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Catalog of Earthquake Hypocenters at Alaskan Volcanoes: January 1 through December 31, 2002

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TABLE OF CONTENTS

Introduction

The Alaska Volcano Observatory (AVO), a cooperative program of the U.S. Geological Survey, the Geophysical Institute of the University of Alaska Fairbanks, and the Alaska Division of Geological and Geophysical Surveys, has maintained seismic monitoring networks at historically active volcanoes in Alaska since 1988 (Power and others, 1993; Jolly and others, 1996; Jolly and others, 2001; Dixon and others, 2002). The primary objectives of this program are the seismic monitoring of active, potentially hazardous, Alaskan volcanoes and the investigation of seismic processes associated with active volcanism. This catalog presents the basic seismic data and changes in the seismic monitoring program for the period January 1, 2002 through December 31, 2002. Appendix G contains a list of publications pertaining to seismicity of Alaskan volcanoes based on these and previously recorded data.

The AVO seismic network was used to monitor twenty-four volcanoes in real time in 2002. These include Mount Wrangell, Mount Spurr, Redoubt Volcano, Iliamna Volcano, Augustine Volcano, Katmai Volcanic Group (Snowy Mountain, Mount Griggs, Mount Katmai, Novarupta, Trident Volcano, Mount Mageik, Mount Martin), Aniakchak Crater, Mount Veniaminof, Pavlof Volcano, Mount Dutton, Isanotski Peaks, Shishaldin Volcano, Fisher Caldera, Westdahl Peak, Akutan Peak, Makushin Volcano, Great Sitkin Volcano, and Kanaga Volcano (Figure 1). Monitoring highlights in 2002 include an earthquake swarm at Great Sitkin Volcano in May-June; an earthquake swarm near Snowy Mountain in July-September; low frequency (1-3 Hz) tremor and long-period events at Mount Veniaminof in September-October and in December; and continuing volcanogenic seismic swarms at Shishaldin Volcano throughout the year. Instrumentation and data acquisition highlights in 2002 were the installation of a subnetwork on Okmok Volcano, the establishment of telemetry for the Mount Veniaminof subnetwork, and the change in the data acquisition system to an EARTHWORM detection system. AVO located 7430 earthquakes during 2002 in the vicinity of the monitored volcanoes.

This catalog includes: (1) a description of instruments deployed in the field and their locations; (2) a description of earthquake detection, recording, analysis, and data archival systems; (3) a description of velocity models used for earthquake locations; (4) a summary of earthquakes located in 2002; and (5) an accompanying UNIX tar-file with a summary of earthquake origin times, hypocenters, magnitudes, and location quality statistics; daily station usage statistics; and all HYPOELLIPSE files used to determine the earthquake locations in 2002.

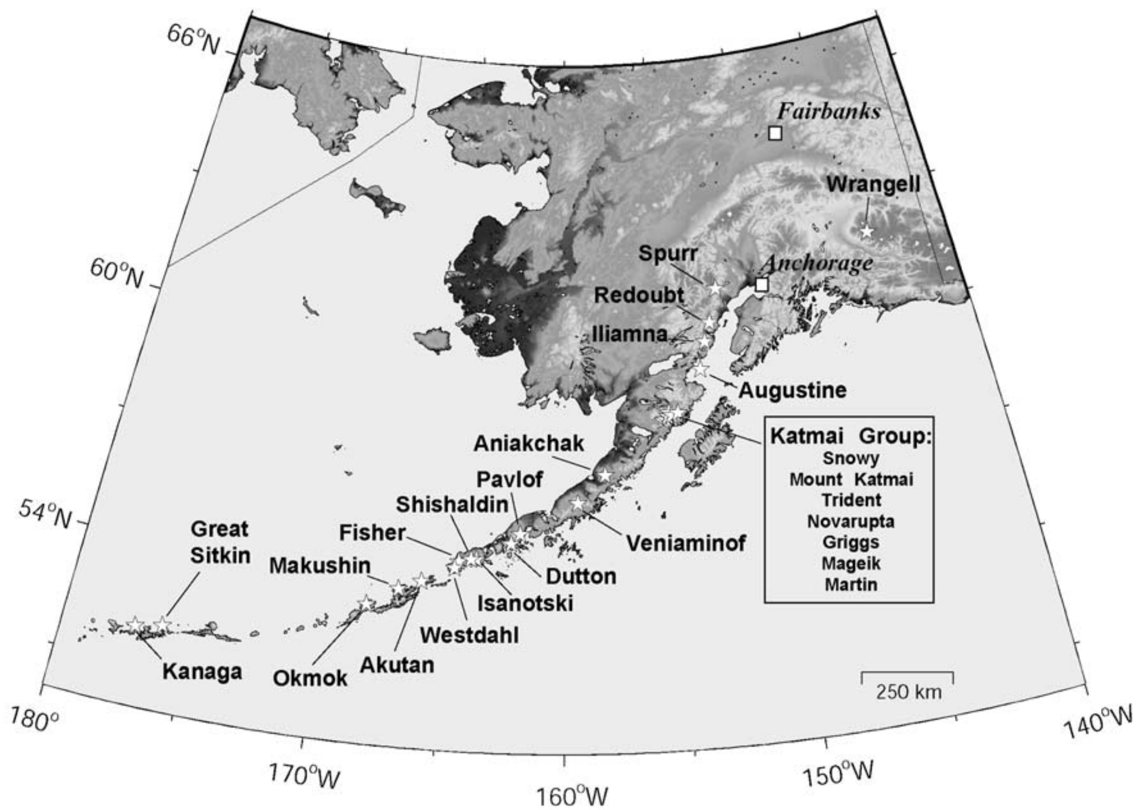

Figure 1. Alaskan volcanoes seismically instrumented by AVO in 2002. Stars show the location of volcanoes and squares show the location of Anchorage and Fairbanks.

Instrumentation

In 2002, a new subnetwork was installed at Okmok Volcano (eight single-component stations) and telemetry was established for the Mount Veniaminof subnetwork. The only change in the existing seismic network was with the Aniakchak subnetwork. The seismic station AJAX was removed and a new station, AZAC, was installed 0.5 km to the northwest of the previous location of AJAX. At the end of 2002, there were 140 permanent seismic stations representing 178 components. In addition to the permanent stations installed by AVO, preliminary work was done for eight broadband sites on Akutan and Okmok Volcanoes planned to be installed in 2003.

Station locations and installation dates for all AVO stations operated during 2002 are contained in Appendix B. Maps showing the locations of stations with respect to individual volcanoes are contained in Appendix C. Other station information such as station calibration information is contained in the HYPOELLIPSE input files and is available for download via computer network as a compressed Unix tar-file. Estimates of each station's operational status through the catalog period are given in Appendix F.

AVO operated 123 short-period vertical-component seismic stations during 2002. All these stations had Mark Products L4 or Teledyne-Geotech S-13 seismometers with a one-second natural period. AVO also operated 16 three-component, short-period instruments during the catalog period. The instruments used at the three component stations were Mark Products L22 seismometers with a 0.5-second period, Mark Products L4 seismometers with a one-second period and Teledyne-Geotech S-13 instruments with a one-second natural period. Guralp CMG-40T 60-second natural period broadband instruments were operated on Augustine Island (AUL) and Akutan Island (AKT) during the report period.

Data were telemetered using voltage-controlled oscillators (VCOs) to transform the ground motion signals from the seismometers to frequency-modulated signals suitable for transmission over a radio link or telephone circuit. AVO used both the A1VCO (Rogers and others, 1980) and McVCO (McChesney, 1999) to modulate signals in the field. These signals were subsequently transmitted via UHF and VHF radio to communication hubs located in Adak, Akutan, Anchorage, Cold Bay, Dutch Harbor, Homer, Kasilof, King Cove, King Salmon, Port Heiden, Sourdough, Sterling, and Tolsona. Signals were then relayed via leased telephone circuits to AVO offices in Anchorage and Fairbanks where the signals were digitized. At the Homer communications hub, the data were digitized at the hub and then directed to AVO offices by modem.

Data Acquisition and Reduction

In January-February 2002, data from AVO subnetworks were digitally recorded at 100 Hz in event-detection mode on PC computers using a modified version of the computer program XDETECT (Rogers, 1993). This program allowed each individual subnetwork to trigger independently. For regional events, a trigger for each subnetwork detecting the event was generated. The event-detected files were transferred to a Sun microcomputer and converted to AH format for routine processing. During the format conversion a one letter code is added to the AH file name to indicate which volcano subnetwork triggered the network. These XDETECT codes are summarized in Table 1.

Table 1: Volcano Subnetwork Designators

Volcano Subnetwork	**XDETECT Code**	**EARTHWORM Code**
Akutan Peak	t	ak
Aniakchak Crater	n	an
Augustine Volcano	a	au
Mount Dutton	d	dt
Iliamna Volcano	i	il
Great Sitkin Volcano	f	gs
Kanaga Volcano	f	ki
Katmai volcanic group	k	ka
Makushin Volcano	m	ma
Pavlof Volcano	v	pv
Redoubt Volcano	r	rd
Regional event	no subnet code	rg
Shishaldin Volcano	h	sh
Mount Spurr	s	sp
Mount Veniaminof	e	vn
Westdahl Peak	w	we
Mount Wrangell	g	wa

In March 2002, a major change was made in the event acquisition system employed by the AVO. The older PC based event acquisition system was replaced by an EARTHWORM acquisition system (Johnson and others, 1995) to standardizing operations with other USGS Volcano Observatories. Two duplicate EARTHWORM acquisition systems were set up in AVO offices in Anchorage and Fairbanks, to provide a backup in case of failure at either location. At this time, the archival format was changed from AH to SAC.

As in the previous detection system, data were triggered based on individual subnets but unlike the previous system, triggered data from regional events were collected into a single trigger. The EARTHWORM modules Carlstatrig and Carlsubtrig was used to create the earthquake triggers. The Carlstatrig parameters were set as follows: LTAtime = 8 seconds, Ratio = 2.3, and Quiet =4. Carlsubtrig was modified so that a two-letter code was appended to the filename of each trigger to identify which subnetwork triggered or if the event was a regional trigger. These EARTHWORM codes are summarized in Table 1.

Event triggers from both detection systems were processed using the interactive seismic data analysis program XPICK (Robinson, 1990), and the earthquake location program HYPOELLIPSE (Lahr, 1999). Each event trigger was visually inspected and classified as either a volcano-tectonic, long-period, hybrid, regional-tectonic, teleseismic, shore-ice, calibration, other non-seismic, or cause unknown event. This classification system was modeled after that described by Lahr and others (1994). The type of event was identified by a classification code (Table 2) and stored in the event location pick file. Event triggers that were created by false signals were deleted at this time. Table 2 shows the classification codes used. Events classified as volcano-tectonic, long-period, or hybrid and having five or more distinct phases at four or more stations were selected for location. Earthquakes with a P-wave and S-wave separation of more than five seconds on the closest stations to the event were assumed to come from non-volcanic sources and

Table 2: Classification codes

Event Classification	**Classification Code**
Volcano-Tectonic	a
Long-Period	b
Hybrid	h
Regional-Tectonic	E
Teleseismic	T
Shore-Ice	i
Calibrations	C
Other non-seismic	o
Cause unknown	x

were typically discarded. The quality of each hypocenter were checked using a computer algorithm that identified events without magnitude, with fewer than three P-phases, with less than one S-phase, and with standard hypocentral errors greater than 15 km. Events not meeting these requirements after further evaluation were removed from the final catalog listing. For the earthquakes located, the average horizontal error was 1.8 km, the average vertical error was 2.8 km, the average number of P-phases used was 6.5, and the average number of S-phases used was 4.8.

Velocity Models

AVO currently employs eight local velocity models and one regional seismic velocity model (Appendix D) to locate earthquakes at the twenty-four monitored volcanoes. All velocity models are one-dimensional models utilizing horizontal layers to approximate the local seismic velocity structures. Each model, with one exception, assumes a series of constant velocity layers. The single exception is the Akutan velocity model (Power and others, 1996), which has a velocity gradient in the top layer overlying a layer with a constant velocity. The local velocity models were developed using a variety of methods.

One or more vertical cylinders are used to model the volcanic source zones on all volcanoes where a local volcano-specific velocity model exists. Earthquakes within these cylindrical volumes are located with a local model and earthquakes outside of the cylindrical volumes are located with the regional model. All cylindrical volumes have a radius of 20 km with the exception of the cylinder centered on Shishaldin Volcano. The cylinder centered on Shishaldin Volcano has a radius of 30 km in order to encompass Isanotski Peaks. The top of each cylinder is set at a depth of –3 km (1.e. 3 km elevation) with respect to sea level and the bottom is set at a depth of 50 km with respect to sea level.

The Akutan, Augustine (Power, 1988), and Iliamna (Roman and others, 2001) velocity models are used to locate hypocenters that lie within a single cylindrical volume centered on each volcano. The Cold Bay velocity model (McNutt and Jacob, 1986) is used to locate hypocenters that fall within single cylindrical volumes centered on Mount Dutton and Pavlof Volcano. Hypocenters on Fisher Caldera, Isanotski Peaks, Shishaldin Volcano, and Westdahl Peak that fall within the cylindrical regions centered on Shishaldin Volcano and Westdahl Peak and are located with the Cold Bay velocity model. Five overlapping cylinders define the area in which the Spurr velocity model (Jolly and others, 1994) is used, four overlapping cylinders define the area in which the Redoubt velocity model (Lahr and others, 1994) is used, and four overlapping cylinders define the area in which the Katmai model (Jolly, 2000) is used. The Andreanof velocity model (Toth and Kisslinger, 1984) is used to locate hypocenters within a volume defined by three cylinders centered on Kanaga Volcano, Mount Moffet, and Great Sitkin Volcano. Specific velocity models for Aniakchak Crater, Makushin Volcano, Mount Veniaminof, and Mount Wrangell have not been developed, thus the regional velocity model (Fogleman and others, 1993) is used to locate hypocenters surrounding these volcanoes. The cylindrical model parameters, regional velocity model, and volcano-specific models used to locate earthquakes in this report are summarized in Appendix D. Figures showing the volcanic source zones modeled by cylinders in map view are shown in Appendix E.

Seismicity

The 7430 earthquakes located in 2002 represent a significant increase in the total number of hypocenters determined by AVO in a single calendar year. This is a dramatic increase from the 1488 earthquakes located in 2001. The numbers of located events for each volcano subnetwork are shown in Table 3. We attribute the increase in located events to the change in the triggering algorithm since increases in detected seismic activity were seen on the majority of subnetworks after the change in the triggering algorithm. If one excludes earthquake swarms located at Snowy Mountain, Shishaldin Volcano and in the Adak region, the effect of the change in the event detection system was a three-fold increase in the number of earthquakes located. If the 2002 earthquake swarms are included, the increase in located events was 450%. Decreases in activity were only seen in the Aniakchak and Makushin subnetworks. At Aniakchak the seismicity rate is low and during 2002, the field instrumentation was plagued by failures that make rate comparisons difficult. In 2001, we located 158 earthquakes at Makushin, which is comparable to the 109 earthquakes located during 2002, and within the normal range of variation.

Table 3: Number of earthquakes located for each subnetwork in 2002.

Volcano Subnetwork	**Earthquakes located in 2001**	**Earthquakes located in 2002**
Mount Wrangell	72	314
Mount Spurr	30	420
Redoubt Volcano	24	91
Iliamna Volcano	41	311
Augustine Volcano	70	226
Katmai volcanic group	540	1581
Aniakchak Crater	12	4
Mount Veniaminof	no network installed	18
Pavlof Volcano	13	88
Mount Dutton	2	0
Shishaldin Volcano	51	2620
Westdahl Peak	3	11
Akutan Peak	3	30
Makushin Volcano	158	109
Great Sitkin Volcano	165	417
Kanaga Volcano	7	21
Totals	1488	7430

Summary

Between January 1, 2002, and December 31, 2002, AVO located 7430 earthquakes that occurred at or near volcanoes in Alaska. Highlights of the AVO seismic monitoring program include low frequency tremor and long period events at Mount Veniaminof, continuing seismic swarms at Shishaldin Volcano, and earthquake swarms near Snowy Mountain and Great Sitkin Volcano. A new seismic subnetwork was installed on Okmok Volcano.

Available for download with this report is a compressed Unix tar-file containing a summary listing of earthquake hypocenters and all the necessary HYPOELLIPSE files including station information, model information, and phase information to relocate earthquake hypocenters. The reader should refer to Lahr (1999) for information on file formats and instructions for configuring and running the location program HYPOELLIPSE. Archives of waveform data are maintained on CDROM at AVO offices in Fairbanks and Anchorage.

Acknowledgements

The contents of this report reflect a great deal of hard work by a large number of people including AVO, AEIC, and USGS personnel and various students, interns and volunteers. We thank Jackie Caplan-Auerbach, Ben Pauk, and Stephanie Prejean, for formal reviews of the text and figures.

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Appendix A: Maps showing the locations of the earthquakes located in 2002.

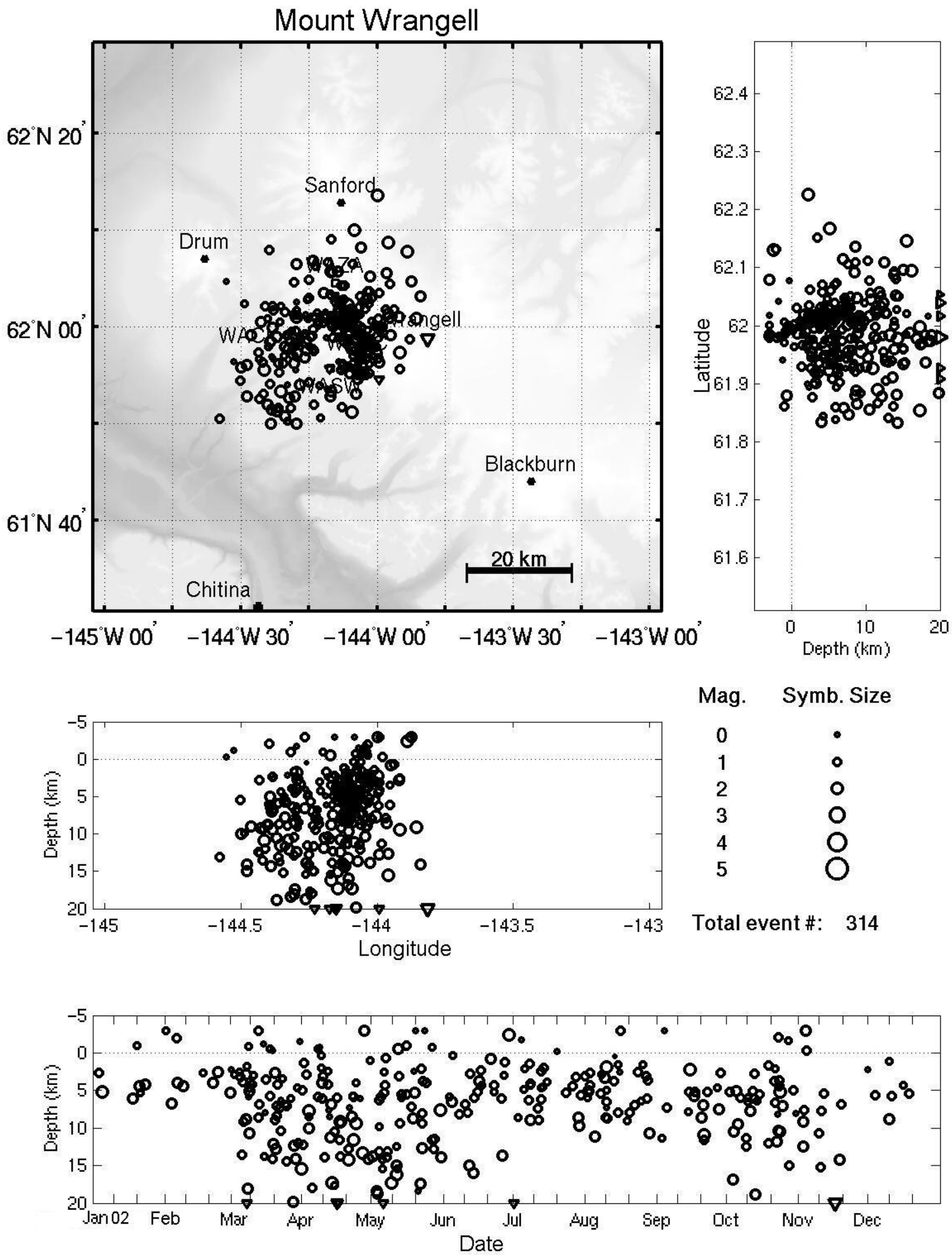


Figure A1. Summary plots of 314 earthquakes located near Mount Wrangell in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

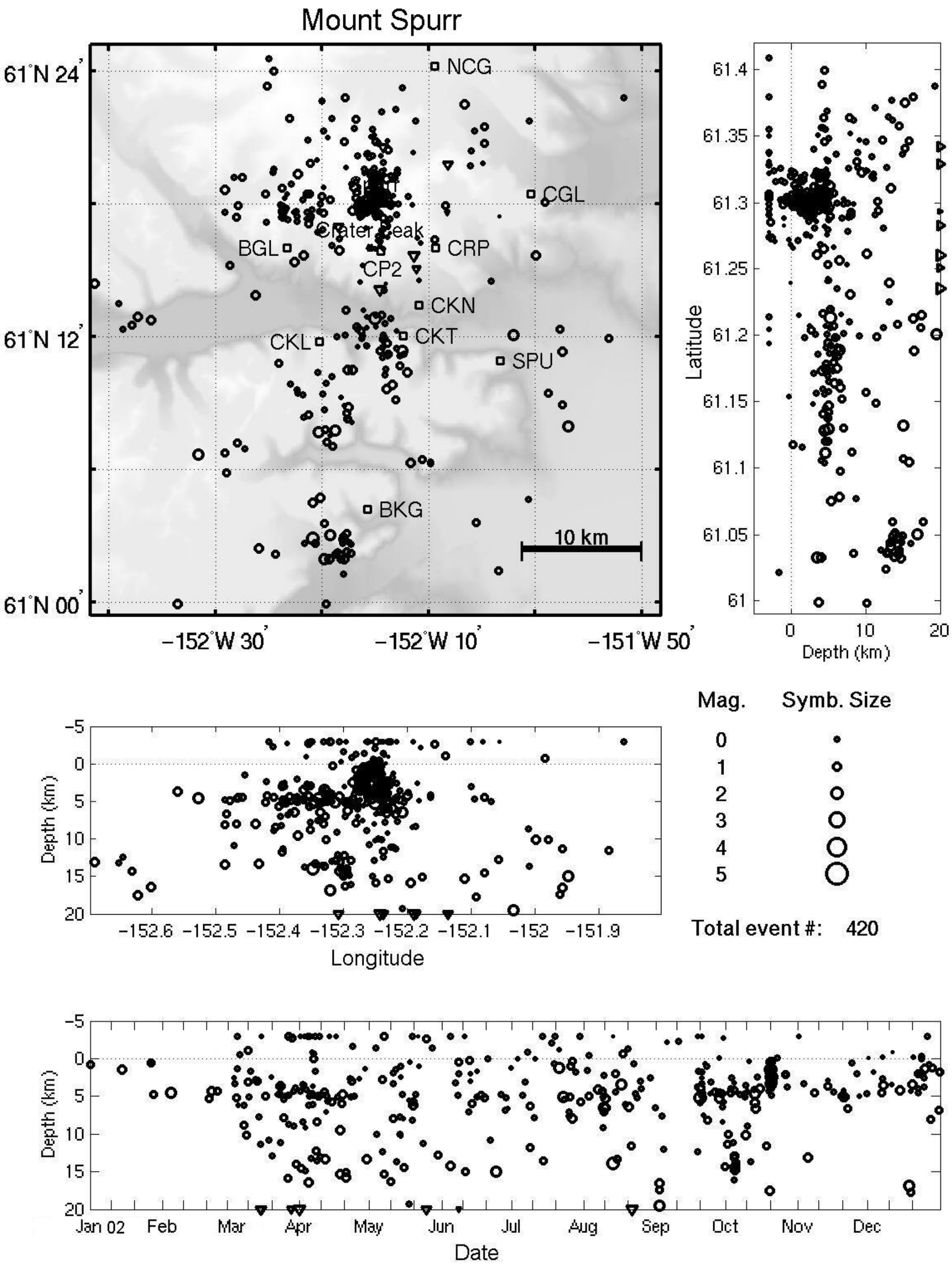


Figure A2. Summary plots of 420 earthquakes located near Mount Spurr in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

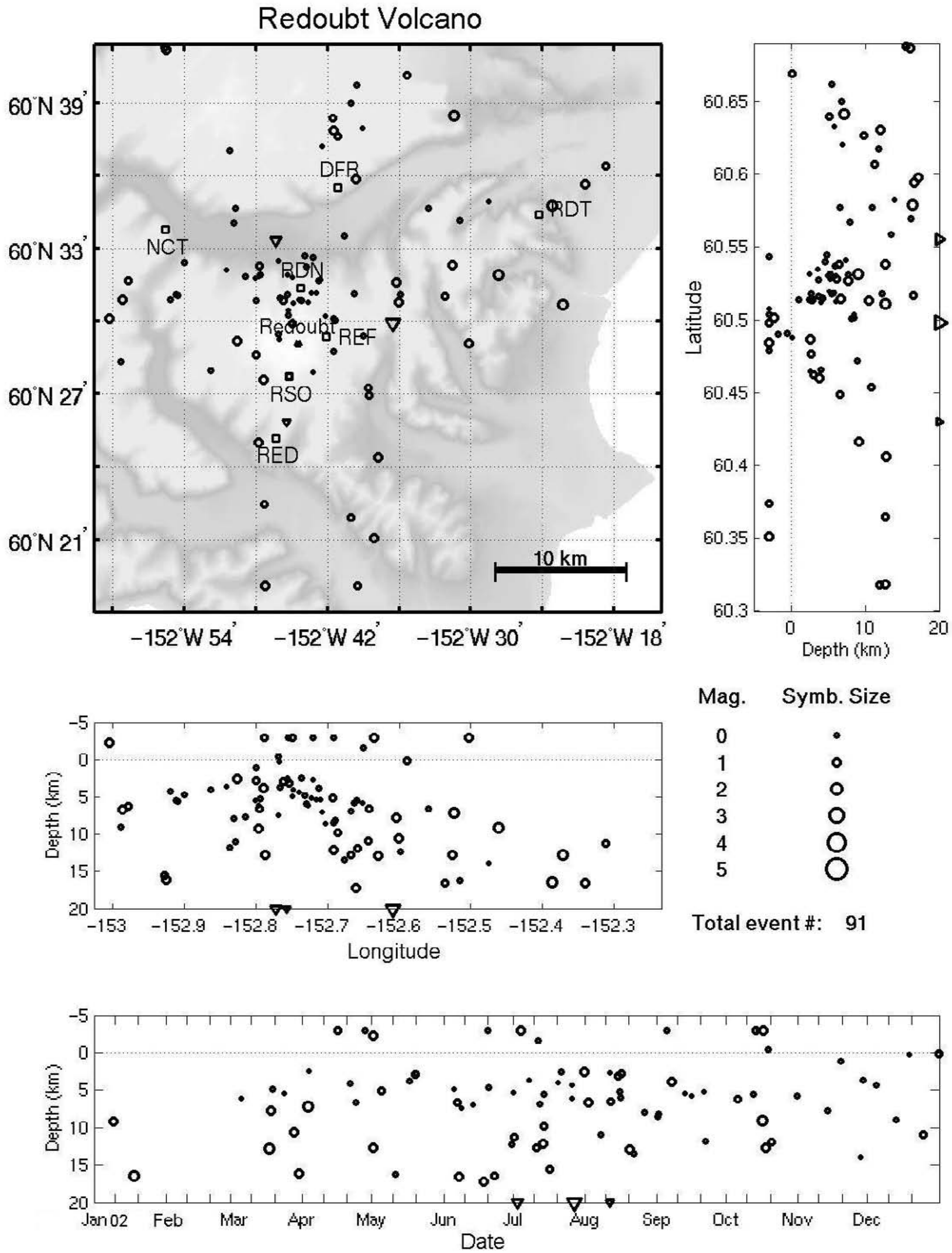


Figure A3. Summary plots of 91 earthquakes located near Redoubt Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

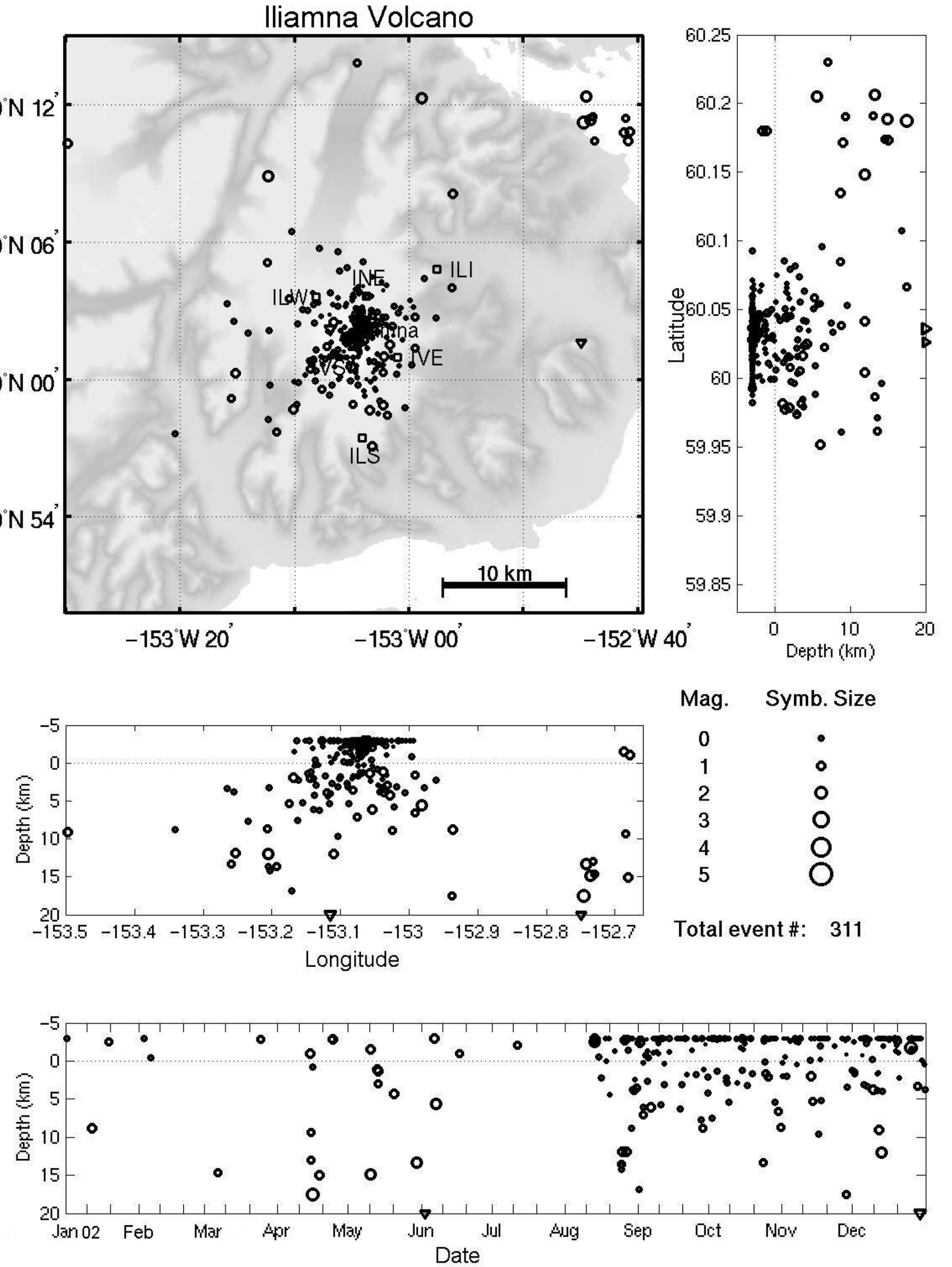


Figure A4. Summary plots of 311 earthquakes located near Iliamna Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The apparent increase in activity is due to several Iliamna seismic stations coming back on-line in late August following the summer field season.

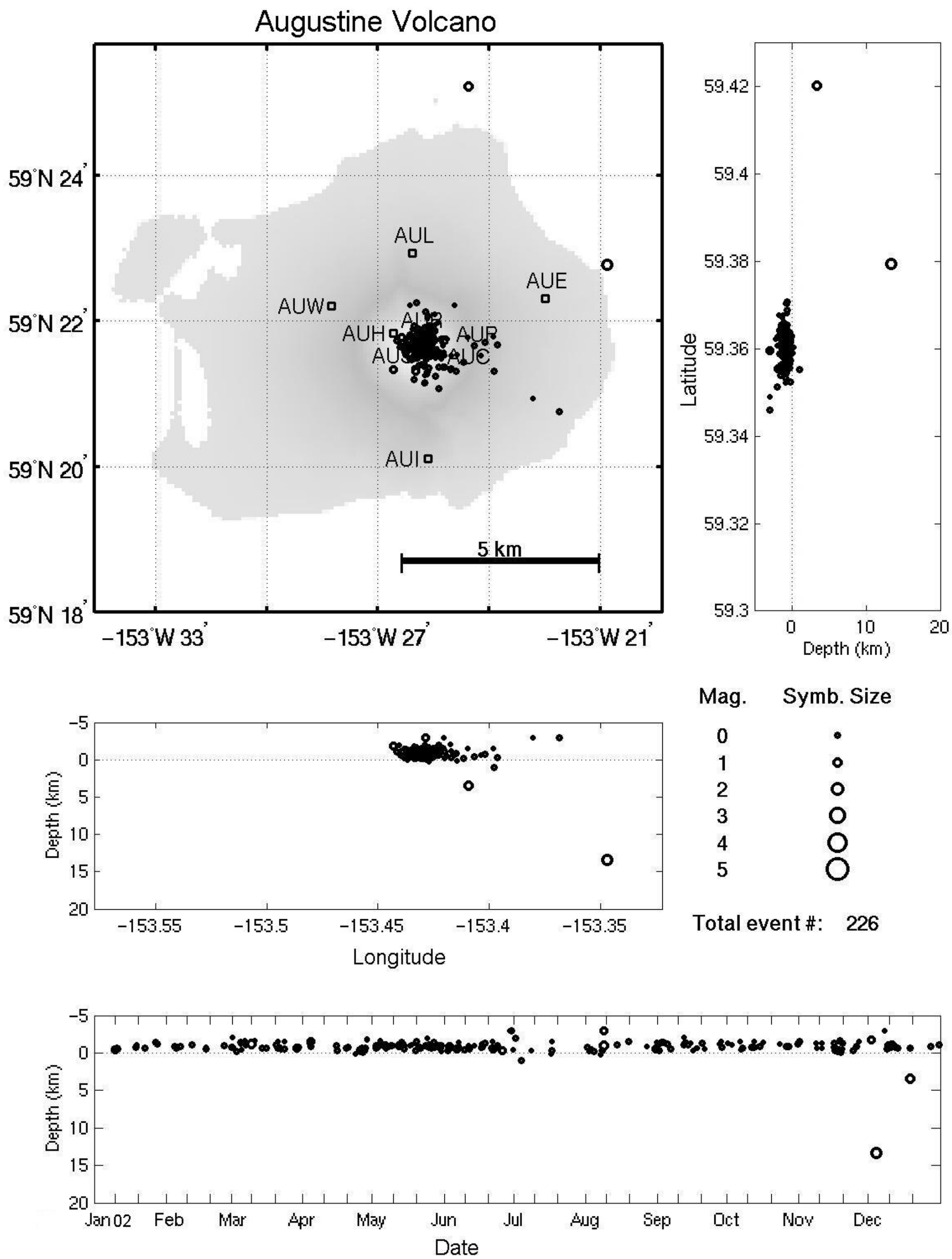


Figure A5. Summary plots of 226 earthquakes located near Augustine Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

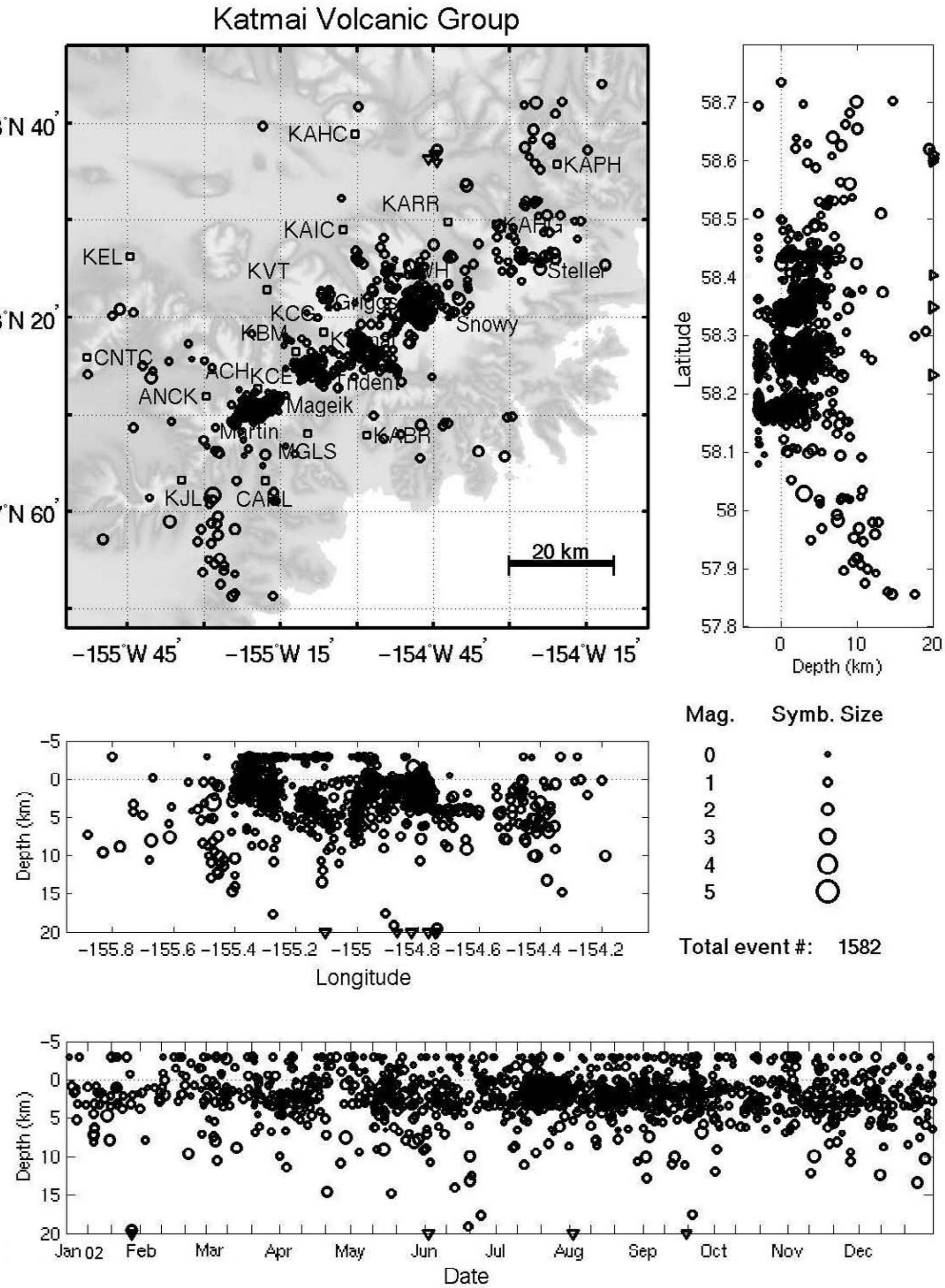


Figure A6. Summary plots of 1582 earthquakes located near the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

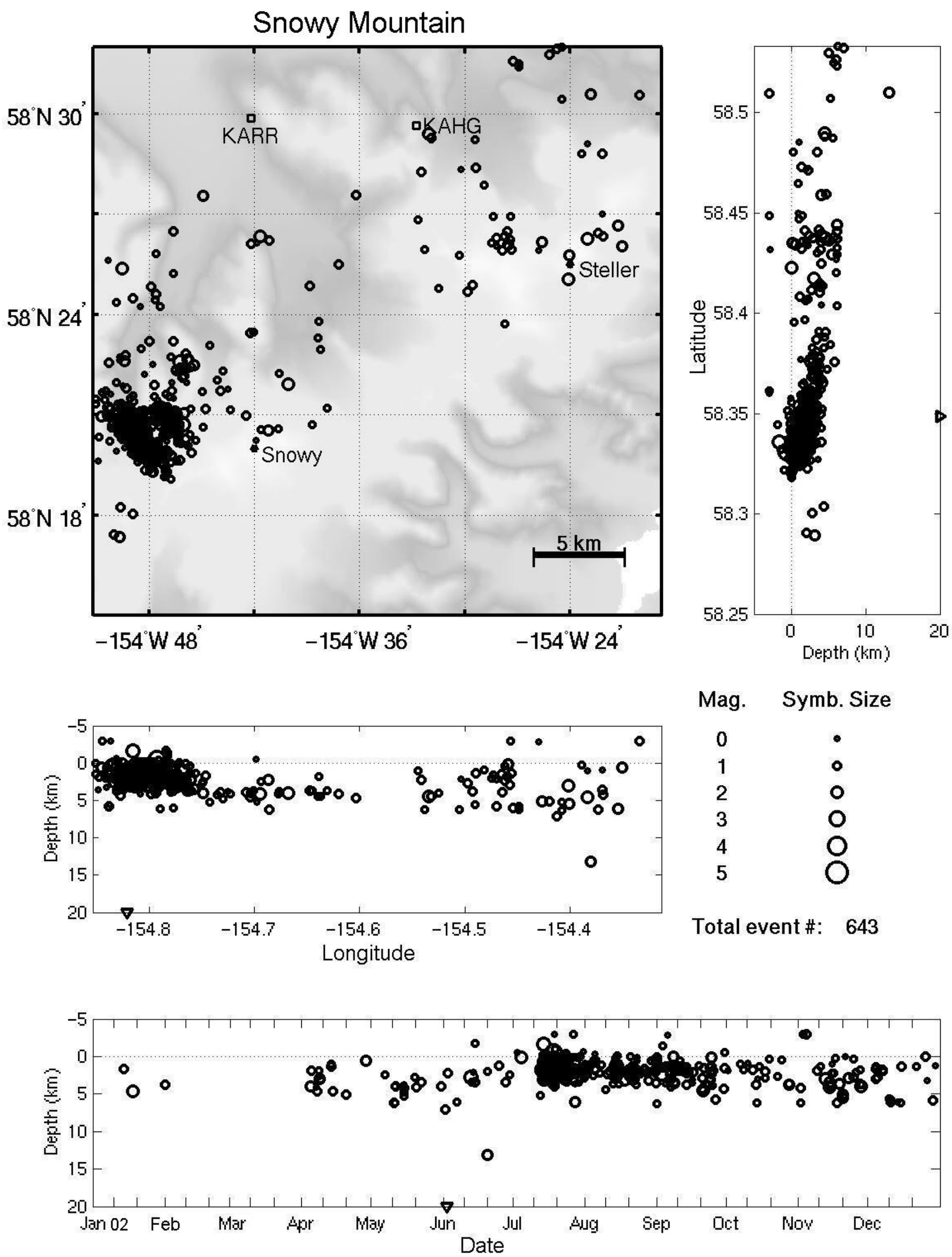


Figure A7. Summary plots of 643 earthquakes located near Snowy Mountain in the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The earthquake swarm 5-10 km west of Snowy Mountain in July-September accounts for 85% of all earthquakes in the Snowy Mountain region.

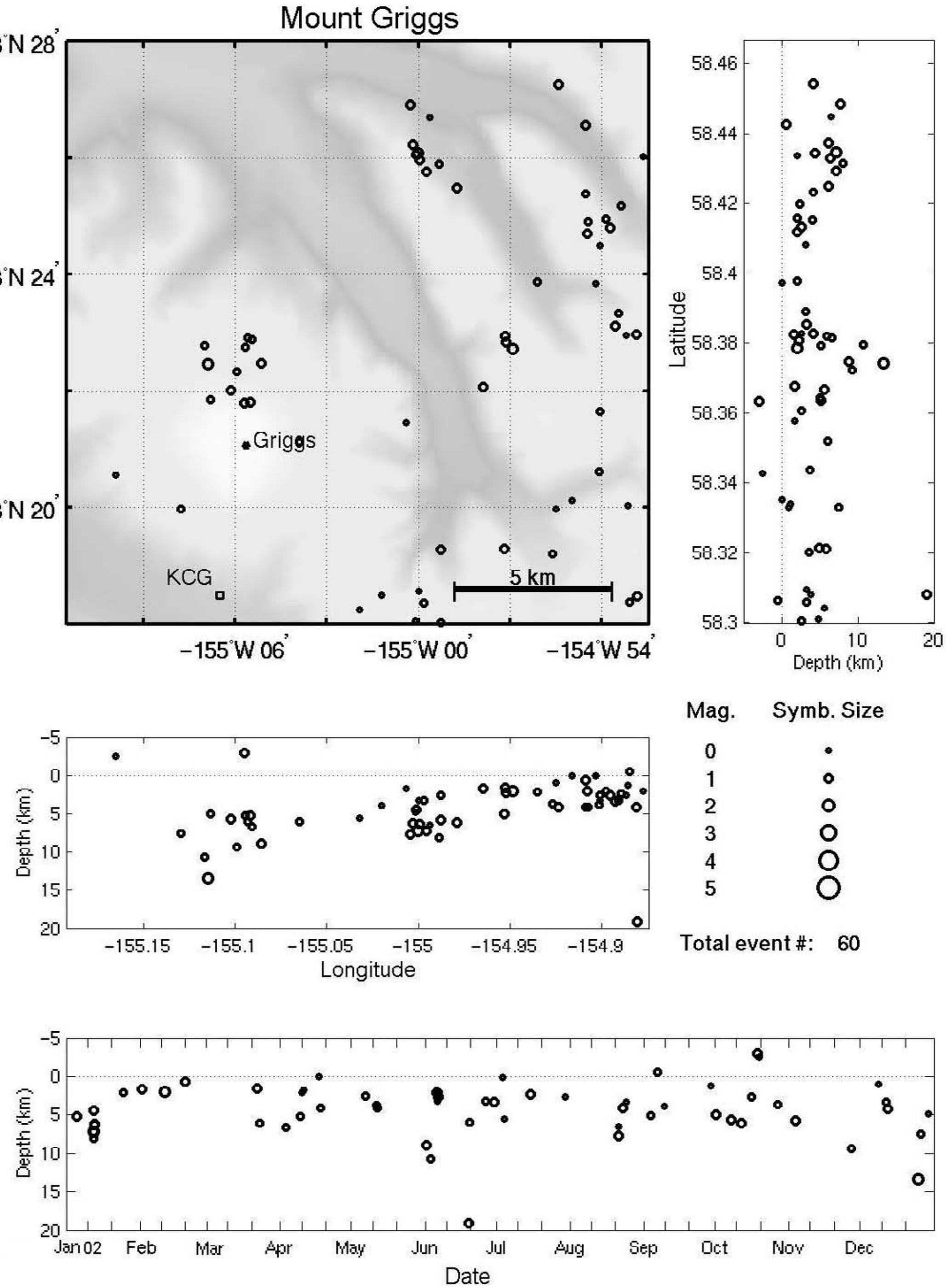


Figure A8. Summary plots of 60 earthquakes located near Mount Griggs in the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

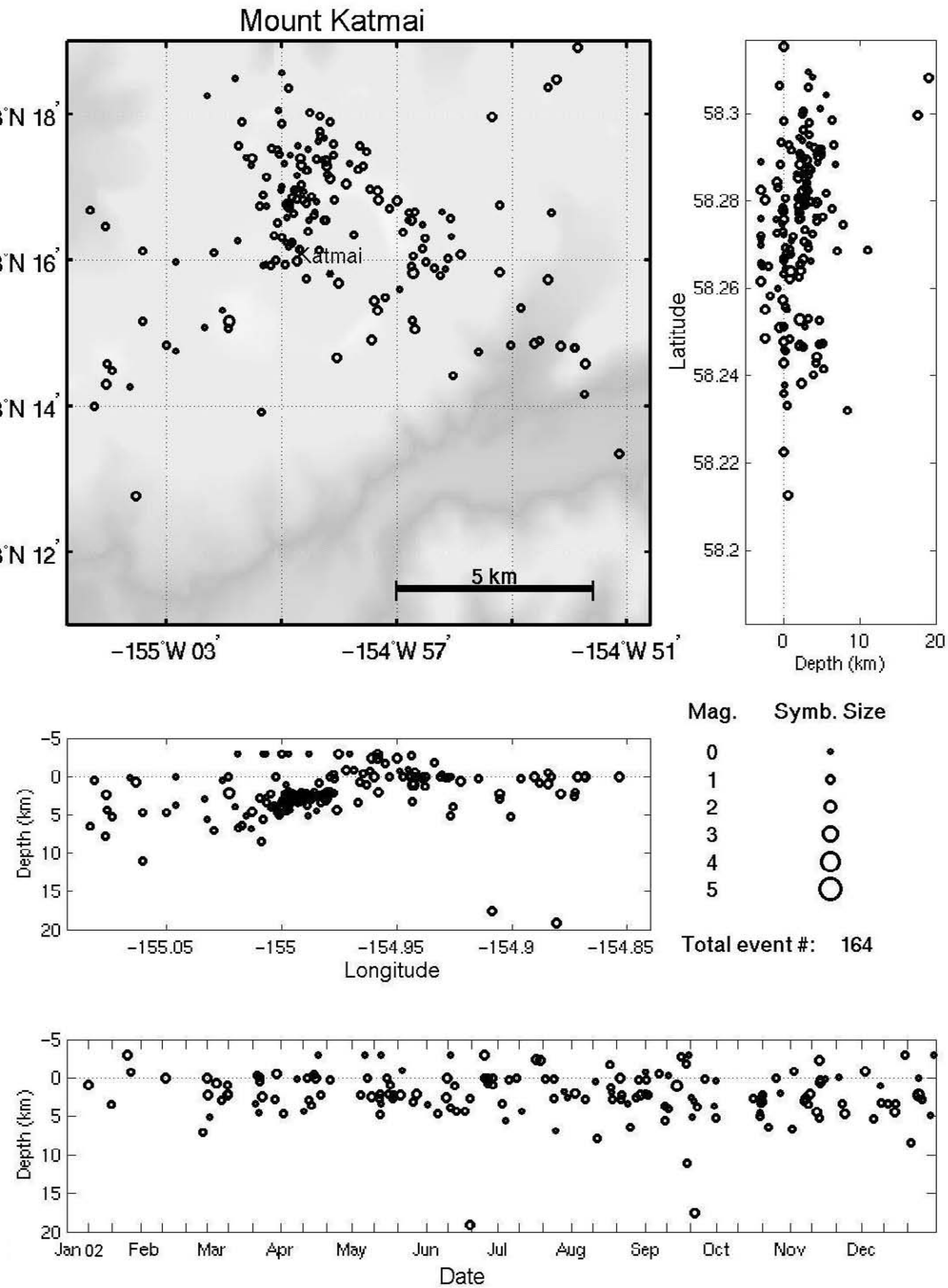


Figure A9. Summary plots of 164 earthquakes located near Mount Katmai in the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

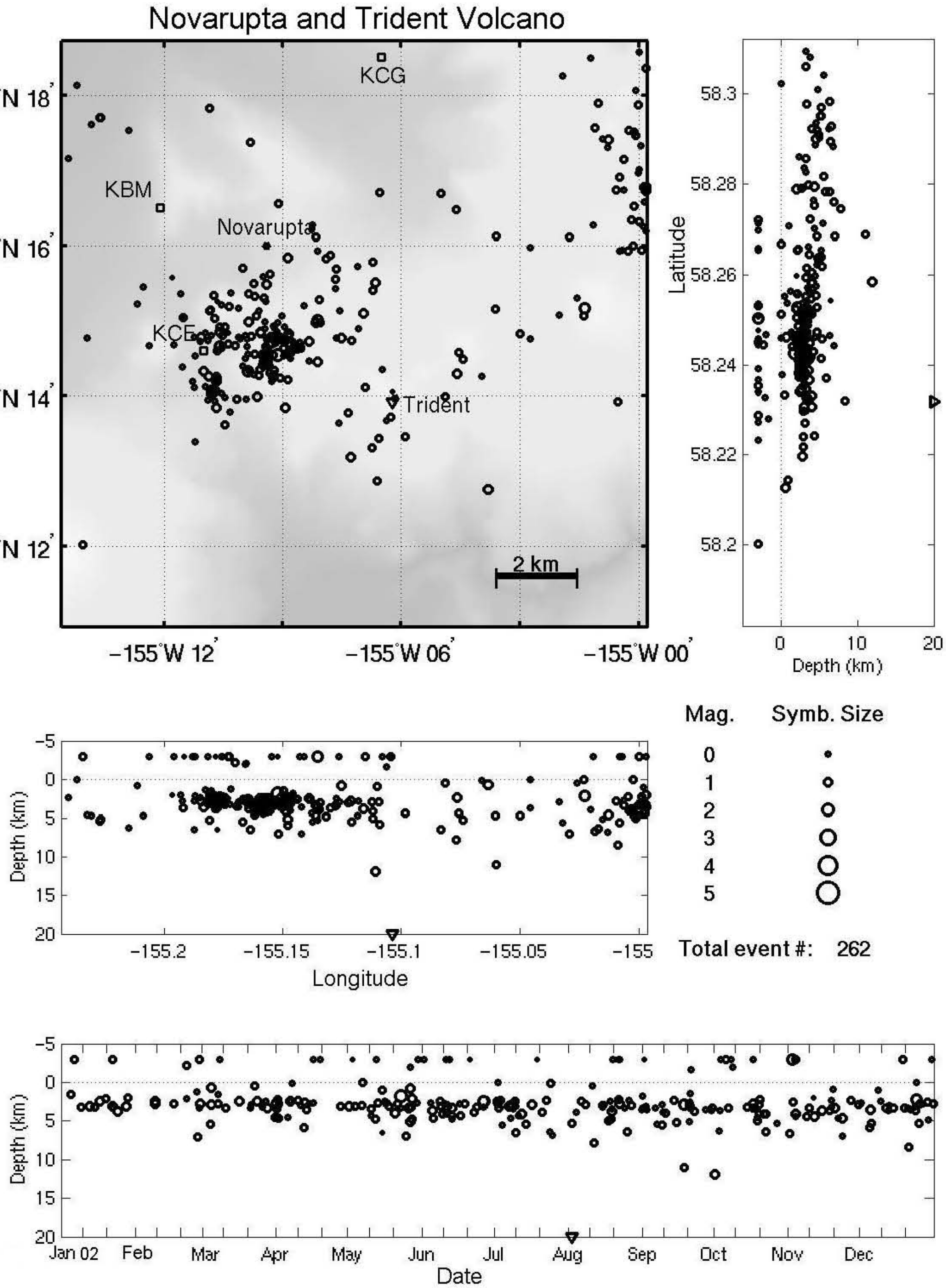


Figure A10. Summary plots of 262 earthquakes located near Novarupta and Trident Volcano in the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

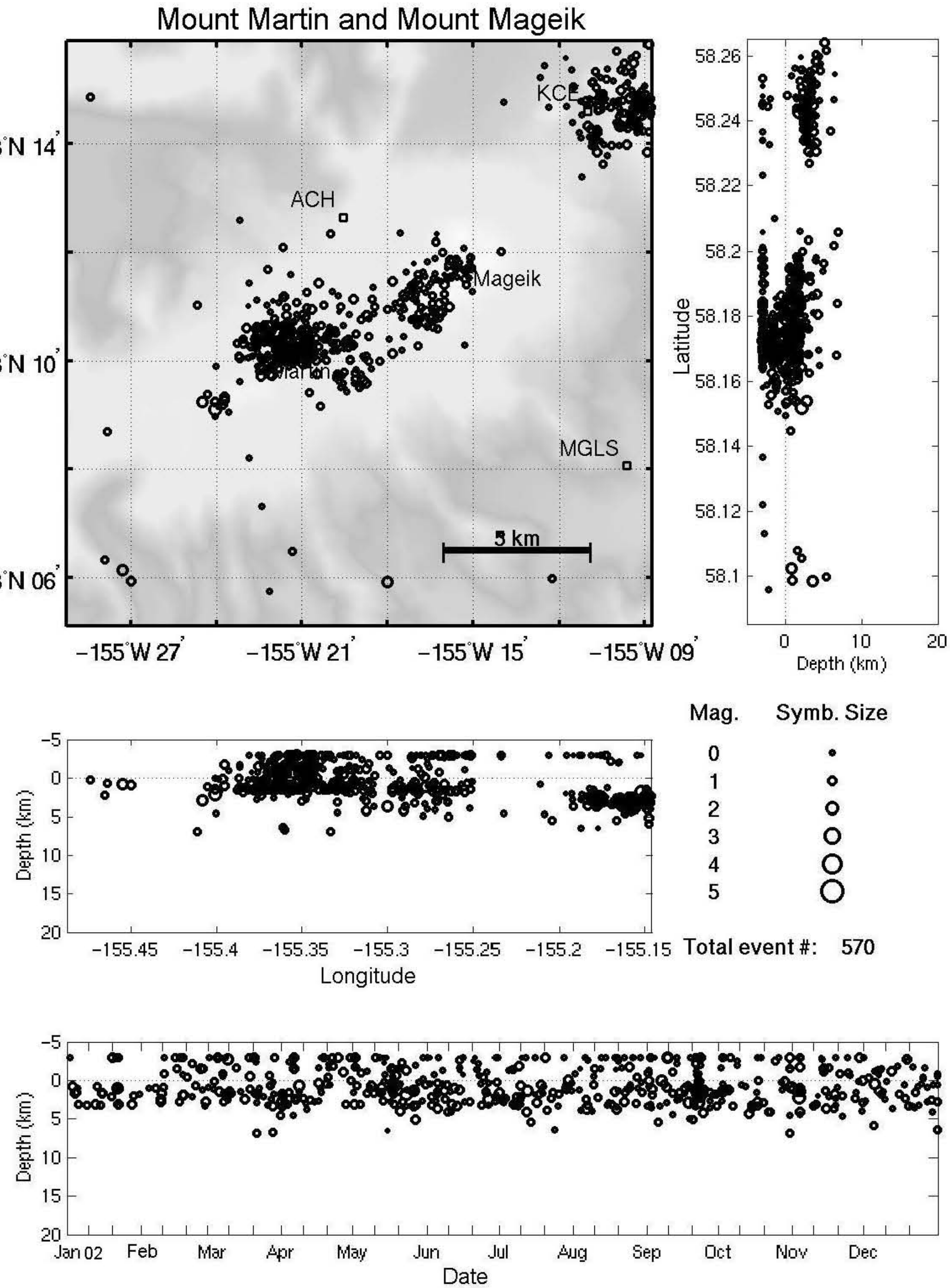


Figure A11. Summary plots of 570 earthquakes located near Mount Mageik and Mount Martin in the Katmai volcanic group in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

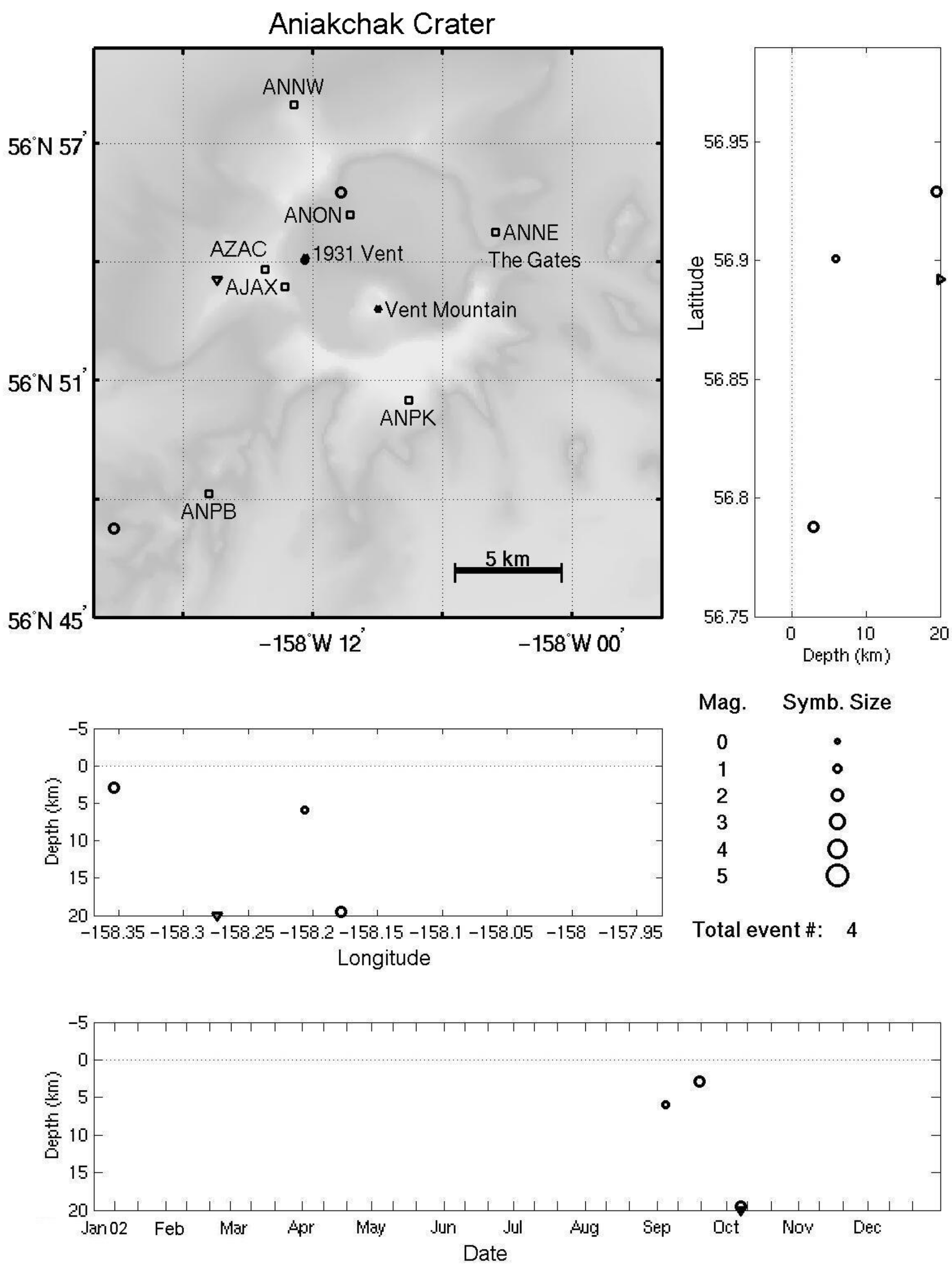


Figure A12. Summary plots of four earthquakes located near Aniakchak Crater in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The Aniakchak subnetwork was repaired in the summer of 2002, and contributed to the apparent lack of seismicity in the first half of 2002.

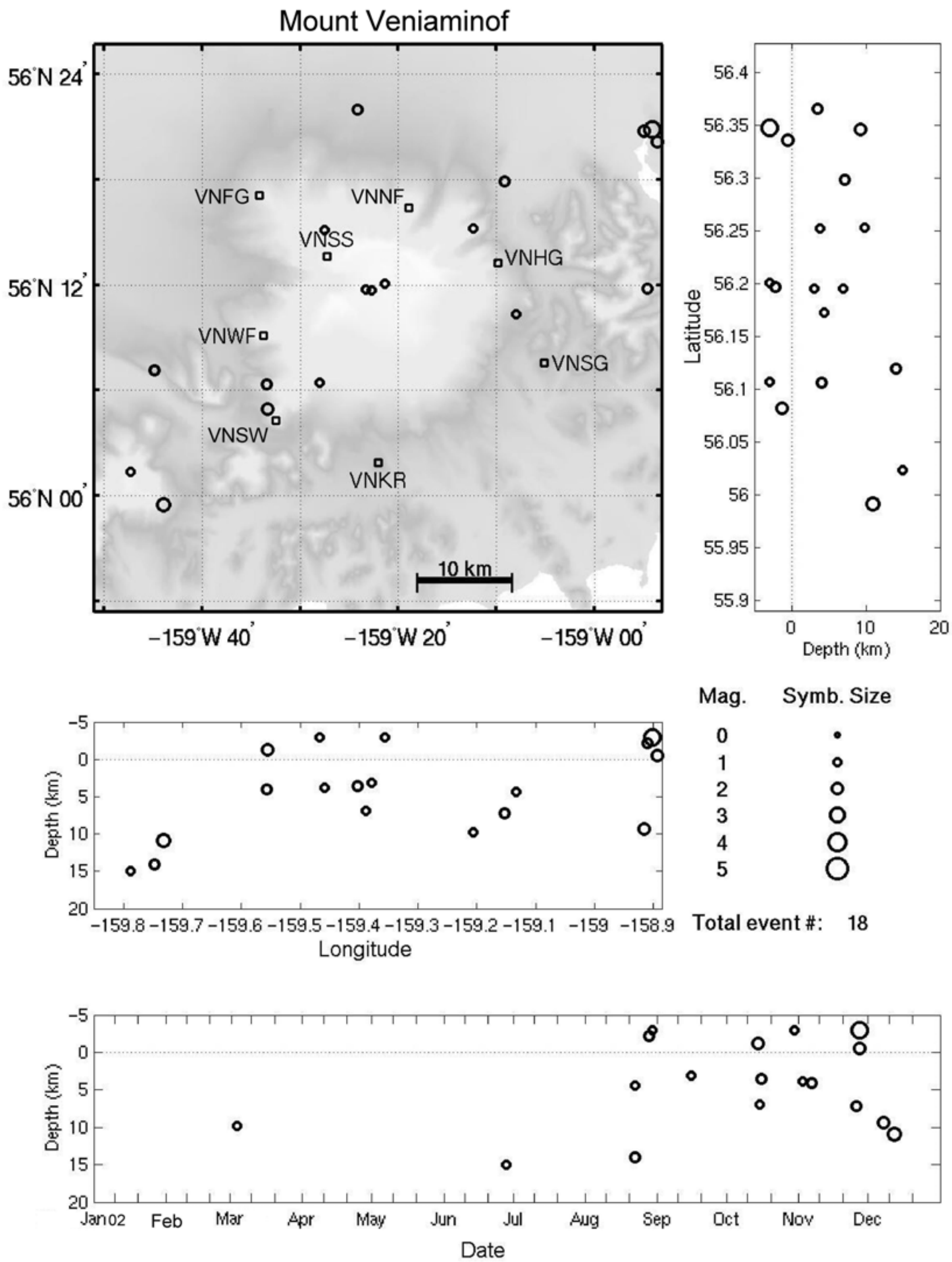


Figure A13. Summary plots of 18 earthquakes located near Mount Veniaminof in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The Veniaminof sub-network telemetry was permanently installed in the summer of 2002.

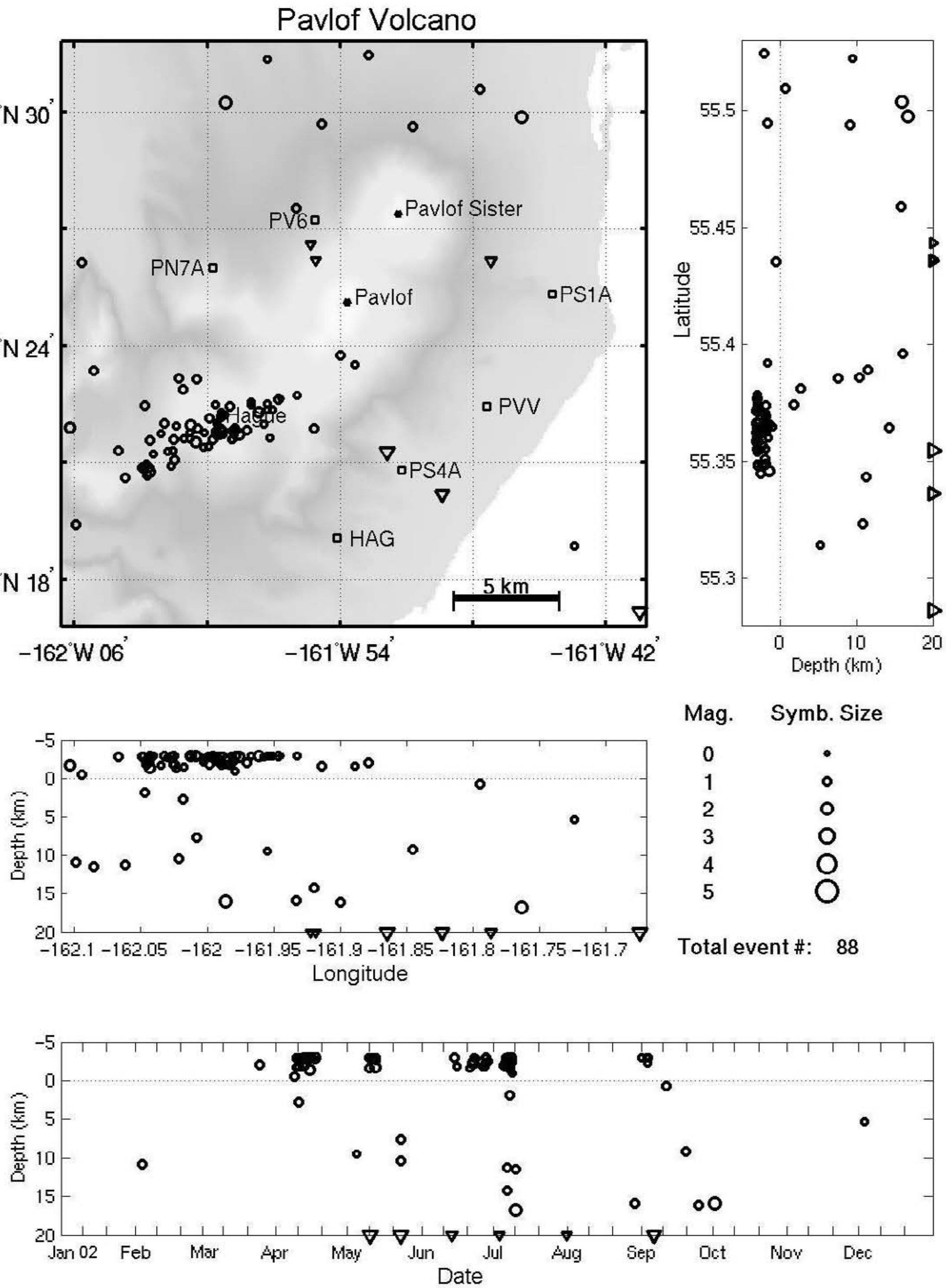


Figure A14. Summary plots of 88 earthquakes located near Pavlof Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

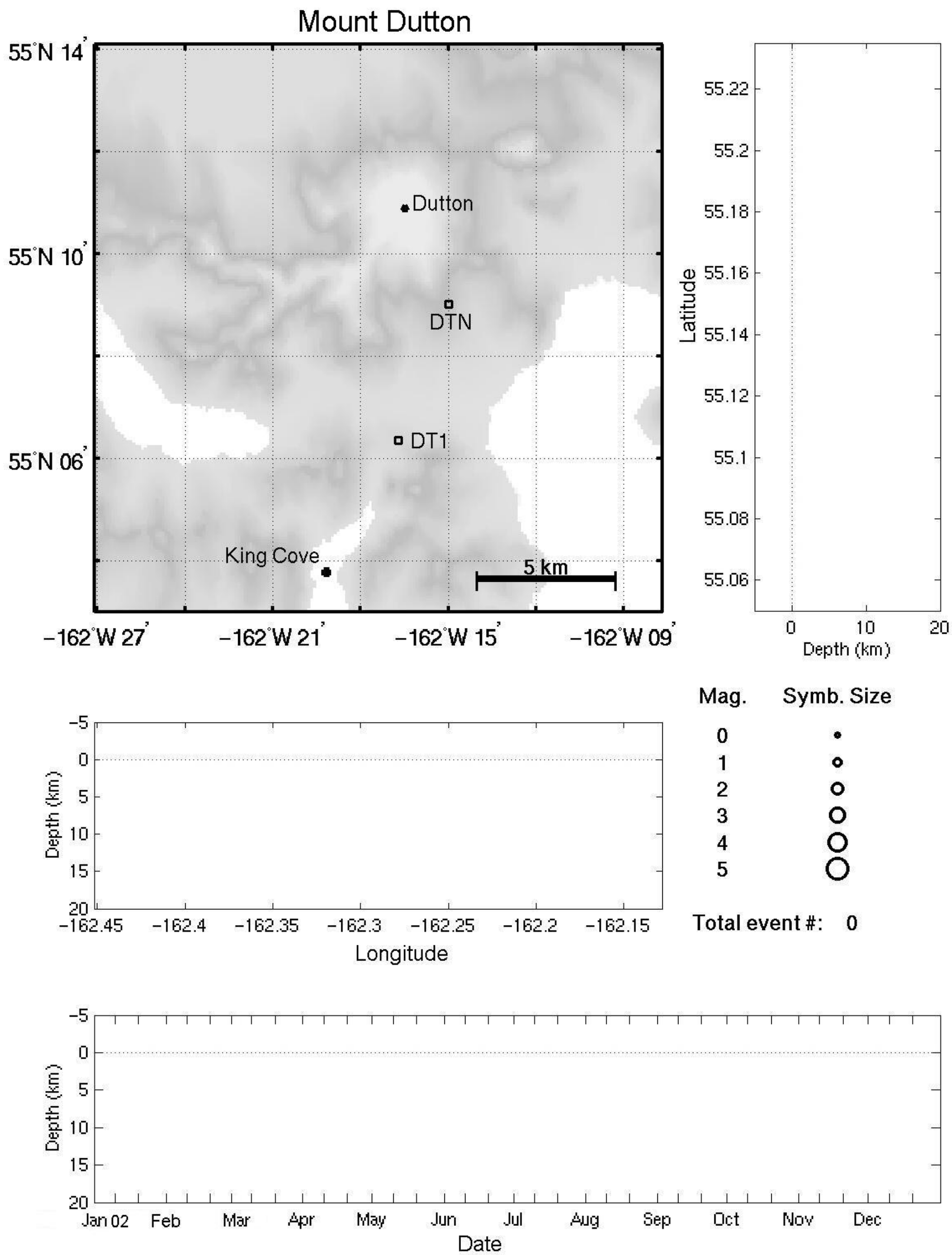


Figure A15. This summary plot shows no earthquakes located near Mount Dutton in 2002. Seismic stations DTN and DT1 were down throughout the year, contributing to the lack of detected seismicity. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

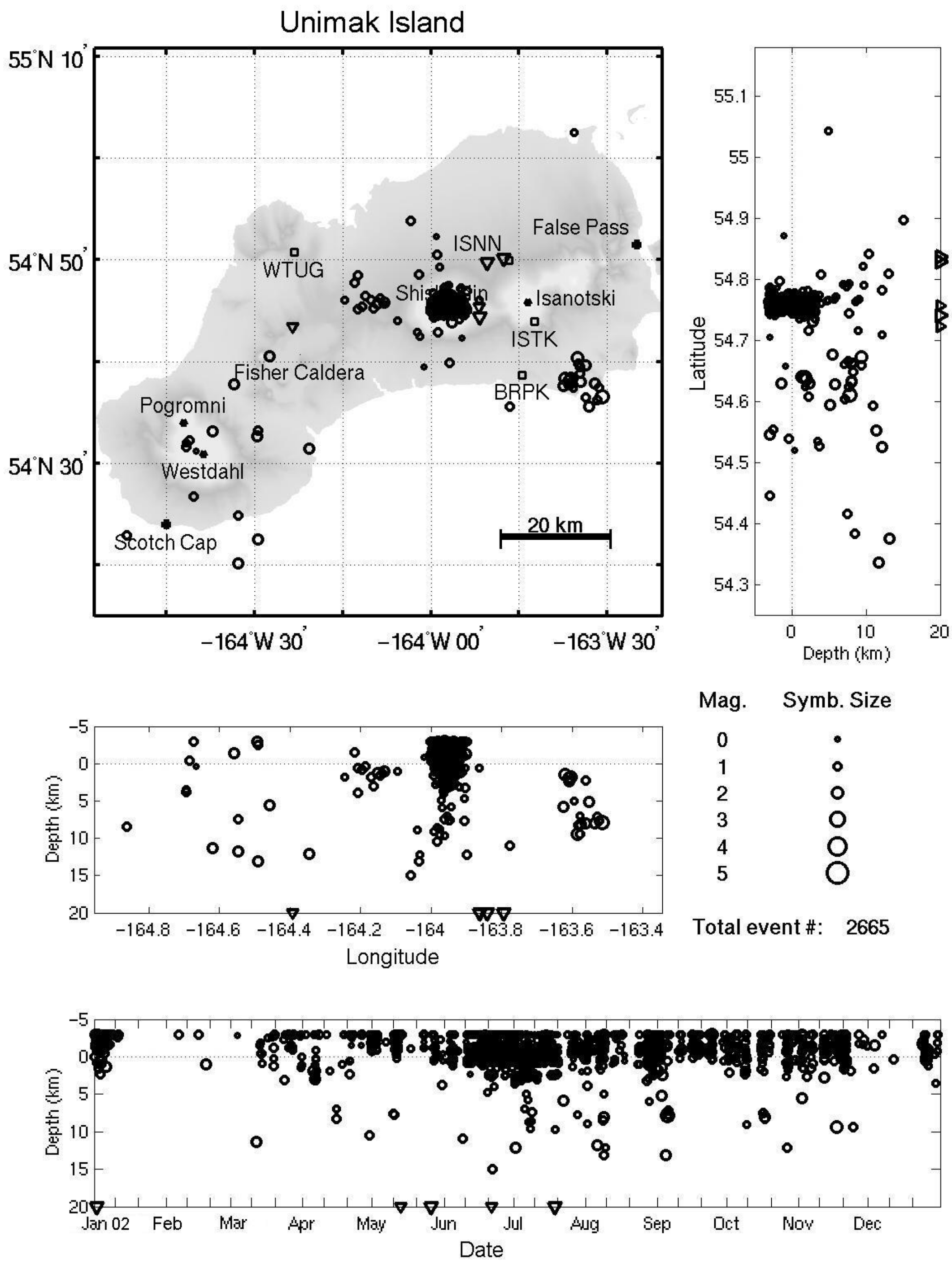


Figure A16. Summary plots of 2665 earthquakes located near Unimak Island in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

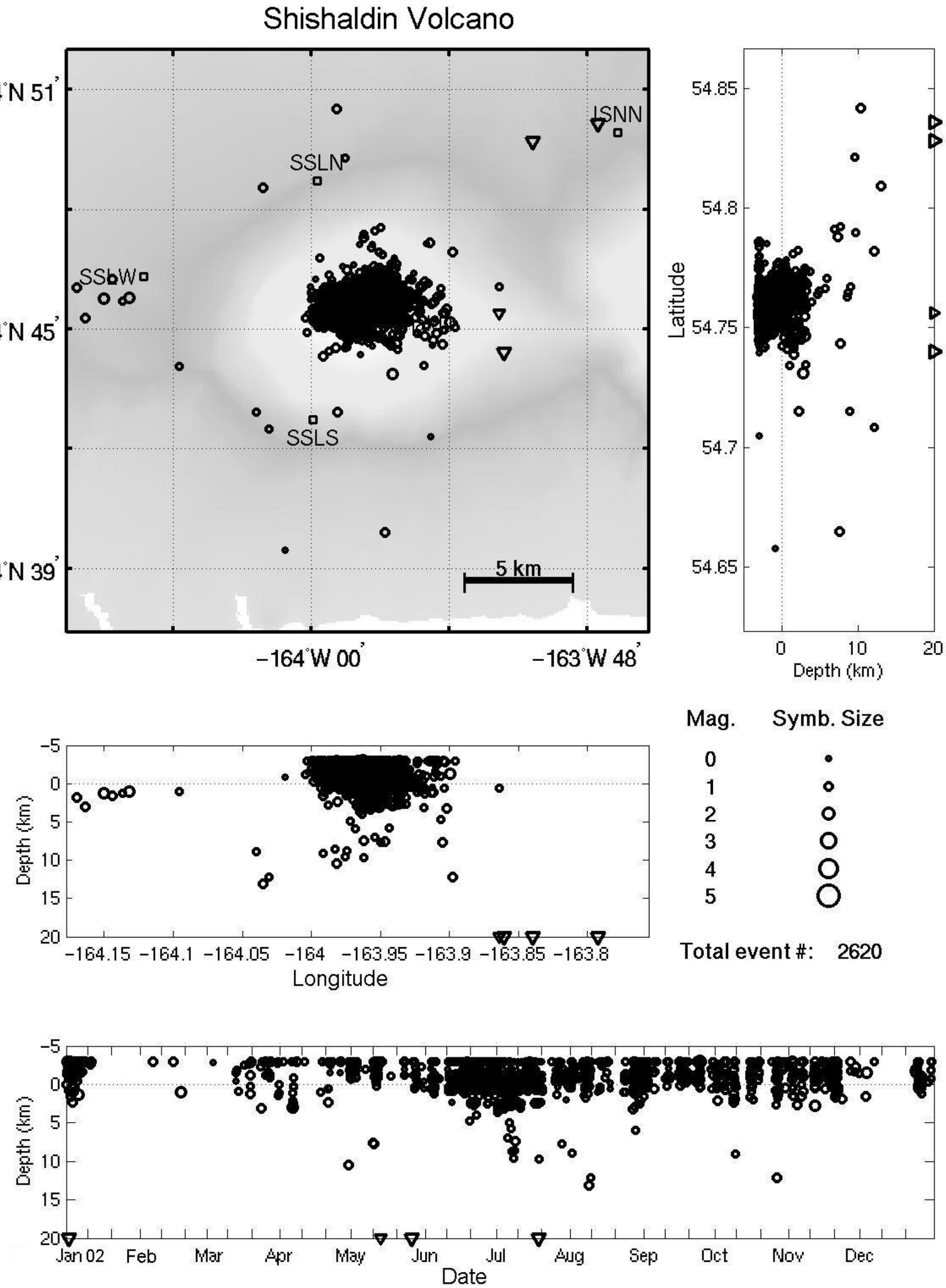


Figure A17. Summary plots of 2620 earthquakes located near Shishaldin Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

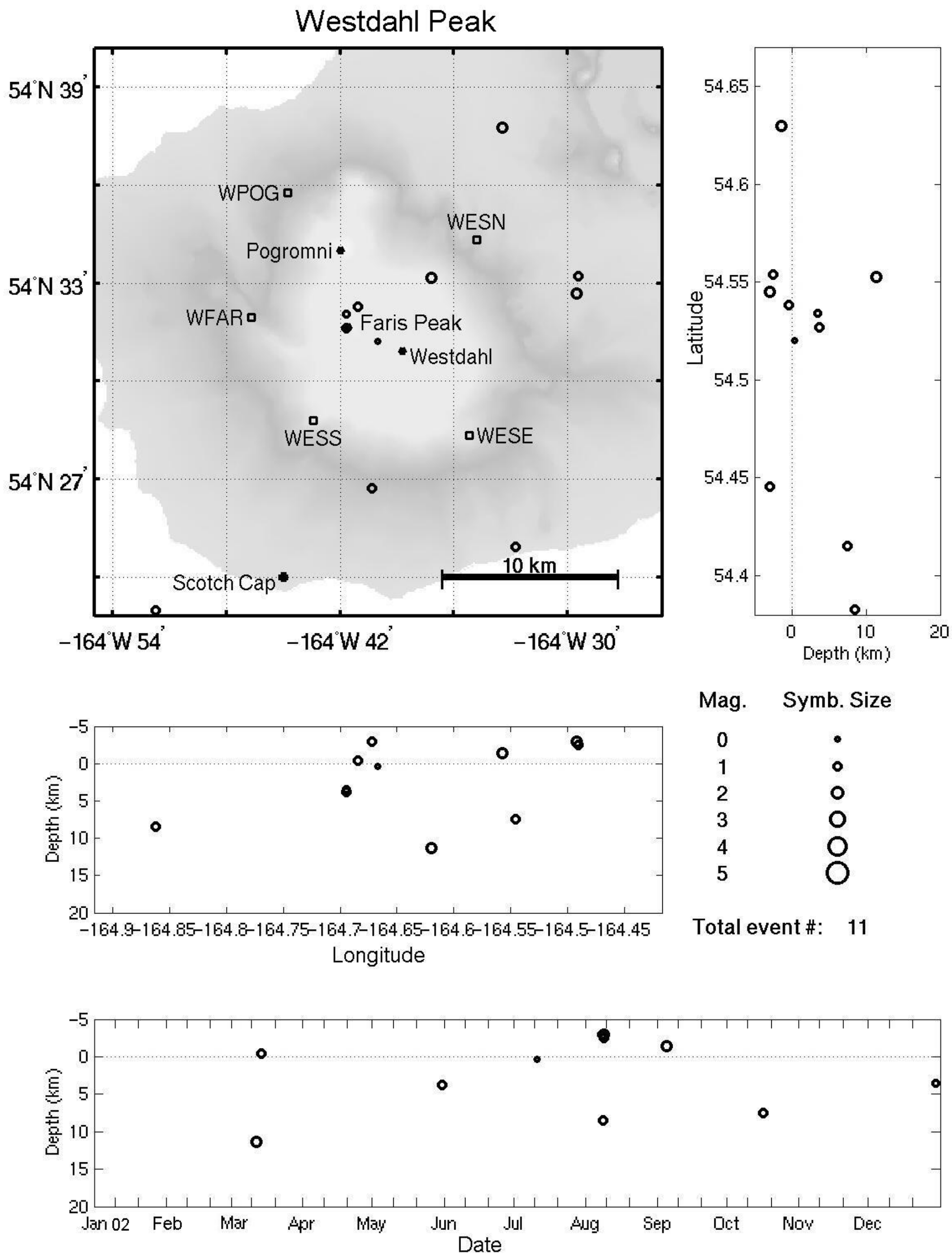


Figure A18. Summary plots of 11 earthquakes located near Westdahl Peak in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

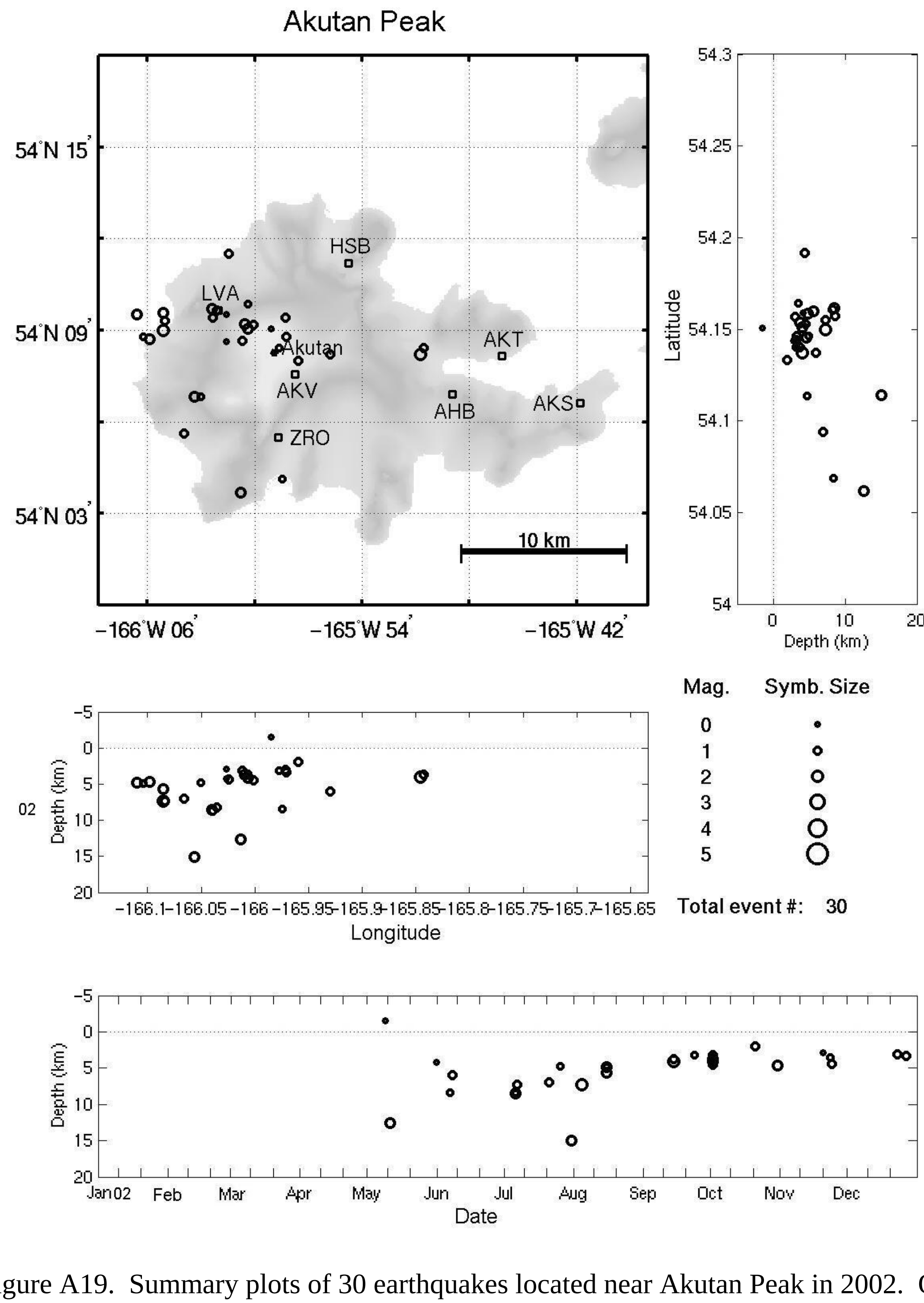


Figure A19. Summary plots of 30 earthquakes located near Akutan Peak in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The apparent increase in seismic activity is an artifact of station outages before May 2002.

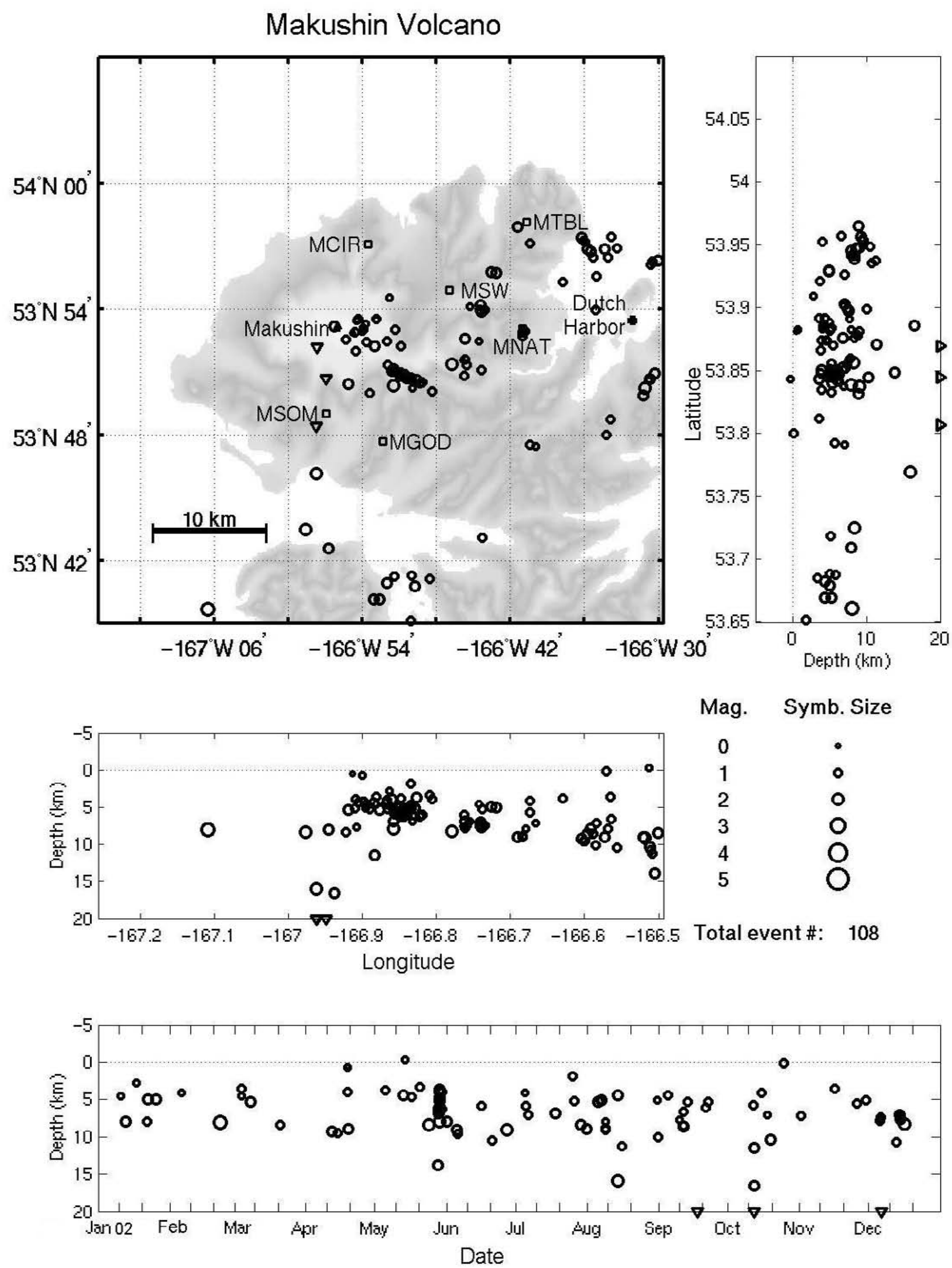


Figure A20. Summary plots of 108 earthquakes located near Makushin Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

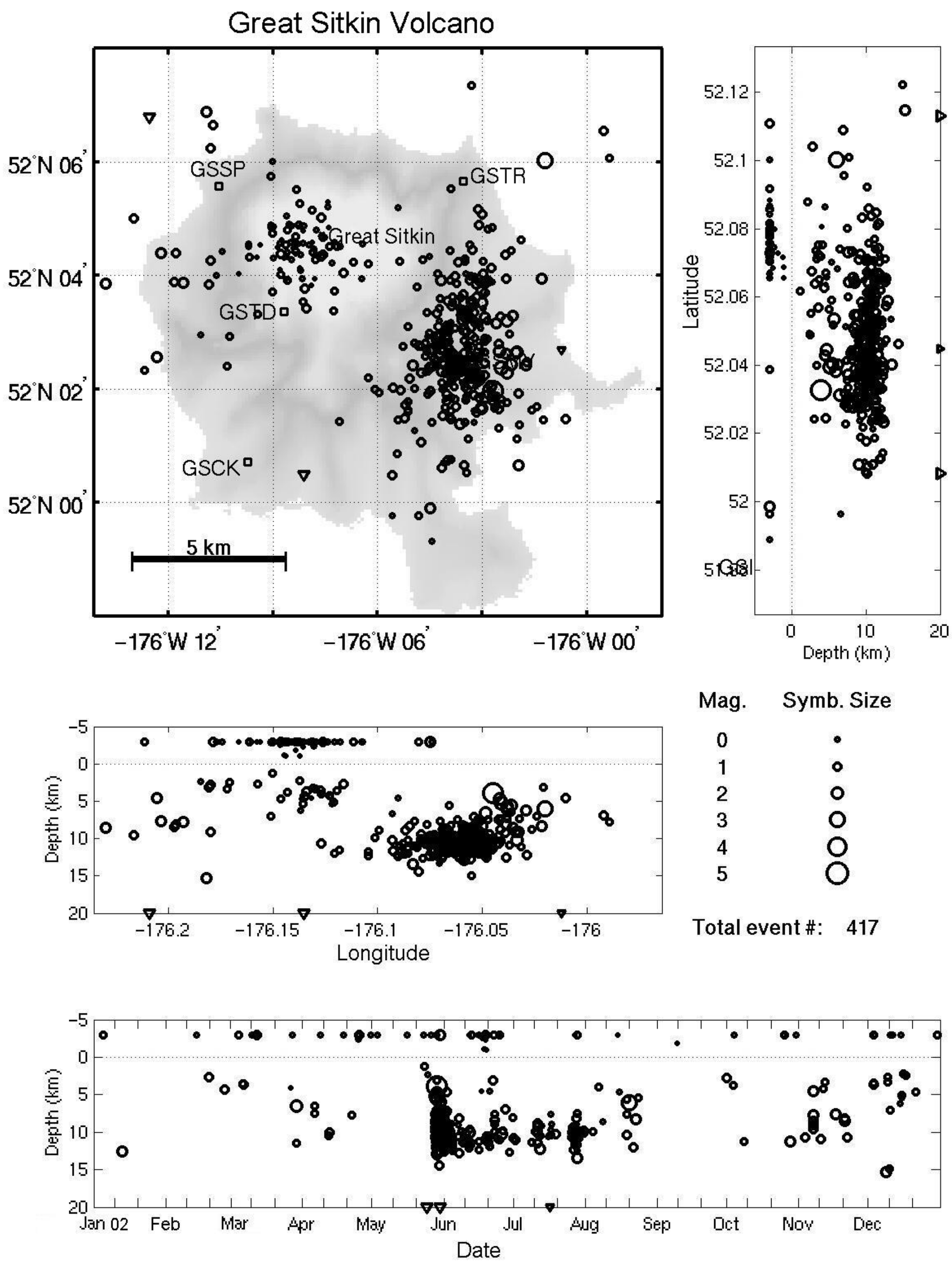


Figure A21. Summary plots of 417 earthquakes located near Great Sitkin Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest. The earthquakes swarm 5-10 km southeast of Great Sitkin Volcano in May and June accounts for 65% of all earthquakes in the Great Sitkin Island region.

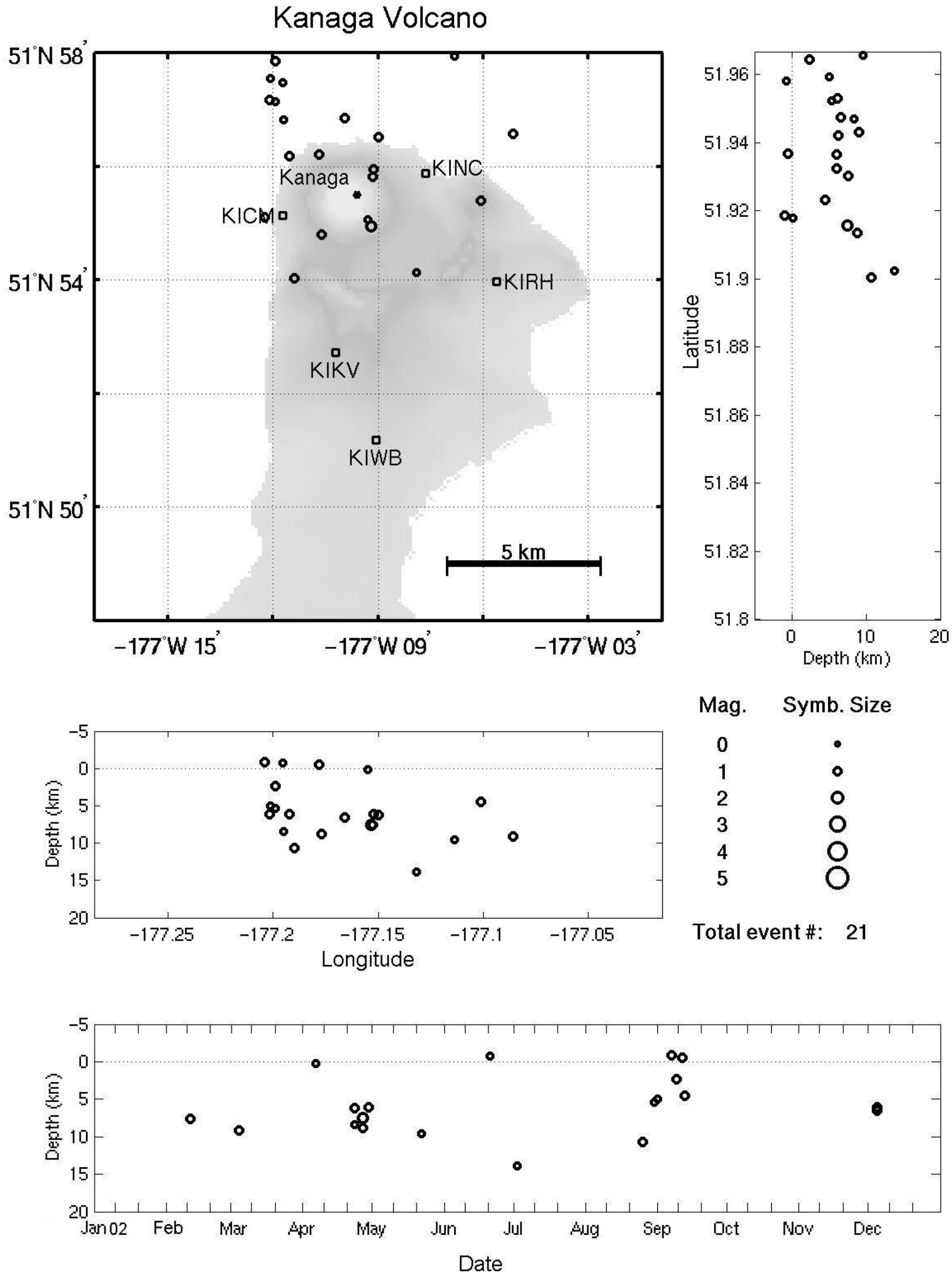


Figure A22. Summary plots of 21 earthquakes located near Kanaga Volcano in 2002. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles scaled with magnitude. Seismic stations are shown by open squares and labeled by station code. (See Appendix B for station information). Closed circles are used to show other points of interest.

Appendix B: Parameters for all AVO seismic stations.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Akutan Peak subnet (7 stations - 11 components)					
AHB	54 06.916	165 48.943	447	L-4	1996/07/24
AKS[3]	54 06.624	165 41.803	213	L-22	1996/07/24
AKT[B]	54 08.15	165 46.2	12	CMG-40T	1996/03/18
AKV	54 07.571	165 57.763	863	L-4	1996/07/24
HSB	54 11.205	165 54.743	497	L-4	1996/07/24
LVA	54 09.655	166 02.024	457	L-4	1996/07/24
ZRO	54 05.494	165 58.678	446	L-4	1996/07/24
Aniakchak Crater subnet (6 stations - 8 components)					
AJAX[R]	56 53.370	158 13.29	967	L-4	2000/07/10
ANNE	56 54.763	158 03.534	705	L-4	1997/07/18
ANNW	56 57.986	158 12.895	816	L-4	1997/07/18
ANON[3]	56 55.188	158 10.293	445	L-22	2000/07/10
ANPB	56 48.141	158 16.847	675	L-4	1997/07/18
ANPK	56 50.499	158 07.572	972	L-4	1997/07/18
AZAC	56 53.727	158 13.841	1057	L-4	2002/07/12
Augustine Volcano subnet (9 stations - 14 components)					
AUC	59 21.596	153 25.469	1175	L-4	1995/09/13
AUE	59 21.531	153 22.365	168	S-13	1980/10/29
AUH	59 21.833	153 26.591	890	S-13	1978/12/01
AUI[3]	59 20.11	153 25.66	293	S-13	1978/04/06
AUL[BS]	59 22.93	153 26.07	360	S-13,CMG-40T	1978/08/27
AUP	59 21.74	153 25.23	1033	S-13	1977/09/22
AUR	59 21.766	153 25.873	1183	L-4	1995/11/01
AUS	59 21.599	153 25.840	1226	L-4	1990/09/01
AUW	59 22.205	153 28.249	276	S-13	1976/10/17
Mount Dutton subnet (4 stations - 4 components)					
BLDY	55 11.670	162 47.018	259	L-4	1996/07/11
DRR3	54 58.015	162 15.671	457	L-4	1996/07/11
DT1	55 06.358	162 16.709	198	L-4	1991/06/21
DTN	55 09.011	162 14.985	366	S-13	1988/07/16
Great Sitkin Volcano subnet (6 stations - 8 components)					
GSCK	52 00.712	176 09.718	384	L-4	1999/09/15
GSIG	51 59.181	175 55.502	407	L-4	1999/09/03
GSMY	52 02.594	176 03.376	418	L-4	1999/09/03
GSSP	52 05.566	176 10.541	295	L-4	1999/09/15
GSTD[3]	52 03.356	176 08.685	873	L-22	1999/09/03
GSTR	52 05.655	176 03.546	536	L-4	1999/09/03
Iliamna Volcano subnet (6 stations - 8 components)					
ILI	60 04.81	152 57.57	823	L-4	1987/09/15
ILS	59 57.454	153 04.083	1107	S-13	1996/08/28
ILW	60 03.60	153 08.17	1722	S-13	1994/09/09
INE	60 03.65	153 03.75	1585	S-13	1990/08/29
IVE[3]	60 00.972	153 00.993	1110	S-13,L-22	1996/09/19
IVS	60 00.55	153 04.85	2332	L-4	1990/08/29

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Kanaga Volcano subnet (6 stations - 6 components)					
KICM	51 55.136	177 11.718	183	L-4	1999/09/15
KIKV	51 52.730	177 10.223	411	L-4	1999/09/15
KIMD	51 45.697	177 14.093	183	L-4	1999/09/15
KINC	51 55.884	177 07.657	198	L-4	1999/09/15
KIRH	51 53.976	177 05.611	309	L-4	1999/09/03
KIWB	51 51.183	177 09.049	244	L-4	1999/09/03
Katmai volcanic group subnet (18 stations - 24 components)					
ACH[3]	58 12.64	155 19.56	960	L-22	1996/07/25
ANCK	58 11.93	155 29.64	869	L-4	1996/07/25
CAHL	58 03.15	155 18.09	807	L-4	1996/07/25
CNTC	58 15.87	155 53.02	1158	L-4	1996/07/25
KABR	58 07.87	154 58.15	884	L-4	1998/08/12
KAHC	58 38.94	155 00.36	1250	L-4	1998/10/12
KAHG	58 29.64	154 32.78	923	L-4	1998/10/12
KAIC	58 29.10	155 02.75	734	L-4	1998/10/12
KAPH[3]	58 35.81	154 20.81	907	L-22	1998/10/12
KARR	58 29.87	154 42.20	610	L-4	1998/10/12
KAWH	58 23.02	154 47.95	777	L-4	1998/10/12
KBM	58 16.50	155 12.10	732	L-4	1991/07/22
KCE	58 14.60	155 11.00	777	L-4	1991/07/22
KCG[3]	58 18.457	155 06.684	762	L-22	1988//08/01
KEL	58 26.401	155 44.442	975	L-4	1988//08/01
KJL	58 03.24	155 34.39	792	L-4	1996/07/25
KVT	58 22.90	155 17.70	457	L-4	1988//08/01
MGLS	58 08.06	155 09.65	472	L-4	1996/07/25
Makushin Volcano subnet (6 stations - 8 components)					
MCIR	53 57.08	166 53.51	800	L-4	1996/07/25
MGOD	53 47.68	166 52.35	695	L-4	1996/07/25
MNAT	53 53.03	166 41.00	390	L-4	1996/07/25
MSOM	53 48.99	166 56.94	50	L-4	1996/07/25
MSW[3]	53 54.88	166 46.96	418	L-22	1996/07/25
MTBL	53 58.16	166 40.71	865	L-4	1996/07/25
Okmok Volcano subnet (8 stations - 8 components)					
OKAS	53 24.319	168 21.686	270	L-4	2003/01/09
OKCF	53 23.689	168 08.299	685	L-4	2003/01/09
OKID	53 28.587	167 49.088	437	L-4	2003/01/09
OKRE	53 31.163	168 09.964	420	L-4	2003/01/09
OKSP	53 15.099	168 17.548	608	L-4	2003/01/09
OKTU	53 22.967	168 02.571	646	L-4	2003/01/09
OKWE	53 28.270	168 14.512	445	L-4	2003/01/09
OKWR	53 26.031	168 12.455	1017	L-4	2003/01/09

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Pavlof Volcano subnet (8 stations - 10 components)					
BLHA	55 42.227	162 03.907	411	L-4	1996/07/11
DOL	55 08.960	161 51.683	442	L-4	1996/07/11
HAG	55 19.068	161 54.150	503	L-4	1996/07/11
PN7A	55 26.009	161 59.757	838	L-4	1996/07/11
PS1A	55 25.321	161 44.425	293	L-4	1996/07/11
PS4A	55 20.811	161 51.233	322	L-4	1996/07/11
PV6[3]	55 27.227	161 55.138	747	L-22	1996/07/11
PVV	55 22.438	161 47.396	161	L-4	1996/07/11
Redoubt Volcano subnet (7 stations - 12 components)					
DFR	60 35.514	152 41.160	1090	L-4	1988/08/15
NCT	60 33.789	152 55.568	1079	L-4	1988/08/14
RDN	60 31.370	152 44.256	1400	L-4	1988/08/13
RDT	60 34.394	152 24.315	930	L-4	1971/08/09
RED[3]	60 25.192	152 46.308	1064	L-4	1990/08/30
REF[3*]	60 29.35	152 42.10	1801	L-22	1992/07/27
RSO	60 27.73	152 45.23	1921	L-4	1990/03/01
Shishaldin Volcano subnet (6 stations - 8 components)					
BRPK	54 38.719	163 44.475	420	L-4	1997/07/27
ISNN	54 49.925	163 46.700	546	L-4	1997/07/27
ISTK	54 43.980	163 42.330	453	L-4	1997/07/27
SSLN	54 48.709	163 59.756	637	L-4	1997/07/27
SSLS[3]	54 42.718	163 59.926	771	L-22	1997/07/27
SSLW	54 46.307	164 07.282	628	L-4	1997/07/27
Mount Spurr subnet (10 stations - 12 components)					
BGL	61 16.02	152 23.30	1207	L-4	1989/08/13
BKG	61 04.21	152 15.76	1009	L-4	1991/07/01
CGL	61 18.46	152 00.40	1082	L-4	1981/09/22
CKL	61 11.79	152 20.27	1265	L-4	1989/08/05
CKN	61 13.44	152 10.89	735	L-4	1991/08/19
CKT	61 12.05	152 12.37	975	L-4	1992/09/16
CP2	61 15.85	152 14.51	1981	L-4	1992/10/23
CRP[3]	61 16.02	152 09.33	1622	L-4	1981/08/26
NCG	61 24.22	152 09.40	1244	L-4	1989/08/06
SPU	61 10.90	152 03.26	800	L-4	1971/08/10
Mount Veniaminof subnet (9 stations - 9 components)					
BPBC	56 35.383	158 27.153	584	L-4	2002/10/03
VNFG	56 17.140	158 33.066	1068	L-4	2002/02/06
VNHG	56 13.267	158 09.853	963	L-4	2002/02/06
VNKR	56 01.871	159 22.068	620	L-4	2002/02/06
VNNF	56 17.022	159 18.961	1153	L-4	2002/06/20
VNSG	56 07.549	159 05.121	761	L-4	2002/02/06
VNSS	56 13.600	159 27.290	1728	L-4	2002/02/06
VNSW	56 04.317	159 33.508	716	L-4	2002/06/20
VNWF	56 09.104	159 33.733	1095	L-4	2002/02/06

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Westdahl Peak subnet (6 stations - 8 components)					
WESE	54 28.344	164 35.188	953	L-4	1998/08/28
WESN	54 34.342	164 34.804	549	L-4	1998/10/17
WESS[3]	54 28.795	164 43.428	908	L-22	1998/08/28
WFAR	54 31.967	164 46.690	640	L-4	1998/08/28
WPOG	54 35.776	164 44.772	445	L-4	1998/10/17
WTUG	54 50.792	164 23.258	636	L-4	1998/10/17
Mount Wrangell subnet (4 stations - 6 components)					
WACK[3]	61 59.178	144 19.704	2280	L-22	2000/07/31
WANC	62 00.192	144 4.194	4190	L-4	2000/07/31
WASW	61 55.692	144 10.346	2164	L-4	2001/08/03
WAZA	61 04.506	144 9.132	2564	L-4	2001/08/03
Regional stations (14 stations - 14 components)					
ADAG	51 58.812	176 36.104	286	L-4	1999/09/15
BGM	59 23.56	155 13.76	625	L-4	1978/09/08
BGR	60 45.45	152 25.06	985	L-4	1991/07/01
CDD	58 55.79	153 38.58	622	S-13	1981/08/17
CNP	59 31.55	151 14.16	564	L-4	1983/07/01
ETKA	51 51.712	176 24.351	290	L-4	1999/09/15
HOM	59 39.50	151 38.60	198	L-4	1976/08/00
MMN	59 11.11	154 20.20	442	S-13	1981/08/22
NNL	60 2.66	151 17.36	381	L-4	1972/08/24
OPT	59 39.16	153 13.78	450	S-13	1974/00/00
PDB	59 47.27	154 11.55	305	S-13	1978/09/09
STLK	61 29.923	151 49.979	945	L-4	1997/09/01
SYI	58 36.60	152 23.45	149	S-13	1990/08/27
XLV	59 27.28	151 40.30	320	S-13	1987/09/16

Station Codes:
[3] Three-component short-period station
[B] Three-component broadband station
[R] Station removed during in 2002
[S] Station also includes a single short-period vertical station
[*]REF also has a low-gain vertical component.

Seismometer Codes:
CMG-40T: Guralp CMG-40T 60 second natural period broadband seismometer
L-4: Mark Products L4 one second natural period seismometer
L-22: Mark Products L22 0.5 second natural period seismometer
S-13: Teledyne Geotech S-13 one second natural period seismometer

Appendix C: Figures showing the location of the permanent AVO regional and volcano-specific seismic stations. In all figures, closed circles show points of interest and open squares show seismic stations.

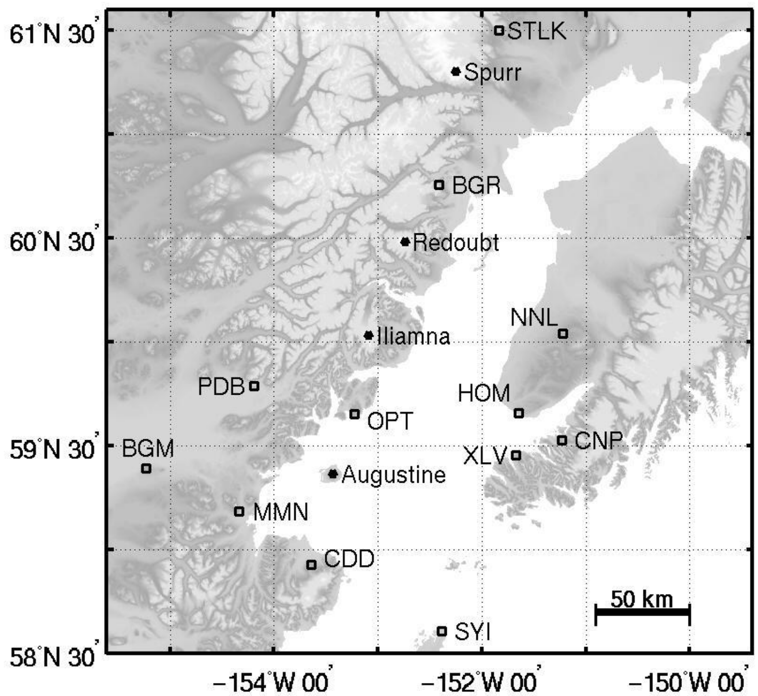


Figure C1. AVO seismic stations in Cook Inlet not associated with any specific volcano.

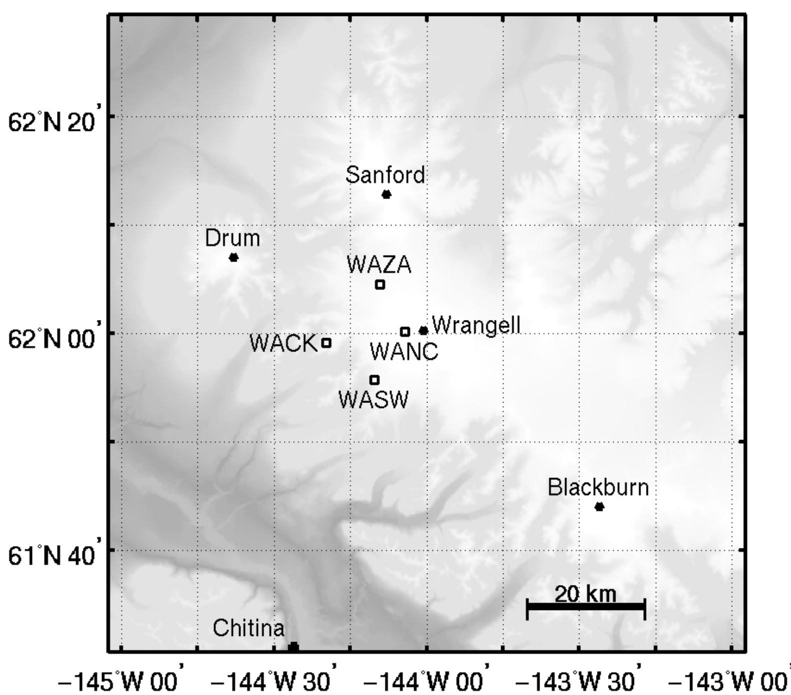


Figure C2. AVO seismic stations near Mount Wrangell.

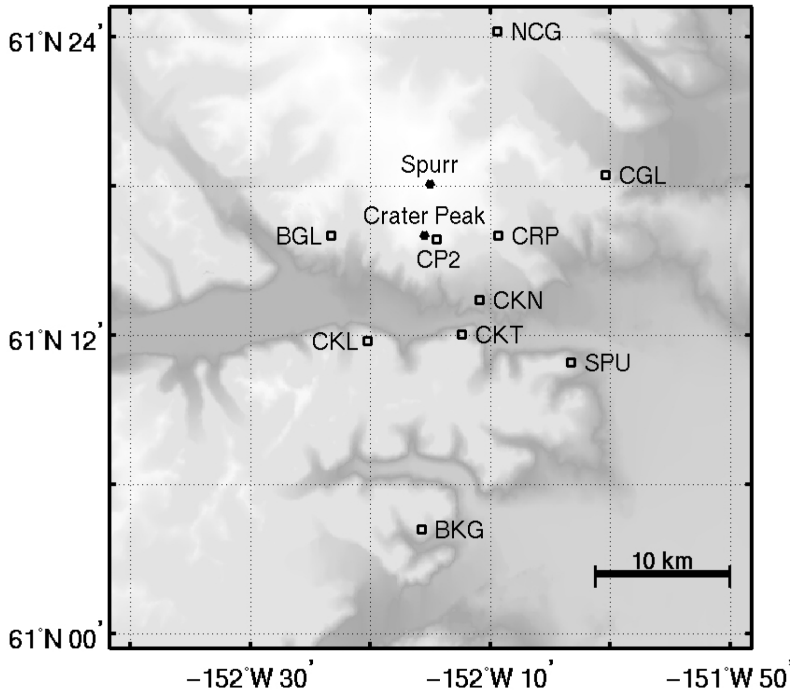


Figure C3. AVO seismic stations near Mount Spurr.

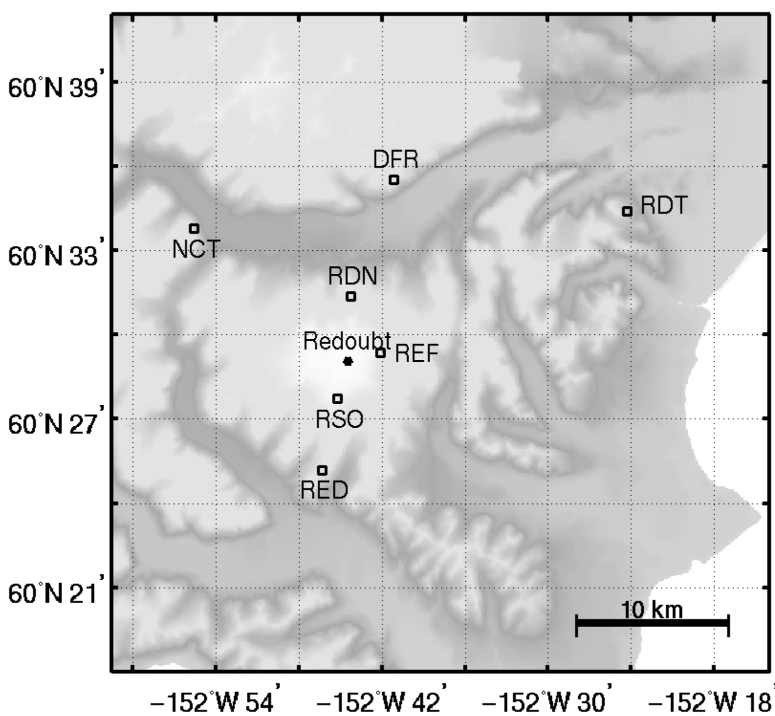


Figure C4. AVO seismic stations near Redoubt Volcano.

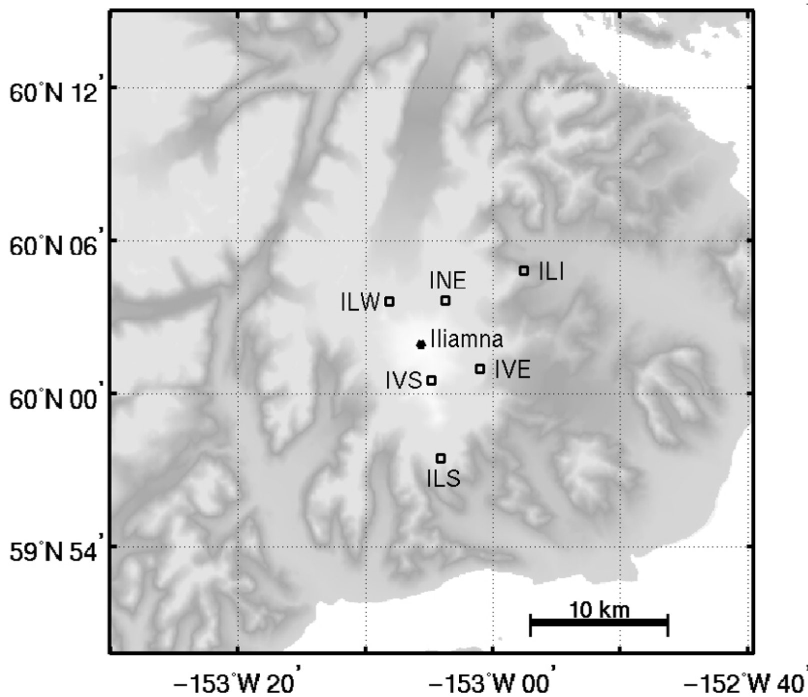


Figure C5. AVO seismic stations near Iliamna Volcano.

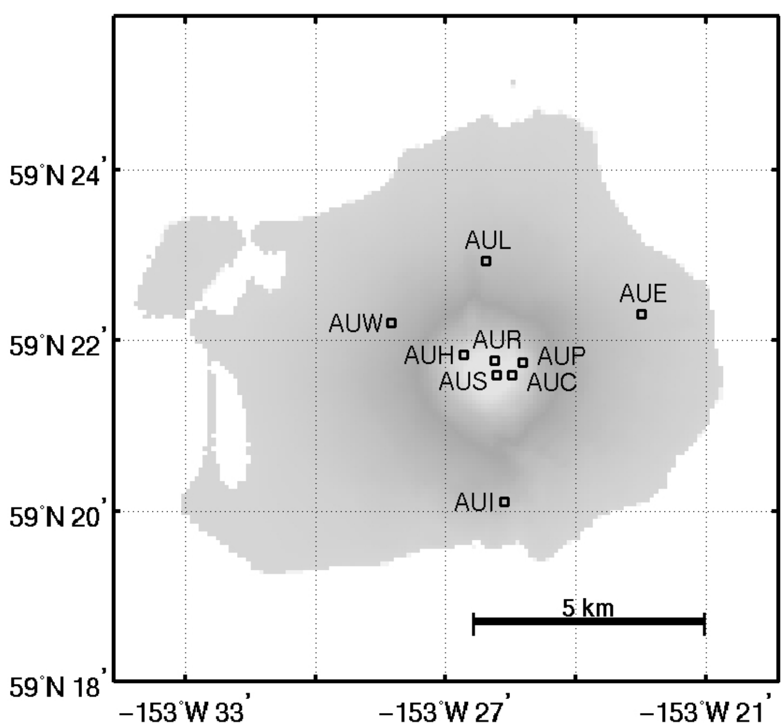


Figure C6. AVO seismic stations near Augustine Volcano.

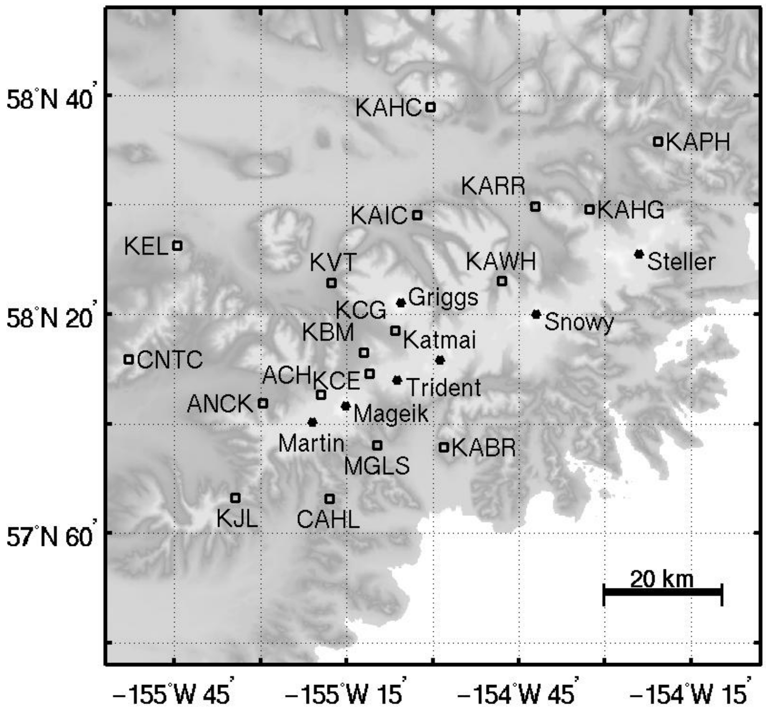


Figure C7. AVO seismic stations near the Katmai volcanic group.

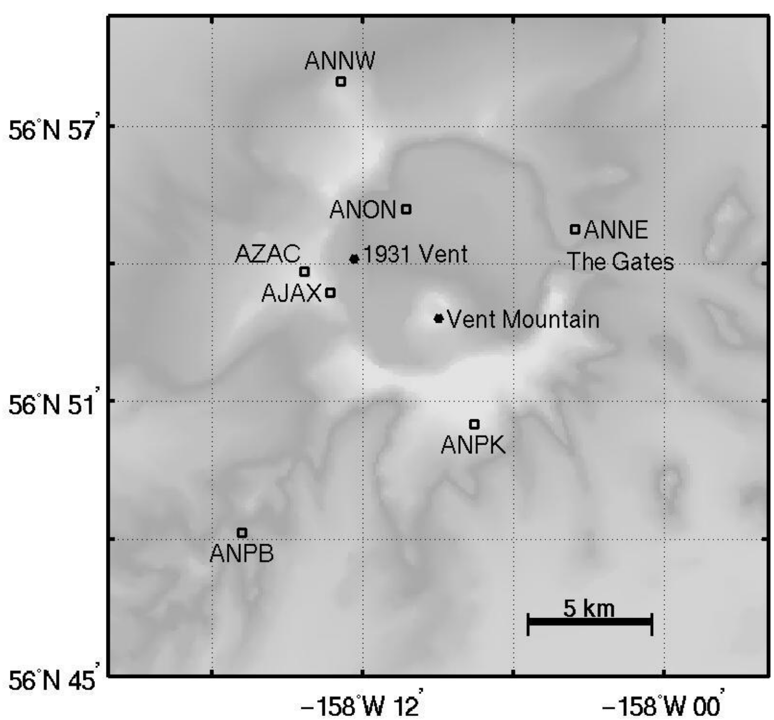


Figure C8. AVO seismic stations near Aniakchak Crater.

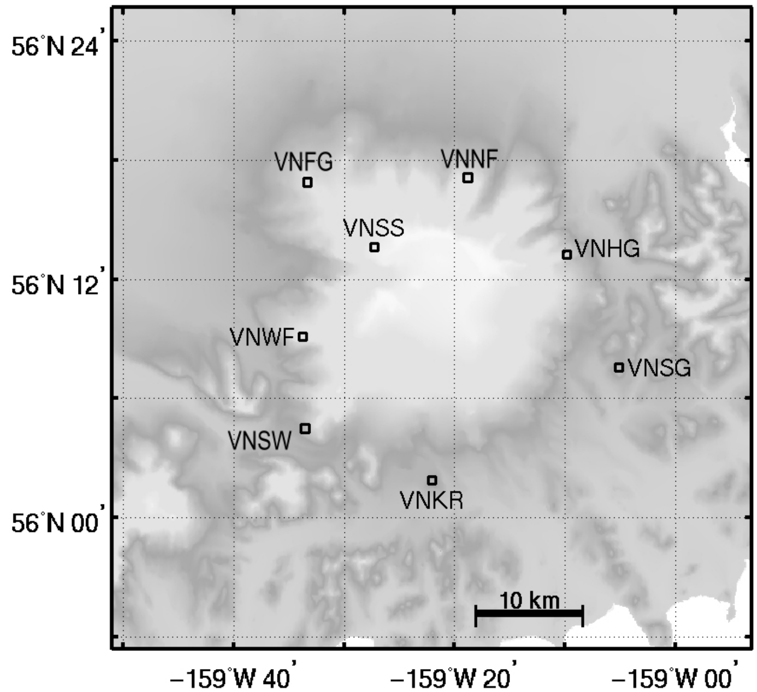


Figure C9. AVO seismic stations near Mount Veniaminof. Seismic station BPBC is not shown and is located 70 km northeast of Mount Veniaminof.

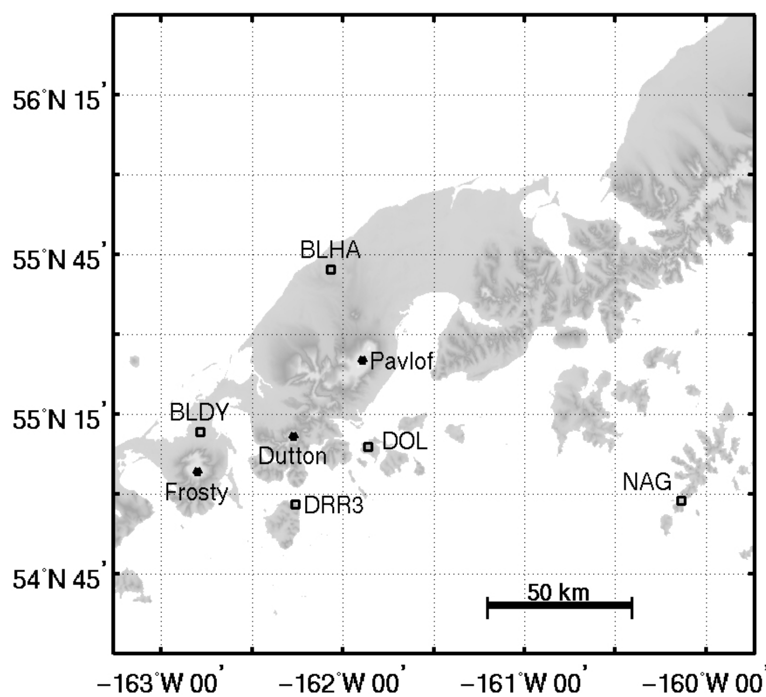


Figure C10. Regional AVO seismic stations on the western end of the Alaska Peninsula. Seismic station NAG is maintained by the Alaska Earthquake Information Center.

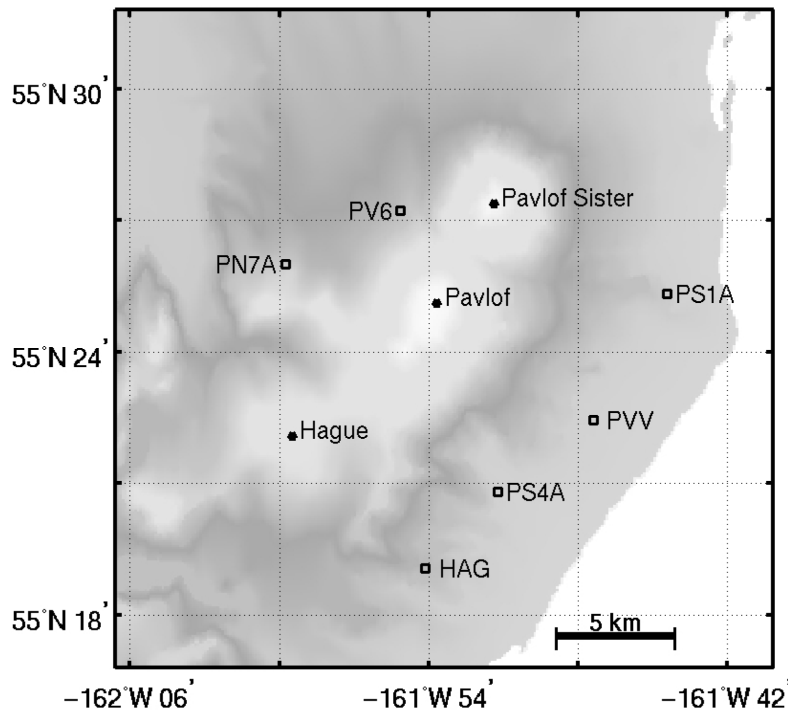


Figure C11. AVO seismic stations near Pavlof Volcano.

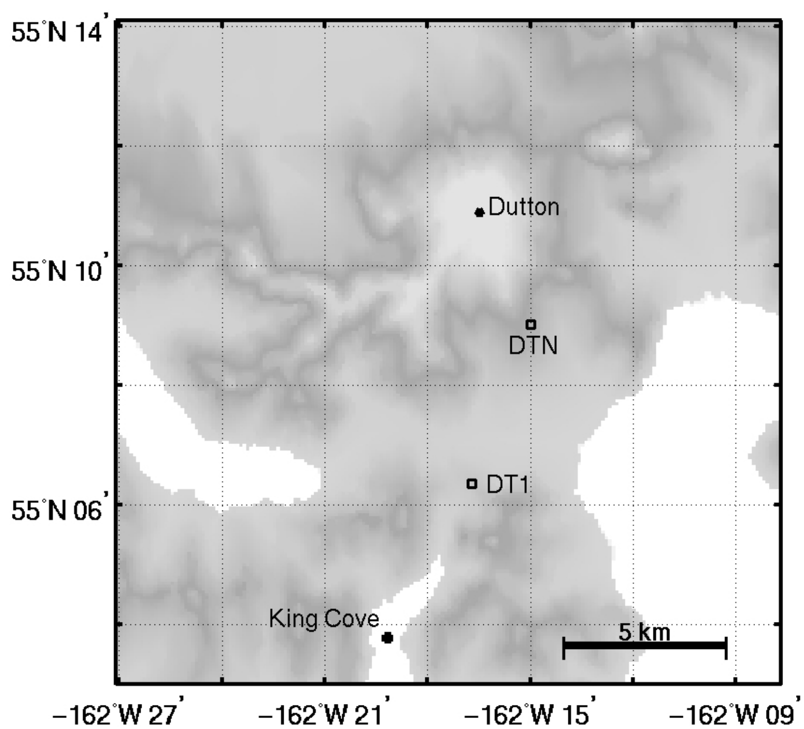


Figure C12. AVO seismic stations near Mount Dutton.

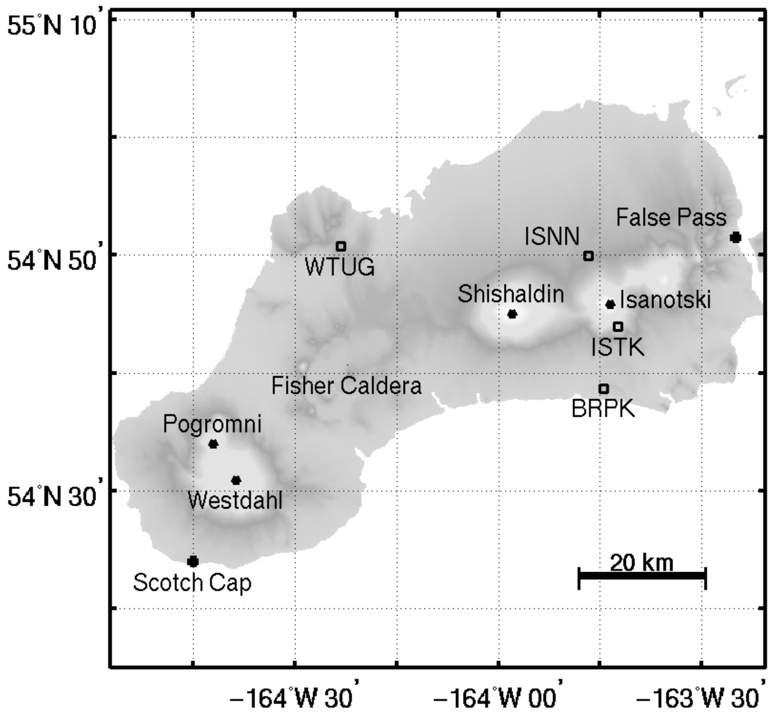


Figure C13. Regional AVO seismic stations on Unimak Island.

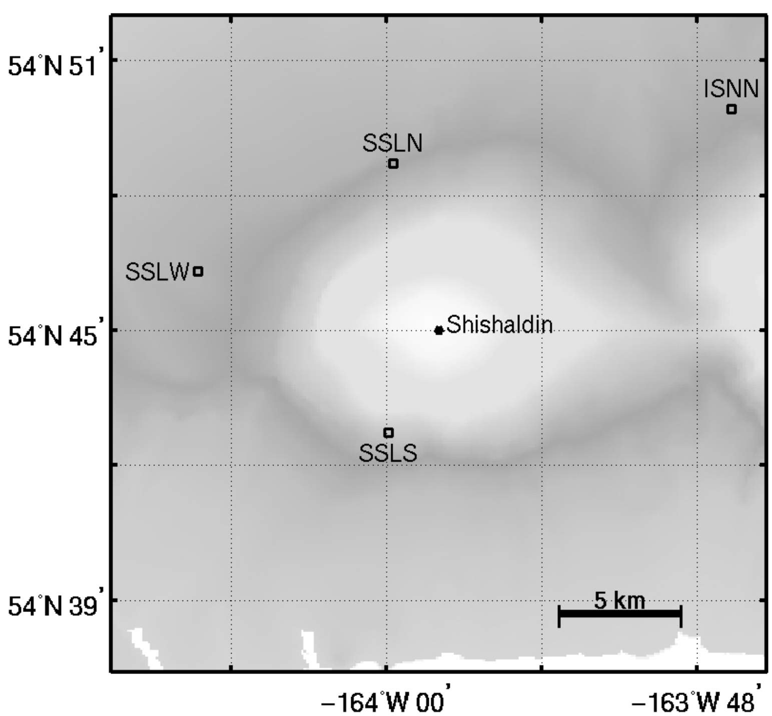


Figure C14. AVO seismic stations near Shishaldin Volcano.

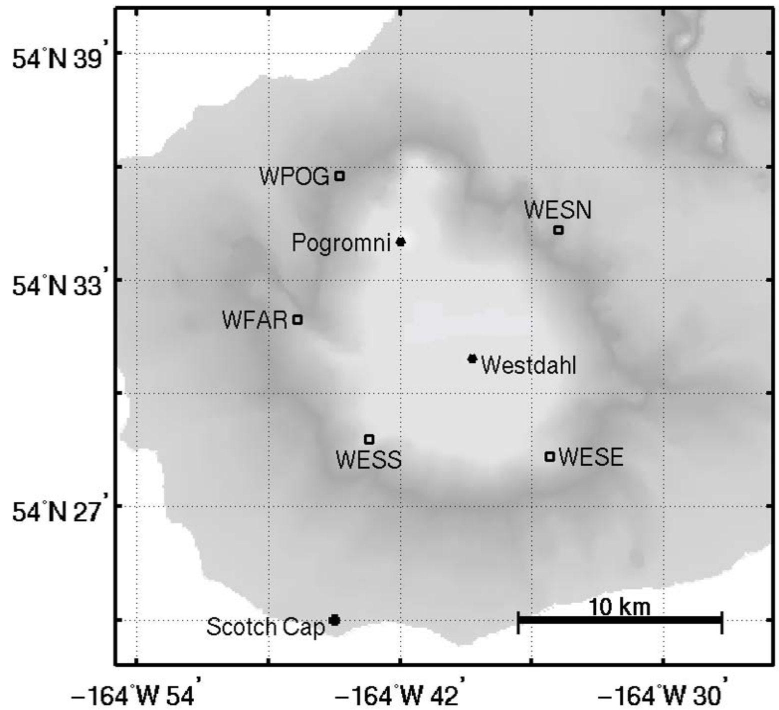


Figure C15. AVO seismic stations near Westdahl Peak.

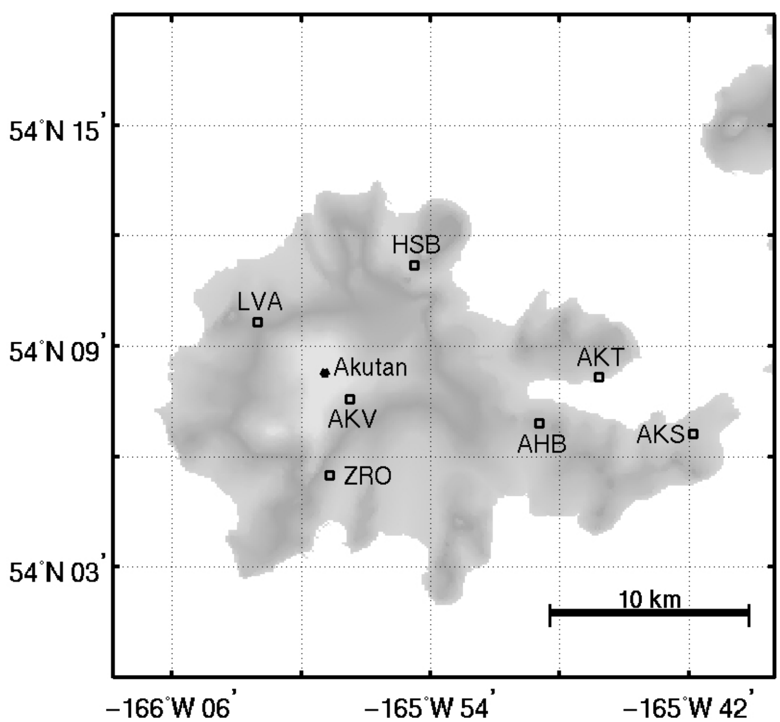


Figure C16. AVO seismic stations near Akutan Peak.

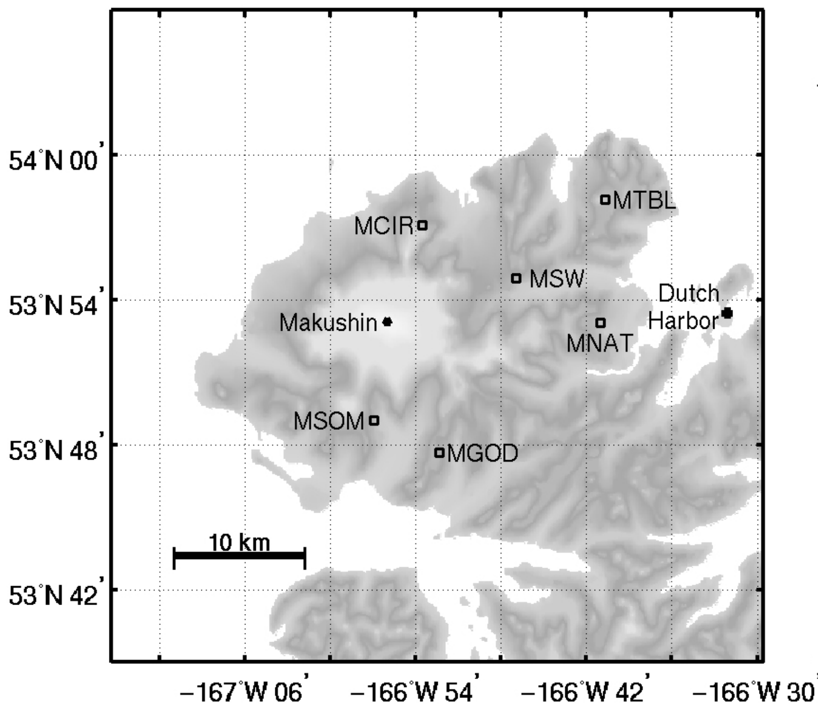


Figure C17. AVO seismic stations near Makushin Volcano.

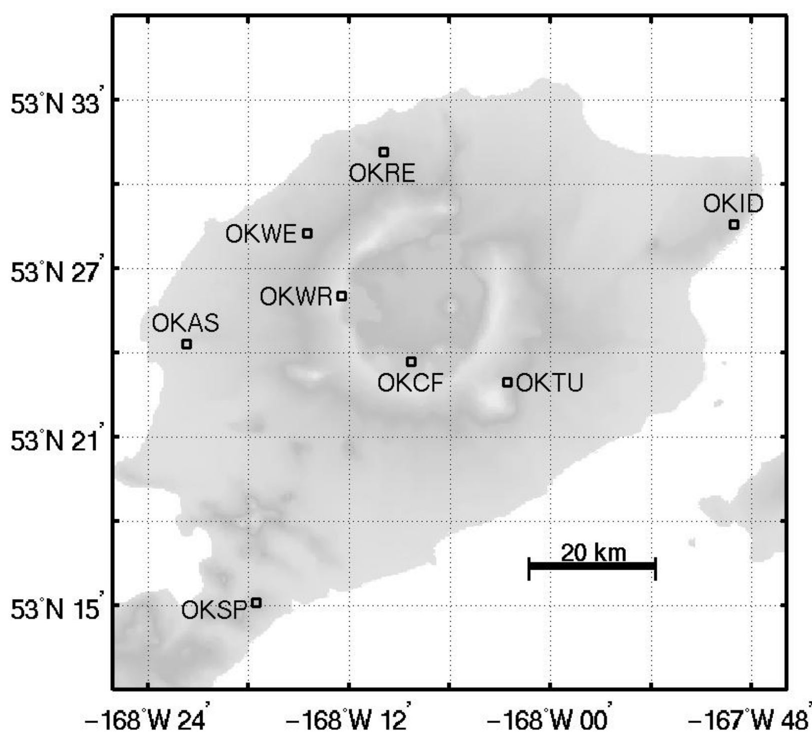


Figure C18. AVO seismic stations near Okmok Volcano.

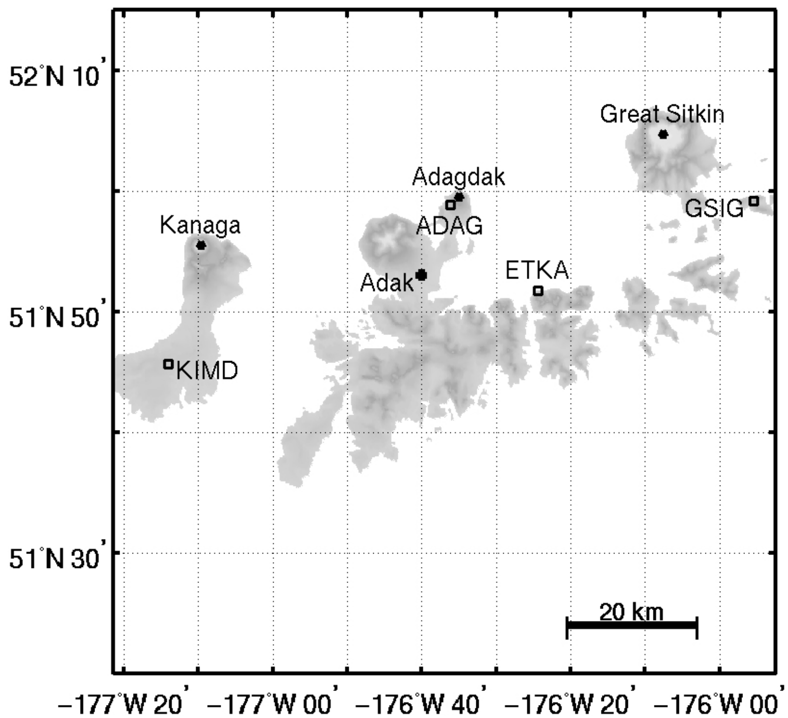


Figure C19. Regional AVO seismic stations around Adak Island.

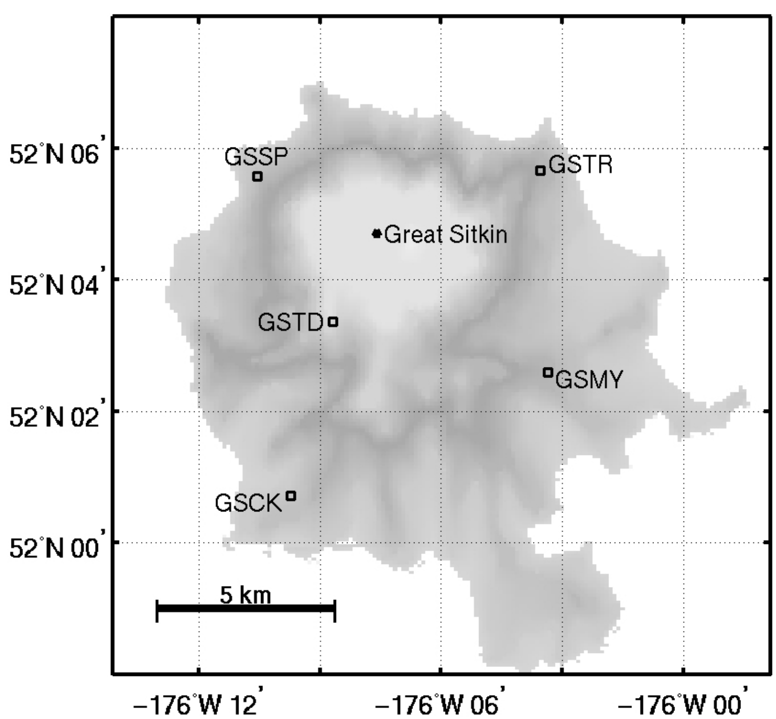


Figure C20. AVO seismic stations near Great Sitkin Volcano.

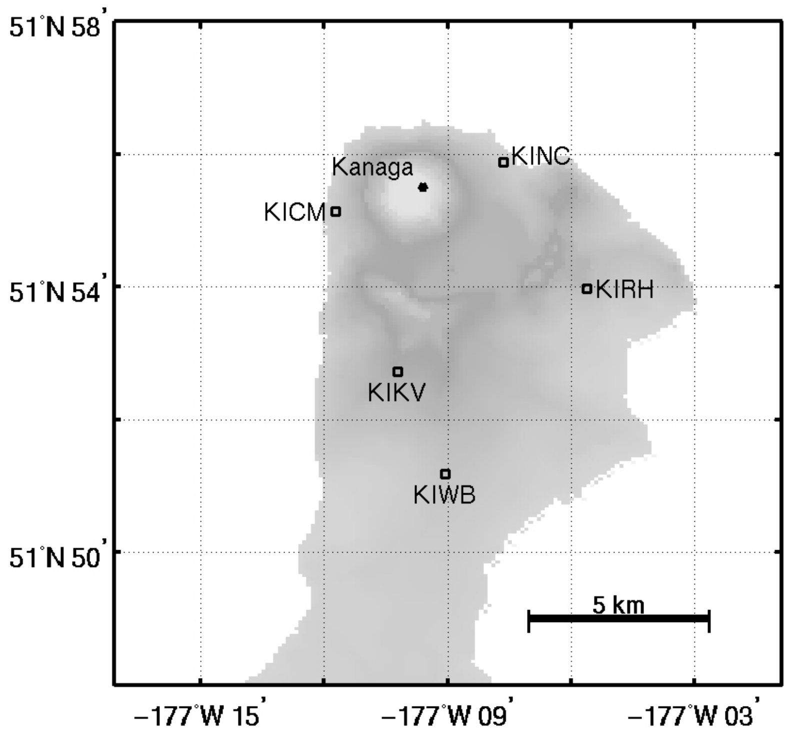


Figure C21. AVO seismic stations near Kanaga Volcano.

Appendix D: Velocity models used in locating the earthquakes described in this report. Following the name of each velocity model is a list of monitored volcanoes for which the model is used. Depths are referenced to sea level, with negative values reflecting height above sea level.

Cylindrical Model Parameters

Velocity Model	Latitude (°N)	Longitude (°W)	Radius (km)	Top (km)	Bottom (km)
Spurr	61.60	152.40	20	-3	50
Spurr	61.47	152.33	20	-3	50
Spurr	61.33	152.25	20	-3	50
Spurr	61.17	152.35	20	-3	50
Spurr	61.00	152.45	20	-3	50
Redoubt	60.83	152.55	20	-3	50
Redoubt	60.66	152.66	20	-3	50
Redoubt	60.49	152.75	20	-3	50
Redoubt	60.34	152.86	20	-3	50
Iliamna	60.03	153.09	20	-3	50
Augustine	59.36	153.42	20	-3	50
Katmai	58.17	155.35	20	-3	50
Katmai	58.29	154.86	20	-3	50
Katmai	58.35	155.09	20	-3	50
Katmai	58.43	154.38	20	-3	50
Cold Bay	55.42	161.89	20	-3	50
Cold Bay	55.18	162.27	20	-3	50
Cold Bay	54.76	163.97	30	-3	50
Cold Bay	54.52	164.65	20	-3	50
Akutan	54.15	165.97	20	-3	50
Andreanof	52.08	176.13	20	-3	50
Andreanof	51.93	176.75	20	-3	50
Andreanof	51.92	177.17	20	-3	50

Regional Velocity Model (for all areas south of 62.5°N not covered by a volcano specific model): Aniakchak Crater, Makushin Volcano, Okmok Volcano, Mount Veniaminof, and Mount Wrangell (Fogleman and others, 1993).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	5.3	-3.0	1.78
2	5.6	4.0	1.78
3	6.2	10.0	1.78
4	6.9	15.0	1.78
5	7.4	20.0	1.78
6	7.7	25.0	1.78
7	7.9	33.0	1.78
8	8.1	47.0	1.78
9	8.3	65.0	1.78

Akutan Velocity Model: Akutan Peak (Power and others, 1996).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	2.30 +0.37 km/sec for each km of depth	-3.0	1.80
2	6.30	7.0	1.80

Andreanof Velocity model: Great Sitkin Volcano, Kanaga Volcano (Toth and Kisslinger, 1984).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	3.50	-3.0	1.73
2	3.88	-2.8	1.73
3	4.25	-2.6	1.73
4	4.62	-2.4	1.73
5	5.00	-2.2	1.73
6	5.50	-2.0	1.73
7	5.62	-1.0	1.73
8	5.74	0.0	1.73
9	5.86	1.0	1.73
10	5.98	2.0	1.73
11	6.10	3.0	1.73
12	6.60	4.0	1.73
13	6.68	5.0	1.73
14	6.80	8.0	1.73
15	6.92	11.0	1.73
16	7.04	14.0	1.73
17	7.16	17.0	1.73
18	7.28	20.0	1.73
19	7.85	23.0	1.73
20	8.05	37.0	1.73

Augustine Velocity Model: Augustine Volcano (Power, 1988).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	2.3	-3.0	1.80
2	2.6	-0.7	1.80
3	3.4	0.0	1.80
4	5.1	1.0	1.80
5	6.3	9.0	1.78
6	8.0	44.0	1.78

Cold Bay Velocity Model: Mount Dutton, Fisher Caldera, Isanotski Peaks, Pavlof Volcano, Shishaldin Volcano and Westdahl Peak (McNutt and Jacob, 1986).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	3.05	-3.00	1.78
2	3.44	0.00	1.78
3	5.56	1.79	1.78
4	6.06	3.65	1.78
5	6.72	10.18	1.78
6	7.61	22.63	1.78
7	7.90	38.51	1.78

Iliamna Velocity model: Iliamna Volcano (Roman and others, 2001) .

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	4.8	-3.0	1.78
2	6.1	-1.6	1.78
3	6.2	1.7	1.78
4	6.3	2.9	1.78
5	6.4	3.1	1.78
6	7.1	16.5	1.78

Katmai Velocity Model: Mount Griggs, Mount Katmai, Mount Mageik, Mount Martin, Novarupta, Snowy Mountain, and Trident Volcano (Jolly, 2000).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	5.0	-3.0	1.78
2	5.3	0.0	1.78
3	5.6	2.0	1.78
4	5.9	4.0	1.78
5	6.1	6.0	1.78
6	6.9	15.0	1.78
7	7.4	20.0	1.78
8	7.7	25.0	1.78
9	7.9	33.0	1.78
10	8.1	47.0	1.78
11	8.3	65.0	1.78

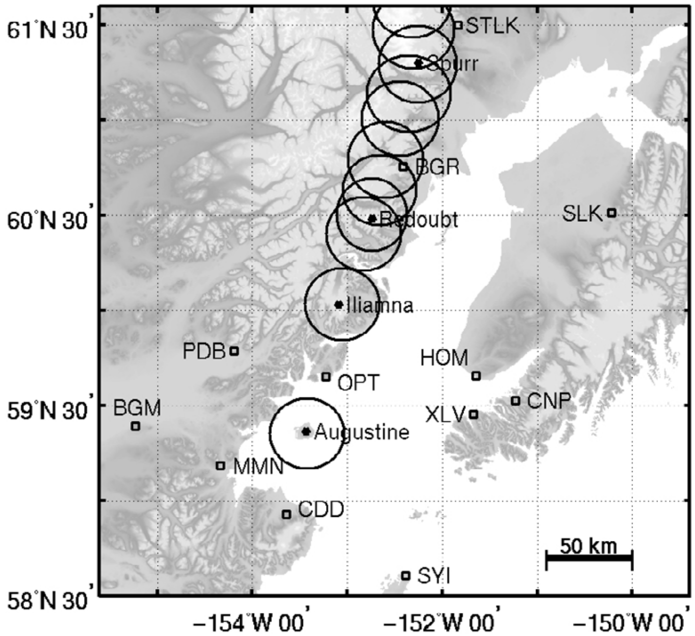
Redoubt Velocity Model: Redoubt Volcano (Lahr and others, 1994) .

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	2.90	-3.0	1.80
2	5.10	-1.7	1.80
3	6.40	1.5	1.72
4	7.00	17.0	1.78

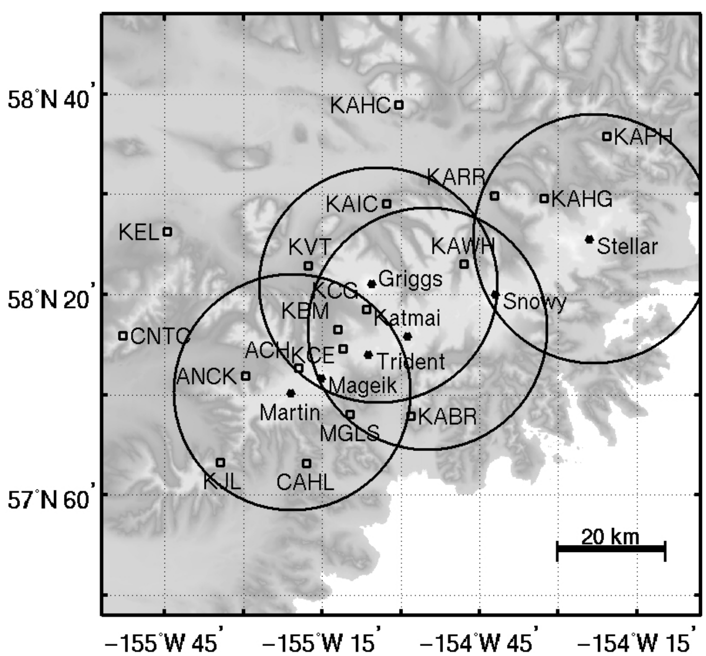
Spurr Velocity Model: Mount Spurr (Jolly and others, 1994).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	5.1	-3.00	1.81
2	5.5	-2.00	1.81
3	6.3	5.25	1.74
4	7.2	27.25	1.78

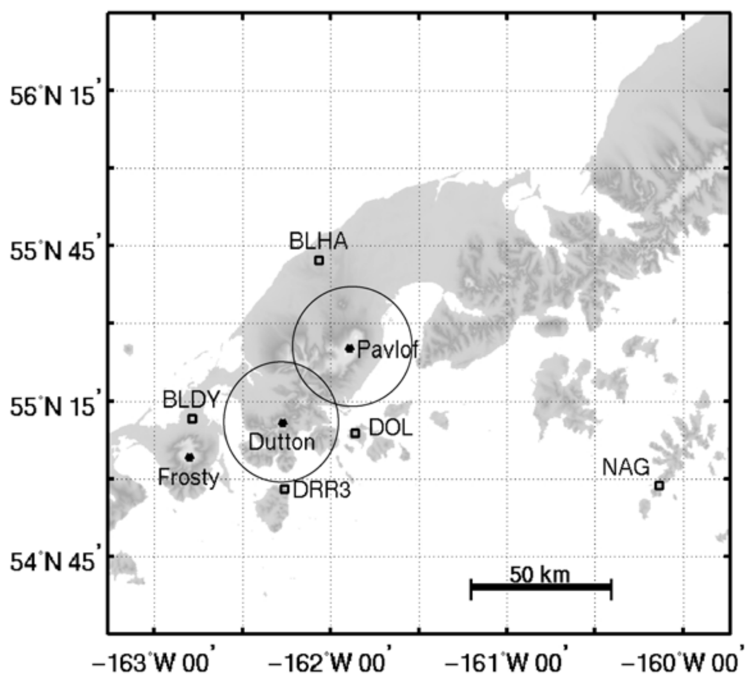
Appendix E: Maps showing the location of the volcanic zones modeled using cylinders.



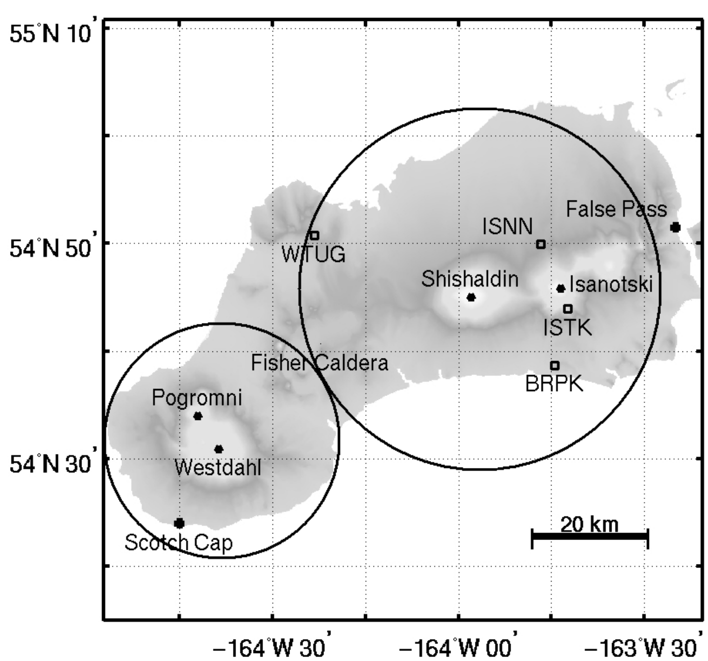
Map E1. Volcanic zones modeled using cylinders as an approximation for the volcanic seismic zones in Cook Inlet.



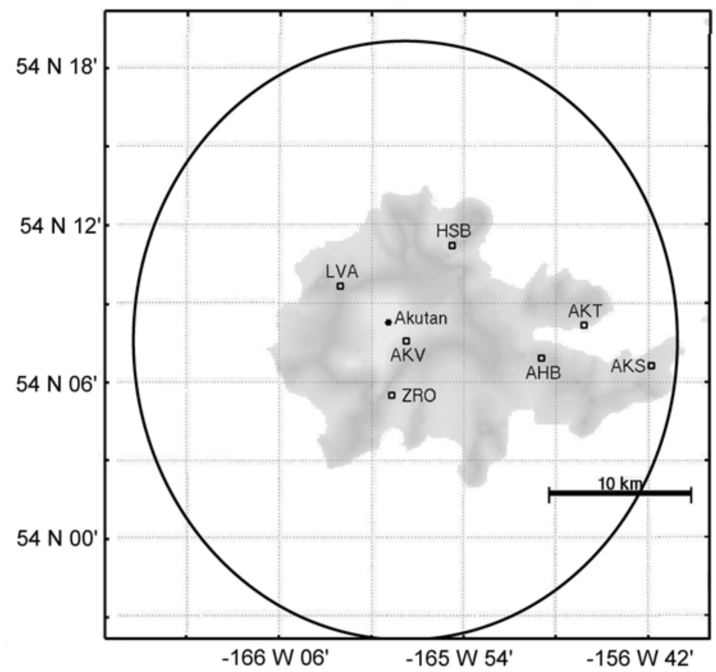
Map E2. Volcanic zone modeled using cylinders as an approximation for the volcanic seismic zone in the Katmai volcanic group.



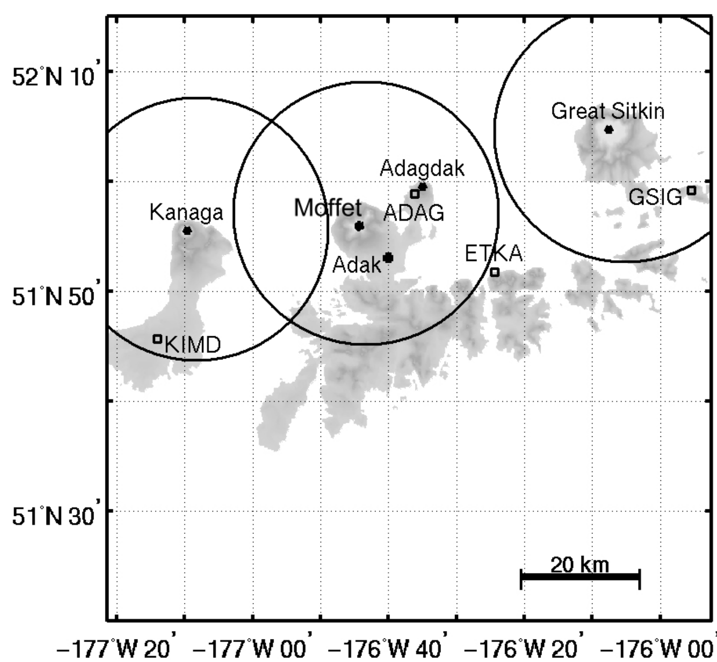
Map E3. Volcanic zones modeled using cylinders as an approximation for the volcanic seismic zones in the Pavlof/Dutton region.



Map E4. Volcanic zones modeled using cylinders as an approximation for the volcanic seismic zones on Unimak Island



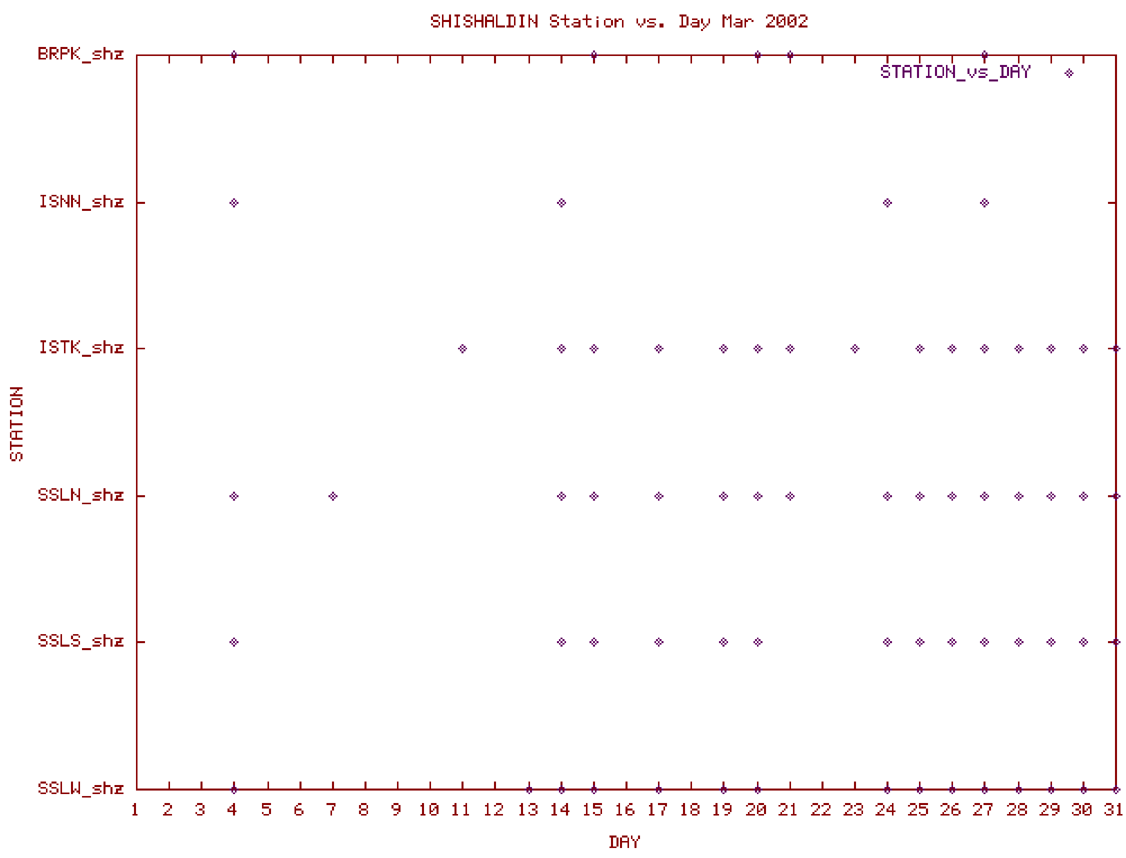
Map E5. Volcanic zone modeled using a cylinder as an approximation for the volcanic seismic zone on Akutan Island.



Map E6. Volcanic zones modeled using cylinders as an approximation for the volcanic seismic zone in the Great Sitkin/Kanaga Island region.

Appendix F: Station usage plots

This appendix contains monthly plots showing station usage per day for each station in each sub-network operated by the AVO. These plots provide a measure of both an individual station's operational health and earthquake frequency of occurrence near a given volcano. It is noted that an absence of seismicity at a given sub-network might imply either a station outage or a lack of seismicity at that station. These plots are in a separate PDF file that is available with this report. Appendix F is 83 pages in length. A sample station use plot is shown below.



Station-use plot for the Shishaldin subnetwork show the stations that were used to located earthquakes in March 2001. The presence of a dot indicates the station was used to locate at least one earthquake by the AVO for the day it represents.

Appendix G: Selected AVO papers published in 2002

Caplan-Auerbach, J., and S. R. McNutt, 2002, New insights into the 1999 eruptions of Shishaldin volcano based on acoustic data. Bulletin of Volcanology, DOI 10.1007/s00445-002-0267-5.

Dean, K., J. Dehn, S. McNutt, C. Neal, R. Moore, and D. Schneider, 2002, The 2001 Eruptions of Mt. Cleveland, Chuginadak Island, Alaska, Eos Transactions of the American Geophysical Union, v.83, p.243, 246-247.

Dixon, J.P, Stihler, S.D., Power, Tytgat, G., Estes, S., Moran, S.C., Paskievitch, J., McNutt, S.R., 2002, Catalog of Earthquake Hypocenters at Alaska Volcanoes: January 1, 2000-December 31, 2001: U.S. Geological Survey Open-file Report 02-342, 56p.

Lu, Z., Power, J.A., McConnell, V.S., Wicks, C., Dzurisin, D., 2002, Preeruptive inflation and surface interferometric coherence and characteristics revealed by satellite RADAR interferometry at Makushin Volcano, Alaska: 1993-2000: Journal of Geophysical Research, v. 107, DOI 10.1029/2001JB000970, p. ECV1-1-13.

Lu, Z., Wicks, C., Dzurisin, D., Power, J.A., Moran, S.C., Thatcher, W., 2002, Magmatic inflation at a dormant stratovolcano: 1996-98 activity at Mount Peulik Volcano, Alaska, revealed by satellite radar interferometry: Journal of Geophysical Research, v. 107, DOI 10.1029/2001JB000471, p. ETG4-1-13.

McNutt, S.R., Volcano Seismology, 2002, Chapter 25 of International Handbook of Earthquake and Engineering Seismology, Lee, W.H.K., H. Kanamori, and P.C. Jennings (eds.), v. 81A, IASPEI, Palo Alto, CA, p. 383-406.

Moran, S.C., Stihler, S.D., and Power, J.A., 2002, A tectonic earthquake sequence preceding the April-May 1999 eruption of Shishaldin Volcano, Alaska: Bulletin of Volcanology, v. 64, DOI 10.1007/s00445-002-0226-1, p. 520-524.

Nye, C.J., Keith, T.E.C., Eichelberger, J.C., Miller, T.P., McNutt, S.R., Moran, S.C., Schneider, D.J., Dehn, J., and Schaefer, J.R., 2002, The 1999 eruptions of Shishaldin Volcano, Alaska: remote monitoring using multiple data streams: Bulletin of Volcanology, v. 64, DOI 10.1007/s00445-002-0225-2, p. 507-519.

Power, J.A., Jolly, A.D., Nye, C.J., Harbin, M.L., 2002, A conceptual model of the Mount Spurr magmatic system from seismic and geochemical observations of the 1992 Crater Peak eruption sequence. Bulletin of Volcanology, v. 64, DOI 10.1007/s00445-002-0201-x, p. 206-218.

Thompson, G., S.R. McNutt, and G. Tytgat, 2002, Three Distinct Regimes of Volcanic Tremor Associated with Eruptions of Shishaldin Volcano, Alaska, April 1999. Bulletin of Volcanology, v. 64, DOI 10.1007/s00445-002-0228-z, p. 535-547.