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Alaska Volcano Observatory Archive of Seismic Drum Records of Eruptions of Augustine Volcano (1986), Redoubt Volcano (1989–90), Mount Spurr (1992), and Pavlof Volcano (1996), and the 1996 Earthquake Swarm at Akutan Peak

Data Report 1146

U.S. Department of the Interior
U.S. Geological Survey

Cover. Aerial photograph showing a vigorous eruption column rising from the summit of Augustine Volcano, Alaska, during the volcano's 1986 eruption. Photograph by M.E. Yount, U.S. Geological Survey, March 31, 1986.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

AVO	Alaska Volcano Observatory
AEC	Alaska Earthquake Center
USGS	U.S. Geological Survey

Alaska Volcano Observatory Archive of Seismic Drum Records of Eruptions of Augustine Volcano (1986), Redoubt Volcano (1989–90), Mount Spurr (1992), and Pavlof Volcano (1996), and the 1996 Earthquake Swarm at Akutan Peak

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Abstract

The advent of continuous digital recording of seismograph stations in Alaska did not occur until the fall of 2002. Continuous records of seismic waveforms prior to 2002 were recorded only in analog form. The Alaska Volcano Observatory (AVO) has a substantial archive of continuous analog records made on helicorders in a collection maintained by the University of Alaska Fairbanks Geophysical Institute. As part of the response to the 2006 Augustine Volcano eruption, the AVO scanned analog drum records of the 1986 Augustine eruption to aid in comparing the progression of volcanic seismicity in 2006 with the seismic record of the 1986 eruption. The scanned records proved useful, prompting subsequent efforts to preserve records from other notable episodes of volcanic unrest as readily available scanned images. The data archive accompanying this report contains scanned images of select drum records for the eruptions at Augustine Volcano (1986), Redoubt Volcano (1989–90), Mount Spurr (1992), and Pavlof Volcano (1996), as well as for the 1996 earthquake swarm at Akutan Peak.

Introduction

Seismic drum (or helicorder) records were a common form of recording and displaying continuous seismic waveform data in the latter part of the 20th century. Drum records were often the only method for reviewing and analyzing seismic data in real time and were therefore critical in forecasting and identifying volcanic activity. However, because of improving cost-effectiveness, continuous digital recording of seismograph data began to supplant analog recording methods in the early 2000s. Many seismological observatories keep boxes of aging paper records in storage facilities, and access to these records is often difficult (access at the Alaska Volcano Observatory [AVO] record archive is no exception). Additionally, paper records fade and become increasingly difficult to read over time. Although the scientific use of paper records diminishes as the length of digital records grow, for some phenomena with long recurrence intervals, such as volcanic eruptions where repeat intervals can be on the order of decades or centuries, these analog recordings of past seismic activity are invaluable in evaluating future periods of unrest.

This report digitally preserves these important seismic records and makes them easily accessible for analysis during future periods of volcanic unrest. The accompanying data archive contains scanned copies of select helicorder records that characterize periods of unrest surrounding eruptions from Augustine Volcano (1986), Redoubt Volcano (1989–90), Mount Spurr (1992), and Pavlof Volcano (1996), as well as the 1996 earthquake swarm at Akutan Peak. The archive is organized into five compressed files available for download at https://doi.org/10.3133/dr1146. Each compressed file contains scanned records for one period of unrest and is named for the respective volcano. Scanned records are presented as individual PDF files named by their respective dates and seismograph stations. Coordinates for the individual stations can be found in appendix D of Dixon and others (2013).

History of Continuous Seismic Recording in Alaska

For approximately four decades starting in the mid-1960s, data from selected seismograph stations in Alaska were recorded on paper drum records by the partners that formed the AVO in 1989. Other analog media were also used during this period to record continuous data in Alaska. Develocorders, which record 16 channels of seismic data on photographic film, were primarily used in locating earthquakes in the Alaska catalog but limited the number of seismograph stations that could be recorded. Records on 16 millimeter (mm) film from before the mid-1990s exist but are difficult to convert to an easy-to-use computer image and require specialized optical equipment with spare or replacement parts that are no longer commercially available. Additionally, the film becomes brittle after many years of storage. Digital computer tape was also used extensively in Alaska to store continuous seismic data, but because tape formats quickly

become obsolete and unreadable, digital tape is not considered a good permanent archive. Drum records have proven to be the most accessible records because the data are immediately available and their readability is not affected by future changes in technology, although there are substantial storage costs associated with archiving drum records. Once large format scanners became commonplace, it was inexpensive to make these records more available as electronic images.

By the early 2000s, the costs of storing continuous data on computer hard drives had become comparable to the costs of archiving data on tape, and in October 2002 the Alaska Earthquake Center (AEC) began archiving continuous digital records from most AVO seismograph stations onto computer hard drives. The AVO recorded continuous data onto DVDs between September 2002 and December 2010, and has maintained a Winston Wave Server (Cervelli and others, 2004) with continuous data since October 2012. AVO continuous data have also been archived at the Incorporated Research Institutions for Seismology Data Management Center since September 2009. At the end of 2007, the last analog helicorders at the AVO were turned off. The AVO, in conjunction with the AEC, stores drum records of Alaskan seismograph stations at the University of Alaska Fairbanks Property/Central Receiving Surplus facility (located off campus in a secured area).

Figure 1. Photograph showing the central analog recording site for the University of Alaska Fairbanks before drum recorders were decommissioned in 2007. Telephone lines ending in racks of discriminators (not shown) are routed to helicorders and computer systems for recording and archiving data.

Drum Record Characteristics

Before 2008, drum records were recorded at both the Geophysical Institute at the University of Alaska Fairbanks (fig. 1) and the U.S. Geological Survey offices in Anchorage. In Fairbanks, data were commonly recorded on Teledyne Geotech model RV-301B or similar drum recorders that used heat-sensitive paper and an electrically-heated thermal stylus. In Anchorage, both Teledyne Geotech model RV-301B and Dyneer model DR-200 drum recorders were used; DR-200 models featured an ink pen. The AVO did not make extensive use of smoked paper records and none are included in this archive.

Typically, a drum was rotated at 60 mm per minute while one or two pens translated across the drum at either 2.5 mm per rotation (in a single pen system) or 1.5 mm per rotation (in a two-pen system). These parameters allowed a single pen system to record 24-hours' worth of data from one seismic station onto a single 96 centimeter (cm) by 30 cm sheet of paper (fig. 2). Two-pen systems were capable of recording data from two stations onto a single drum record (the reduced pen translation

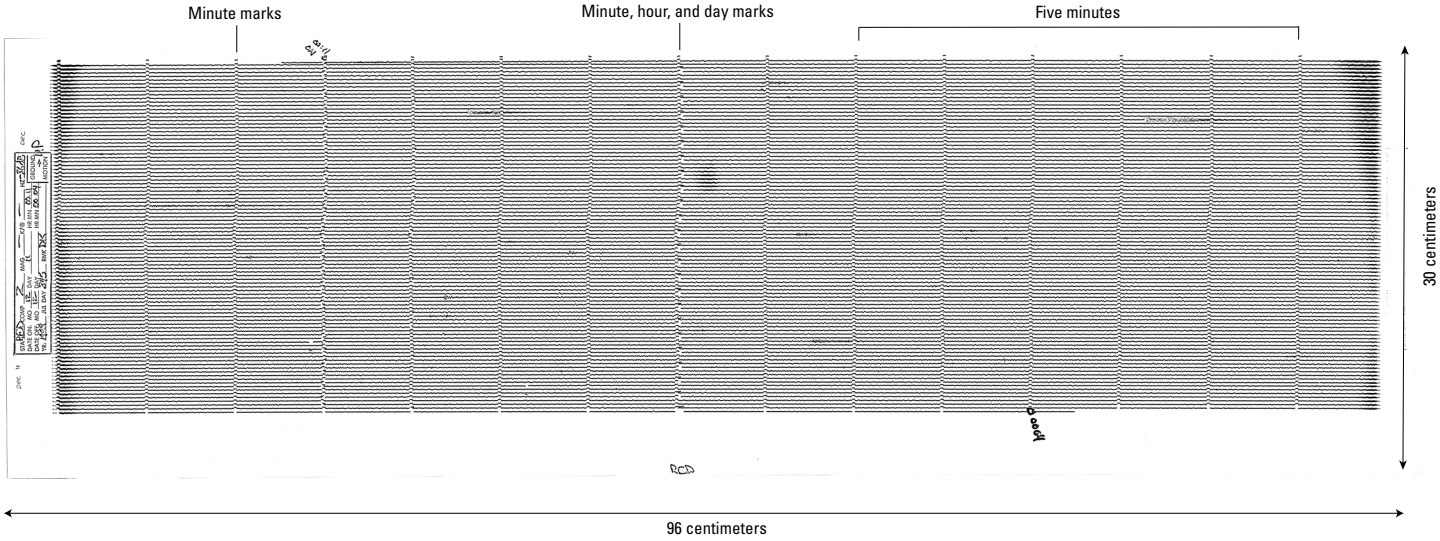


Figure 2. Scanned image of a drum record from a single pen system recorded in Fairbanks using a thermal stylus and heat-sensitive paper. Data are from seismic station RED beginning 00:11 Coordinated Universal Time (UTC), December 11, 1989, and ending 00:40 UTC, December 12, 1989.

distance per rotation meant that a single sheet of 96 cm by 30 cm paper could still fit 24 hours' worth of data from each station; fig. 3). Two-pen systems were used often in Fairbanks and occasionally in Anchorage. Regardless of the system used, each line of a drum record typically contained 15 minutes of data, and time progressed in line from left to right and down the page, as shown in figures 2–4. To indicate divisions of time (minutes, hours, days) within a record, pens would typically offset by 2.0 mm at the start of every minute, 4 mm at the start of every hour, and 6 mm at the start of every day (fig. 2).

Thermal and ink pens each had their advantages and disadvantages. Ink pens needed to be refilled periodically and were capable of clogging, whereas thermal pens required little maintenance. However, thermal paper cost significantly more than paper that could accept an ink trace. In terms of recording data, a disadvantage of heat-sensitive paper was that high frequency signals (often associated with local earthquakes) did not allow the hot stylus to contact the paper long enough to record the stylus movement. This resulted in an apparent gap in the recorded data for the duration of any high frequency signal. A disadvantage

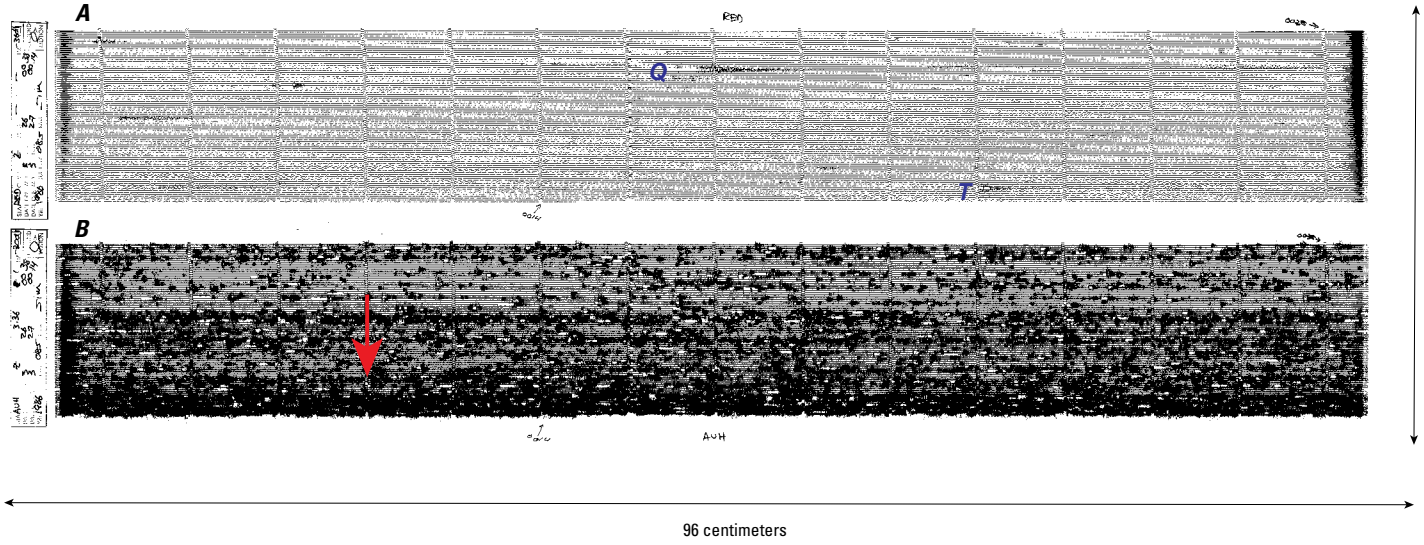


Figure 3. Scanned image of a drum record from a two-pen system, showing data from two seismograph stations recorded on heat-sensitive paper with a thermal stylus. *A,* March 26, 1986, data from station RED near Redoubt Volcano. Q indicates a magnitude 2.8 earthquake located 50 kilometers (km) east of Iliamna Volcano and 50 km northwest of Homer, Alaska, at a depth of 62 km; T indicates a teleseismic magnitude 6.3 earthquake located in western Brazil at a depth of 610 km. *B,* March 26, 1986, data from station AUH on Augustine Volcano showing the buildup in microearthquake activity that preceded the onset of the 1986 eruption of Augustine Volcano. Red arrow notes the onset time of explosive activity at roughly 08:57 Coordinated Universal Time (Power and Lalla, 2010).

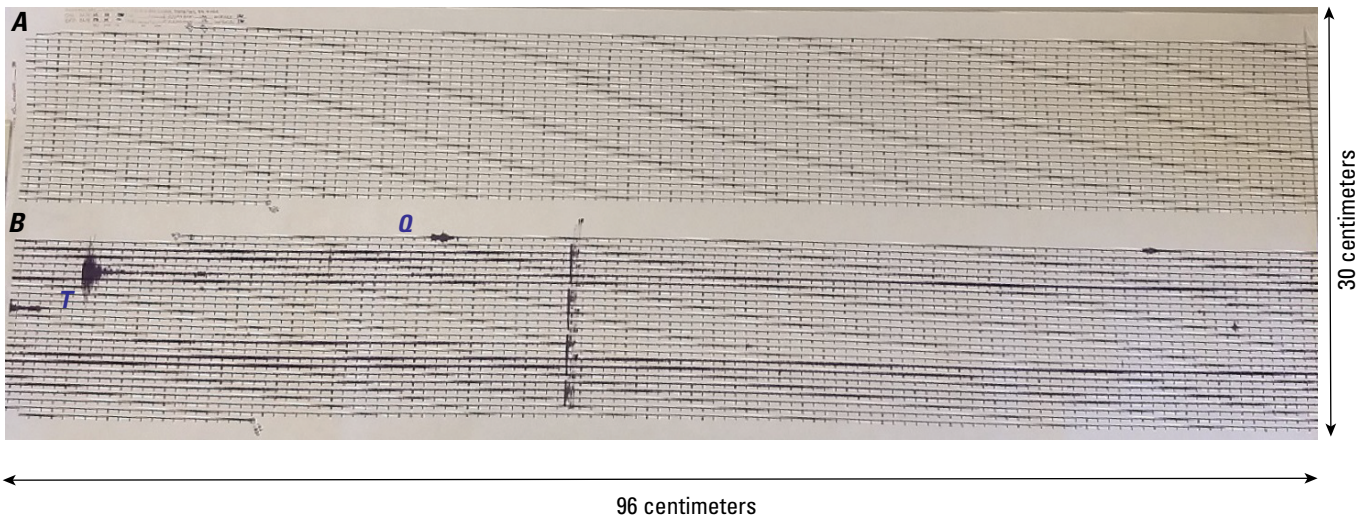


Figure 4. Scanned image of a two-pen drum record from May 4, 2000, showing data from seismograph stations recorded on paper and ink. *A,* Data from station KEL near Mount Kelez in the Katmai volcanic region. *B,* Data from station PVV, located 8 kilometers (km) southeast of Pavlof Volcano. Q indicates a magnitude 4.0 earthquake located 80 km east of Mount Peulik and 190 km southwest of Kodiak, Alaska, at a depth of 55 km; T indicates a teleseismic magnitude 6.7 earthquake located in Pulau Sulawesi, Indonesia, at a depth of 26 km.

of ink pens was that they tended to overwrite or obscure signals during high frequency or high amplitude events. Despite these disadvantages, the data quality was sufficient with either thermal or ink pens, and the choice between the two was primarily an economic decision. Typically, once an observatory had chosen a pen system, it continued to operate that system no matter the change in cost of supplies or maintenance as it was inefficient to maintain both types of pen systems at one site. A situation with dual systems was possible if observatories with different recording equipment merged their operations.

Drum records are difficult to convert to full digital records. Several techniques have been developed (Michelini and others, 2005; Taylor and Yang, 2010; Kahn and others, 2012; Bogiatzis and Ishii, 2016) but none consider the curvature of the record made by a swinging armature. The application of a Bezier filter has been used to resolve this problem (Daniel Burk, Michigan State University, written commun., 2019). These techniques are time consuming, requiring substantial manual corrections following an automated process, and although they are improving with additional development, they remain better suited for short-duration singular events (such as a large tectonic earthquake or nuclear explosion) than long-duration events (like volcanic eruptions, for which the necessary data commonly span hours or days). Volcanic records are also more difficult to digitize because signal traces tend to overlap on the paper record. The most cost-effective way to preserve drum records of volcanic events is to save a scanned image detailed enough to preserve the signals—for most scanning programs, this requires scanning at a resolution of at least 600 pixels per inch. Scanned records at the AVO are saved as portable document format (PDF) files.

Drum Record Archive

Since the 1986 Augustine Volcano eruption, 21 periods of significant volcanic unrest at 11 volcanoes have been recorded to paper (table 1). Fifteen of these periods of unrest also have continuous digital records, but five—the 1986 Augustine Volcano eruption, 1989-90 Redoubt Volcano eruption, 1992 Mount Spurr eruption, 1996 Pavlof Volcano eruption, and an energetic earthquake swarm at Akutan Peak in 1996—are recorded only on paper records.

Representative paper drum records for these periods of unrest in the Aleutian arc have been made available as PDF scans and have already been an invaluable resource in studying past eruptions. During the Augustine Volcano eruption in 2006, drum records from the previous eruption in 1986 were scanned and saved as PDF files, which aided in real-time hazard efforts as well as retrospective analysis of the 1986 eruption in comparison with the 2006 eruption. The value of the 1986 Augustine Volcano eruption helicorder scans prompted efforts to scan the paper records for the Redoubt Volcano (1989–90), Mount Spurr (1992), and Pavlof Volcano (1996) eruptions, as well as the 1996 Akutan Peak earthquake swarm. The resulting scans, in addition to scans of drum records for the 1986 Augustine Volcano eruption, are included in the data archive accompanying this report.

Not all seismograph stations that recorded these events had their records scanned but a sample was chosen from the available data that best represented the activity recorded. The records selected for inclusion are the longest available for each event, even if technical problems at the time of recording

Table 1. Volcanoes with identified elevated color codes for the period 1988–2007.

[The 1986 eruption of Augustine Volcano occurred before the use of the level of concern color code but is included here because it is part of this archive]

Period of unrest	Highest level of concern during period of unrest
Akutan Peak	
March–May 1996[1]	Orange
Augustine Volcano	
July 1985–September 1986[1]	n/a
November 2005–August 2006[1]	Red
Fourpeaked Mountain	
September 2006	Yellow
April–June 2007	Yellow
Mount Katmai	
January 2006	Yellow
Korovin Volcano	
February–March 2005	Yellow
February–March 2006	Yellow
April–September 2007	Yellow
Pavlof Volcano	
September 1996–June 1997[1]	Red
Redoubt Volcano	
February 1990–March 1993[1]	Red
Shishaldin Volcano	
February–September 1999	Yellow
February 2000	Yellow
May–October 2004	Yellow
Mount Spurr	
June 1992–March 1993[1]	Red
July 2004–February 2006	Yellow
Tanaga Volcano	
October–November 2005	Yellow
Mount Veniaminof	
April–October 2004	Yellow
January–March 2005	Orange
September–December 2005	Yellow
March–September 2006	Yellow
April 2007	Yellow

[1]Period of unrest included in the online digital archive.

resulted in breaks in the records. If there were multiple stations with equally long periods of recording, not all records were scanned owing to budget constraints. Records spanning short periods of time were also omitted because of budget constraints.

At about the time of the cessation of analog recordings, the AVO changed its alert notification system from a level of concern color code (green, yellow, orange, and red) to a dual volcano alert level (normal, advisory, watch, and warning) and aviation color code (green, yellow, orange, and red) system (Gardner and Guffanti, 2006). For this report, the level of concern color code that was used before October 2006 is used to describe past activity.

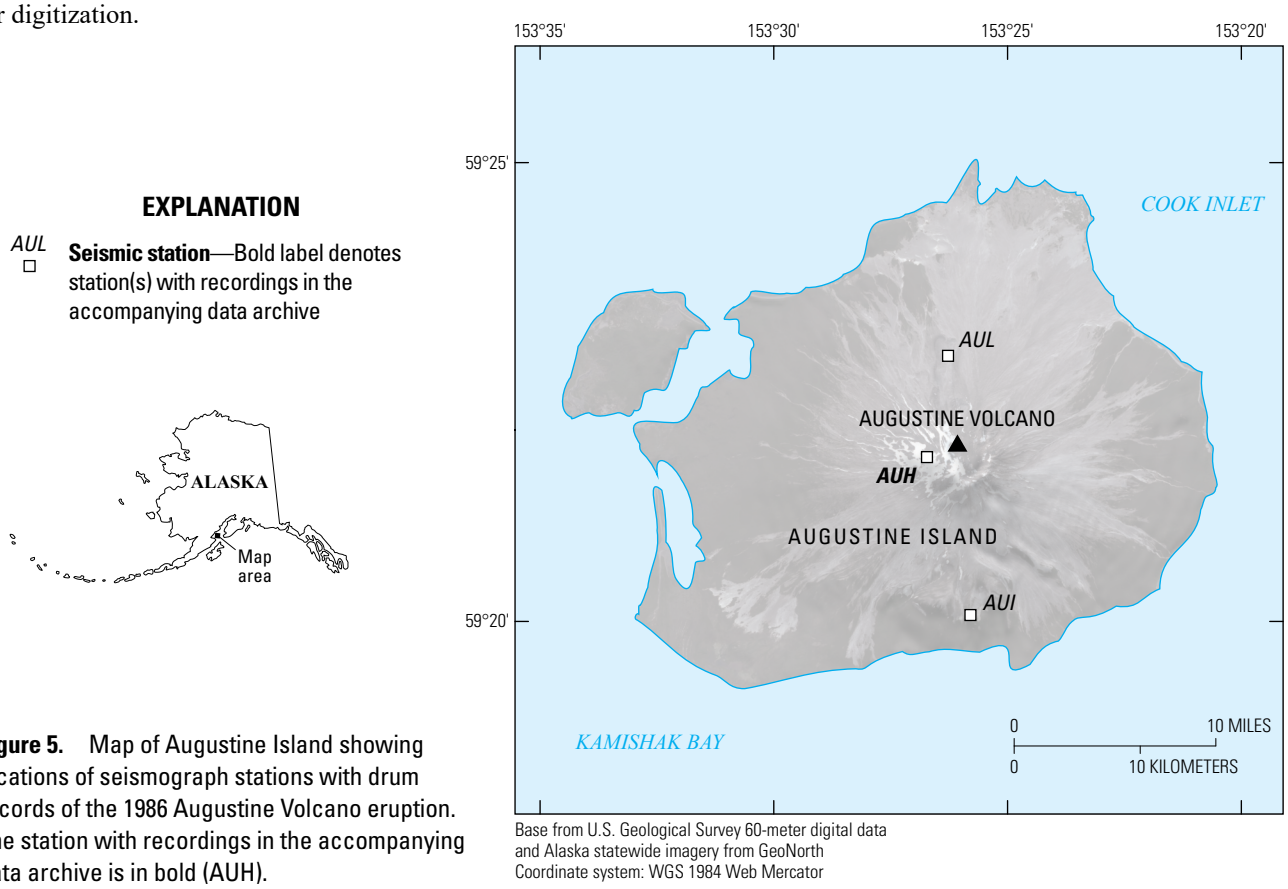
1986 Augustine Volcano Eruption

Precursory seismicity for the 1986 Augustine Volcano eruption started in July 1985 and was followed by three phases of activity. The helicorder dataset includes the final month (February 28–March 25, 1986) of precursory activity, the explosive phase (March 26–April 8, 1986), and the first of two dome building phases (April 21–May 7, 1986; Power, 1988). The second dome building phase (August 10–September 10, 1986) is not represented in this archive. The Augustine eruption occurred before the use of the level of concern code. Seismograph station AUH had the most complete record during the period of unrest (table 2, fig. 5) and thus was chosen for digitization.

Table 2. Seismograph stations and records included in the accompanying data archive for the 1986 Augustine Volcano eruption.

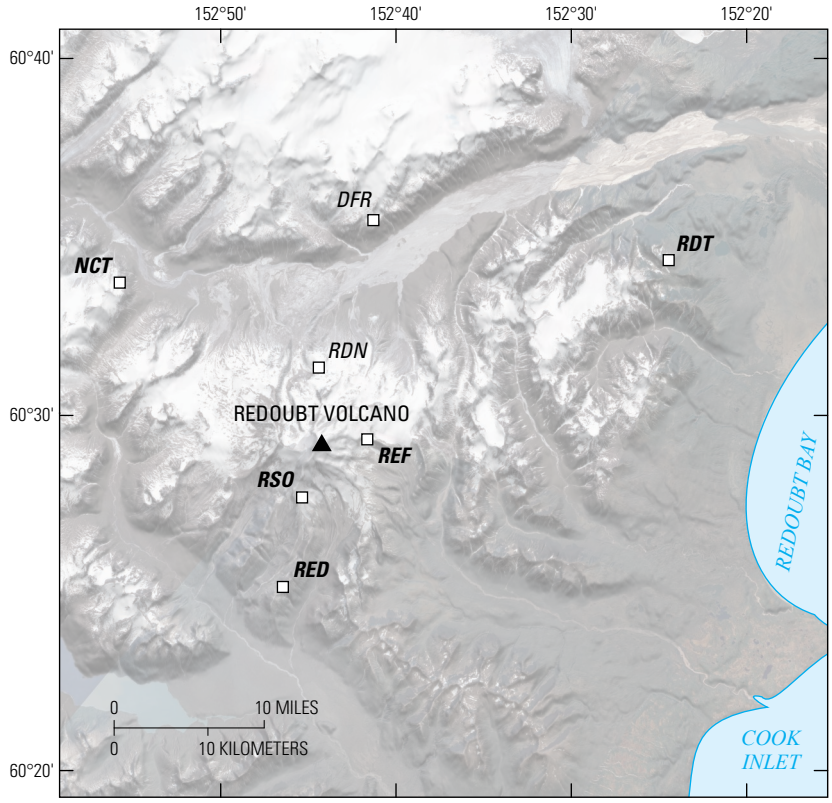
Record start date	Record end date	Time span (days)
AUH		
February 28, 1986	March 31, 1986	32
April 20, 1986	May 9, 1986	19
RED[1]		
February 28, 1986	March 28, 1986	29
PDB[1]		
March 29, 1986	March 31, 1986	3
April 20, 1986	May 9, 1986	19

[1]Seismograph station not in the Augustine Volcano network but included by virtue of having been recorded by a two-pen system and therefore sharing the same drum record as data from an intended station.



Base from U.S. Geological Survey 60-meter digital data and Alaska statewide imagery from GeoNorth
Coordinate system: WGS 1984 Web Mercator

Figure 5. Map of Augustine Island showing locations of seismograph stations with drum records of the 1986 Augustine Volcano eruption. The station with recordings in the accompanying data archive is in bold (AUH).



1989–90 Redoubt Volcano Eruption

Redoubt Volcano erupted on December 14, 1989, following a swarm of earthquakes that began less than 24 hours before the eruption (Brantley, 1990). From the initial explosion on December 14, 1989, and through the final explosion in April 1990, the level of concern color code was raised to RED six times. Seismograph stations NCT (152 days), RDT (174 days), RED (144 days), and REF (163 days) provided a long-term record of the five-month eruption (table 3, fig. 6). Seismograph station RSO (94 days) was installed during the second half of the eruption (Power and others, 1994).

Figure 6. Map of Redoubt Volcano showing locations of seismograph stations with drum records of the 1989–90 Redoubt Volcano eruption. Stations with recordings in the accompanying data archive are in bold (NCT, RDT, RED, RSO).

Table 3. Seismograph stations and records included in the accompanying data archive for the 1989–90 Redoubt Volcano eruption.

Record start date	Record end date	Time span (days)
NCT		
January 2, 1990	January 12, 1990	11
January 14, 1990	May 10, 1990	117
May 20, 1990	June 12, 1990	24
RDT		
October 11, 1989	December 12, 1989	63
December 14, 1989	April 3, 1990	111
RED		
October 11, 1989	October 23, 1989	13
November 1, 1989	January 12, 1990	73
February 10, 1990	April 10, 1990	58
REF		
January 2, 1990	January 12, 1990	11
January 14, 1990	June 14, 1990	152
RSO[1]		
March 5, 1990	March 10, 1990	4
March 17, 1990	June 14, 1990	90
AUL[2]		
January 14, 1990	January 14, 1990	1
CRP[2]		
January 2, 1990	January 12, 1990	11
January 14, 1990	June 12, 1990	150
SPU[2]		
October 11, 1989	December 12, 1989	63

[1]Drum record for station RSO during March 8–9 is missing.

[2]Seismograph station not in the Redoubt Volcano network but included by virtue of having been recorded by a two-pen system and therefore sharing the same drum record as data from an intended station.

1992 Mount Spurr Eruption

On June 27, 1992, the Crater Peak vent of Mount Spurr erupted after four decades of quiescence (Keith, 1995). The eruption was preceded by 10 months of increased seismicity, including a 19-hour period of precursory volcanic tremor spanning June 26 and 27. Two more explosions occurred on August 18 and September 16–17, as well as two other periods of increased seismic activity (including volcanic tremor and earthquake activity) beginning October 2 and November 9 that did not lead to eruptions. All five events led the AVO to raise the level of concern color code to RED. Seismograph station CRP recorded for 79 days and was the only station to record all three explosive events. Stations BGL (91 days) and SPU (89 days) recorded two of the three eruptions. Together, stations BGL, CRP, and SPU provide the most complete record of the Mount Spurr eruption (table 4, fig. 7).

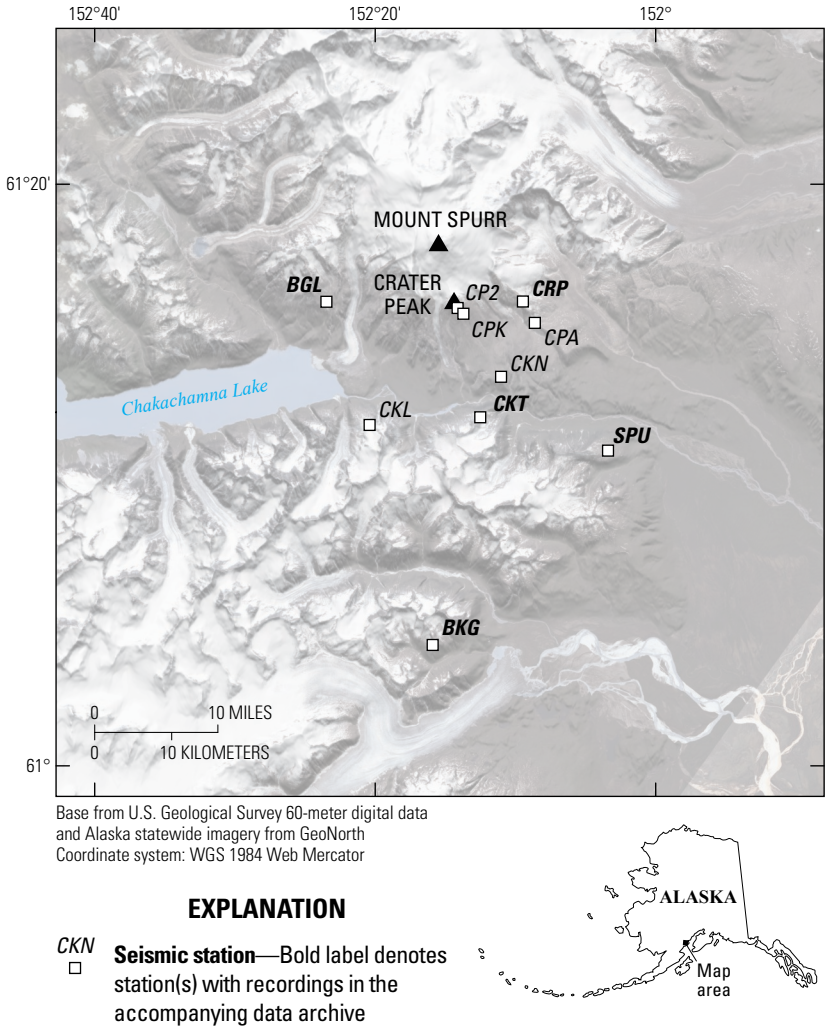


Figure 7. Map of Mount Spurr showing locations of seismograph stations with drum records of the 1992 Mount Spurr eruption. Stations with recordings in the accompanying data archive are in bold (BGL, CRP, SPU).

Table 4. Seismograph stations included in the accompanying data archive for the 1992 Mount Spurr eruption.

Start Date	End Date	Time span (days)
BGL		
June 25, 1992	June 29, 1992	5
August 15, 1992	September 4, 1992	21
September 19, 1992	October 27, 1992	39
June 25, 1992	June 29, 1992	5
August 15, 1992	September 4, 1992	21
BKG		
September 21, 1992	September 22, 1992	2
CKT		
September 23, 1992	September 23, 1992	1
CRP		
June 23, 1992	June 23, 1992	1
June 26, 1992	June 29, 1992	4
August 15, 1992	August 19, 1992	5
August 22, 1992	October 29, 1992	69
SPU		
August 15, 1992	September 19, 1992	38
September 21, 1992	October 26, 1992	36
November 10, 1992	November 24, 1992	15
INE[1]		
September 24, 1992	October 27, 1992	34
October 30, 1992	November 6, 1992	7
November 10, 1992	November 10, 1992	1
RDW[1]		
August 19, 1992	August 19, 1992	1

[1]Seismograph station not in the Mount Spurr network but included by virtue of having been recorded by a two-pen system and therefore sharing the same drum record as data from an intended station.

1996 Earthquake Swarm at Akutan Peak

On March 10, 1996, residents of Akutan, Alaska, became alarmed by a seismic swarm of felt earthquakes (Neal and McGimsey, 1997). After four days of increased seismicity, the level of concern color code was raised to ORANGE for Akutan Peak and a response was organized. A field crew installed seismograph stations on Akutan Island on March 19; more stations were installed in the following week (Power and others, 1996). As the rate of seismicity decreased, the level of concern code was dropped to YELLOW and then to GREEN on May 3. Three stations (AK2, AKM, and AKT) recorded for more than 40 days (table 5, fig. 8) during the time Akutan Peak was at an elevated level of concern color code. Seismograph station AK1, installed a few days before AK2, recorded until AK2 was established.

1996 Pavlof Volcano Eruption

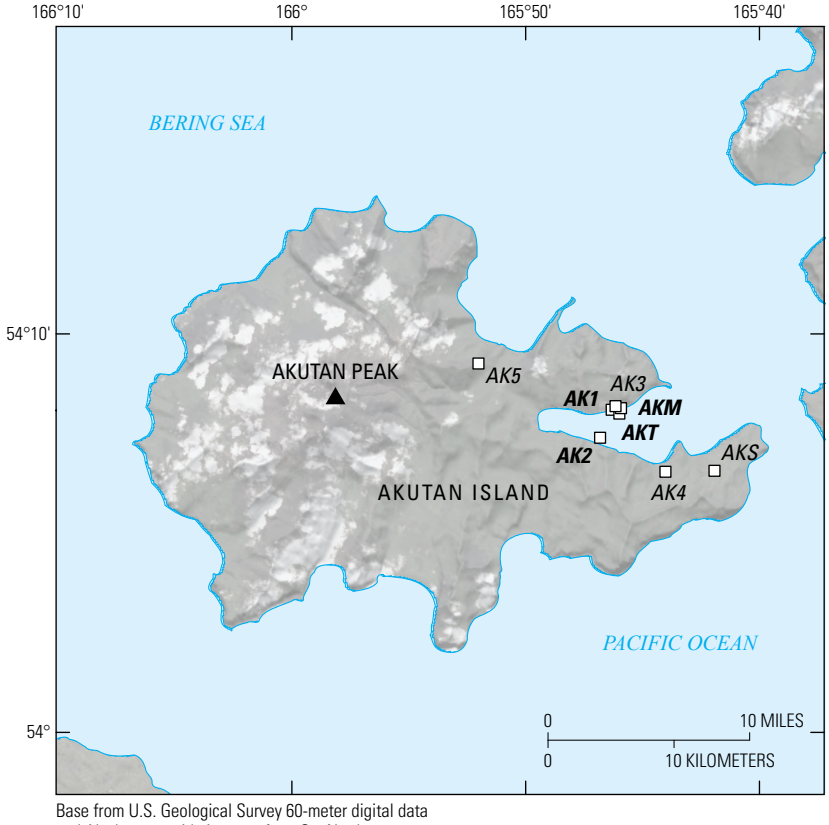
The level of concern color code for Pavlof Volcano was raised to ORANGE status on September 16, 1996, after the start of an eruption with no significant precursory activity (Neal and McGimsey, 1997). Thirteen more changes in the color code were made, including brief escalations to RED status on October 19, November 4, and December 27–28. Following the December explosion, the color code moved to ORANGE on December 28, YELLOW on December 29, and GREEN on April 4, 1997. Two seismograph stations, PV6 and PVV, recorded for the entire period that Pavlof was at ORANGE or higher status and are included in this archive (table 6, fig. 9).

Table 5. Seismograph stations included in the accompanying data archive for the 1996 earthquake swarm at Akutan Peak.

Station	Start date	End date	Time span (days)
AK1	March 20, 1996	March 22, 1996	2
AK2	March 22, 1996	May 2, 1996	42
AKM	March 20, 1996	May 2, 1996	44
AKT	March 19, 1996	May 2, 1996	45

Table 6. Seismograph stations included in the accompanying data archive for the 1996 Pavlof Volcano eruption.

Station	Start date	End date	Time span (days)
PV6	September 16, 1996	January 11, 1997	118
PVV	September 12, 1996	January 10, 1997	121



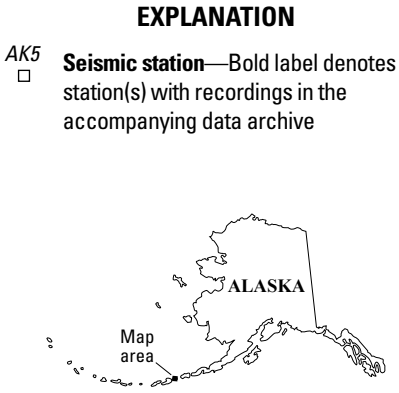


Figure 8. Map of Akutan Island showing locations of seismograph stations with drum records of the 1996 earthquake swarm at Akutan Peak. Stations with recordings in the accompanying data archive are in bold (AK2, AKM, AKT).

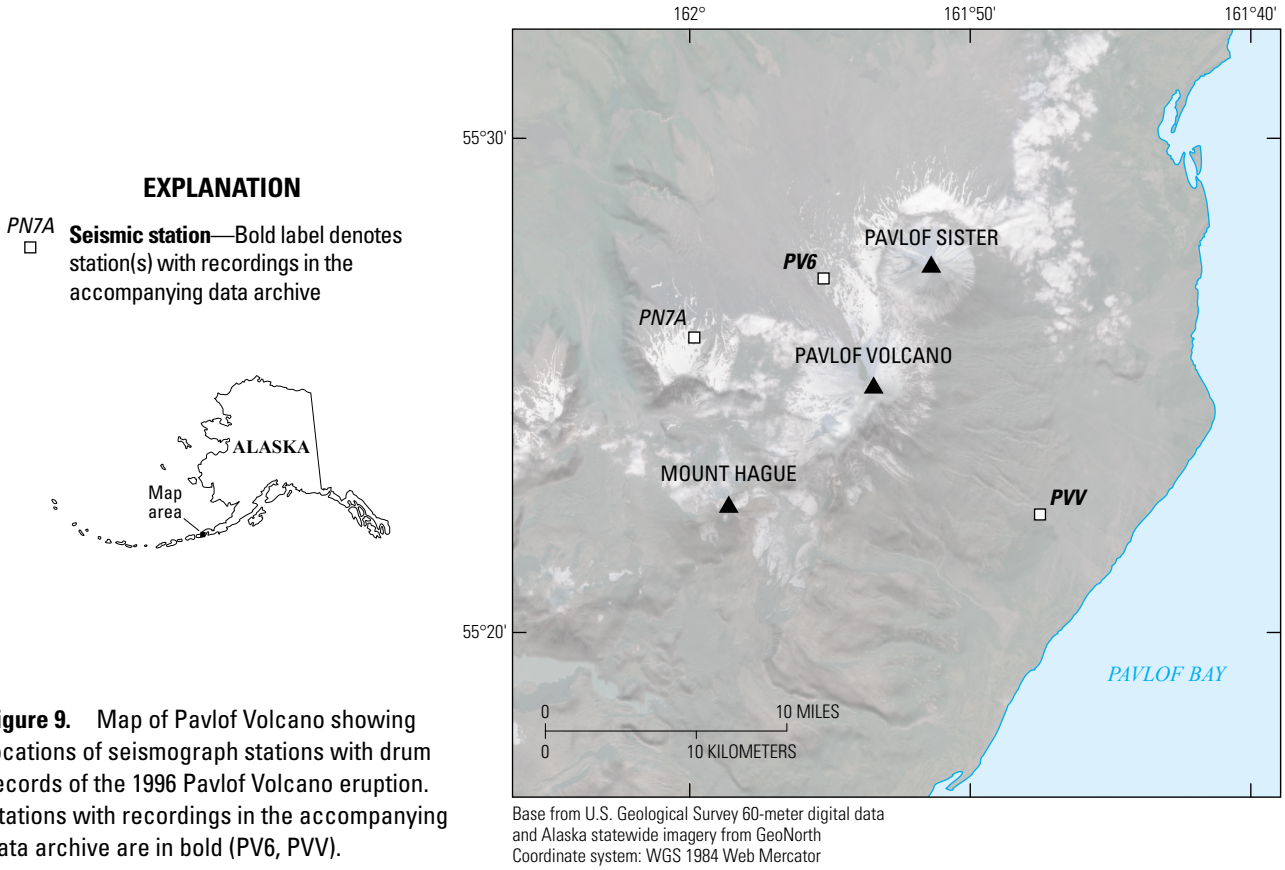


Figure 9. Map of Pavlof Volcano showing locations of seismograph stations with drum records of the 1996 Pavlof Volcano eruption. Stations with recordings in the accompanying data archive are in bold (PV6, PVV).

Summary

Five sets of drum records for periods of significant volcanic unrest have been preserved as PDF files in the data archive accompanying this report. These scanned images of helicorder records are a representative sample of the only existing continuous seismic records of the 1986 Augustine Volcano eruption, the 1989–90 Redoubt Volcano eruption, the 1992 Mount Spurr eruption, the 1996 Pavlof Volcano eruption, and the prolonged seismic swarm at Akutan Peak in 1996. We hope these records will prove useful in interpreting future episodes of seismic unrest at these volcanoes. Additional records covering these and perhaps other periods of unrest may be available at the University of Alaska Fairbanks Geophysical Institute.

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