



# Chronology and References of Volcanic Eruptions and Selected Unrest in the United States, 1980- 2008

By Angela K. Diefenbach, Marianne Guffanti, and John W. Ewert

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## Part I

### Introduction

The United States ranks as one of the top countries in the world in the number of young, active volcanoes within its borders. The United States, including the Commonwealth of the Northern Mariana Islands, is home to approximately 170 geologically active (age <10,000 years) volcanoes (Siebert and Simkin, 2002-). As our review of the record shows, 30 of these volcanoes have erupted since 1980, many repeatedly. In addition to producing eruptions, many U.S. volcanoes exhibit periods of anomalous activity, *unrest*, that do not culminate in eruptions.

Monitoring volcanic activity in the United States is the responsibility of the U.S. Geological Survey (USGS) Volcano Hazards Program (VHP) and is accomplished with academic, Federal, and State partners. The VHP supports five Volcano Observatories—the Alaska Volcano Observatory (AVO), Cascades Volcano Observatory (CVO), Yellowstone Volcano Observatory (YVO), Long Valley Observatory (LVO), and Hawaiian Volcano Observatory (HVO). With the exception of HVO, which was established in 1912, the U.S. Volcano Observatories have been established in the past 27 years in response to specific volcanic eruptions or sustained levels of unrest. As understanding of volcanic activity and hazards has grown over the years, so have the extent and types of monitoring networks and techniques available to detect early signs of anomalous volcanic behavior. This increased capability is providing us with a more accurate gauge of volcanic activity in the United States.

The purpose of this report is to (1) document the range of volcanic activity that U.S. Volcano Observatories have dealt with, beginning with the 1980 eruption of Mount St. Helens, (2) describe some overall characteristics of the activity, and (3) serve as a quick reference to pertinent published literature on the eruptions and unrest documented in this report.

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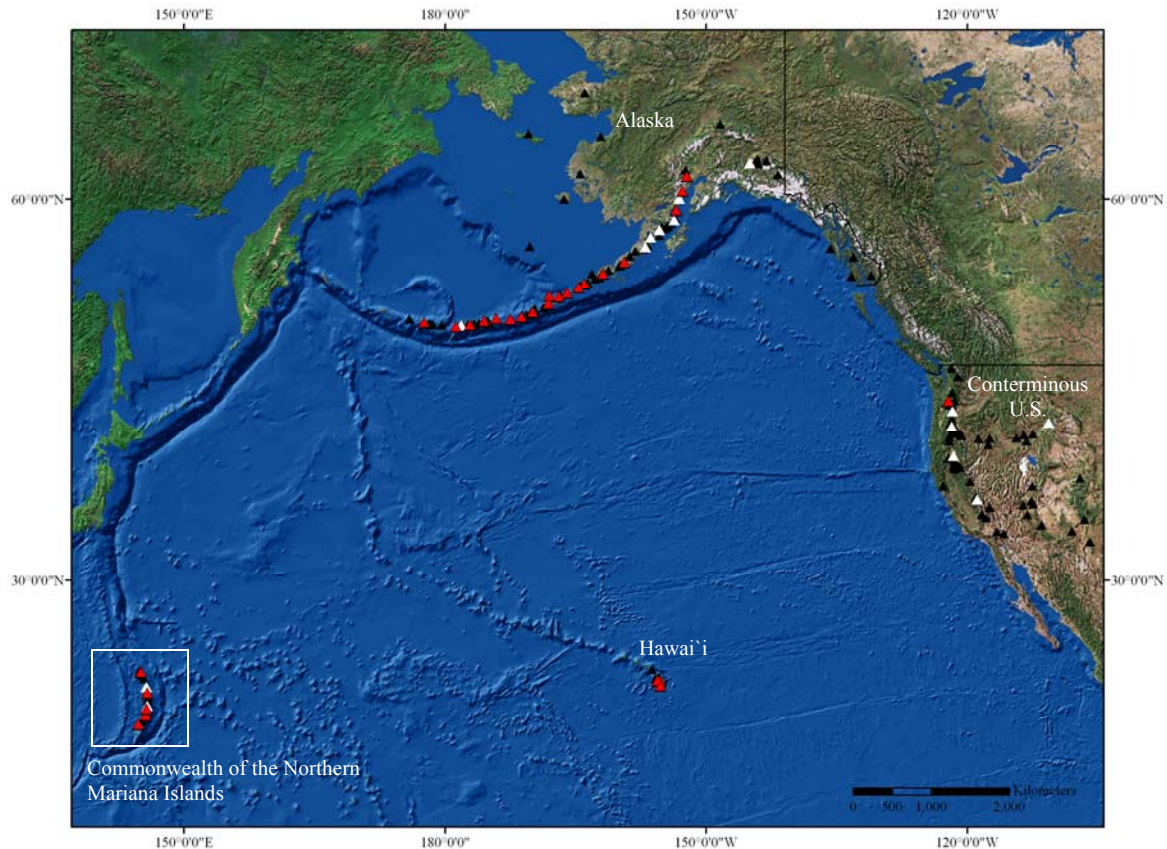


Figure 1. Geographic distribution of volcanic centers in the United States. Volcanoes that have erupted since 1980 are displayed as red triangles, and volcanoes that have produced episodes of unrest without eruption are displayed as white triangles. The remainder of all U.S. volcanic centers are displayed as black triangles.

## Methodology

### Eruption Criteria

Eruption data were acquired from the Smithsonian Institution's Global Volcanism Program (GVP) Web site ([www.volcano.si.edu](http://www.volcano.si.edu)) and activity reports of the five U.S. volcano observatories. Criteria used to define and document eruptive events were adopted from the GVP and are discussed below. We adopted the GVP criteria to maintain consistency with the global catalog of volcanic activity maintained by the GVP.

As defined by the GVP, an eruption is the arrival of solid volcanic products at the Earth's surface. Following this definition, volcanic events such as steam emissions (that do not produce ash), no matter how vigorous, are not counted as eruptions in this report. Arrival of juvenile magma at the surface, however, is also not required; eruptions that eject non-juvenile material are included in the GVP definition of an eruption and are included in this report. The end of an eruption is determined by the conclusion of

eruptive activity, even though a formal declaration by an observatory may not occur until months later.

The word eruption, in singular form, has had variable definitions applied to it with respect to the duration of volcanic activity. Depending on the observer, an eruption can be defined as a single event that lasts hours to an eruptive episode on a decadal time scale. In this report, with a few exceptions, we have separated volcanic eruptions into independent events if the period of quiet between eruptive events exceeds three months. This standardization, established by the GVP, provides a consistent accounting of recent volcanic eruptions.

Volcanic eruptions listed in this report are confirmed by the USGS or a State, Federal or academic partner of the USGS. Because some volcanoes are remote or lack monitoring stations, especially some in Alaska and the Commonwealth of the Northern Mariana Islands, there are several reports of “suspected” eruptions in the GVP database and in observatory activity logs (Siebert and Simkin, 2002-). The “suspected” reports in the GVP database and observatory activity logs often come from eyewitness accounts of eruptive activity or from ground-based monitoring data that suggest volcanic activity, but were not confirmed visually or on the basis of satellite images by USGS scientists. To provide reliable documentation of volcanic eruptions, any “suspected” events were omitted, and only those eruptions confirmed by the USGS or its partner agencies are included in this report.

## Unrest Criterion

Although eruptions are typically preceded by unrest that may last for days to months, not all unrest culminates in eruption. In this report, we distinguish unrest as unusual *non-eruptive* activity from precursory unrest that has led to eruption. Owing to the variable character of background activity at individual volcanoes, specifying such activity as unrest in a consistent manner can be problematical. Activity such as steam plumes, thermal anomalies, seismic events, or degassing may be anomalous at one volcano, but typical background activity at another. Moreover, detection and characterization of unrest is often dependent on the historical record of a volcano, as determined by years of direct observation, or data from ground-based monitoring networks, records that are not available at many U.S. volcanoes (Ewert and others, 2005). For the purpose of this report, we selected unrest episodes based on the criterion that a volcano observatory responded in some way to each episode listed in this report. Observatory responses may have included an alert-level notification or information release describing changes in volcanic behavior (Gardner and Guffanti, 2006) or may have consisted of actions, such as the installation of monitoring equipment or additional fieldwork performed by scientists to gather more information about the unrest. Most cases of unrest reported here involved both a formal alert-level notification or information release to the public and field-based investigations by an observatory.

The record of unrest duration is provided by data from visual observations, ground-based monitoring networks, and/or remote-sensing platforms. The end of an episode of unrest usually is determined by the cessation of anomalous activity of unrest (for example, end of earthquake swarm, deformation has stopped, degassing is no longer occurring). In some cases the duration of unrest may be associated or confirmed with an alert-level notification or information release that states the end of the episode of unrest.

A special case of unrest is the record of nearly continuous (1980 to present) unrest of Yellowstone and Long Valley calderas. Owing to the large size of the underlying magma systems and their complex tectonic settings, Yellowstone and Long Valley calderas exhibit some form of unrest such as earthquakes, ground deformation, and degassing activity, on a frequent, recurring basis. In general, caldera unrest is characterized by extended periods of background unrest that may last for decades (Newhall and Dzurisin, 1988). Such is the case at Yellowstone and Long Valley calderas since the beginning of this report period, and we have designated them as exhibiting continuous unrest.

## Documentation

Publications in the form of journal articles, GVP monthly reports, conference abstracts, and USGS reports constitute the selected references about each eruptive or unrest episode in Part II of this report. The list of references included in this report typically is incomplete for each volcano or each volcanic event. For eruptions or episodes of unrest that have resulted in the publication of a substantial literature, such as the eruptions of Mount St. Helens or the unrest at Long Valley Caldera, we have included only research publications that provide key information, summarize the event comprehensively, or elicit other published literature. In other cases, such as the eruption of Kiska in 1990, the number of published studies is few. For these events, all known publications were included. The headers indicate in Part II whether the citations are selected or comprehensive.

## Eruptions and Unrest

Because its vast geography encompasses several different tectonic regimes, the United States is home to a spectrum of volcanism that includes explosive stratovolcanoes, effusive shield volcanoes, and restless calderas. The resultant styles of eruption and unrest are as diverse as the volcano types and range in eruptive class from small-magnitude lava flows to significant pyroclastic eruptions and in signatures of unrest from phreatic explosions to hazardous degassing.

During the past 29 years, 43 volcanoes within the United States have produced 95 eruptions and 32 episodes of unrest (table 1; fig. 2). More than half of the 30 eruptive volcanoes have erupted two or more times. The majority (77 percent) of U.S. eruptions has occurred in Alaska. Akutan volcano in Alaska has produced the most eruptions (11) in the past 29 years, followed by Veniaminof (10), Cleveland (9), and Pavlof (8).

Table 1 of this report will be updated as warranted by events and is available online at [http://volcanoes.usgs.gov/activity\\_since\\_1980/](http://volcanoes.usgs.gov/activity_since_1980/).

The total numbers of eruptions and unrest episodes reported here are minimum values. Unrest or small eruptions of isolated volcanoes with little to no ground-based monitoring may have gone unnoticed. The number of suspected eruptive events (>20) reported by the GVP and observatory activity logs alone suggest that volcanic activity in the United States may be more abundant than what is reported in table 1.

An increase in the number of reported episodes of volcanic unrest during the past 29 years began shortly after AVO was established in 1988 and became a consistent source of activity reporting (fig. 3). Since 1996, AVO has installed seismic networks on more than two dozen Aleutian volcanoes, thus greatly improving its ability to detect signs of unrest (Brantley and others, 2004). In addition to expanded ground-based monitoring, AVO began routine and systematic use of remote sensing to monitor Alaskan volcanoes and to detect activity that otherwise might have gone unnoticed in the absence of ground-based sensor networks.

Satellite-based methods for volcano surveillance have improved substantially in the past two decades. A technique useful for detecting unrest is Interferometric Synthetic Aperture Radar (InSAR), which measures surface deformation at volcanic centers (Lu and others, 1997). A specific example of the success of InSAR was its ability to detect aseismic uplift that began in 1998 west of South Sister volcano (Wicks and others, 2002), activity that likely would not have been recognized before the application of InSAR (fig. 4). Due to the InSAR results, additional instrumentation was installed, and the ongoing deformation is also monitored by yearly field campaigns.

Table 1. Description and chronology of volcanic eruptions and unrest in the United States from 1980 through 2008.

<b>GVP<sup>a</sup> VOLCANO NUMBER</b>	<b>VOLCANO</b>	<b>ERUPTION DATES (MM/DD/YYYY) AND VEI<sup>b</sup> VEI in parenthesis</b>	<b>UNREST EPISODE: MM/DD/YYYY</b>
<b>Hawai'i</b>			
1302-00-	Lo`ihi Seamount	02/25/1996-08/09/1996 <sup>c</sup> (0)	
1302-01-	Kīlauea	03/11/1980-03/11/1980 (0) 04/30/1982-05/01/1982 (0) 09/25/1982-09/26/1982 (0) 01/03/1983-present (1)	
1302-02=	Mauna Loa	03/25/1984-04/15/1984 (0)	Inflation and deep seismicity: 04/24/2002-present
<b>Conterminous U.S.</b>			
1201-05-	Mount St. Helens, Washington	03/27/1980-10/26/1986 (5) 12/07/1989-01/06/1990 (2) 11/05/1990-02/14/1991 (3 <sup>d</sup> ) 10/01/2004-01/??/2008 (2)	Elevated seismicity: 01/01/1995- 10/??/1995 Elevated seismicity and CO <sub>2</sub> detection: 05/??/1998- 07/??/1998



<b>GVP<sup>a</sup> VOLCANO NUMBER</b>	<b>VOLCANO</b>	<b>ERUPTION DATES (MM/DD/YYYY) AND VEI<sup>b</sup> VEI in parenthesis</b>	<b>UNREST EPISODE: MM/DD/YYYY</b>
1202-01-	Mount Hood, Oregon		Earthquake swarm: 07/06/1980- 08/05/1980 Earthquake swarm: 01/11/1999- 01/14/1999 Earthquake swarm: 01/10/2001- 01/19/2001 Earthquake swarm: 06/29/2002- 06/29/2002
1202-08-	South Sister, Oregon		Uplift began 1998* – continues at present (earthquake swarm: 03/23/2004-03/25/2004)
1203-02-	Medicine Lake, California		Earthquake swarm: 09/29/1988- 11/15/1988
120314-A	Long Valley Caldera, California		Recurrent earthquake swarms, changes in thermal springs and gas emissions, and uplift since 05/25/1980 and CO <sub>2</sub> emission from ground since 05/01/1989
1205-01-	Yellowstone Caldera, Wyoming		Recurrent earthquake swarms and ground deformation (uplift and subsidence), changes in hydrothermal features: 1980- present
<b>Alaska</b>			
1101-02-	Kiska	06/01/1990-06/01/1990 (2)	
1101-06-	Sugarloaf Peak (Semisopochnoi)	04/13/1987-05/26/1987 (2 <sup>c</sup> )	
1101-07-	Gareloi	08/07/1980-09/17/1980 (3 <sup>c</sup> ) 01/15/1982-01/15/1982 (3) 09/04/1987-? (1 <sup>c</sup> ) 08/17/1989-? (1)	
1101-08-	Tanaga		Earthquake swarm: 10/01/2005- 11/25/2005
1101-11-	Kanaga	01/05/1994-06/23/1995 (2)	
1101-13-	Kasatochi	08/07/2008-08/08/2008 (4 <sup>d</sup> )	
1101-16-	Korovin (Atka)	03/04/1987-03/18/1987 (2) 06/30/1998-06/30/1998* (3) 11/25/2006-03/03/2007 (1)	Earthquake swarms, steam, and ash plumes: 02/23/2005-05/07/2005
1101-18-	Seguam	12/27/1992-12/30/1992 (2) 05/28/1993-08/19/1993* (2)	
1101-19-	Amukta	09/04/1987-09/04/1987* (1) 07/??/1996-09/??/1996 (1)	

GVP <sup>a</sup> VOLCANO NUMBER	VOLCANO	ERUPTION DATES (MM/DD/YYYY) AND VEI <sup>b</sup> VEI in parenthesis	UNREST EPISODE: MM/DD/YYYY
1101-24-	Cleveland	07/12/1984-07/12/1984 (1) 04/28/1986-05/27/1986 (2) 06/19/1987-08/28/1987 (3) 05/25/1994-05/25/1994 (3) 05/05/1997-05/05/1997 (2) 02/02/2001-04/15/2001 (3) 04/27/2005-09/27/2005 (2) 02/06/2006-10/28/2006 (3) 06/??/2007-09/04/2008* (2)	
1101-29-	Okmok	03/24/1981-03/24/1981 (3 <sup>c</sup> ) 07/08/1983-07/08/1983 (2) 11/18/1986-02/26/1988* (2) 02/13/1997-05/23/1997 (3) 07/12/2008-08/??/2008 (4 <sup>d</sup> )	Earthquake swarm: 05/11/2001- 05/15/2001
1101-30-	Bogoslof	07/06/1992-07/24/1992 (3)	
1101-31-	Makushin	05/??/1980-? (1) 01/30/1995-01/30/1995 (1)	Elevated seismicity: 07/??/2000- 06/??/2001
1101-32-	Akutan	07/08/1980-07/08/1980 (2) 10/07/1982-05/??/1983 (2) 02/03/1986-06/14/1986 (2) 01/31/1987-06/24/1987 (2) 03/26/1988-07/20/1988 (2) 02/27/1989-03/31/1989 (2) 01/22/1990-01/22/1990* (2) 09/06/1990-10/01/1990 (2) 09/15/1991-11/28/1991* (2) 03/08/1992-05/31/1992 (2) 12/18/1992-? (1)	Intense earthquake swarm and intrusion with ground cracks: 03/10/1996-03/18/1996
1101-34-	Westdahl	11/29/1991-01/15/1992* (3)	
1101-36-	Shishaldin	03/19/1986-03/??/1987 (2) 12/23/1995-05/16/1996* (3) 06/02/1997-06/02/1997 (1) 02/09/1999-05/28/1999 (3) 02/17/2004-05/17/2004 (2)	Small phreatic explosions: 09/25/1999-02/04/2000 Increased seismicity: 05/15/2002-08/16/2002* Earthquakes, tremor, and thermal anomalies: 02/22/2005-02/22/2005
1102-011	Dutton		Earthquake swarm: 07/10/1988- 08/08/1988
1102-03-	Pavlof	11/08/1980-11/13/1980 (3) 09/25/1981-09/27/1981 (3) 07/11/1983-07/18/1983 (2 <sup>c</sup> ) 11/14/1983-12/18/1983 (3) 04/16/1986-08/13/1988 (3) 01/05/1990-03/05/1990 (2) 09/16/1996-01/03/1997 (2) 08/15/2007-09/13/2007 (2)	

<b>GVP<sup>a</sup> VOLCANO NUMBER</b>	<b>VOLCANO</b>	<b>ERUPTION DATES (MM/DD/YYYY) AND VEI<sup>b</sup> VEI in parenthesis</b>	<b>UNREST EPISODE: MM/DD/YYYY</b>
1102-07-	Veniaminof	06/02/1983-04/17/1984 (3) 11/29/1984-12/09/1984 (2) 07/30/1993-08/28/1994* (2) 04/17/1995-11/30/1995 (1) 09/28/2002-03/23/2003 (1) 02/19/2004-09/??/2004 (2) 01/04/2005-02/25/2005* (2) 09/07/2005-11/04/2005 (1) 03/03/2006-09/07/2006 (1) 02/22/2008-05/03/2008* (2 <sup>d</sup> )	
1102-11-	Chiginagak		Fumarolic activity and steam plumes: 10/22/1997-08/21/1998 Changes in hydrothermal features, gas emissions, and a lahar occurred: 11/??/2004-07/??/2005*
1102-14-	Martin		Strong seismic swarm: 01/08/2006-01/22/2006
1102-26-	Fourpeaked	09/17/2006-09/17/2006 (2)	
1102131/ 1102-13-	Ukinrek Maars/Ugashik- Peulik		Earthquake swarm: 05/08/1998- 06/15/1998
1103-01-	Augustine	03/27/1986-09/10/1986 (4) 12/??/2005-03/31/2006 (3)	
1103-02-	Iliamna		Earthquake swarm and elevated gas emission: 05/10/1996- 02/??/1997
1103-03-	Redoubt	12/14/1989-06/??/1990 (3)	Elevated gas emissions and increase in heat output: 07/??/2008-present
1103-04-	Spurr	06/27/1992-09/17/1992 (4)	Elevated seismicity, melt pit at summit, and increase in CO <sub>2</sub> and SO <sub>2</sub> emissions: 07/??/2004- 02/??/2006
<b>Commonwealth of the Northern Mariana Islands</b>			
0804-16=	Agrigan		Increased fumarolic activity: 08/01/1990-10/06/1990
0804-17=	Pagan	05/15/1981-05/01/1985* (4) 09/04/1987-09/04/1987 (1) 08/24/1988-10/12/1988 (2) 04/13/1992-04/13/1992 (1) 01/15/1993*-11/??/1993 (2) 12/04/2006-12/08/2006 (1)	
0804-20=	Anatahan	05/10/2003-07/12/2003* (3) 04/12/2004-09/03/2005* (3) 03/20/2006-06/26/2006* (2) 11/27/2007-02/??/2008* (1)	Earthquake swarm, crater lake refills: 03/30/1990-10/31/1990 Earthquake swarm: 05/29/1993- 09/??/1993 Elevated seismicity: 02/??/2008- 10/??/2008
0804-141	Ahyi	04/24/2001-04/25/2001 <sup>c</sup> (0)	
0804-192	Sarigan		Earthquake swarm: 08/09/2005- 08/19/2005

<b>GVP<sup>a</sup> VOLCANO NUMBER</b>	<b>VOLCANO</b>	<b>ERUPTION DATES (MM/DD/YYYY) AND VEI<sup>b</sup> VEI in parenthesis</b>	<b>UNREST EPISODE: MM/DD/YYYY</b>
0804-202	Ruby	10/11/1995-10/25/1995 <sup>c</sup> (0)	
0804-211	NW Rota-1	2003*-02/??/2008* <sup>c</sup> (0)	

<sup>a</sup>Global Volcanism Program.

<sup>b</sup>Volcanic Explosivity Index (eruption magnitude).

<sup>c</sup>Submarine eruption.

<sup>d</sup>Provisional VEI assignment based on eruption column height. A formal VEI has not been assigned owing to how recently the event occurred.

<sup>e</sup>Inferred VEI assignment due to difficulty of designation or based on anecdotal evidence

\* and ? represent approximate or unknown dates, respectively.



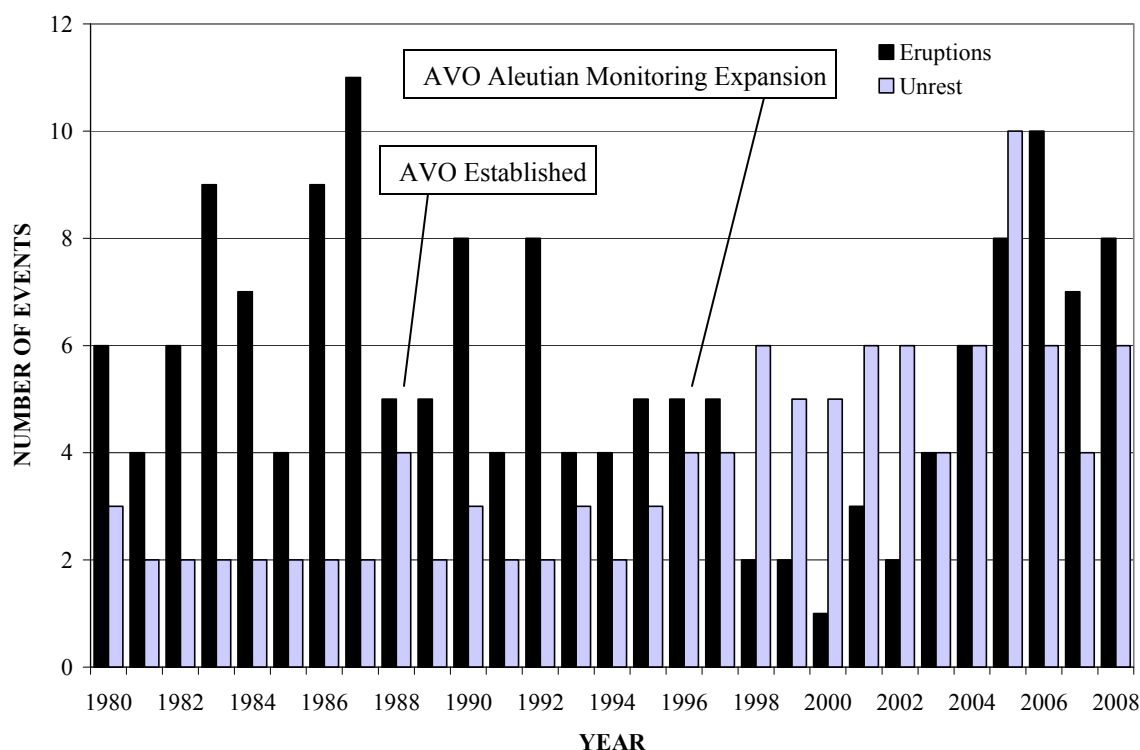


Figure 3. Number of volcanic eruptions and episodes of selected unrest that occurred during the course of each year, from 1980 to 2008. The number plotted is a summation of those events that are either ongoing across years or new. The establishment of AVO in 1988 and the beginning of the AVO monitoring expansion in 1996 provided a more reliable report of volcanic unrest in Alaska. The minimum number of unrest events is always maintained at two due to the continuous unrest of Yellowstone and Long Valley calderas (1980 to present).

## Frequency and Magnitude

Including continuing volcanic events that span a calendar year, within the reporting period there have been, on average, five volcanic eruptions and five episodes of unrest occurring each year in the United States. With the exception of 1985 and 2000, at least one eruption has started in each year of the past nearly three decades (fig. 2). Counting year-spanning eruptions and episodes of unrest, every year between 1980 and 2008 included a volcanic event, including 1985 and 2000 when six and nine events, respectively, occurred within or throughout those years (fig. 3). The maximum number of events to occur during a 12-month period was in 2005, when a total of 18 events (10 episodes of unrest and 8 eruptions) were reported. Note that this is not counting concurrent events, rather that 18 events occurred at some point within this 12-month timeframe by either continuing into 2005 from a previous year or beginning in 2005.

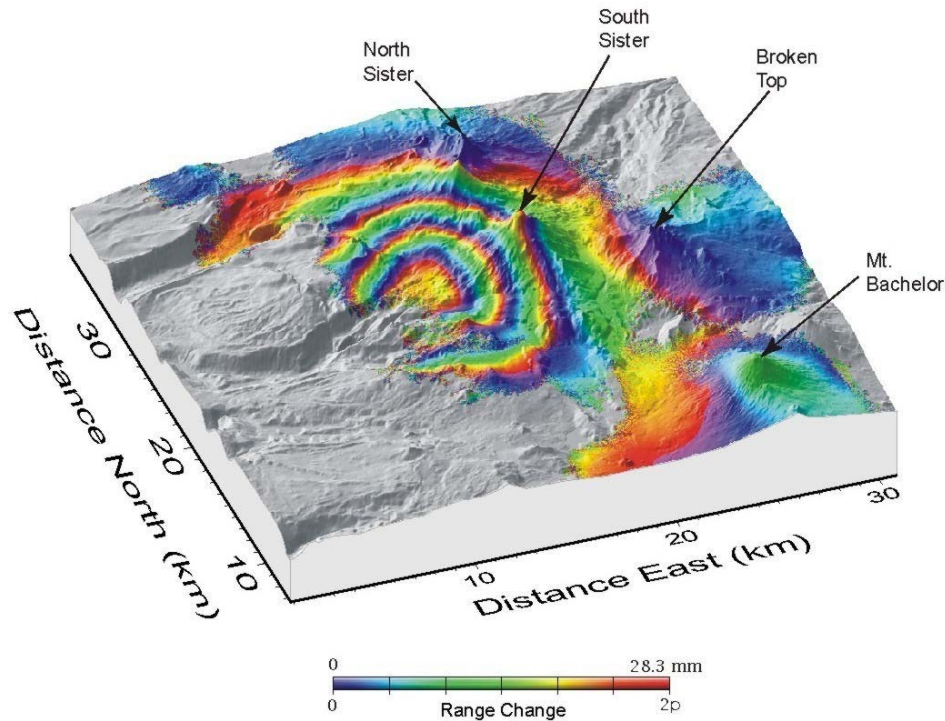


Figure 4. Active surface deformation first detected by InSAR in 2001 west of South Sister volcano in central Oregon. The above interferogram was constructed from data spanning 1996 to 2000 and draped over a 30 m digital elevation model (Wicks and others, 2002). Each range change (full color cycle) represents 2.8 cm of uplift. The maximum uplift (not pictured above) that occurred at South Sister between 1998 and 2000 was ~10 cm (Wicks and others, 2002). Since 2001, the USGS has deployed other ground-based monitoring instrumentation to track the ongoing deformation at South Sister.

The volcanic explosivity index (VEI; Newhall and Self, 1982) describes a relative measure of the size and energy of a volcanic eruption on a scale of 0-8 (low to high). Historical records of worldwide VEI display a log-linear relation between frequency and size; that is, many small eruptions and few large eruptions (Simkin and Siebert, 1999). As reported in table 1 and as seen in fig. 5, the 68 recorded U.S. eruptions with VEI >1 also follow a log-linear trend. The largest eruption to take place in the past 29 years in the U.S. was the May 18, 1980, eruption of Mount St. Helens (VEI 5). Pagan (1981-1985), Spurr (1992), Augustine (1986), and Kasatochi (2008) all produced VEI 4 eruptions.

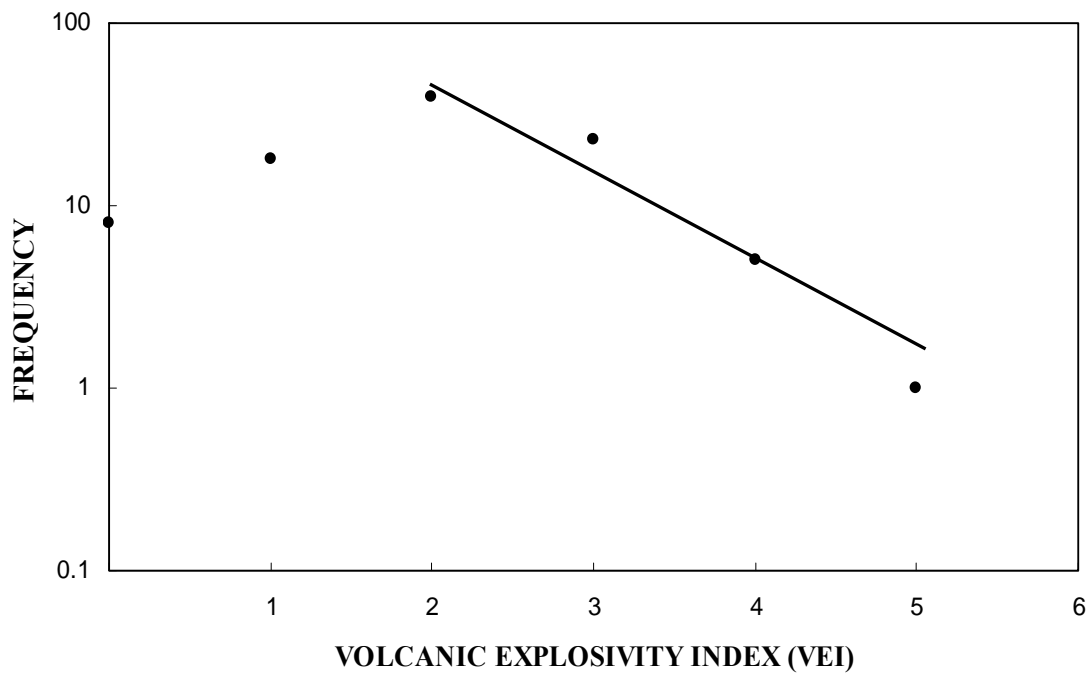


Figure 5. Frequency and magnitude (VEI) of 95 eruptions from 1980 to 2008 at U.S. volcanoes. The best-fit line is an exponential regression determined from 68 eruptions with assigned  $\text{VEI} \geq 2$ . Eruptions of low magnitude (VEI 1 and 0) are not included in the best-fit line because they are difficult to distinguish from available field criteria, resulting in misrepresentation of the frequency of small events. For a list of VEI assigned to individual eruptions see table 1.

## Durations

The durations of eruptions range widely at U.S. volcanoes (fig. 6) from time scales of hours to decades. Reporting a simple average duration of volcanic events greatly exaggerates the typical durations. Median durations provide better insight into the recent activity of U.S. volcanoes. The median duration of volcanic eruptions reported here is 1.6 months, a value consistent with global data reported by Simkin and Siebert (1999). We do not report a median duration of unrest because our record is a select subset of unrest events and, therefore, does not fully represent a comprehensive dataset.



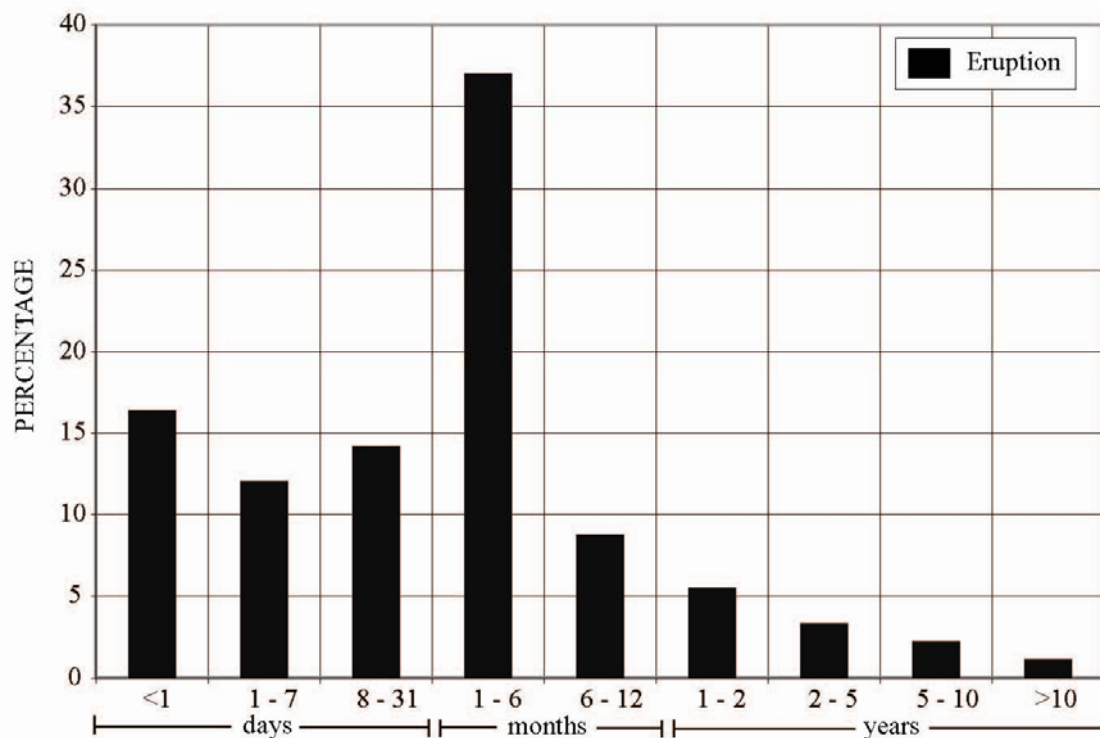


Figure 6. Frequency histogram of duration of eruptions. The vertical axis is the percentage of the totals of 92 eruptions (excluding three events absent of a stop date). The horizontal axis is time separated into days, months, and years. Median duration of eruptions in the U.S., as reported from 1980 to 2008, is 1.6 months.

## Conclusion

The nearly three decades of events listed in this report provide a snapshot of volcanic activity in the United States. However, three-quarters of the potentially active volcanoes in the U.S., that are not discussed here, also pose threats to infrastructure, economic activity, and people on the ground and in the air (Ewert and others, 2005; Ewert, 2007). Moreover, recurrence intervals between large eruptions typically are longer than the scope of this report's time line (Simkin and Siebert, 1999); thus, the largest, most hazardous eruptions are under represented here.

The United States is a volcanically vigorous country, and it experiences frequent volcanic unrest and eruptive activity each year. During the past 29 years, U.S. volcanoes have produced large explosive eruptions (five with  $VEI \geq 4$ ), as well as numerous smaller ones, long-lived eruptions (notably Kilauea volcano), and diverse signatures of unrest. The great range of volcanic activity and attendant hazards in the United States warrants a robust program of monitoring and research to understand volcanic processes and the attendant hazards.

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1101-06-

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1101-16-

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**Seguam**

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