Catalog of Earthquake Hypocenters at Alaskan Volcanoes: January 1 through December 31, 2003

By James P. Dixon[1], Scott D. Stihler[2], John A. Power[3], Guy Tytgat[2], Seth C. Moran[4], John J. Sánchez[2], Stephen R. McNutt[2], Steve Estes[2], and John Paskievitch[3]

Open-File Report 2004-1234

2004

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

[1] Alaska Volcano Observatory, U. S. Geological Survey, 903 Koyukuk Drive, Fairbanks, AK 99775-7320
[2] Alaska Volcano Observatory, Geophysical Institute, 903 Koyukuk Drive, Fairbanks, AK 99775-7320
[3] Alaska Volcano Observatory, U. S. Geological Survey, 4200 University Drive, Anchorage, AK 99508-4667
[4] Cascades Volcano Observatory, U. S. Geological Survey, 1300 SE Cardinal Ct., Bldg. 10, Vancouver, WA 99508

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; Dixon and others, 2003). The primary objectives of this program are the near real time seismic monitoring of active, potentially hazardous, Alaskan volcanoes and the investigation of seismic processes associated with active volcanism. This catalog presents the calculated earthquake hypocenter and phase arrival data, and changes in the seismic monitoring program for the period January 1 through December 31, 2003.

The AVO seismograph network was used to monitor the seismic activity at twenty-seven volcanoes within Alaska in 2003. These include Mount Wrangell, Mount Spurr, Redoubt Volcano, Iliamna Volcano, Augustine Volcano, Katmai volcanic cluster (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, Okmok Caldera, Great Sitkin Volcano, Kanaga Volcano, Tanaga Volcano, and Mount Gareloi (Figure 1). Monitoring highlights in 2003 include: continuing elevated seismicity at Mount Veniaminof in January-April (volcanic unrest began in August 2002), volcanogenic seismic swarms at Shishaldin Volcano throughout the year, and low-level tremor at Okmok Caldera throughout the year. Instrumentation and data acquisition highlights in 2003 were the installation of subnetworks on Tanaga and Gareloi Islands, the installation of broadband installations on Akutan Volcano and Okmok Caldera, and the establishment of telemetry for the Okmok Caldera subnetwork. AVO located 3911 earthquakes in 2003 (Table 1).

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 2003; and (5) an accompanying UNIX tar-file with a summary of earthquake origin times, hypocenters, magnitudes, phase arrival times, and

location quality statistics; daily station usage statistics; and all HYPOELLIPSE files used to determine the earthquake locations in 2003.

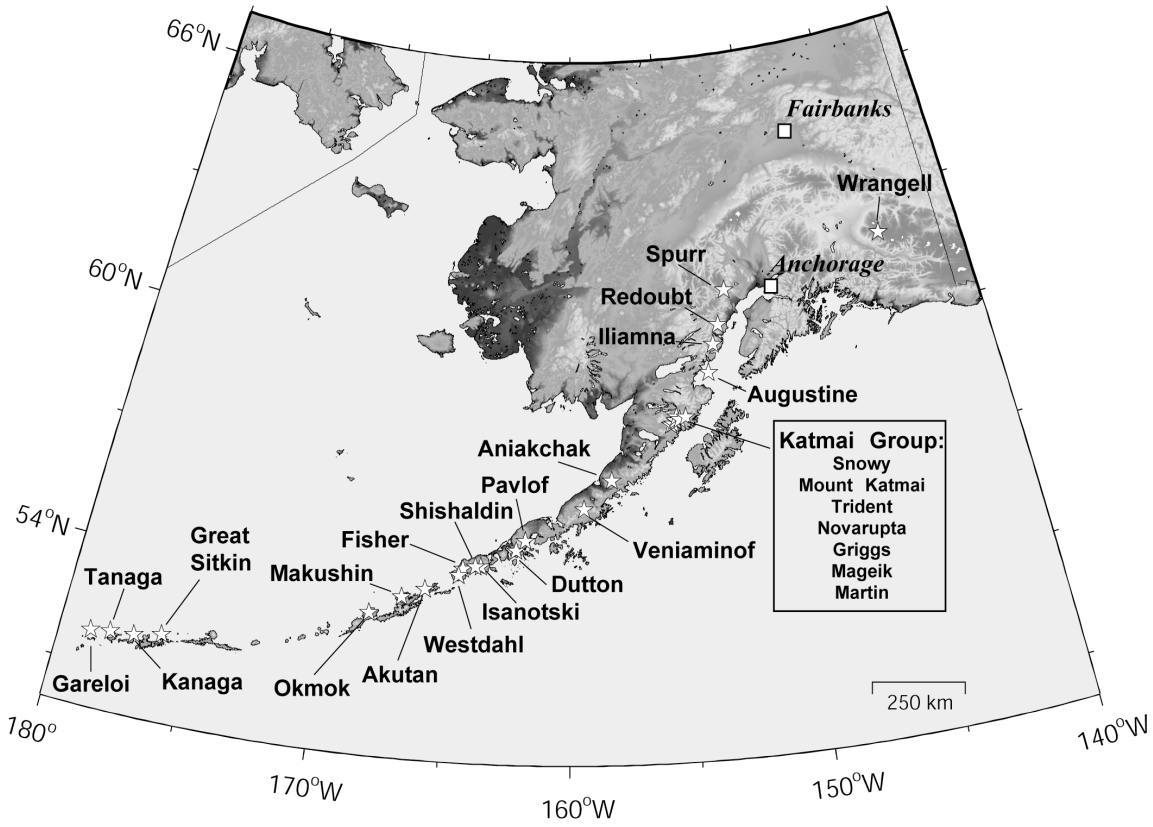


Figure 1. Alaskan volcanoes seismically instrumented by AVO in 2003. Stars show the location of volcanoes and squares show the location of Anchorage and Fairbanks.

Table 1: Number of earthquakes located per year by AVO for the last eight years.

Year	Earthquakes located per year	Volcanoes with seismograph networks
1996	6466	15
1997	2930	17
1998	2873	19
1999	2769	21
2000	1551	21
2001	1427	23
2002	7242	24
2003	3911	27

Instrumentation

In 2003, the AVO seismograph network was expanded from 140 to 160 permanent seismograph stations. The AVO seismograph network is composed of nineteen subnetworks with 4-18 seismograph stations per subnetwork, and 14 regional seismograph stations. In June, broadband seismograph stations were installed on Akutan Volcano though timing problems precluded the use of any broadband data. In August, the Okmok subnetwork became operational and new subnetworks were installed to monitor Tanaga Volcano and Mount Gareloi. Other changes to the existing network were the addition of the seismograph station MREP to the Makushin subnetwork and the removal of seismograph station AUC on Augustine Volcano. The 160 permanent seismograph stations have a total of 216 components.

AVO operated 134 short-period vertical-component seismograph stations during 2003. All these stations had either Mark Products L4 or Teledyne-Geotech S-13 seismometers with a one-second natural period. AVO also operated 18 three-component, short-period instruments during the catalog period. The instruments used at sites with three component sensors 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 seismometers with a one-second natural period. Nine broadband stations were operated with either Guralp CMG-40T 60-second natural period seismometers or Guralp CMG-6TD 30-second natural period seismometers. Typical calibration curves for stations using the L-4, L22, S-13 and CMG-40T sensors are shown in Figures 2-5.

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. The vast majority of seismograph stations use the McVCO as all A1VCO's are being phased out. 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. At the Adak, Dutch Harbor and Homer communication hubs, the data were digitized at the hub and then directed to AVO offices via the Intranet. From all other

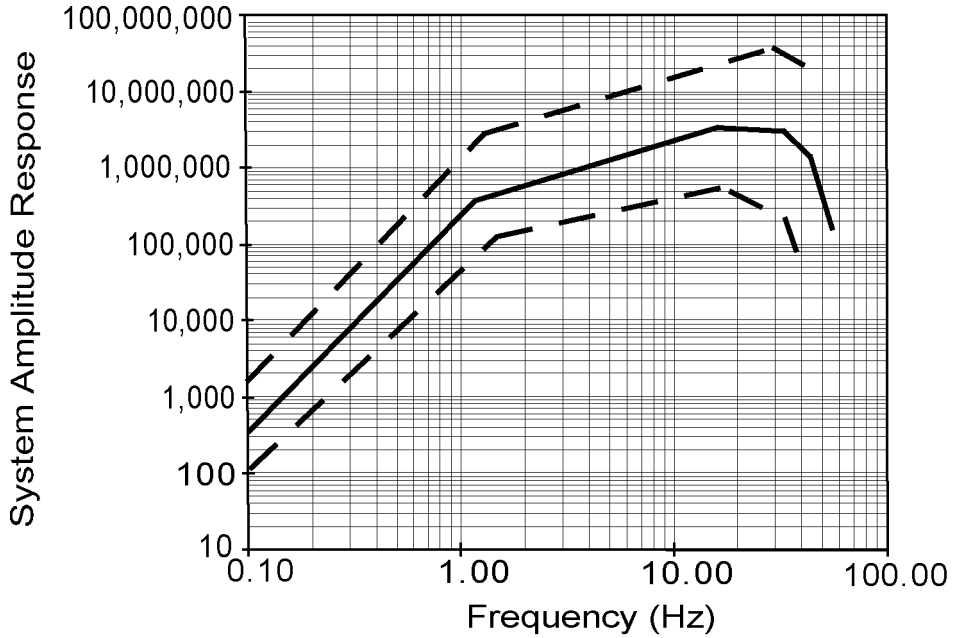


Figure 2. Representative calibration curves for stations using a Mark Products L4 seismometer. The solid line illustrates the typical calibration curve and the dashed lines show the range of calibration curves for all AVO stations using an L4 seismometer.

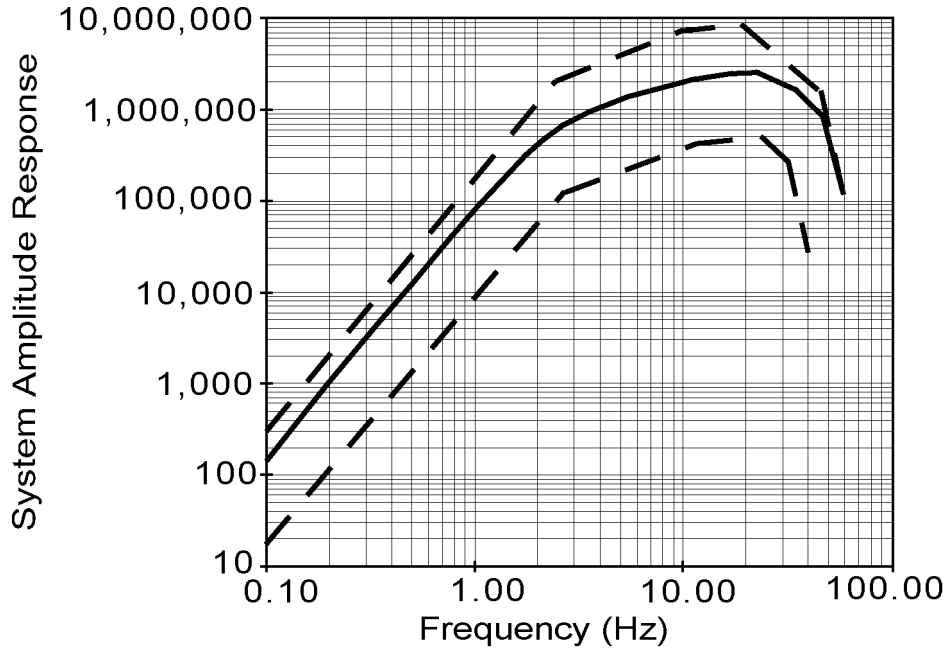


Figure 3. Representative calibration curves for stations using a Mark Products L22 seismometer. The solid line illustrates the typical calibration curve and the dashed lines show the range of calibration curves for all AVO stations using an L22 seismometer.

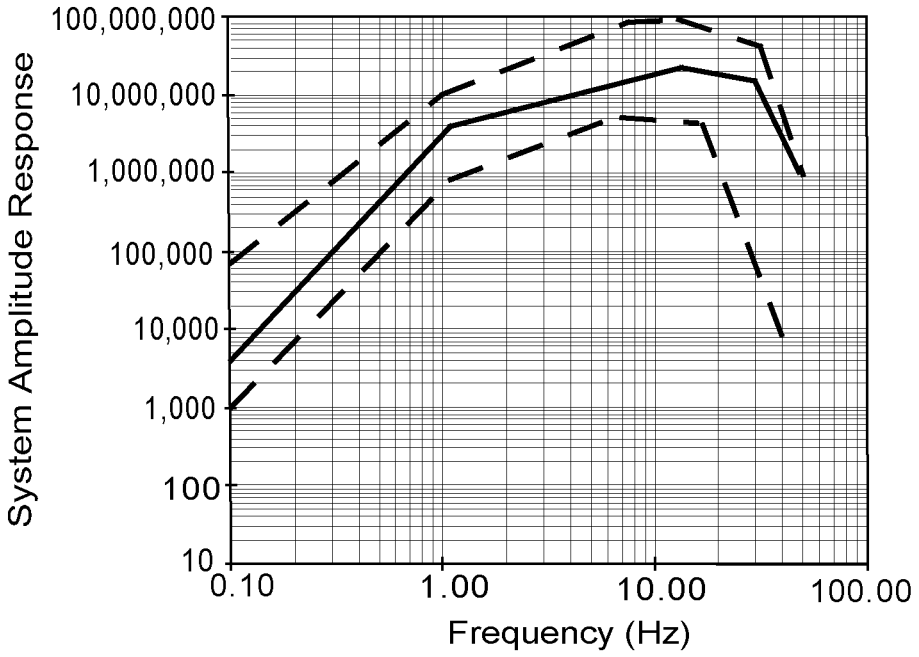


Figure 4. Representative calibration curves for stations using a Teledyne-Geotech S-13 seismometer. The solid line illustrates the typical calibration curve and the dashed lines show the range of calibration curves for all AVO stations using an S-13 seismometer.

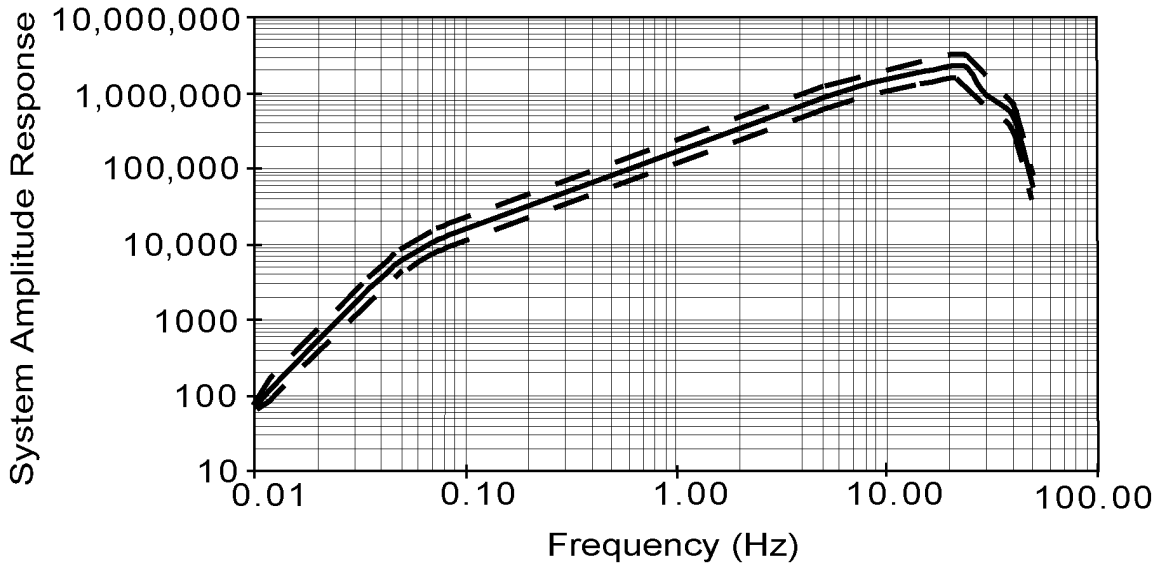


Figure 5. Representative calibration curves for stations using a Guralp CMG-40T seismometer. The solid line illustrates the typical calibration curve and the dashed lines show the range of calibration curves for all AVO stations using a Guralp CMG-40T seismometer.

hubs, signals were relayed via leased telephone circuits to AVO offices in Anchorage and Fairbanks where the signals were digitized.

Locations and descriptions for all AVO stations operated during 2003 are contained in Appendix B. Maps showing the locations of stations with respect to individual volcanoes are contained in Appendix C. Estimates of each station's operational status for the catalog period are shown in Appendix D. Other station information, such as calibration information contained in the file CALDATA.PRM, is available within the associated compressed UNIX tar-file.

Data Acquisition and Reduction

Data acquisition for the AVO seismograph network was accomplished with duplicate EARTHWORM systems (Johnson, 1995) set up in AVO offices in Anchorage and Fairbanks, providing a backup in case of failure at either location. Event data were saved when three stations in a defined subnetwork were triggered by an event. If four or more subnetworks triggered on the same event, all data were saved in a single trigger. The EARTHWORM modules Carlstatrig and Carlsubtrig were used to create the triggered data. The Carlstatrig parameters were set as follows: LTA time = 8 seconds, Ratio = 2.3, and Quiet = 4. Carlsubtrig was modified such 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 network codes are summarized in Table 2. All data are saved in SAC format.

Event triggers were processed daily 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 false triggers were deleted. Each subsequent event was identified by a classification code (Table 3) stored in the event location pick file. This classification system was modeled after that described by Lahr and others (1994). Earthquakes with a P-wave and S-wave separation of greater than five seconds on the first arriving stations to were assumed to come from non-volcanic sources and were typically discarded. The quality of each hypocenter was checked using a computer algorithm that identified events without magnitude, with fewer than three P-phases, with less than two S-phases, 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 all the 2003 earthquakes in the AVO catalog, the average root-mean-square travel-time error was 0.148, the average number of P-phases used was 6.8, and the average number of S-phases used was 5.1.

Table 2: Volcano Subnetwork Designators

Volcano Subnetwork	Network Code
Akutan Peak	ak
Aniakchak Crater	an
Augustine Volcano	au
Mount Dutton	dt
Iliamna Volcano	il
Mount Gareloi	ga
Great Sitkin Volcano	gs
Kanaga Volcano	ki
Katmai Volcanic Cluster	ka
Makushin Volcano	ma
Okmok Caldera	ok
Pavlof Volcano	pv
Redoubt Volcano	rd
Regional event	rg
Shishaldin Volcano	sh
Mount Spurr	sp
Tanaga Volcano	ta
Mount Veniaminof	vn
Westdahl Peak	we
Mount Wrangell	wa

Table 3: Classification codes

Event Classification	Classification Code
Volcano-Tectonic (VT)	a
Low-Frequency (LF)	b
Hybrid	h
Regional-Tectonic	E
Teleseismic	T
Shore-Ice	i
Calibrations	C
Other non-seismic	o
Cause unknown	x

Velocity Models

AVO currently employs eight local velocity models and one regional seismic velocity model (Appendix D) to locate earthquakes at 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.

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 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 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 (Searcy, 2003) 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 E. Figures showing the volcanic source zones modeled by cylinders in map view are shown in Appendix F.

Seismicity

The 3911 earthquakes located in 2003 represent the fourth highest yearly total determined by AVO in a single calendar year since recording began in 1989 and a decrease from the 7242 earthquakes located in 2002. The numbers of located events in 2002 and 2003 for each volcano subnetwork are shown in Table 4. Highlights of the

Table 4: Number of earthquakes located for each seismograph subnetwork in 2002 and 2003. Earthquakes are associated with the closest subnetwork. The totals for 2003 are broken into three event types: volcanic-tectonic (VT), Low-frequency (LF) and other (all event types are shown in Table 2).

Volcano Subnetwork	Earthquakes located in 2002	Earthquakes located in 2003	2003 VT	2003 LF	2003 Other
Mount Wrangell	309	105	11	94	0
Mount Spurr	504	549	290	168	91
Redoubt Volcano	104	79	64	6	9
Iliamna Volcano	315	617	156	440	21
Augustine Volcano	230	110	105	0	5
Katmai Vol. Cluster	1582	1131	1085	44	2
Aniakchak Crater	6	17	8	7	2
Mount Veniaminof	30	75	53	4	18
Pavlof Volcano	221	227	40	60	127
Mount Dutton	39	37	11	0	26
Shishaldin Volcano	2658	411	121	256	34
Westdahl Peak	17	80	62	17	1
Akutan Peak	39	77	43	24	10
Makushin Volcano	124	100	83	4	13
Okmok Caldera	n/a	69	57	2	10
Great Sitkin Volcano	980	113	106	5	2
Kanaga Volcano	45	90	79	2	9
Tanaga Volcano	n/a	5	5	0	0
Mount Gareloi	n/a	19	13	5	1
Totals	7242	3911	2424	1138	381

2003 seismicity include continuing elevated seismicity at Mount Veniaminof in January-April (volcanic unrest began in August 2002), volcanogenic seismic swarms at Shishaldin Volcano throughout the year, and low-level tremor on Okmok Caldera throughout the year. These highlights are not well represented by the events in the 2003 catalog since in all three cases, the majority of the triggered events associated with the seismic activity were not locatable. The magnitude of completeness for each seismograph subnetwork is shown in Table 5.

Table 5: Magnitude of completeness (Mc) for AVO seismograph subnetworks calculated using ZMAP (Weimer, 2001) for the 2003 Catalog. Earthquakes from 2004 were included to calculate the Mc for the Aniakchak, Tanaga and Gareloi subnetworks since the sample size in 2003 was insignificant to compute a Mc for these subnetworks.

Volcano Subnetwork	**Mc**
Mount Wrangell	0.9
Mount Spurr	0.3
Redoubt Volcano	0.6
Iliamna Volcano	-0.2
Augustine Volcano	0.0
Katmai Volcanic Cluster	0.5
Aniakchak Crater	1.7
Mount Veniaminof	1.6
Pavlof Volcano	0.6
Mount Dutton	1.4
Shishaldin Volcano	0.5
Westdahl Peak	0.4
Akutan Peak	1.2
Makushin Volcano	1.2
Okmok Caldera	1.2
Great Sitkin Volcano	0.9
Kanaga Volcano	0.9
Tanaga Volcano	1.5
Mount Gareloi	1.5

The decrease in the number of earthquakes located in 2003 compared to those in 2002 at the Augustine and Wrangell subnetworks were a result of station failures in 2003 (Appendix D). The Iliamna and Dutton regions saw an increased number of located earthquakes in 2003 that were related to the completion of deferred station maintenance

in the summer of 2003. The Veniaminof network was operational for only part of 2002 hence the apparent increase in activity. The networks for Okmok, Gareloi and Tanaga were installed this year allowing no comparison to previous years.

The decrease of seismic activity for the Katmai Volcanic Cluster and Great Sitkin Volcano were the result of significant earthquake swarms in 2002. Both volcanic regions had at least one significant earthquake swarm in 2002 and none in 2003. The number of earthquakes located at Shishaldin Volcano is significantly lower than in 2002. In 2003, the character of the Shishaldin events changed such that the events were more difficult to locate, resulting in fewer earthquakes located in 2003. However, based on manual earthquake counts (Figure 6) we feel the overall seismicity rate at Shishaldin did not significantly decline. The seismic activity at Westdahl Peak has shown a significant increase in seismicity that is apparently not a result of station operation (Appendix D). The decrease of seismicity at Kanaga is an example of the variability seen on Aleutian

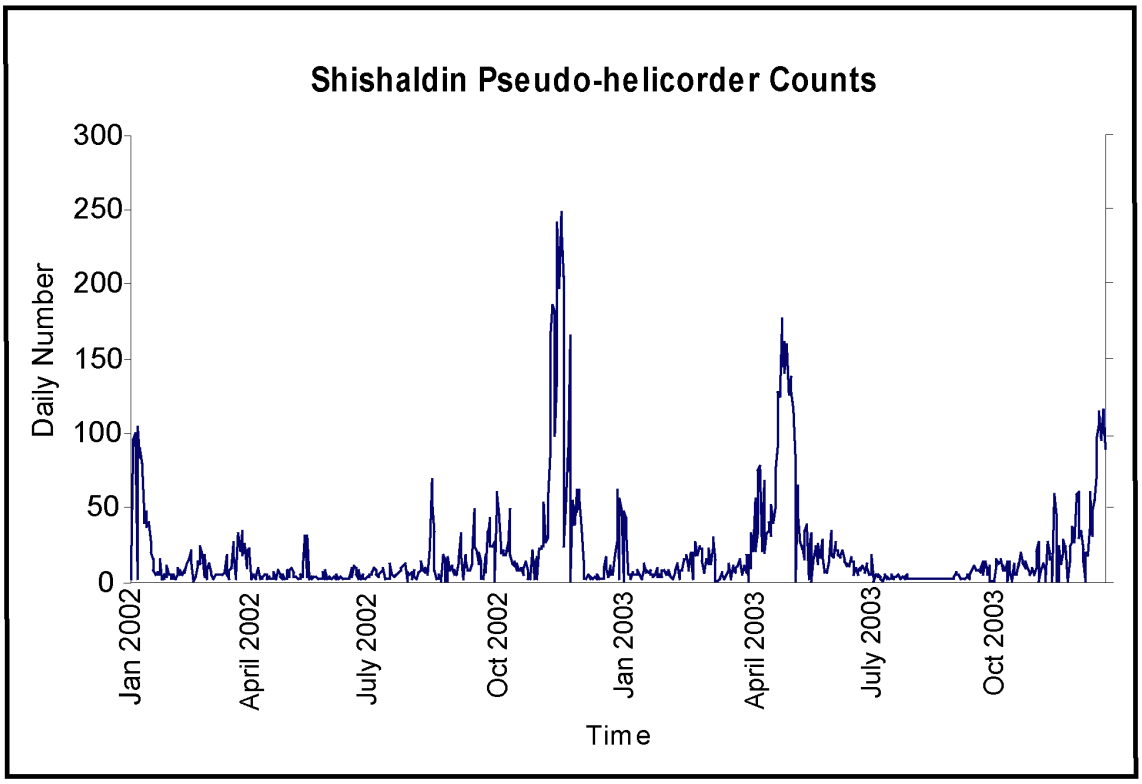


Figure 6: Pseudo-helicorder counts for Shishaldin Volcano. Pseudo-helicorder records are created using a bandpass filter (0.8-5.0 Hz) on the continuous digital record. Events counted are local events with minimum peak-peak amplitude of 500 counts.

volcanoes. The Kanaga seismicity was at an all time high in 2002 but the seismicity in 2003 is more typical of the seismicity recorded since the subnetwork was installed. Seismicity at the remaining subnetworks in 2003, Spurr, Redoubt, Aniakchak, Pavlof, and Makushin, was similar to that in 2002.

Summary

Between January 1, 2003, and December 31, 2003, AVO located 3911 earthquakes that occurred at or near volcanoes in Alaska. Monitoring highlights in 2003 include continuing elevated seismicity at Mount Veniaminof in January-April (volcanic unrest began in August 2002), volcanogenic seismic swarms at Shishaldin Volcano throughout the year, and low-level tremor on Okmok Caldera throughout the year. New seismic subnetworks were installed on Tanaga and Gareloi Islands and broadband stations were installed on Akutan Volcano and within Okmok Caldera.

Available for download with this report is a compressed Unix tar-file containing a summary listing of earthquake hypocenters and all the necessary HYPOELLIPSE input files to recalculate the hypocenters including station locations and calibration, velocity model, and phase information. 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, and Stephanie Prejean, for formal reviews of the text and figures.

References

Dixon, J.P, Stihler, S.D., Power J.A., 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.

Dixon, J.P., Stihler, S.D., Power J.A., Tytgat, G., Moran, S.C., Sánchez, J., Estes, S., McNutt, S.R., Paskievitch, J., 2003, Catalog of Earthquake Hypocenters at Alaska Volcanoes: January 1 – December 31, 2002: U.S. Geological Survey Open-file Report 03-267, 58p.

Fogleman, K.A., Lahr, J.C., Stephens, C.D., and Page, R.A., 1993, Earthquake locations determined by the southern Alaska seismograph network for October 1971 through May 1989: U.S. Geological Survey Open-file Report 93-309, 54p.

Johnson, C.E., Bittenbinder, A., Bogaert, B., Dietz, L., Kohler, W., 1995, EARTHWORM: A Flexible Approach to Seismograph network Processing, Incorporated Research Institutions for Seismology Newsletter, v. 14, no. 2, p. 1-4.

Jolly, A.D., Page, R.A., and Power, J.A., 1994, Seismicity and stress in the vicinity of Mt. Spurr volcano, south-central Alaska: Journal of Geophysical Research, v. 99, p. 15305-15318.

Jolly, A.D, Power, J.A., Stihler, S.D., Rao, L.N., Davidson, G., Paskievitch, J., Estes, S., Lahr, J.C., 1996, Catalog of earthquake hypocenters for Augustine, Redoubt, Iliamna, and Mount Spurr Volcanoes, Alaska: January 1, 1991 – December 31, 1993: U.S. Geological Survey Open-file Report 96-70, 90p.

Jolly, A.D., Stihler, S.D., Power, J.A., Lahr, J.C., Paskievitch, J., Tytgat, G., Estes, S., Lockhart, A.B., Moran, S.C., McNutt, S.R., Hammond, W.R., 2001, Catalog of earthquake hypocenters at Alaskan Volcanoes: January 1, 1994 – December 31, 1999: U.S. Geological Survey Open-file Report 01-189, 202p.

Lahr, J.C, Chouet, B.A., Stephens, C.D., Power, J.A., Page, R.A., 1994, Earthquake classification, location, and error analysis in a volcanic environment: Implications for the magmatic system of the 1989-90 eruptions at Redoubt Volcano, Alaska: Journal of Volcanology and Geothermal Research, v. 62, p. 137–152.

Lahr, J.C., 1999, HYPOELLIPSE: A Computer Program for Determining Local Earthquake Hypocentral Parameters, Magnitude, and First Motion Pattern: U.S. Geological Survey Open File Report 99-23, 116p.

McChesney, P.J., 1999, McVCO Handbook 1999: U.S. Geological Survey, Open-File Report 99-361, 48p.

McNutt, S.R., and Jacob, K.H., 1986, Determination of large-scale velocity structure of the crust and upper mantle in the vicinity of Pavlof volcano, Alaska: Journal of Geophysical Research, v. 91, p. 5013-5022.

McNutt, S.R., 2002, Seismology: The State of Knowledge of the Aleutian Arc, 2002, 3rd Biennial Workshop on Subduction Processes emshasizing the Kurile-Kamchatka-Aleutian Arcs.

Power, J.A., 1988, Seismicity associated with the 1986 eruption of Augustine Volcano, Alaska: University of Alaska Fairbanks, Masters thesis, 149p.

Power, J.A., Paskievitch, J.F., Richter, D.H., McGimsey, R.G., Stelling, P., Jolly, A.D., Fletcher, H.J., 1996, 1996 seismicity and ground deformation at Akutan Volcano, Alaska: EOS Transactions of the American Geophysical Union, v. 77, p. F514.

Power, J.A., March, G.D., Lahr, J.C., Jolly, A.D., Cruse, G.R., 1993, Catalog of earthquake hypocenters at Redoubt Volcano and Mount Spurr, Alaska: October 12, 1989-December 31, 1990: U.S. Geological Survey Open-File Report, 93-685-A, 57p.

Robinson, M., 1990, XPICK users manual, version 2.7: Seismology Lab, Geophysical Institute, University of Alaska Fairbanks, 93p.

Rogers, J.A., Maslak, S., and Lahr, J.C., 1980, A seismic electronic system with automatic calibration and crystal reference: U.S. Geological Survey Open-file Report 80-324, 130p.

Roman, D.C., Power, J.A., Moran, S.C., Cashman, K.V., Stihler, S.D., 2001, Unrest at Iliamna Volcano, Alaska in 1996, Evidence for a magmatic intrusion: EOS Transactions of the American Geophysical Union, v. 82, p. F1329.

Searcy, C.K., 2003, Station Corrections for the Katmai Region Seismograph network: U.S. Geological Survey Open-file Report 03-403, 16p.

Toth, T., and Kisslinger, C., 1984, Revised focal depths and velocity model for local earthquakes in the Adak seismic zone: Bulletin of the Seismological Society of America, v. 74, p. 1349-1360.

Wiemer, S., 2001, A software package to analyze seismicity: ZMAP, Seismological Research Letters 72, 373-382.

Appendix A: Maps showing the locations of the earthquakes located in 2003.

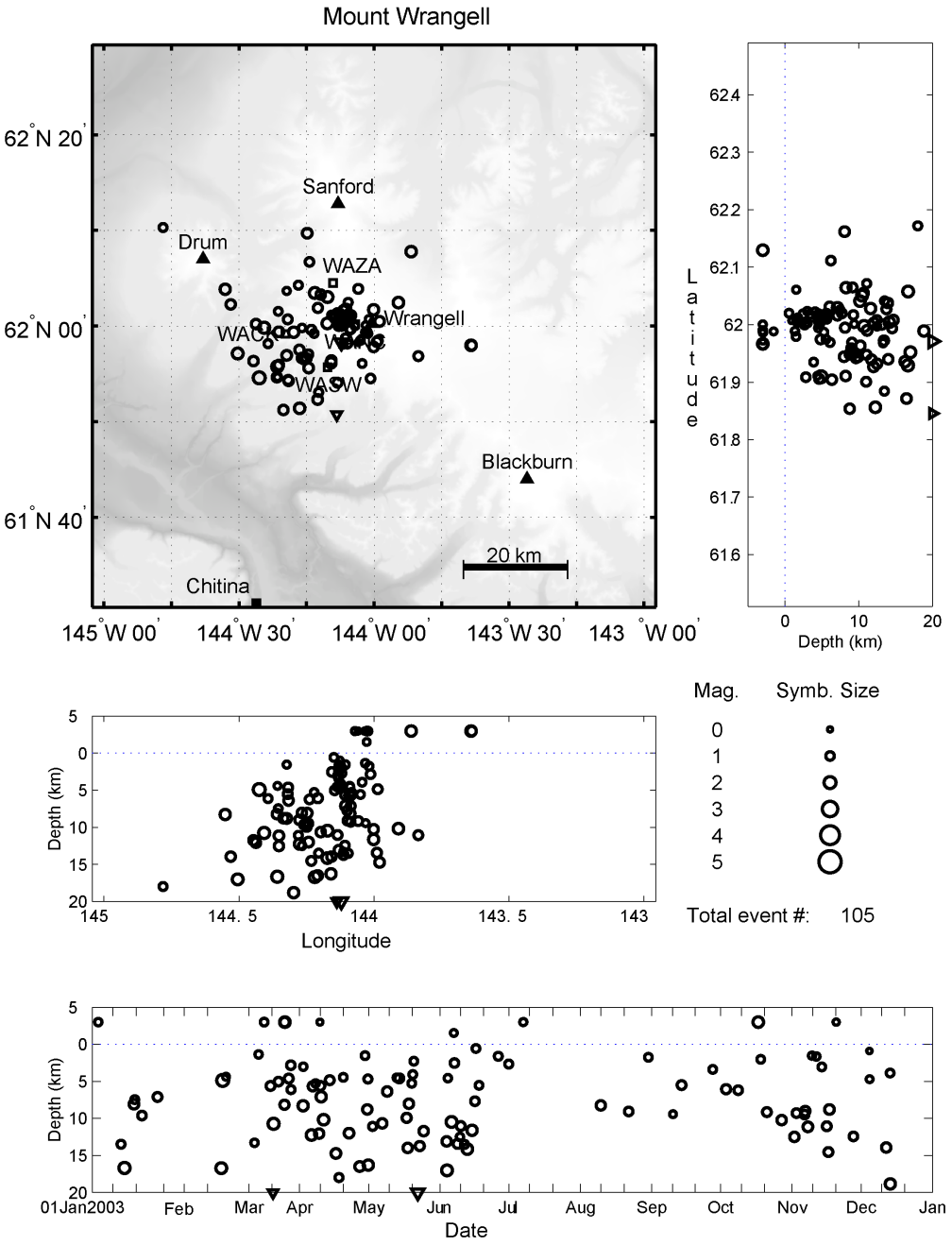


Figure A1. Summary plots of 105 earthquakes located near Mount Wrangell in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

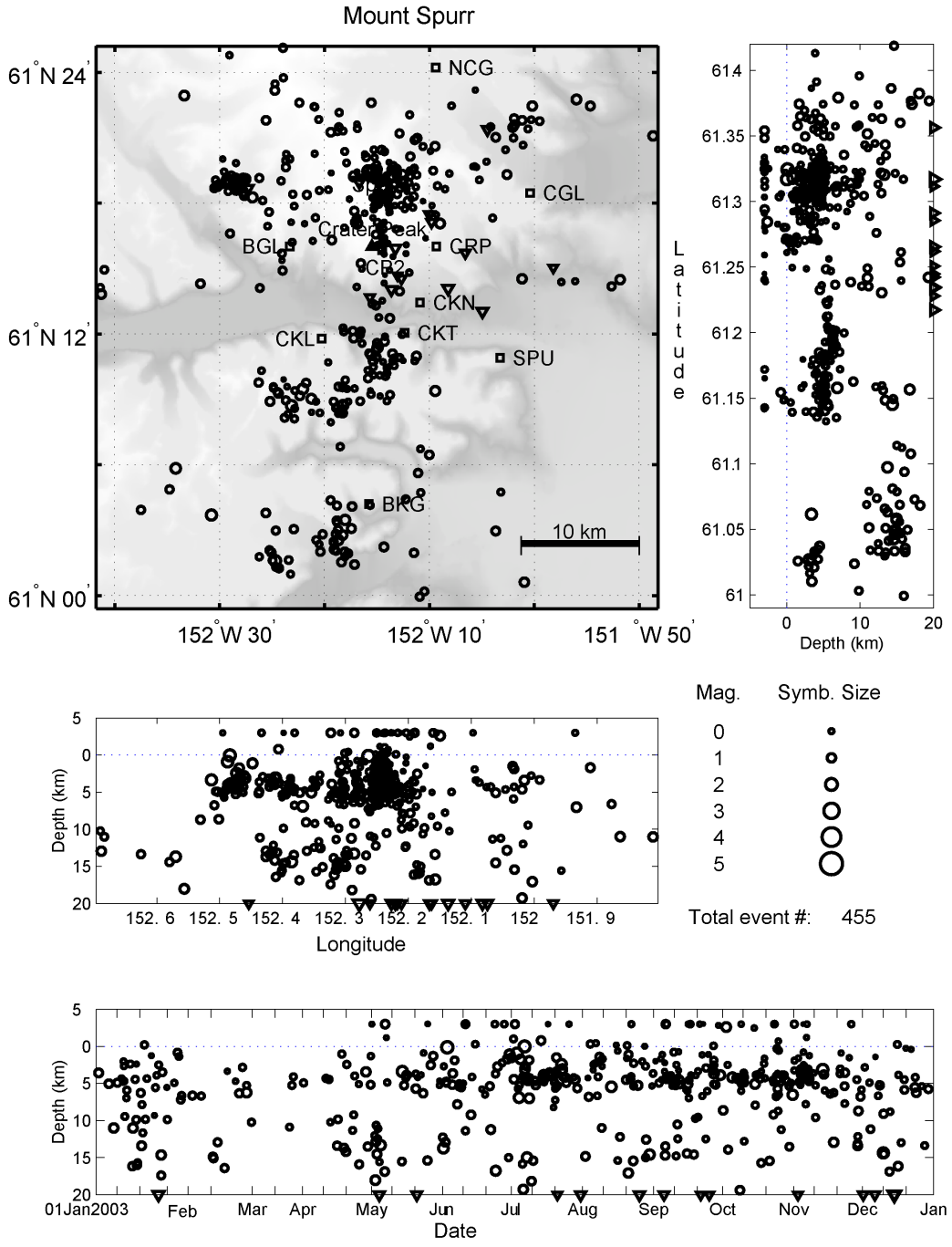


Figure A2. Summary plots of 455 earthquakes located near Mount Spurr in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

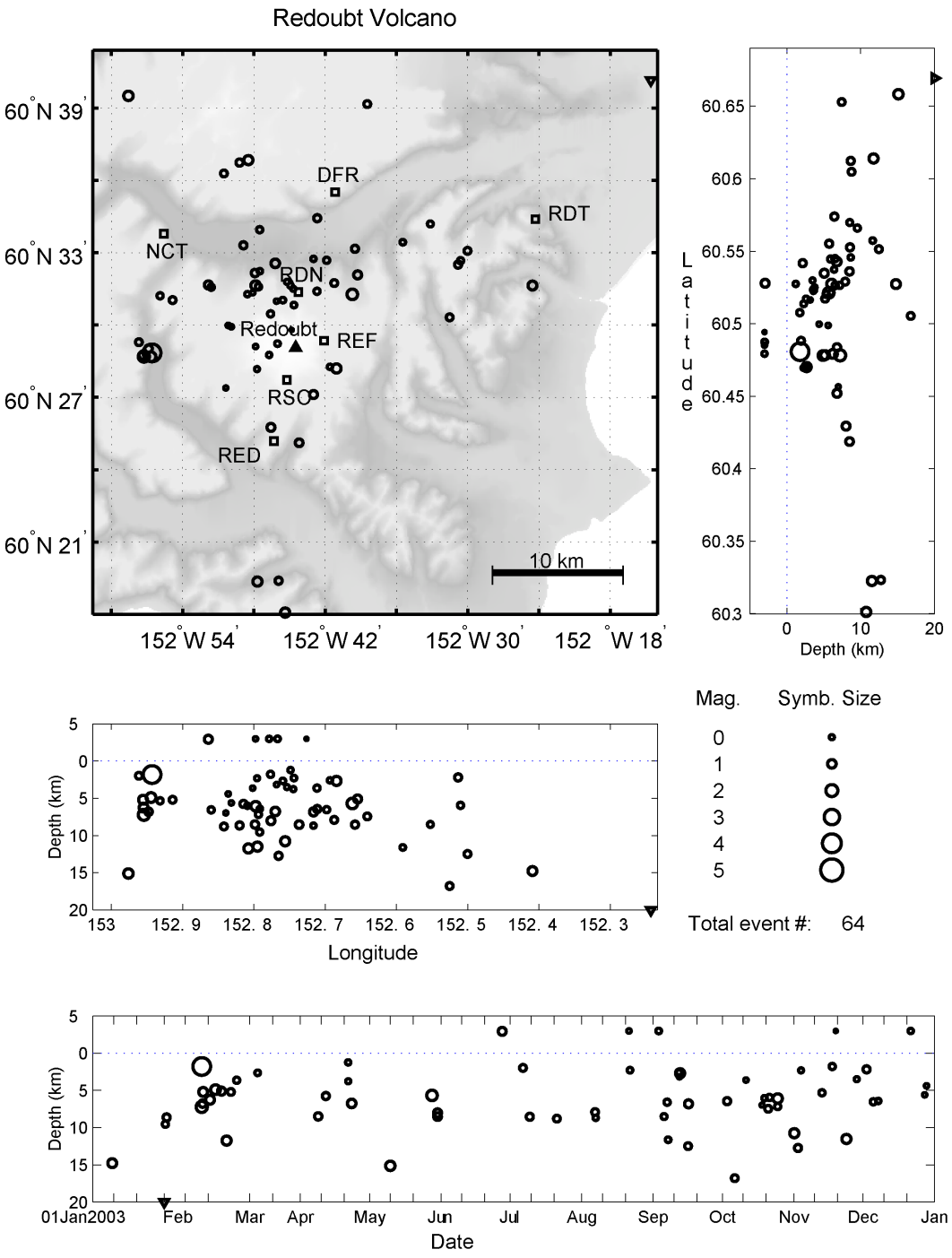


Figure A3. Summary plots of 64 earthquakes located near Redoubt Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

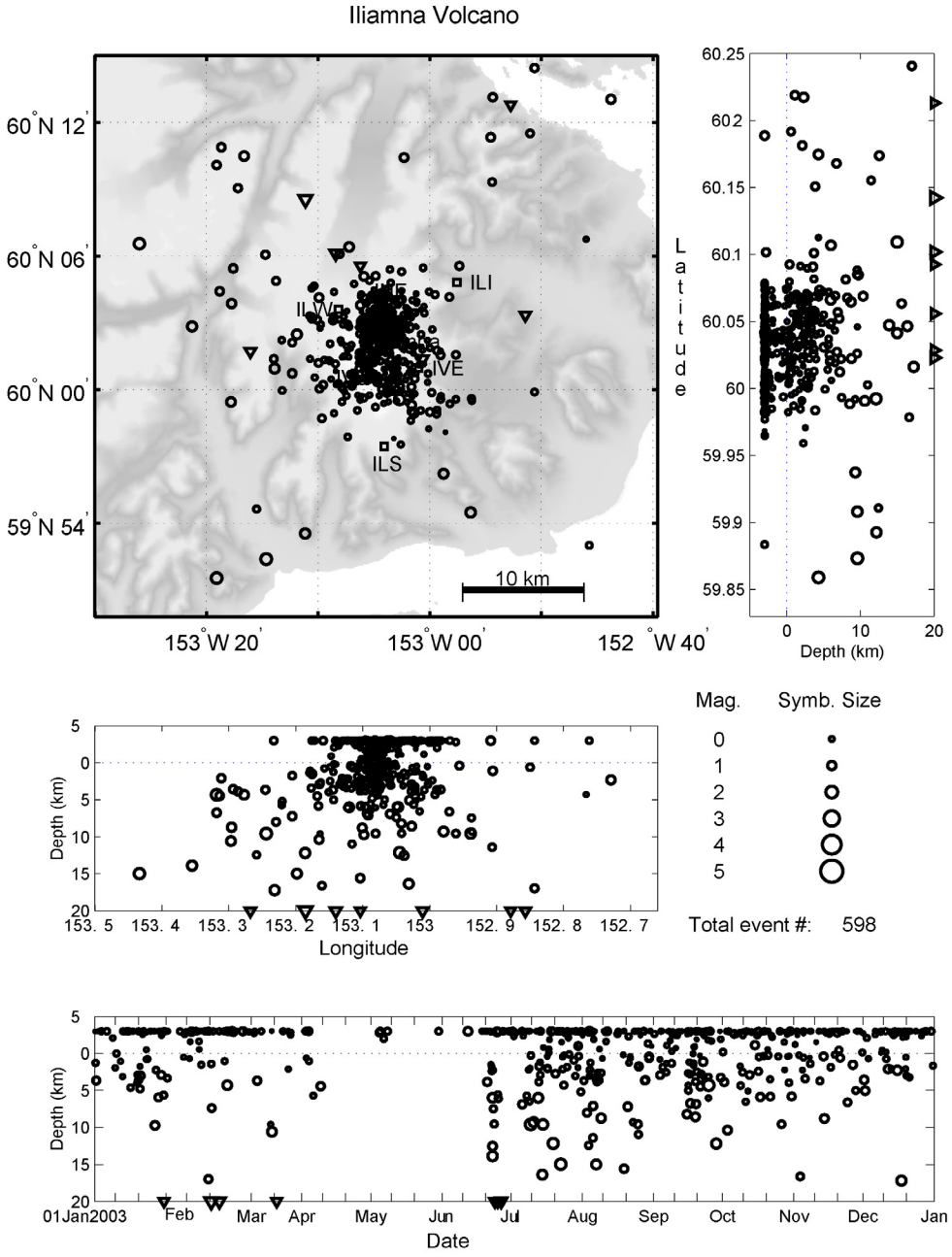


Figure A4. Summary plots of 598 earthquakes located near Iliamna Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

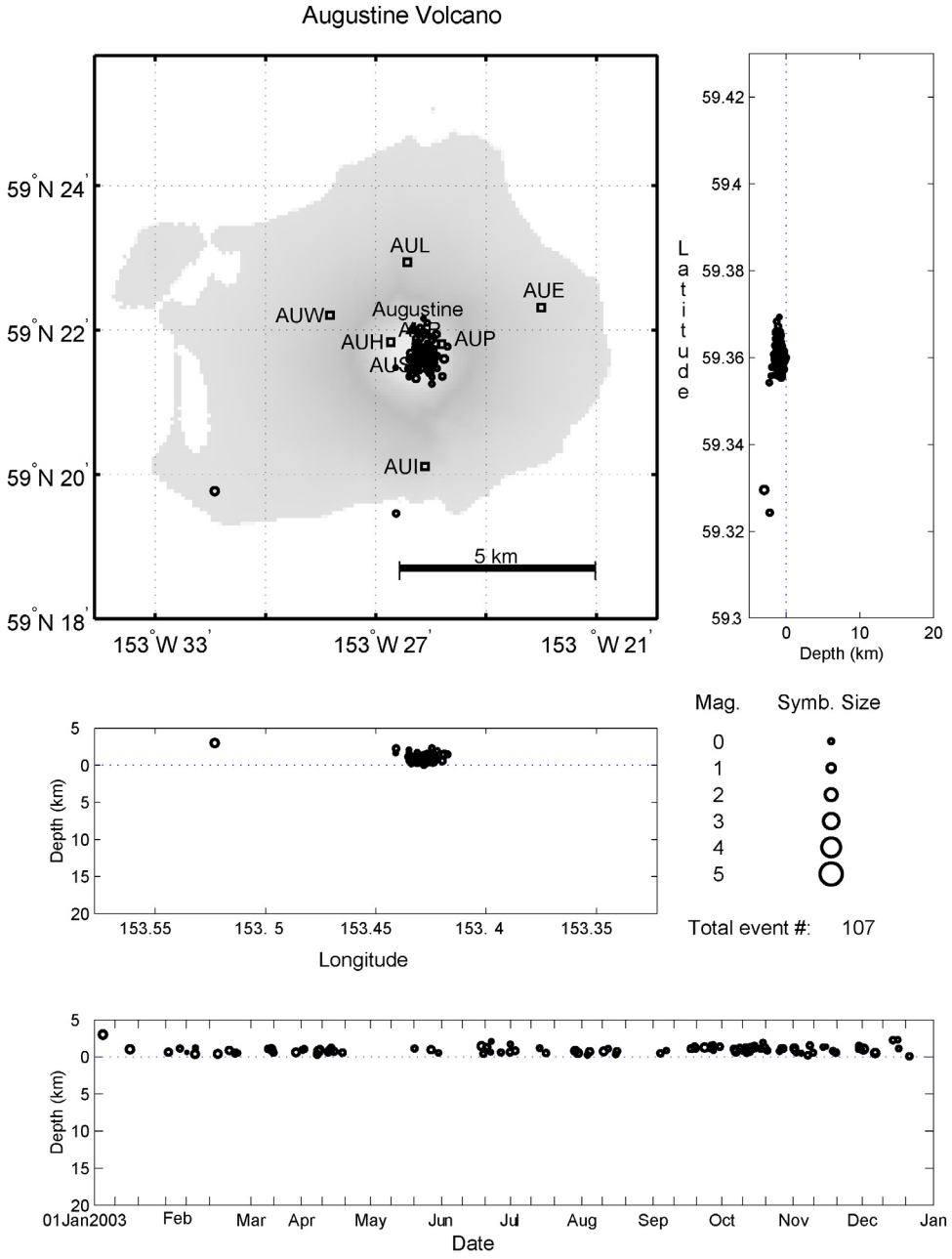


Figure A5. Summary plots of 107 earthquakes located near Augustine Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

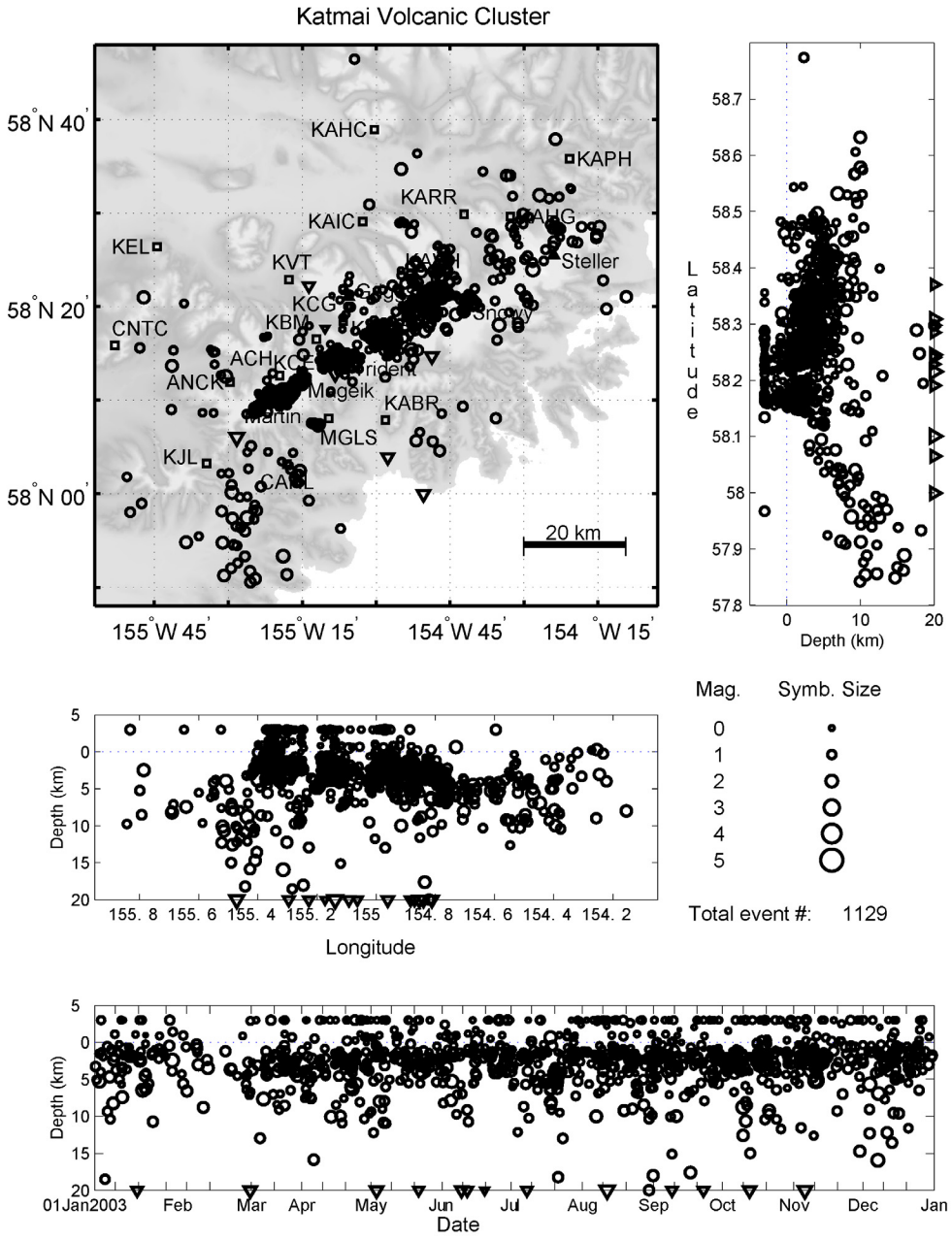


Figure A6. Summary plots of 1129 earthquakes located near the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

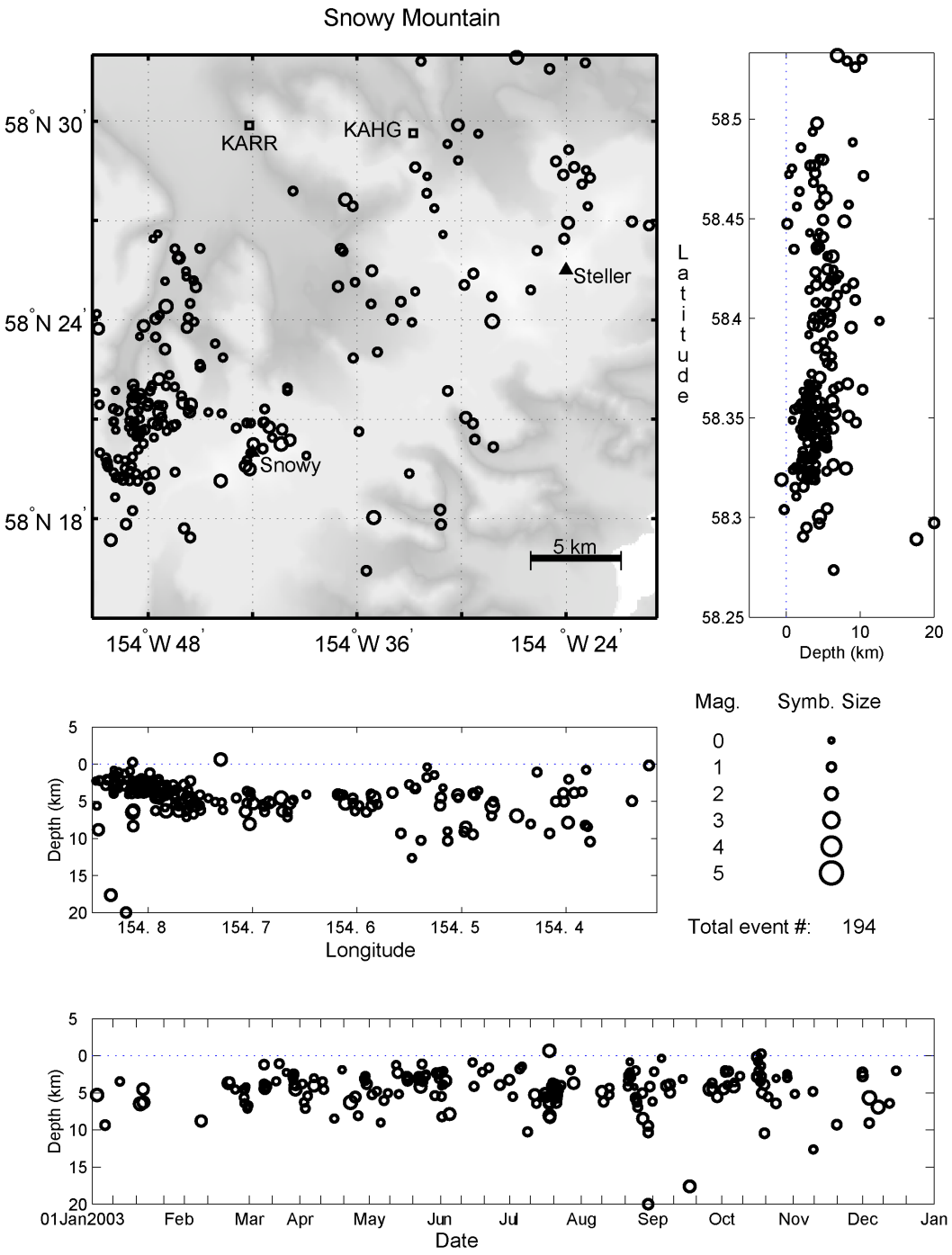


Figure A7. Summary plots of 194 earthquakes located near Snowy Mountain in the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

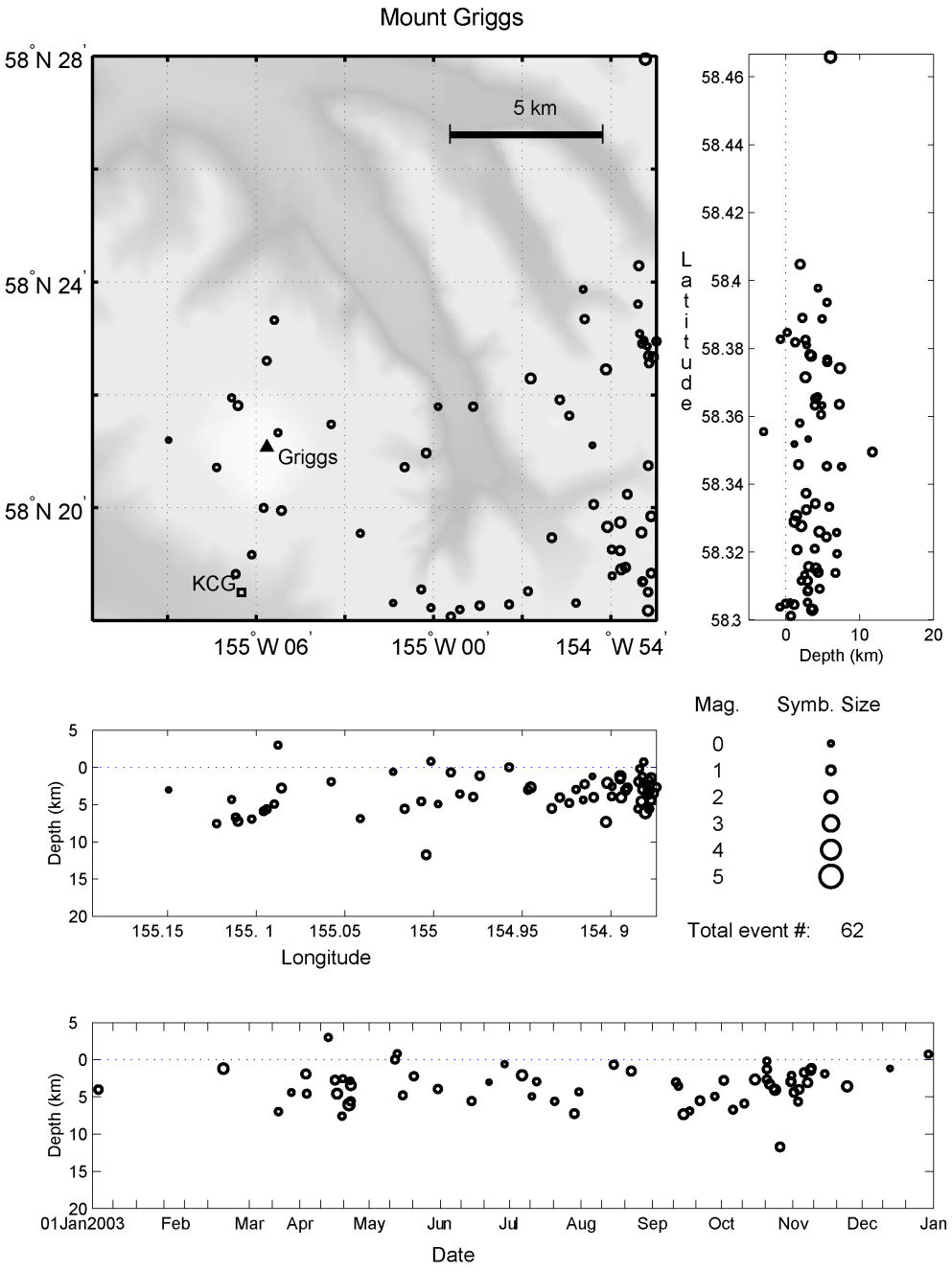


Figure A8. Summary plots of 62 earthquakes located near Mount Griggs in the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

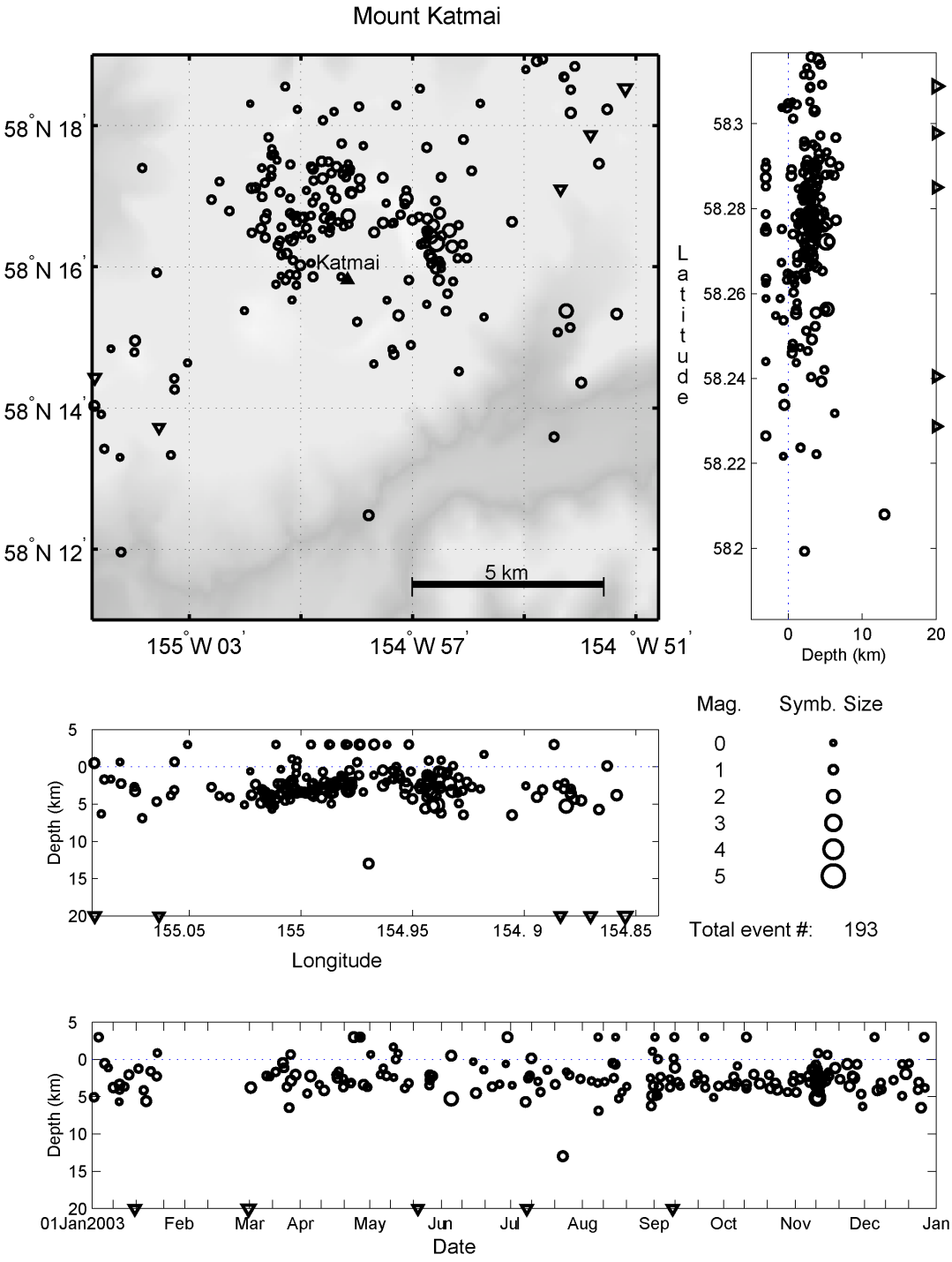


Figure A9. Summary plots of 193 earthquakes located near Mount Katmai in the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

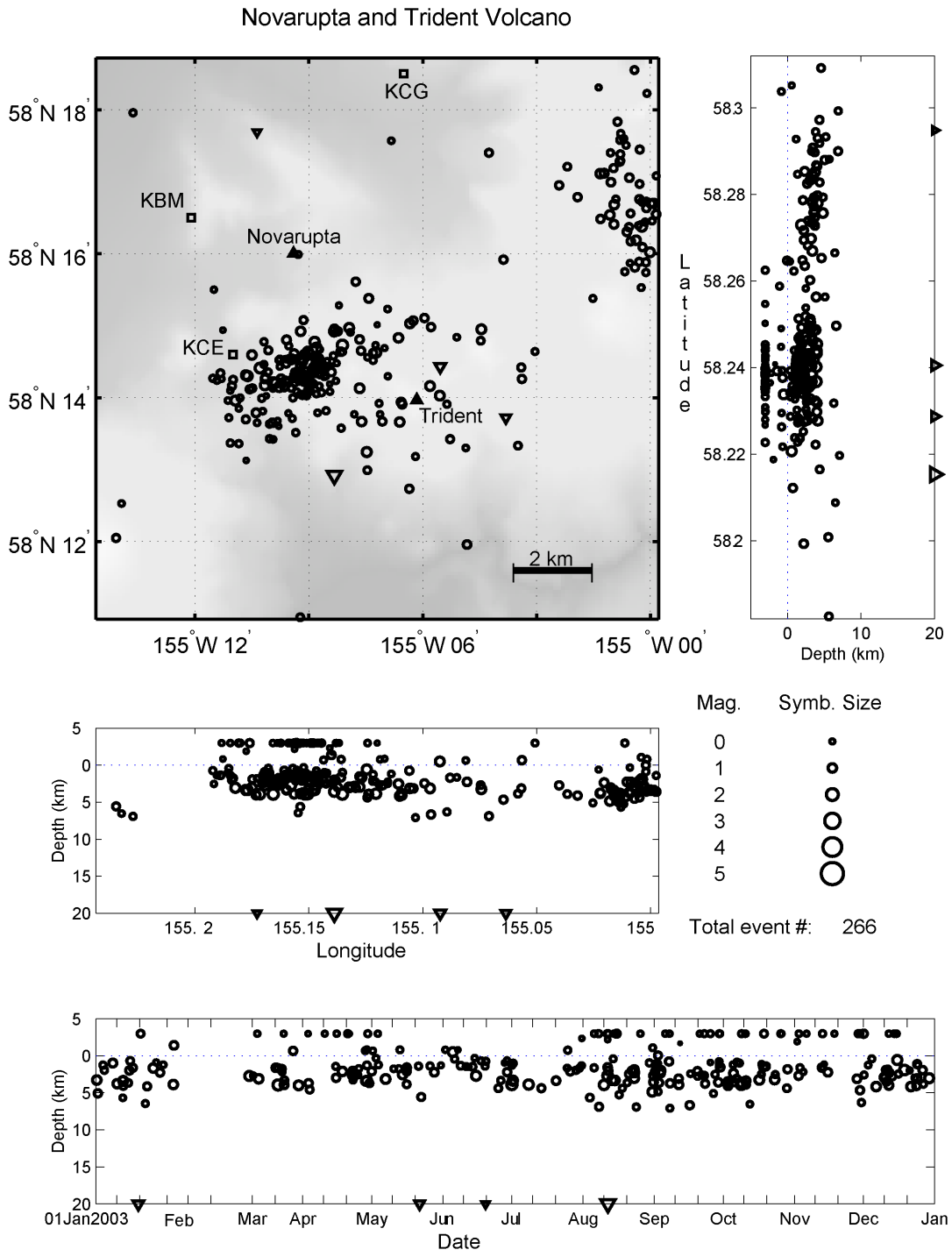


Figure A10. Summary plots of 266 earthquakes located near Novarupta and Trident Volcano in the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

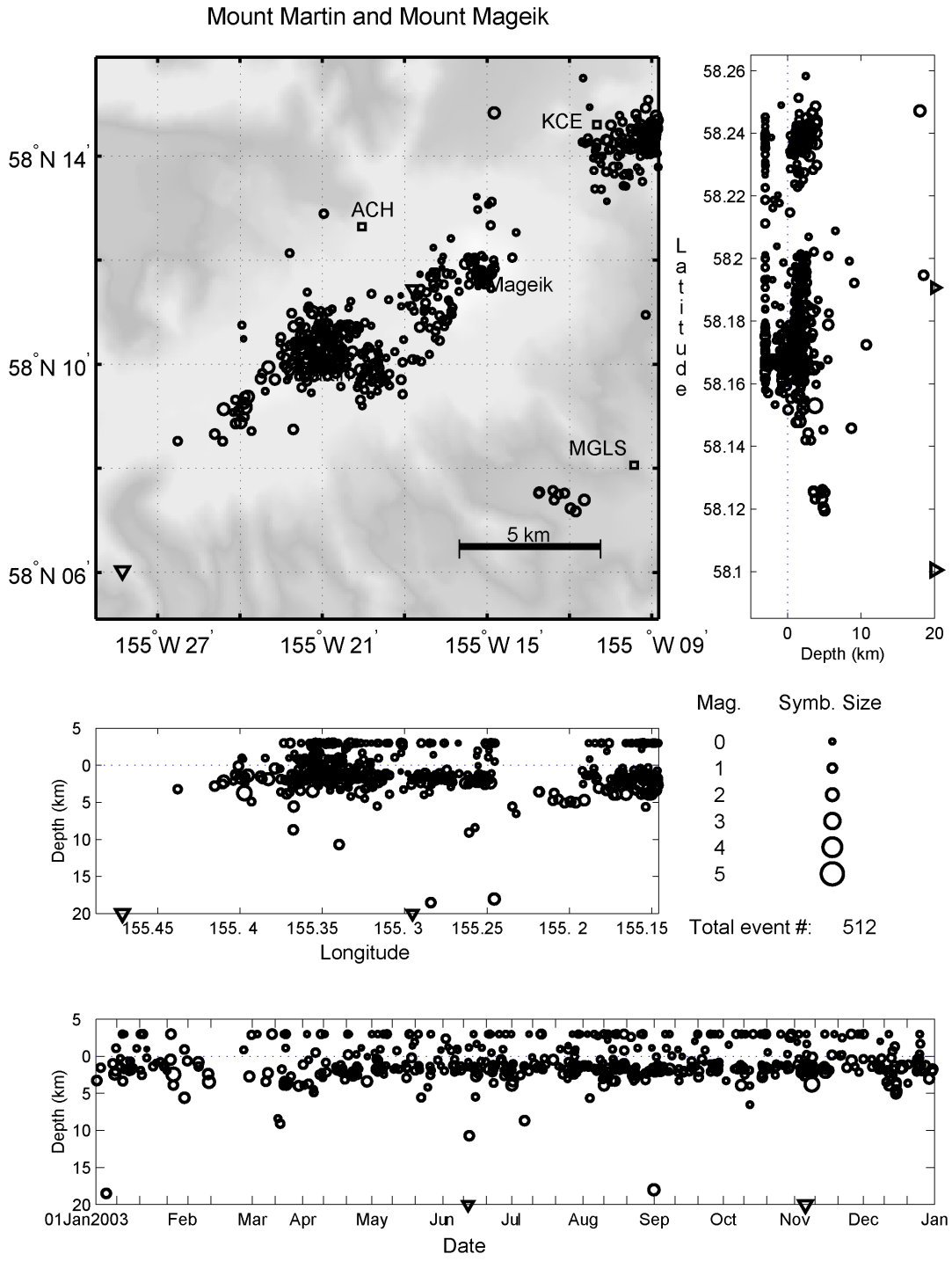


Figure A11. Summary plots of 512 earthquakes located near Mount Mageik and Mount Martin in the Katmai volcanic cluster in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

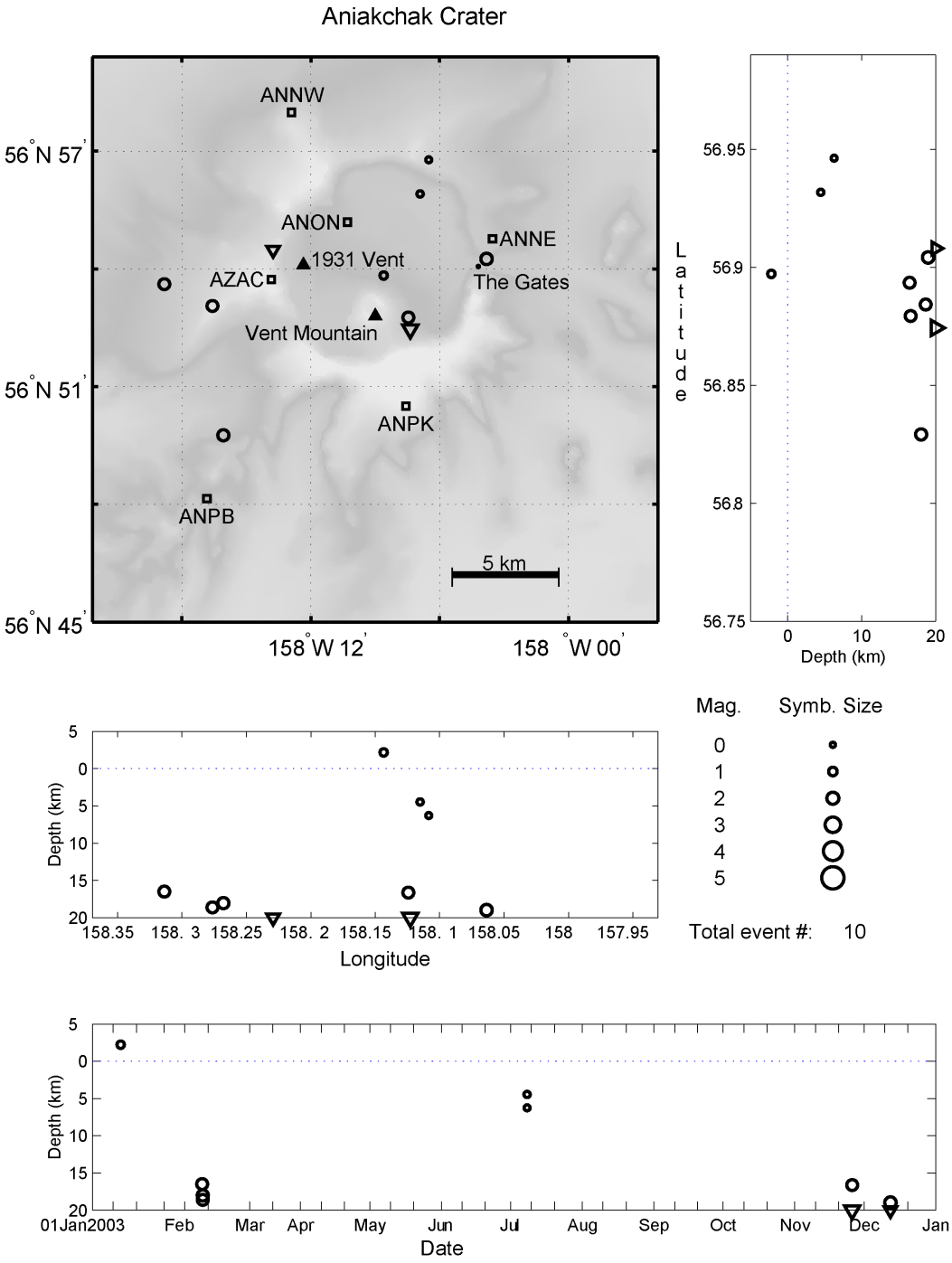


Figure A12. Summary plots of ten earthquakes located near Aniakchak Crater in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

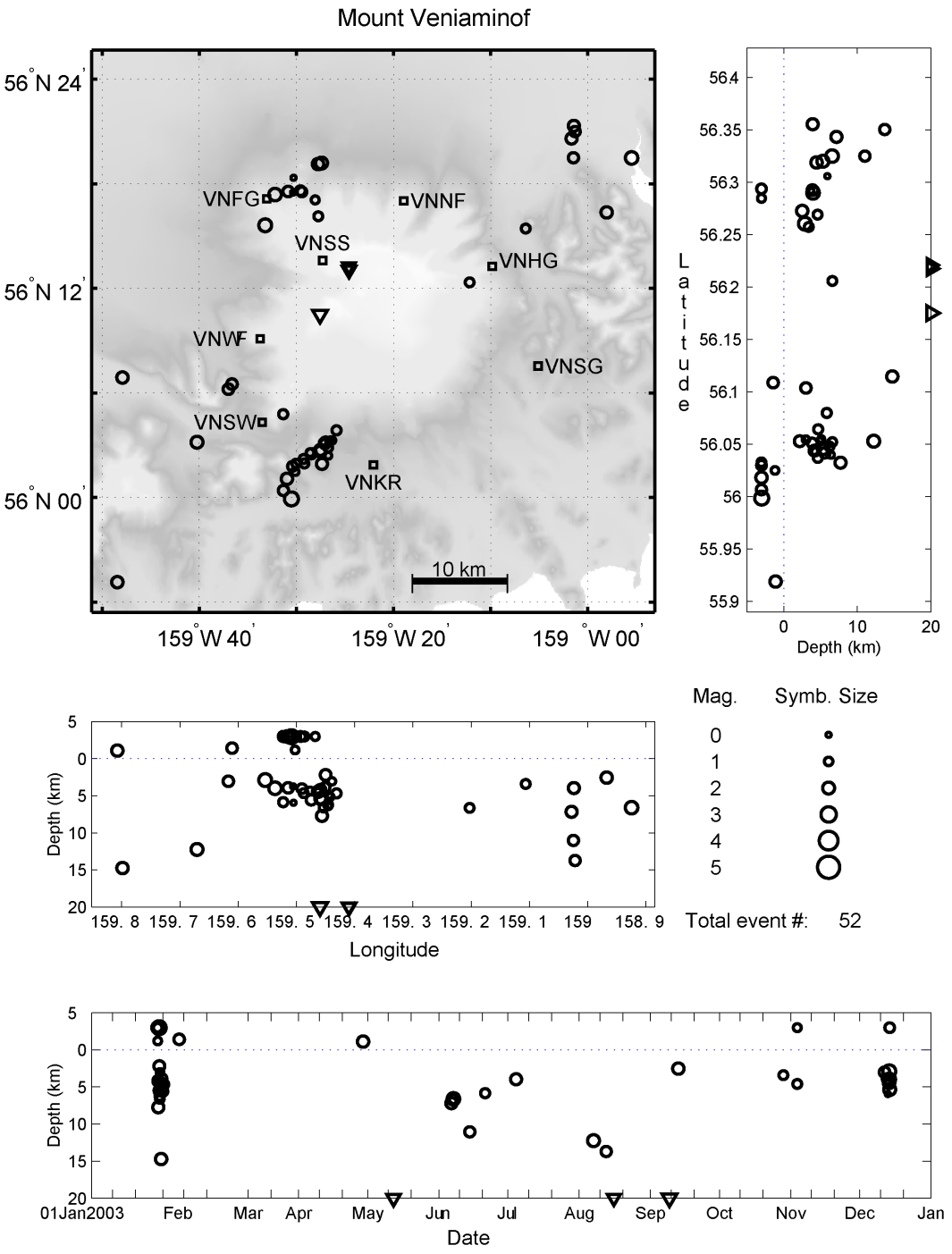


Figure A13. Summary plots of 52 earthquakes located near Mount Veniaminof in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

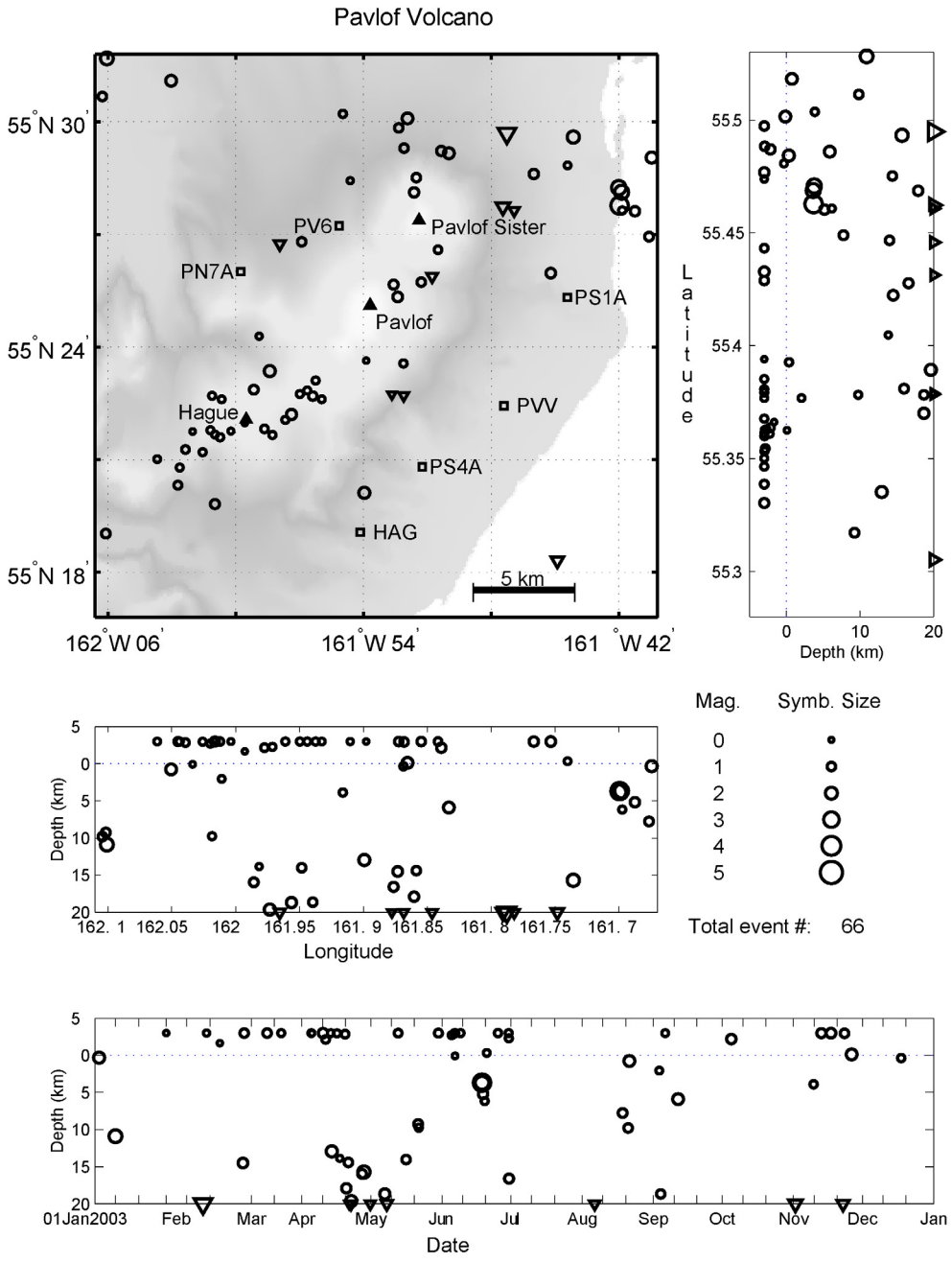


Figure A14. Summary plots of 66 earthquakes located near Pavlof Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

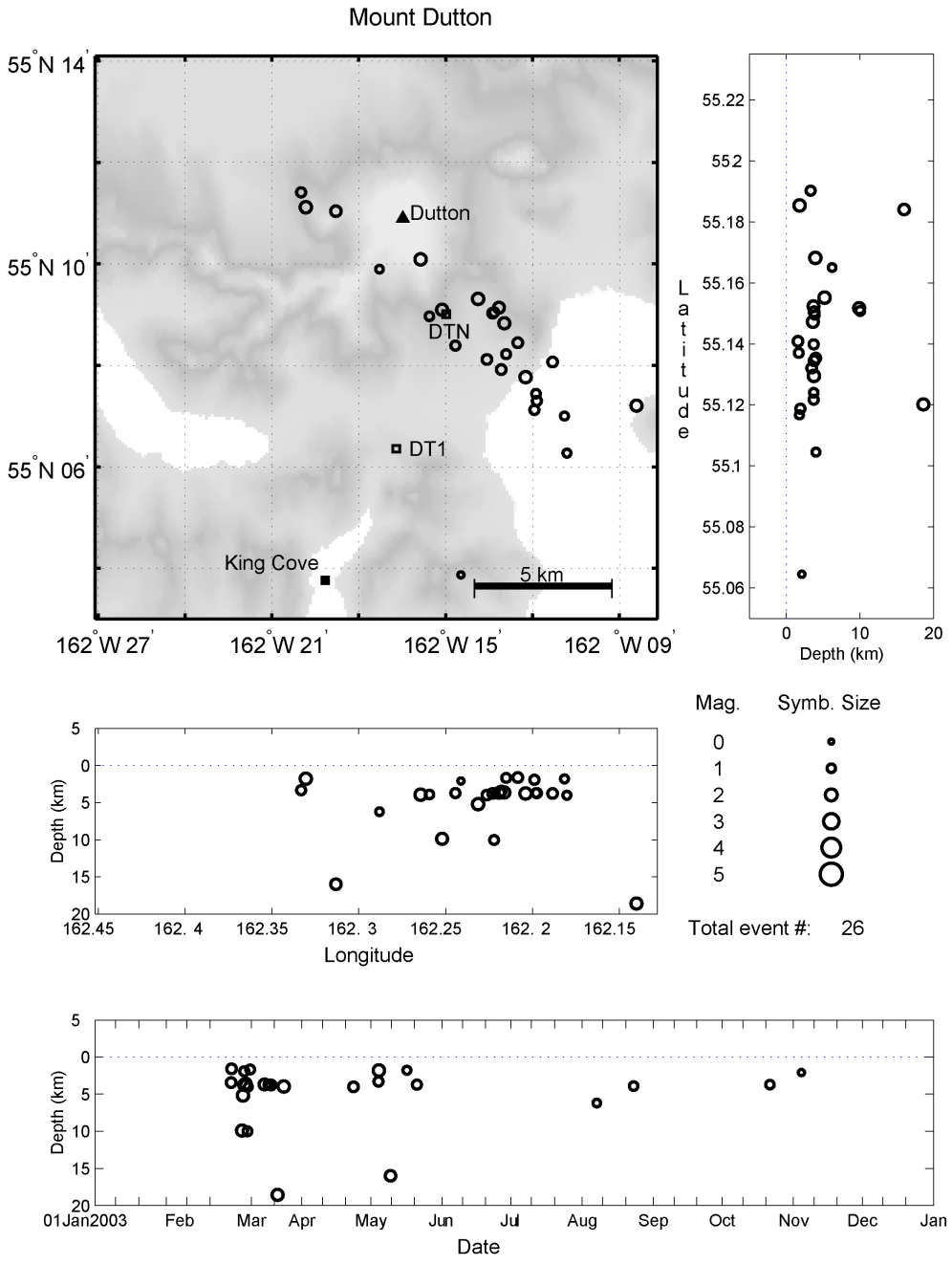


Figure A15. This summary plot shows 26 earthquakes located near Mount Dutton in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

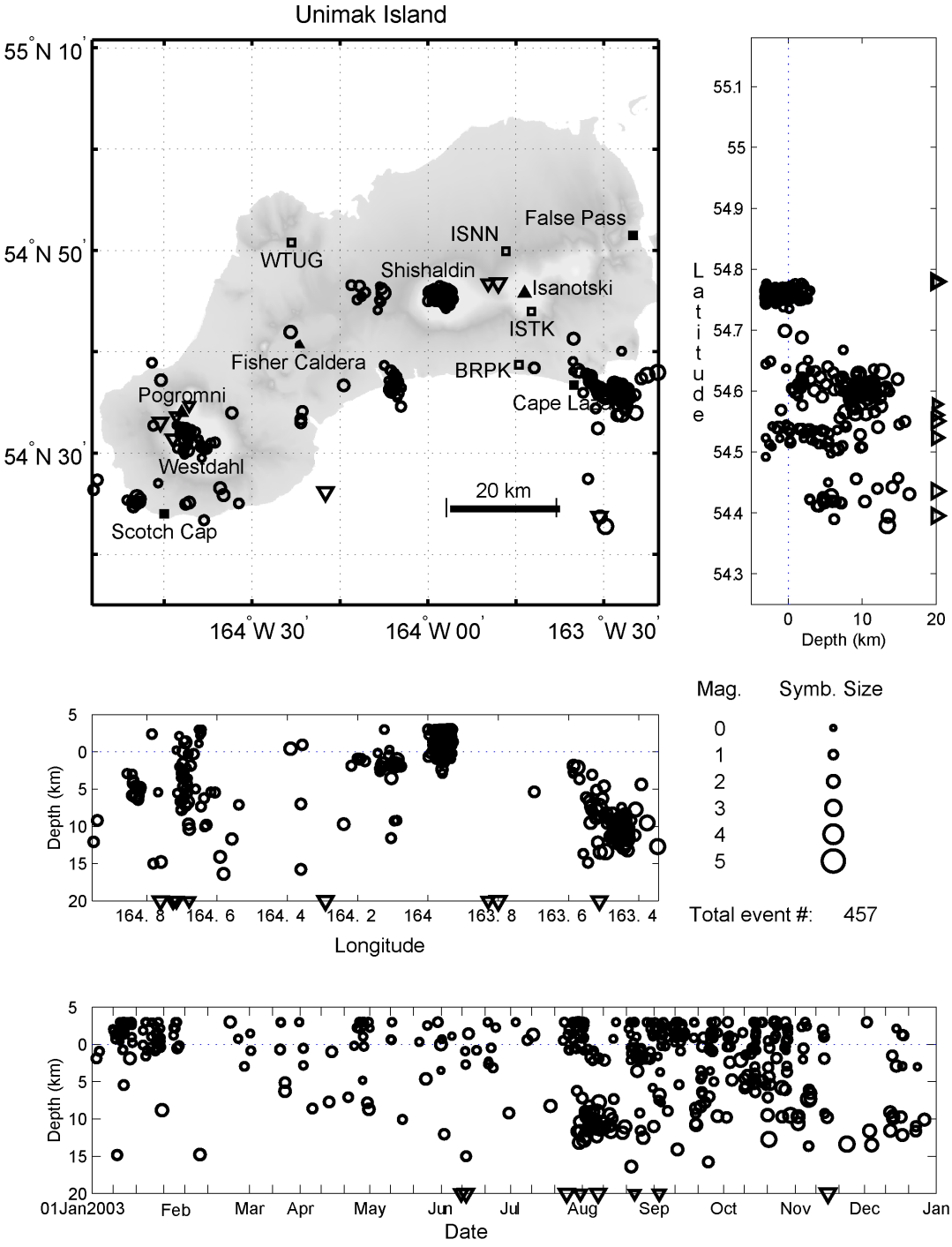


Figure A16. Summary plots of 457 earthquakes located near Unimak Island in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

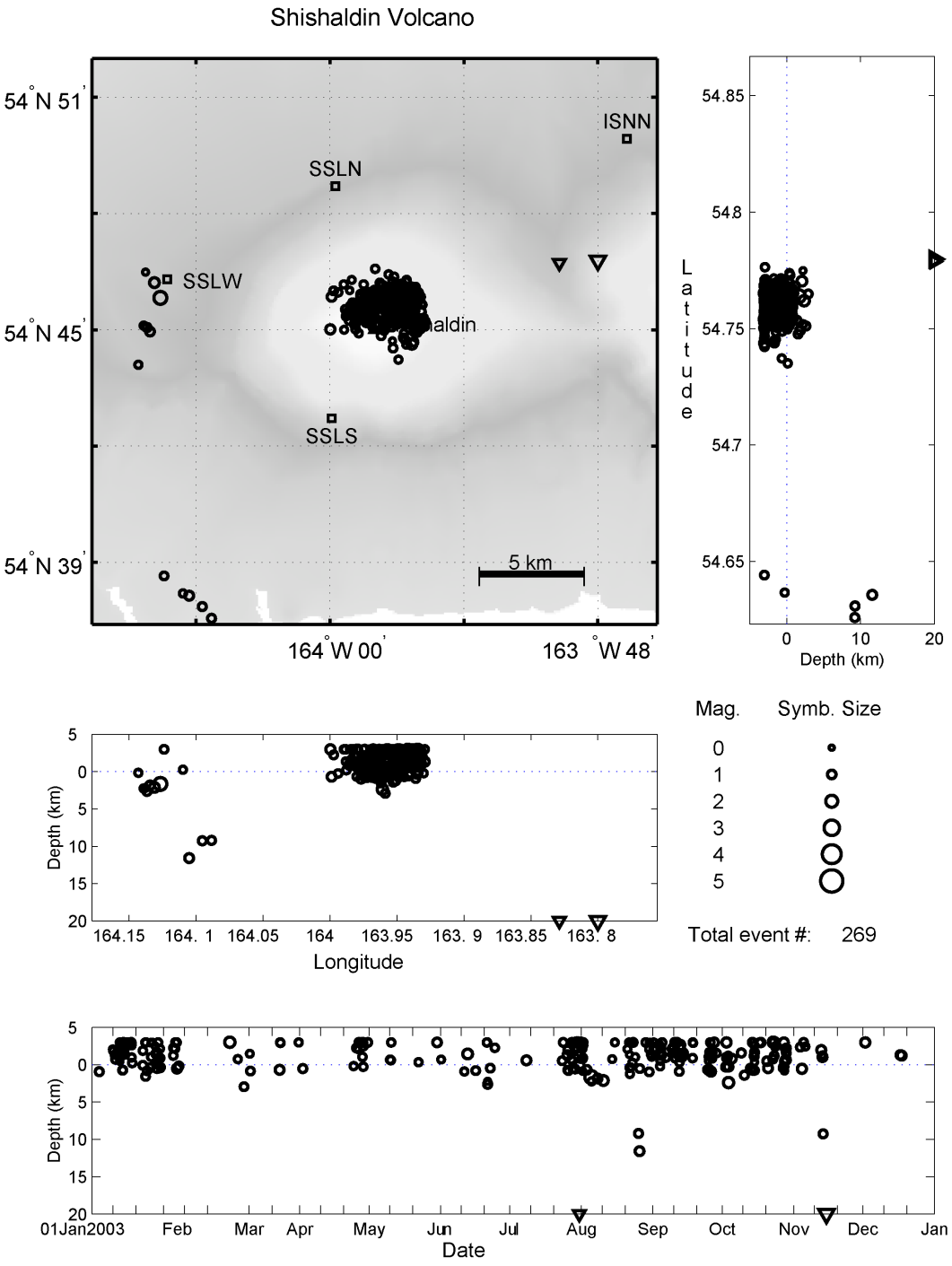


Figure A17. Summary plots of 269 earthquakes located near Shishaldin Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

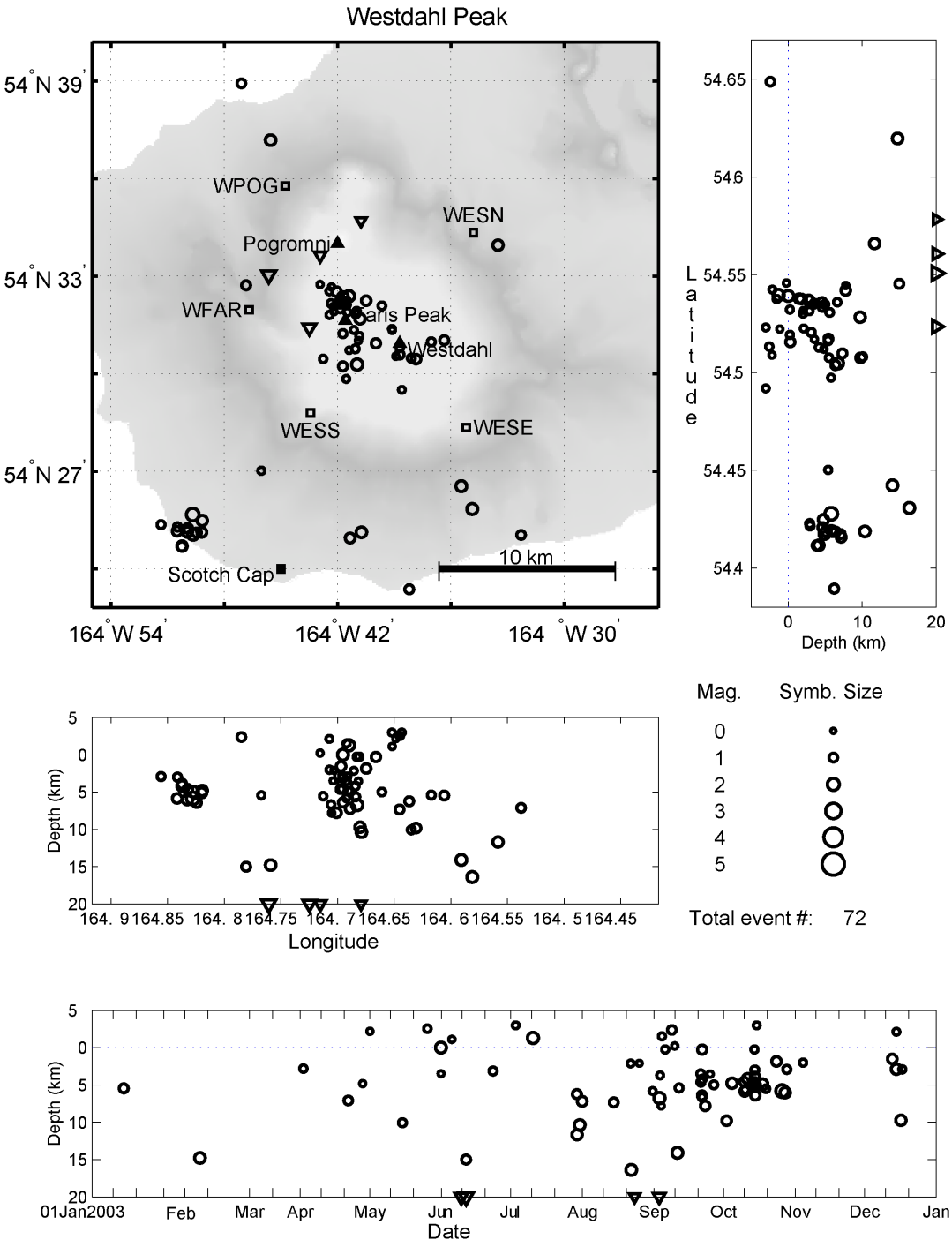


Figure A18. Summary plots of 72 earthquakes located near Westdahl Peak in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

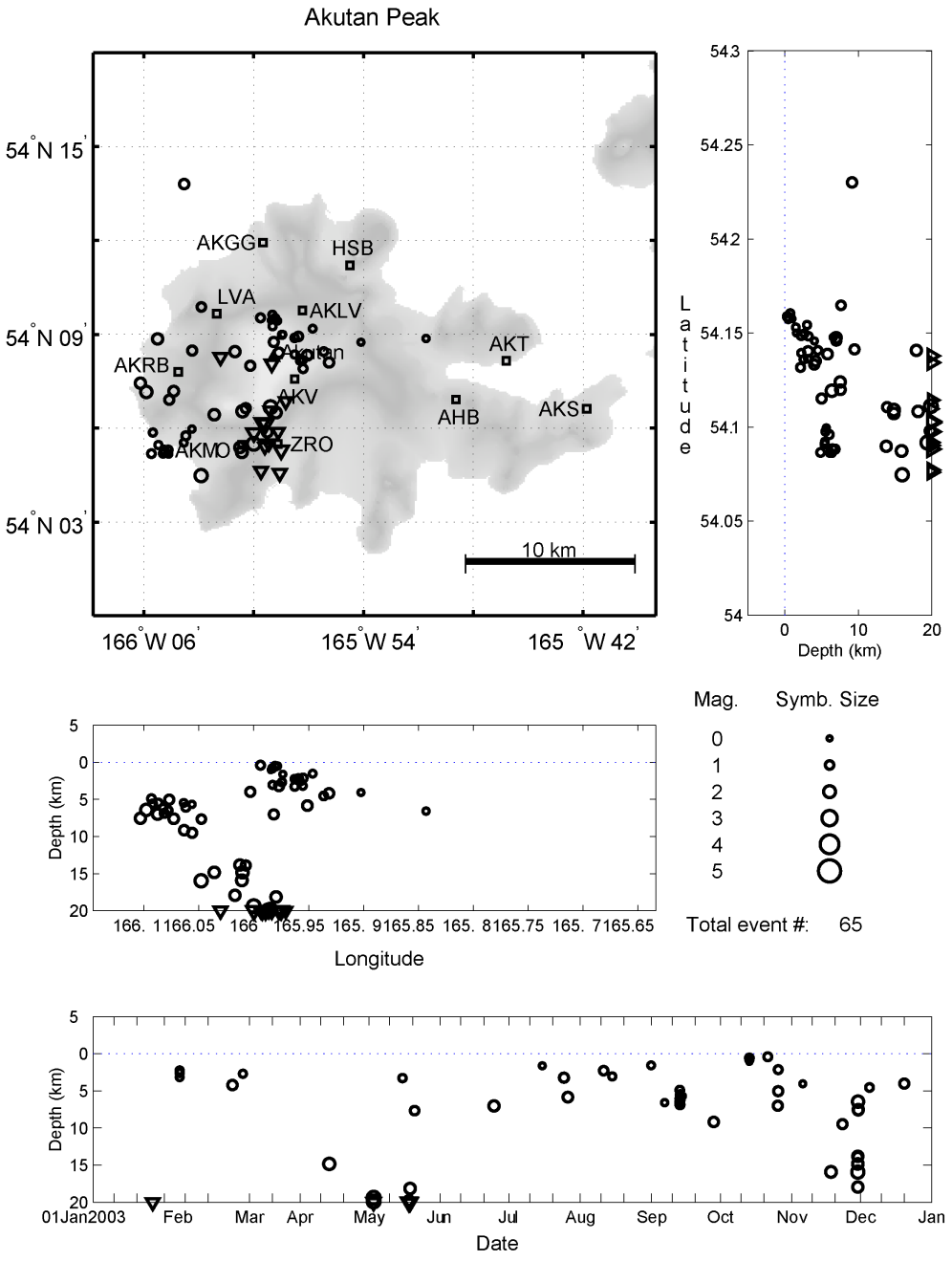


Figure A19. Summary plots of 65 earthquakes located near Akutan Peak in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

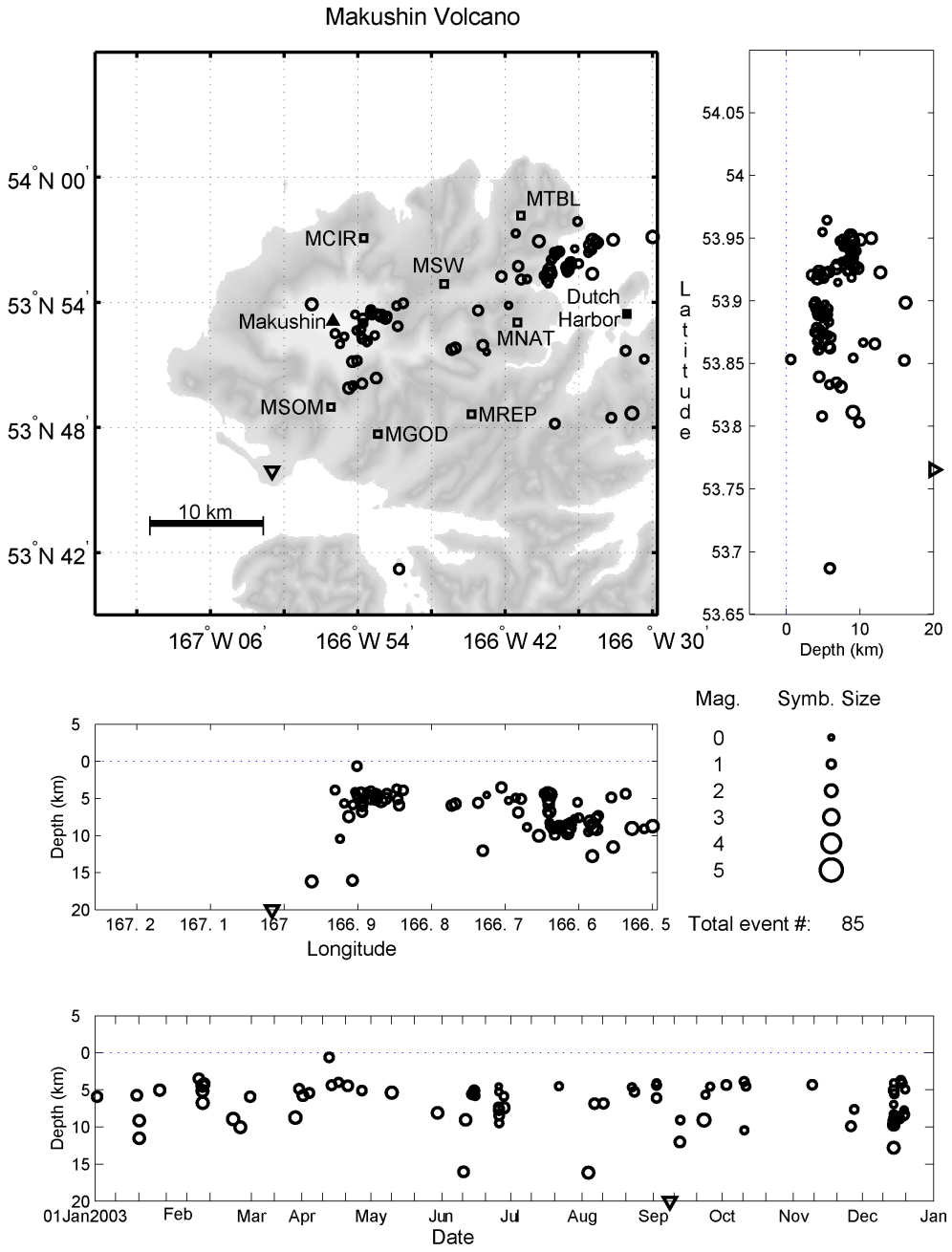


Figure A20. Summary plots of 85 earthquakes located near Makushin Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

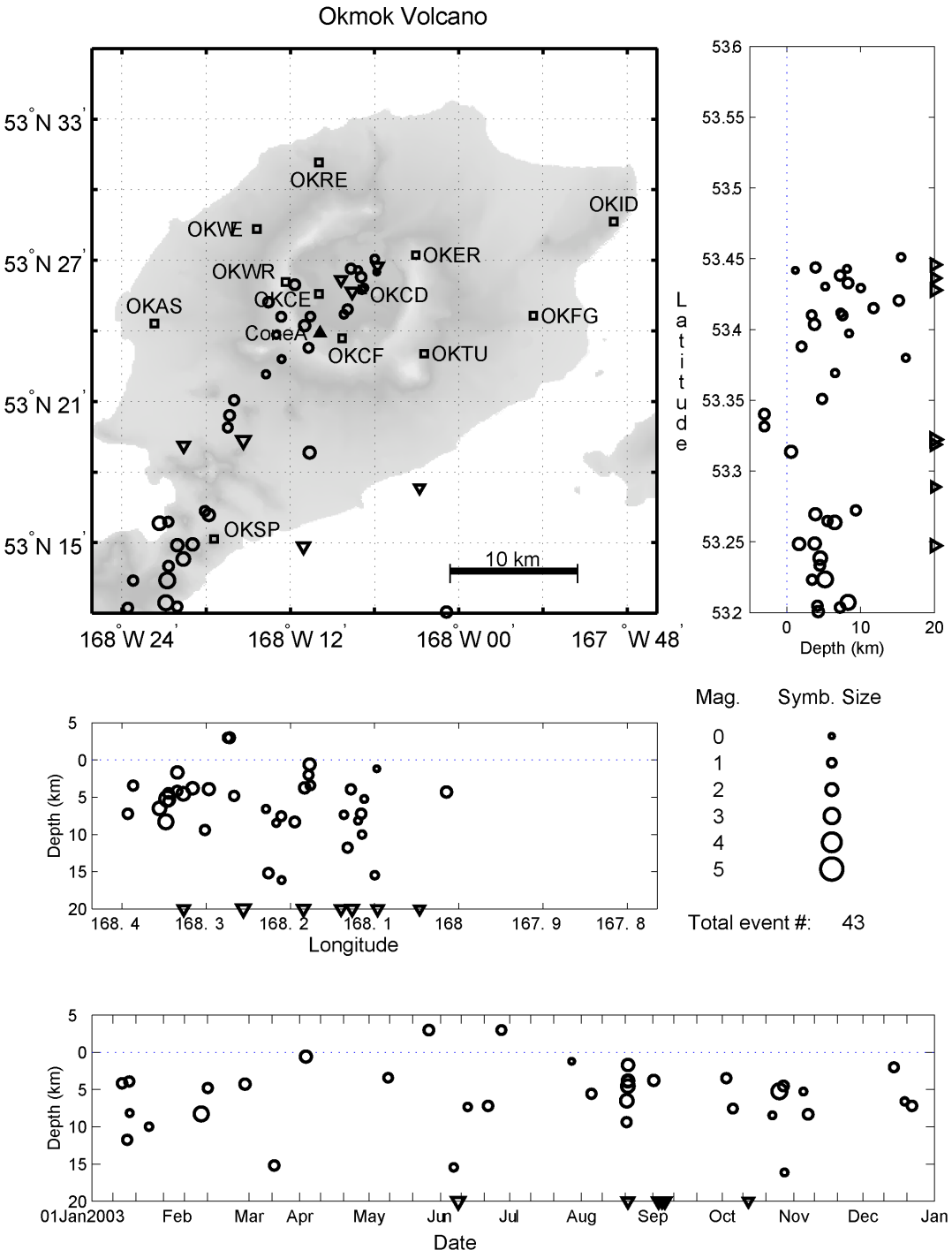


Figure A21. Summary plots of 43 earthquakes located near Okmok Caldera in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

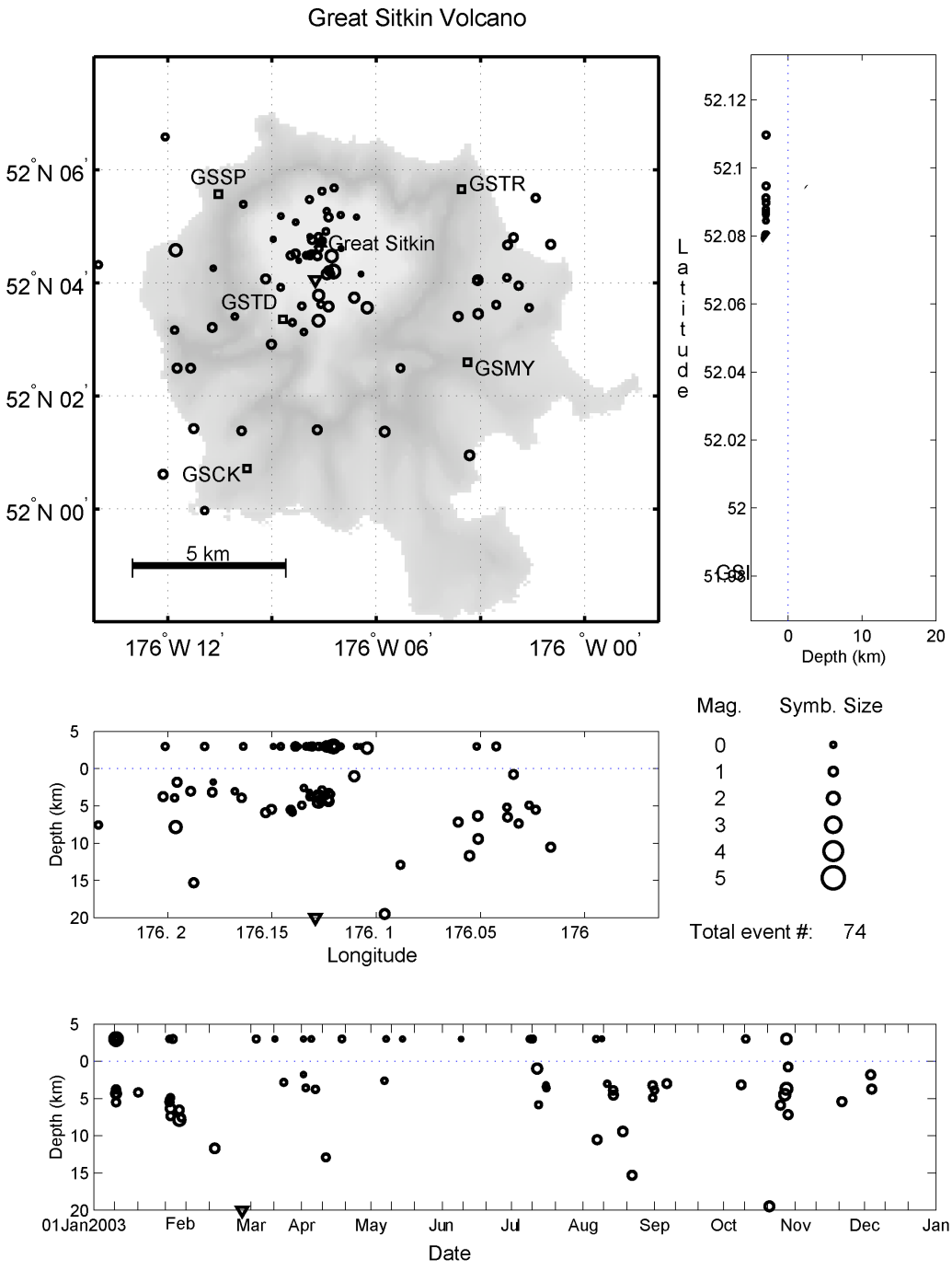


Figure A22. Summary plots of 74 earthquakes located near Great Sitkin Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

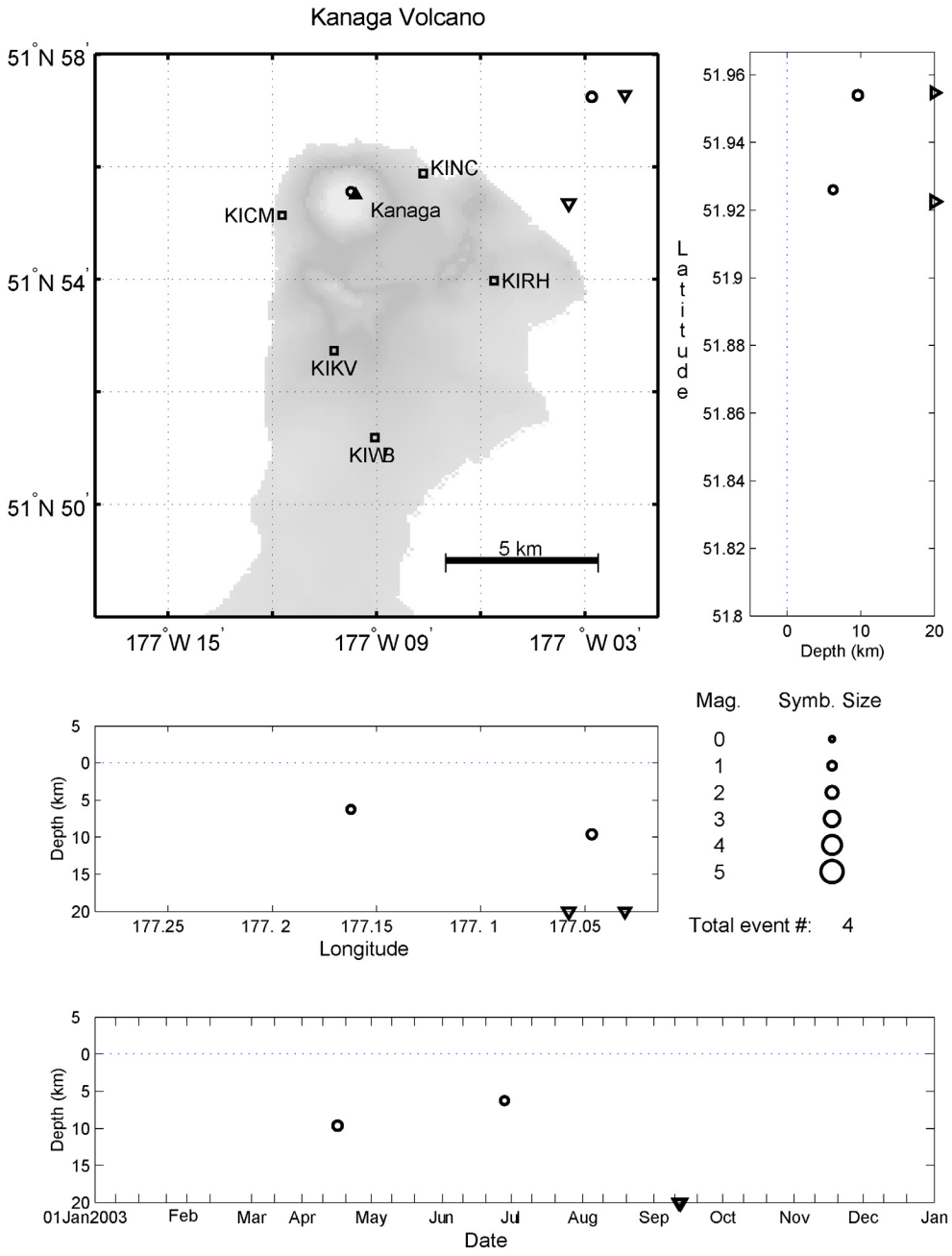


Figure A23. Summary plots of four earthquakes located near Kanaga Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest.

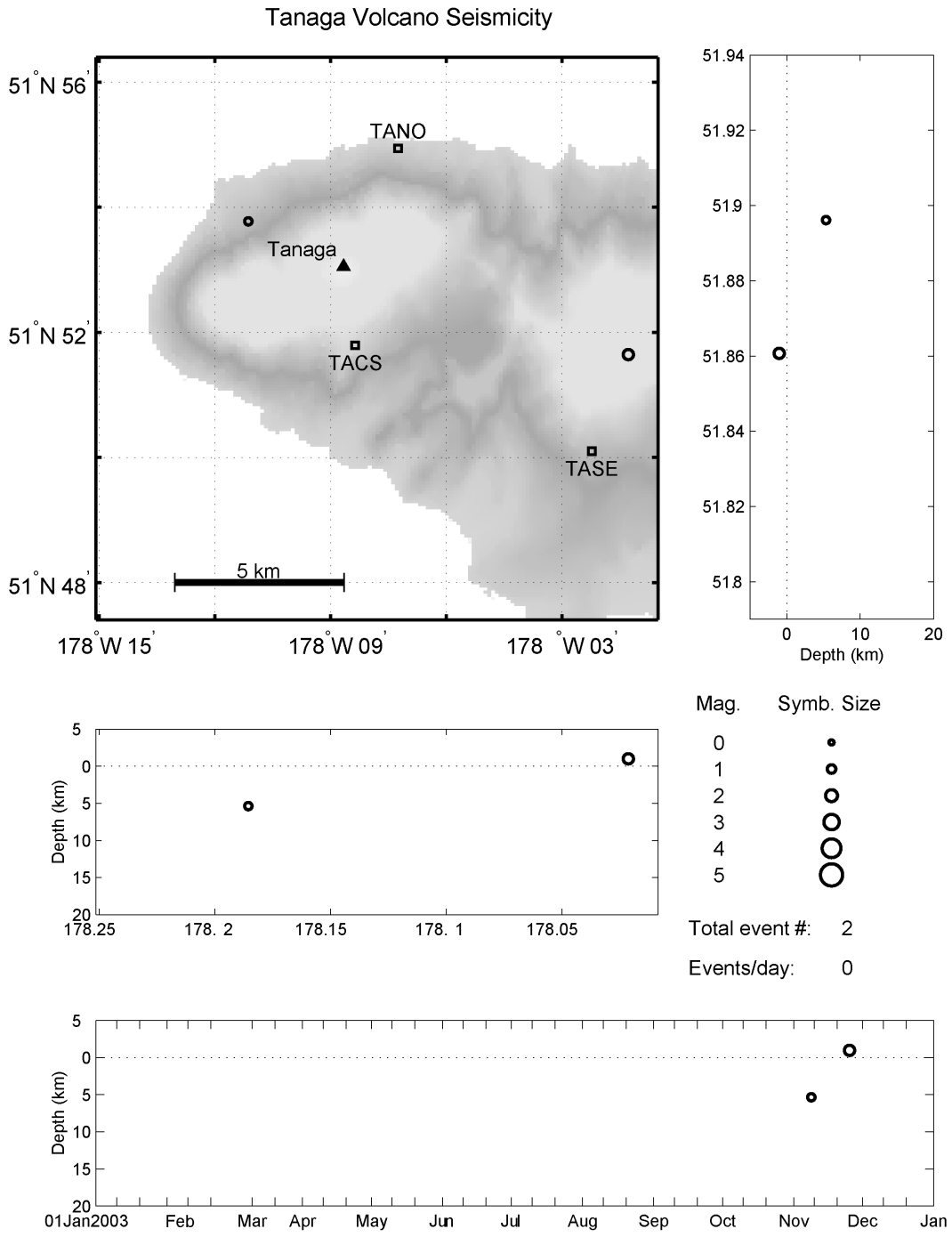


Figure A24. Summary plots of two earthquakes located near Tanaga Volcano in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest. The Tanaga subnetwork was completed in late October 2003.

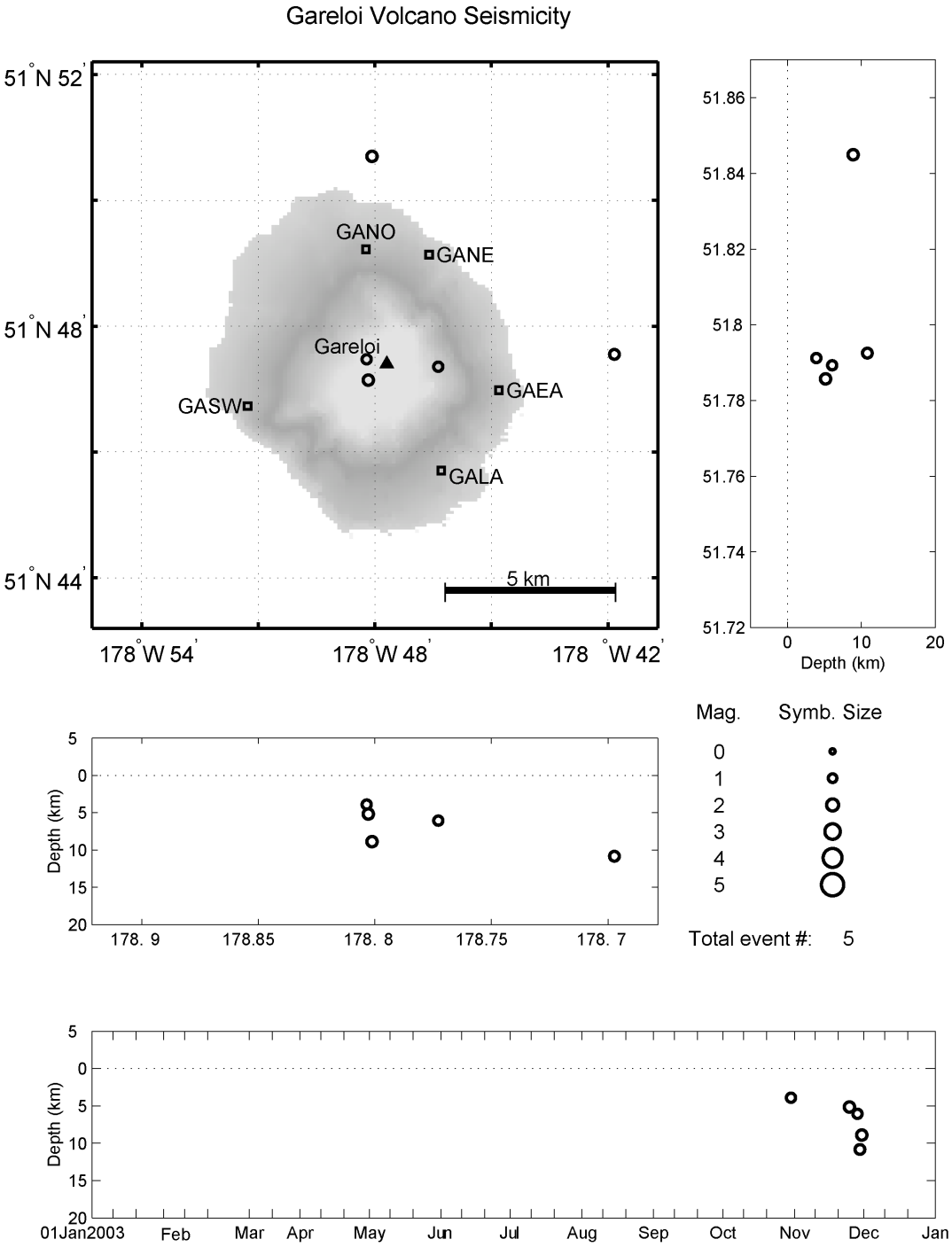


Figure A25. Summary plots of five earthquakes located near Mount Gareloi in 2003. Open circles scaled with magnitude show hypocenter locations shallower than 20 km. Hypocenters with depths of 20 km and deeper are shown by open triangles. Hypocenters symbols are scaled with magnitude. Seismograph stations are shown by open squares and labeled by station code. (See Appendix B for station information). Solid triangles are used to show volcanic centers and closed squares are used to show other points of interest. The Gareloi subnetwork was completed in late October 2003.

Appendix B: Parameters for all AVO seismograph stations.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Akutan Peak subnet (11 stations - 23 components)					
AHB	54 06.916	165 48.943	447	L-4	1996/07/24
AKGG[B]	54 11.930	165 59.495	326	CMG-6TD	2003/06/27
AKLV[B]	54 09.762	165 57.336	551	CMG-6TD	2003/07/02
AKMO[B]	54 05.471	166 00.634	277	CMG-6TD	2003/06/25
AKRB[B]	54 07.803	166 04.125	334	CMG-6TD	2003/06/29
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)					
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	2003/07/12
Augustine Volcano subnet (8 stations - 13 components)					
AUC[R]	59 21.596	153 25.469	1175	L-4	1995/09/13
AUE	59 22.308	153 22.504	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 22.937	153 26.142	360	S-13,CMG-40T	1978/08/27
AUP	59 21.805	153 25.210	1033	S-13	1977/09/22
AUR	59 21.766	153 25.876	1204	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 (5 stations - 5 components)					
BLDY	55 11.670	162 47.018	259	L-4	1996/07/11
DOL	55 08.960	161 51.683	442	L-4	1996/07/11
DRR3	54 58.014	162 15.665	457	L-4	1996/07/11
DT1	55 06.427	162 16.859	198	L-4	1991/06/21
DTN	55 08.744	162 15.419	396	S-13	1988/07/16
Gareloi Volcano subnet (6 stations - 8 components)					
GAEA	51 46.980	178 44.810	326	L-4	2003/08/30
GAKI	51 33.267	178 48.725	99	L-4	2003/09/01
GALA	51 45.704	178 46.292	315	L-4	2003/08/30
GANE	51 49.135	178 46.603	325	L-4	2003/09/02
GANO	51 49.220	178 48.230	451	L-4	2003/09/02
GASW[3]	51 46.731	178 51.276	248	L-22	2003/08/30

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
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 04.877	152 57.502	771	L-4	1987/09/15
ILS	59 57.454	153 04.083	1107	S-13	1996/08/28
ILW	60 03.585	153 08.222	1646	S-13	1994/09/09
INE	60 03.65	153 03.75	1585	S-13	1990/08/29
IVE[3]	60 01.014	153 00.981	1173	S-13,L-22	1996/09/19
IVS	60 00.55	153 04.85	2332	L-4	1990/08/29
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 Cluster 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 (7 stations - 9 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
MREP	53 48.629	166 44.736	785	L-4	2002/01/01
MSOM	53 48.978	166 56.187	146	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

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Okmok Volcano subnet (12 stations - 18 components)					
OKAS	53 24.319	168 21.686	270	L-4	2003/01/09
OKCD[B]	53 25.818	168 06.737	459	CMG-6TD	2003/01/09
OKCE[B]	53 25.622	168 09.858	515	CMG-6TD	2003/01/09
OKCF	53 23.689	168 08.299	685	L-4	2003/01/09
OKER	53 27.223	168 03.071	956	L-4	2003/01/09
OKFG[B]	53 24.642	167 54.690	201	CMG-6TD	2003/01/09
OKID	53 28.645	167 48.972	437	L-4	2003/01/09
OKRE	53 31.163	168 09.964	420	L-4	2003/01/09
OKSP	53 15.156	168 17.431	608	L-4	2003/01/09
OKTU	53 23.035	168 02.466	646	L-4	2003/01/09
OKWE	53 28.328	168 14.388	445	L-4	2003/01/09
OKWR	53 26.084	168 12.333	1017	L-4	2003/01/09
Pavlof Volcano subnet (7 stations - 9 components)					
BLHA	55 42.227	162 03.907	411	L-4	1996/07/11
HAG	55 19.068	161 54.150	503	L-4	1996/07/11
PN7A	55 26.020	161 59.713	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 27.217	161 55.112	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 38.730	163 44.449	393	L-4	1997/07/27
ISNN	54 49.937	163 46.706	466	L-4	1997/07/27
ISTK	54 43.929	163 42.376	704	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	817	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

AVO Stations-continued.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Seismometer	Station open date
Tanaga Volcano subnet (6 stations - 8 components)					
TACS	51 51.792	178 08.363	918	L-4	2003/08/28
TAFL	51 45.396	177 53.867	186	L-4	2003/08/28
TAFP[3]	51 54.003	177 58.997	440	L-22	2003/08/27
TANO	51 54.942	178 07.249	269	L-4	2003/08/24
TAPA	51 48.932	177 48.770	640	L-4	2003/08/27
TASE	51 50.099	178 02.222	682	L-4	2003/08/24
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
Westdahl Peak subnet (6 stations - 8 components)					
WESE	54 28.389	164 35.038	953	L-4	1998/08/28
WESN	54 34.600	164 34.703	549	L-4	1998/10/17
WESS[3]	54 28.828	164 43.333	908	L-22	1998/08/28
WFAR	54 32.029	164 46.567	640	L-4	1998/08/28
WPOG	54 35.837	164 44.606	445	L-4	1998/10/17
WTUG	54 50.847	164 23.117	636	L-4	1998/10/17
Mount Wrangell subnet (4 stations - 6 components)					
WACK[3]	61 59.178	144 19.703	2280	L-22	2000/07/31
WANC	62 00.189	144 4.195	4190	L-4	2000/07/31
WASW	61 55.692	144 10.346	2164	L-4	2001/08/03
WAZA	62 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 55.771	153 38.558	622	S-13	1981/08/17
CNP	59 31.552	151 14.088	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 02.66	151 17.36	381	L-4	1972/08/24
OPT	59 39.192	153 13.796	634	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 2003
[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
CMG-6TD: Guralp CMG-6TD 30 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 seismograph stations. In all figures, closed triangles show volcanic centers and open squares show seismograph stations.

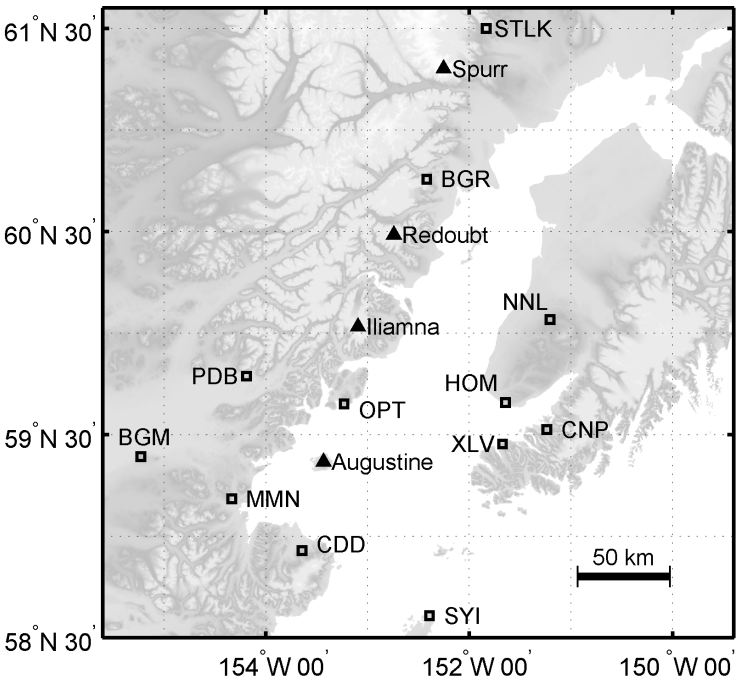


Figure C1. Regional AVO seismograph stations in Cook Inlet. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

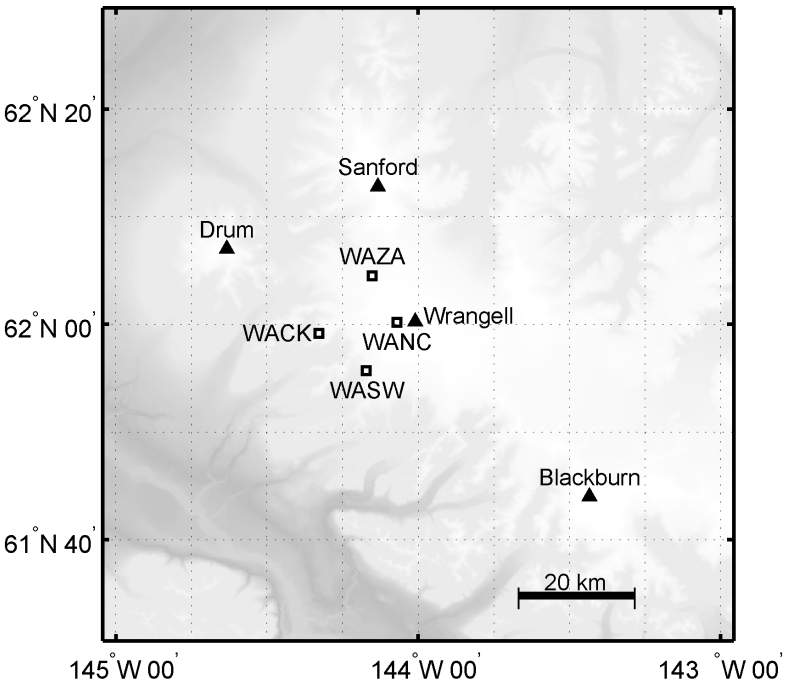


Figure C2. AVO seismograph stations near Mount Wrangell. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

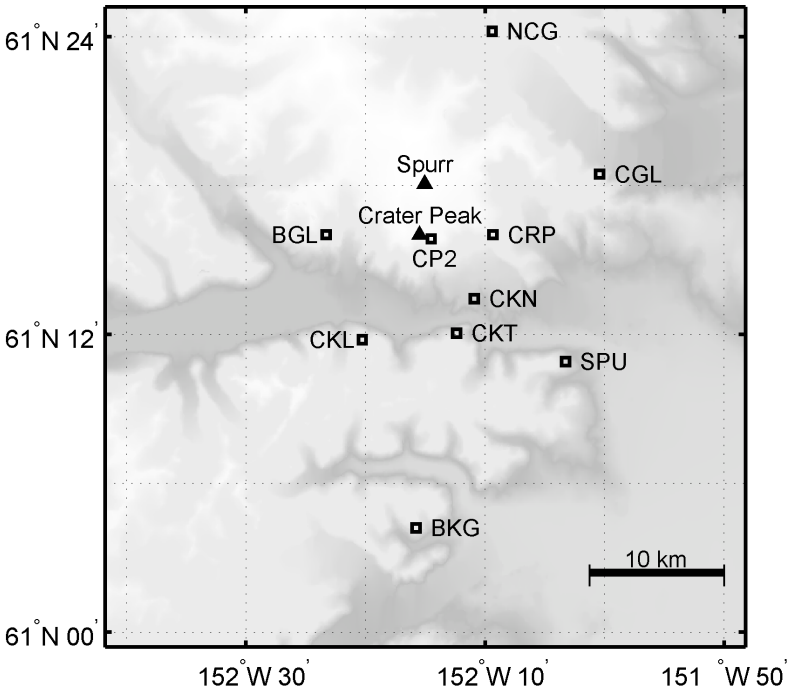


Figure C3. AVO seismograph stations near Mount Spurr. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

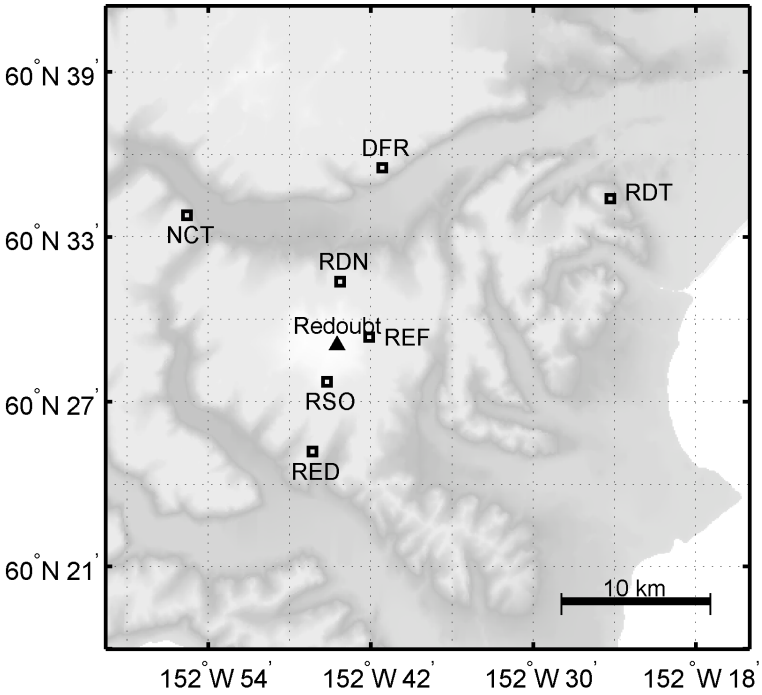


Figure C4. AVO seismograph stations near Redoubt Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

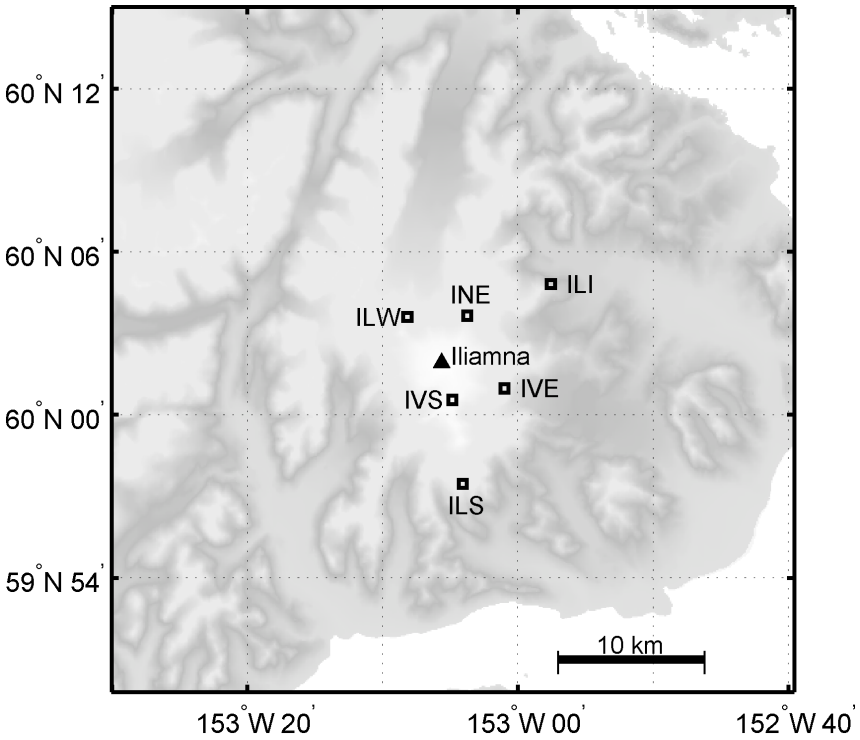


Figure C5. AVO seismograph stations near Iliamna Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

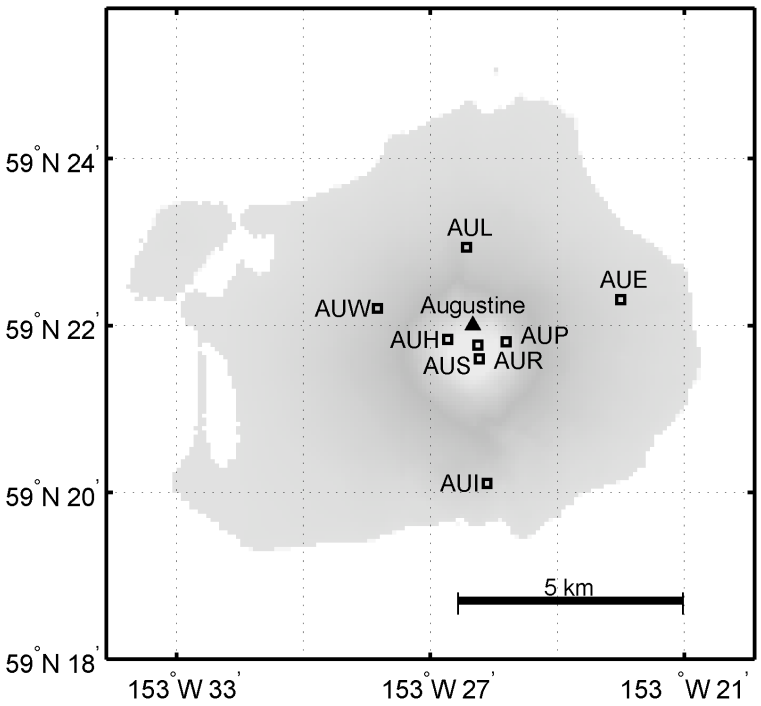


Figure C6. AVO seismograph stations near Augustine Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

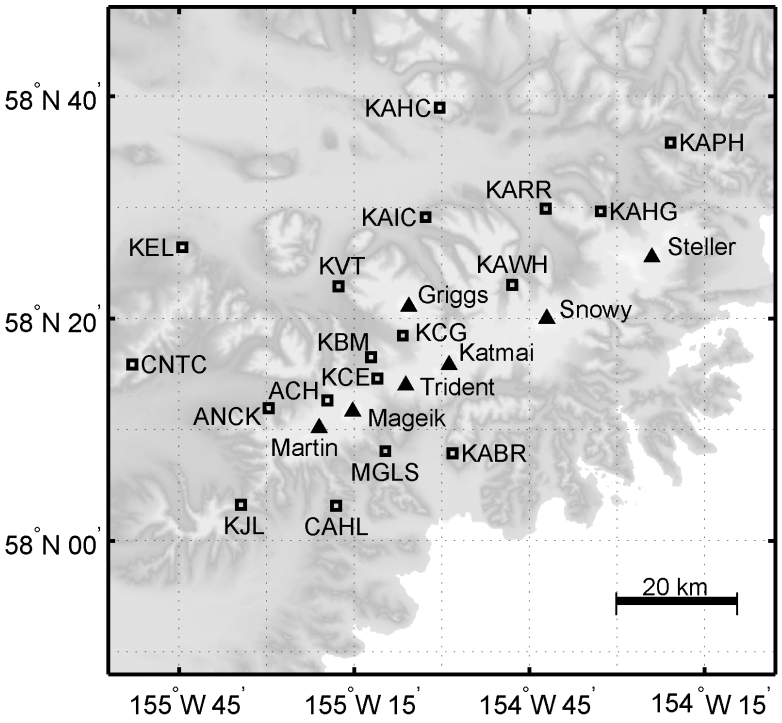


Figure C7. AVO seismograph stations near the Katmai volcanic cluster. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

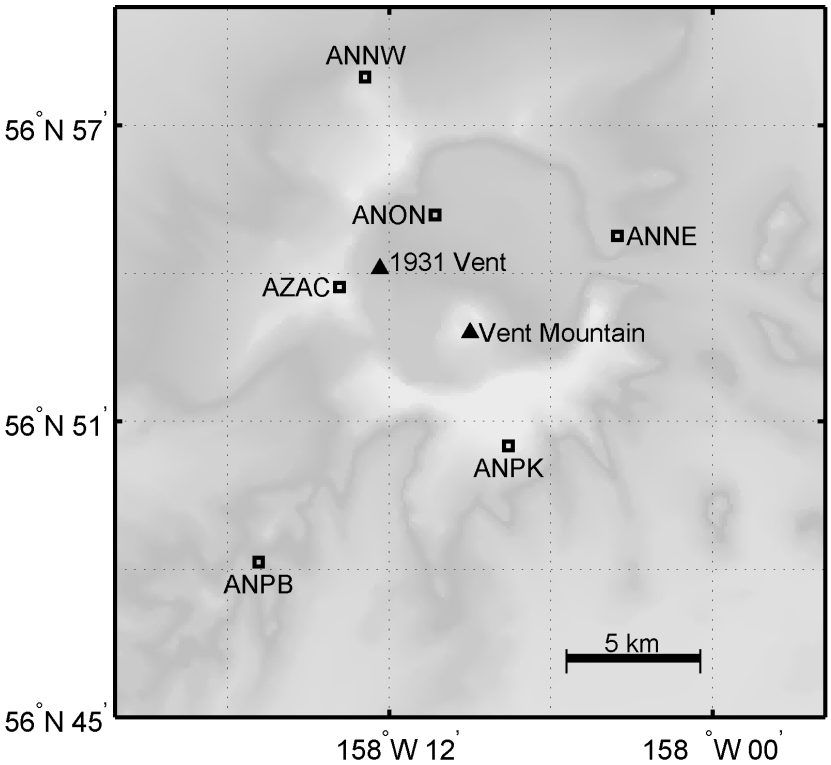


Figure C8. AVO seismograph stations near Aniakchak Crater. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

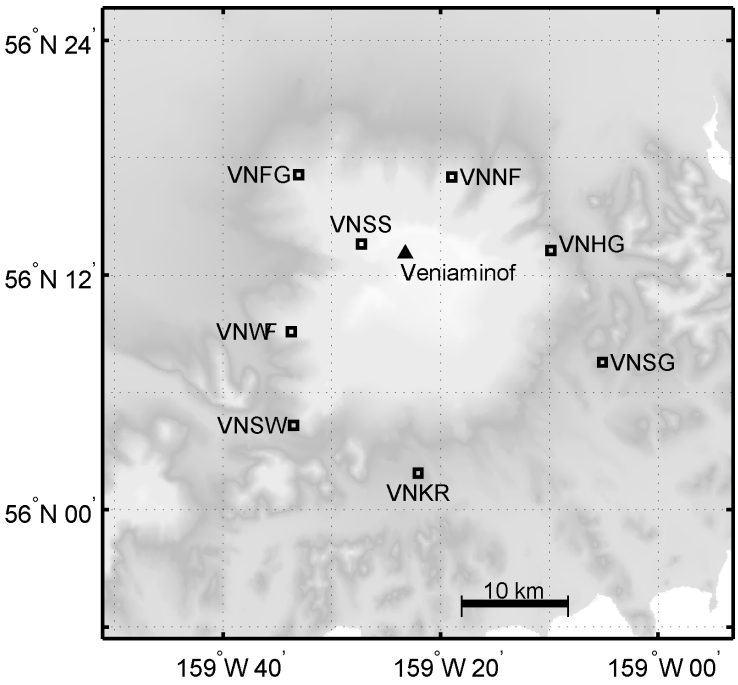


Figure C9. AVO seismograph stations near Mount Veniaminof. Seismograph station BPBC is not shown and is located 70 km northeast of Mount Veniaminof. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

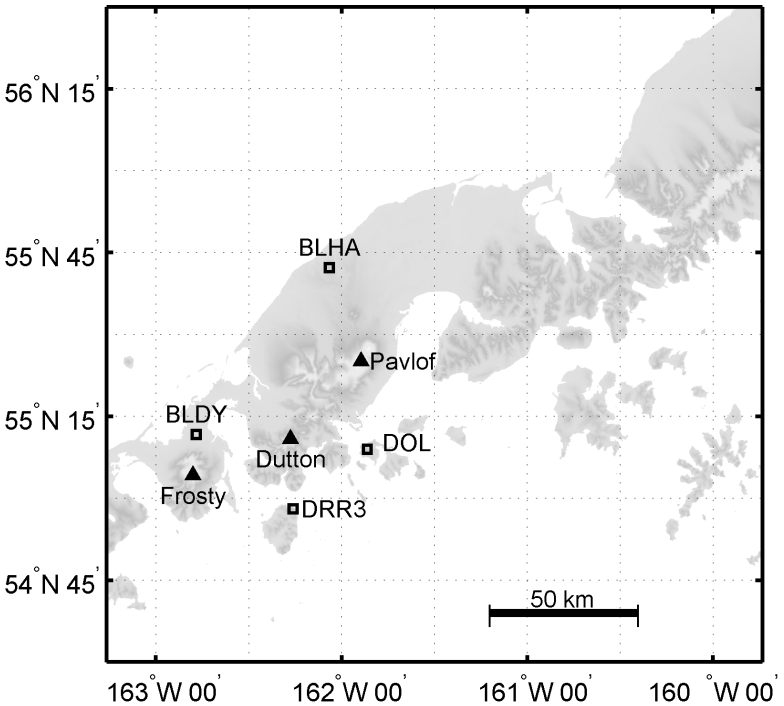


Figure C10. Regional AVO seismograph stations on the western end of the Alaska Peninsula. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

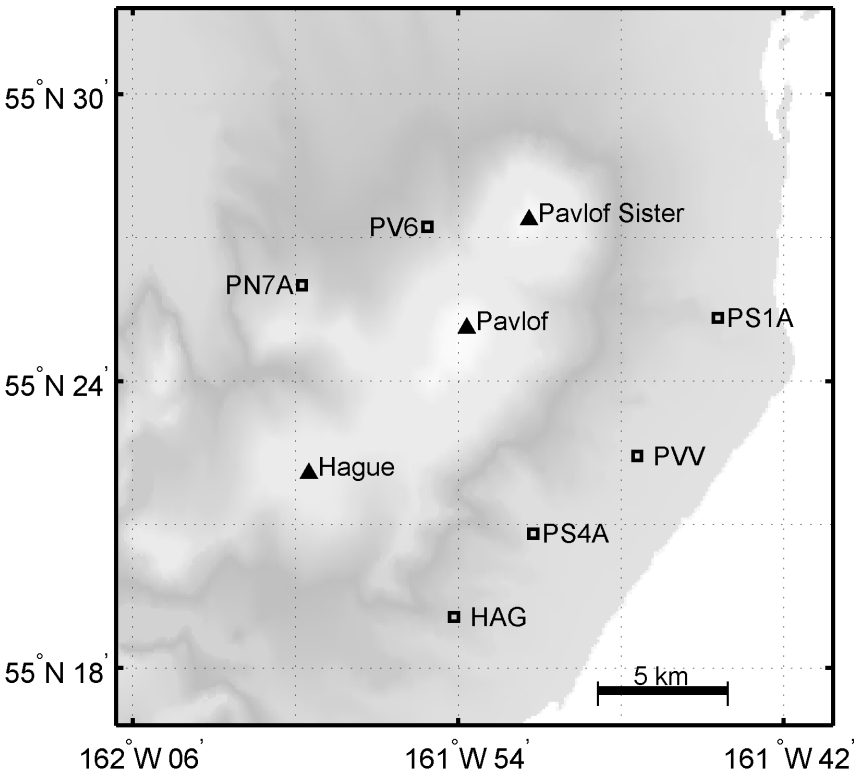


Figure C11. AVO seismograph stations near Pavlof Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

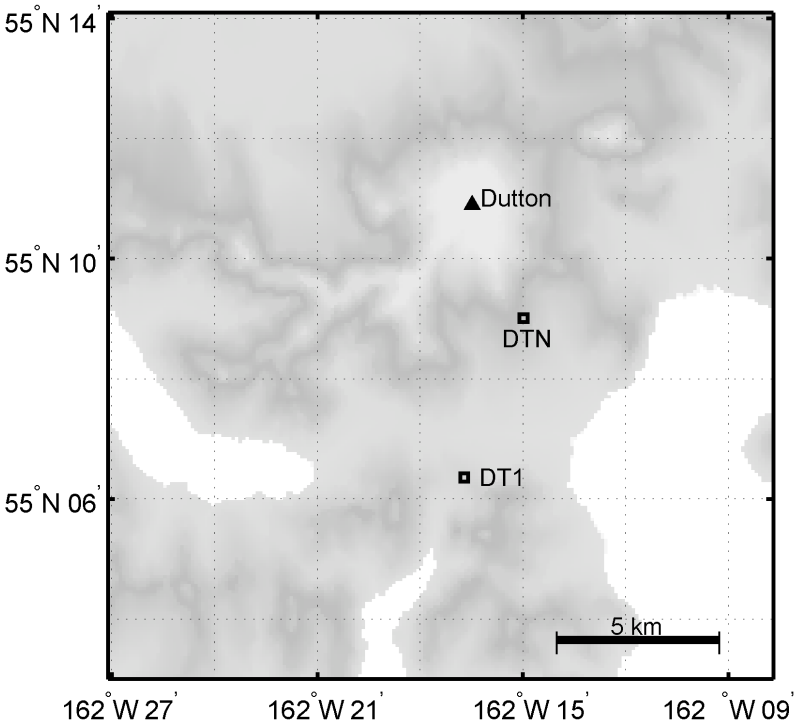


Figure C12. AVO seismograph stations near Mount Dutton. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

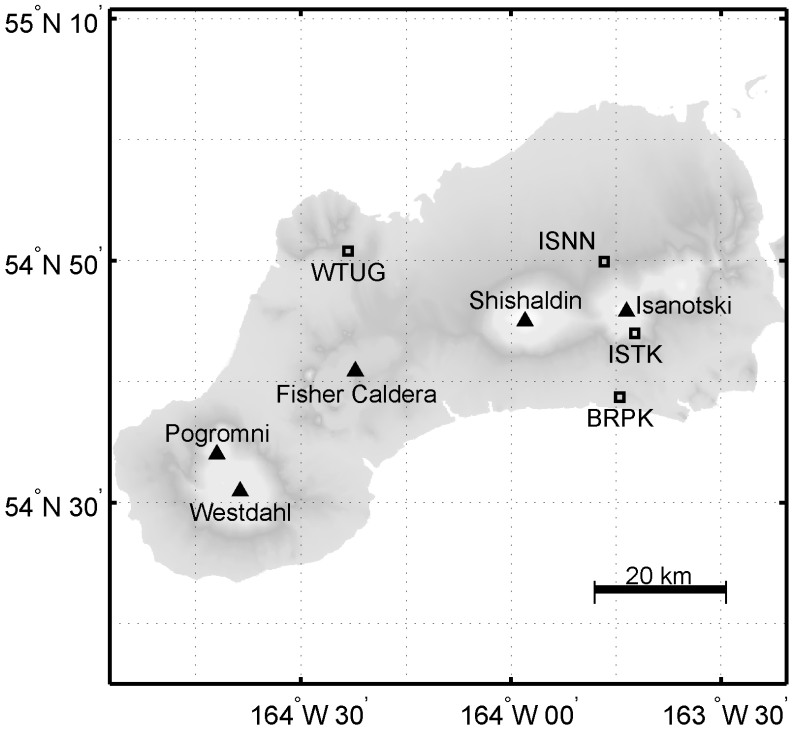


Figure C13. Regional AVO seismograph stations on Unimak Island. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

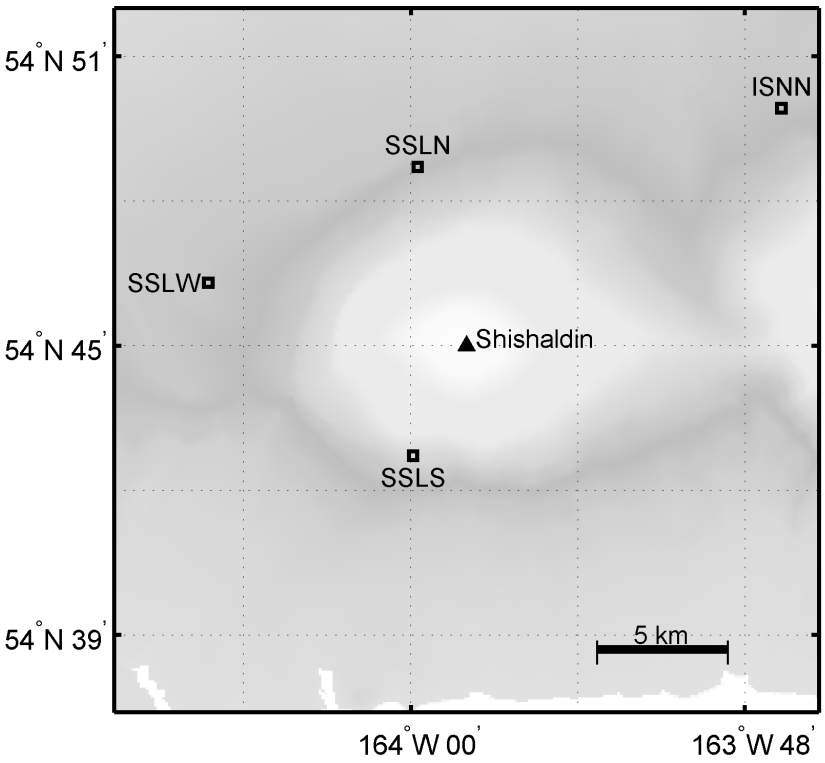


Figure C14. AVO seismograph stations near Shishaldin Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

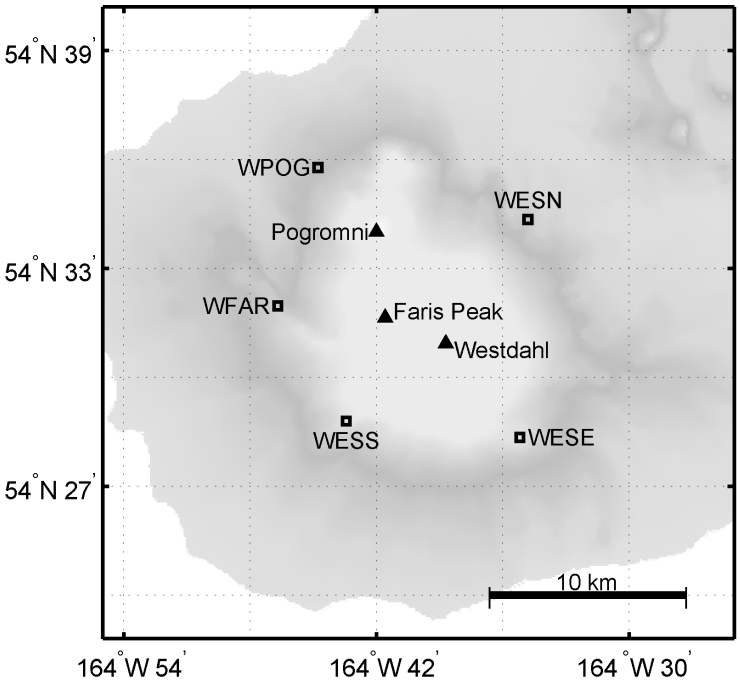


Figure C15. AVO seismograph stations near Westdahl Peak. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

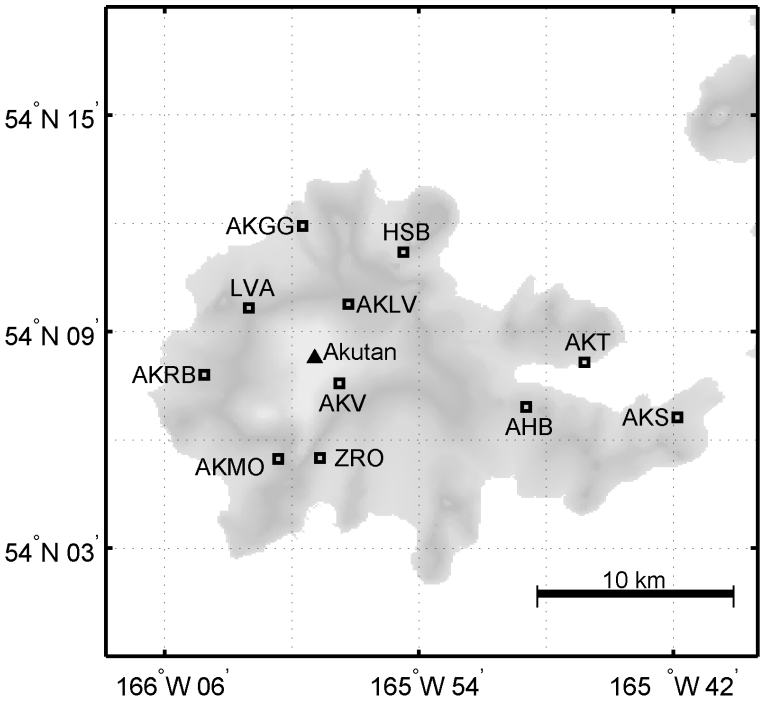


Figure C16. AVO seismograph stations near Akutan Peak. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

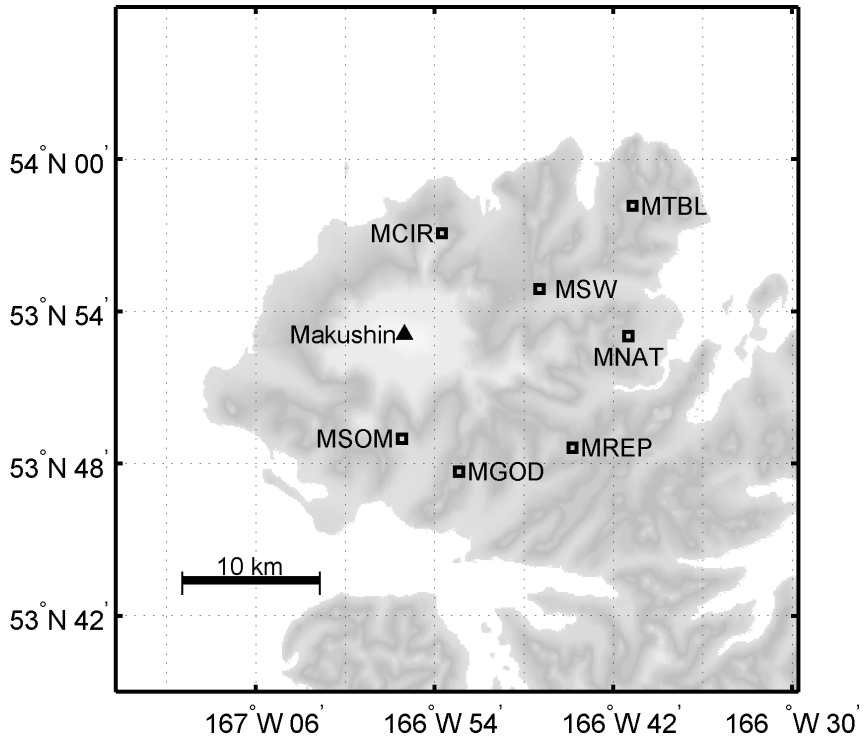


Figure C17. AVO seismograph stations near Makushin Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

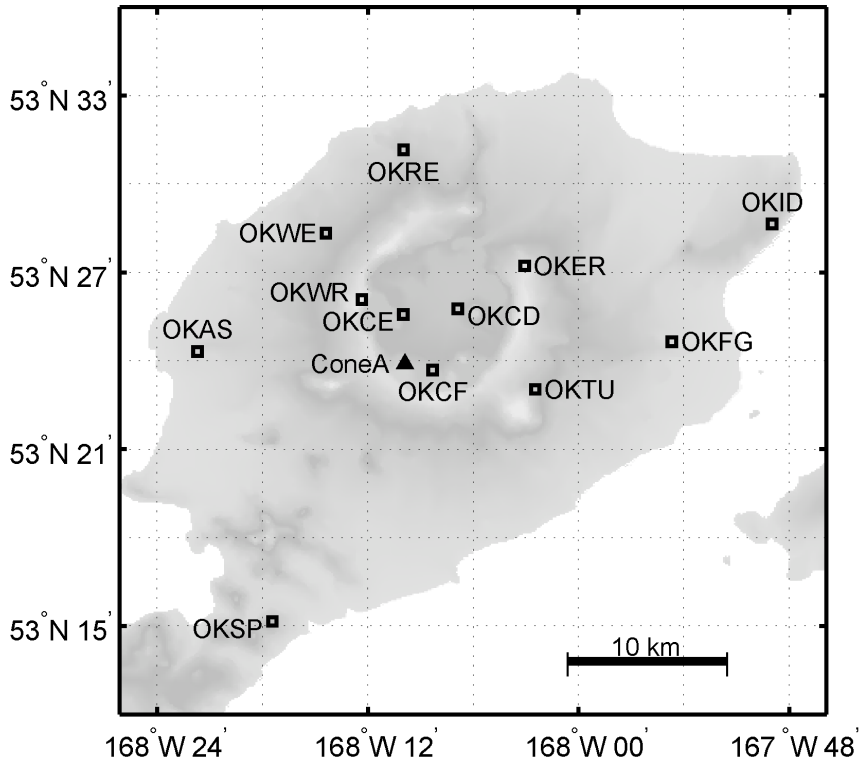


Figure C18. AVO seismograph stations near Okmok Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

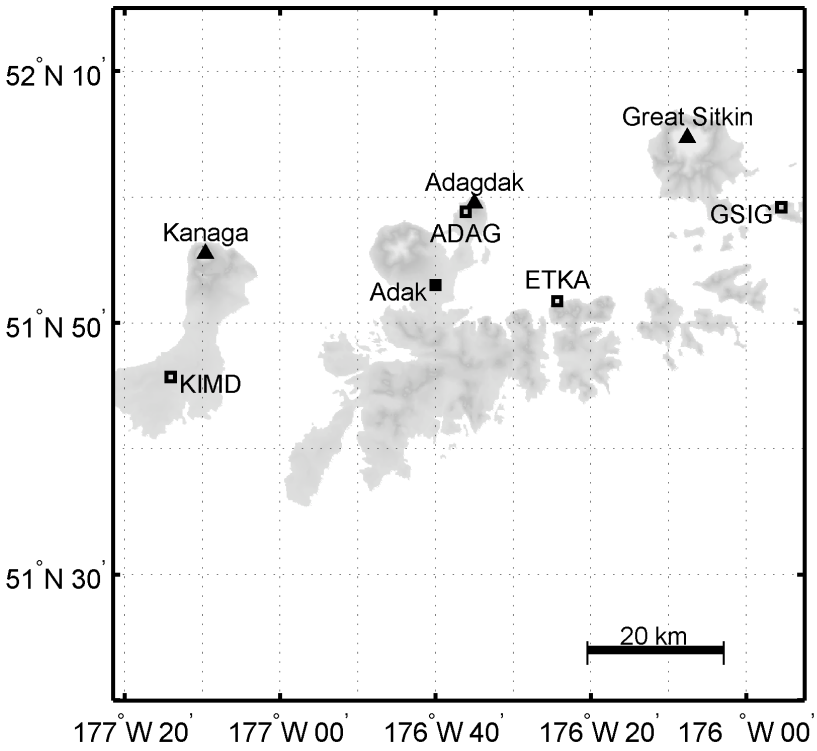


Figure C19. Regional AVO seismograph stations around Adak Island. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

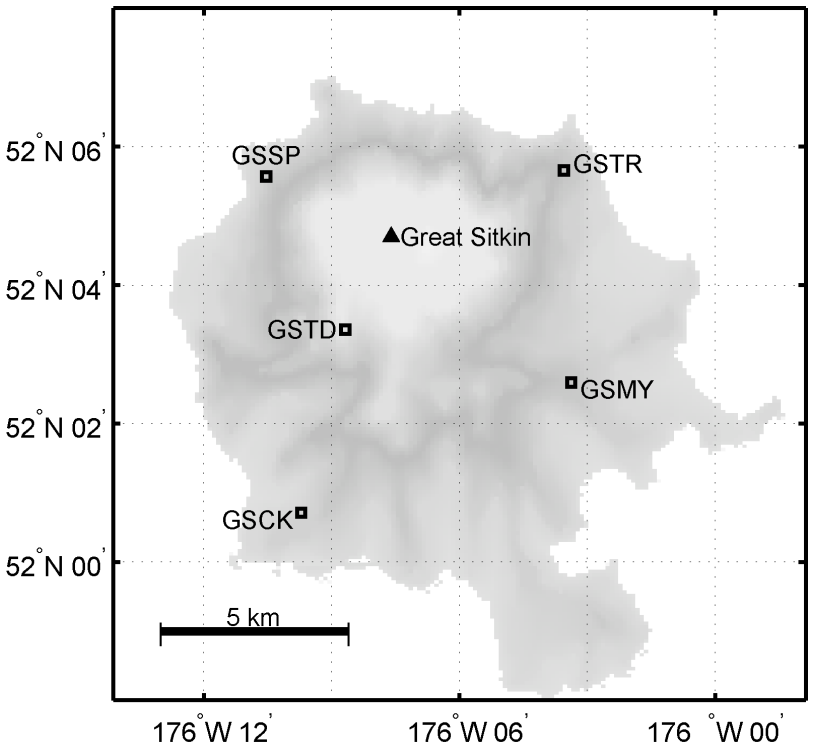


Figure C20. AVO seismograph stations near Great Sitkin Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

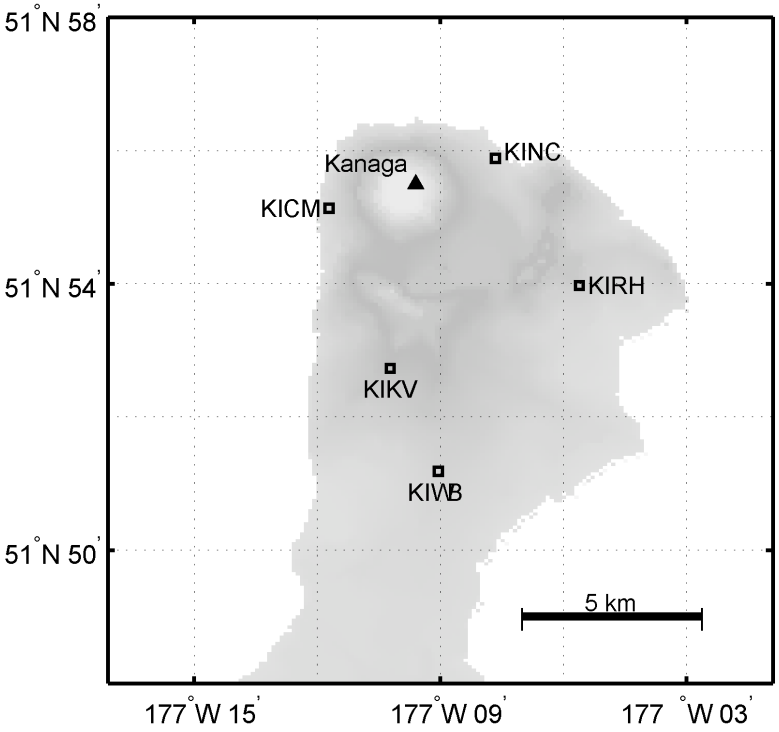


Figure C21. AVO seismograph stations near Kanaga Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

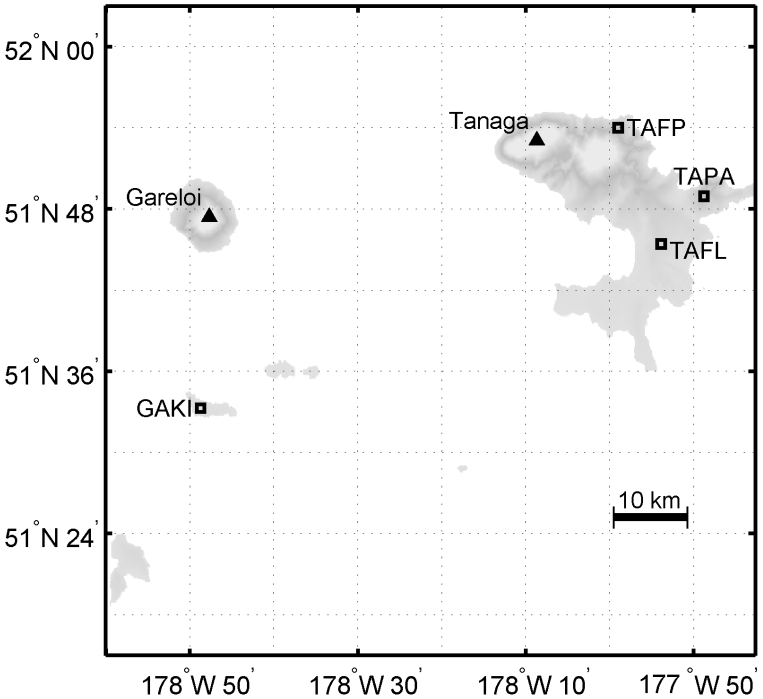


Figure C22. Regional AVO seismograph stations around Tanaga Volcano and Mount Gareloi. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

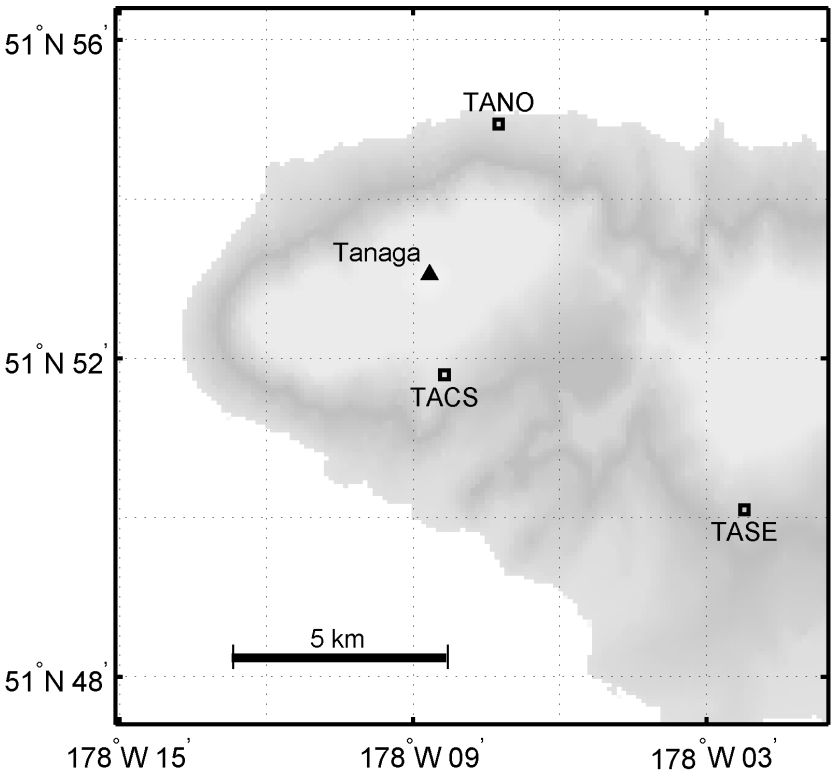


Figure C23. AVO seismograph stations near Tanaga Volcano. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

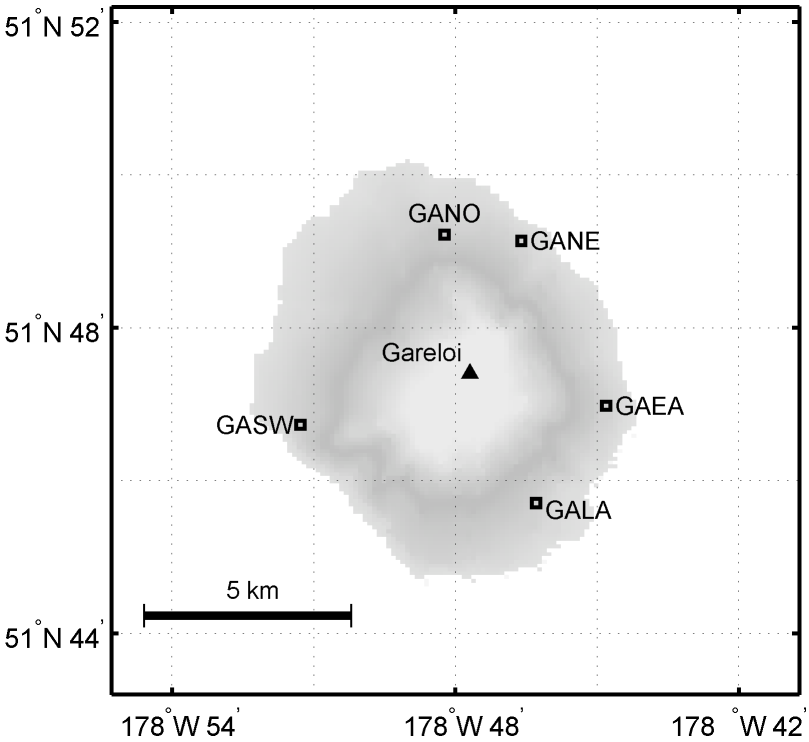
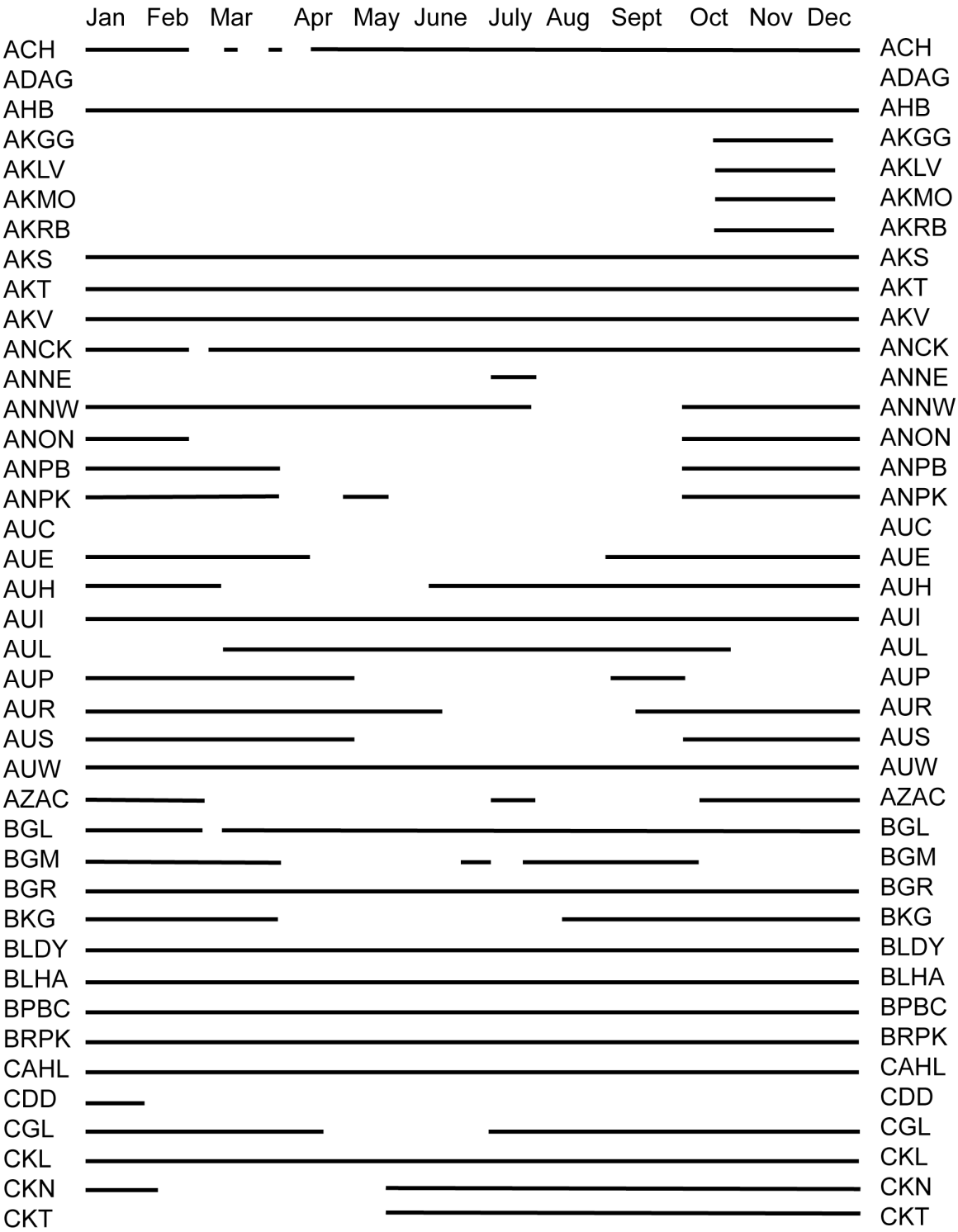
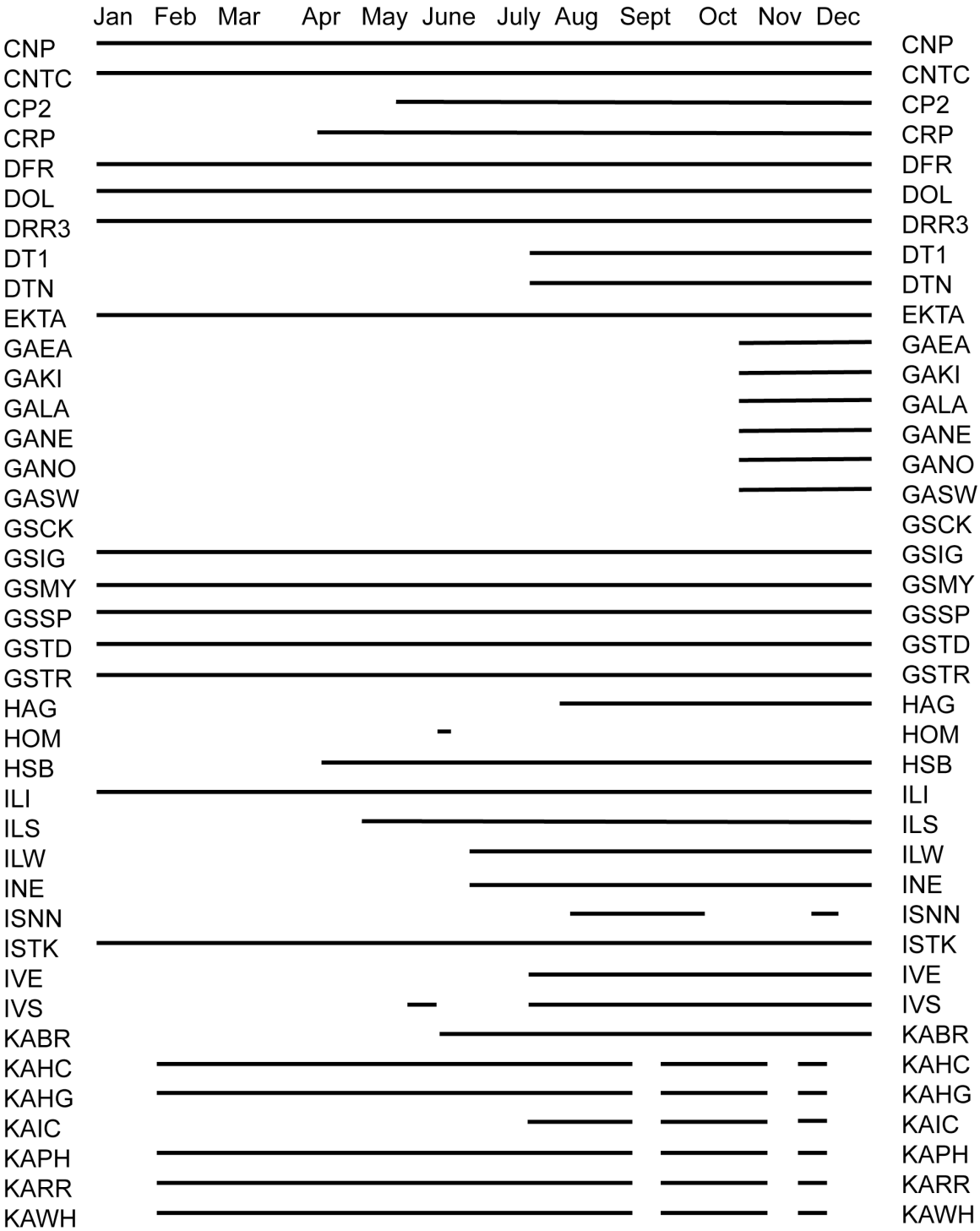
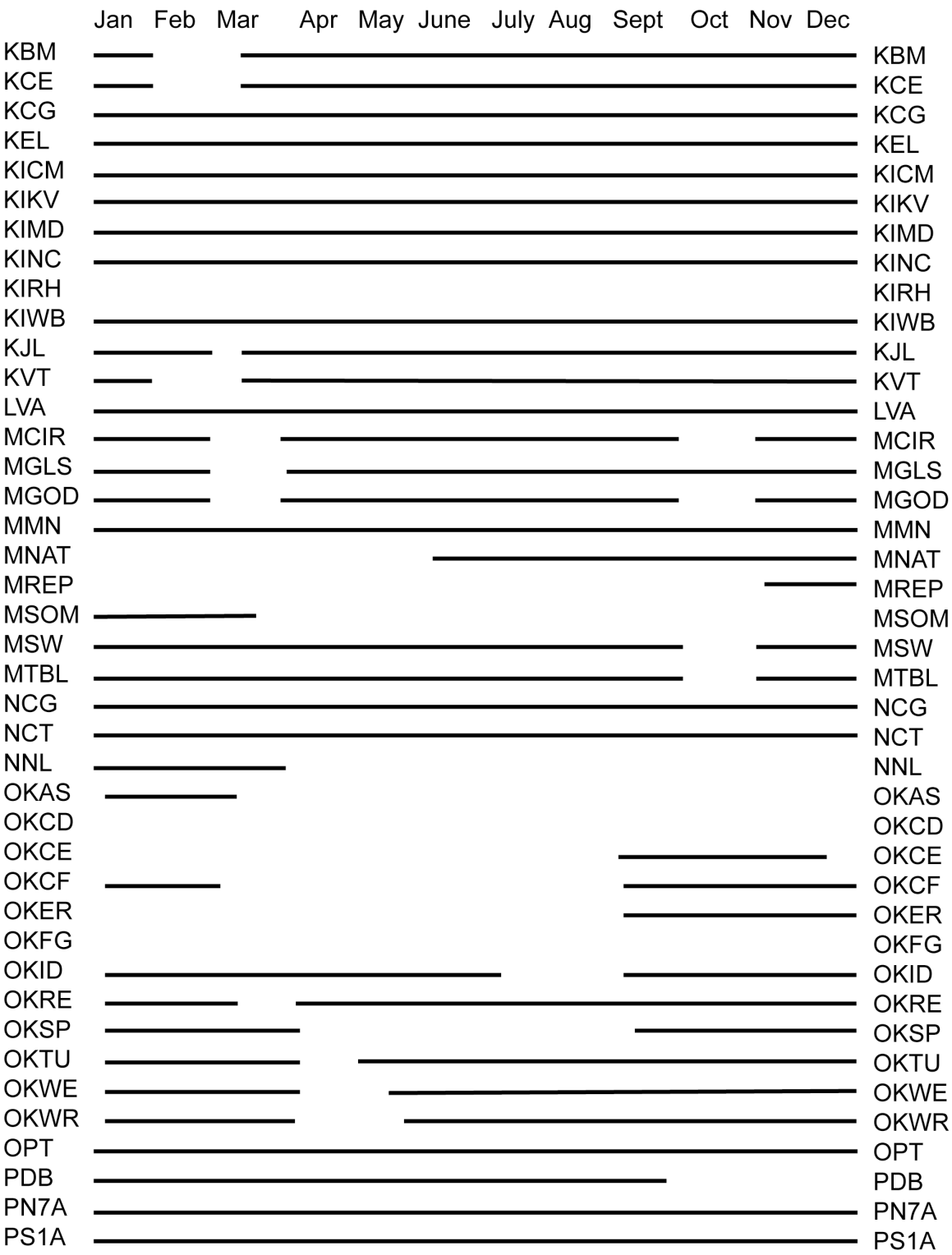


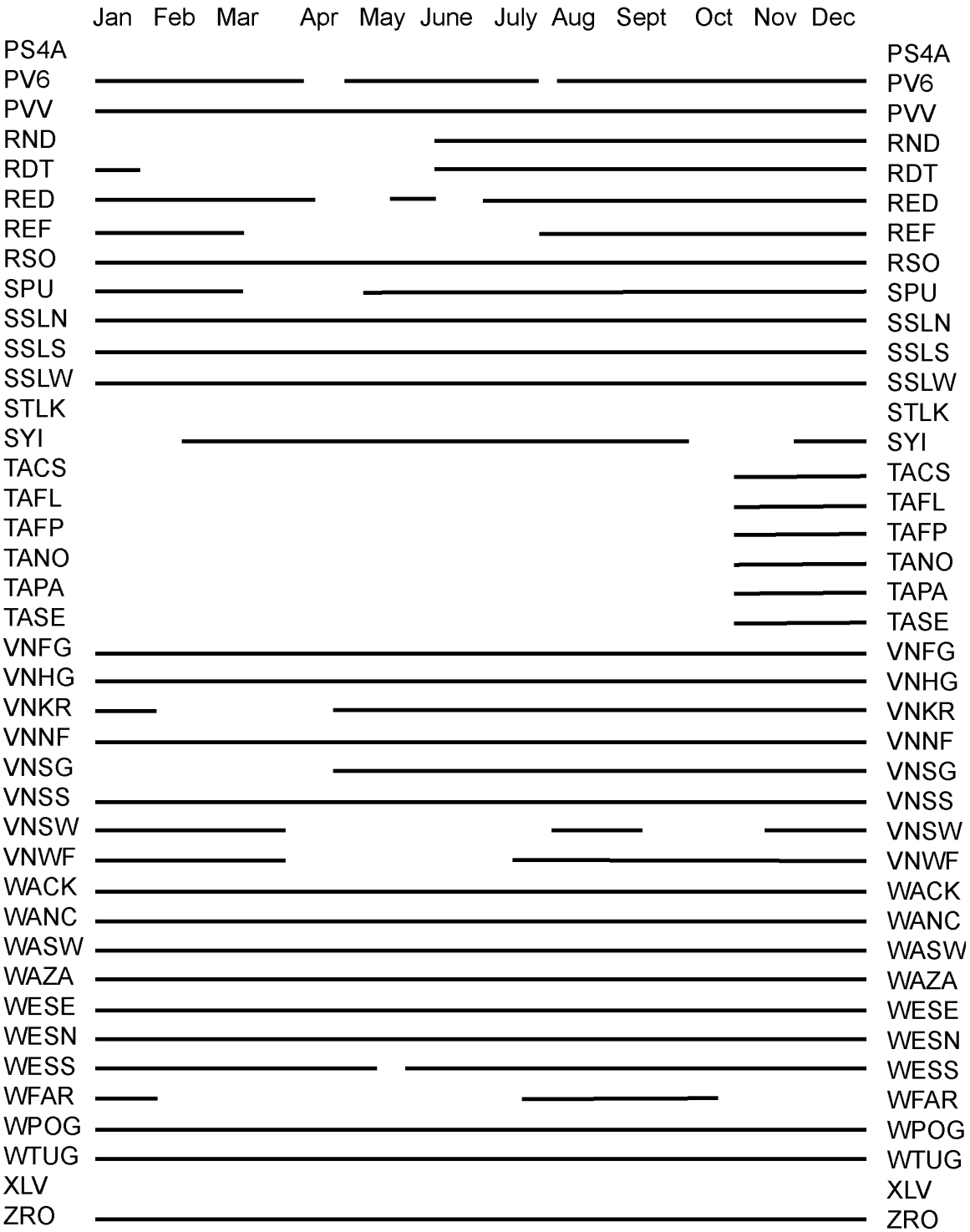
Figure C22. AVO seismograph stations near Mount Gareloi. Seismograph stations are shown by open squares. Closed triangles show volcanic centers.

Appendix D: Estimate of operational status for all AVO stations. A solid bar indicates periods of time a station was operational based on daily station use plots and weekly operational checks.




Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
CNP
CNTC
CP2
CRP
DFR
DOL
DRR3
DT1
DTN
EKTA
GAEA
GAKI
GALA
GANE
GANO
GASW
GSCK
GSIG
GSMY
GSSP
GSTD
GSTR
HAG
HOM
HSB
ILI
ILS
ILW
INE
ISNN
ISTK
IVE
IVS
KABR
KAHC
KAHG
KAIC
KAPH
KARR
KAWH


Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
KBM
KCE
KCG
KEL
KICM
KIKV
KIMD
KINC
KIRH
KIWB
KJL
KVT
LVA
MCIR
MGLS
MGOD
MMN
MNAT
MREP
MSOM
MSW
MTBL
NCG
NCT
NNL
OKAS
OKCD
OKCE
OKCF
OKER
OKFG
OKID
OKRE
OKSP
OKTU
OKWE
OKWR
OPT
PDB
PN7A
PS1A


Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
PS4A
PV6
PVV
RND
RDT
RED
REF
RSO
SPU
SSLN
SSLS
SSLW
STLK
SYI
TACS
TAFL
TAFP
TANO
TAPA
TASE
VNFG
VNHG
VNKR
VNNF
VNSG
VNSS
VNSW
VNWF
WACK
WANC
WASW
WAZA
WESE
WESN
WESS
WFAR
WPOG
WTUG
XLV
ZRO

Appendix E: 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
Redoubt	60.19	152.98	20	-3	50
Redoubt	59.87	153.17	20	-3	50
Redoubt	59.70	153.25	20	-3	50
Redoubt	59.53	153.34	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 (Searcy, 2003).

Layer number	Vp (km/sec)	Top of layer (km)	Vp/Vs
1	5.05	-3.0	1.78
2	5.10	1.0	1.78
3	5.41	2.0	1.78
4	5.49	3.0	1.78
5	5.65	4.0	1.78
6	5.67	5.0	1.78
7	5.69	6.0	1.78
8	5.76	7.0	1.78
9	5.80	8.0	1.78
10	6.00	9.0	1.78
11	6.04	10.0	1.78
12	6.08	12.0	1.78
13	6.30	15.0	1.78
14	6.73	20.0	1.78
15	7.54	25.0	1.78
16	7.78	33.0	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 F: Maps showing the location of the volcanic zones modeled using cylinders described in Appendix E.

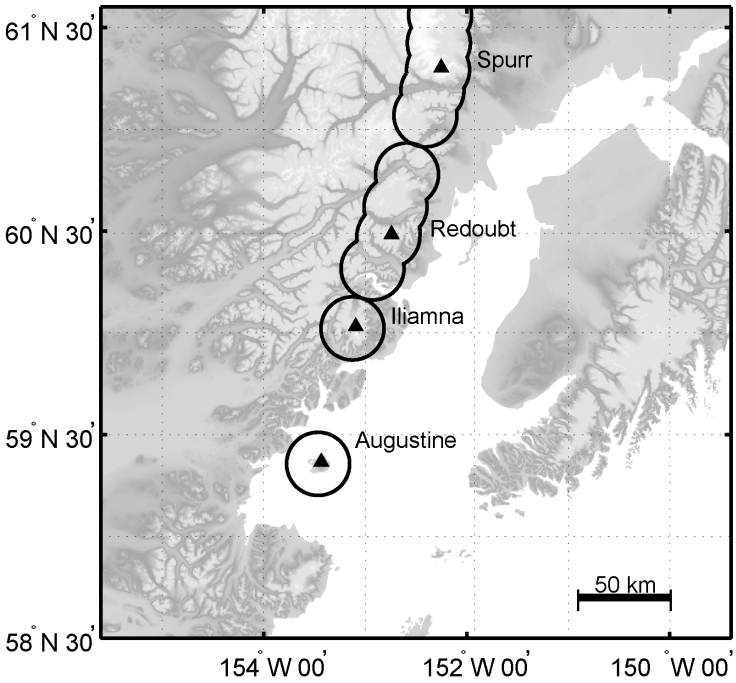


Figure F1. Volcanic zones for the Cook Inlet Volcanoes. Five overlapping cylinders model the Spurr volcanic zone. Four overlapping cylinders model the Redoubt volcanic zone. A single cylinder models the Iliamna and Augustine volcanic zones.

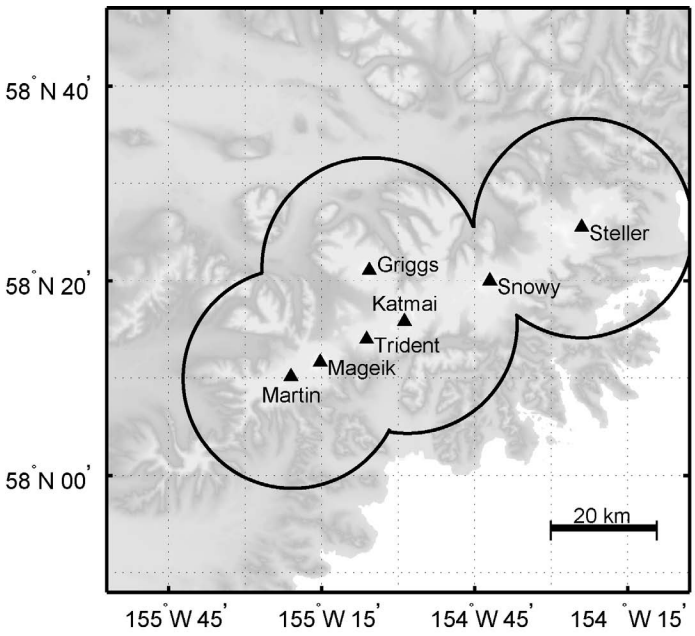


Figure F2. Volcanic zone for the Katmai volcanic cluster. The volcanic zone is modeled using four cylinders centered on Mount Martin, Mount Katmai, Mount Griggs and Mount Steller.

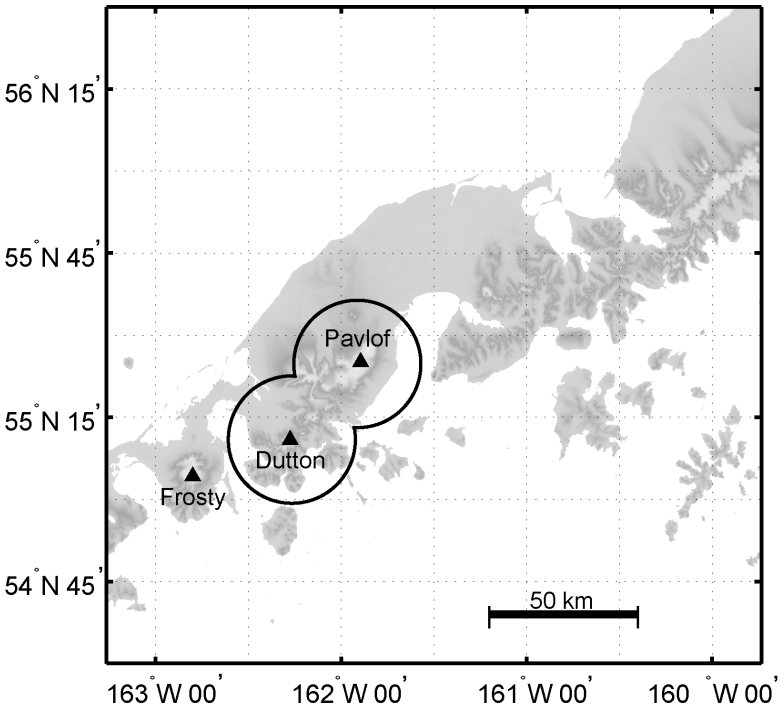


Figure F3. Volcanic zone for Pavlof Volcano and Mount Dutton. The volcanic zone is modeled using two cylinders centered on Mount Dutton and Pavlof Volcano.

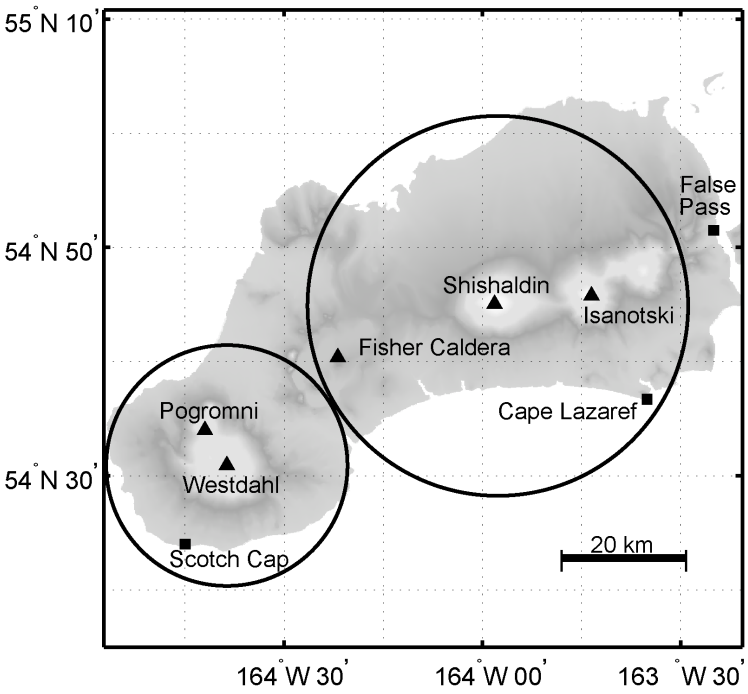


Figure F4. Volcanic zones on Unimak Island. The volcanic zones are modeled using a cylinder centered on Westdahl Peak and a cylinder centered on Shishaldin Volcano.

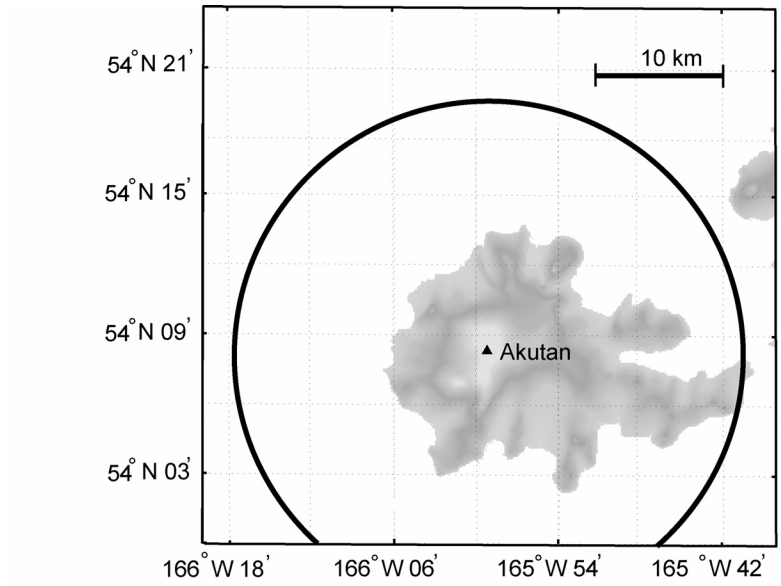


Figure F5. Volcanic zone for Akutan Volcano. The volcanic zone is modeled using a single cylinder.

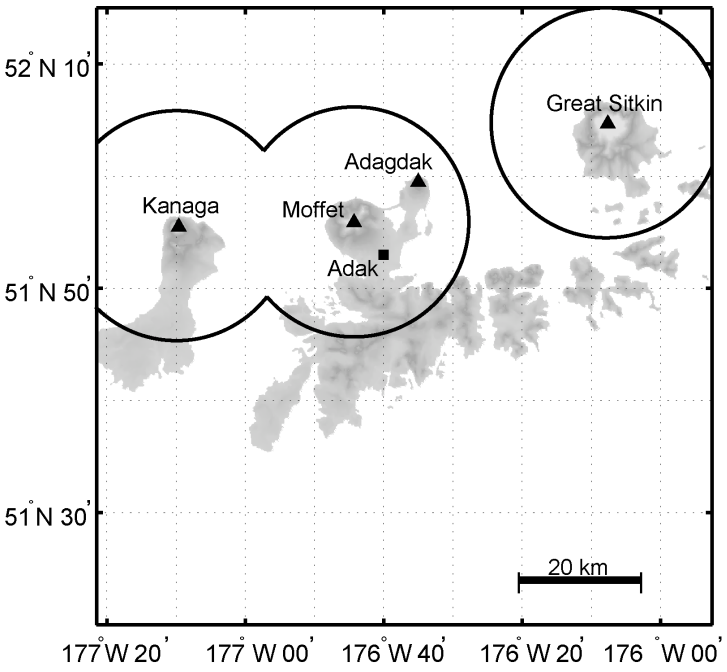


Figure F6. Volcanic zones in the Adak region. The volcanic zones are modeled using cylinders centered on Kanaga Volcano, Mount Moffet, and Great Sitkin Volcano.

Appendix G: Selected AVO papers published in 2003

Benoit, J. P., and McNutt, S. R., 2003, Duration-amplitude distribution of volcanic tremor: Journal of Geophysical Research, v. 108, n. B3, p. 2146-2159.

Caplan-Auerbach, J., and S.R. McNutt, 2003, New Insights into the 1999 Eruptions of Shishaldin Volcano Based on Acoustic Data. Bulletin of Volcanology, DOI: 10.1007/s00445-002-0267-5.

Dixon, J.P, Stihler, S.D., Power J.A., Tytgat, G., Moran, S.C., Sánchez, J., Estes, S., McNutt, S.R., Paskievitch, J., 2003, Catalog of Earthquake Hypocenters at Alaska Volcanoes: January 1 – December 31, 2002: U.S. Geological Survey Open-file Report 03-267, 58p.

Hamburger, M., S.R. McNutt, D. Dzurisin, J. Fink, D. Hill, C. Meertens, C. Newhall, S. Owen, J. Power, 2003, EarthScoping the Inner Workings of Magmatic Systems, Eos Transaction American Geophysical Union, v. 84, no. 25, p. 235.

Moran, S.C., 2003, Multiple seismogenic processes for high-frequency earthquakes at Katmai National Park, Alaska: Evidence from stress tensor inversions of fault-plane solutions: Bulletin of the Seismological Society of America, v. 93(1), p. 94-108.

Searcy, C.K, 2003, Station Corrections for the Katmai Region Seismograph network: U.S. Geological Survey Open-file Report 03-403, 16p.