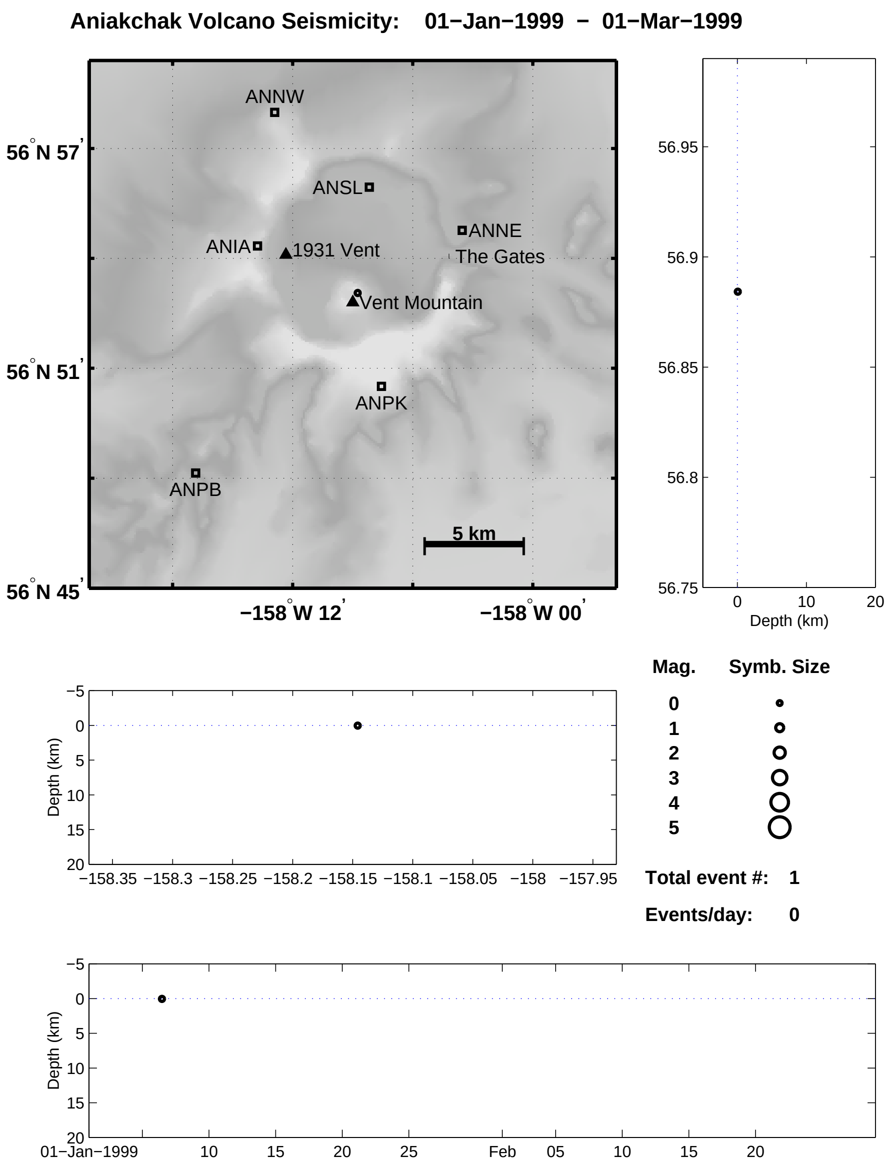

Figure 19a: Locatable Aniakchak seismic events in space and time for January through February.

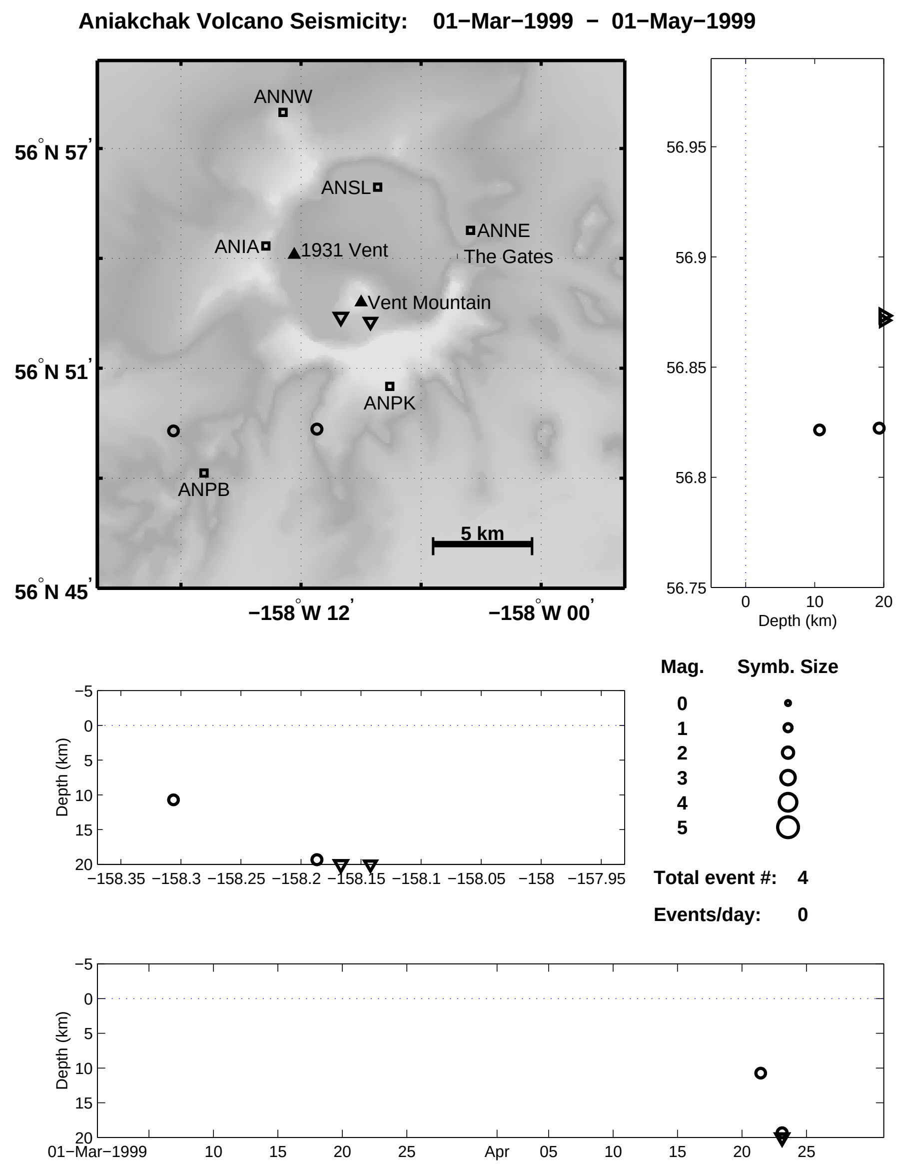

Figure 19b: Locatable Aniakchak seismic events in space and time for March through April.

Aniakchak:

January-February 1999:

One earthquake was located in the Aniakchak region during January-February 1999 (figs. 19a, 26a and 27a). This event was located about 0.5 km north-northeast of Vent Mountain (4 km east-southeast of the 1931 Vent) and had a magnitude of M_L=0.1 with a shallow hypocentral depth. This was only the fourth Aniakchak event to have been located since the seismic network was installed in the summer of 1997. Based upon the 5-month mean seismicity rate one would expect there to be one event located over a two-month time period. Therefore, the number of located events for January-February 1999 was in agreement with the mean rate estimate.

March-April 1999:

During March-April 1999 there were a total of four earthquakes located in the Aniakchak region (figs. 19b, 26b and 27b). The largest of these earthquakes had a magnitude of M_L=2.0 and was located about 1 km southwest of Vent Mountain (~4 km southeast of the 1931 Vent). This earthquake had a relatively deep hypocentral depth of about 24 km. There were two additional “deep” events located in the Aniakchak region during this period. One of these events was located fairly close to the M_L=2.0 event. This earthquake was located ~1 km south-southeast of Vent Mountain (~5 km southeast of the 1931 Vent) and had a hypocentral depth of about 21 km. The other relatively deep event was located about 7 km south-southwest of Vent Mountain and had a depth of about 19 km. Since the hypocentral depth of this event was less than 20 km its location was not indicated by an inverted triangle as was the case with the other two deep events. The final Aniakchak earthquake was located about 11 km southwest of the 1931 Vent and had a hypocentral depth of nearly 11 km. The number of Aniakchak events located during this two-month period doubled the total number of earthquakes located in this region since the Aniakchak seismic network became operational in July 1997.

Pavlof:

January-February 1999:

Two earthquakes were located in the Pavlof region during January-February 1999 (figs. 20a, 26a and 27a). The largest of the two events had a magnitude of ML=1.1, was located about 1 km north-northeast of Hague (~8 km southwest of Pavlof), and had a hypocentral depth of about 2 km. The second Pavlof event was located about 2 km west-southwest of Hague (~11 km southwest of Pavlof) and had a shallow hypocentral depth. The number of events located in the Pavlof region during January-February was twice that of the previous two-month period. This value was, however, in agreement with the number of located events predicted from the 2-year mean seismicity rate for Pavlof.

March-April 1999:

No earthquakes were located in the Pavlof region during March-April 1999 (figs. 26b and 27b). As usual, both the Helicorder and detected event counts for Pavlof were very low. The Pavlof stations appear to have been operating during this two-month period so the lack of located events appears to be real and is not the result of station outages.

Dutton:

January-February 1999:

A single event was located in the Dutton region during January-February 1999 (figs. 21a, 26a and 27a). This earthquake had a magnitude of M_L=1.4 and was located beneath Belkofski Bay (~13 km southeast of Dutton) at a

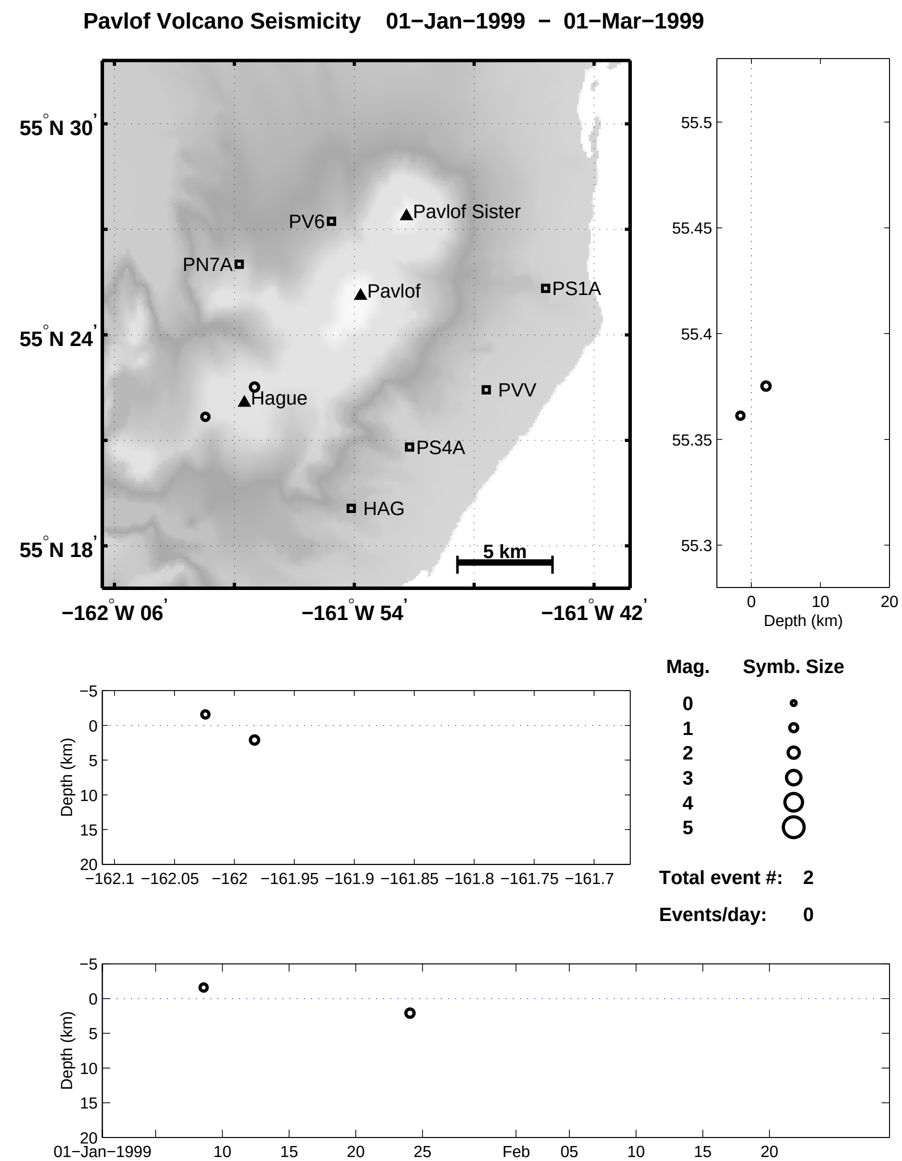

Figure 20a: Locatable Pavlof seismic events in space and time for January through April.

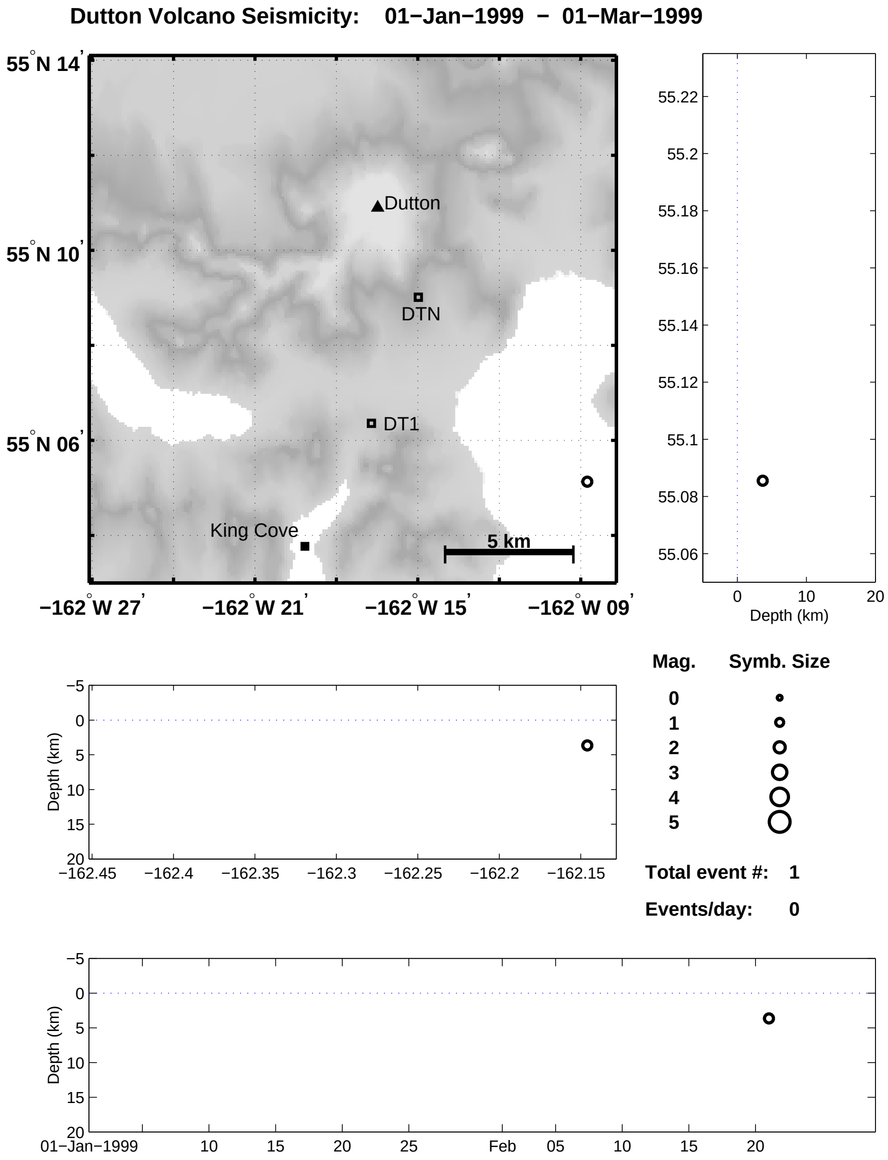

Figure 21a: Locatable Dutton seismic events in space and time for January through February.

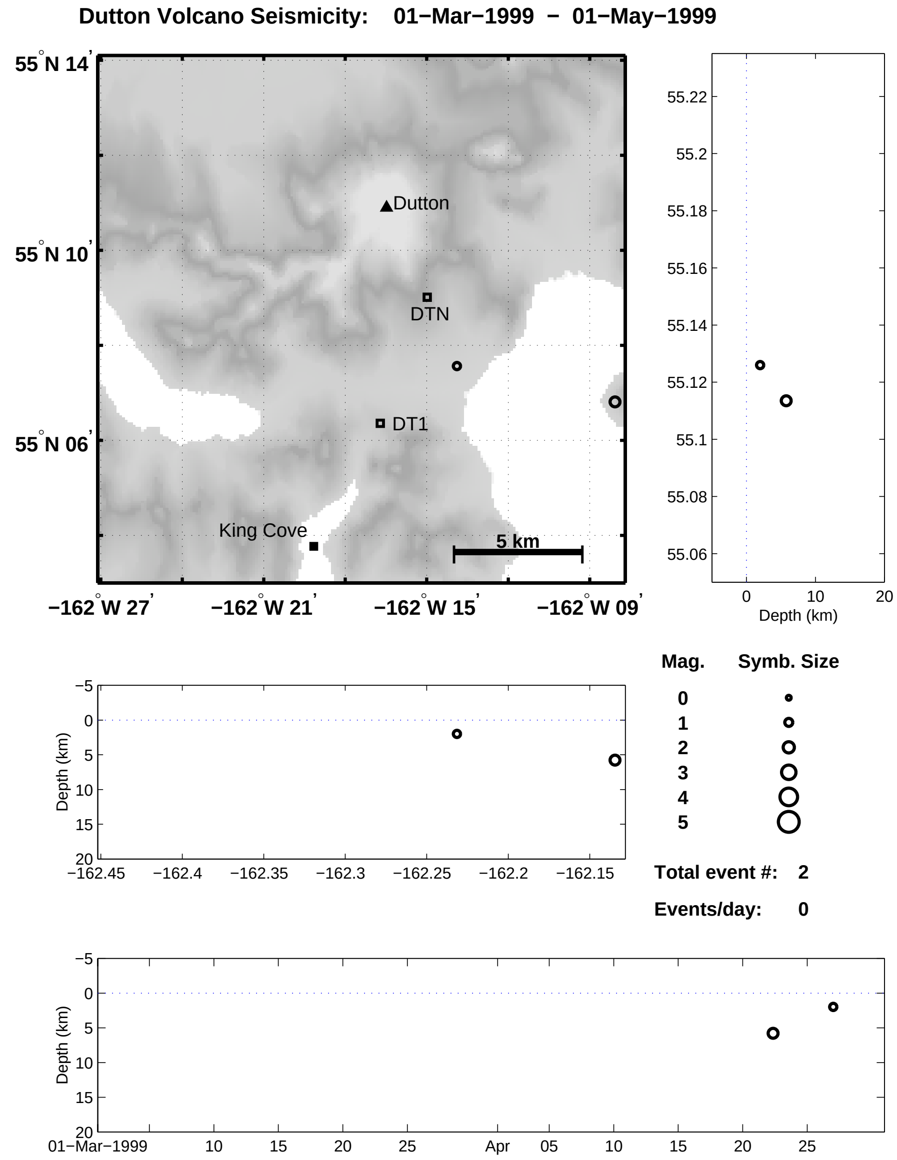

Figure 21b: Locatable Dutton seismic events in space and time for March through April.

hypocentral depth of about 2 km. The number of earthquakes located in the Dutton region during this two-month period was the same as that of November-December 1998. This value was also in agreement with the number of located events predicted from the 2-year mean seismicity rate for Dutton.

March-April 1999:

During March-April 1999 there were two earthquakes located in the Dutton region (figs. 21b, 26b and 27b). The largest of the two events had a magnitude of ML=1.6 and was located about 12 km southeast of Dutton and had a hypocentral depth of 6 km. The second event was located about 7 km south-southeast of Dutton at a hypocentral depth of 2 km. The number of earthquakes located in the Dutton region during March-April was twice that of January-February. This was also the case with respect to the number of events predicted from the mean seismicity rate.

Shishaldin:

January-February 1999:

There were a total of 12 earthquakes located in the Shishaldin region during January-February 1999 (figs. 22a, 26a and 27a). The largest such event had a magnitude of M_L=2.4. This earthquake was located off the southeastern shore of Unimak Island about 4 km east-southeast of Cape Lazaref and had a hypocentral depth of about 8 km. Also in this region was a M_L=2.3 event which was located about 8 km southeast of Cape Lazaref with a depth of nearly 9 km. The ten other events were located closer to Shishaldin. Three of these events were located about 10-15 km southwest of Shishaldin with hypocentral depths of ~7-10 km. The remaining seven events were located within about 2 km of the summit of Shishaldin and had shallow hypocentral depths. No Shishaldin events were located during the previous two-month period. The number of located earthquakes during January-February was greater than the eight located events estimated from the Shishaldin 1-year mean seismicity rate.

March-April 1999:

During March-April 1999 there were a total of 814 events located in the Shishaldin area (figs. 22b, 26b and 27b). Six of these events were located in the Cape Lazaref region. Four of these events were located about 9-13 km southeast of Cape Lazaref. The final two events in this area were located 1 km south-southeast of Cape Lazaref and about 13 km east-northeast of the Cape. On March 4, 1999 at 12:26 UTC (3:26 am AST) a magnitude M_L=5.0 earthquake occurred about 16 km west of Shishaldin at shallow hypocentral depth. The remaining 808 of the 814 earthquakes plotted in figure 22b represent the M_L=5.0 mainshock and the subsequent aftershocks. However, some of the aftershocks were located too far to the west to be plotted on this figure. An additional 47 earthquakes appear on the Westdahl seismicity map (fig. 23b) which would bring the number of non-Cape Lazaref events up to 855. Unfortunately, the Westdahl map does not extend sufficiently to the east to include all of the located Shishaldin aftershocks. The total number of earthquakes located as part of the mainshock/aftershock sequence during this two-month period was found to be 861. The aftershocks were located in a diffuse ~11 km wide zone extending from 7 to 18 km west to west-southwest of Shishaldin. The largest of these aftershock had a magnitude of M_L=4.4 and was located about 14 km west-southwest of the summit of Shishaldin. During this two-month period there were nine aftershocks having magnitudes of $M_L \geq 3.0$ of which two had magnitudes of $M_L \geq 4.0$.

We have had many discussions about the relation, if any, of the M=5.0 earthquake and the activity of Shishaldin Volcano. The following discussion is intended to identify the key observations and issues.

Dave Schneider (pers. comm.) noted that there was an apparent increase in the relative size of the Shishaldin hotspot immediately following the M_L=5.0 event. This suggests that the activity at Shishaldin and the mainshock/aftershock sequence may have been related. One possible explanation for the observed relationship between the earthquake sequence and the increase in thermal activity would be for the earthquakes to have been triggered by the movement of magma in the epicentral region. In this case, one could envision the eruption of Shishaldin being fed by a magma body located in the epicentral region. Under the proper conditions the stresses associated with the movement of the magma trigger the earthquakes. The transport of this new magma to the summit area of Shishaldin could also explain the increase in activity as observed by the satellite imagery. Another scenario would be for the movement of magma to have triggered earthquakes by a somewhat more indirect means. Stresses associated with magma movement beneath Shishaldin itself could possibly have triggered the earthquakes further to the west in the epicentral area. Local extensional stresses related to magma movement at Shishaldin could translate into westward compression in the epicentral region. If a fault in the epicentral area was already near failure, the additional compressive stresses associated with magma transport may have been sufficient to induce rupture, thus generating the M_L=5.0 to the west of Shishaldin (C. Nye, pers. comm.). Additional magma at Shishaldin resulting from this transport may, in turn, have been reflected in an increase in the thermal signature of the volcano. A third possibility was that this earthquake sequence was simply tectonic in nature and totally unrelated to volcanic activity at Shishaldin. The shaking associated with the occurrence of this moderate earthquake may have altered the “plumbing system” at Shishaldin in such as way as to increase the volcanic activity.

The focal mechanism of the M_L=5.0 event provides some insight on which of the above scenarios was more likely. The fault-plane solution of this earthquake indicated that the mainshock was produced by nearly pure strike-slip fault movement (S. Moran, pers. comm.). If the earthquakes were produced by magma transport in the epicentral region then the focal mechanisms of these earthquakes should indicate an extensional stress regime (i.e. normal faulting) or at least a large component of normal faulting in this region. A strike-slip fault solution having almost entirely lateral movement suggests that the earthquakes were not produced by magma transport in the immediate epicentral area.

The two nodal planes of this focal mechanism, one of which represents the actual fault-plane, were oriented nearly northeast-southwest and northwest-southeast (S. Moran pers. comm.). Determining which of these two planes actually represents the fault-plane is somewhat problematic. In many cases the nodal plane representing the fault is delineated by the orientation of the aftershock zone. However, in the case of the aftershocks associated with the M_L=5.0 event the aftershock zone is not really very linear but rather forms what can be best described as an amorphous blob. Since the regional stress-field was such that the compressional stresses were oriented in the northwesterly direction (J. Freymueller pers. comm.), the northwest-southeast orientated nodal plane would be the preferred fault-plane. A fault-plane having this orientation would be more consistent with the regional stress direction than the alternative fault orientation (i.e. the northeast-southwest nodal plane).

The combination of a northwest-southeast trending fault and regional compression in the northwesterly direction would be consistent with

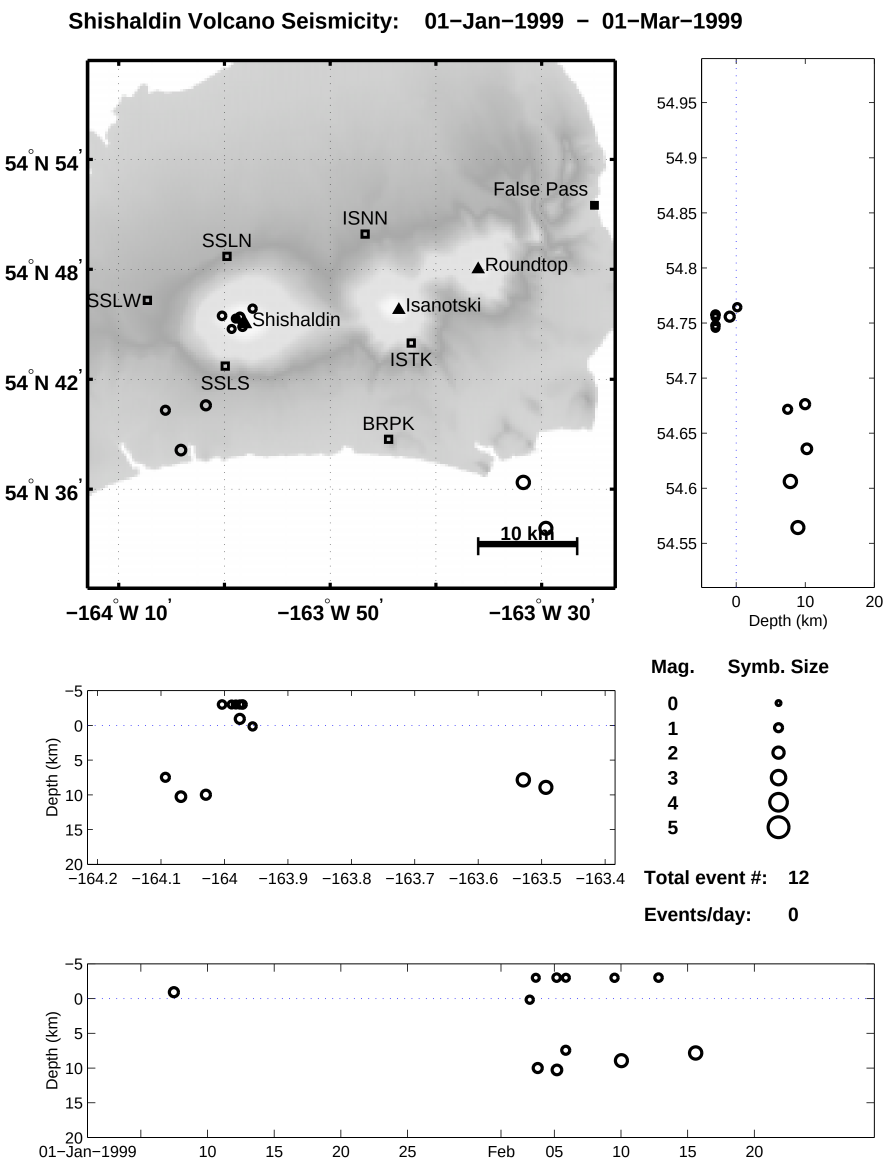

Figure 22a: Locatable Shishaldin seismic events in space and time for January through February.

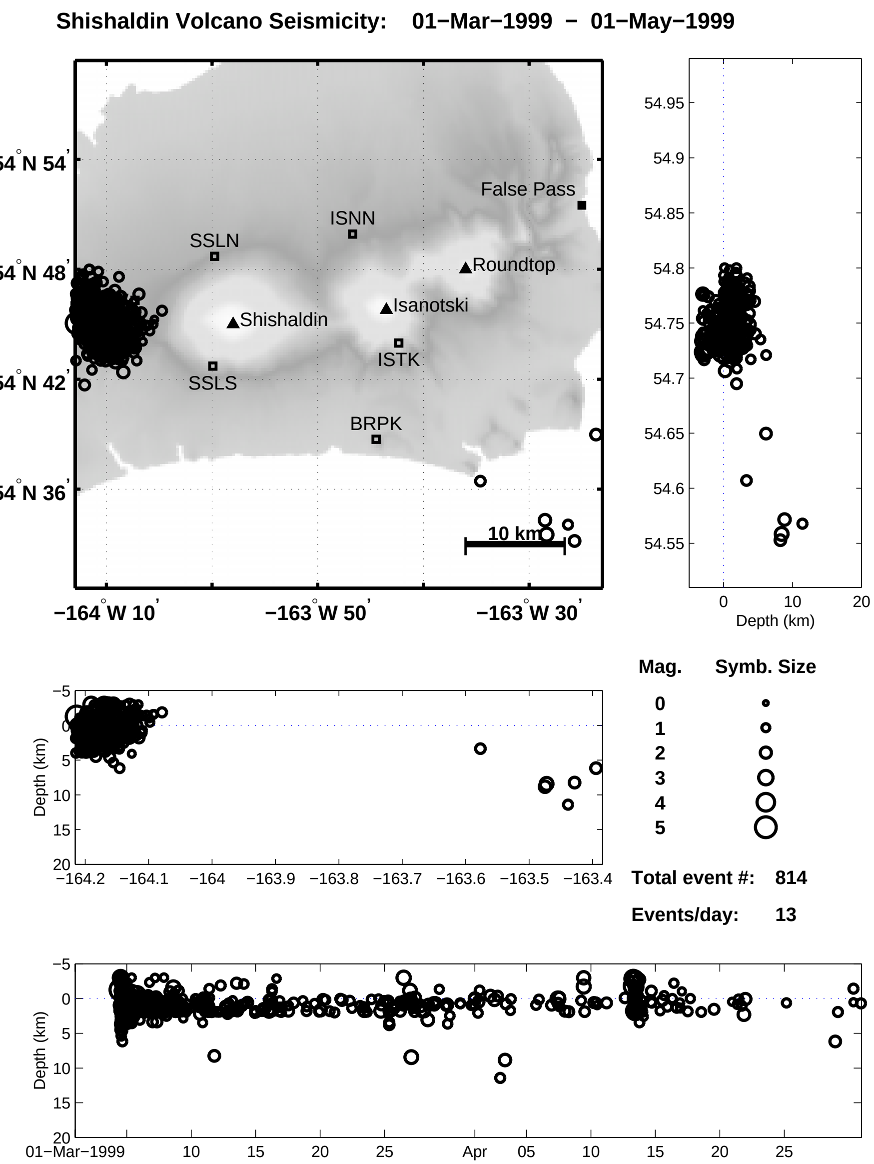

Figure 22b: Locatable Shishaldin seismic events in space and time for March through April.

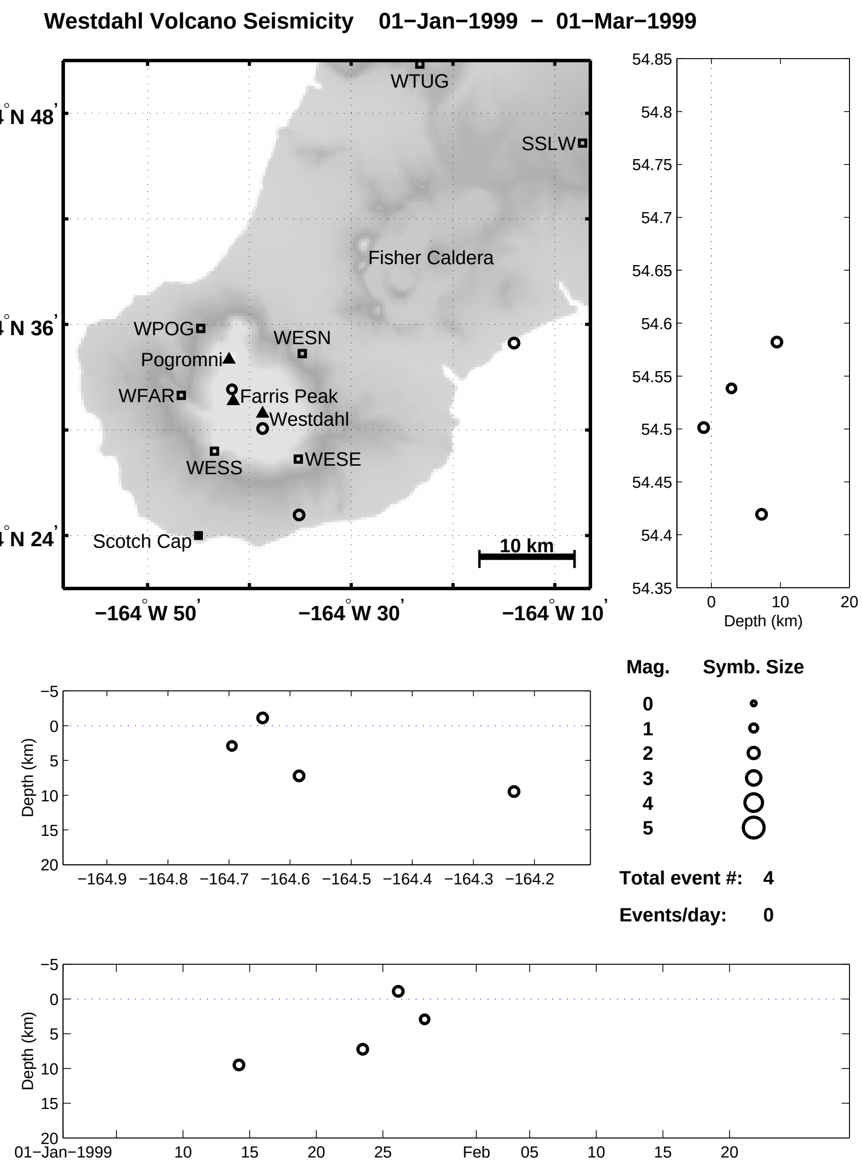

Figure 23a: Locatable Westdahl seismic events in space and time for January through February.

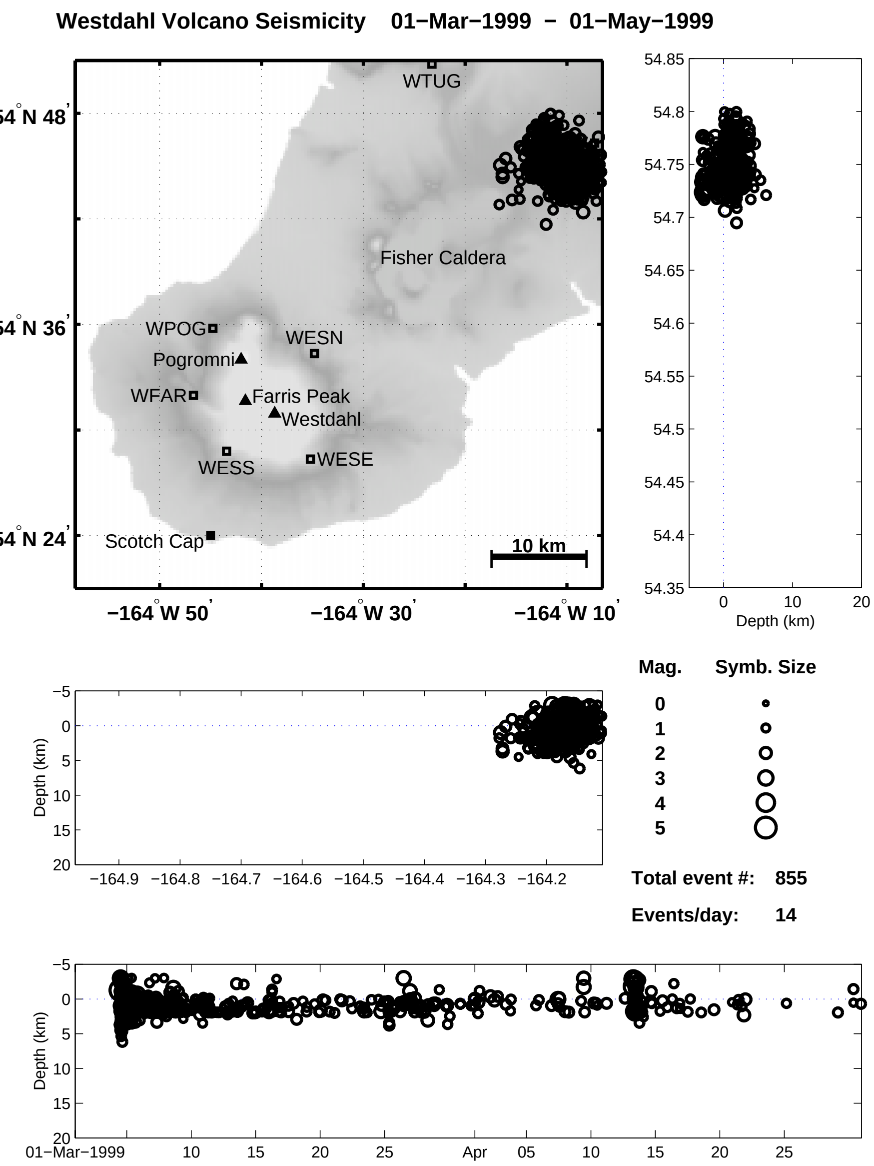

Figure 23b: Locatable Westdahl seismic events in space and time for March through April. Most of these events are related to the Shishaldin activity (see fig. 22b).

movement along this fault being induced by perturbations in the local stress-field due to magma transport at Shishaldin. Westward compression in the epicentral area resulting from magma movement at Shishaldin would have an additive effect on the regional stresses in the epicentral area. If near rupture conditions existed along a fault in this area then these added stresses may have been sufficient to have triggered the M_L=5.0 earthquake.

Although less tantalizing, both the focal mechanism and the regional stress data are also consistent with the seismicity in the epicentral area being part of the normal regional tectonic activity unrelated to volcanism at Shishaldin. The earthquakes may have been regional tectonic earthquakes that just happened to be located in the general area of an ongoing volcanic eruption. Considering the relative seismic and volcanic activity which characterize the Aleutian Islands, such coincidental occurrences should be common. Even if the M_L=5.0 event was of tectonic origin, the shaking associated with the it may still have produced an increase in the volcanic activity by altering the magma transport system (i.e. the plumbing system) so as to increase the flow of magma. Of course, it is also possible that the coincidence in the timing of the occurrence of the earthquakes and the increase in the relative size of the hotspot at Shishaldin was entirely fortuitous. The two most likely explanations for the coincident timing of the M_L=5.0 earthquake with the increase in volcanic activity observed on satellite imagery are that: (1) magma transport at Shishaldin not only resulted in an increase in hotspot size but also perturbed the local stress-field sufficiently to trigger the M_L=5.0 earthquake or (2) the shaking associated with a moderate sized regional tectonic earthquake in the Shishaldin region altered the volcanic plumbing system such that magma flow was increased thus resulting in a larger thermal signature.

Westdahl:

January-February 1999:

Four earthquakes were located in the Westdahl region during January-February 1999 (figs. 23a, 26a and 27a). The smallest of these events had a magnitude of M_L=1.2 and was located about 1 km north-northwest of Farris Peak (~4 km northwest of Westdahl) at a depth of about 3 km. The remaining three earthquakes all had magnitudes of M_L=1.5. One of these events was located about 2 km south-southeast of Westdahl and had a shallow hypocentral depth. Another of these events was located about 12 km south-southeast of Westdahl at a hypocentral depth of about 7 km. The remaining event was located about 15 km east-southeast of the center of Fisher Caldera (~28 km northeast of Westdahl) and had a hypocentral depth of nearly 10 km. No earthquakes were located in the Westdahl region during November-December 1998. Thus far, there have been insufficient data from the Westdahl network to determine a meaningful mean seismicity rate for this region.

March-April 1999:

No earthquakes were located in the Westdahl region that were not related to the ML=5.0 “Shishaldin” event and associated aftershocks (figs. 23b, 26b and 27b). As noted above, 47 aftershocks were plotted on figure 23b that did not appear on the corresponding Shishaldin seismicity map (i.e. figure 22b). However, for the same reason, six of the more easterly aftershocks were plotted on figure 22b but not on figure 23b.

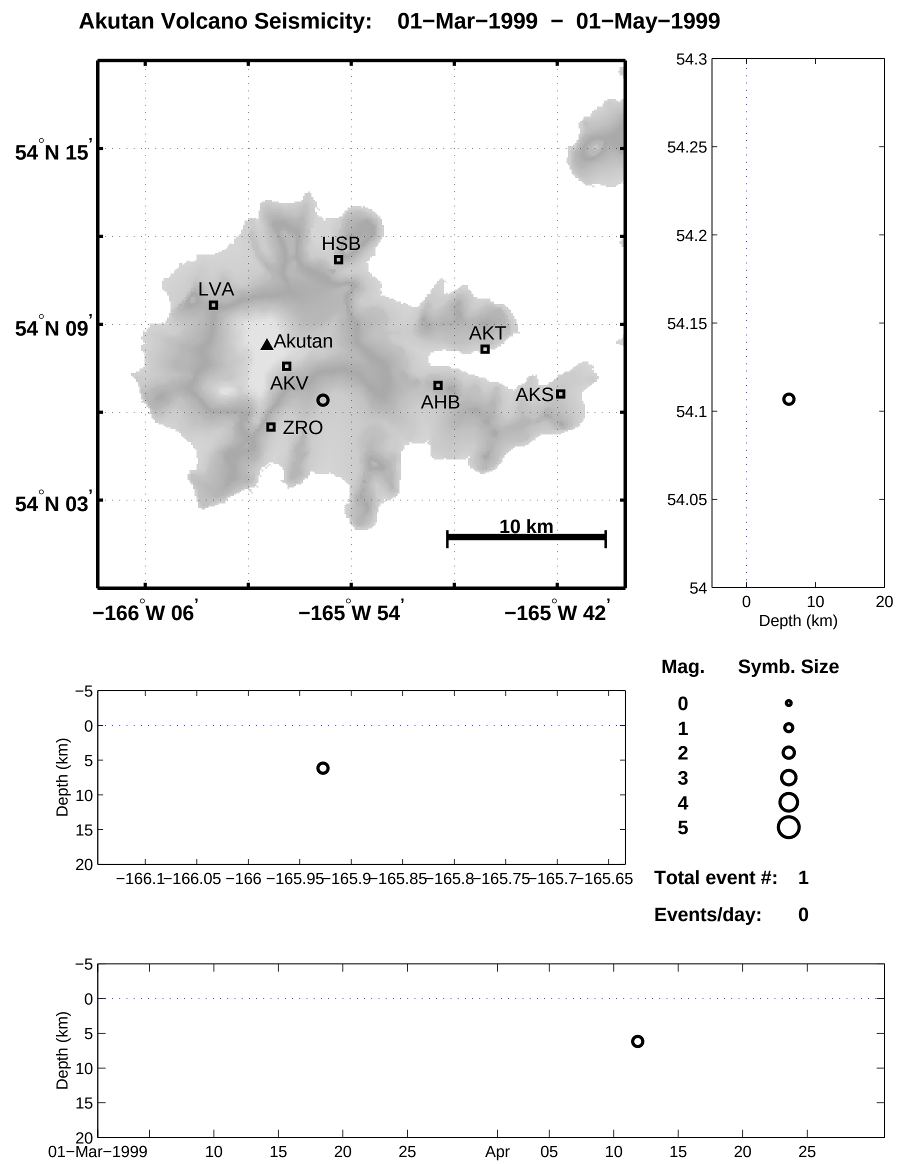

Figure 24b: Locatable Akutan seismic events in space and time for March through April. (A plot for figure 24a was not generated because there were no earthquakes during the January-February time period.)

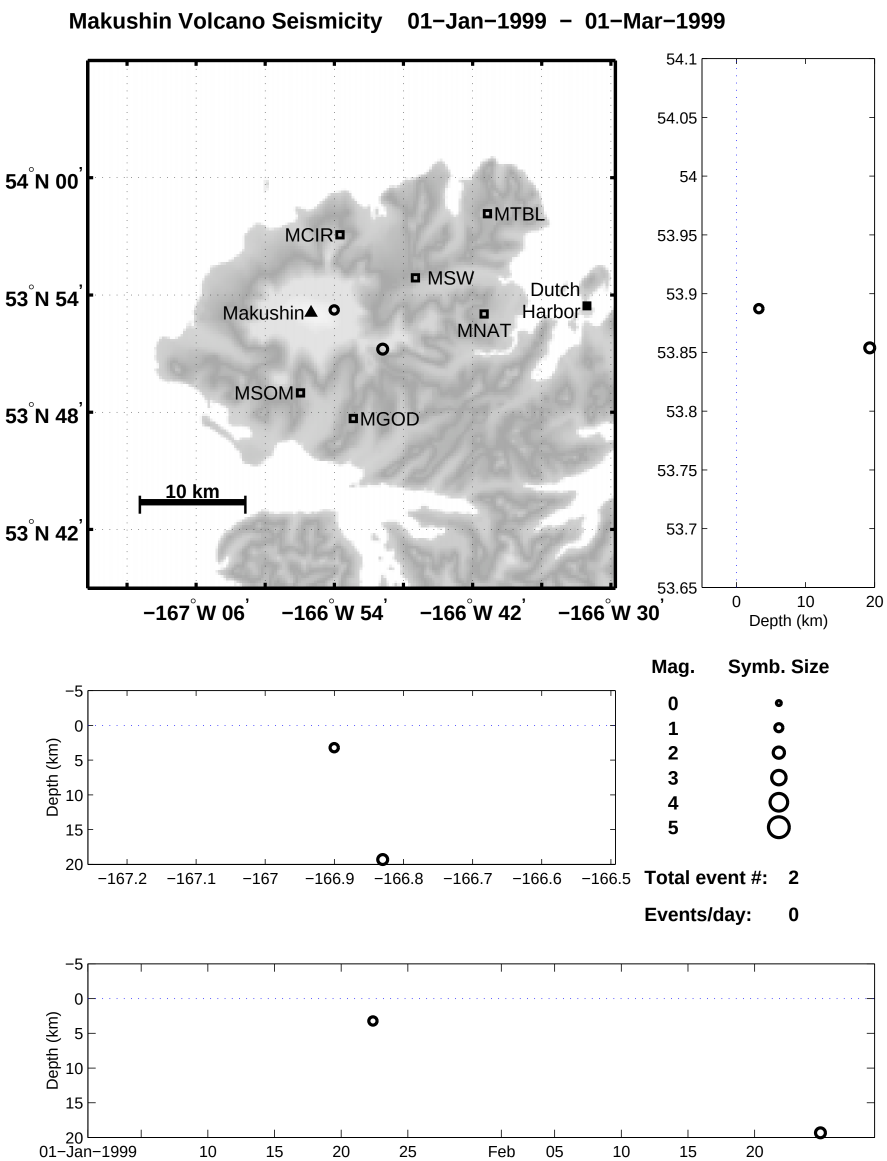

Figure 25a: Locatable Makushin seismic events in space and time for January through February.

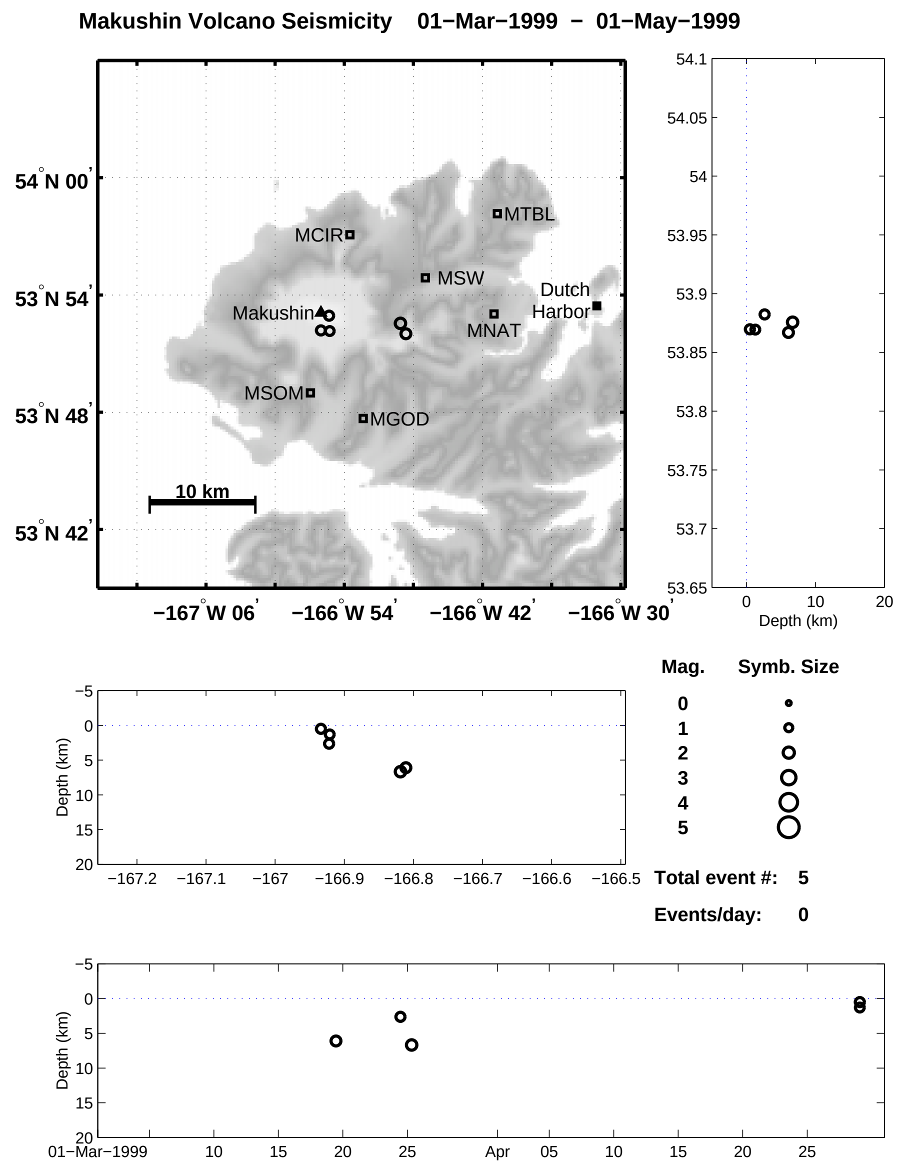

Figure 25b: Locatable Makushin seismic events in space and time for March through April.

Akutan:

January-February 1999:

There were no earthquakes located in the Akutan region during January-February 1999. The Helicorder and detected event counts also indicated the level of activity at Akutan to have been low during this two-month period (figs. 26a and 27a). A single earthquake was located in this region during the previous two-month period. Based upon the Akutan two-year mean seismicity rate one would expect seven earthquakes to have been located in the Akutan region over a two-month period.

March-April 1999:

One earthquake was located in the Akutan region during March-April 1999 (figs. 24b, 26b and 27b). This event had a magnitude of M_L=1.7 and was located about 5 km southeast of the summit of Akutan and had a hypocentral depth of 6 km. The number of events located during this two-month period was greater than that of January-February 1999, but was much lower than the seven such events predicted from the mean seismicity rate.

Makushin:

January-February 1999:

Two earthquakes were located in the Makushin region during January-February 1999 (figs. 25a, 26a and 27a). The largest of these events had a magnitude of M_L=1.6 and was located about 7 km southeast of Makushin and had a hypocentral depth of over 19 km. The remaining earthquake was located about 2 km east-southeast of Makushin and had a depth of about 3 km. The number of events located in this region during this two-month period was half that of November-December 1998. This value was also much lower than the 11 earthquakes predicted from the two-year mean seismicity rate.

March-April 1999:

During March-April 1999 a total of five earthquakes were located in the Makushin region (figs. 25b, 26b and 27b). The largest such earthquake had a magnitude of ML=1.8 and was located about 7 km east-southeast of Makushin and had a hypocentral depth of ~7 km. A second event was located in nearly the same area (i.e. ~8 km east-southeast of Makushin). The remaining three earthquakes were clustered near the summit of Makushin. One of these events was about 1 km southeast of the summit and had a hypocentral depth of 3 km. The other two events were located about 2-3 km south of the summit and had hypocentral depths of 1 km. Although the number of earthquakes located in the Makushin area during March-April was greater than that of the previous two-month period, it was only about half the number of such events one would expect from the mean seismicity rate.

Scott Stihler, John Sanchez, Gordon Bower, Scott Dreher, Pete Stelling, Glenn Thompson, Aaron Pearson, Ellen Wilson, Bob Hammond, Guy Tytgat, Steve McNutt, Art Jolly, Seth Moran and John Power

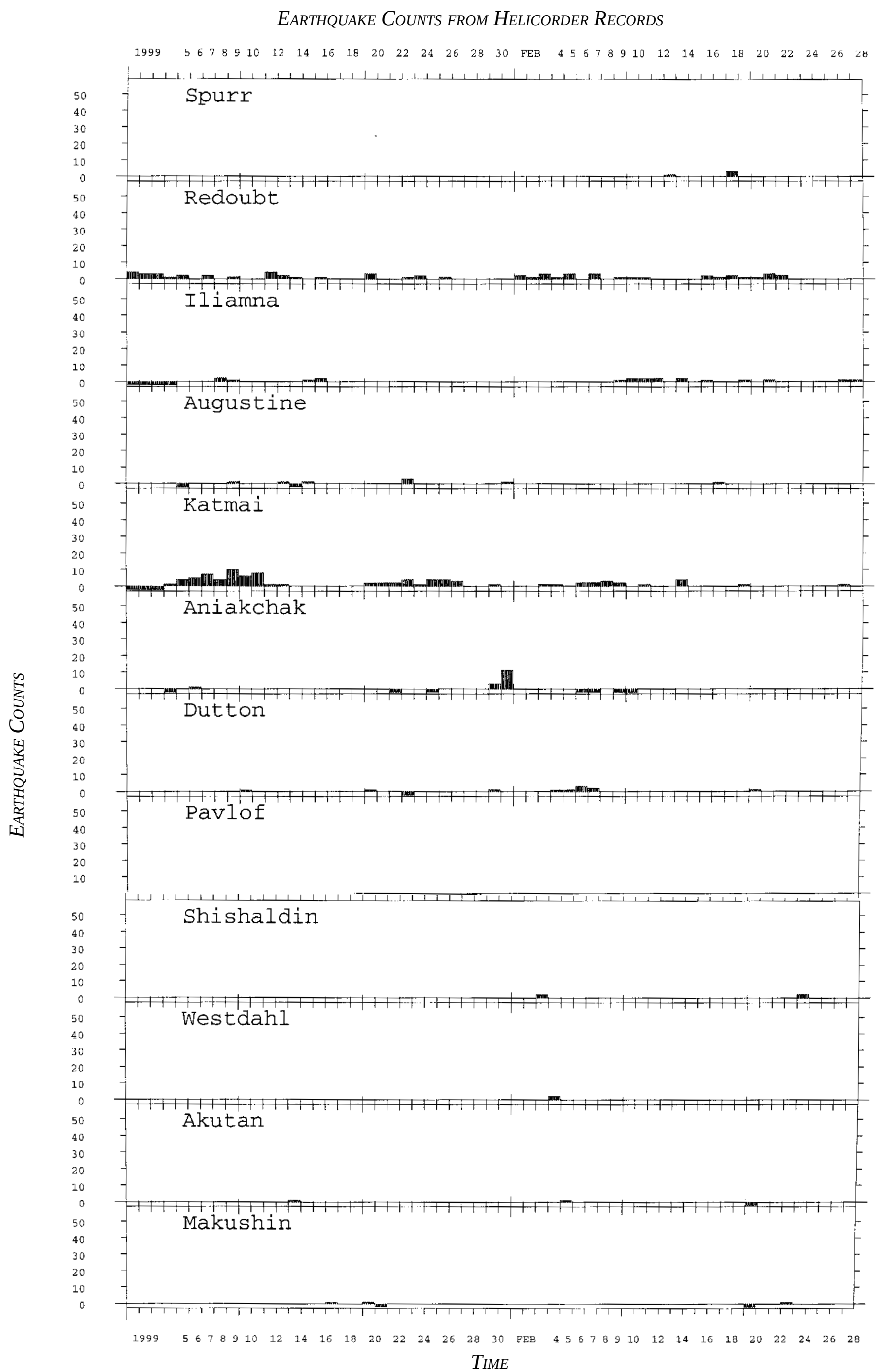

Figure 26a: Histogram of seismic events counted from Helicorder records during January through February.

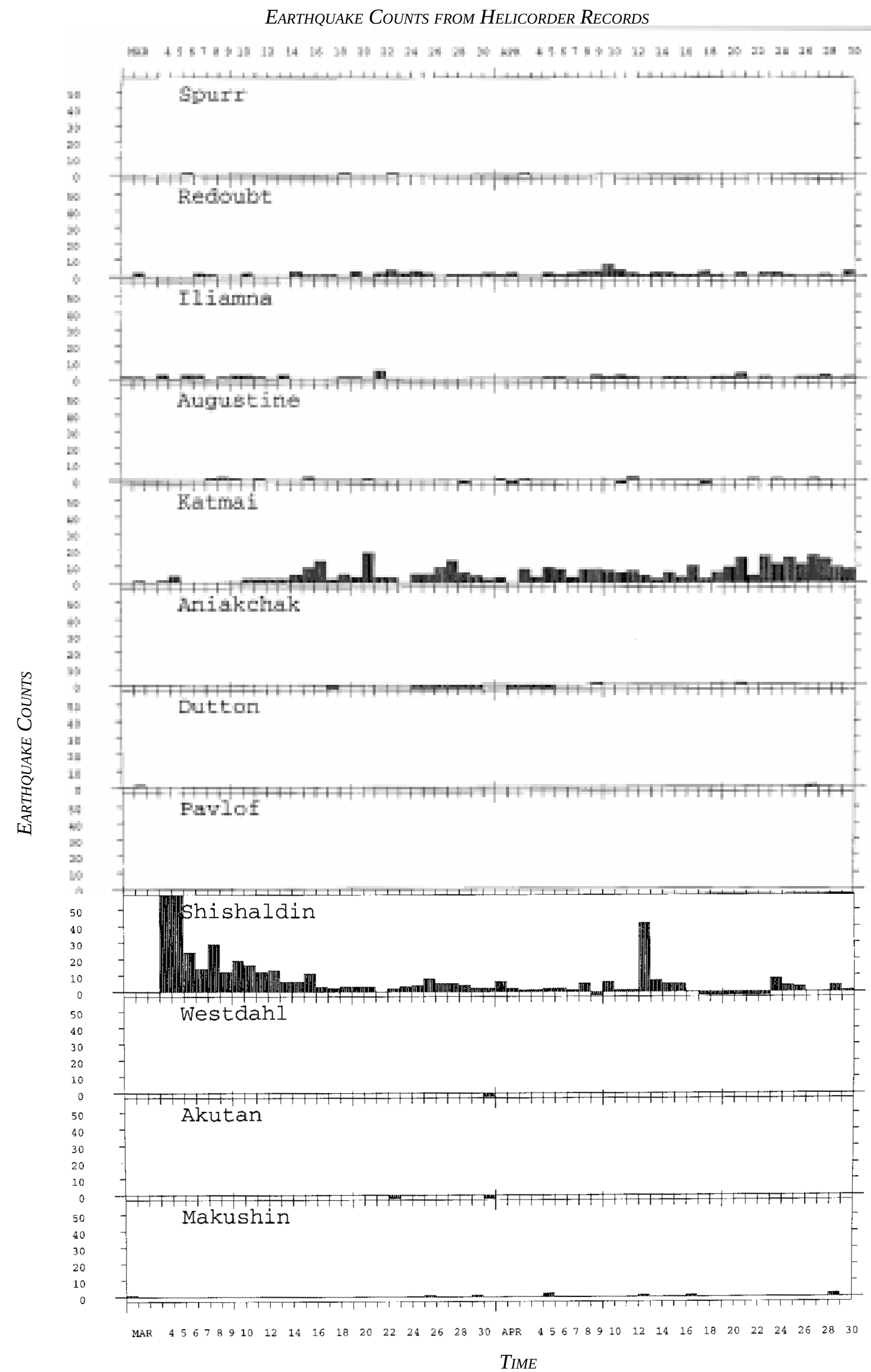

Figure 26b: Histogram of seismic events counted from Helicorder records during March through April.