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2022 Volcanic Activity in Alaska and the Northern Mariana Islands—Summary of Events and Response of the Alaska Volcano Observatory

Scientific Investigations Report 2024–5108

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

Cover. Aerial photograph of north view to Mount Edgecumbe and Crater Ridge behind on May 19, 2022. Photograph by M. Kaufman, University of Alaska Fairbanks–Alaska Volcano Observatory.

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Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot (ft)	0.000305	kilometer (km)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	3,281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Velocity	
meter per second (km/s)	3,281	foot per second (ft/s)
	Mass flow	
metric ton per day (t/d)	1.1022	ton, long [2,240 lb] per day
metric ton per day (t/d)	0.9842	ton, short [2,000 lb] per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Altitude, as used in this report, refers to distance above sea level of a location in the air.

Elevation, as used in this report, refers to distance above sea level of a location on the land surface.

Depth, as used in this report, refers to distance below sea level.

Locations in latitude and longitude are presented in decimal degrees referenced to the World Geodetic System 1984 (WGS84) datum, unless otherwise noted.

Abbreviations

AKDT	Alaska daylight time; UTC–8 hours
AKST	Alaska standard time; UTC–9 hours
ASL	above sea level
AVO	Alaska Volcano Observatory
ChST	Chamorro standard time; UTC +10 hours
GNSS	Global Navigation Satellite System
GVP	Smithsonian Institution Global Volcanism Program
HADT	Hawaii-Aleutian daylight time; UTC–9 hours
HAST	Hawaii-Aleutian standard time; UTC–10 hours
MIR	mid-infrared
M_L	local magnitude
#	number
PIREP	pilot weather report
SO_2	sulfur dioxide
SWIR	short-wave infrared
TROPOMI	the TROPOspheric Monitoring Instrument
USGS	U.S. Geological Survey
UTC	coordinated universal time; same as Greenwich mean time
VIIRS	Visible Infrared Imaging Suite
VLP	long-period

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Abstract

In 2022, the Alaska Volcano Observatory responded to eruptions, volcanic unrest or suspected unrest, increased seismicity, and other significant activity at 11 volcanic centers in Alaska and in the Northern Mariana Islands. Eruptive activity in Alaska consisted of repeated small, ash-producing, phreatomagmatic explosions from Mount Young on Semisopochnoi Island; the eruption of a thick lava flow within the summit crater at Great Sitkin Volcano; and weak explosive activity and the eruption of small, channelized flows at Pavlof Volcano. Uplift and an increase in seismicity were detected at Mount Edgecumbe, a long-dormant volcano in southeastern Alaska. Anomalous seismicity was also detected at three other volcanoes, including Trident Volcano, Takawangha volcano, and Davidof volcano. Other activity documented in 2022 includes ash resuspension events at Mount Katmai and Aniakchak Crater, and Mount Cleveland had a period of unrest, but no eruptive activity took place. In the Commonwealth of the Northern Marianas Islands, hydroacoustic detections and a submarine plume observed in satellite data at Ahyi seamount indicated underwater eruptive activity there.

Introduction

The Alaska Volcano Observatory (AVO) is a joint program of the U.S. Geological Survey (USGS); the University of Alaska Fairbanks, Geophysical Institute; and the Alaska Division of Geological & Geophysical Surveys. Formed in 1988, AVO uses Federal, State, and university resources to (1) monitor and study Alaska's hazardous volcanoes (fig. 1) to assess the nature, timing, and likelihood of volcanic activity; (2) assess volcanic hazards associated with anticipated activity, including the kinds of events, their effects, and areas at risk; and (3) provide timely and accurate information on volcanic hazards, and warnings of impending dangerous activity, to officials (local, State, and Federal) and the public, including the aviation sector. AVO also monitors the volcanoes in the Commonwealth of the Northern Mariana Islands (fig. 1).

AVO volcano monitoring program involves daily analyses of satellite and webcam imagery, seismicity, and infrasound detections; occasional overflights and ground visits; airborne and ground-based gas measurements; and the compilation of visual observations taken from observatory personnel, resident, mariner, and pilot weather report accounts (PIREPs; reports of meteorological phenomena encountered by aircraft in flight). AVO also monitors volcano ground deformation using real-time data from permanent Global Navigation Satellite System (GNSS) stations and Interferometric Synthetic Aperture Radar (InSAR) imagery (for example, Lee and others, 2010).

Observations from these multiple sources inherently relate to several different datums. Ash altitudes are listed in feet above sea level with their metric conversion given in parentheses. Ash altitudes are commonly from PIREPs or, for ash resuspension events from the National Weather Service, are based on analysis of satellite imagery, and the altitudes given herein can be somewhat imprecise. Earthquake depths are modeled in relation to the World Geodetic System of 1984 (WGS 1984), and the accuracy of depth given directly relates to how many stations were used to record the event (that is, accuracy of depth decreases with less recording stations). The summit elevations of the volcanoes are derived from the 2019 InSAR data (U.S. Geological Survey, 2019). These elevations may differ from past AVO annual summaries, which were taken directly from the AVO database (https://avo.alaska.edu).

With this information, AVO assigns each monitored volcano an Aviation Color Code and Volcano Alert Level, which indicate its current activity status (Gardner and Guffanti, 2006). No assignment is given to volcanoes that lack local seismic monitoring and appear to be at background level. However, these seismically unmonitored volcanoes are assigned an Aviation Color Code and Volcano Alert Level if regional seismic networks or other monitoring streams (for instance, satellite monitoring) indicate ongoing activity or elevated unrest. The Aviation Color Code addresses the hazards to aviation posed by a volcano, whereas the Volcano Alert Level addresses the hazards on the ground. Although the Aviation Color Code and Volcano Alert Level are usually changed together, there could be situations where they are changed independently. For instance, a volcano might produce

[1] U.S. Geological Survey.

[2] University of Alaska Fairbanks.

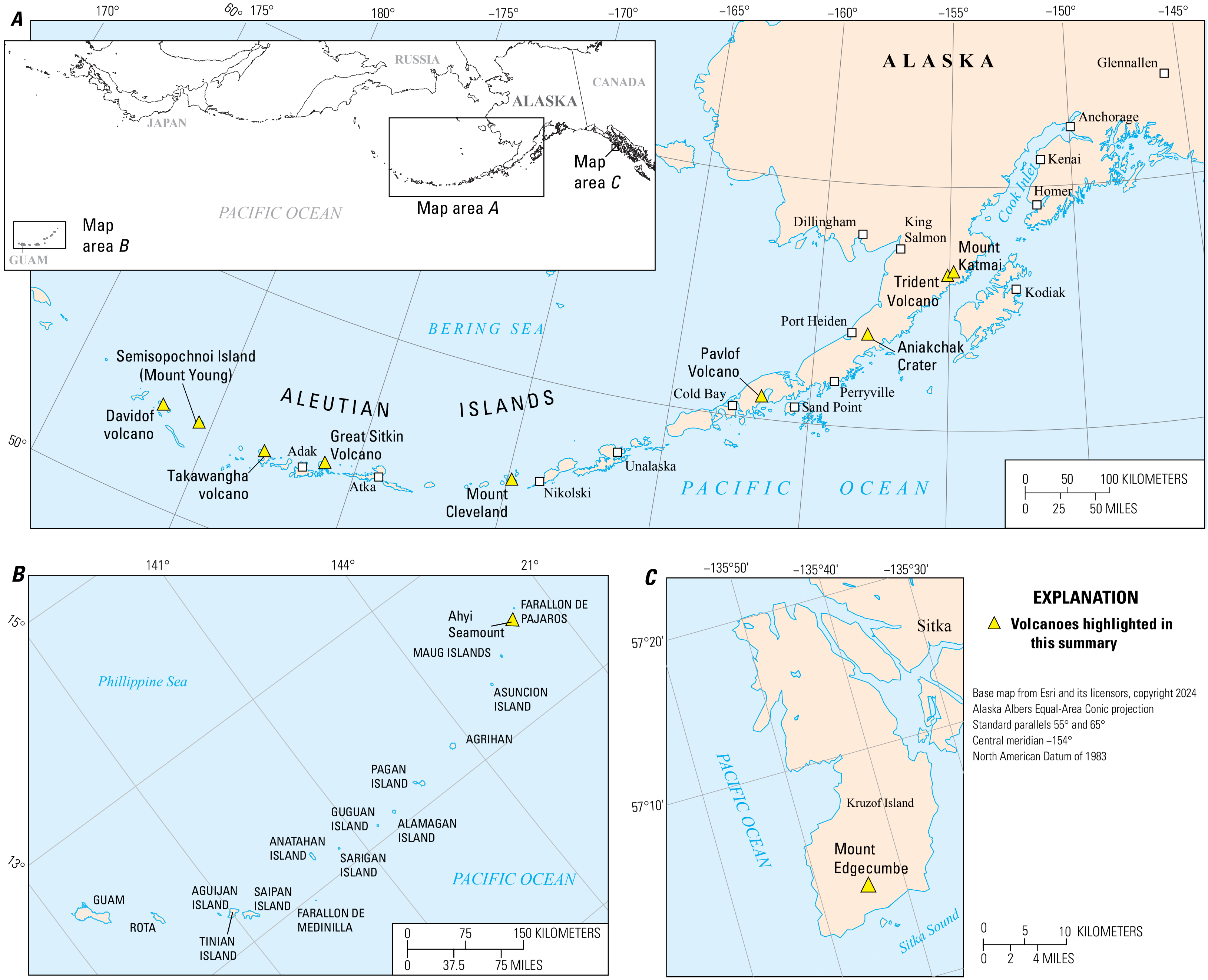


Figure 1. Map of Alaska (*A*), Commonwealth of the Northern Mariana Islands (*B*), and Kruzof Island (*C*) showing volcanoes highlighted in this summary.

lava flows that are dangerous on the ground, which would require a Volcano Alert Level of **WARNING**, but the hazard to aviation would be minimal, meriting an Aviation Color Code of **ORANGE**. Where possible, Volcano Alert Level announcements contain additional explanations of volcanic activity and expected hazards. Tables 1 and 2 define each Aviation Color Code and Volcano Alert Level.

Duty scientists are responsible for compiling all monitoring data to provide scheduled and event-driven public notices, as appropriate. AVO scientists also participate in a weekly remote-sensing rotation, during which time they produce daily reports summarizing satellite and webcam observations at volcanoes with elevated Aviation Color Codes and Volcano Alert Levels. The reports also describe any notable observations at other volcanoes the AVO monitors. All observations are archived in a relational database. A second group of scientists from AVO and the USGS National Earthquake Information Center monitors volcano seismicity and infrasound using local and regional sensors. This team compiles three separate seismic reports daily, spaced ~8 hours apart. Like the daily remote sensing reports, the seismic reports are catalogued in a relational database. Many AVO scientists fill two of these roles simultaneously.

What is a "Historically Active Volcano"?

AVO defines an active volcano as a volcanic center that has recently had an eruption (see "What is an 'Eruption' ") or a period of intense deformation, seismic activity, or fumarolic activity; these are inferred to reflect the presence of magma at shallow levels beneath the volcano. AVO considers the historical period in Alaska to be since 1741, when written records of volcanic activity began. Based on a rigorous reanalysis of all volcanic activity accounts in Alaska (from many sources), Cameron and others (2023) concluded that 54 Alaskan volcanoes fit these criteria. We concur with this number in this report, but with a slight reclassification—we consider Novarupta to be a subfeature of Mount Katmai but also count Tanaga Volcano and Takawangha volcano as separate volcanoes. As geologic understanding of Alaskan volcanoes improves through additional fieldwork and modern radiometric dating techniques, our list of active volcanoes will continue to evolve.

Table 1. Definitions of the Aviation Color Codes used by United States volcano observatories.

Aviation Color Code	Definition
GREEN	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased, and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
RED	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely, or eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].
UNASSIGNED	Ground-based instrumentation is insufficient to establish that volcano is at typical background level (GREEN/NORMAL). When activity at such a volcano increases to the point of being detected by remote sensing instruments, distant seismic networks, or eyewitness reports, an alert level and color code are assigned accordingly. When activity decreases, volcano goes back to UNASSIGNED without going through GREEN/NORMAL.

Table 2. Definitions of the Volcano Alert Levels used by United States volcano observatories.

Volcano Alert Level	Definition
NORMAL	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased, and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway but poses limited hazards.
WARNING	Highly hazardous eruption is imminent, underway, or suspected.
UNASSIGNED	Ground-based instrumentation is insufficient to establish that volcano is at typical background level (GREEN/NORMAL). When activity at such a volcano increases to the point of being detected by remote sensing instruments, distant seismic networks, or eyewitness reports, an alert level and color code are assigned accordingly. When activity decreases, volcano goes back to UNASSIGNED without going through GREEN/NORMAL.

"What is an "Eruption"?

The specific use of the term "eruption" varies from scientist to scientist and has no universally agreed-upon definition. Here, we adopt the usage of Siebert and others (2010, p. 17), who define eruptions as "* * * events that involve the explosive ejection of fragmental material, the effusion of liquid lava, or both." The critical elements of this definition are the verbs "ejection" and "effusion," which refer to dynamic surface processes that pose some level of hazard. The presence or absence of "juvenile material," or newly erupted rock, which can sometimes be ambiguous, is not relevant to this use of the term eruption, particularly when communicating a potential hazard. This definition does not, however, include passive volcanic degassing or hydrothermal fluid discharge.

This report summarizes eruptive activity and other notable unrest associated with volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands during 2022 (tables 3, 4) and briefly describes AVO's response. It contains information about all identified volcanic unrest, even if no formal public notification was issued at the time. Observations, images, and information that are typically not published elsewhere are included in this report. Similar summaries of volcanic unrest and AVO's response have been published annually since 1992.

The volcanoes in this report are presented in geographic order from east to west along the Aleutian Arc, and afterward by the Commonwealth of the Northern Mariana Islands, which is presented from north to south. Each entry has a title block containing information about that volcano: its identifier number (#) assigned by the Smithsonian Institution Global Volcanism Program (GVP); its latitude, longitude, and summit elevation; the name of its geographic region; and an abbreviated summary of its 2022 activity. The title block is followed by a description of the volcano and a summary of its past activity, then a detailed account of its activity during the year, often with accompanying tables, images, figures, or all three. This information is derived from formal public AVO information products, internal online electronic logs compiled by AVO staff, and published material.

AVO sometimes uses informal volcano names for clarity; the names provided by the official U.S. Board on Geographic Names (through the Geographic Names Information System) may match poorly with the volcanoes themselves. For example, Bogoslof volcano comprises more islands than Bogoslof Island. Alaska also has volcanoes without official place names, such as Takawangha volcano, which require the use of informal names.

Table 3. Summary of activity at Alaskan and Northern Mariana Islands volcanoes in 2022, including but not limited to confirmed eruptions, possible eruptions, increases in seismicity, observations of fumarolic activity, and other notable events.

[Volcanoes presented in geographic order from east to west along the Aleutian arc, and north to south in the Commonwealth of Northern Mariana Islands. Volcano locations shown in figure 1]

Volcano	Type of activity
Mount Edgecumbe	Ground deformation; elevated seismicity
Mount Katmai (Novarupta)	Resuspension of 1912 ash
Trident Volcano	Elevated seismicity
Aniakchak Crater	Resuspension of ash
Pavlof Volcano	Explosive eruption with ash emissions, lava flows, and lahars
Mount Cleveland	Elevated surface temperatures and gas emissions
Great Sitkin Volcano	Eruption of lava flow
Takawangha volcano	Elevated seismicity
Semisopochnoi Island (Mount Young)	Weak explosive activity; ash and gas emissions
Davidof volcano	Elevated seismicity
Ahyi seamount	Hydroacoustic detections, indicating underwater explosions; plume of discolored water observed?

In this report, volcano locations (in decimal degrees latitude and longitude) are taken from AVO's database of Alaskan volcanoes (Cameron and others, 2022). The depth of Ahyi seamount below sea level comes from Tepp and others (2019). Measurements are presented in the International System of Units, except for altitudes, which are reported in feet above sea level (ASL), in line with federal aviation standards, followed by meters (m) in parentheses. Date references are given in universal coordinated time (UTC), followed by local time, unless specified otherwise. General date references (without times) are followed by the local date when it differs from the UTC date—where the UTC and local dates match, only one date is shown. Most volcanoes in Alaska are in the Alaska standard time (AKST) or Alaska daylight time (AKDT) zones, but all Aleutian volcanoes west of Umnak Island (see the community of Nikolski, Alaska, on fig. 1) are in the Hawaii-Aleutian standard time (HAST) or Hawaii-Aleutian daylight time (HADT) zones. Ahyi seamount falls within the Chamorro standard time (ChST) zone. During 2022, daylight saving time ran from March 13 to November 6.

Table 4. Aviation Color Code and Volcano Alert Level changes during 2022 at volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands discussed in this report.

[Volcanoes presented in geographic order from east to west along the Aleutian arc, and north to south in the Commonwealth of Northern Mariana Islands. See tables 3 and 4 for definitions of Aviation Color Codes and Volcano Alert Levels. Dates shown as MM/DD/YYYY. Times shown in parentheses as HH:MM in coordinated universal time (UTC) and local time (Alaska daylight time/Alaska standard time). —, not applicable]

Aviation Color Code/ Volcano Alert Level	Date and time of change	
	UTC	Local
Mount Edgecumbe		
UNASSIGNED	No change entire year	—
Mount Katmai (Novarupta)		
GREEN/NORMAL	No change entire year	—
Trident Volcano		
GREEN/NORMAL	Beginning of year	—
UNASSIGNED	03/16/2022 (17:50)	03/16/2022 (09:50)
GREEN/NORMAL	03/18/2022 (23:33)	03/18/2022 (15:33)
YELLOW/ ADVISORY	09/29/2022 (22:56)	09/29/2022 (14:56)
GREEN/NORMAL	10/19/2022 (22:06)	10/19/2022 (14:06)
Aniakchak Crater		
GREEN/NORMAL	No change entire year	—
Pavlof Volcano		
ORANGE/WATCH	Beginning of year	—
YELLOW/ ADVISORY	12/17/2022 (20:33)	12/17/2022 (11:33)
Mount Cleveland		
UNASSIGNED	Beginning of year	—
YELLOW/ ADVISORY	05/11/2022 (00:19)	05/10/2022 (15:19)
Great Sitkin Volcano		
ORANGE/WATCH	No change entire year	—
Takawangha volcano		
GREEN/NORMAL	Beginning of year	—
YELLOW/ ADVISORY	11/19/2022 (01:34)	11/18/2022 (16:34)
Semisopochnoi Island (Mount Young)		
ORANGE/WATCH	Beginning of year	—
YELLOW/ ADVISORY	07/08/2022 (17:03)	07/08/2022 (09:03)
ORANGE/WATCH	08/21/2022 (23:01)	08/21/2022 (15:01)
YELLOW/ ADVISORY	09/29/2022 (22:57)	09/29/2022 (14:57)
ORANGE/WATCH	11/07/2022 (22:08)	11/07/2022 (13:08)
YELLOW/ ADVISORY	11/23/2022 (21:30)	11/23/2022 (12:30)
ORANGE/WATCH	12/28/2022 (20:46)	12/28/2022 (11:46)
Davidof volcano		
UNASSIGNED	Beginning of year	—
YELLOW/ ADVISORY	01/26/2022 (19:07)	01/26/2022 (10:07)
UNASSIGNED	04/22/2022 (01:02)	04/21/2022 (17:02)
Ahyi seamount		
UNASSIGNED	Beginning of year	—
YELLOW/ ADVISORY	11/28/2022 (22:54)	11/28/2022 (13:54)

Volcanic Activity in Alaska

Mount Edgecumbe

GVP# 315040
57.051°, −135.761°
1,010 m
Kruzof Island, southeast Alaska

GROUND DEFORMATION AND ELEVATED SEISMICITY

Mount Edgecumbe is a 976-m-high stratovolcano on Kruzof Island located 25 kilometers (km) west of Sitka, Alaska, 928 km southeast of Anchorage, Alaska (fig. 1), and 15 km east of the Queen Charlotte-Fairweather Fault Zone, a major transform fault system in southeast Alaska. Mount Edgecumbe and the subaerial portion of the surrounding volcanic field lie within the Tongass National Forest. The volcano comprises a broad volcanic field of lava domes and craters on southern Kruzof Island and is composed primarily of basalt, basaltic andesite, and andesite lava flows, whereas the adjacent edifice of Crater Ridge consists of overlapping rhyolite domes (Riehle and others, 1992).

The offshore area surrounding Mount Edgecumbe has been active during the past 600,000 years (Riehle and others, 1992). A period of increased eruptive activity at Mount Edgecumbe 14,600 to 13,100 years ago has been attributed to ice loss after the Last Glacial Maximum (Praetorius and others, 2016), driven by decompression melting (for example, Jull and McKenzie, 1996). This activity produced at least one widespread regional tephra (ash) layer about 1 m thick near Sitka and more than 30 m thick on parts of Kruzof Island (Riehle, 1996). There are no written observations of eruptions from the volcanic field, although Tlingit oral history describes small eruptions with uncertain timing, possibly as recent as 800 years ago (Kitka, 1988). Notably, Larsen and others (2005) reported rapid uplift of the region since the late 1700s, which they attribute to viscoelastic relaxation of the mantle owing to the melting of the Little Ice Age glaciers, and Elliott and others (2010) and Hu and Freymueller (2019) similarly linked ongoing regional uplift and its varying rates to elastic and viscoelastic responses to ongoing glacial melting.

The primary hazards of past eruptions are likely hazards in future eruptions. Past hazards have been volcanic ash emissions that produced local and regional ashfall and drifting ash clouds. Volcanic lahars, pyroclastic flows, and lava flows have also occurred on the flanks of Mount Edgecumbe.

On April 11, 2022, the regional seismic network encompassing Mount Edgecumbe recorded a local magnitude (M_L) 2.1 earthquake, which the Alaska Earthquake Center located under Kruzof Island. Records from the nearest seismograph in Sitka (25 km east) indicated that a seismic swarm started at 10:00 UTC (02:00 AKDT) on April 11

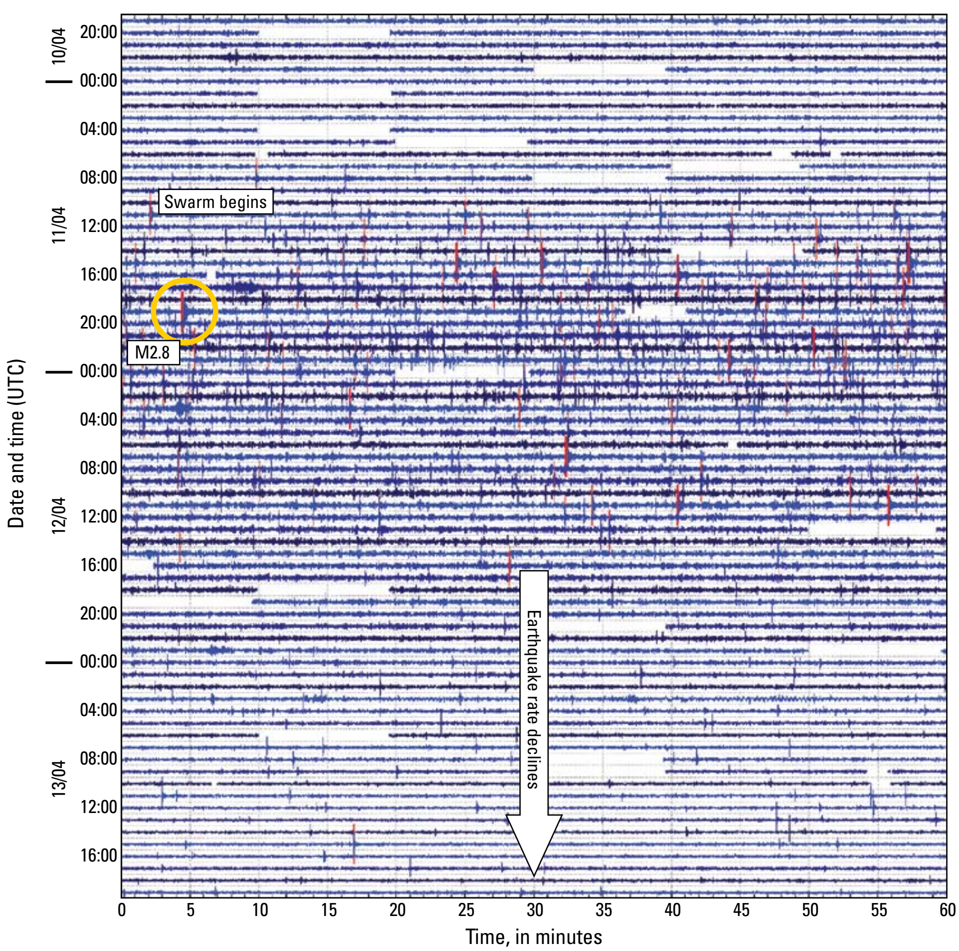


Figure 2. Helicorder plot of the earthquake swarm northeast of Mount Edgecumbe volcano that started at about 10:00 UTC (02:00 AKDT) on April 11, 2022, as recorded by seismic station SIT. The earthquake rate waned to background frequency by April 13. The largest earthquake of the sequence (M2.8), which occurred at 19:04 UTC (11:04 AKDT) on April 11, is circled in yellow. The SIT seismic station is located in Sitka, Alaska, 25 km east of the volcano, and is operated by the National Tsunami Warning Center. The repeating pattern of line colors for the seismic trace, using shades of blue, is for visual acuity purposes to help distinguish each hour-long trace from the next. The seismic trace is red where the seismic amplitude is electronically clipped at the scale used in this figure.

(fig. 2), and events ranging from M_L 1 to M_L 2.8 were clustered broadly to the northeast of Mount Edgecumbe near Crater Ridge (fig. 3). Earthquake rates declined during the following week. Retrospective analysis of seismic data in 2022 revealed that the 2022 swarm was preceded by a similar swarm in 2020 (fig. 3) that was initiated by a magnitude 3.0 earthquake on January 2 of that year. That swarm lasted into mid-2021 (Grapenthin and others, 2022). The seismic catalog contains no other located events in this region back to 1990. Retrospective analysis of the closest single-station seismic data in Sitka revealed that seismicity first began to increase in June 2019 (Grapenthin and others, 2022).

Interferometric analysis of satellite radar observations acquired by the European Space Agency's Sentinel-1 satellite since its launch in 2014 showed ground inflation (fig. 4), centered about 3 km east of Mount Edgecumbe, that started in August 2018 and evolved at a steady rate (fig. 5). About 25 centimeters (cm) of deformation occurred in the satellite line-of-sight between then and the end of November 2021, corresponding to a deformation rate as much as 7 centimeters per year. Grapenthin and others (2022) modeled this deformation as owing to magma migrating from a magma reservoir about 20 km deep through a narrow conduit into a 10-km-deep tabular body dipping about 22 degrees east.

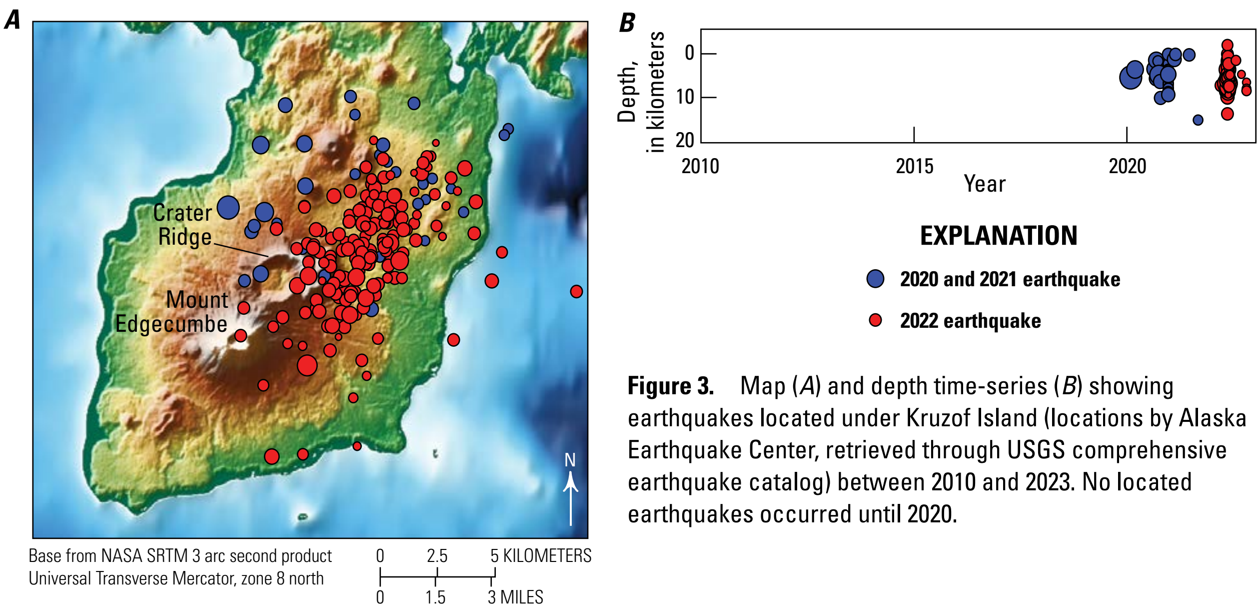


Figure 3. Map (*A*) and depth time-series (*B*) showing earthquakes located under Kruzof Island (locations by Alaska Earthquake Center, retrieved through USGS comprehensive earthquake catalog) between 2010 and 2023. No located earthquakes occurred until 2020.

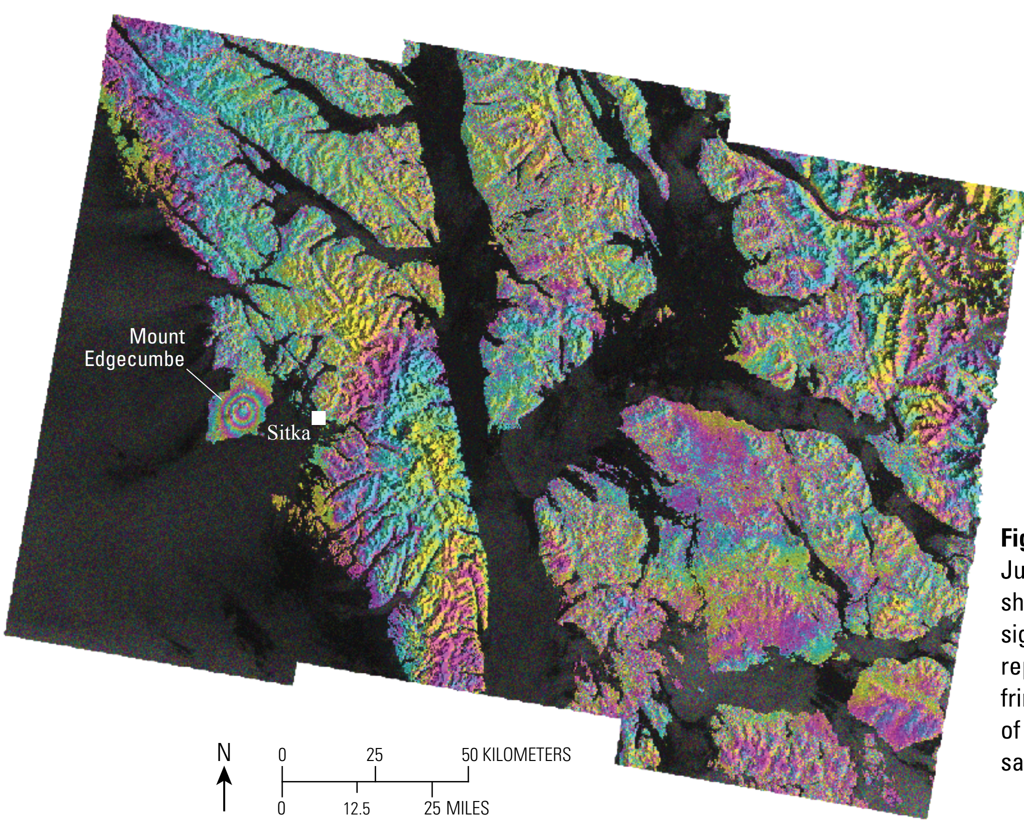
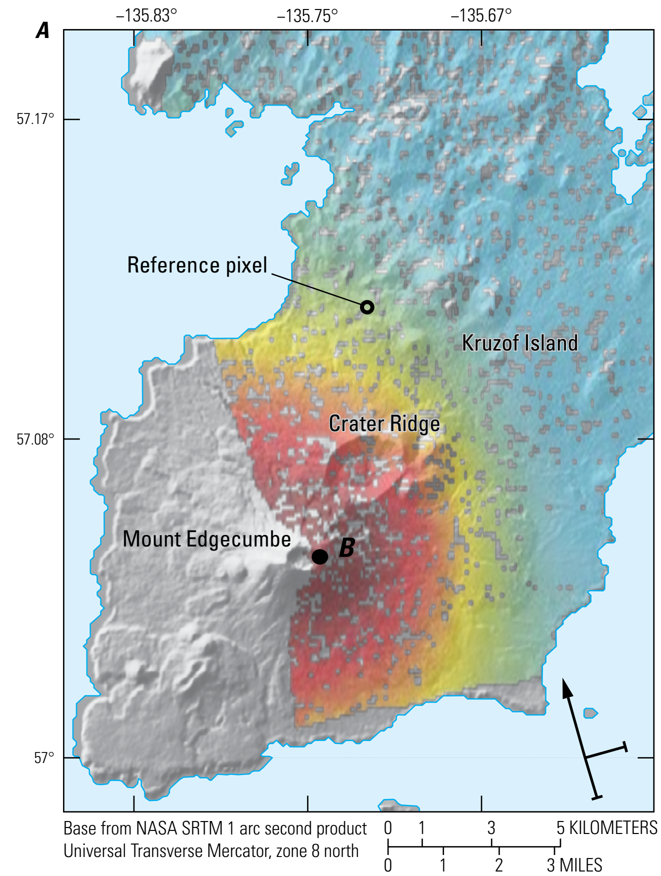


Figure 4. Interferogram spanning June 28, 2018, to July 5, 2019, showing a clear bullseye inflation signal near Mount Edgecumbe. Each repeating set of rainbow-colored fringes represents ~2.8 centimeters of ground deformation toward the satellite along its line of sight.



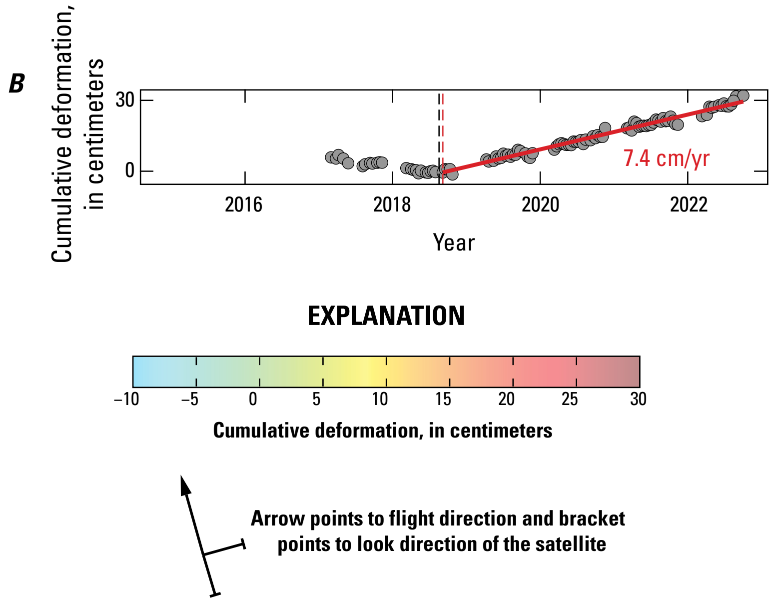


Figure 5. Map (*A*) and graph (*B*) of Mount Edgecumbe InSAR time series spanning September 8, 2018, to February 14, 2023, showing ~30 centimeters of cumulative deformation in the satellite line-of-sight (ascending path 79), roughly centered on Mount Edgecumbe. Point on the crater rim identifies the location of the time series for this pixel shown in *B*. The rate of deformation (red line in *B*) starting in August 2018 is ~7.4 centimeters/year (cm/yr).

Because the deformation rate did not change during the week-long episode of seismic tremor, and background unrest at the unmonitored volcano was not well understood, the Aviation Color Code and Volcano Alert Level for Mount Edgecumbe were kept at **UNASSIGNED**. Information statements detailing the initial seismic activity and the deformation analysis were distributed on April 13 and April 22, respectively. AVO scientists visited Sitka May 1–3 to brief officials, perform media interviews, and conduct public meetings on the new activity. On May 19–20, a single seismic and GNSS site were installed at Mount Edgecumbe, and a gas flight was conducted.

Mount Katmai (Novarupta)

GVP# 312170
58.279°, −154.953°
2,057 m
Alaska Peninsula

RESUSPENSION OF 1912 ASH

Mount Katmai is located on the Alaska Peninsula about 160 km northeast of City of Kodiak, Alaska, and 430 km southwest of Anchorage (fig. 1). The 1912 eruption of Mount Katmai and its satellite vent Novarupta, the largest eruption of the 20th century globally, is thought to have been fed by a shallow sill from a magma body beneath Mount Katmai (Hildreth and Fierstein, 2000). The eruption produced approximately 17 cubic kilometers (km^3) of tephra-fall deposits and 11 km^3 of pyroclastic material (total dense-rock equivalent volume of ~13.5 km^3) that filled nearby valleys on both sides of the Aleutian Range (Hildreth and Fierstein, 2012). The pyroclastic deposit in these valleys is as much as 200 m thick, and some areas remain almost entirely devoid of vegetation more than a century after the eruption. When the landscape is free of snow, and particularly when the ground has little moisture content, strong winds can pick up ash and create large ash clouds. The wind can then transport the resuspended ash, often southeast across Shelikof Strait, Kodiak Island, and the Gulf of Alaska, but also in other directions. These ash clouds are often seen by individuals downwind and are recorded in satellite imagery, where they appear to originate from a broad area rather than a specific volcanic source. Although they resemble dispersing volcanic ash clouds in satellite imagery, they are not the result of present-day volcanic activity.

This resuspension phenomenon has been observed and documented many times during the past several decades (Hadley and others, 2004; Wallace and Schwaiger, 2019), including five times in 2022. AVO issued Information

Statements for these events, and the National Weather Service (NWS) Alaska Aviation Weather Unit (AAWU) issued significant meteorological information statements (SIGMETs) for aviators. No changes in the Aviation Color Code and Volcano Alert Level were warranted, and Mount Katmai remained **GREEN** and **NORMAL** throughout the year.

The first ash resuspension event of the year from the Mount Katmai (Novarupta) region occurred on April 9 (April 8 AKDT), when strong northwesterly winds picked up loose volcanic ash and carried it to the southeast toward Kodiak Island (fig. 6). Residents of the City of Kodiak, Alaska, reported very dusty conditions that day. AAWU reported cloud heights as much as ~8,000 ft (~2,400 m) ASL. Two more ash resuspension events occurred the following month—on May 13, strong northwesterly winds carried ash to the southeast toward Kodiak Island, and on May 20, strong easterly winds carried ash to the west-northwest. AAWU reported ash heights as much as ~6,000 ft (~1,800 m) ASL for the two events. Next, on June 30, strong winds again resulted in a cloud of resuspended ash that drifted northwest, and AAWU again reported ash heights as much as ~6,000 ft (~1,800 m) ASL. Finally, in the morning on October 9, strong northwesterly winds near Mount Katmai picked up loose volcanic ash, carrying it southeast toward Kodiak Island. AAWU reported ash heights as much as ~5,000 ft (~1,500 m) ASL for this last ash resuspension event of 2022.

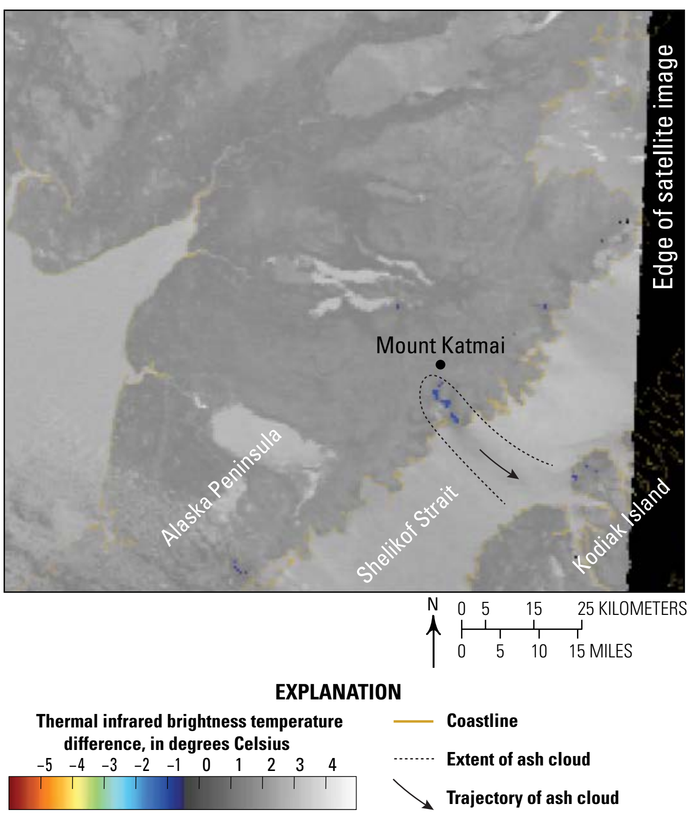


Figure 6. Satellite image of NOAA-20 Visible Infrared Imaging Suite brightness temperature difference acquired on April 9, 2022, at 00:24 UTC (16:24 AKDT on April 8), showing resuspended ash plume extending across the Shelikof Strait to Kodiak Island. The source of the ash is snow-free ground in the Katmai River drainage, south of Mount Katmai.

Trident Volcano

GVP# 312160
58.234°, −155.103°
1,849 m
Alaska Peninsula

ELEVATED SEISMICITY

Trident Volcano, a part of the Mount Katmai group of volcanoes within Katmai National Park and Preserve on the Alaska Peninsula, is located 148 km southeast of King Salmon, Alaska, and 440 km southwest of Anchorage (fig. 1). Trident Volcano consists of a complex of four cones and several lava domes, all andesite and dacite in composition, that are as high as 1,849 m. An eruption beginning in 1953 produced about 0.5 km^3 of fragmental material and intercalated lava flows that constructed a new cone, known informally as southwest Trident (Coombs and others, 2000; Hildreth and others, 2000). This eruption continued sporadically through 1974 and produced ash (an initial plume rose to ~30,000 ft [~9,100 m] ASL), bombs, and lava at different times. Fumaroles remain active on the summit of southwest Trident and on the southeast flank of the oldest, central cone.

AVO detected a swarm of earthquakes beneath Trident Volcano beginning on August 24, 2022, that lasted several days. These earthquakes represented the beginning of an elevated period of unrest in the vicinity of Trident Volcano that persisted for the rest of calendar year 2022. Owing to the elevated seismicity, AVO released an Information Statement on September 14 and then raised the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on September 29. The earthquake rate briefly decreased during early October, and AVO moved Trident Volcano back to Aviation Color Code **GREEN** and Volcano Alert Level **NORMAL** on October 19. However, in late October the rate began to increase again to above-background levels, although not enough to warrant raising the Aviation Color Code and Volcano Alert Level.

Figure 7 depicts the daily rate, depth, and magnitude of earthquakes in the vicinity of Trident Volcano during late August and early September 2022. The swarm of earthquakes that started on August 24 consisted of mainly deep volcano-tectonic earthquakes that displayed shallowing hypocenters during the four days afterward. The average depths of the events migrated from 25 to 15 km depth during this period.

On August 28, near the end of the upward-migrating swarm, an unusual very-long-period (VLP) earthquake, with the main portion of its energy at nearly 10 seconds period (0.1 hertz [Hz] frequency), occurred beneath Trident Volcano. VLP seismicity is commonly associated with magma movement and further indicated a magmatic origin for the unrest. The three-component displacement record of this earthquake on a seismic station in the Mount Katmai region is shown in Figure 8. The location of the VLP earthquake was determined using the high-frequency (> 1 Hz) portion of its signal and assigned a M_L of 0.5; however, since most of its energy was below 1 Hz, the VLP earthquake had greater moment release than indicated by its local magnitude.

After the earthquake rate had increased in late October, an earthquake with a M_L 4.0 occurred on November 20, 2022, to the west of Trident Volcano and south of Novarupta (fig. 9). This was the largest earthquake in the Mount Katmai area during 2022. The epicenters of all earthquakes with magnitude larger than 2.0 in the vicinity of Trident Volcano are plotted in Figure 9.

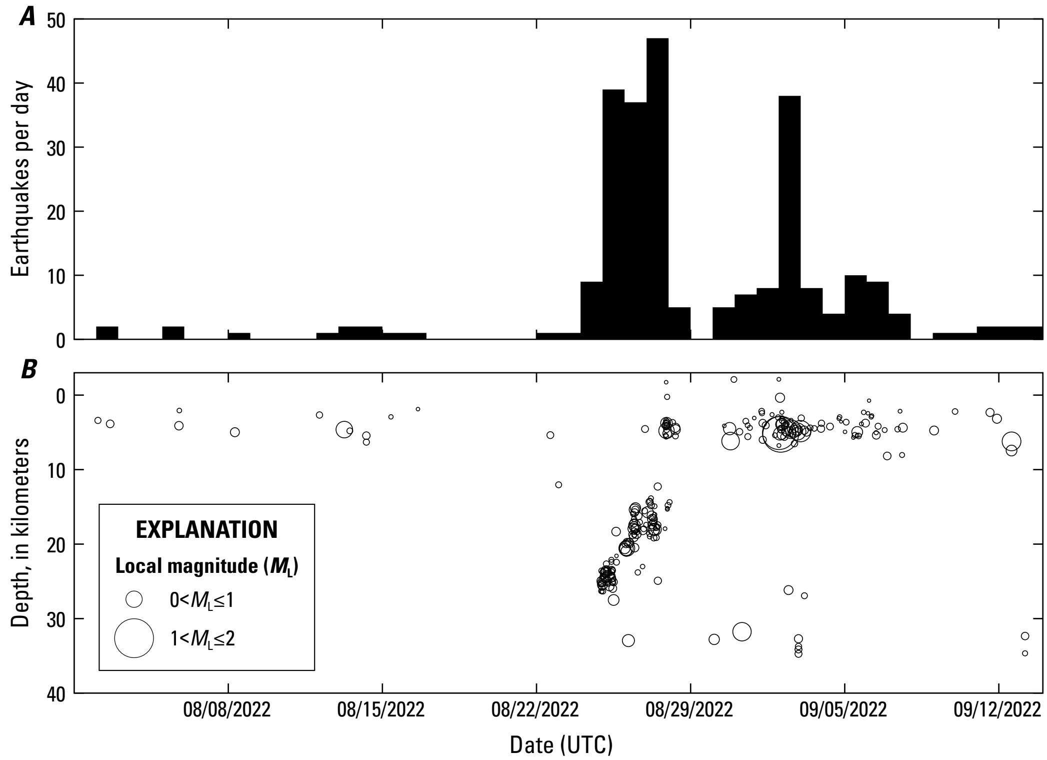


Figure 7. Plots showing daily rate (*A*) and depth and magnitude (*B*) of earthquakes located by the Alaska Volcano Observatory in the vicinity of Trident Volcano during August–September 2022. The earthquakes shallowed in depth between August 24 and 28 and elevated rates of shallow (< 5 kilometers depth) seismicity ensued between August 28 and September 5. Dates shown in month, day, and year format in coordinated universal time (UTC).

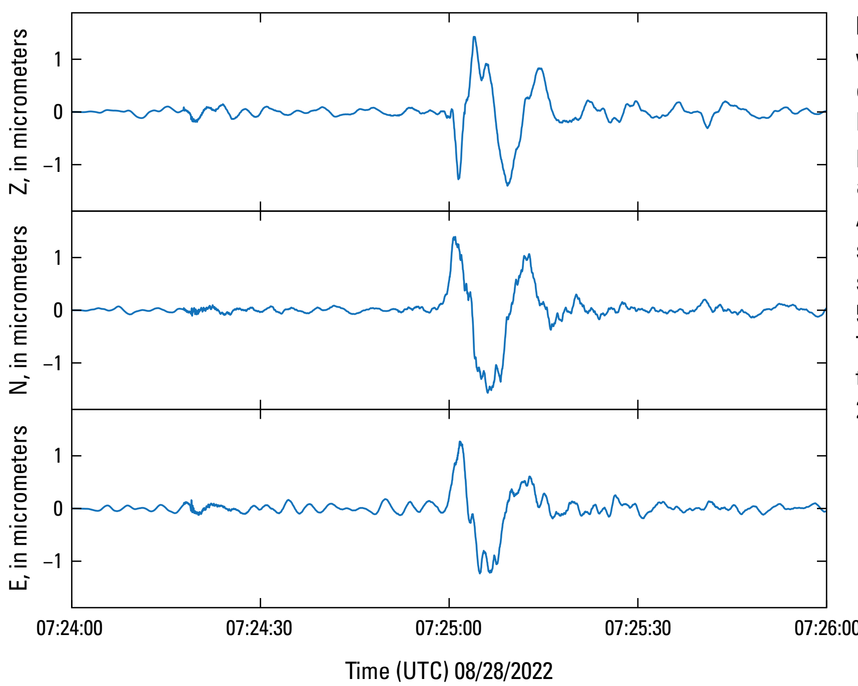


Figure 8. Three-component waveforms (Z, vertical; N, north; E, east) from station KAKN in the Mount Katmai region for an unusual very-long-period (VLP) earthquake that occurred around 7:25 UTC on August 28, 2022. A location was computed using the small, high-frequency portion of the signal from this event within the upper 5 kilometers beneath Trident Volcano. The event occurred near the end of the shallowing swarm between August 24–28 shown in figure 1.

Daily earthquake rate and earthquake magnitudes are plotted for the 5 years from the beginning 2018 to the end of 2022 in the vicinity of Trident Volcano in Figure 10. The same plots are shown for earthquakes in the vicinity of Mount Martin and Mount Mageik in Figure 11. The earthquake rate at Trident Volcano during late 2022 was clearly above background after the upward-migrating swarm during August 2022 (fig. 10). The earthquake rate at Mount Martin and Mount Mageik became slightly elevated before and during the upward-migrating swarm and increased through the end of the calendar year (fig. 11). Although the rate by the end of 2022 near Mount Martin and Mount Mageik was elevated, it was not higher than a similar seismicity increase observed in late 2019 (Orr and others, 2023). The earthquakes near

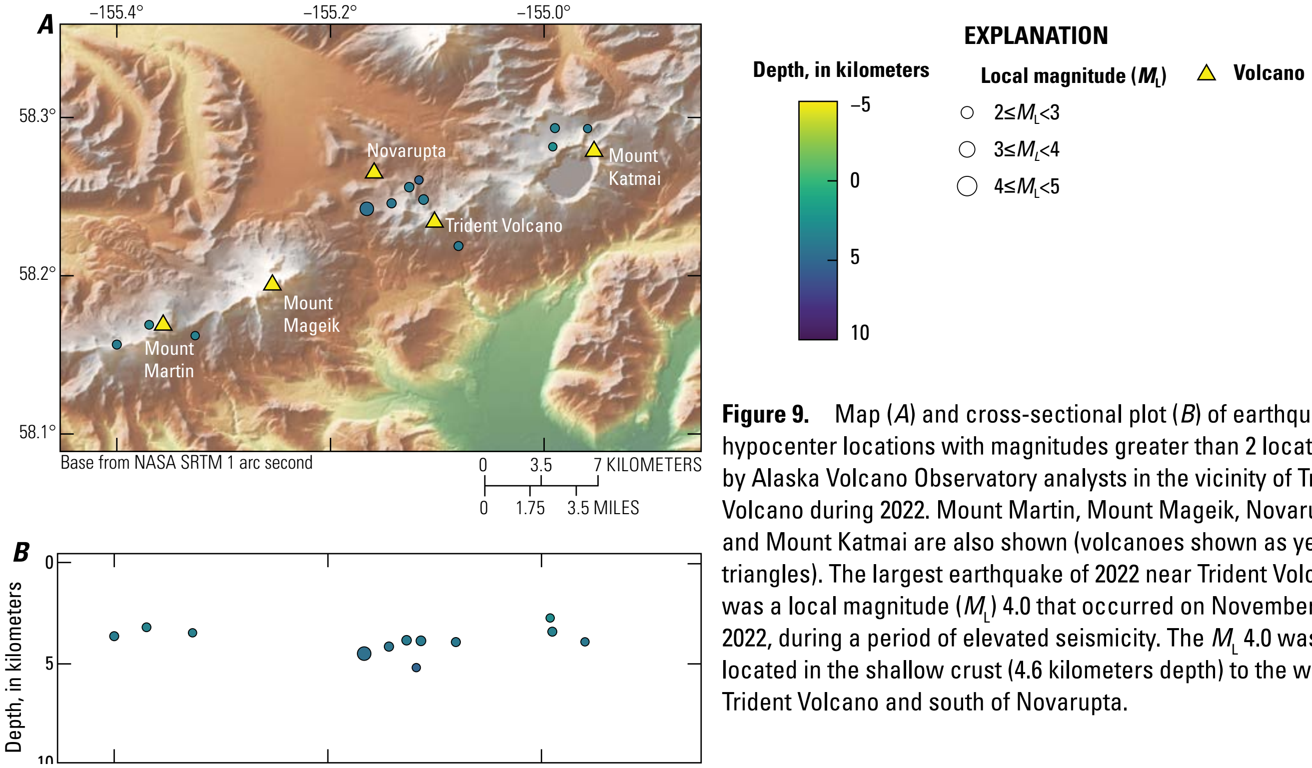


Figure 9. Map (*A*) and cross-sectional plot (*B*) of earthquake hypocenter locations with magnitudes greater than 2 located by Alaska Volcano Observatory analysts in the vicinity of Trident Volcano during 2022. Mount Martin, Mount Mageik, Novarupta, and Mount Katmai are also shown (volcanoes shown as yellow triangles). The largest earthquake of 2022 near Trident Volcano was a local magnitude (M_L) 4.0 that occurred on November 20, 2022, during a period of elevated seismicity. The M_L 4.0 was located in the shallow crust (4.6 kilometers depth) to the west of Trident Volcano and south of Novarupta.

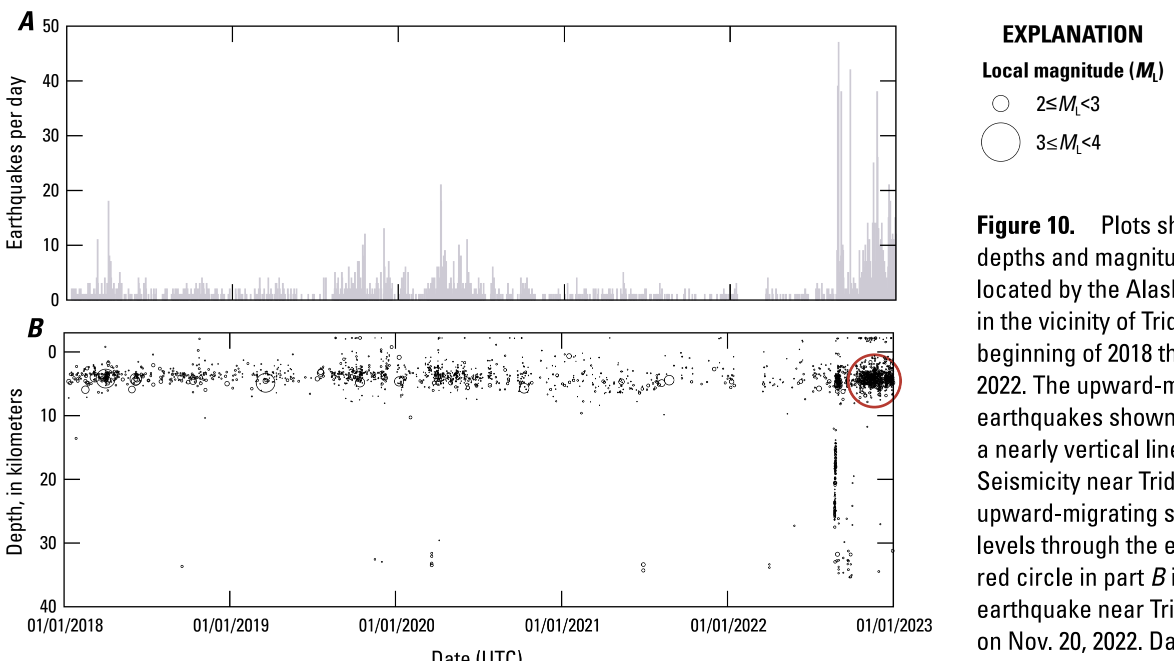


Figure 10. Plots showing daily rate (*A*) and depths and magnitudes (*B*) of earthquakes located by the Alaska Volcano Observatory in the vicinity of Trident Volcano from the beginning of 2018 through to the end of 2022. The upward-migrating swarm of deep earthquakes shown in figure 7 appears as a nearly vertical linear feature at this scale. Seismicity near Trident Volcano following the upward-migrating swarm continued at high levels through the end of the calendar year. The red circle in part *B* is the local magnitude 4.0 earthquake near Trident Volcano that occurred on Nov. 20, 2022. Dates given in month, day, year format in coordinated universal time (UTC).

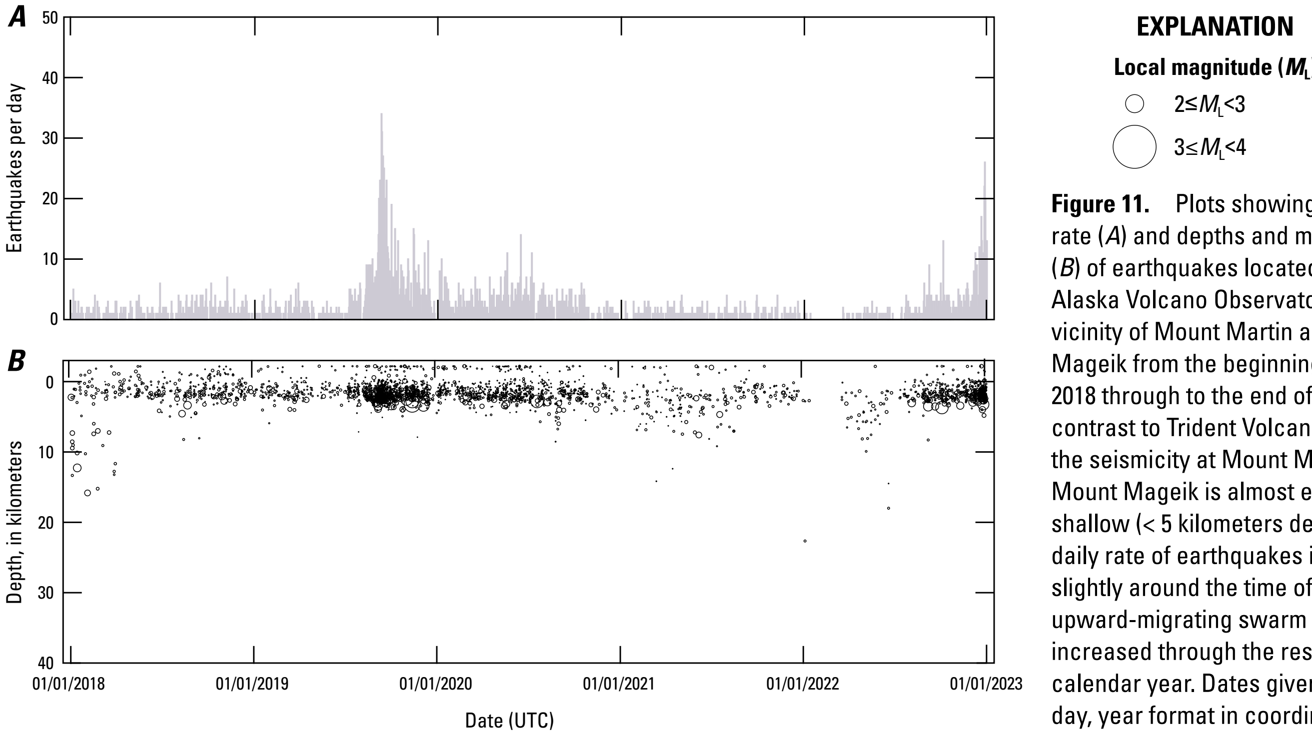


Figure 11. Plots showing daily rate (*A*) and depths and magnitudes (*B*) of earthquakes located by Alaska Volcano Observatory in the vicinity of Mount Martin and Mount Mageik from the beginning of 2018 through to the end of 2022. In contrast to Trident Volcano (fig. 9), the seismicity at Mount Martin and Mount Mageik is almost entirely shallow (< 5 kilometers depth). The daily rate of earthquakes increased slightly around the time of the upward-migrating swarm and then increased through the rest of the calendar year. Dates given in month, day, year format in coordinated universal time (UTC).

Mount Martin and Mount Mageik are all shallow (< 5 km depth), whereas deeper seismicity down to 30 km depth occurs in the vicinity of Trident Volcano. Figures 7, 10, and 11 put the 2022 seismicity increase in the Mount Katmai region into perspective given the background rates over this 5-year period.

Aniakchak Crater

GVP# 312090
56.906°, −158.209°
1,298 m
Alaska Peninsula

RESUSPENSION OF ASH

Aniakchak Crater is located on the Alaska Peninsula about 25 km east-southeast of Port Heiden, Alaska, and about 665 km southwest of Anchorage (fig. 1). It is a circular caldera 10 km in diameter and 1 km deep that formed about 3,400 years ago during a catastrophic event that erupted 75 km^3 of material (Miller and Smith, 1987; Dreher and others, 2005; Bacon and others, 2014). Several lava domes, lava flows, and scoria cones occupy the interior of the caldera (Neal and others, 2000); the largest intracaldera cone is Vent Mountain, which is 2.5 km in diameter and stands 430 m above the floor of the caldera. The only historical eruption at Aniakchak Crater was a powerful explosive event in 1931 that covered a large part of the eastern Alaska Peninsula with ash (Nicholson and others, 2011). When the landscape is snow-free, particularly when the ground has little moisture content, strong winds can pick up loose ash from the flanks of the volcano and create large, resuspended ash clouds that can pose a hazard to aviation.

On June 30, 2022, an observer in Port Heiden reported that strong winds had entrained and resuspended ash from the region north of Aniakchak Crater and carried it north over Bristol Bay. The resuspension event was also visible in webcam views from Port Heiden (fig. 12). AAWU did not issue a SIGMET for aviators, but AVO issued an Information Statement. There were no reports of ashfall at Port Heiden. The Aviation Color Code and Volcano Alert Level remained GREEN and NORMAL for Aniakchak Crater during 2022.

Figure 12. Webcam image of east-facing view from Port Heiden collected on June 30, 2022, at 19:39 UTC (11:39 AKDT), showing resuspended ash north of Aniakchak Crater.

Pavlof Volcano

GVP #312030
55.417°, −161.894°
2,526 m
Alaska Peninsula

EXPLOSIVE ERUPTION WITH ASH EMISSIONS, LAVA FLOWS, AND LAHARS

Pavlof Volcano, a conical stratovolcano composed of basaltic andesite lava flows and pyroclastic rocks, is located on the Alaska Peninsula about 60 km northeast of the City of Cold Bay, Alaska, and 950 km southwest of Anchorage (figs. 1, 13). Eruptions at Pavlof Volcano normally range in style from Hawaiian fountaining to Strombolian bursts, although more violent ultrastrombolian to subplinian explosive behavior has been documented (Waythomas and others, 2006). Pavlof Volcano, having at least 38 eruptions since 1790, is considered one of the most active volcanoes in North America (Miller and others, 1998). The volcano is dominantly an open vent system, and many of its eruptions have little precursory seismicity or ground deformation visible in InSAR (Lu and Dzurisin, 2014; Pesicek and others, 2018). The last significant eruption at Pavlof Volcano occurred in March 2016 and was characterized by continuous seismic tremor, infrasound detections, and an ash cloud that rose to a maximum altitude of about 30,000 ft (~9,100 m) ASL and generated lightning (Fee and others, 2017; Cameron and others, 2020).

2022 Overview

A prolonged eruption began at Pavlof Volcano on August 5, 2021, and continued into 2022, with the volcano starting the year at Aviation Color Code **ORANGE** and Volcano Alert Level **WATCH**. Pavlof Volcano continued erupting throughout 2022, with the focus of activity at vents on the upper southeast flank of the edifice. No previous historical eruptions were known to have occurred in this area, although two documented eruptions occurred from vents nearby on the south flank, in 1986 and 2007. No significant unrest was detected after December 2, 2022, and by the end of the month the level of seismic activity had returned nearly to background levels. The Aviation Color Code and Volcano Alert Level were lowered to **YELLOW** and **ADVISORY** on December 17.

The 2021–2022 Pavlof Volcano eruption lasted 484 days, making it the longest duration historical eruptive period. The development of vents on the upper southeast flank and the long duration of the eruption were unexpected. The previous eruption in 2016 produced a 130×160-m-diameter crater on the north side of the summit. No significant eruptive activity occurred from the 2016 crater during the 2021–2022 eruption, indicating that this part of the magmatic conduit system was blocked, probably by solidified lava from the 2016 eruption.

January 2022 Observations

Lava effusion at Pavlof Volcano during January took place from several small vents on the upper southeast flank of the volcano about 300 m southeast of the volcano's summit

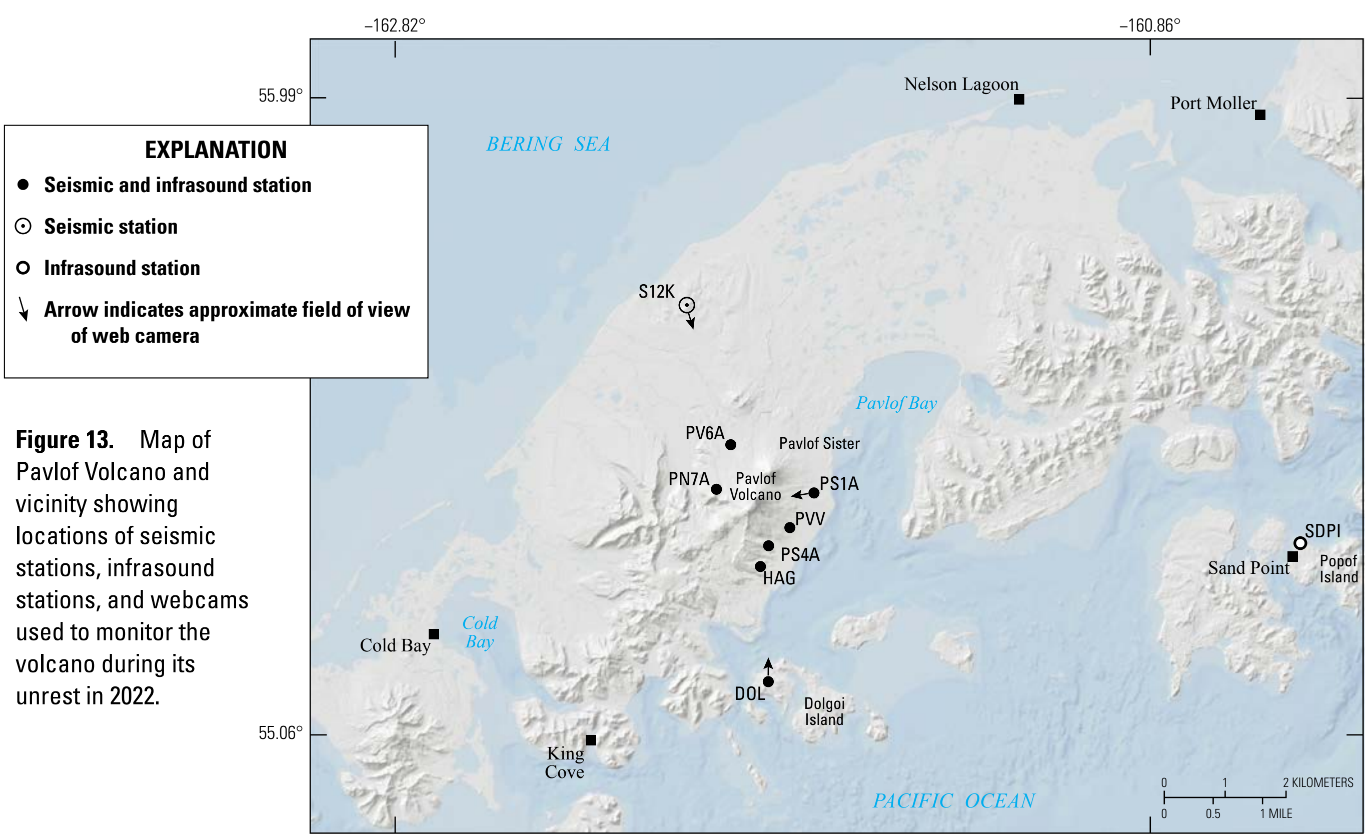


Figure 13. Map of Pavlof Volcano and vicinity showing locations of seismic stations, infrasound stations, and webcams used to monitor the volcano during its unrest in 2022.

Base map from Esri and its licensors, copyright 2022 (fig. 14). The narrow, linear lava flows produced elevated surface temperatures that were apparent in satellite imagery, including Advanced Very High Resolution Radiometer mid-infrared (MIR) images, Visible Infrared Imaging Suite (VIIRS) MIR images, and WorldView short-wave infrared (SWIR) images (fig. 15). Small explosions and volcanic and infrasonic tremor were detected in seismic and infrasound data throughout most of January 2022. Although none of the January explosions were particularly large, they did produce small tephra cones and ballistic ejecta as far as about 200 m from the rim of the 2021–2022 eruption crater.

Spatter-fed lava flows extended 1–2 km down the volcano's southeast flank (figs. 14–17) and interacted with snow and ice to produce water-rich lahars (figs. 16, 17).

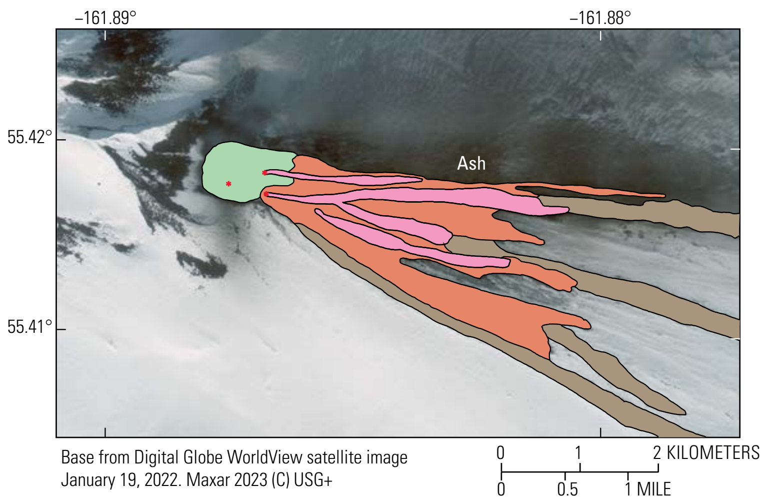


Figure 14. Annotated satellite image showing eruptive deposits and lava flows in the active vent area on the upper southeast flank of Pavlof Volcano, January 19, 2022.

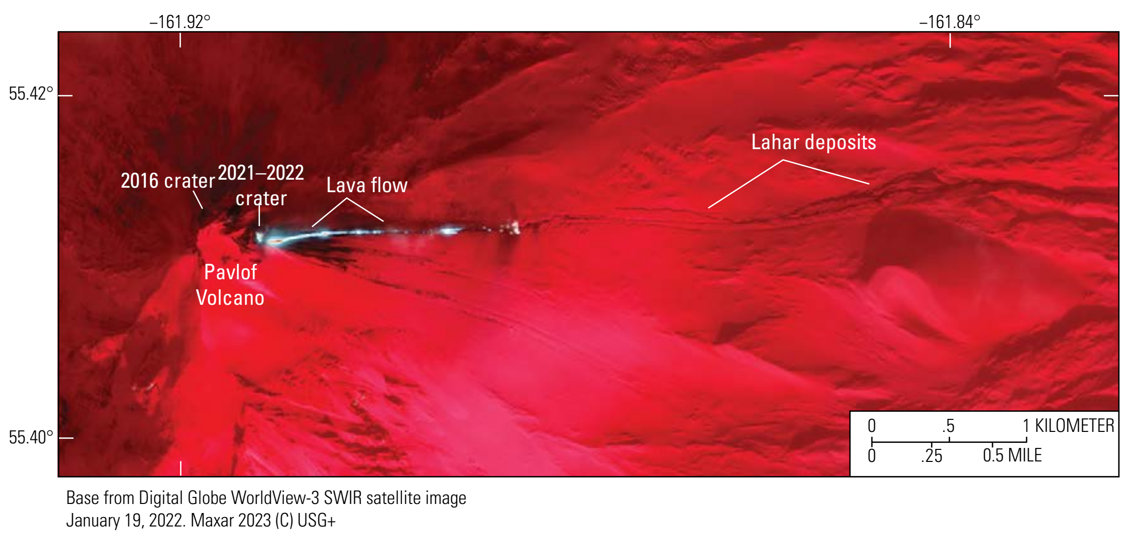


Figure 15. Annotated short-wave infrared image of features and deposits on Pavlof Volcano observed on January 19, 2022.

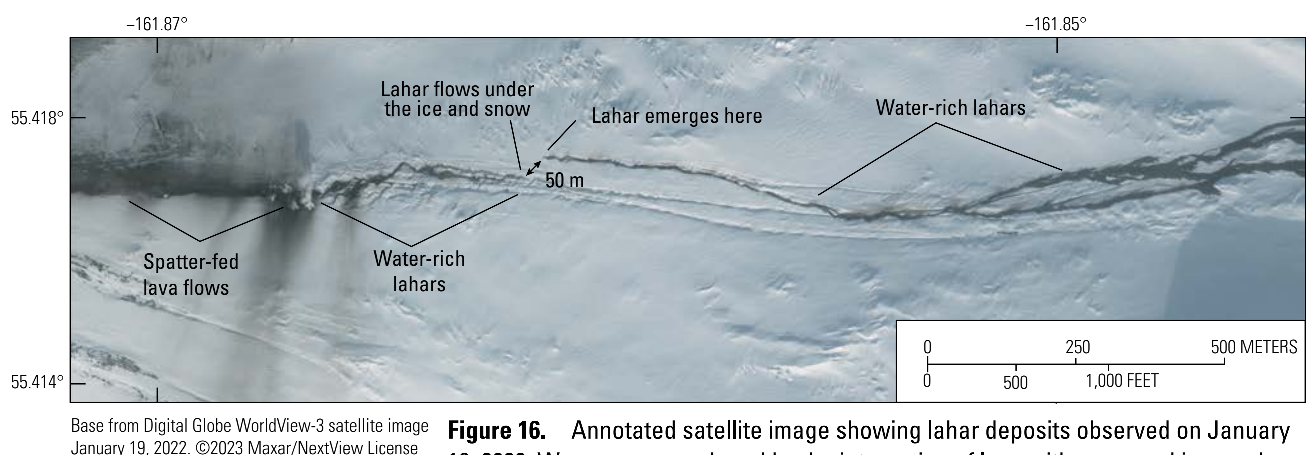


Figure 16. Annotated satellite image showing lahar deposits observed on January 19, 2022. Warm water produced by the interaction of lava with snow and ice produced an unusual en- or subglacial drainage pattern as the flows traversed the lower flanks of Pavlof Volcano.

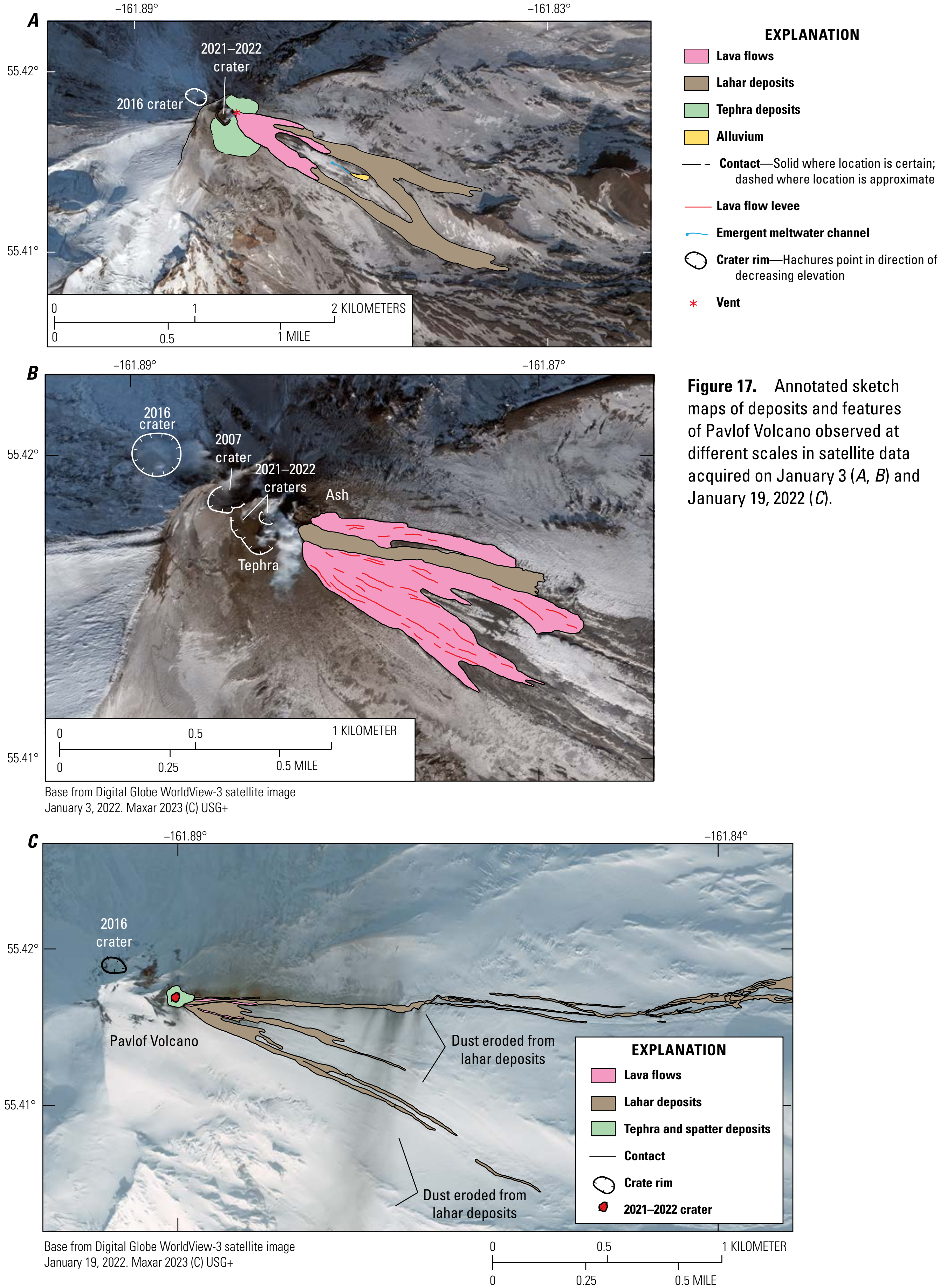


Figure 17. Annotated sketch maps of deposits and features of Pavlof Volcano observed at different scales in satellite data acquired on January 3 (*A*, *B*) and January 19, 2022 (*C*).

The lahars were influenced by the porous nature of the snow and ice and, in a few instances, disappeared and presumably flowed en- or subglacially before re-emerging downslope to flow again on the surface (figs. 16, 17*C*).

February 2022 Observations

Lava effusion from at least one vent continued into February 2022 and fed lava flows 0.5–1 km in length that covered about 2,000 m^2 on the upper southeast flank of the volcano (fig. 18). The lava effusion was generally coincident with periods of sustained volcanic tremor (fig. 19). As in January 2022, the lava flows produced distinct thermal signals that were apparent in satellite imagery.

An unusual, apparently water rich deposit on the upper north flank of the volcano was observed in a February 28, 2022, satellite image (fig. 18*C*). These deposits were possibly expelled from the 2016 crater, or they may record mass flows initiated by seismic shaking of the volcano during eruptive activity in late February 2022. Infrasound detections with sources located in the vicinity of the 2016 crater indicate that material may have been ejected somewhat forcibly from the crater. There were no observations of ash emissions in late February 2022 nor was there any other unusual activity at the 2016 crater throughout the remainder of the 2021–2022 eruption.

March 2022 Observations

A Sentinel-2 SWIR image from March 4, 2022, showed hot eruptive products at and around a single active vent on the upper southeast flank of the volcano (fig. 20). A tephra cone with a 40×30 m summit crater and a new ~1-km-long lava flow on the upper southeast flank were recognized in high-resolution satellite data from March 5 (fig. 21).

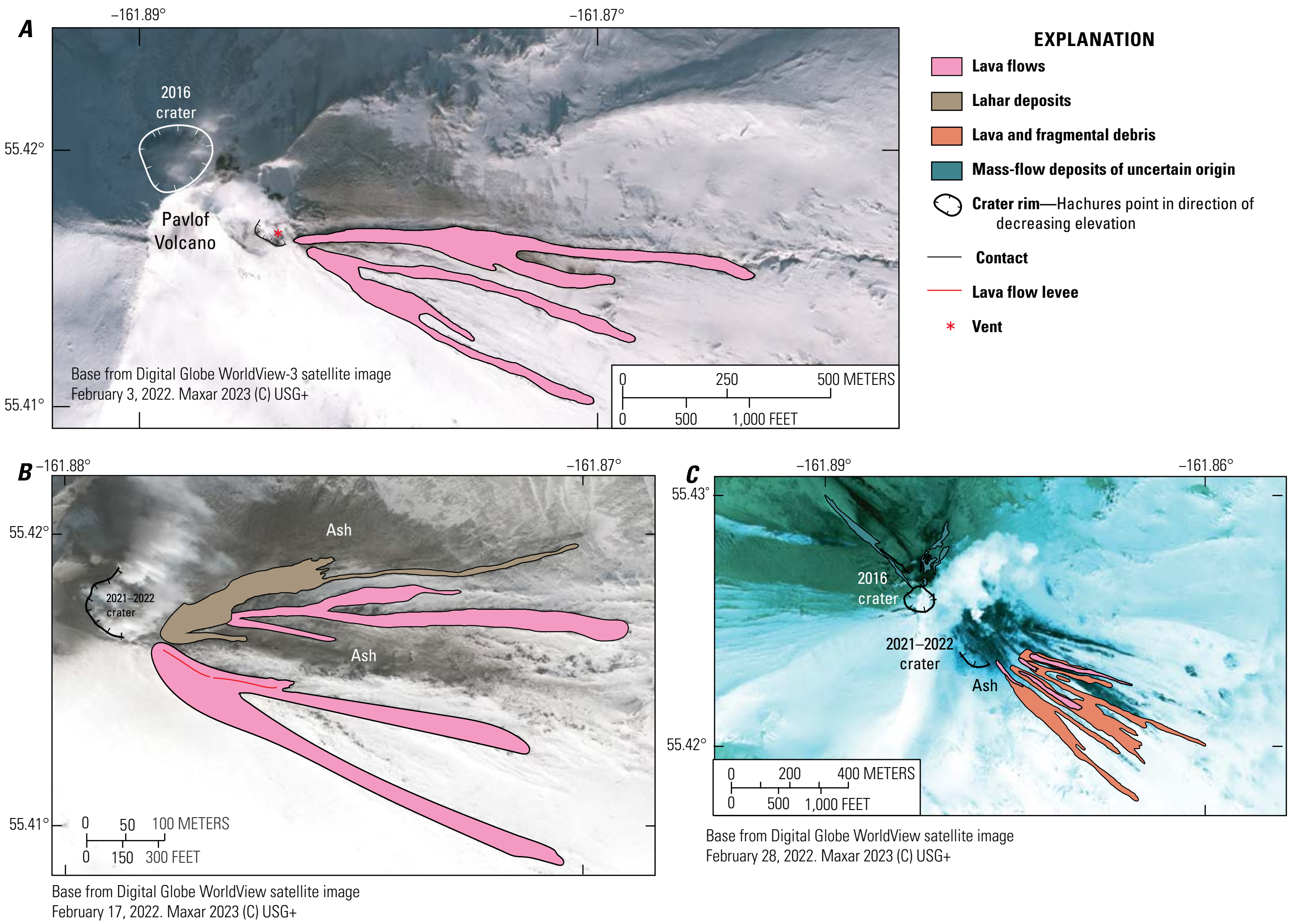


Figure 18. Annotated sketch maps of deposits and features of Pavlof Volcano observed at different scales in satellite data acquired on February 3 (*A*), 17 (*B*), and 28 (*C*), 2022.

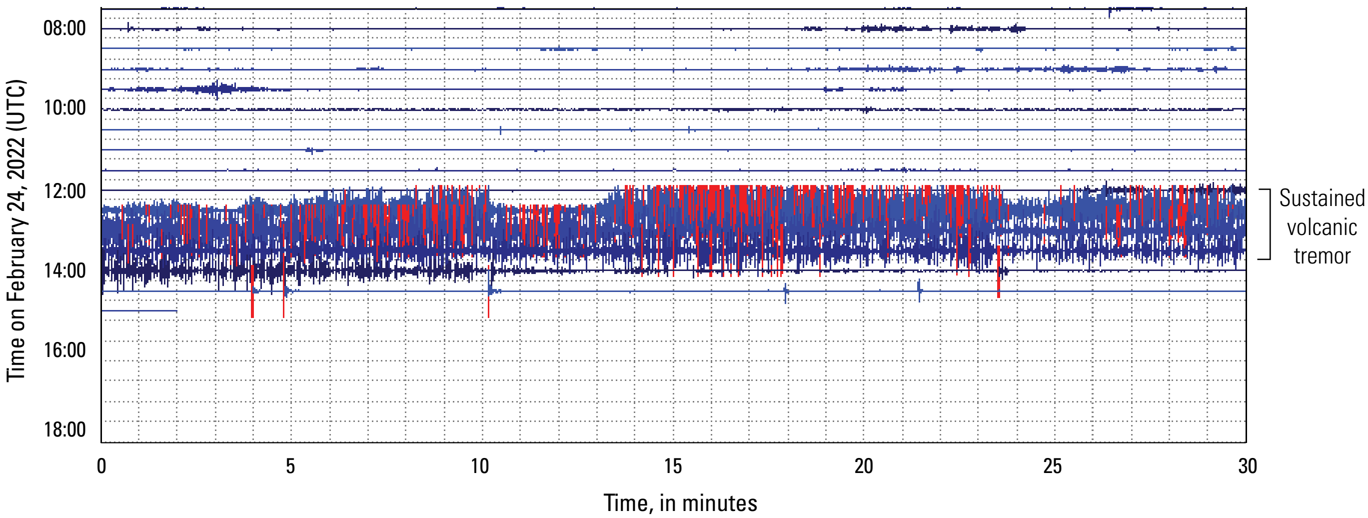


Figure 19. Graph showing sustained volcanic tremor in helicorder record from station PVV (fig. 13) on February 24, 2022. The repeating pattern of line colors for the seismic trace, using shades of blue, is for visual acuity purposes to help distinguish each hour-long trace from the next. The seismic trace is red where the seismic amplitude is electronically clipped at the scale used in this figure.

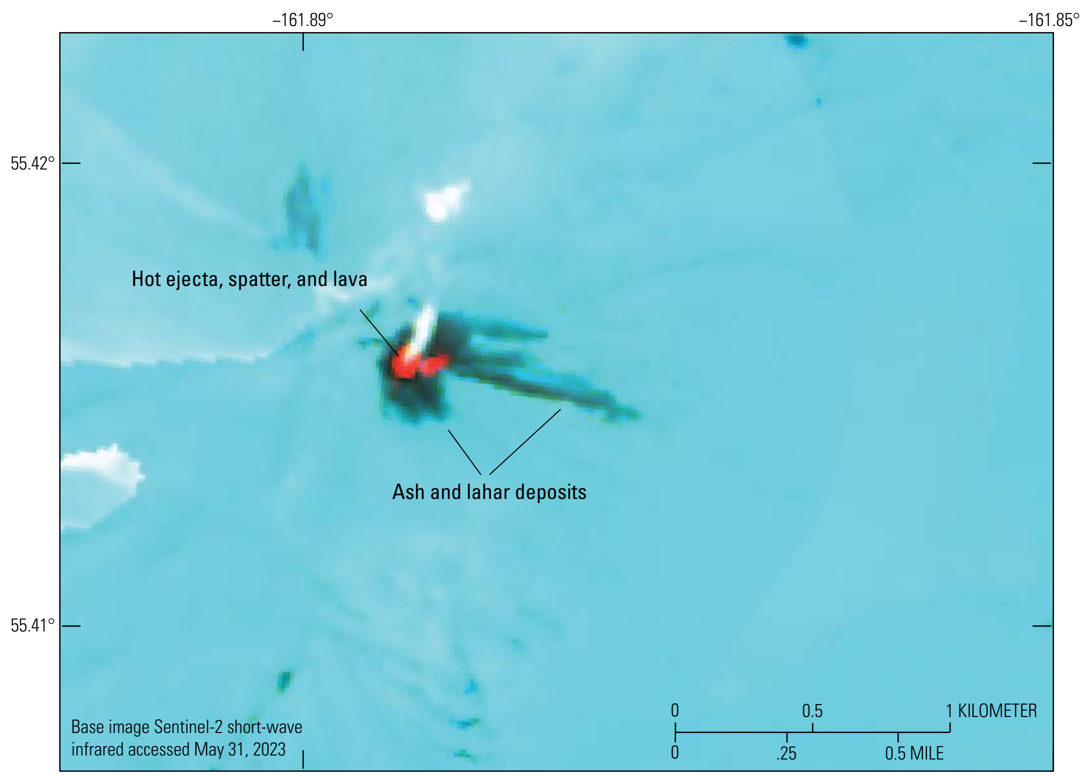


Figure 20. Annotated short-wave infrared satellite image showing area of hot ejecta, ash, and lahar deposits on the upper southeast flank of Pavlof Volcano. Satellite image from March 4, 2022.

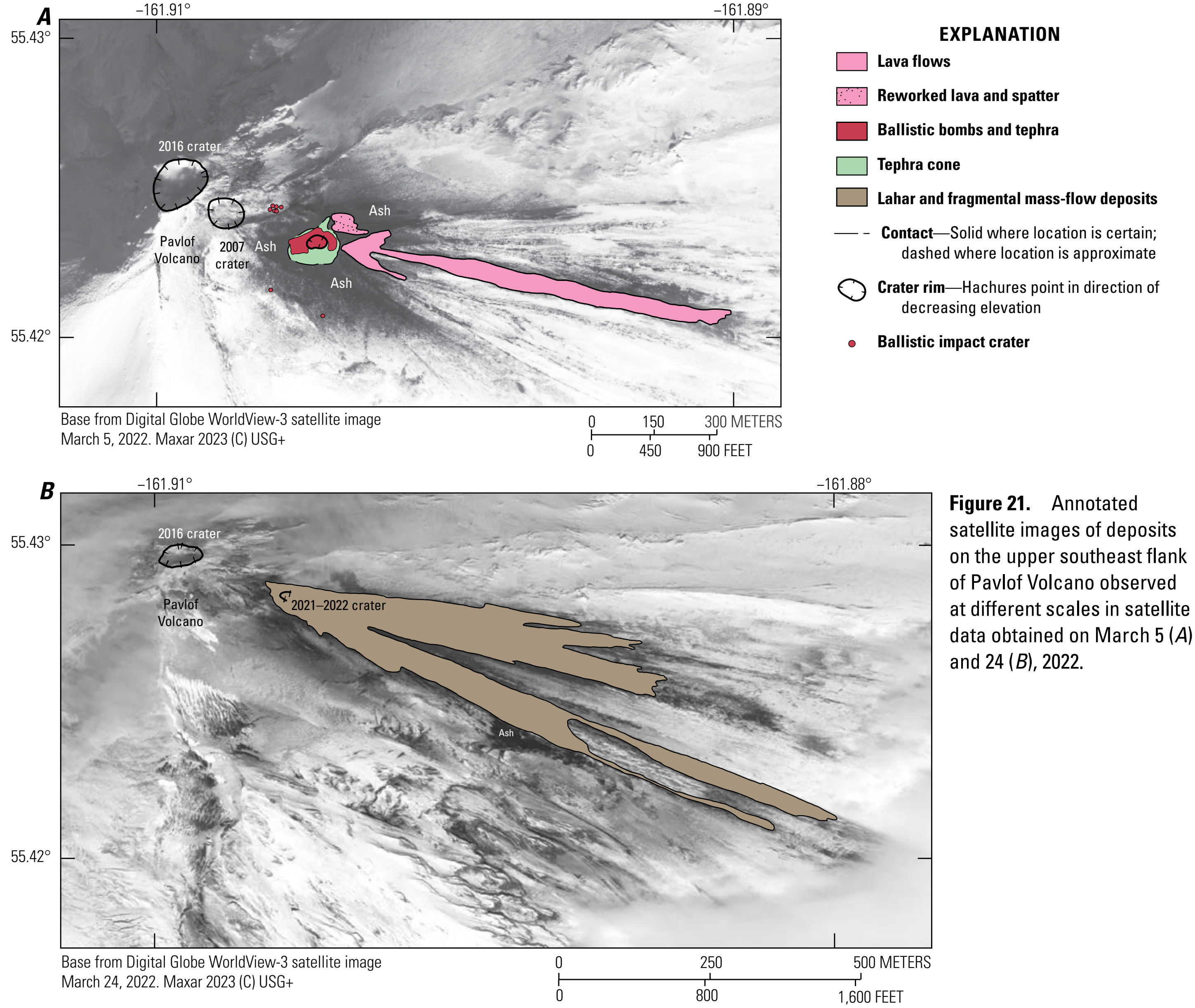


Figure 21. Annotated satellite images of deposits on the upper southeast flank of Pavlof Volcano observed at different scales in satellite data obtained on March 5 (*A*) and 24 (*B*), 2022.

A satellite image from March 7 also showed elevated surface temperatures near the upper east flank vent, likely associated with continued accumulation of lava spatter. The March 7 image also showed ash deposits around the vent, and a dark, snow-free mass-flow deposit extending southeast about 750 m downslope from the vent area.

Moderate seismic tremor was detected throughout March 2022 and was often accompanied by explosions that were detected by local infrasound sensors. The explosions produced ballistic ejecta and small amounts of tephra fall around the vent (fig. 21*A*). Lahar and fragmental mass-flow deposits were evident in satellite data from March 24, 2022 (fig. 21*B*). Elevated surface temperatures were observed intermittently in VIIRS MIR data when Pavlof Volcano was cloud free, which indicated that frequent lava fountaining or spattering occurred throughout March.

Sulfur dioxide (SO_2) was detected in tropospheric monitoring instrument (TROPOMI) satellite data on March 12 (two detections), 24, and 25. The amount of SO_2 was estimated at 0.03–0.06 kilotons (kt) on March 12, but these estimates have low confidence because they are just above the detection threshold. The SO_2 emission rate for the larger value is about 200 tons per day (t/d). The SO_2 mass detected on March 24, and about 30 minutes later on March 25, was about 0.014 kt, and the associated emission rate was 100–300 t/d.

April 2022 Observations

Eruptive activity continued with little change during April 2022. Elevated surface temperatures associated with lava effusion were observed in satellite data when views were cloud free. Lava flows erupted in April were small and observed only intermittently (fig. 22). On April 6, a lava flow about 400 m in length, extending southeast from the vent, was observed in satellite data (fig. 22*B*). This flow increased in length to about 1.2 km by April 8 (fig. 22*C*). By the end of April 2022, ash and fragmental debris formed a fan-shaped accumulation (fig. 23*D*) that obscured many of the lava flows on the upper southeast flank of the volcano.

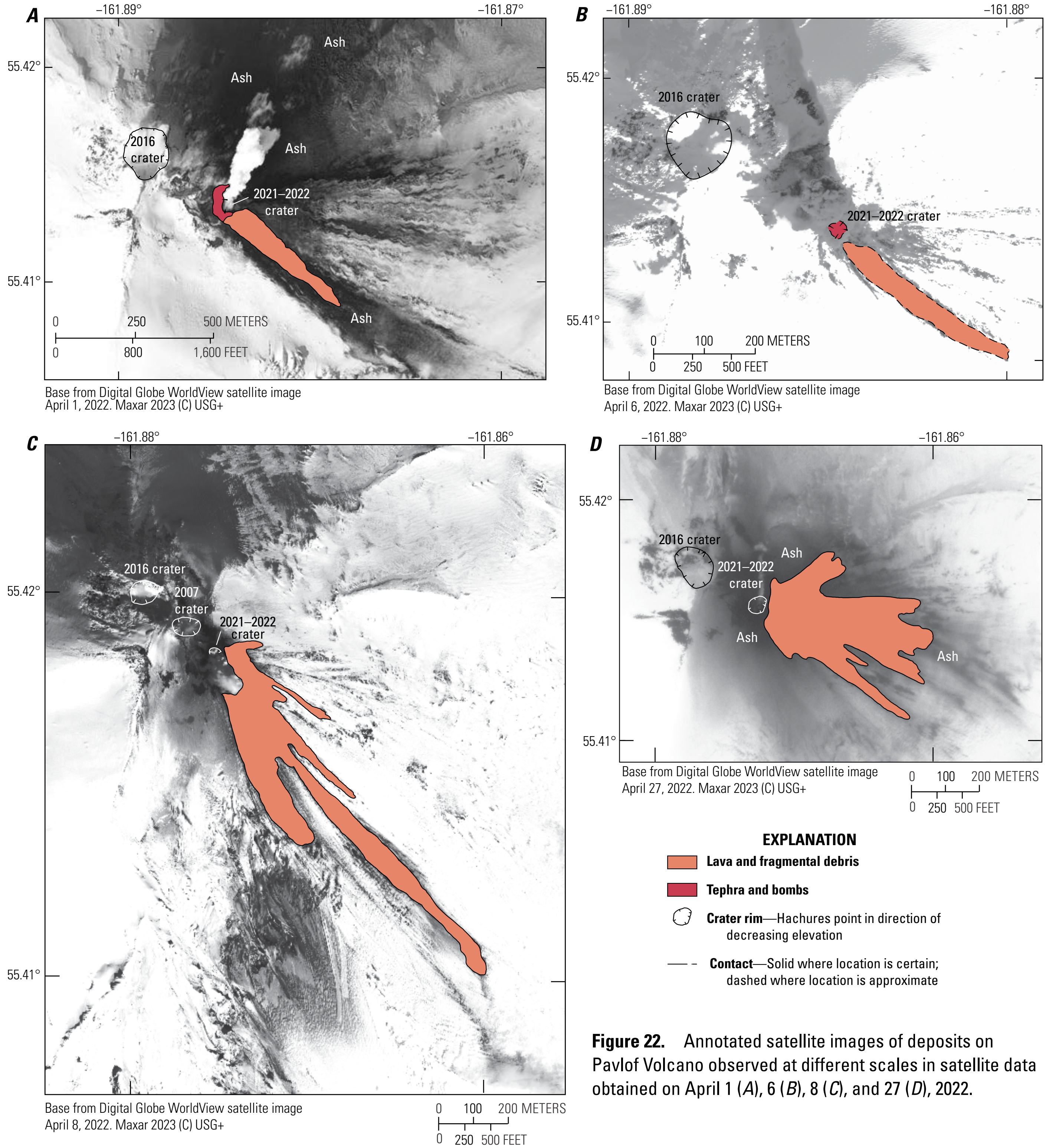


Figure 22. Annotated satellite images of deposits on Pavlof Volcano observed at different scales in satellite data obtained on April 1 (*A*), 6 (*B*), 8 (*C*), and 27 (*D*), 2022.

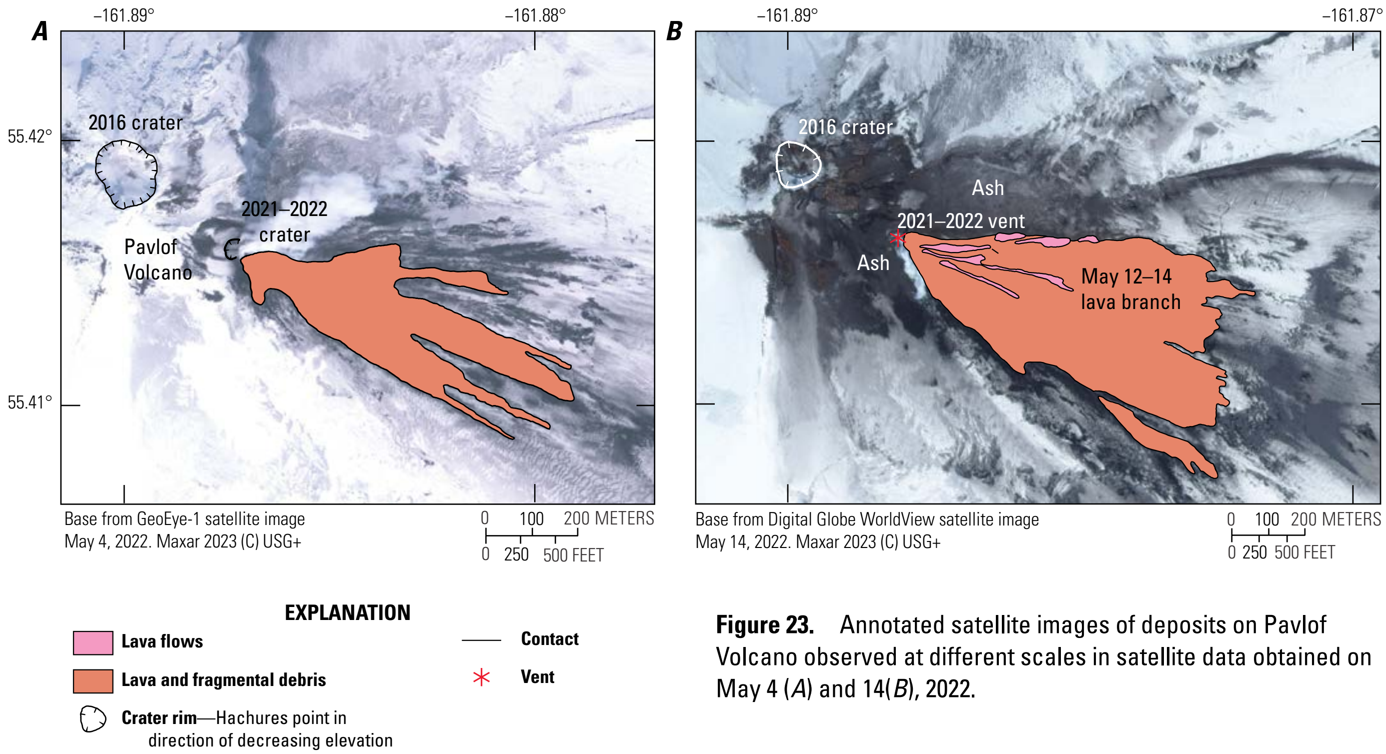


Figure 23. Annotated satellite images of deposits on Pavlof Volcano observed at different scales in satellite data obtained on May 4 (*A*) and 14(*B*), 2022.

Minor ash emissions were observed in webcam images during the month, and trace amounts of ash fall occurred on the upper part of the edifice within about 500 m of the vent. Seismic tremor, consistent with continued low-level activity, was present throughout the month and was interrupted by small explosions detected on April 20, 21, and 23. SO_2 emissions were detected in TROPOMI satellite data on April 30. The SO_2 mass was about 0.018 kt and the emission rate was roughly 100 t/d.

May 2022 Observations

The 500-m-long lava flow observed at the end of April remained active into early May 2022, although it was mantled with fragmental debris (fig. 23*A*). The flow and associated fragmental deposits formed a triangular-shaped debris fan on the upper southeast flank of Pavlof Volcano (fig. 23*A*). Unfortunately, the May 4, 2022, satellite image was obtained at a shallow view angle (about 23 degrees off nadir) and this resulted in significant image distortion, making the image problematic as a mapping base. On May 12–14, a new lava branch, about 400 m long, developed northeast of the main lava-flow complex (fig. 23*B*). All the flows had lengthened slightly by the end of the month, and the longest branch reached about 300 m in length. Eruptive activity at Pavlof Volcano throughout the month of May was also characterized by periods of intermittent seismic tremor and elevated surface temperatures, which is consistent with the observed minor effusion of lava. No significant explosions or ash emissions occurred.

June 2022 Observations

The periods of seismic tremor and elevated surface temperatures consistent with lava effusion continued during June. A June 11 SWIR image showed a new flow extending south about 300 m from a small vent on the upper southeast flank of Pavlof Volcano (fig. 24*A*). The June 11 WorldView-3 satellite image also indicated multiple sources of lava (fig. 24*B*). SO_2 emissions of about 0.01 kt were detected on June 12. By the end of the month, another lava branch had developed to the east-southeast of the active vent. The flow was about 380 m long on June 27.

July 2022 Observations

Unrest characterized by periods of seismic tremor and elevated surface temperatures continued into July 2022. By July 26, a small tephra cone with a small summit crater developed over the active vent (fig. 25). The cone was the result of episodic explosive activity and ejection of ballistic particles and tephra that occurred intermittently throughout the month. Although minor ash emissions were reported by passing pilots, no substantial amount of ash emissions was observed in webcam or satellite data in July.

SO_2 emissions were detected by satellite on July 8, 26, and 27. On July 8, about 0.01 kt of SO_2 was detected in TROPOMI data, which corresponded to an emission rate of around 100 t/d. Similar amounts of SO_2 were detected on July 26 and 27 (0.02 kt on July 26, and 0.01 kt on July 27). The estimated emission rate on July 26 was also about 100 t/d.

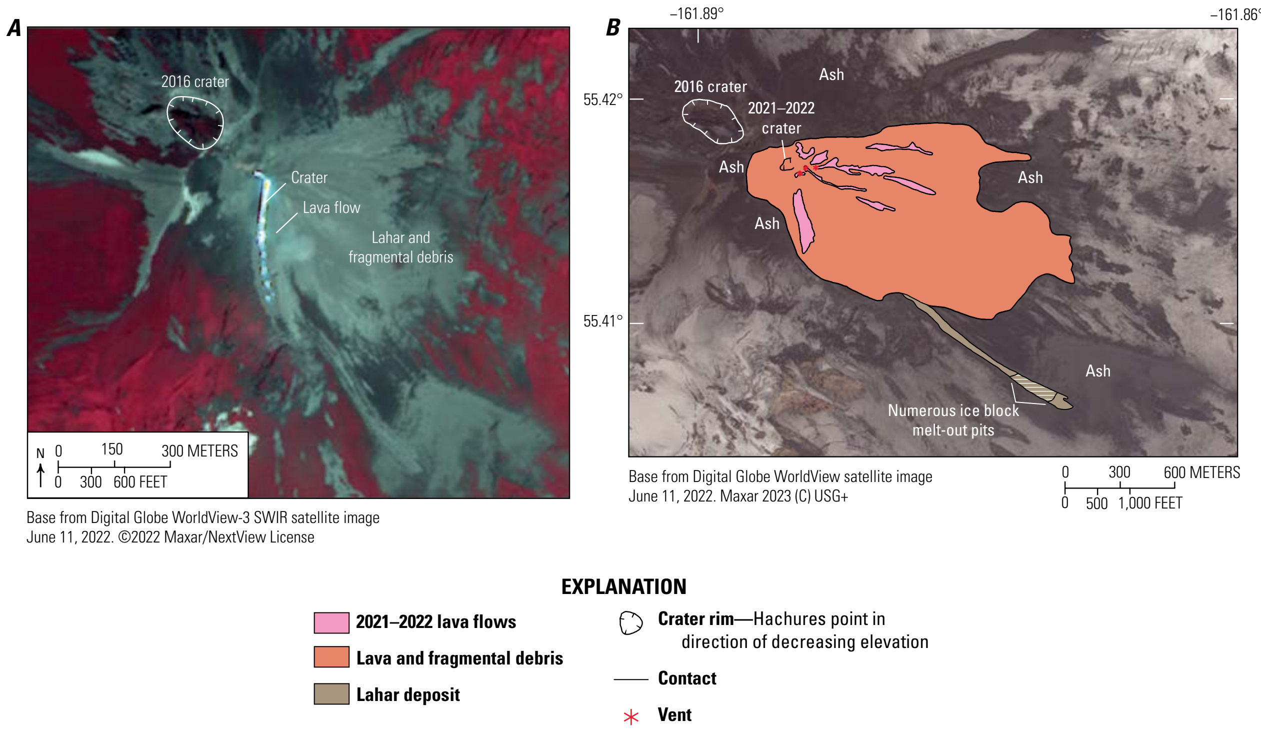


Figure 24. Annotated satellite images showing a lava flow extending south (*A*) and apparent deposits (*B*) on the upper southeast flank of Pavlof Volcano, June 11, 2022.

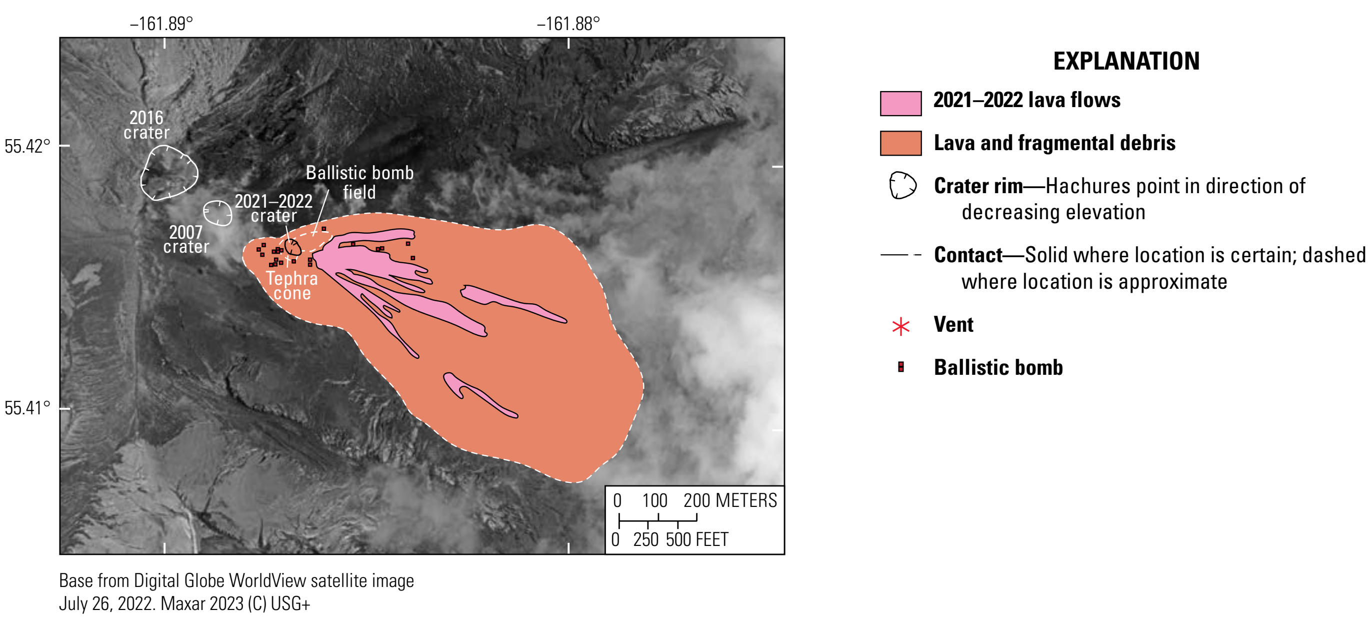


Figure 25. Annotated satellite image of deposits in the active vent area of Pavlof Volcano obtained on July 26, 2022.

August 2022 Observations

Small explosions, minor ash emissions, and limited eruption of lava characterized eruptive activity in August 2022 (fig. 26). Explosions associated with ash emissions up to ~12,000 ft (~3,700 m) ASL occurred intermittently throughout the month (fig. 26*B*). These explosions were short lived, and the ash dissipated quickly near the summit. Periods of sustained tremor punctuated by explosion signals characterized the seismicity.

In late August, incandescence at the active vent was observed in webcam images from a new camera installed on the lower southeast flank of the volcano (station PS1A, fig. 13). The incandescence was associated with low-level lava fountaining or spattering within the main 2021–2022 crater. The lava and spatter in the crater produced a minor thermal feature evident in satellite data when clear conditions prevailed. SO_2 emissions were detected in TROPOMI satellite data on August 24, corresponding to a poorly constrained emission rate of less than 100 t/d.

September 2022 Observations

Detection of elevated surface temperatures and low-level seismic tremor continued into September 2022, which indicated that minor eruptive activity was ongoing. Satellite data from September 5 indicated that additional lava was extruded and had produced a lava flow about 200 m long. Webcam images occasionally captured minor ash emissions and nighttime incandescence.

Minor ash and lahar deposits were observed on the southeast flank of the volcano in webcam images from September 11 to 13. The lahar deposits extended about 900 m from the vent, and the ash deposits formed a trace accumulation on snow around the vent. The active lava flow observed on September 5 was also evident in satellite images obtained on September 16 (fig. 27), and by then the flow was about 300 m in length.

Low-level eruptive activity continued for the remainder of the month as indicated by seismic tremor and slightly elevated surface temperatures observed in satellite data. However, the volcano was frequently obscured by clouds, and nothing else noteworthy was observed in satellite or webcam views.

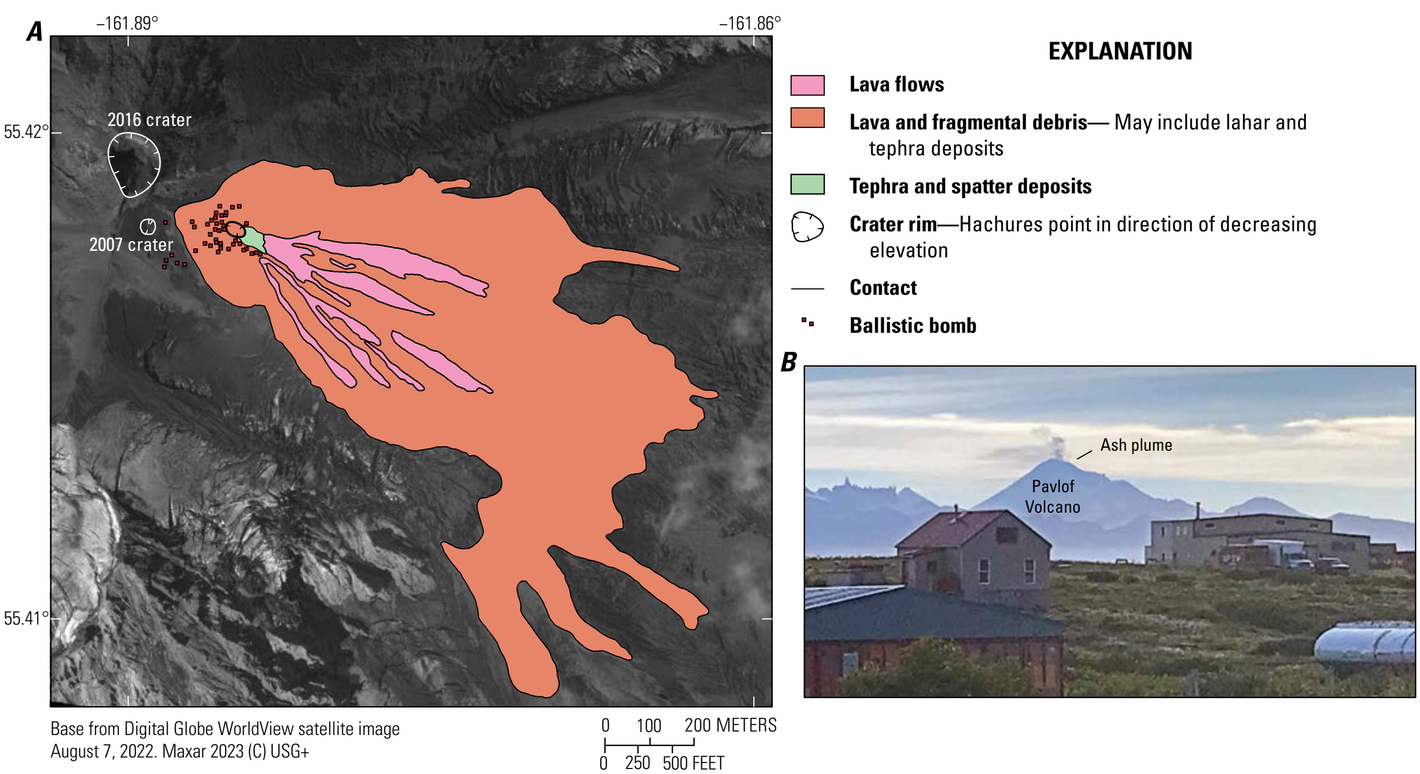


Figure 26. Annotated satellite image showing deposits on Pavlof Volcano observed in satellite data obtained on August 7, 2022, (*A*) and photograph (*B*) of ash emission at Pavlof Volcano, August 18, 2022, as observed from Cold Bay. Photograph by M. Haney, U.S. Geological Survey-Alaska Volcano Observatory.

October 2022 Observations

A satellite image obtained on October 1, 2022, showed a lava flow several hundred meters long that was likely erupted sometime after September 16 (fig. 28). Clouds obscured the volcano for much of the next two weeks of October. Nevertheless, low-level seismic tremor and occasional thermal signals were detected, which included several small explosions during October 7–13 that were likely responsible for the minor ash emissions and incandescent ejecta observed in occasional clear nighttime webcam images.

By the end of October, the rate and magnitude of explosions detected in seismic and infrasound data increased to several detections per day. This activity produced only minor amounts of ash and localized ejecta that accumulated around the active vent (fig. 29).

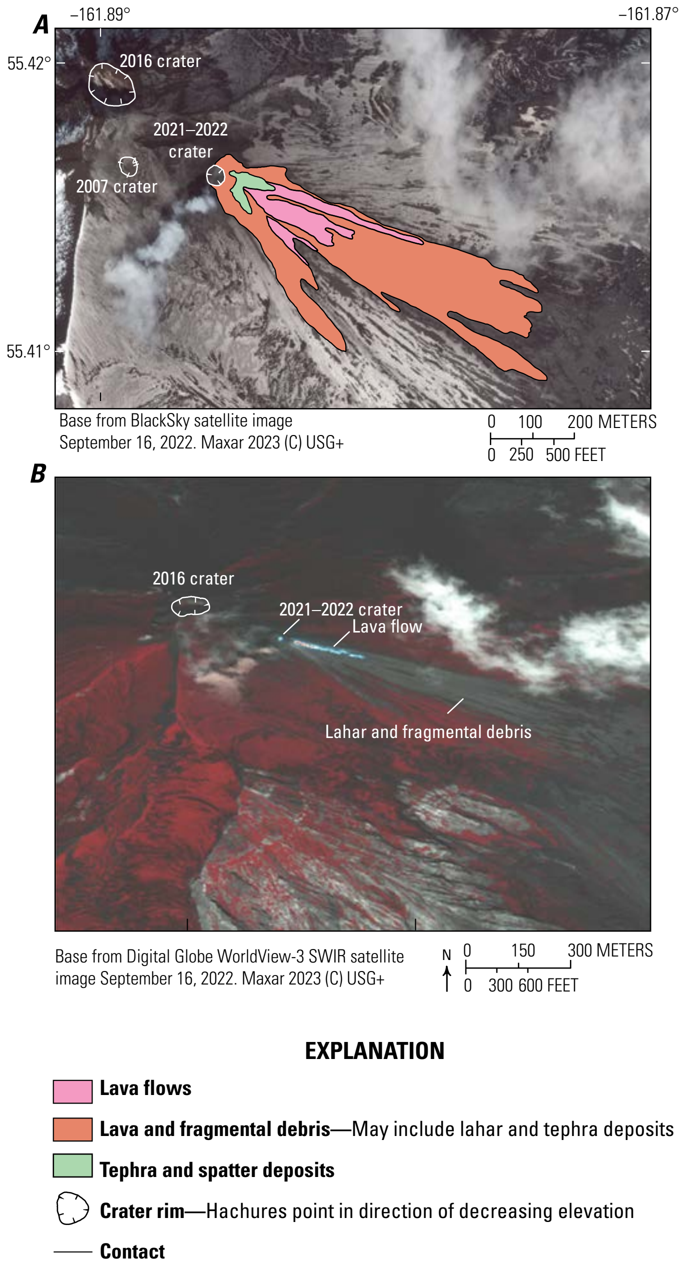


Figure 27. Annotated satellite image (*A*) and short-wave infrared satellite image (*B*) of deposits observed on Pavlof Volcano obtained on September 16, 2022.

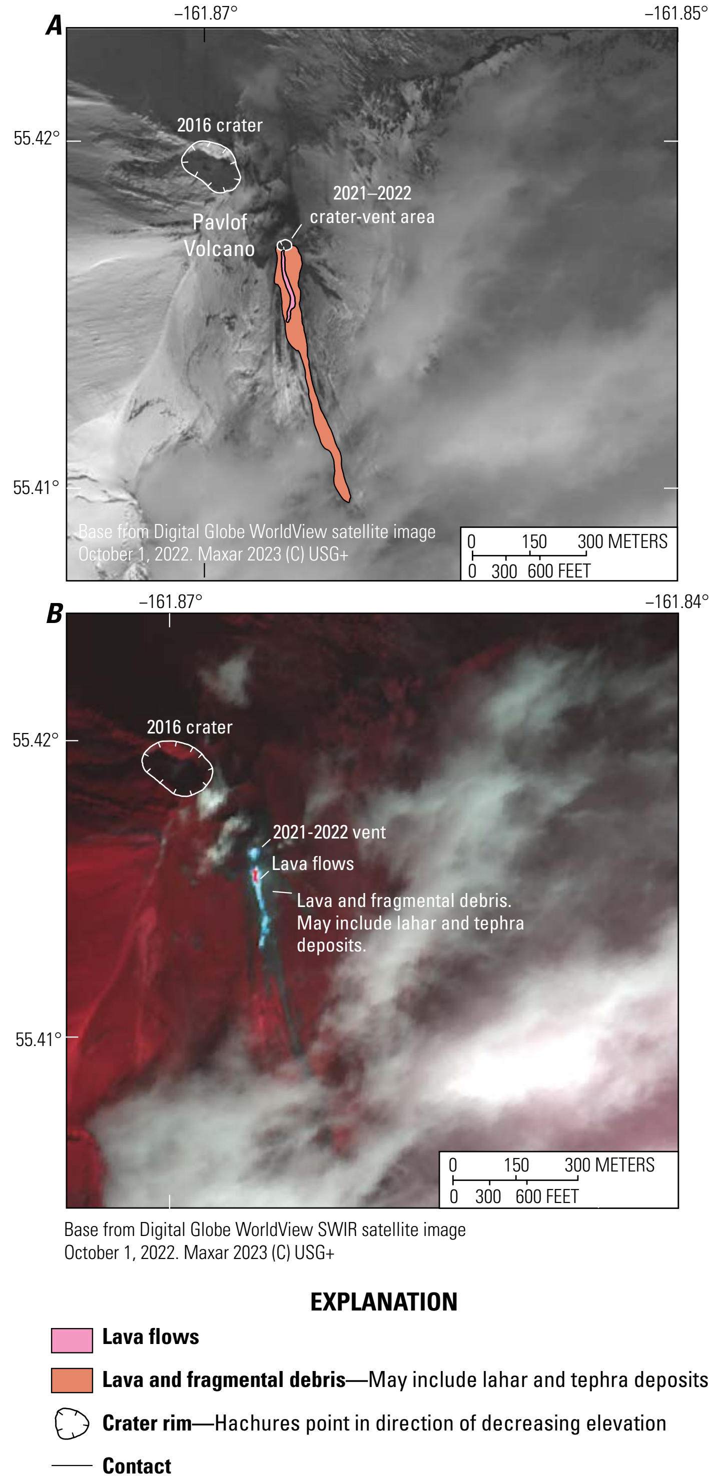


Figure 28. Annotated satellite image (*A*) and short-wave infrared satellite image (*B*) of deposits observed on Pavlof Volcano on October 1, 2022.

Figure 29. Image of southeast flank of Pavlof Volcano from webcam at station PS1A, October 21, 2022. Diffuse ash cloud is seen drifting northeast over Pavlof Sister.

November 2022 Observations

Explosions were detected in seismic and infrasound data almost daily during November 2022. These explosions were likely responsible for the trace amounts of ashfall and ballistic ejecta that were deposited in a small area northeast of the main crater (fig. 30). Satellite observations from November 12 indicated a new lava flow and associated lahar deposits. The lava flow extended about 400 m from a small vent about 200 m south of the crater (fig. 30). Mass-flow deposits, consisting mostly of snow and minor amounts of rock debris extended beyond the lahar deposits and reached about 2 km beyond the crater (fig. 30*A*). An accumulation of spatter just south of the crater also was apparent in the November 12 satellite image (fig. 30).

Lava fountaining and incandescent spatter were observed in nighttime webcam views on November 14. These observations coincided with sustained seismic and infrasonic tremor.

An abrupt increase in tremor from about 3:22–3:47 on November 29 (18:22–18:47 AKST, November 28)—a span of roughly 25 minutes—alerted us to a vigorous burst of activity (fig. 31). Prior to this increase, the seismicity was characterized by continuous low-level tremor. Although minor spattering may have been occurring, there was no other indication that the volcano was behaving explosively. A subsequent review of webcam images of the south flank of the volcano from just before sunset, from 2:03–3:33 on November 29 (17:03 to 18:33 AKDT, November 28) (fig. 32), indicated a large mass flow, which coincided with the elevated

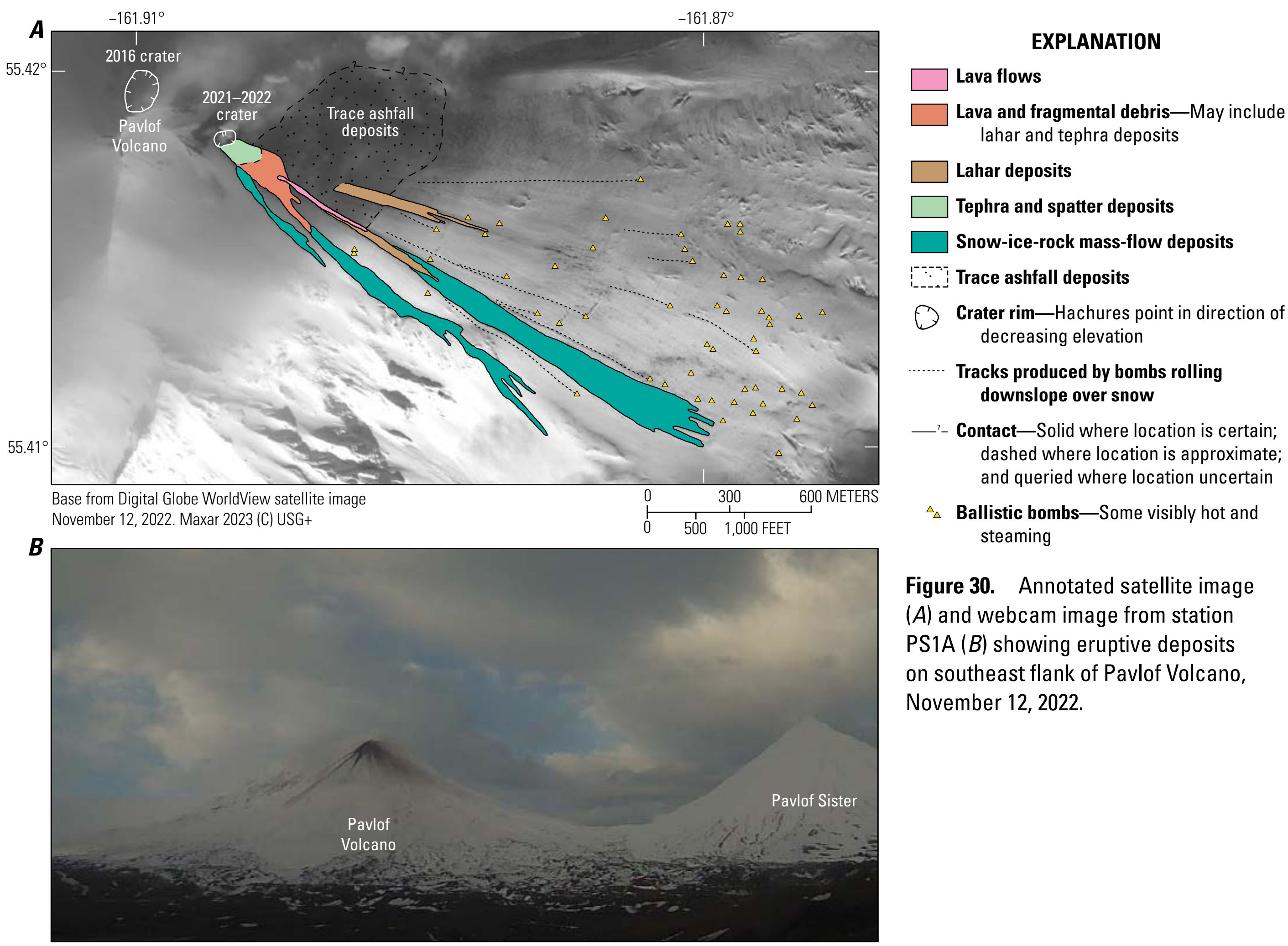


Figure 30. Annotated satellite image (*A*) and webcam image from station PS1A (*B*) showing eruptive deposits on southeast flank of Pavlof Volcano, November 12, 2022.

tremor observed. A Sentinel-2 satellite image and webcam images of the volcano the following day (fig. 33) confirmed that an extensive deposit covered most of the south flank of the volcano. The mass flow initiated a small, secondary ash cloud that rose roughly 15,000–20,000 ft (4,600–6,000 m) ASL and then quickly dissipated.

The mass flow was likely the result of a collapse of accumulated spatter associated with lava fountaining. Such spatter accumulations commonly develop during eruptions of Pavlof Volcano (Waythomas and others, 2017). As the spatter builds up and forms a mound, it may become gravitationally unstable and collapse. When this occurs, hot granular mass flows result. The mass flows are typically hot and capable of eroding and melting snow and ice on the volcano, which leads to the formation of lahars that may travel several kilometers down the flank of the volcano (fig. 33).

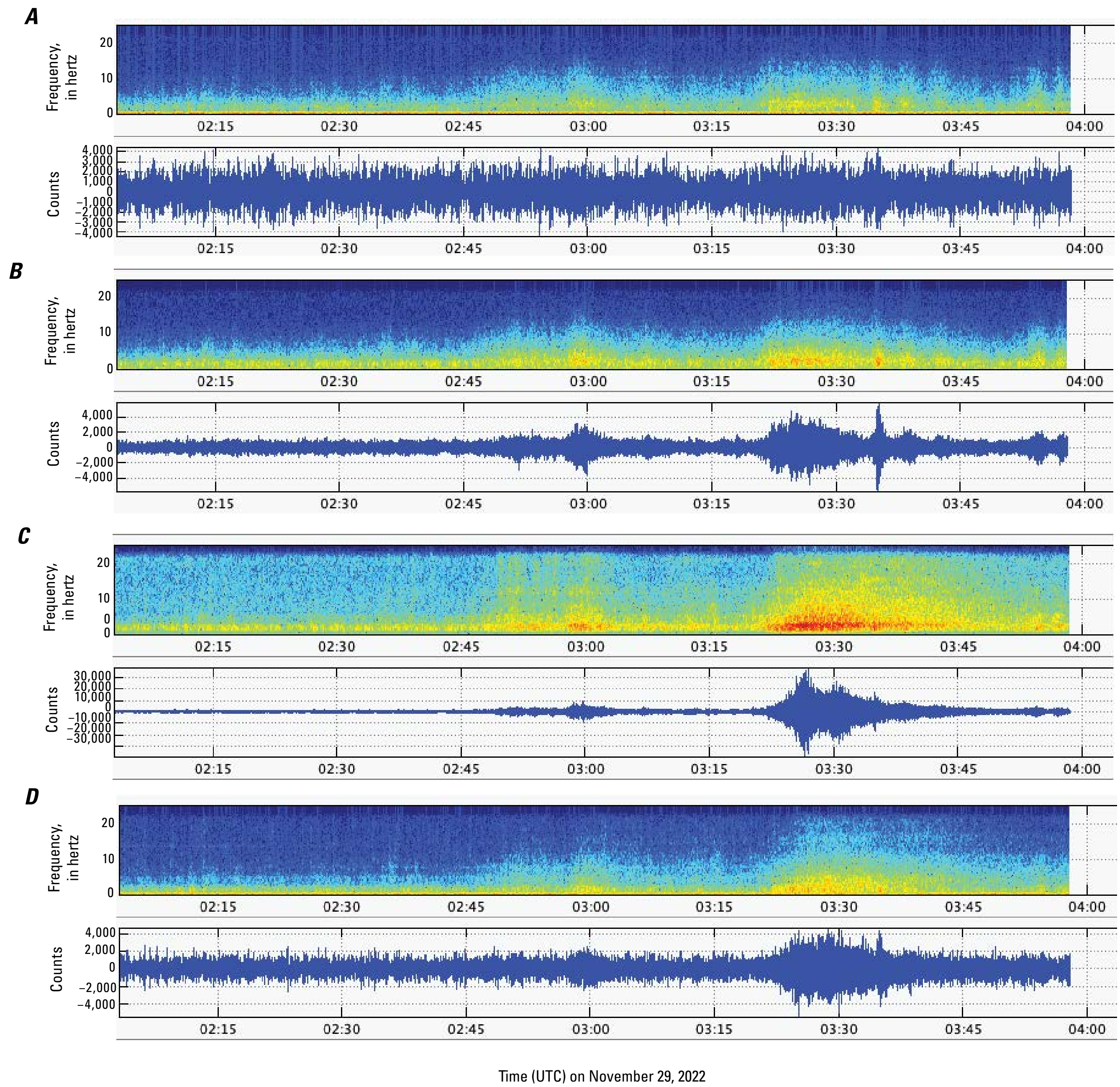


Figure 31. Seismic records from stations PN7A (*A*), PV6A (*B*), PVV (*C*), and PS1A (*D*) of mass-flow event from about 18:22–18:47 AKST on November 28 (November 29 coordinated universal time [UTC]), 2023.

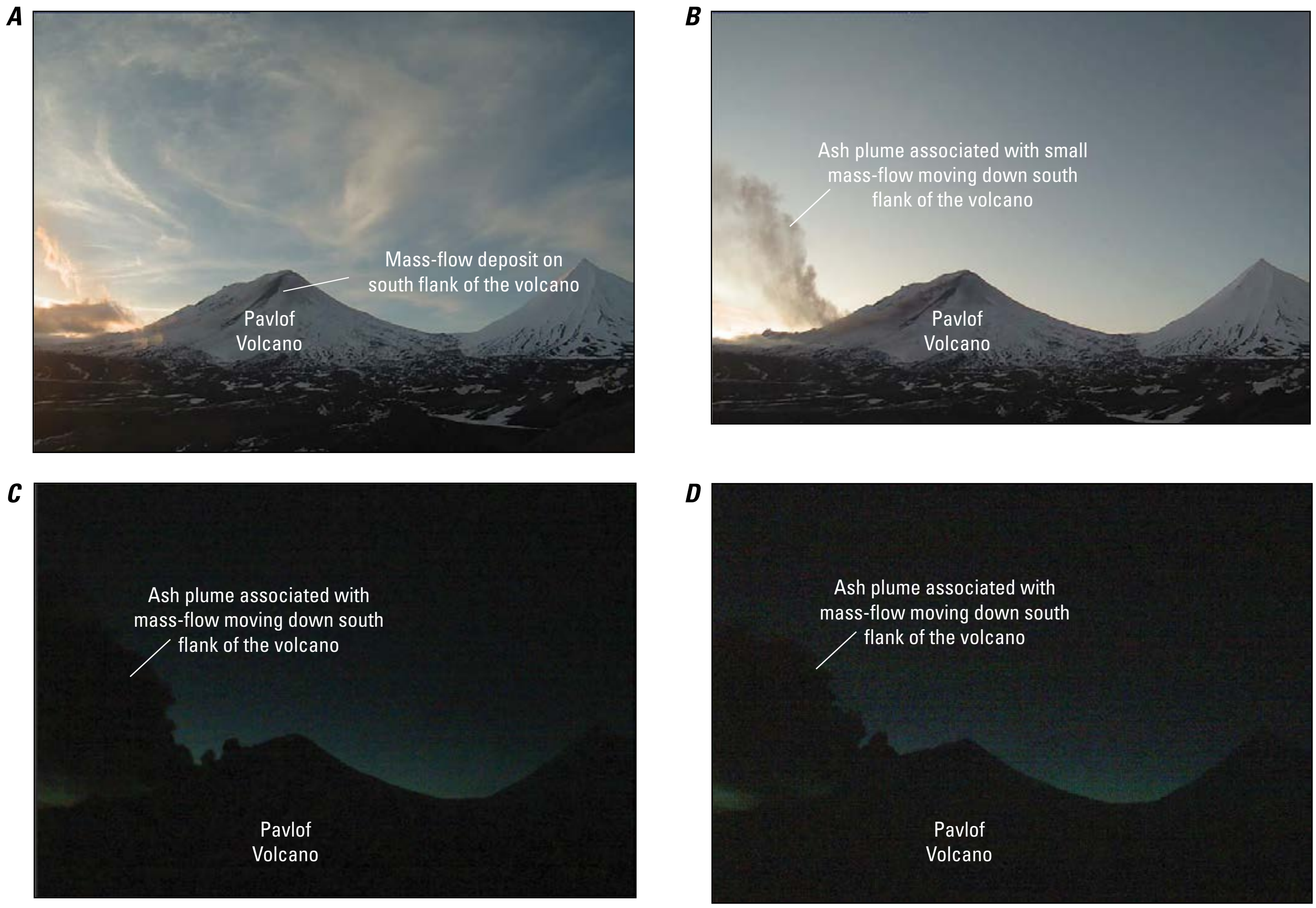


Figure 32. Webcam images of an ash plume derived from a mass flow on the south flank of Pavlof Volcano taken from station PS1A at 17:03 (*A*), 17:33 (*B*), 18:30 (*C*), and 18:33 (*D*) AKDT, November 28.

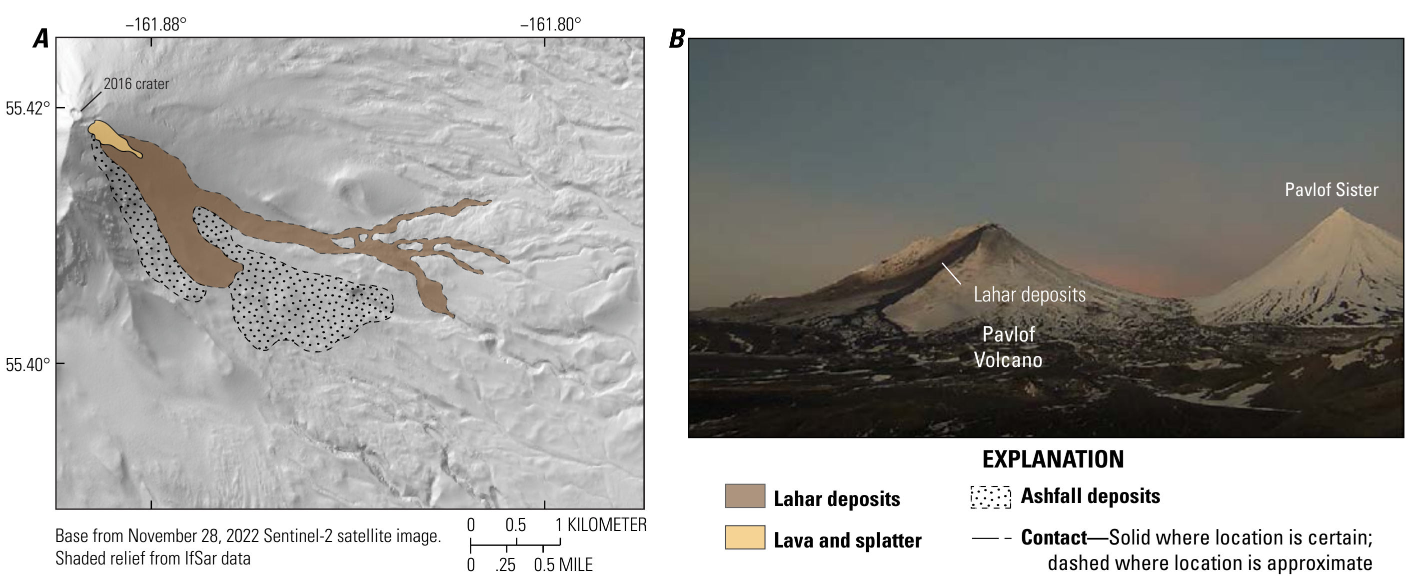


Figure 33. Annotated satellite image from November 28, 2022, (*A*) and webcam image from station PS1A taken November 29, 2022, (*B*) showing eruptive deposits generated on the southeast flank of Pavlof Volcano.

December 2022 Observations

Pavlof Volcano remained relatively active through the first two weeks of December 2022. Nearly continuous tremor and occasional small explosions were detected in seismic data, and elevated surface temperatures were observed in satellite data when views of the volcano were not obscured by clouds. A mass-flow feature consisting of a channel in the snow and ice, about 2 km long, was observed in webcam images from December 8 (fig. 34). The channel was probably formed by a small, hot, mass flow associated with a minor spatter pile collapse. This feature likely formed in early December and may have been coincident with the detection of elevated surface temperatures on December 2.

Intermittent periods of low-level seismic tremor continued through the end of the month, but no explosions were detected after December 7. As a result of declining levels of unrest, AVO lowered the status of Pavlof Volcano to Aviation Color Code **YELLOW** and Volcano Alert Level **ADVISORY** on December 17, and the 2021–2022 eruption was declared to be over.

Elevated surface temperatures and minor steaming from the active vent continued to be observed when satellite and webcam views were clear. A high-resolution satellite image acquired on December 27 showed a small area of strongly elevated temperatures within the recently active vent on the upper eastern flank of the volcano, but no sign of eruptive activity was observed.

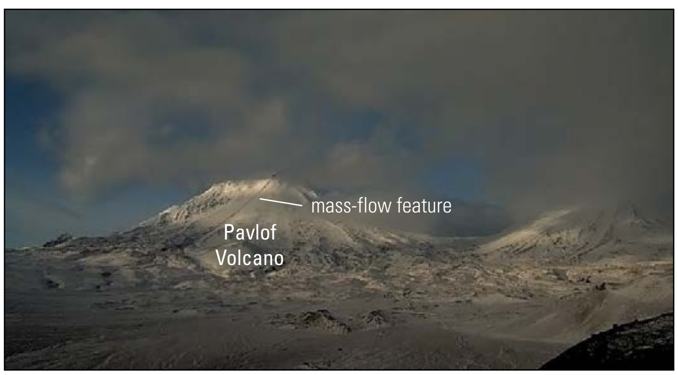


Figure 34. Webcam image of Pavlof Volcano from station PS1A, December 8, 2022, showing mass-flow feature on the south flank of the volcano.

Mount Cleveland

GVP #311240
52.822°, −169.945°
1,745 m
Chuginadak Island, Islands of Four Mountains, Aleutian Islands

ELEVATED SURFACE TEMPERATURES, GAS EMISSIONS

Mount Cleveland forms the west side of the uninhabited Chuginadak Island, which is part of the Islands of the Four Mountains group in the east-central Aleutian Islands (fig. 1). Mount Cleveland is ~75 km west of the community of Nikolski and 1,525 km southwest of Anchorage. Its historical eruptions have been characterized by short-lived ash explosions, lava fountaining, lava flows, and pyroclastic flows. In February 2001, after 6 years of quiescence, Mount Cleveland had three explosive events that sent ash to altitudes as high as ~30,000 ft (~9,100 m) ASL, produced a pyroclastic flow that reached the ocean, and erupted a blocky lava flow (Dean and others, 2004; McGimsey and others, 2005). Intermittent explosive eruptions took place every year from 2001 to 2020 (Iezzi and others, 2020)—the last explosive eruption at Mount Cleveland occurred in June 2020 (Orr and others, 2024a).

Overall, 2022 was a quiet year at Mount Cleveland. Only minor unrest occurred, and no explosions were reported. No signs of activity were reported through the early part of the year (fig. 35), and the volcano was at **UNASSIGNED** status.

Starting on May 5, SO_2 emissions (fig. 36) and elevated surface temperatures (figs. 37, 38) began to be observed almost daily in satellite imagery, which indicated an above-background level of unrest. In response, AVO raised the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on May 11 (May 10 HADT). The elevated surface temperatures and gas emissions continued through the following months, with SO_2 emission rates early on as high as 800–900 t/d. The gas plumes were commonly detected at an altitude of ~5,000 ft (~1,500 m) ASL, although there was some variability.

High-resolution satellite data showed some minor morphological changes within the crater in May. These morphological changes included an area of subsidence first identified on May 19 and two small pits (together about 15×20 m in area) that formed on the south side of the crater by May 21. The area of subsidence and the two pits were each gas emission sites (fig. 39).

By mid-June, the summit thermal anomalies had become less pronounced and were observed less frequently. This was mirrored by gas emissions, which similarly became less prominent. From mid-June through early July, small rockfalls and additional minor subsidence were seen in the crater. The unrest continued to wane slowly, and elevated surface temperatures and SO_2 emissions were observed only rarely thereafter. However, this activity was above background, and Mount Cleveland was kept at Aviation Color Code **YELLOW** and Volcano Alert Level **ADVISORY** through the rest of the year.

We hypothesize that the unrest in 2022 was caused by a pulse of magma rising beneath Mount Cleveland. The increased heat flux that occurred consequently led to the elevated surface temperatures and SO_2 emissions, as well as the subsidence and collapse observed within the volcano's summit crater. The increased heat flux waned gradually thereafter, resulting in fewer SO_2 and temperature detections.

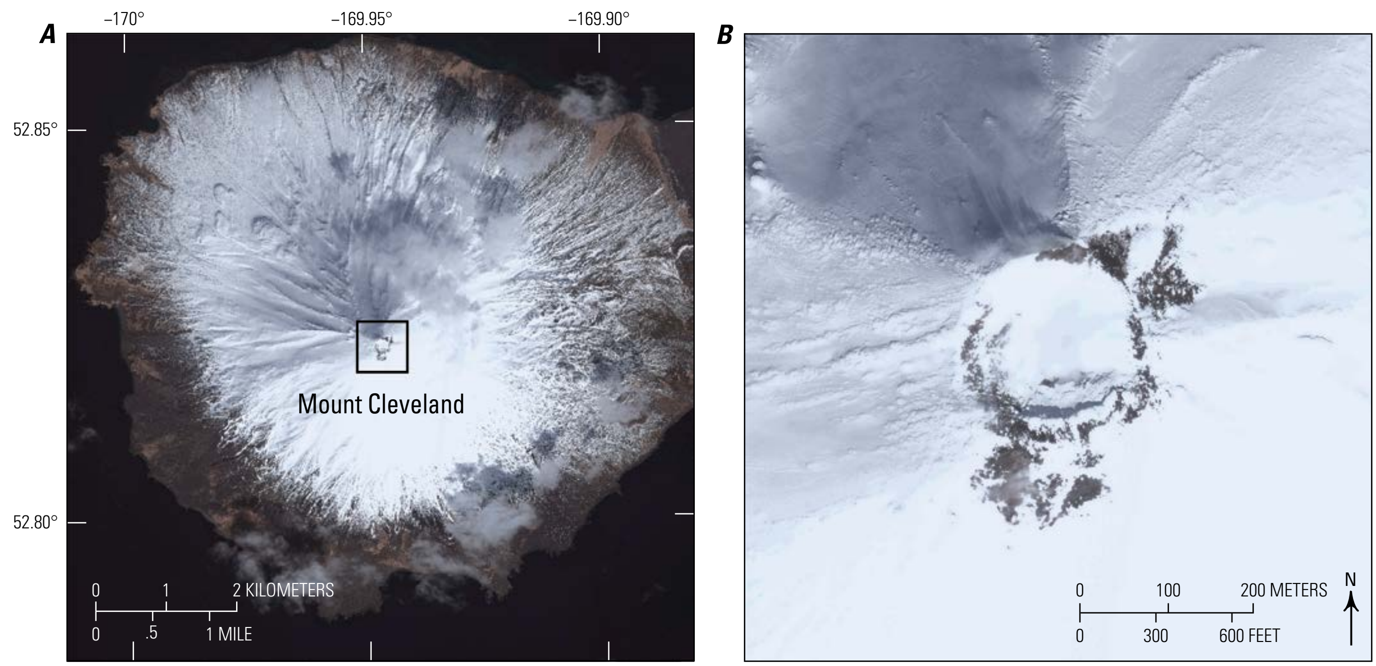


Figure 35. Satellite images (*A*, *B*) of Mount Cleveland taken on April 8, 2022. Black box in *A* indicates extent shown in *B*. Close-up view of the summit of Mount Cleveland in *B* shows no significant gas emissions and a mostly snow-covered crater floor, which indicates no substantial volcanic unrest.

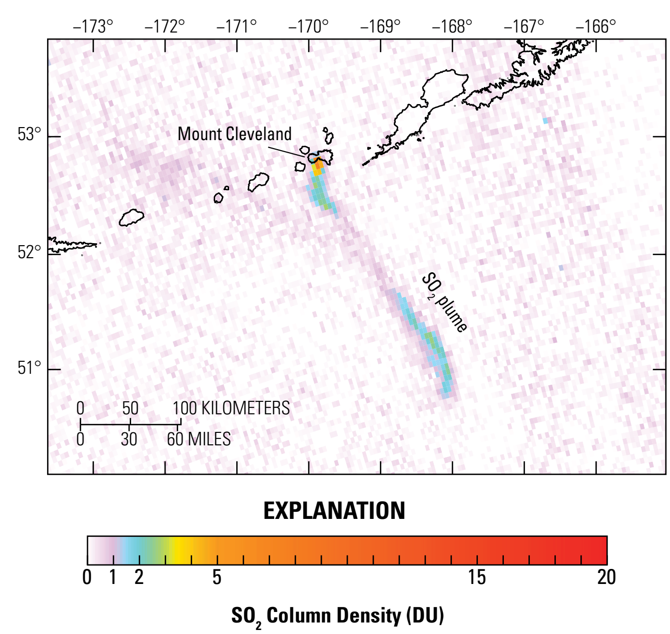


Figure 36. Map of SO_2 gas emissions as detected by tropospheric monitoring instrument that shows a volcanic gas plume drifting south-southeast from Mount Cleveland on May 31, 2022.

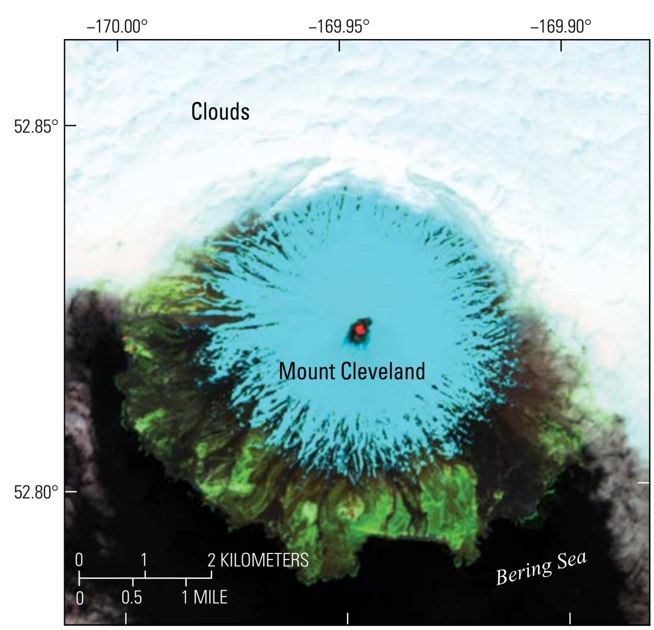


Figure 37. Short-wave infrared satellite image of Mount Cleveland from May 17, 2022, showing a thermal anomaly (red feature) at the summit of the partially snow-covered volcano. Thick cloud cover can be seen on the northern half of Mount Cleveland.

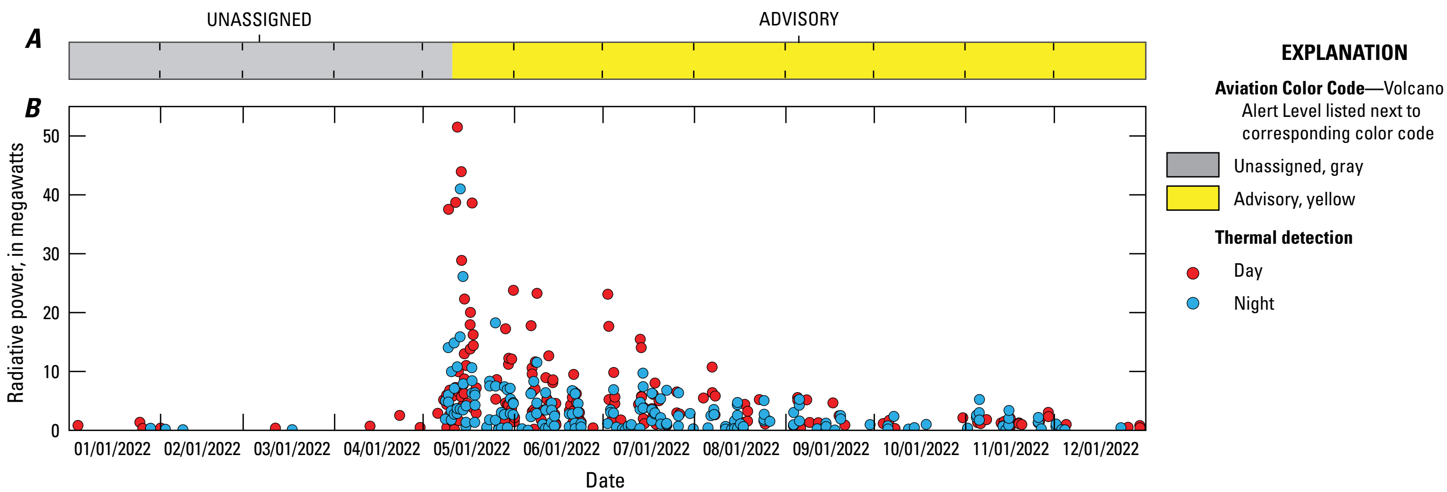


Figure 38. Timeline of observed activity at Mount Cleveland in 2022. *A*, Color bar timeline showing Aviation Color Code and Volcano Alert Level. *B*, Graph showing radiative power of thermal anomalies detected at Mount Cleveland during 2022 in the middle infrared and thermal infrared bands of the Visible Infrared Imaging Radiometer Suite (VIIRS) by the Hotspot Learning and Identification Network (HotLINK, Saunders-Shultz and others, 2024). One false-positive detection was removed from the dataset after manual inspection.

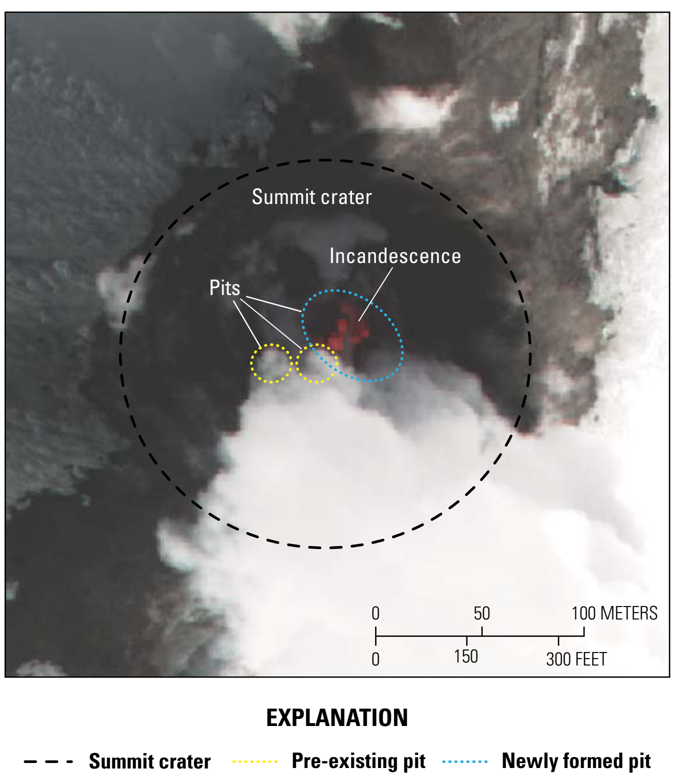


Figure 39. Satellite image of the summit crater of Mount Cleveland on May 25, 2022, showing incandescence (seen as red features in the image) and fuming from a newly formed central pit and fuming from two new smaller pits. Image is a composite of the panchromatic image overlain on the near-infrared image.

Takawangha Volcano

GVP #311090
51.867°, −178.027°
1,442 m
Tanaga Island, Andreanof Islands, Aleutian Islands

ELEVATED SEISMICITY

Takawangha volcano is a remote stratovolcano located on the northeast part of Tanaga Island, in the Andreanof Islands, roughly 95 km west of the City of Adak, Alaska, and 1,880 km southwest of Anchorage (fig. 1). Takawangha volcano's summit is mostly ice-covered, except for four young craters that have erupted ash and lava flows in the past few thousand years. Parts of the volcano's edifice are hydrothermally altered and may be unstable, which could lead to localized debris avalanches from its flanks (Coombs and others, 2007). Takawangha volcano lies across a topographic saddle from historically active Tanaga Volcano to the west (fig. 40). Although no historical eruptions are known from Takawangha volcano, field work shows that recent eruptions have occurred (Jicha and others, 2012), and historical eruptions attributed to Tanaga Volcano may instead have come from Takawangha volcano. In recent times, a noteworthy earthquake sequence occurred at Takawangha volcano in 2017 but did not lead to eruptive activity (Dixon and others, 2020).

Beginning early November 2022, seismic activity at Takawangha volcano increased steadily above background rates and occurred along an arc-like trend extending eastward

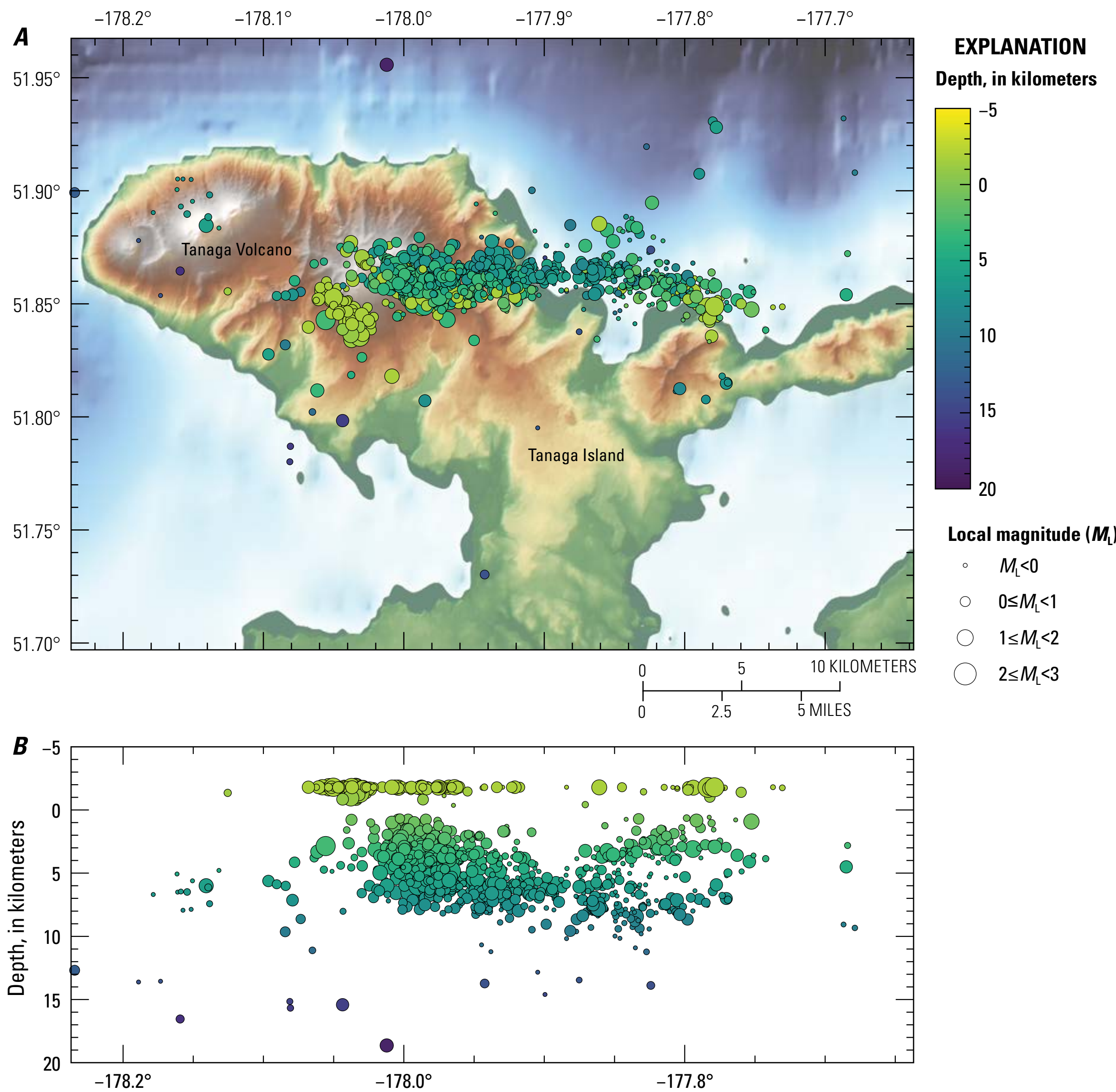


Figure 40. Map of Tanaga Island (*A*) and cross-sectional plot (*B*) of earthquake hypocenter locations near Takawangha volcano in 2022. The apparent depth bimodality is an artifact of the model used to locate the earthquakes. The shallowest earthquakes—those located above sea level—are those where the depth is poorly determined.

from the volcano (fig. 40*A*) at depths mostly 1–9 km below sea level (fig. 40*B*). The intensifying earthquake activity, possibly caused by the movement of magma beneath the volcano, prompted AVO to raise the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** on November 19 (November 18 HAST). The week after this change marked the height of the seismic burst, during which 283 earthquakes of magnitudes as high as M_L 3.7 occurred in rapid succession (fig. 41). Although seismic rates declined thereafter, they remained above background levels through the end of the year (fig. 41). No other associated signs of unrest, such as steaming, thermal signals, and deformation, were observed.

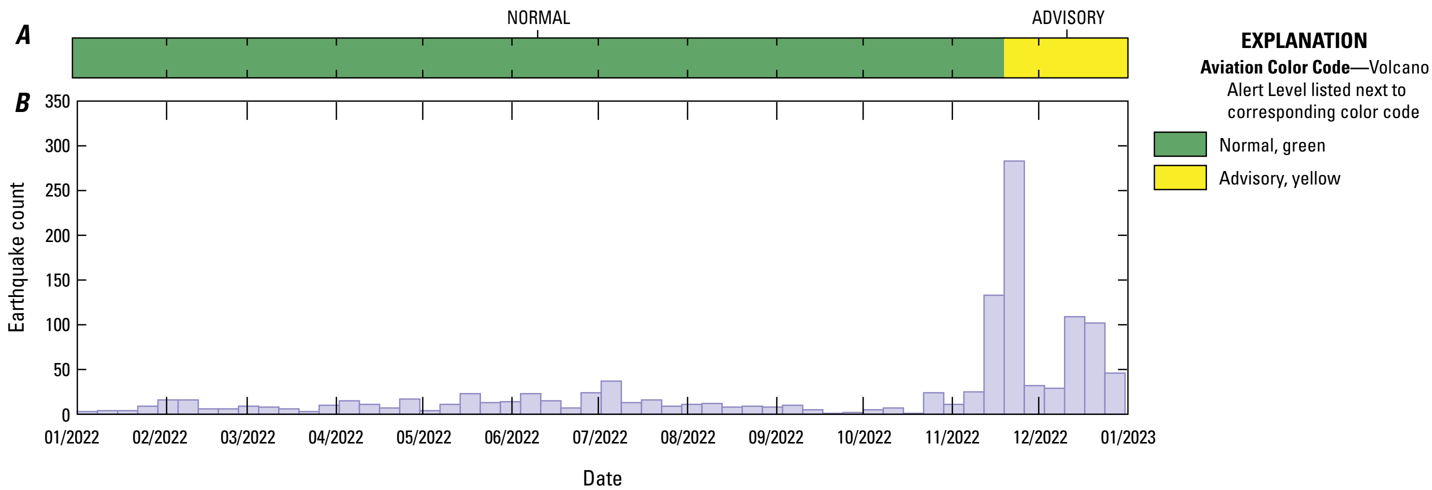


Figure 41. Timeline of observed activity at Takawangha volcano in 2022. *A*, Color bar timeline showing Aviation Color Code and Volcano Alert Level during 2022. *B*, Histogram of earthquakes occurring per week at Takawangha volcano in 2022. Dates are given in month, day, year format.

Great Sitkin Volcano

GVP #311120
52.077°, −176.111°
1,743 m
Great Sitkin Island, Andreanof Islands, Aleutian Islands

ERUPTION OF LAVA FLOW

Great Sitkin Volcano is a basaltic andesite volcano located 40 km northeast of the City of Adak, Alaska, and 1,880 km southwest of Anchorage (fig. 1). It constitutes most of the northern half of Great Sitkin Island, part of the Andreanof Islands group of the central Aleutian Islands (Waythomas and others, 2003a, 2003b). The volcano consists of an older caldera that is partly filled by a younger parasitic cone, which itself contains a summit crater 2–3 km in diameter partly filled by young lava flows.

Great Sitkin Volcano erupted at least twice in the 20th century. In 1974, a lava dome formed in the summit crater during which time at least one ash cloud, with a maximum altitude of ~10,000 ft (~3,000 m) ASL, was observed (Associated Press, 1974). A poorly documented eruption in 1945 also produced a lava dome, which was then partially destroyed by the 1974 eruption. One eruption at Great Sitkin Volcano has an unconstrained date but may have occurred within the past 280 years. This event produced pyroclastic flows that partly filled a valley on the southwest flank of the volcano (Waythomas and others, 2003b).

A period of increased unrest at Great Sitkin Volcano began in late July 2016, which was characterized by an elevated frequency of earthquakes, anomalous steaming from its summit crater, and small explosive events (Dixon and others, 2020). This activity culminated in a Vulcanian explosion on May 25, 2021, and subsequently in mid-July by an effusive eruption that began to gradually fill the summit crater and overtop the crater rim in two places (Orr and others, 2024b). Effusion continued unabated thereafter, and the volcano was kept at **ORANGE** and **WATCH** for the rest of 2021 and all of 2022 (fig. 42*A*).

Lava flow activity in 2021 and the first half of 2022 (herein referred to as episode 1) was characterized by the spreading of the flow outward from the vent within the summit crater (fig. 43). After an initial period of relatively high effusion rate in 2021, the rate declined, and the first half of 2022 was characterized by a low, relatively steady rate. Volume estimates from optical and radar satellite images returned effusion rates of approximately 0.2 m^3/s (fig. 42*B*). Elevated surface temperatures and moderate volcanic radiative power values were also noted in clear satellite images during this interval (fig. 42*C, D*). Very few earthquakes were located, although station outages from April 19 to June 5 (fig. 42*E*) briefly compromised earthquake detection.

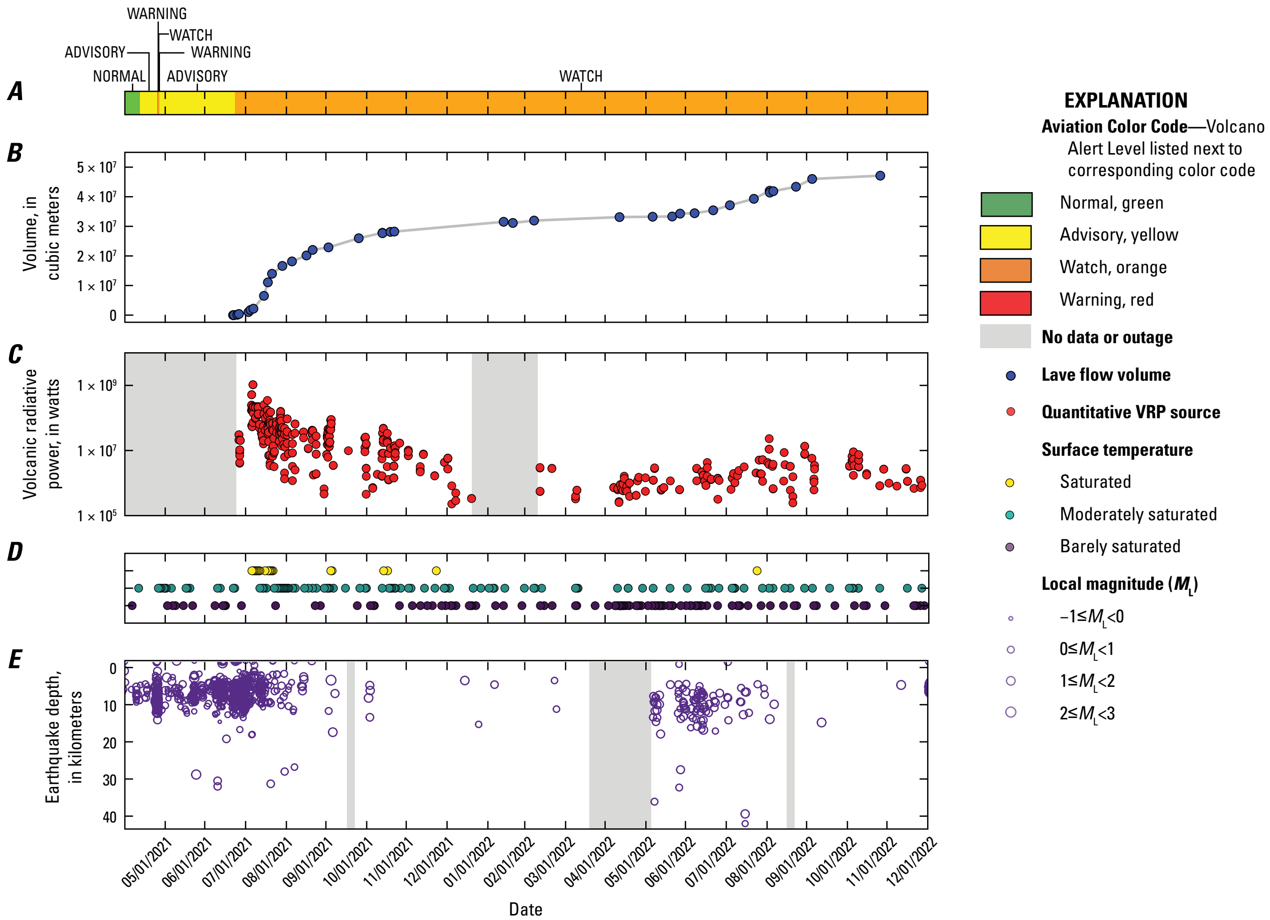


Figure 42. Timeline of observed activity at Great Sitkin Volcano from May 2021 through the end of 2022. *A*, Timeline of the Aviation Color Code and Volcano Alert Level at Great Sitkin Volcano. *B*, Cumulative lava flow volume estimated from flow extent in satellite visible and radar images and assumed or measured flow thickness. *C*, Quantitative time series of thermal emissions at Great Sitkin Volcano from Visible Infrared Imaging Radiometer Suite (VIIRS) imagery (courtesy NOAA/CIMSS experimental Volcanic Cloud Analysis Toolkit system Pavolonis and others, 2018). *D*, Time series of qualitative descriptions of elevated surface temperatures made by the Alaska Volcano Observatory duty remote sensing checks of low-earth orbit satellite images. *E*, Time series of located earthquake magnitudes and depths.

Eruptive activity increased again starting in June (fig. 42), and satellite images showed new lava extruding from the vent and overtopping the earlier flow (fig. 44). This second period of flow growth, herein referred to as episode 2 to distinguish it from the earlier flow activity of episode 1, was accompanied by an increased estimated lava effusion rate of 1–2.5 m^3/s, an increase in the rate of located earthquakes, and an increase in estimated volcanic radiative power (fig. 42). The overtopping lava flow spread to the south and east but remained confined within the summit crater before reaching the eastern margin of the episode 1 lava flow in November.

Relatively few clear satellite images were acquired in fall 2022 to assess flow rate; however, between September 22 and November 25, the discharge rate slowed to approximately 0.25 m^3/s, similar to the rate observed in the spring (fig. 42). Earthquake rates and radiative power values also declined to levels close to those observed in the spring. Flow growth through the end of the year was primarily to the east, and lava advanced farther into the summit crater ice field. The flow appeared to follow the contact between the ice and the underlying rock of the crater floor, causing deformation and melting of the ice field as it was undercut.

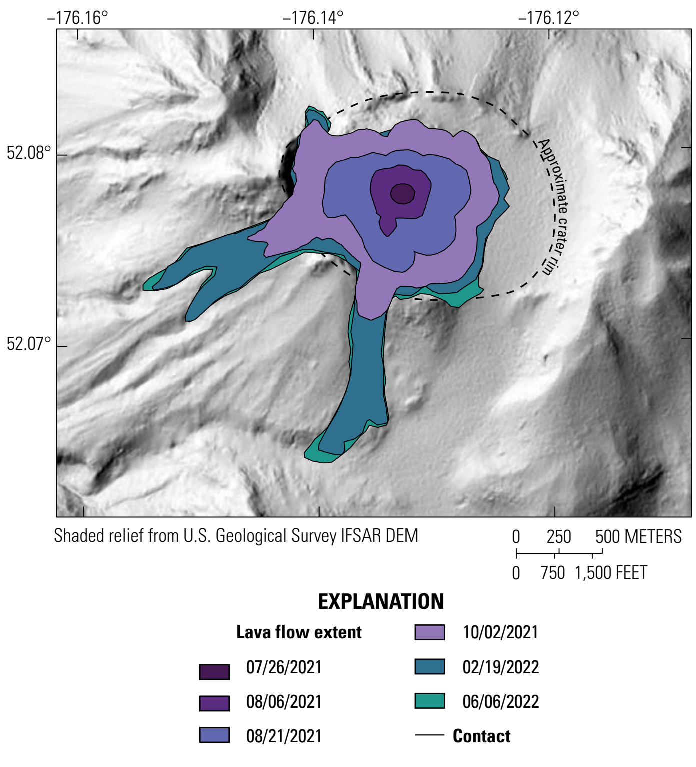


Figure 43. Map of the summit of Great Sitkin Volcano showing approximate lava flow extents for selected dates during episode 1 of the 2021–2022 eruption, as derived from high-resolution satellite images. Flow extents overlay a shaded-relief base image derived from the U.S. Geological Survey interferometric synthetic aperture radar digital elevation model.

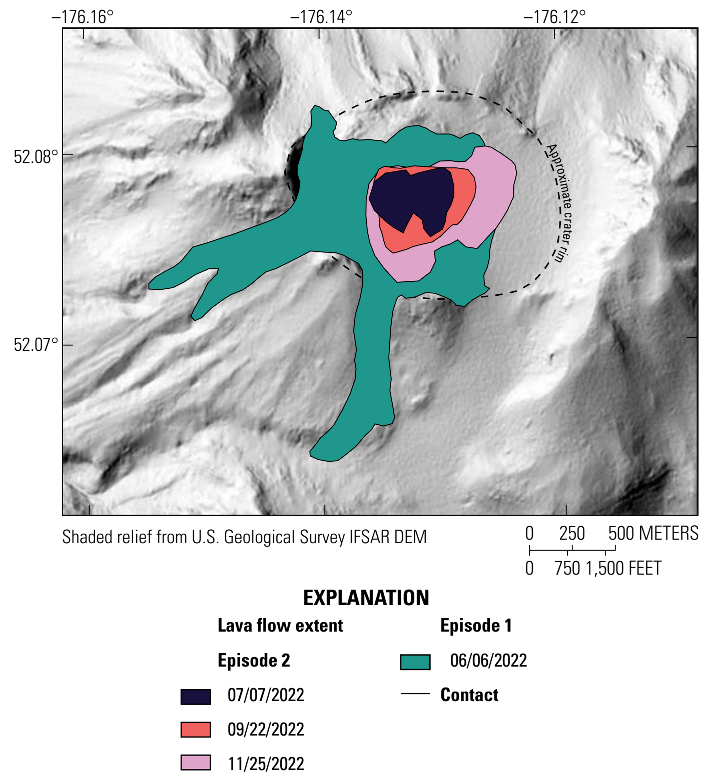


Figure 44. Map of the summit of Great Sitkin Volcano showing approximate lava flow extents for selected dates during episode 2 of the 2021–2022 eruption, compared to the final extent of episode 1 on June 6, 2022, as derived from high-resolution satellite images. Flow extents overlay a shaded-relief base image derived from the U.S. Geological Survey interferometric synthetic aperture radar digital elevation model.

Seismic activity throughout 2022 was generally low, although rates of located earthquakes were clearly higher than background rates during June–September, which was concurrent with the transition to the new extrusion of lava from the vent and an increase in effusion rate. Most of these earthquakes were in a cluster 1.5–7 km northwest of the vent, at depths 3–18 km below sea level, and all were less than local magnitude 2 (fig. 45).

The cause of the extrusion of lava in summer 2022 (episode 2) is not known. The overtopping lava flow of episode 2 was distinctly lighter in color in visible satellite imagery than the lava of episode 1 (fig. 46), reflecting a possible petrologic change, perhaps to a more silicic composition. Alternatively, the increased seismicity and radiative power imply that a simple increase in effusion rate could be the cause. A third option is that this change might simply be a question of head pressure—it became easier for the vent to begin supplying a new flow than to continue pushing viscous lava into the old one and adding to its relatively large aerial extent. In this scenario, the increased effusion rate observed initially would be a consequence of the new extrusion and not the cause. The answer may be a combination of these proposed causes. Direct observation and analyses of the episodes 1 and 2 lava flows should help resolve this question.

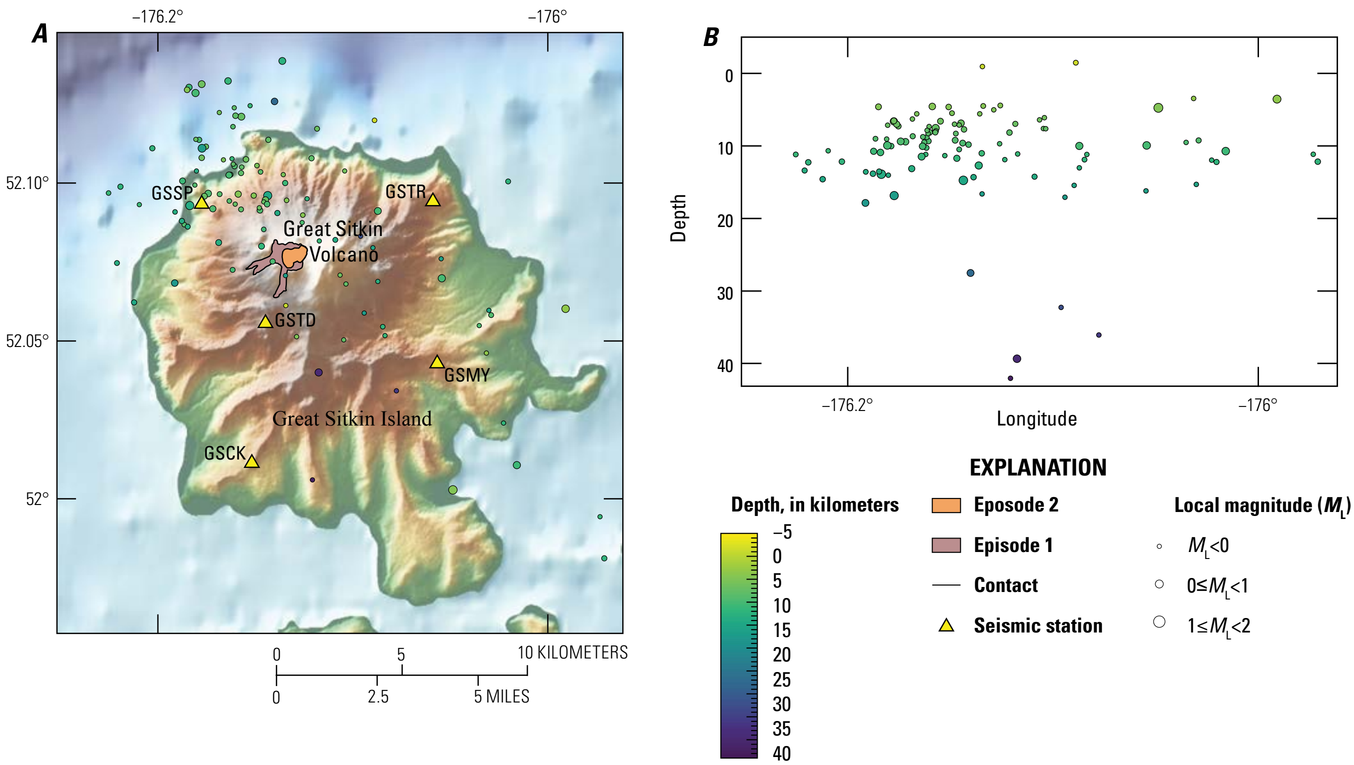


Figure 45. Map (*A*) and cross-sectional plot (*B*) of earthquake hypocenter locations near Great Sitkin Volcano in 2022. Approximate lava flow extents for episodes 1 and 2 are based on satellite imagery from November 25, 2022. Seismic station GSTD was offline for all of 2022, and the entire network was offline from mid-April to early June.

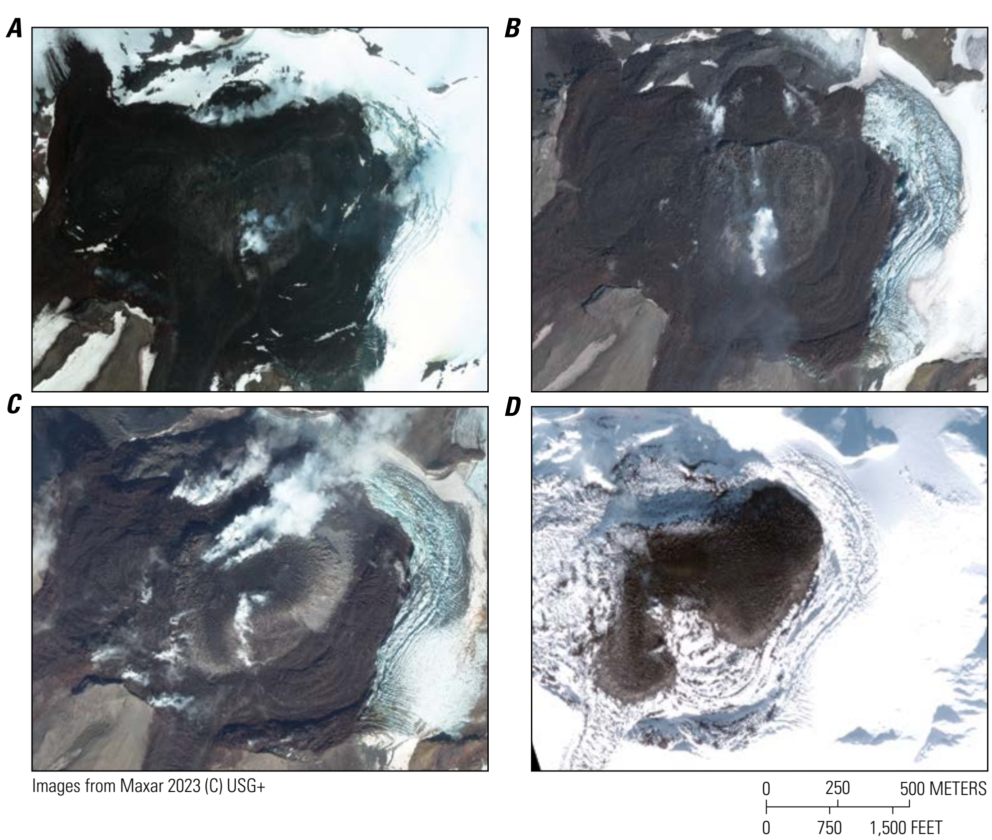


Figure 46. Satellite images of the Great Sitkin Volcano lava flows in 2022. *A*, GeoEye-1 satellite image taken on June 26. *B*, Worldview-3 satellite image taken on August 22. *C*, GeoEye-1 satellite image taken on September 22. *D*, BlackSky satellite image taken on November 5. All images share the same approximate scale shown in part *D* with slight variations owing to image angle.

Semisopochnoi Island (Mount Young)

GVP #311060
51.929°, 179.598°
815 m
Semisopochnoi Island, Rat Islands, Aleutian Islands

ELEVATED SEISMIC ACTIVITY, WEAK EXPLOSIVE EVENTS, AND ASH AND GAS EMISSIONS

Semisopochnoi Island is a young, uninhabited volcanic island in the western Aleutian Islands, ~260 km west of the City of Adak, Alaska, and 2,110 km southwest of Anchorage (fig. 1). Its largest feature is a 7-km-wide caldera that formed 6,900–5,000 years ago; it also has many post-caldera cones (Coombs and others, 2018). The last recorded eruption before its most recent activity (beginning in 2018) took place in 1987 at Sugarloaf Peak, on the south end of the island. This event produced a 90-km-long plume visible in satellite images, and pilots later reported ash deposited on the volcano's flanks (Reeder, 1990). Mount Young, a cluster of three cones within Semisopochnoi Island's volcanic caldera, has also erupted repeatedly in the Holocene and has produced crystal-rich basaltic andesite lavas and tephra from all three cones. Most fall deposits associated with the cones are consistent with small- to moderate-sized ash clouds, although some coarse units dominated by lapilli indicate eruption intensities with a volcanic explosivity index as high as 3 (Coombs and others, 2018). The most recent non-eruptive unrest at Semisopochnoi Island volcano before the 2018 eruption was a period of increased seismicity and deformation in 2014–2015. Modeling by DeGrandpre and others (2019) explained this as the result of the rapid intrusion of 0.072 km^3 of magma (as two batches) into a spheroidal magma storage zone ~8 km beneath the caldera.

Eruptive activity at Semisopochnoi Island during 2022 was characterized by frequent low-level ash emissions and explosions from Mount Young (fig. 47; table 5). At the start of the year, Semisopochnoi Island was at **ORANGE** and **WATCH** owing to the ongoing explosive activity and ash emissions (Orr and others, 2024b) (fig. 48; fig. 49*A*, *B*). AVO lowered the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** on July 8, after a hiatus in explosions and ash emissions that started June 12. Volcanic unrest remained elevated during this period, and seismicity and gas emissions were observed.

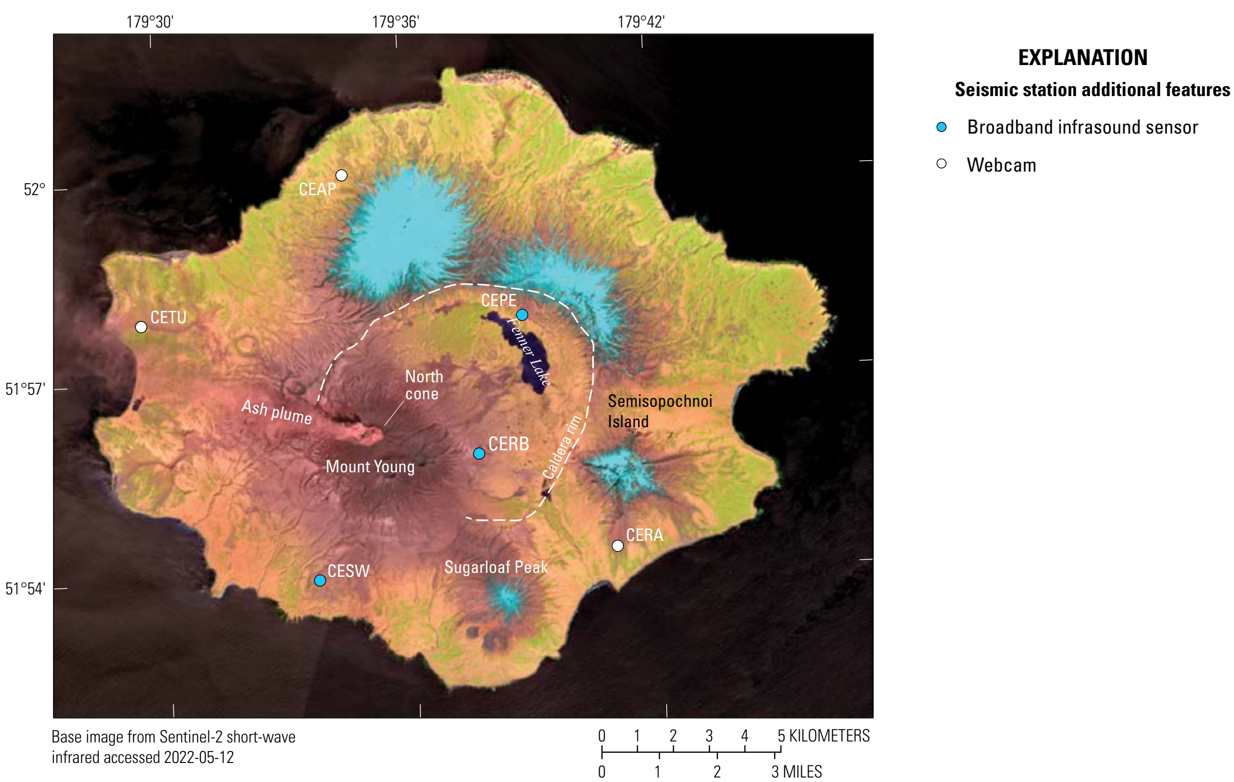


Figure 47. False-color short-wave infrared satellite image from May 12, 2022, of Semisopochnoi Island showing minor ash emissions from the active north cone of Mount Young. The seismic monitoring network (white circles) comprises six 3-component broadband seismometers. Snow appears blue, vegetation appears as green to tan, and bare ground and ash deposit appear brown to gray.

Table 5. Summary of activity and observations at Semisopochnoi Island in 2022.

Color Code/Alert Level	Date	Observation description
ORANGE/WATCH	01/01/2022	Eruption continues; small explosions detected in seismic and infrasound data. Small ash emissions visible in webcam images when weather conditions permit.
YELLOW/ADVISORY	07/08/2022	Hiatus in ash emissions and explosions from June 12 – August 20. Elevated seismicity and degassing activity continue.
YELLOW/ADVISORY	07/14/2022	Upgrades to a satellite telemetry link improve transmission of monitoring data from the Little Sitkin Island and Semisopochnoi Island networks.
ORANGE/WATCH	08/21/2022	Short-lived explosion produced ash emissions below ~20,000 ft (~6,100 m) ASL on 08/21. Minor ash emissions also observed several times in early September.
YELLOW/ADVISORY	09/29/2022	No ash emissions or explosive activity observed since September 15. Seismic activity decreased, although still above background.
ORANGE/WATCH	11/07/2022	Small explosions detected in geophysical data October 31 and November 7; tremor detected November 5 and 6. AVO lost data transmission from station CERB on November 7.
YELLOW/ADVISORY	11/23/2022	Seismic activity elevated but decreased; no explosions since November 7; vapor plume continues.
ORANGE/WATCH	12/28/2022	Ash emissions return, minor ash deposits on fresh snow seen on webcam images from December 27. Persistent steam plume to 1,500 m (5,000 ft) containing possible volcanic ash.

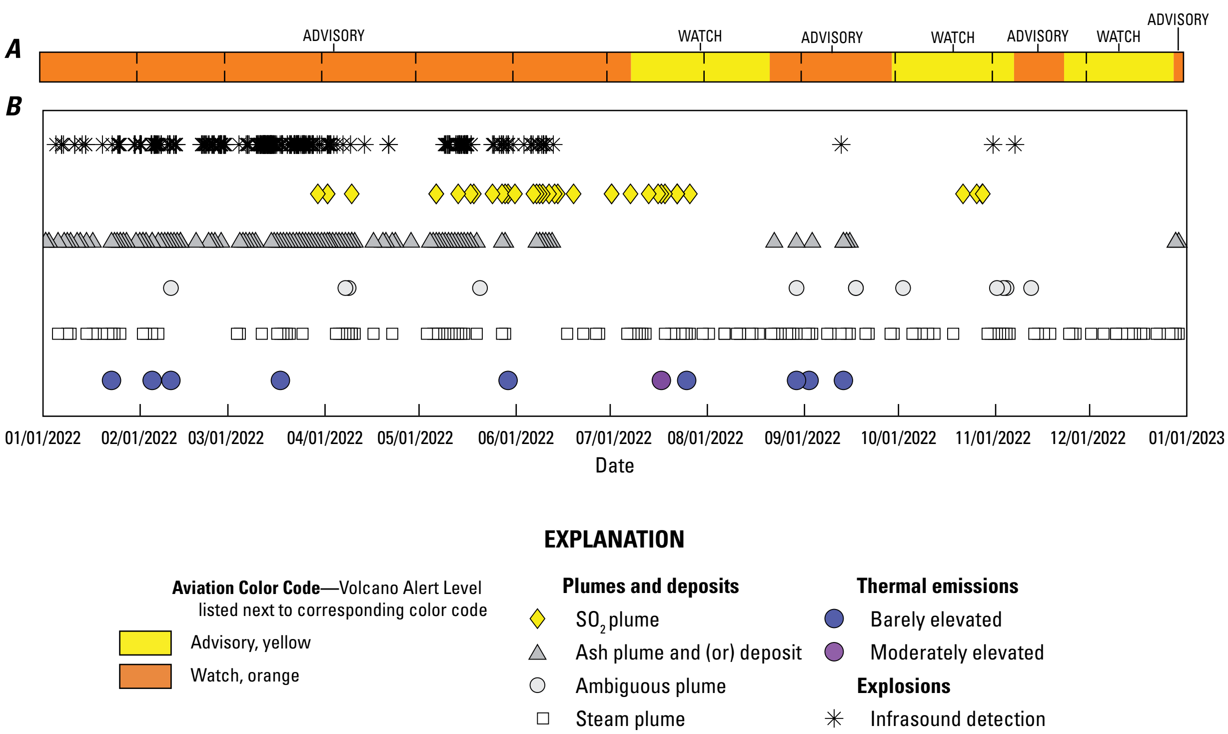


Figure 48. Timeline of observed activity at Semisopochnoi Island in 2022. *A*, Timeline of the Aviation Color Code and Volcano Alert Level. *B*, Timeline of outward indications of volcanic unrest showing explosions detected in infrasound data and detection of volcanic plumes, deposits, and thermal emissions through satellite and webcam remote sensing data.

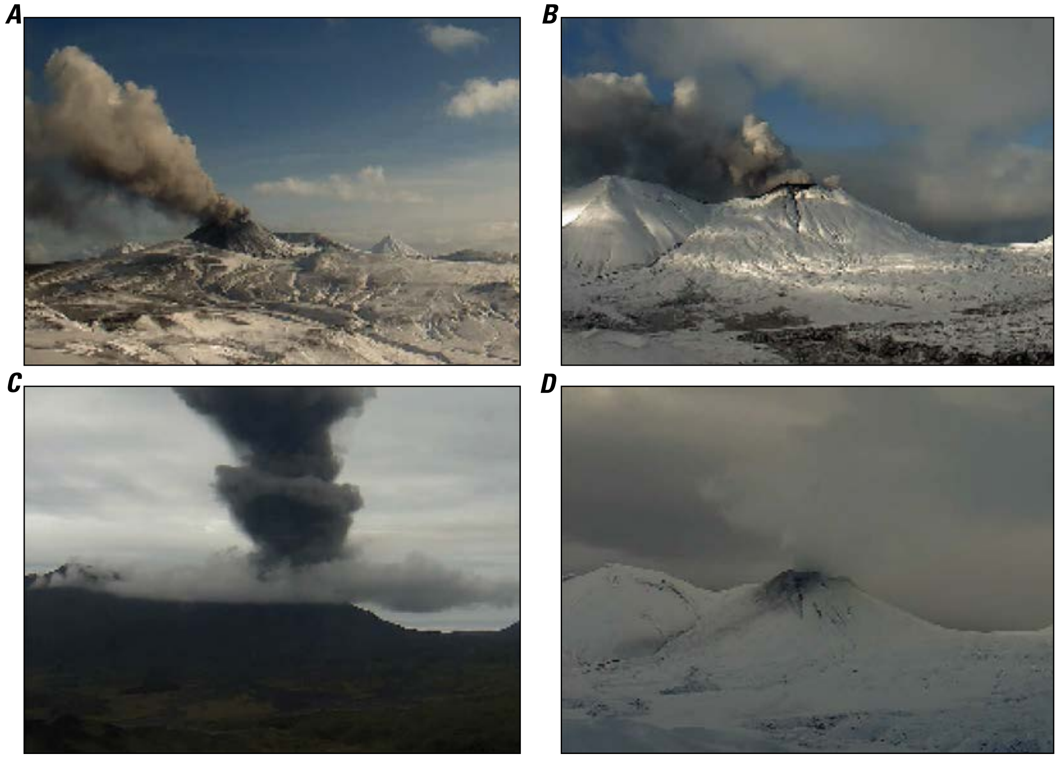


Figure 49. Webcam images of the 2022 Semisopochnoi Island activity from the north crater of Mount Young (see figure 48 for camera locations). *A*, Webcam image from station CETU showing ash plume and recent ash deposits on snow taken on February 12, 2022, at 14:47 HAST (00:47 UTC on February 13). *B*, Webcam image from station CEPE showing ash plume and small lahar taken on March 17, 2022, at 11:27 HADT (20:27 UTC). *C*, Webcam image from station CEPE showing ash plume extending above the field of view taken on August 21, 2022, at 12:58 HADT (21:58 UTC). *D*, Webcam image from station CEPE showing steam plume and small tephra deposit taken on December 27, 2022, at 16:01 HAST (02:01 UTC).

The volcano was elevated to **ORANGE** and **WATCH** on August 21 in response to a short-lived explosion that produced a plume that stayed below the ~20,000 ft (~6,100 m) cloud deck visible in satellite data at that time (fig. 49*C*). Minor ash emissions were subsequently observed several more times through early September and last observed on September 15. In response to this cessation in observed ash emissions, as well as an overall decline in seismicity, AVO lowered the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** on September 29, 2022.

A couple small explosions were detected in geophysical data on October 31 and November 7, and seismic tremor was observed on November 5 and 6. These detections led AVO to again raise the Aviation Color Code to **ORANGE** and Volcano Alert Level to **WATCH** on November 7, although no ash emissions or deposits associated with these events were observed in remote sensing data. Unfortunately, data transmission from the closest geophysical network station, CERB (fig. 47), was lost on November 7, reducing AVO's ability to detect very low level activity.

Steam emissions and elevated seismicity continued during the following few weeks, but no more explosions were detected. AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on November 23, in response to this lack of eruptive activity and the decline in seismic activity. However, webcam images on December 27 showed minor ash deposits on fresh snow and a steam plume that likely contained minor ash (fig. 49*D*). AVO therefore ended the year by raising the Aviation Color Code and Volcano Alert Level back to **ORANGE** and **WATCH** on December 28. Overall, there were more than 300 explosions detected in infrasound data from Mount Young during 2022 (fig. 48*B*).

Davidof Volcano

GVP# 311040
51.954°, 178.326°
325 m
Rat Islands
(Davidof, Khvostof, and Pyramid Islands) Aleutian Islands

EARTHQUAKE SWARM

Davidof volcano is a mostly submerged stratovolcano, truncated by a caldera, in the Rat Islands group in the western Aleutian Islands (Nelson, 1959), about 350 km west of the City of Adak, Alaska, and 2,200 km west of Anchorage (fig. 1). The subaerial part of the volcano comprises Davidof, Khvostof, and Pyramid Islands, which encircle Crater Bay, a 2.5-km-diameter caldera (fig. 50). The islands are built up from interbedded lava flows and explosive deposits. The volcano has been sparsely studied, but in 2021, Alaska

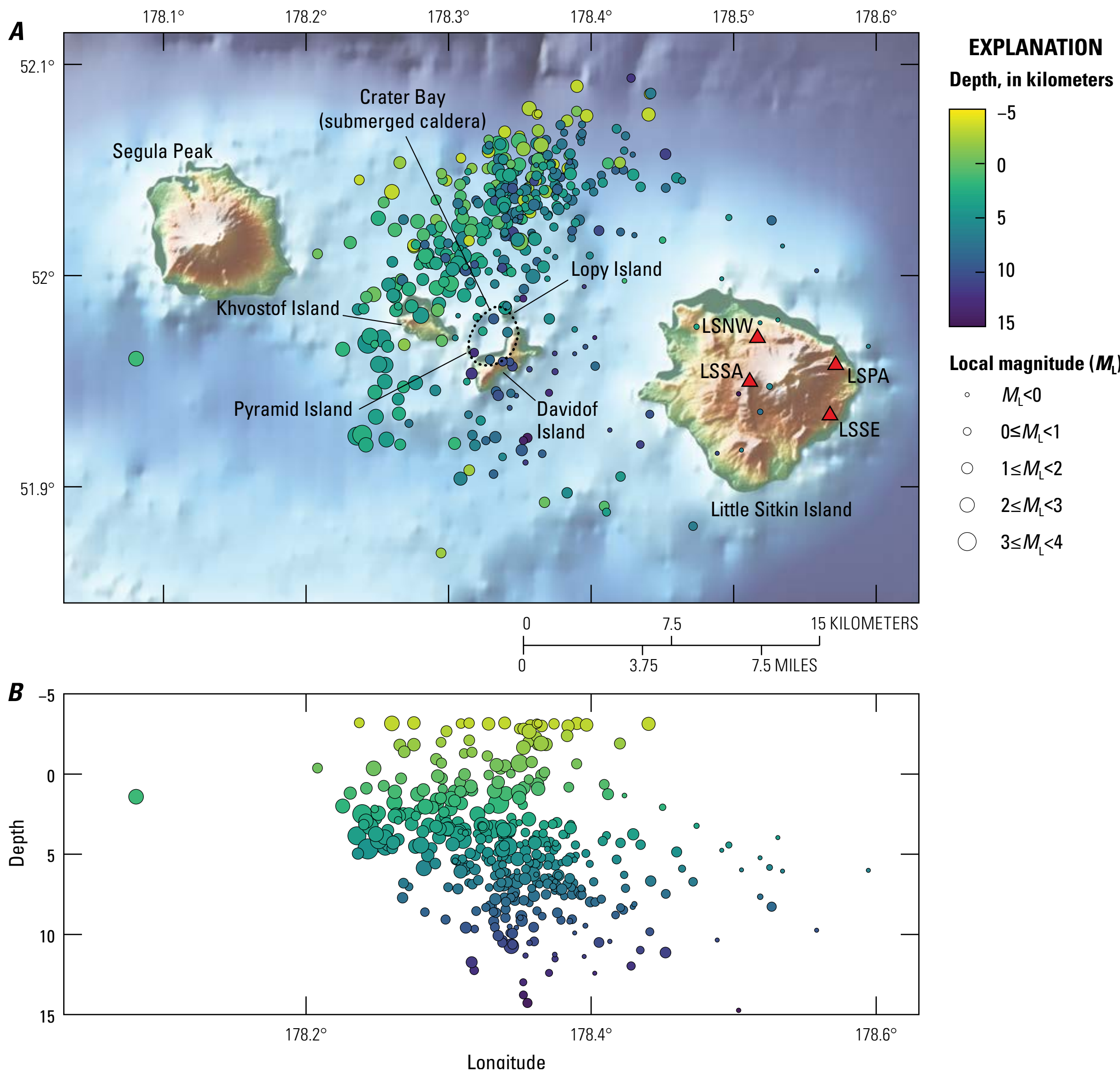


Figure 50. Map (*A*) and cross-sectional plot (*B*) of earthquake hypocenter locations near Davidof volcano in 2022. The shallowest earthquakes—those located above sea level—are those where the depth is poorly determined. Davidof volcano is an informal name for the volcanic system that comprises Davidof, Khvostof, and Pyramid Islands. Segula Peak and Little Sitkin Island are also shown for geographical context.

Volcano Observatory geologists documented thick sequences of rhyolite to andesite pyroclastic flow and fall deposits that represent the most recent explosive eruptions (Orr and others, 2024b). The ages of these deposits are unknown, but they seem older than Holocene deposits from nearby Segula Peak and Little Sitkin Island. There are no known historical eruptions from Davidof volcano.

An earthquake swarm occurred in the vicinity of Davidof volcano during December 7–20, 2021, which prompted AVO to briefly elevate the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** (Orr and others, 2024b). The volcano was lowered back to **UNASSIGNED** on December 29. Then, at 17:31 UTC (07:31 HAST) on January 21, 2022, after a month of relative quiescence, earthquake activity resumed, extending from 16 km north-northwest to 7 km west-southwest of the volcano (fig. 50). Like the 2021 swarm, the 2022 swarm consisted of relatively high magnitude events, and the largest event recorded was a magnitude 4.6 at 04:31 UTC on January 26 (January 25 at 18:31 HAST) during the peak of activity (fig. 51). The increased seismic activity prompted AVO to raise the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** later that day on January 26 (fig. 51).

Heightened seismic activity at Davidof volcano persisted through the next few months, with occasional energetic bursts (fig. 51). Although magnitude 4 seismic events were mostly confined to the initial few days of the swarm, several magnitude 3 events occurred occasionally throughout the swarm. Event rates and magnitudes waned gradually over the course of the swarm, and after weeks of slow decline, AVO lowered the volcano to **UNASSIGNED** on April 22. By late 2022, event rates had dropped to less than 10 earthquakes per month.

The seismicity at Davidof volcano generally followed a northeast-southwest trending lineation in the area northwest of the volcano (fig. 51), but this trend in locations was interpreted as an artifact caused by the earthquakes being located outside of the regional seismic network. The closest seismic stations were the 4 stations located on Little Sitkin Island, approximately 12 km southeast of Davidof volcano. The earthquakes also demonstrated a relatively large range of depths, in which some events were located above sea level and the deepest event was located at 14.7 km below sea level. Earthquake activity may or may not have been associated with volcanic unrest or tectonic activity. No signs of unrest were observed in satellite imagery or other geophysical data.

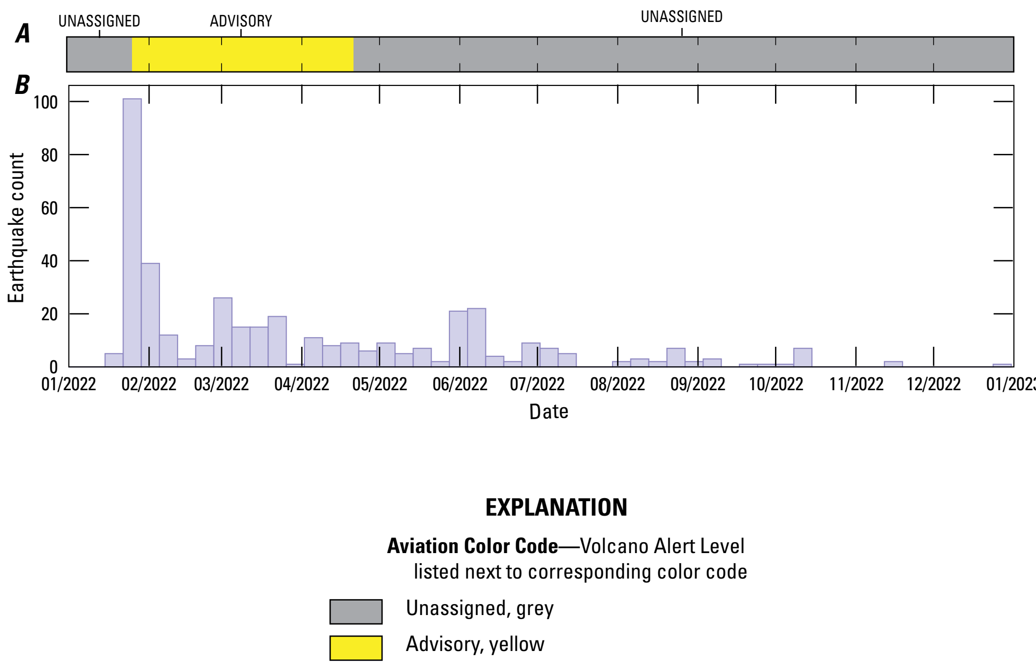


Figure 51. Timeline of observed activity and Alaska Volcano Observatory's response to activity at Davidof volcano. *A*, Color bar timeline showing Aviation color Code and Volcano Alert Level of Davidof volcano during 2022. *B*, Histogram of earthquakes occurring per week at Davidof volcano in 2022, highlighting period of elevated Aviation Color Code and Volcano Alert Level. Davidof volcano is an informal name for the volcanic system that comprises Davidof, Khvostof, and Pyramid Islands.

Volcanic Activity in the Commonwealth of the Northern Mariana Islands

Ahyi Seamount

GVP# 284141
20.42°, 145.03°
−79 m
Commonwealth of the Northern Mariana Islands

HYDROACOUSTIC DETECTIONS SUGGESTING UNDERWATER EXPLOSIONS; PLUME OF DISCOLORED WATER

Ahyi seamount is a large conical submarine volcano that rises to within 79 m of the sea surface near the north end of the Commonwealth of the Northern Mariana Islands (fig. 1), about 18 km southeast of the island of Farallon de Pajaros and 600 km north of Saipan Island. The remote location of the seamount has made eruptions difficult to detect, although several have been documented. The most recent submarine eruptive activity prior to 2022 occurred in 2014 and was detected by the regional Commonwealth of the Northern Mariana Islands seismic network and more distant seismic stations, and by hydroacoustic stations at Wake Island, 2,270 km to the east (Tepp and others, 2019). Submarine explosions during the eruption were also heard and felt by NOAA scuba divers at Farallon de Pajaros, and a multibeam sonar bathymetric survey collected afterward found that a crater about 100 m deep had formed at the summit of the volcano (Tepp and others, 2019).

Another apparent submarine eruption of Ahyi seamount began in October 2022 and continued through the end of the year. Activity did not breach the ocean surface; however, plumes of discolored water were frequently observed in clear satellite images. Regional seismic stations in the Marianas Islands were mostly offline in 2022 during the eruption, but underwater pressure sensors at Wake Island repeatedly detected signals from the direction of Ahyi seamount that may have been from underwater explosions, volcanic earthquakes, or both. Frequent detection of the hydroacoustic signals from mid-October into November prompted the U.S. Geological Survey to issue an information statement on November 14. The Aviation Color Code and Volcano Alert Level were raised to **YELLOW** and **ADVISORY** on November 28 (fig. 52), after plumes of discolored water over Ahyi seamount were observed repeatedly in satellite images (fig. 53).

Although access to data from the Wake Island hydroacoustic array was not available to observatory staff for much of October 2022, a retrospective analysis showed acoustic detections starting on October 5. These continued at a rate as high as about 600 events per day through November 11 (fig. 52). Detections continued thereafter at a lower rate

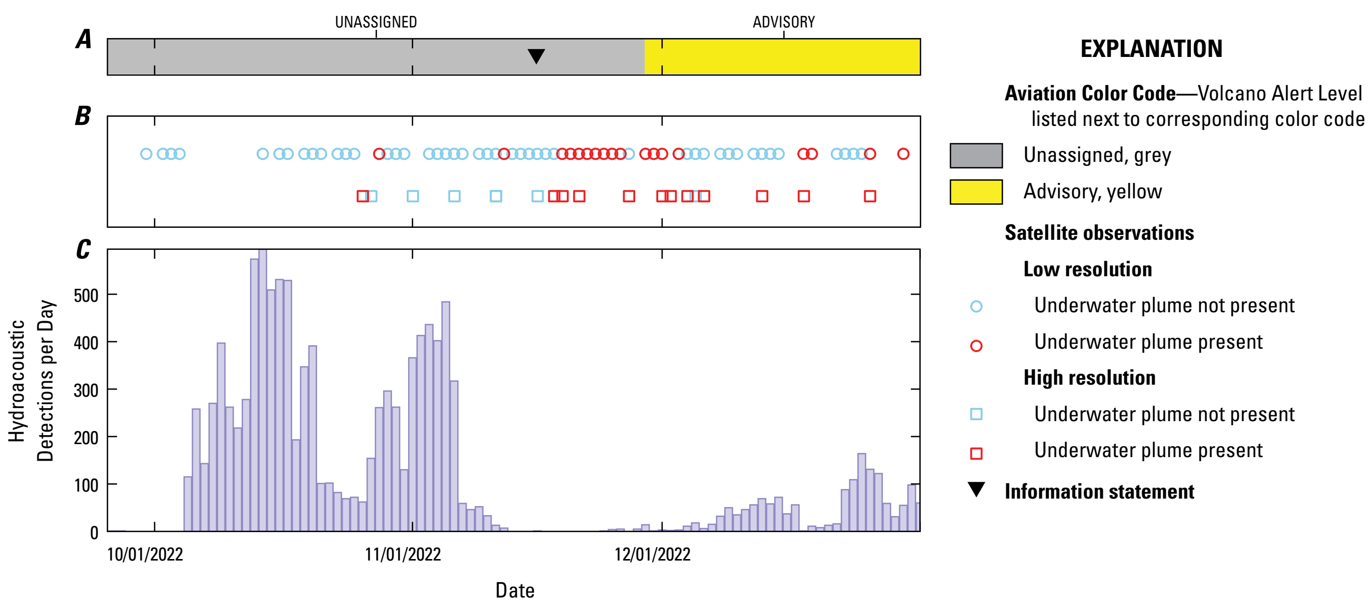


Figure 52. Timeline of observed activity at Ahyi seamount, a large conical submarine volcano about 18 kilometers southeast of the island of Farallon de Pajaros, from late September through the end of December 2022. *A*, Color bar timeline showing the Aviation Color Code and Volcano Alert Level. An information statement was issued at 21:14 UTC on November 14. *B*, Graph showing timeline of cloud-free low-resolution (Sentinel-2, Visible Infrared Imaging Radiometer Suite, and Moderate Resolution Imaging Spectroradiometer) and high-resolution (Sentinel-2, Landsat, WorldView-1, -2, and -3) satellite observations. *C*, Histogram of hydroacoustic events per day detected by the Wake Island array from the direction of Ahyi seamount.

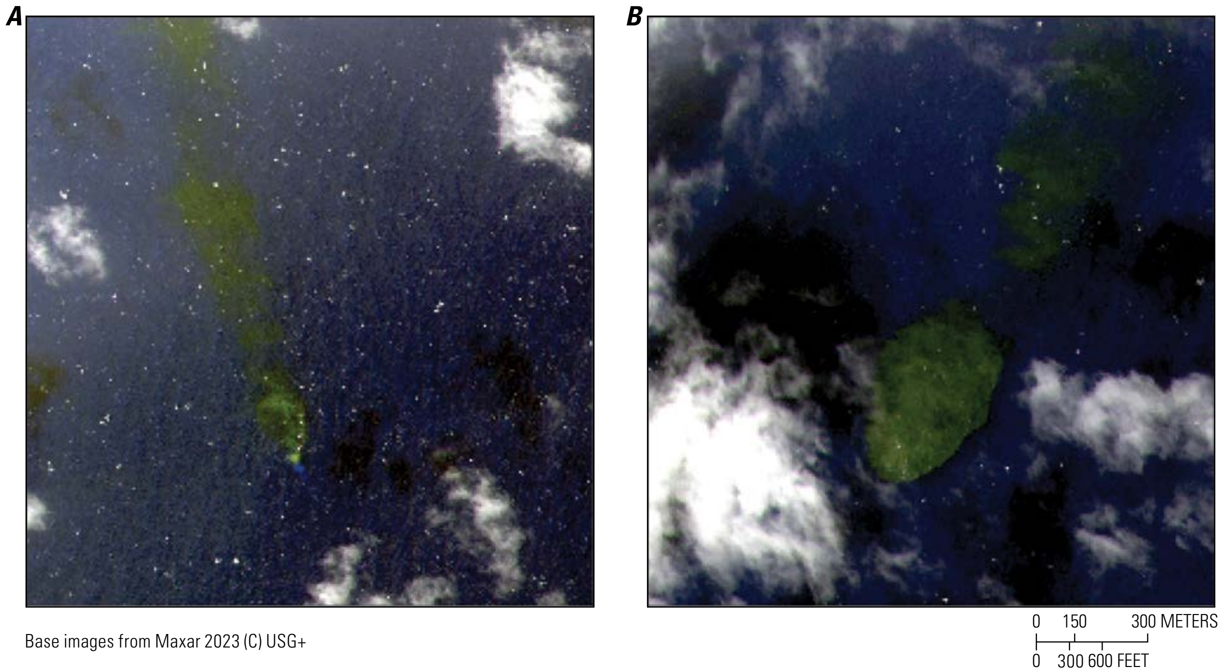


Figure 53. False color WorldView-3 and Worldview-2 satellite images showing plumes of greenish discolored seawater over Ahyi seamount on November 18 at 00:50 UTC (10:50 ChST) (*A*) and December 2 at 00:47 UTC (10:47 ChST) (*B*). Images are a combination of bands 5, 3, and 1, which are roughly equivalent to red, green, and coastal blue (400–450 nanometers) visible light. The coastal blue band is often used to better visualize submarine sediment plumes. The images have been further enhanced using image processing software to better show the plumes.

(<10 per day) until mid-December, when they increased again with as many as about 160 (but generally less than 100) events per day occurring through the end of the year (fig. 52). These event detections were based on an automatic detection algorithm (Lyons and others, 2020) and thus may not all reflect volcanic signals from Ahyi seamount.

Retrospective analysis of satellite images found the first sign of a plume of discolored seawater in an October 26 Landsat satellite image (fig. 52), and a lower-resolution satellite image from Sentinel-3 also showed hints of a plume on October 28. An unambiguous plume, extending 1.4 km north from near the summit of Ahyi seamount, was finally seen in a November 8 WorldView-3 satellite image. Ocean surface plumes were frequently observed thereafter in cloud-free satellite images through the end of the year (figs. 52, 53). Like the hydroacoustic signals, the source of these plumes is not clear. They may have been caused by sediment, ash, or sulfur particles drifting with the current and could have resulted from an erupting vent, vigorous hydrothermal activity, or possibly even small submarine landslides. However, the clear point-source origin of the plumes near the summit of the seamount, associated with hydroacoustic activity and lack of similar plumes observed during the quiescent period between the 2014 and 2022, strongly indicate they were related to underwater eruptive activity.

Initial uncertainty about the source of signals observed in 2022 is reflected in the observatory response. The recognition of hydroacoustic signals, in collaboration with the Laboratorie de Géophysique in Tahiti, resulted in an information statement issued on November 14 (fig. 52), noting that the signals were consistent with an undersea volcanic source and the reporting of possible discoloration of seawater in a November 6 satellite image. Later analysis of the November 6 image, however, showed the discoloration to be a normal atmospheric cloud. It was a prescient observation though—Landsat and Sentinel-3 images definitively exhibiting plumes of discolored seawater were soon found. Repeated observations of plumes in clear, high-resolution satellite images thereafter finally prompted a formal increase of the Aviation Color Code and the Volcano Alert Level to **YELLOW** and **ADVISORY** at 22:54 UTC on November 28 (November 29 at 08:54 Chamorro standard time), where they remained through the end of the year.

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Glossary of Selected Terms and Acronyms

A

andesite Volcanic rock composed of about 57–63 weight percent silica (SiO_2).

ash Fine fragments (less than 2 millimeters across) of lava or rock formed in an explosive volcanic eruption.

B

basalt Volcanic rock composed of about 45–52 weight percent silica (SiO_2).

basaltic andesite Volcanic rock composed of about 52–57 weight percent silica (SiO_2).

C

caldera Large, roughly circular depression commonly caused by volcanic collapse.

D

dacite Volcanic rock composed of about 63–69 weight percent silica (SiO_2).

F

fumarole Small opening or vent from which hot gases are emitted.

H

Holocene Geologic epoch that extends from the present to about 11,700 years ago.

I

incandescence The high-temperature emission of light.

infrasound Low-frequency sound waves, below the threshold of human hearing.

intracaldera Refers to a point or area within the caldera.

L

lahar Flow of a mixture of pyroclastic material, sediments and organic ground cover, and water.

lava Molten rock that has reached the Earth's surface.

local magnitude (M_L) Earthquake magnitude scale based on the amplitude of ground motion as measured by a standard seismograph.

long-period earthquake Earthquake with dominant frequency content between 1 and 5 hertz. Used interchangeably with the term low-frequency earthquake.

M

magma Molten rock below the surface of the Earth.

P

pyroclast Individual particle ejected during a volcanic eruption; commonly classified by size (for example, ash and lapilli).

S

satellite vent Subsidiary volcanic vent located on the flank of a larger volcano.

earthquake swarm Flurry of closely spaced earthquakes or other ground shaking activity; often precedes an eruption.

steam emissions General term used to indicate visible (partially condensed) degassing of mixed, and typically unquantified, gas compositions from volcanoes and thermal areas.

stratovolcano Steep-sided volcano, commonly conical in shape, built of interbedded lava flows and fragmental deposits from explosive eruptions. Also called a stratocone or composite cone.

Strombolian Type of explosive volcanic eruption characterized by intermittent bursts of fluid lava, commonly basalt or basaltic andesite, from a vent or crater as gas bubbles rise through a conduit and burst at the surface.

T

tremor Low-amplitude, continuous earthquake activity commonly associated with magma movement.

V

vent Opening in the Earth's surface through which magma erupts or volcanic gases are emitted.

volcanic explosivity index Scale that describes the size of explosive volcanic eruptions based on magnitude and intensity.

volcano-tectonic earthquake Earthquake generated within or near a volcano by brittle rock failure resulting from strain induced by volcanic processes.

Vulcanian Type of volcanic eruption that ejects material to heights less than about 20 km (12 miles) and lasts on the order of seconds to minutes. They are characterized by discrete, violent explosions, the ballistic ejection of blocks and bombs, atmospheric shock waves, the emission of tephra, and small-scale pyroclastic density currents.

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