Pleistocene volcano. Based on this map and previous work, we have removed Mount Gordon from this threat assessment, and it is now listed in AVO and SI-GVP VOTW databases as Pleistocene in age. Ewert and others (2005) had classified Mount Gordon as a very low threat volcano.

There are five volcanic systems in Alaska for which we do not yet have definitive data regarding their most recent eruptive activity and they are therefore included in this threat assessment. These systems have probably been active in Holocene time and are retained on the list, but they are mentioned here to acknowledge their uncertain status regarding their potential for future eruptive activity. As more becomes known, they may eventually be dropped from our list. The five systems with uncertain status include **Buldir Volcano**, **Davidof Island**, **Bobrof Volcano**, and **Mount Adagdak**, in the Aleutian Islands and **Mount Denison** on the Alaska Peninsula.

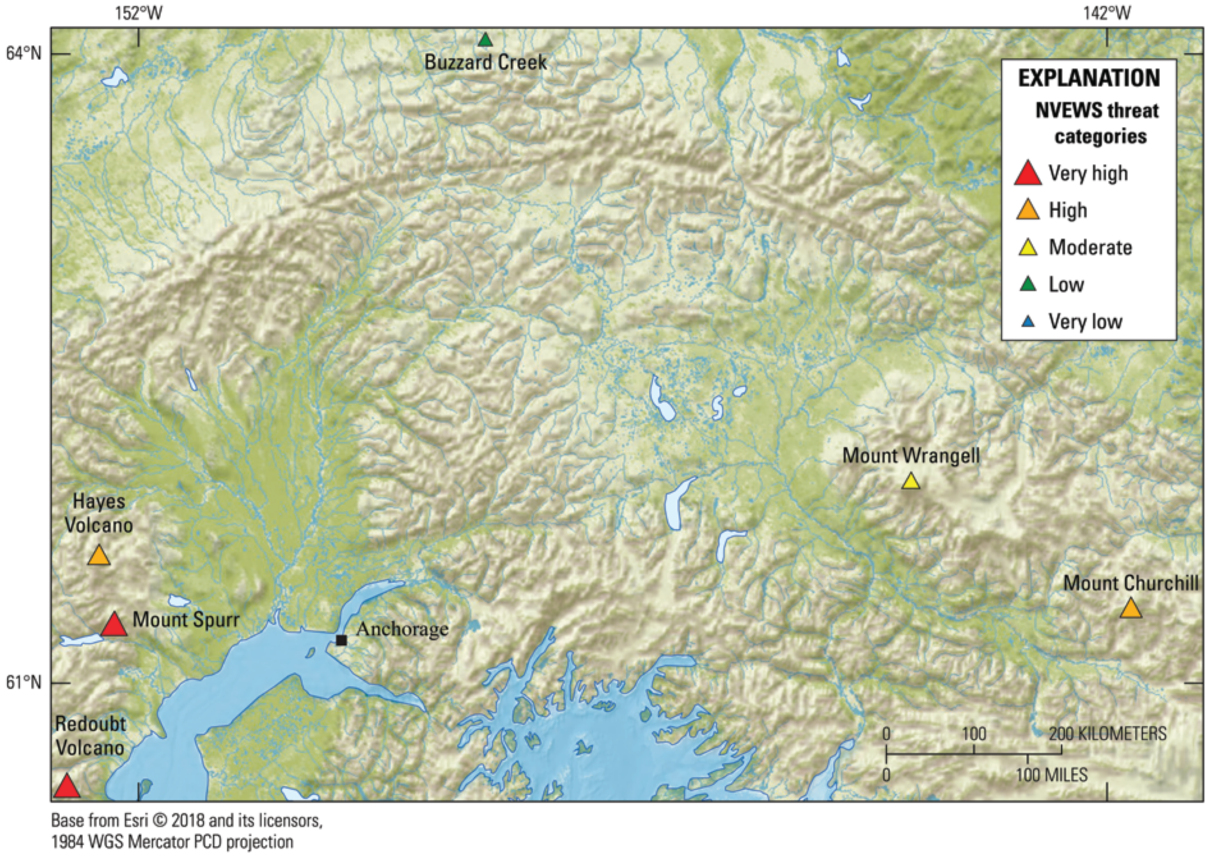

Figure 14. Map showing volcano locations in northern Cook Inlet and central Alaska. NVEWS, National Volcano Early Warning System.

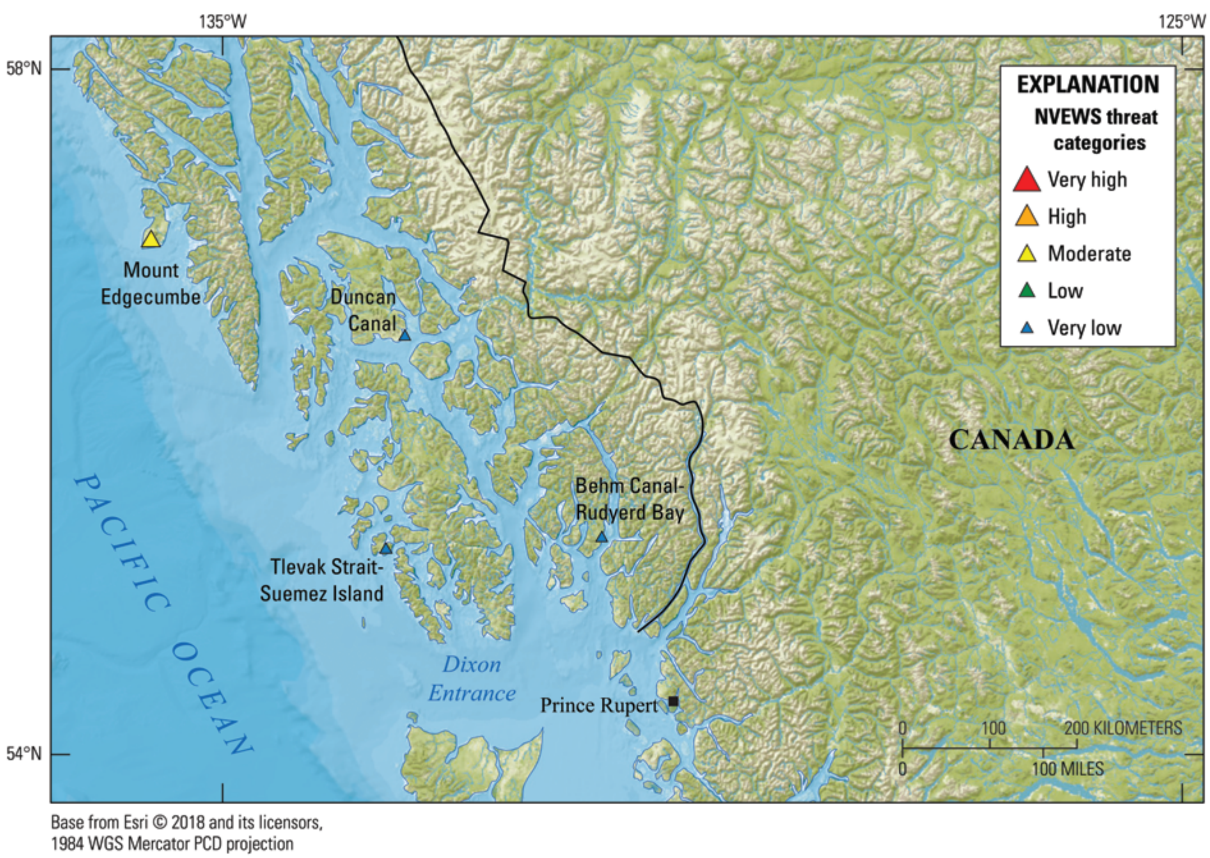

Figure 15. Map showing volcano locations in southeastern Alaska. NVEWS, National Volcano Early Warning System.

Nomenclature Updates or Other Changes

One volcano (Atka Island) included in the 2005 threat assessment (Ewert and others, 2005) has been split into separate volcanoes (**Atka volcanic complex** and **Korovin Volcano**) based on field mapping and analysis by AVO geologists. The SI-GVP VOTW and AVO databases now list Atka volcanic complex and Korovin Volcano separately.

One volcanic system (**Table Top-Wide Bay**) included in the 2005 threat assessment (Ewert and others, 2005) is now simply referred to as Wide Bay cone. The lower parts of the cone are glaciated, but the upper parts appear not to be. McConnell and others (1998) report an $^{40}Ar/^{39}Ar$ age of 68±14 ka for Table Top Mountain, and map Wide Bay cone as Holocene age based on field relations that suggest Wide Bay cone is at least somewhat younger. Wide Bay cone is currently classified as Pleistocene age in the SI-GVP VOTW database, and is considered as Holocene age by AVO (https://avo.alaska.edu/volcanoes/volcinfo.php?volcname=Wide%20Bay%20cone). Wide Bay cone can be considered as proxy for the SW-NE-trending volcanic field of cones and flows that passes through Makushin Volcano but is considered by the SI-GVP VOTW to be chemically and petrologically distinct from Makushin

One volcanic system, referred to as **Stepovak** in the 2005 assessment by Ewert and others (2005), is now referred to as the Stepovak Bay group which incorporates four volcanic vents (Stepovak Bay 1, Stepovak Bay 2, Stepovak Bay 3, and Stepovak Bay 4) located along an approximately 30-kilometer (km)-long ridge on the Alaska Peninsula. Stepovak Bay 1 is Pleistocene age and the other three are Holocene age (Yount and others, 1985; Wood and Kienle, 1990). The SI-GVP VOTW lists Stepovak Bay 2–4 separately in the Holocene database and Stepovak Bay 1 in the Pleistocene database.

Figure 16. Map showing volcano locations in western Alaska and the Bering Sea. NVEWS, National Volcano Early Warning System.

Hawaii

No changes were made to the list of active and potentially active Hawaiian volcanoes used for this threat assessment (fig. 17). See table 3 for a listing of Hawaiian volcanoes.

Commonwealth of the Northern Mariana Islands

The Commonwealth of the Northern Mariana Islands (CNMI) is an unincorporated organized territory of the United States with political and legal status similar to that of Guam and the U.S. Virgin Islands. No volcanoes were dropped from the list and the net result of the new research and information in the region is that we now include 19 CNMI volcanoes in this threat assessment, an increase of 6 from those listed by Ewert and others (2005) and Ewert (2007) (fig. 18). See table 3 for a listing of volcanoes in the CNMI.

The Mariana Islands are part of the Izu-Bonin-Mariana arc system that stretches over 2,800 km from near Tokyo, Japan, to beyond Guam (Stern and others, 2003). Here we are concerned only with the subaerial and submarine volcanoes in U.S. territory that pose potential hazards to life and property. There are nine subaerial Mariana volcanoes extending from Anatahan Island in the south to Farallon de Pajaros in the north. Submarine volcanoes are found among the islands and extend south of Anatahan Island to the vicinity of Guam, and to approximately 200 km northwest of Farallon de Pajaros. Our criteria for including submarine volcanoes in this updated threat assessment have changed somewhat from those used by Ewert and others (2005) and Ewert (2007). We now include intermediate composition volcanoes less than 400 meters (m) below sea level (b.s.l.), and silicic caldera systems less than 1,000 m b.s.l. Further explanation is provided in the Scoring Update section that follows.

In the late 1990s the Mariana Arc was designated as a special study site for the National Science Foundation (NSF) MARGINS Program. In 2003, the first Submarine Ring of Fire Expedition to the Marianas area was funded by the National Oceanographic and Atmospheric Administration's (NOAA) Office of Ocean Exploration and the NOAA Vents Program (the latter as part of an ongoing investigation of the oceanic impacts of hydrothermal venting) (Merle and others, 2003; Baker and others, 2008). Subsequent cruises were made in 2004 and 2006 as part of the Ring of Fire and Vents programs. As a result of the extensive acoustic mapping done during the cruises, bathymetric data for the Mariana Arc are greatly improved, and there are better data on the general composition of the submarine volcanoes as well as about which volcanoes have actively venting hydrothermal systems. Consequently, we have added six volcanoes to the threat assessment database (from north to south): Fukujin seamount, Kasuga 2, Daikoku seamount, Zealandia Bank, South Sarigan seamount, and East Diamante (see appendix). Of note, Stern and Hargrove (2003) and Stern and others (2014) have identified an area they call

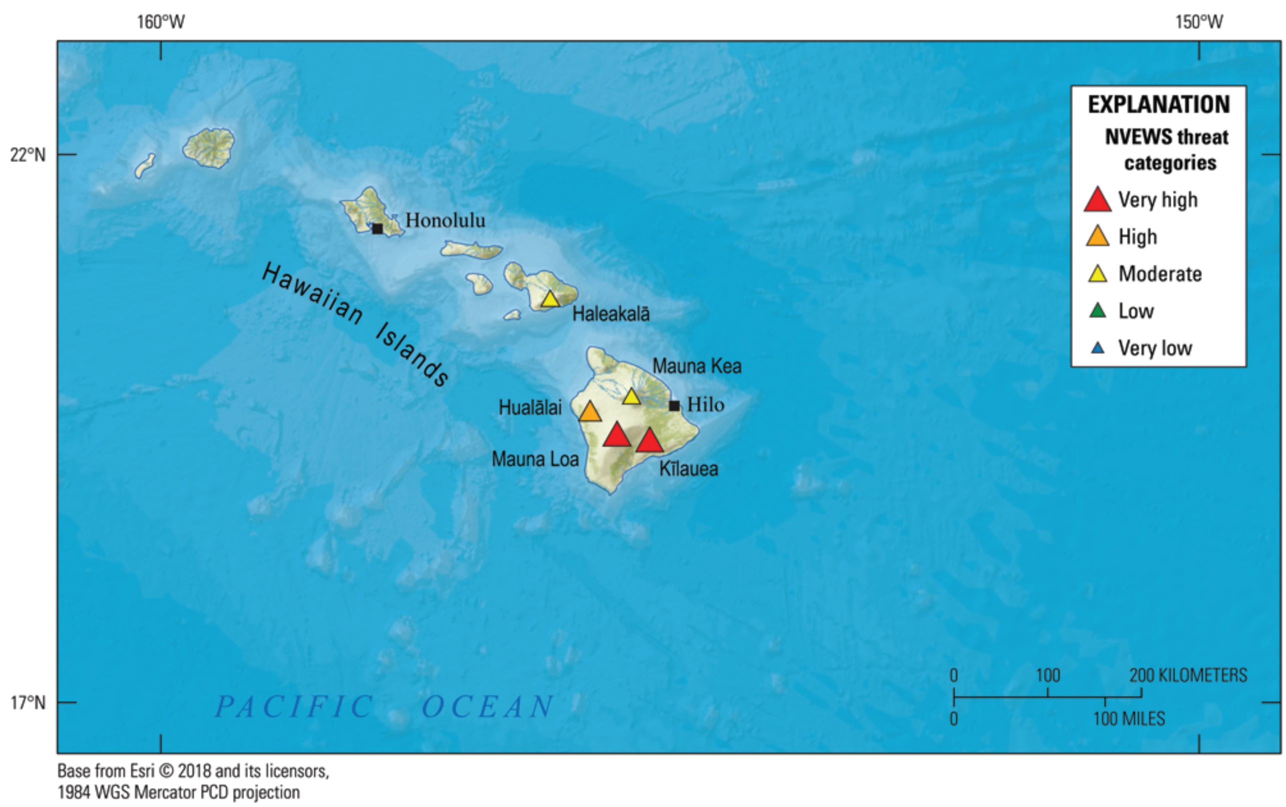

Figure 17. Map showing volcano locations in Hawaii, which is in the area of responsibility of the Hawaiian Volcano Observatory (Hawaii and American Samoa). NVEWS, National Volcano Early Warning System.

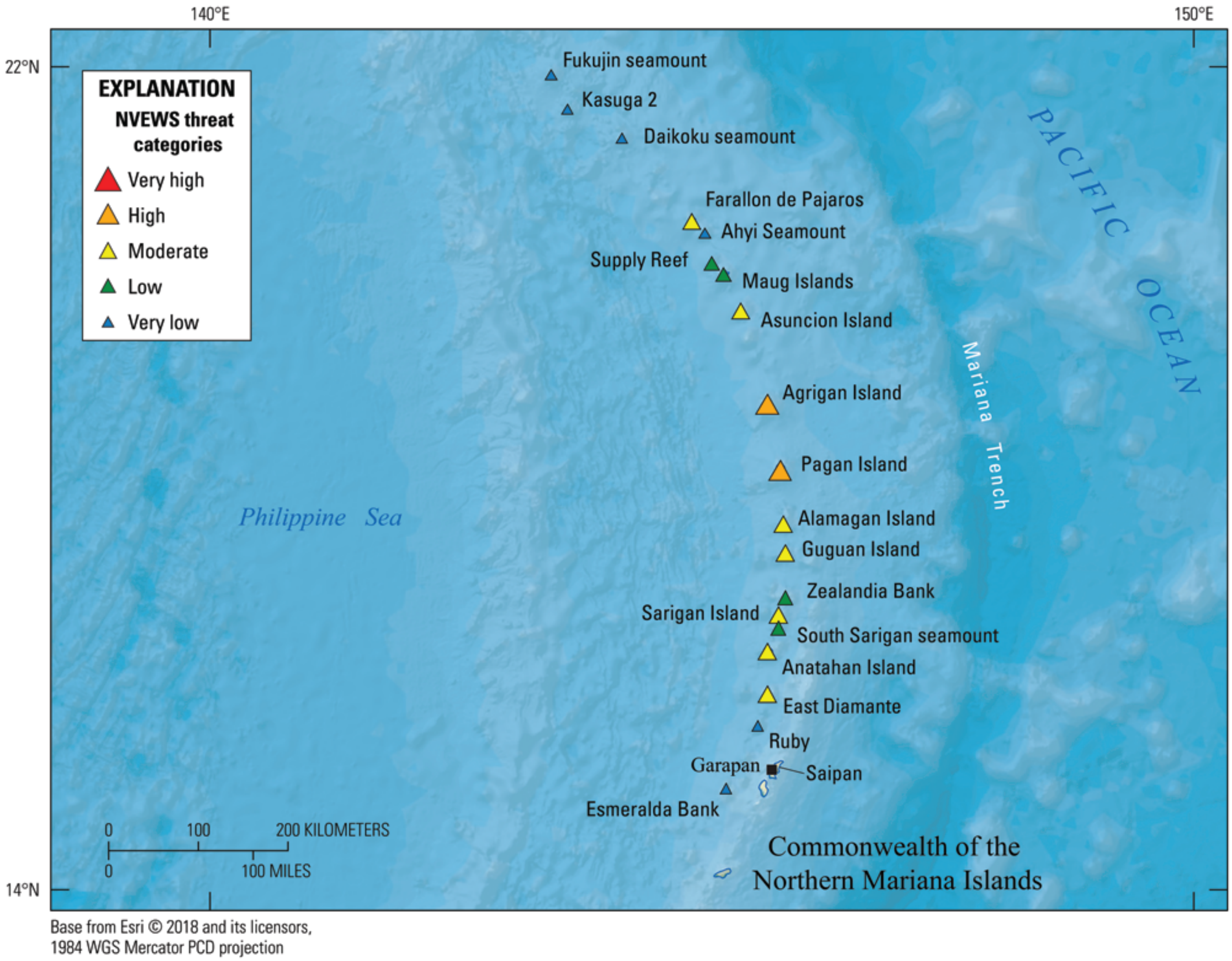

Figure 18. Map showing volcano locations in the Commonwealth of the Northern Mariana Islands, which is in the area of responsibility of the Alaska Volcano Observatory. NVEWS, National Volcano Early Warning System.

the Anatahan felsic province in which there are highly silicic volcanic centers apparently capable of producing large magnitude (volcanic explosivity index [VEI] ~6) explosive eruptions. East Diamante, Sarigan Island, South Sarigan seamount, Anatahan Island, and Zealandia Bank all fall within the Anatahan felsic province. The identification of the Anatahan felsic province, reaching almost to Saipan, argues for more diligent volcano monitoring in the area.

Three additional seamounts in the Mariana Arc may fit our new criteria for inclusion in this assessment but were omitted owing to a lack of data on their eruptive histories. These seamounts are Cheref (<109 m b.s.l), located between Asuncion and Agrigan Islands; West Saipan (292 m b.s.l.); and West Tinian (35 m b.s.l.) (Merle and others, 2003). These three seamounts are classified as inactive by Baker and others (2008) owing to null hydrothermal signatures when surveyed in 2003. If further research indicates that these are Holocene age, or they become active, they will likely be included in subsequent threat assessments.

American Samoa

American Samoa is an unincorporated and unorganized territory of the United States. Since 1951, Federal administration of American Samoa has resided with the Department of the Interior. American Samoa was mistakenly left out of the previous U.S. national volcanic threat assessment (Ewert and others, 2005) and that oversight is now addressed. The net result of including American Samoa volcanoes in the U.S. volcanic threat assessment is the addition of three volcanoes to the list of potentially active U.S. volcanoes (from west to east): **Tutuila Island**, **Ofu-Olosega**, and **Ta‘ū Island** (fig. 19) See table 3 for a listing of volcanoes in American Samoa.

The four principal islands of American Samoa (Tutuila, Ofu, Olosega, and Ta‘ū) consist of coalesced Pleistocene-age shield volcanoes, all of which are in the waning stages of eruptive activity (for example, Stearns, 1944; Stice and McCoy, 1968; McDougall, 2010). The volcanoes of American

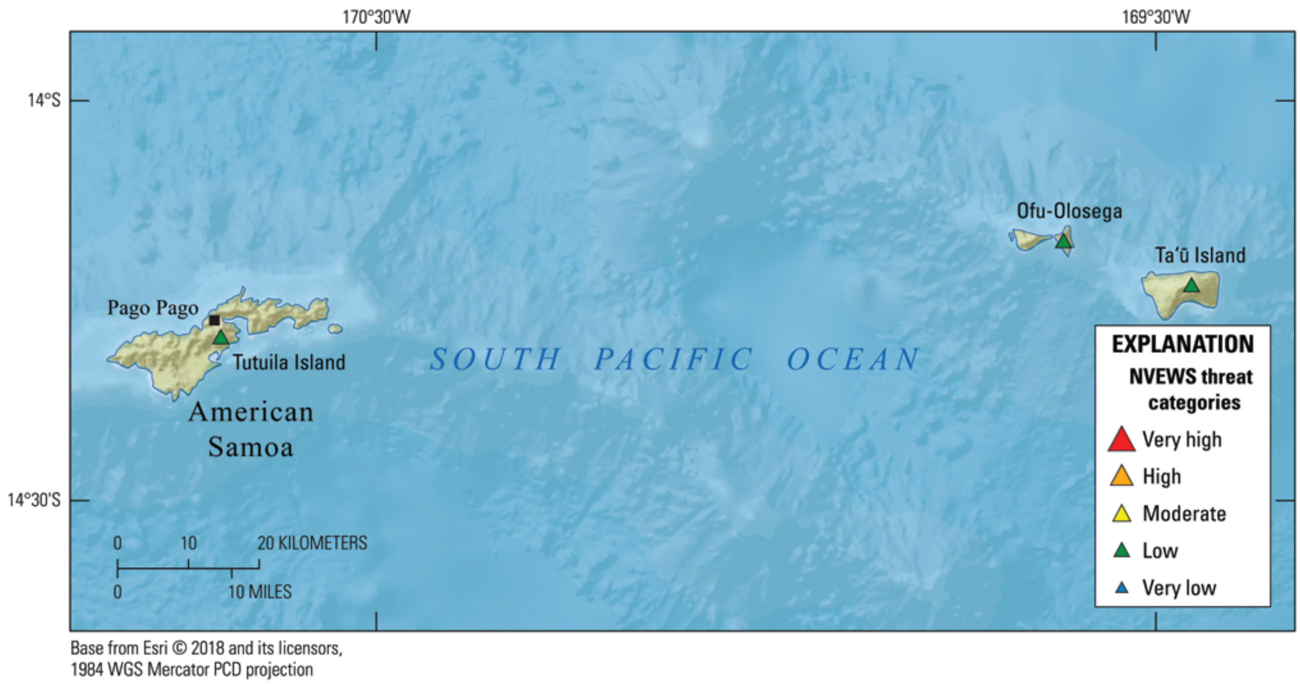

Figure 19. Map of volcano locations in American Samoa, which is in the area of responsibility of the Hawaiian Volcano Observatory. NVEWS, National Volcano Early Warning System.

Samoa are all the product of volcanism related to the passing of the Pacific Plate over the Samoan hotspot, with the age of volcanic products becoming gradually younger to the east (McDougall, 2010). This is a situation similar to that of the Hawaiian Islands and other intraplate volcanic island chains in the Pacific. The SI-GVP treats the volcanoes of Ofu and Olosega Islands as a single volcanic system and we follow that nomenclature here. Holocene-age eruptions are thought to have occurred on Tutuila, Ofu, and Ta'ū Islands, but only on Tutuila is there a firm ^{14}C age date (240–640 C.E.) on cultural artifacts that are overlain by tephra (Addison and others, 2006) to confirm this. The only historical (written records in the area begin the early 18th century) eruptions in American Samoa occurred in 1866 from a submarine vent 3 km east of Olosega on a shallow ridge between Olosega and Ta'ū Islands. This eruption built a cone to within 45 meters of the ocean surface (Sterns, 1944). Other probable historical eruptions (1973 and 1995) have come from the Vialulu'u seamount, 45 km east of Ta'ū Island (Hart and others, 2000). Vialulu'u seamount is not included in the threat assessment owing to its effusive eruptive character, basaltic composition, and depth (>590 m b.s.l.).

Scoring Update for U.S. Volcanic Threat

The volcanic threat scoring matrix employed by Ewert (2007) is the basis for this updated threat assessment. It consists of 15 hazard factors and 9 exposure factors (table 4). Individual hazard and exposure factors are scored for each volcano as explained in table 4; the hazard and exposure scores are summed independently, and the product of the sums is the overall threat score. To aid in distinguishing the threat groupings (bins), an additional subscore (termed the aviation threat score) was calculated for each volcano. The aviation threat score is the product of four hazard factors (maximum VEI, explosive activity, major explosive activity, and eruption recurrence) plus the two aviation exposure factors. The overall threat score and the aviation threat score are reported in table 2, the appendix, and shown graphically in figure 20. Hazard factor scores were updated for volcanoes where new research has identified Holocene eruptive activity or clarified our understanding of Holocene eruptive history and the occurrence of particular hazards such as tephra fall or pyroclastic density currents. With respect to the exposure factors, changes to population and regional aviation exposure affected all volcanoes. The most numerous scoring changes made in the threat matrix since 2005 have been made among the hazard factors, particularly those accounting for observed eruptive activity or unrest.

Minor modifications to a few of the original hazard and exposure factors were made to account for new research and observations related to submarine volcanism, an improved method to account for seismicity at poorly monitored volcanoes, and improved methods to calculate regional and local aviation exposure. These changes are described as follows.

Table 4. Threat ranking system to prioritize U.S. volcanoes for the National Volcano Early Warning System.

[See Ewert (2007) for details. Score as indicated in individual factor description. Changes to the ranking system appear in red and are described in the text. >, greater than; m, meters; km, kilometers]

Hazards Factors	Score
Volcano type	
If volcano type is cinder cone, basaltic field, small shield, or fissure vents	0
If volcano type is stratocone, lava domes, complex volcano, maar or caldera	1
Maximum volcano explosivity index (VEI)	
If maximum known VEI≤2	0
If maximum known VEI=3 or 4	1
If maximum known VEI=5 or 6	2
If maximum known VEI≥7: Score	3
If no maximum VEI is listed by GVP and if volcano type=0	0
If no maximum VEI is listed by GVP but volcano type=1	1
If no known Holocene eruptions and the volcano is not a silicic caldera system	0
Explosive activity	
If explosive activity (VEI≥3) within the past 500 years	1
Major explosive activity	
If major explosive activity (VEI≥4) within past 5,000 years	1
Eruption recurrence	
If eruption interval is 1–99 years	4
If eruption interval is 100–1,000 years	3
If eruption interval is 1,000 to several thousand years	2
If eruption interval is 5,000–10,000 years, or if no Holocene eruptions but it is a large-volume restless silicic system that has erupted in the last 100,000 years	1
If no known Holocene eruption	0
Holocene pyroclastic flows?	
If yes	1
Holocene lava flows?	
If Holocene lava flows have traveled beyond the immediate eruption site or flanks and reached populated areas	1
Holocene lahars?	
If Holocene lahars have traveled beyond the flanks and reached populated areas	1
Holocene tsunami(s)?	
Has it produced a tsunami within the Holocene? If yes	1
Hydrothermal explosion potential?	
If the volcano has had Holocene phreatic explosive activity, and (or) the volcano has thermal features that are extensive enough to pose a potential for explosive activity	1
Sector collapse potential?	
If the volcano has produced a sector collapse in Quaternary-Holocene time and has re-built its edifice, or, has high relief, steep flanks and demonstrated or inferred alteration	1
Primary lahar source?	
If volcano has a source of permanent water/ice on edifice, water volume >106 m^3	1

Table 4. Threat ranking system to prioritize U.S. volcanoes for the National Volcano Early Warning System.—Continued

Historical Unrest Factors	Score
Observed seismic unrest	
Since the last eruption, in the absence of eruptive activity, within 20 km of the volcanic edifice? If yes If seismic monitoring of a volcano has never been sufficient to detect the small magnitude swarms of shallow volcano-tectonic, or deep long-period earthquakes that often characterize seismic unrest, then a score of 0.5 is assigned for this unrest factor.	1
Observed ground deformation	
Since the last eruption, in the absence of eruptive activity, inflation or other evidence of magma injection? If yes	1
Observed fumarolic or magmatic degassing	
Since the last eruption, in the absence of eruptive activity, either heat source or magmatic gases? If yes	1
Total of Hazard Factors	
Exposure Factors	**Score**
Ground-based population ($\log_{10}$)	
Calculated primarily with LandScan population database. Visitor statistics for volcanoes in National Parks and other destination recreation areas are added to the ground-based population factor where available. Population outside the 30 km radius and included within the extent of Holocene flow deposits or reasonable inundation modeling of flowage processes are added to the ground-based population factor. This latter calculation is used only at volcanoes that have a primary lahar hazard (for example, Cascade stratovolcanoes) or significant lava flow hazard (for example, Mauna Loa).	
Historical fatalities?	
If yes, and a permanent population is still present	1
Historical evacuations?	
If yes, and a permanent population is still present	1
Local aviation exposure	
If any type volcano is within 50 km of an airport with scheduled passenger service it receives a score of 1; if a type 1 volcano is within 300 km of an airport with scheduled passenger service it receives a score of 1; if a type 1 volcano is within 300 km of a major international airport it receives a score of 2.	
Regional aviation exposure	
This score is based on the $\log_{10}$ of approximate daily passenger traffic in each region. At present, in the U.S., this score ranges from 4.06 to 5.68. The regional risk code is applied only to *type 1* volcanoes and those *type 0* volcanoes that have produced explosive eruptions.	
Power infrastructure	
Is there power infrastructure (for example, power generation/transmission/distribution for electricity, oil, or gas) within flowage hazard zones, or in an area frequently downwind of the volcano and close enough to considered at some risk? If yes	1
Transportation infrastructure	
Is there transportation infrastructure (for example, port facilities, rail lines, major roads) within flowage hazard zones, or in an area frequently downwind of the volcano and close enough to considered at some risk? If yes	1
Major development or sensitive areas	
Are there major developments or sensitive areas threatened (for example, National Park facilities, flood control projects, government facilities, developed tourist/recreation facilities, manufacturing or other significant economic activity)? If yes	1
Volcano is a significant part of a populated island	
Holocene volcanic deposits cover >25 percent of land mass. If yes	1
Total of Exposure Factors	
Sum of all hazard factors x Sum of all exposure factors = Relative threat ranking	

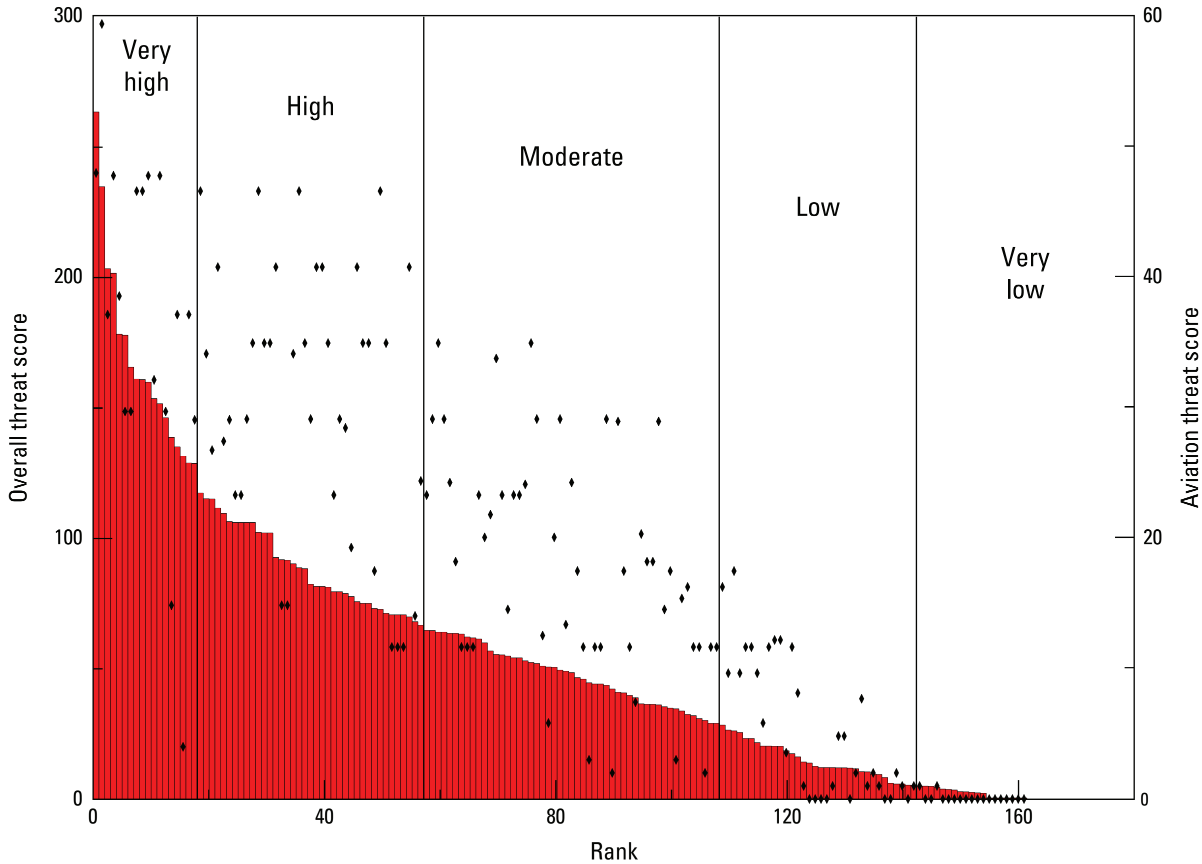

Figure 20. Graph showing overall threat scores for U.S. volcanoes (bars) with corresponding aviation threat score for each volcano (diamonds). Categories of overall threat as in tables 2 and 3.

Hazards Factors

Changes to Criteria Used to Include Submarine Volcanoes in the U.S. Volcanic Threat Assessment

The combination of greater attention being paid to submarine arc volcanoes by oceanographic researchers and recent remarkable submarine eruptions from South Sarigan seamount (2010) in the Marianas (Green and others, 2013; Searcy, 2013) and Havre Seamount (2012) in the Kermadecs (Carey and others, 2014; Rotella and others, 2015) caused us to reevaluate the potential hazards from submarine volcanoes. Mastin and Witter (2000) report eruptions from intermediate-composition (andesite) volcanoes down to 400 m b.s.l., breaking the surface and creating a marine hazard to shipping and an ash hazard to aviation. In 2012, Havre Seamount erupted dacite- to rhyolite-composition pumice from depths of 900–1,400 m b.s.l. in a day-long eruption which generated an aerial plume and huge rafts of pumice across the southwest Pacific (Carey and others, 2014). Historical reports of eruptions from submarine arc volcanoes are scant, and until very recently, data about depths and magnitudes of such eruptions have been practically nonexistent. Whether a submarine volcano produces a plume that breaks the surface and creates an aerial plume depends on a number of factors including composition and volatile content of the magma, intensity and magnitude of the eruption, and the depth below sea level of the vent. Simply stated, larger eruptions involving more silicic and gas-rich magmas will be able to break the sea surface from greater depths than will smaller ones. Hazards created by submarine eruptions include, but are not limited to, ash hazards to aviation if the eruption produces an airborne ash plume, foundering of marine vessels owing to loss of buoyancy if the vessel transits the eruption site, and generation of large tsunami waves that may impact nearby shorelines.

Revised criteria for including submarine volcanoes: Include if intermediate composition (andesite-dacite) and summit depth <400 m b.s.l. Include if silicic composition (rhyodacite-rhyolite) and summit depth <1,000 m b.s.l.

Changes to Unrest Factors

Growth of monitoring networks operated by the USGS, its affiliated state and university partners, and the NSF-supported Earthscope program since the first national volcanic threat assessment (Ewert and others, 2005), has allowed us to more accurately characterize the geophysical activity of an increasing number of volcanoes. Similarly, the expanding use of satellite-based interferometric synthetic aperture radar (InSAR) techniques has permitted year-to-year tracking of ground deformation at some otherwise unmonitored or undermonitored U.S. volcanoes (for example, Lu and Dzurisin, 2014). The growth of satellite-based thermal and sulfur dioxide remote sensing since 2005, combined with ongoing airborne and ground-based campaign surveys of passive volcanic gas emissions, has provided a more complete evaluation of degassing behavior of U.S. volcanoes. Nevertheless, our ability to detect important changes in behavior at many U.S. volcanoes remains hampered by the absence of ground-based sensors, particularly for ephemeral and sometimes subtle changes related to periods of magma intrusion into crustal magma reservoirs.

Ewert and others (2005) scored the binary seismic and (or) deformation unrest factors as not determined (nd) at 93 volcanoes. In the original analysis, calculations of the sums used to create the hazard subscore treated the nd notations as zeros, thereby creating a slight downward bias in the aggregate scores. This bias mainly affects the low and very low threat volcanoes, most of which remain poorly studied and monitored. In this update we address this statistical oversight by adopting the strategy of mean imputation, which amounts to substituting a value of 0.5 for any missing data when computing the sums (Little and Rubin, 2014). For example, for the seismic factor, if there has never been any effective seismic monitoring at a volcano, a score of 0.5 is given for seismic unrest to reflect the uncertainty surrounding this type of unrest. A total of 23 volcanoes, all in Alaska, have thus received a score of 0.5 for seismic unrest. In addition, we have been able to remove all nd scores for deformation, but acknowledge that this determination is largely based on satellite-based InSAR surveys (for example, Lu and Dzurisin, 2014), and that short-duration deformation signals may remain undetected in the absence of in situ global positioning system (GPS) monitoring.

Revised criteria for scoring seismic unrest: If seismic monitoring of a volcano has never been sufficient to detect the small magnitude swarms of shallow volcano-tectonic, or deep long-period earthquakes that often characterize seismic unrest, then a score of 0.5 is assigned for this unrest factor.

Exposure Factors

Of the nine exposure factors included in the threat matrix, the only factors that required updating across all volcanoes were those related to population—the ground-based and airborne population exposure factors. The method used to calculate the regional aviation exposure (daily airborne population) was updated. We note that although there were some large changes (mainly increases) in some raw scores, the impact of the changes is muted because we take the $\log_{10}$ of the raw numbers to generate the population factor scores to keep the factors at a similar scale. Additionally, the criteria for scoring the binary local aviation exposure was changed to account for the impact of airborne volcanic ash and ash fall on airports served by scheduled turboprop service. These changes are described below.

Ground-based Population

To estimate ground-based population exposed to volcanic hazards, Ewert and others (2005) and Ewert (2007) used the global LandScan 2002 population database produced by Oak Ridge National Laboratory (Dobson and others, 2000) in conjunction with coordinate data from the SI-GVP VOTW database to calculate the $\log_{10}$ of ambient population within 30 km. This factor is termed the volcano population index for 30 km, or VPI_{30} (Ewert and Harpel, 2004). The rationale for using the VPI_{30} is described by Ewert (2007).

We used the LandScan 2014 population database to calculate VPI_{30} for each volcano in this update of the threat assessment. The LandScan 2014 population database has the same spatial resolution (1 km) as the 2002 release used in the original threat assessment. Some changes in the ground-based population numbers are evident. Some of the changes reflect actual changes in population, and other changes, particularly in sparsely populated areas, result from the dynamic nature of the remote sensing, census, and other input data used to create the LandScan database. The creators of LandScan explicitly state that the different releases of LandScan should not be used as a change detection or migration tool (https://landscan.ornl.gov/frequently-asked-questions). Changes in residential population exposure over time can be quantified using raw census data combined with other geospatial datasets in a well-controlled study, for example, Diefenbach and others (2015). Such a detailed treatment of population change near all U.S. volcanoes is beyond the scope of this report and we chose to follow the methodology of Ewert (2007) using the updated LandScan 2014 population database to calculate ground-based population exposure.

At volcanoes that have flowage hazard zones that extend beyond 30 km into populated areas (lahars in the Cascade Range of Washington, Oregon, and California, or lava flows from Hawaiian volcanoes), published flowage hazard zone databases were combined with LandScan 2014 data to estimate the additional population exposure in the hazard zones, which was added to the VPI_{30}. Volcanoes thus treated include Kīlauea, Mauna Loa, and Mauna Kea with hazard zones from Wright and others (1992); Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams with hazard zones from Schilling (1996); Mount Hood with hazard zones from Schilling and others (2008c), Mount Jefferson with hazard zones from Schilling and others (2007); Three Sisters with hazard zones from Schilling and others (2008b); Newberry Volcano with hazard zones from Schilling and others (2008d); Crater Lake with hazard zones from Schilling and others (2008a); Mount Shasta with hazard zones from White and others (2011); and Lassen volcanic center with hazard zones from Robinson and Clynne (2012).

Thirty-four (about 21 percent) of the volcanic systems included in this assessment lie within or partly within land areas managed as national parks or monuments (table 5). Owing to their status as national parks and monuments, ground-based population estimates employing census, LandScan, or other geospatial data sets for these volcanoes do not capture the additional ground-based population related to site visitation. For instance, the LandScan database indicates that there are approximately 995 persons within 30 km of the coordinate given for Yellowstone (not far from Old Faithful geyser), yet visitation to Yellowstone National Park was over 4.25 million people in 2016. Similar situations exist for most other national park and national monument volcanoes. In this report we used annual visitor statistics for 2016 compiled by the National Park Service (2017). Visitor statistics for Mount St. Helens are from 2011, reported by Mros-O'Hara and Van der Mast (2012). Visitor statistics for the Valles Caldera National Preserve, managed by the National Park Service since 2015, are obtained from the 2013 report to Congress by the Valles Caldera Trust (2013). Seasonal visitor statistics for Newberry Volcano were provided by the U.S. Forest Service Newberry National Volcanic Monument (Scott McBride, written commun., 2018). Annual visitor statistics for volcanoes managed as national parks or monuments were divided by 365 to produce a nominal average population whose safety would potentially be affected by volcanic activity, and this number was added to the estimates of people used to calculate VPI30 and the >30 km flowage hazard zone to arrive at the total exposure factor for ground-based population.

We note that recent detailed studies of community and population exposure to volcano hazards in the Cascade Range have been done at Mount Rainier (Wood and Soulard, 2009; Cakir and Walsh, 2012), Mount Hood (Burns and others, 2011; Mathie and Wood, 2013), and for the five principal stratovolcanoes in the Cascades of Washington State (Diefenbach and others, 2015). Studies such as these at high and very high threat volcanoes are important steps toward hazard mitigation, as the results can be used by communities at risk to understand more precisely their vulnerabilities and deal with the hazards they face.

Table 5. U.S. National Parks and Monuments containing volcanoes addressed in this threat assessment.

National Park (NP) or National Monument (NM)	Volcano or volcanoes partly or wholly within the Park or Monument
Mount Rainier NP	Mount Rainier
Crater Lake NP	Crater Lake
Lava Beds NM	Medicine Lake
Lassen Volcanic NP	Lassen volcanic center
Devils Postpile NM	Mammoth Mountain
Death Valley NP	Ubehebe Crater
Sunset Crater NM	San Francisco Volcanic Field
Valles Caldera National Preserve	Valles Caldera
Yellowstone NP	Yellowstone caldera
Craters of the Moon NM	Craters of the Moon
Lake Clark NP	Illiamna Volcano, Redoubt Volcano
Katmai NP	Mount Martin, Mount Mageik, Trident Volcano, Novarupta, Mount Griggs, Mount Katmai, Snowy Mountain, Mount Denison, Mount Steller, Kukak Volcano, Kaguyak Crater, Fourpeaked Mountain, Mount Douglas
Aniakchak NM	Aniakchak Crater
Hawai'i Volcanoes NP	Kīlauea, Mauna Loa
Haleakalā NP	Haleakalā
El Malpais NM	Zuni-Bandera volcanic field
Wrangell-St. Elias NP	Mount Wrangell, Mount Churchill
Mount St. Helens National Volcanic Monument (managed by U.S. Forest Service)	Mount St. Helens
Newberry National Volcanic Monument (managed by U.S. Forest Service)	Newberry Volcano

Regional Aviation Exposure Factor

Volcanic ash hazards to aviation are well known and the USGS volcanic threat assessment takes hazards to aircraft and airports into account with exposure factors scored for regional and local aviation (fig. 21). The regional aviation exposure factor was developed by Ewert and others (2005) to capture the average number of people in volcanic airspace aboard enroute commercial aircraft. To estimate this factor, Ewert and others (2005) defined six volcanic airspace regions (fig. 22) and used airport statistics on enplaned passengers for the principal airports located in and near volcanic areas.

In this update, we conducted a geospatial analysis of people transiting U.S. volcanic airspace, which we think provides a more accurate factor score, particularly for Alaska regional airspace, owing to the much greater number of passengers and flights that transit the area without arriving or departing from airports within the area. The computer coding to accomplish this task was created by Dr. P. Cervelli at the USGS Volcano Science Center. To begin, we used the air carrier statistics database, also known as the T-100 data bank, for 2016 (U.S. Department of Transportation, Bureau of Transportation Statistics, 2017). From the T-100 data bank we used the T-100 Segment (all carriers), which combines domestic and international flight segment data reported by U.S. and foreign air carriers, and contains nonstop segment data by aircraft type and service class for transported passengers, freight and mail, available capacity, scheduled departures, departures performed, aircraft hours, and load factor. The database includes origin and destination airports for each segment. Using geospatial coordinate data for each origin-destination pair, great circle routes for each segment were calculated. We defined seven volcanic airspace regions, adding a region for Salton Buttes in far southern California (Salton Buttes was not included in Ewert and others [2005]). Airspace regions were defined for Alaska, Hawaii, the CNMI, the Cascade Range (including Clear Lake volcanic field in Northern California), California-Nevada, Salton Buttes, and the intermountain west area of the conterminous United States (fig. 22). If calculated great circle segments intersected an airspace box, the database was queried for each day of 2016 for aircraft type and enplaned passengers on each segment to determine the total passengers on jet aircraft. The regional aviation factor was not scored in the newly added American Samoa region owing to the generally nonexplosive nature of the volcanoes there.

Large changes in the raw numbers of people using U.S. volcanic airspace are noted for Alaska and the conterminous United States, where more than 60,000 and 250,000 persons, respectively, can be expected in the volcanic airspaces on a daily basis, compared to approximately 20,000 and 100,000, respectively, reported previously by Ewert and others (2005) and Ewert (2007). As noted above, because we take the $\log_{10}$ of the raw numbers to score the factor, the impact of the changes on the overall threat scores is muted.

Local Aviation Factor

Local threats to aviation by volcanoes are principally to airports. The local aviation exposure factor developed by Ewert and others (2005) explicitly recognized jet-service airports as the installations of most concern. In reviewing the exposure factors for this update of the assessment, it came to our attention that this factor was not accurately capturing ash impacts to airports in Alaska that have scheduled turboprop service. This was particularly the case for the Unalaska airport at Dutch Harbor in the eastern Aleutian Islands, which has incurred service interruptions on several occasions owing to airborne volcanic ash from nearby volcanoes. Recognizing this shortcoming in the local aviation factor, we have rescored a number of volcanoes in the eastern Aleutian Islands for this factor and modified the criteria for scoring the local aviation factor. This change had no threat-score impact in the other regions.

Revised criteria for scoring local aviation exposure: If any type volcano (see table 4) is within 50 km of an airport with scheduled passenger service it receives a score of 1; if a type 1 volcano is within 300 km of an airport with scheduled passenger service it receives a score of 1; if a type 1 volcano is within 300 km of a major international airport it receives a score of 2.

Figure 21. Collapsed hangars, damaged aircraft, and covered runways at Clark Air Force Base on June 22, 1991, owing to heavy ashfall from the eruption of Pinatubo Volcano, Philippines. Photograph by R.L. Hoblitt, U.S. Geological Survey.

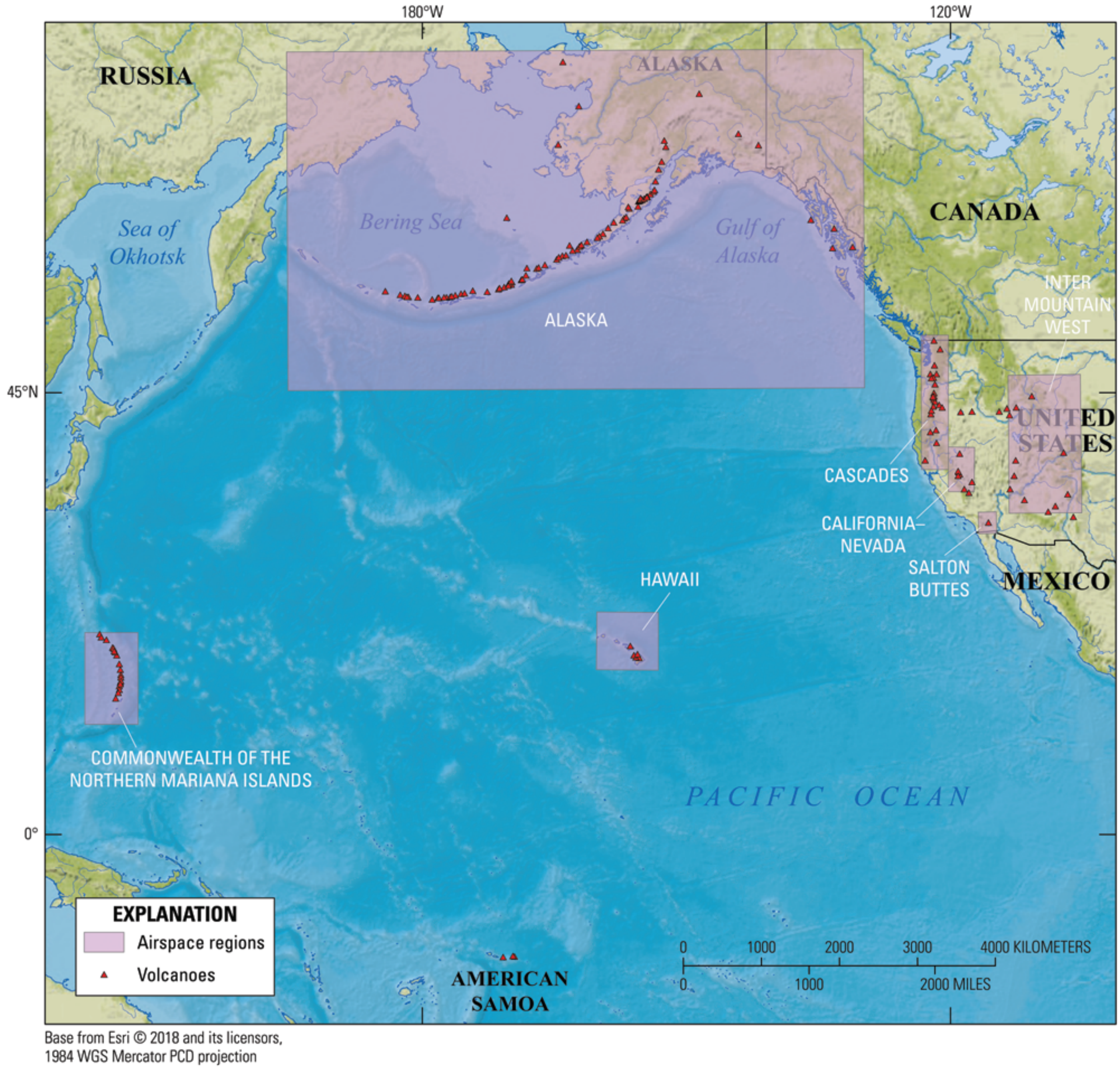

Figure 22. Map showing airspace regions used to calculate regional aviation exposure factor.

Changes to Threat Rankings

Changes to the overall volcanic threat rankings are described here by threat category. The scoring system developed by Ewert (2007) is used, modified as described above (table 4). The scoring system employs 15 hazard factors and 9 exposure factors, which are added within the two categories and then multiplied to generate a threat score for each volcano. The scored factors for the volcanoes assessed in this update are tabulated in the accompanying spread sheet (appendix) and the overall threat score is rounded to the nearest whole number before grouping. The results are presented in tables 2 and 3, and graphically in figures 6–19. The overall threat scores for U.S. volcanoes range from a high of 263 (for Kīlauea) to 0 (for Fukujin seamount, Kasuga 2, Daikoku seamount, Ahyi Seamount, Esmeralda Bank, and Ruby in the CNMI; and Imuruk Lake in Alaska). In Ewert (2007) the scores ranged from 262 to 0. Given the nearly identical range of scores, we have maintained the approximate numeric boundaries between the five threat categories as were chosen by Ewert and other (2005). Within all five threat categories there are changes in relative rankings of volcanoes, and in a few cases, volcanoes moved up or down between categories owing to changes in our understanding of their hazard, unrest, and exposure factors.

Very High Threat Volcanoes

Ewert (2007) listed 18 volcanoes with overall threat scores greater than 128 in the very high threat category. All of the original 18 volcanoes remain in this category.

High Threat Volcanoes

Ewert (2007) listed 37 volcanoes with overall threat scores ranging from 63 to 109 in the high threat category. In this update, we list 39 volcanoes with scores of 67 through 117 as high threat. Notable changes in this category include the addition of Salton Buttes, California, which did not appear in the original threat assessment, and the elevation of Fourpeaked Mountain, Alaska, from the low threat category following eruptive activity in 2006. Fourpeaked Mountain is the only volcano that changed by more than one threat category in this update.

As explained in the section above about the changes made to the list of volcanoes considered in this update, Atka volcanic complex and Korovin Volcano, Alaska, were divided into separately named volcanoes, and Mono Craters and Inyo domes, California, were combined into a single named volcano. Also, Mount Cleveland, Mount Douglas, Fisher Caldera, Kasatochi Island, Mount Moffett, and Snowy Mountain (Alaska), were elevated from the moderate threat category based on recognition of hazard and exposure factors not documented in 2007, and (or) unrest that was observed.

Moderate Threat Volcanoes

Ewert (2007) listed 48 volcanoes with overall threat scores ranging from 30 to 63 in the moderate threat category. In this update, we list 49 volcanoes with scores of 30 through 65 as moderate threat. Notable changes in this category include the addition of Soda Lakes (Nevada), and East Diamante (CNMI) which did not appear in the original threat assessment. Also, with scoring factors updated, Takawangha volcano, Kagamil Volcano, and St. Michael Island (Alaska) moved from low to moderate threat. Mount Dutton, Mount Gareloi, Pavlof Sister, and Mount Wrangell (Alaska), and Alamagan Island and Anatahan Island (CNMI), decreased from high threat to moderate threat. Mount Sanford (Alaska) and Steamboat Springs (Nevada) were the only moderate threat volcanoes removed from the assessment entirely.

Low Threat Volcanoes

Ewert (2007) listed 35 volcanoes with overall threat scores ranging from 6 to 30 in the low threat category. In this update, we list 34 volcanoes with scores of 6 through 29 as low threat. Notable changes in this category include the addition of Tana (Alaska), Tutuila Island, Ofu-Olosega, and Ta‘ū Island (American Samoa), and Zealandia Bank and South Sarigan seamount (CNMI), none of which appeared in the original threat assessment. Amak Island (Alaska) decreased from moderate threat, and Blue Lake crater (Oregon), Carrizozo Mountain (New Mexico), and Supply Reef (CNMI), increased from very low threat to low threat. Isanotski Peaks, Nunivak Island, and Mount Sergief (Alaska) were the only low threat volcanoes removed from the assessment entirely.

Very Low Threat Volcanoes

Owing mainly to volcanoes being removed from the threat assessment based on better knowledge of their eruptive histories, the very low threat category underwent the greatest changes. Ewert (2007) listed 32 volcanoes with overall threat scores ranging from 0 to 6 in the very low threat category. In this update, we list 21 volcanoes with scores of 0 through 5 as very low threat. Notable changes are mainly the removal from the assessment of Mount Gordon and the Kookooligit Mountains (Alaska); Four Craters Lava Field, Jackies Butte, Lava Mountain, and Mount Washington (Oregon); Amboy Crater, Big Cave, Brushy Butte, Eagle Lake volcanic field, Lavic Lake volcanic field, Tumble Buttes, and Twin Buttes (California); and Bald Knoll and Santa Clara volcanic field (Utah). Red Hill-Quemado volcanic field (New Mexico), Diakoku, Fukujin seamount, and Kasuga 2 (CNMI) were added to the assessment. Duncan Canal (Alaska), Esmeralda Bank, and Ruby (CNMI) decreased from low threat to very low threat.

Discussion

The updated national volcanic threat assessment presented here is not a forecast or indication of which volcanoes are most likely to erupt next. Rather, it is an indicator of the potential severity of impacts that may result from future eruptions at any given volcano. As such, the assessment can be used to help guide and prioritize volcano research, hazard assessment, emergency planning and preparation, and monitoring efforts by Federal, state, and local government.

Some broad patterns can be seen in the threat assessment results. Volcanoes in Alaska and CNMI lie on convergent tectonic plate margins, and as a consequence, contain dominantly more explosive volcanoes (90 percent type 1) (table 4; appendix). The more complex tectonic settings present in the conterminous United States (CONUS) result in a greater variation of volcano types, and only about 56 percent of CONUS volcanoes are type 1. If we had assessed only the hazards aspects of U.S. volcanoes, then the generally more explosive volcanoes in Alaska and CNMI would be more strongly represented in the higher (more hazardous) ranks. Because we include exposure factors in the assessment, volcanoes in CONUS are more strongly represented in the highest threat category owing to the greater nearby ground-based and airborne population, and more critical infrastructure exposed to volcano hazards. In this regard, it is worth highlighting some aspects of the

18 very-high-threat volcanoes identified by Ewert and others (2005), Ewert (2007) and this report (fig. 1, table 2). Eleven of the 18 volcanoes are in Washington, Oregon, and California, where explosive and often snow- and ice-covered edifices can project flowage hazards long distances to reach densely populated and highly developed areas. Five of the 18 volcanoes are in Alaska, near important population centers, economic infrastructure, or below busy air traffic corridors. The remaining two very high threat volcanoes are on the Island of Hawai‘i, where densely populated and highly developed areas now exist on the flanks of highly active volcanoes. Large eruptions from any of these very high threat volcanoes could cause regional- or national-scale disasters.

The high- and moderate-threat categories are dominated by Alaskan volcanoes, 77 and 59 percent, respectively. In these categories the generally more active and more explosive (than those in CONUS or the CNMI) volcanoes in Alaska can have a substantial effect on national and international aviation. Large eruptions anywhere from volcanoes in high and moderate categories could also cause significant disasters. None of the five Hawaiian volcanoes are less than moderate threat.

The low-threat category is dominated by CONUS and Alaskan volcanoes, 32 and 47 percent, respectively. In this case, greater hazards (Alaska) and greater exposure (CONUS) tend to balance each other. The very low threat category is dominated by CONUS and CNMI volcanoes, 48 and 29 percent, respectively. In this case, the greater proportion of type 0 volcanoes in CONUS, and submarine volcanoes in CNMI, account for their greater representation in the least threatening category.

Summary

This update of the U.S. volcanic threat assessment (Ewert and others, 2005) considers field and laboratory research that has been reported since the first assessment to add and remove volcanoes from the list of potentially active volcanoes, and to update the hazard and exposure factors used to produce a relative threat ranking of volcanoes. The ranked volcanoes are divided into five threat categories. These threat categories and separate subscores (for example, aviation threat score or ground-based population) have been used to develop a strategy for the USGS to prioritize volcanic risk mitigation through research, monitoring, hazard assessment, and community engagement (U.S. Geological Survey, 2007; Holmes and others, 2012).

The net result of this update is that we now include 161 volcanoes in the U.S. volcanic threat assessment, 8 fewer than Ewert and others (2005). As with all assessments, this one is a snapshot in time and the threat scores, and even some of the volcanoes, presented in this report are subject to change as new data on past eruptive activity emerge and (or) as unrest and eruptions occur, and exposure factors change as areas near volcanoes are developed.

The prioritization of risk mitigation efforts is a cornerstone in the development of the National Volcano Early Warning System. The results of the threat ranking are also an effective communication tool with which to engage stakeholders and the public in discussions of volcanic activity and hazards in the U.S. with the goal of developing emergency preparedness, coordination, and response plans.

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Appendix. U.S. Volcanic Threat Score Sheet.

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