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Abstract

During October and November 2008 an earthquake swarm occurred in the Arctic Ocean off the Queen Elizabeth Islands. The activity was sporadic but reached a peak in mid-November when fifty earthquakes large enough to be located occurred over a two day period (17-18 November). Eleven of the earthquakes, nine of which occurred during those two days, were of magnitude 5.0 or greater. Regional moment tensor inversions were performed for these eleven earthquakes. The majority of the focal mechanisms were indicative of thrust faulting on a NE-SW striking plane roughly parallel to the continental margin. Depths, ranging from 6-20 km, correspond to the mid-crust. It is not clear whether the unusually high non-double couple component for many of the solutions is an artifact of the inversion process or is indicative of a true non-double source. Swarm activity is often associated with magmatic or other geothermal activity and it is possible but not confirmed that the non-double couple component is related to the migration of fluids within the crust. The occurrence of a large number of earthquakes in a small area allows for calibration between magnitude scales for the north, where the attenuation relations are less well known than in southern Canada. A primary observation was the m_b determined from Canadian stations (regional distances) tends to be smaller than m_b by other organizations using teleseismic data. On the other hand, m_b determined from the Yellowknife array data is a good match to the teleseismic magnitude suggesting that this path is close to the global average.

Introduction

During October and November 2008 an earthquake swarm centered at approximately 79.5º N and 115º W occurred in the Arctic Ocean near the base of the continental slope off the Queen Elizabeth Islands (Figures 1 and 2). The activity reached a peak on 17 and 18 November when twenty-five events large enough to be located occurred each day. Nine of these events as well as two earlier events were of magnitude 5.0 or greater. Although the immediate epicentral area had experienced very little seismic activity in the past, the regions surrounding the swarm had been more active with swarm activity having been observed in many of the adjacent regions.

Swarms are generally defined as a significant, localized short-term increase in the seismicity rate without an obvious mainshock. They are often, but not exclusively, associated with magmatic or other geothermal activity.

Recent improvements to the Canadian National Seismograph Network (CNSN) and the existence of many temporary Polaris stations in the north, have led to a significant increase in the number of broadband stations in the north. The resulting high-quality dataset for northern earthquakes, especially the larger ones, allows them to be studied in more detail than would have been possible in the recent past.

Regional moment tensor inversions are used to determine the focal mechanisms, depths and moment magnitudes of the larger events in the swarm. The occurrence of a large number of earthquakes over a small area allows for calibrations between magnitude scales in this region. The latter is particularly important as the M_L scale is generally used as a default in this region for lack of a better choice despite the fact that the attenuation relations derived for California may not be appropriate.

Swarm Chronology

The swarm activity began on 7 October 2008 although it wasn't immediately recognized as such. Six earthquakes were located in the epicentral region that day including the largest earthquake of the sequence, which had an M_W of 5.7. The following day another eight earthquakes were located, one of which had an M_W of 5.3. There was another event on 10 October and then none for over a month.

In mid-November the swarm activity began in earnest, with twenty-five events located on the 17th and another twenty-five on the 18th. Nine of these events had magnitudes greater than 5.0. The activity continued at a lower rate for a few more days. Since the end of November 2008 there have been a few more events but the activity has been sporadic (Figure 3). In all likelihood there were many more small events that were not recorded or not recorded well enough to be located. Only two seismograph stations were within 1000 km of the swarm: Eureka at approximately 570 km and Resolute at approximately 720 km. The smallest earthquake that could be located had a magnitude of 2.0 but the cumulative number of earthquakes as a function of magnitude suggests that the catalog is complete above magnitude 2.6-2.7.

Focal Mechanisms and Depths

Although there were no seismograph stations less than 570 km from the swarm there were many stations at regional distances (up to 1500 km). Data from these stations were used for regional moment tensor inversions (Kao et al, 1998) for the eleven events of magnitude (M_L) 5.0 or greater. This method allows focal mechanism, depth and moment magnitude to be determined (Figure 4a-k and Table 1). The results reveal predominantly thrust faulting on northeast-southwest striking planes (Figure 4a-k) more or less parallel to the continental slope although there are a few events with a higher strike-slip component or different orientation. The depths range from 6 to 20 km and all except two are in the 11-17 km range implying that the earthquakes are occurring predominantly in the mid-crust assuming continental crust. However, it should be noted that this region lies in the continent-ocean transition zone where the continental crust is thinning and the depths may be more indicative of lower crust. The focal mechanisms are indicative of a stress field dominated by northwest-southeast compression.

One pervasive and unusual feature of the solutions is a high compensated linear vector dipole (CLVD or non-double couple) component (18-65%). A very rough rule of thumb is that a CLVD component of less than 20% is generally not meaningful and can stem from all the various uncertainties and trade-offs in modeling. It is not clear whether the high values for these events are artifacts of the inversion, perhaps stemming from an incorrect velocity model or high noise level, or whether they are real in the sense of the sources not being pure double couples. Examples of non-double sources include but are not restricted to explosions, fluid injection or movement and landslides. A high CLVD component can also result from source complexity in the cases where the source consists of individual subevents whose focal mechanisms are pure double couples but which are very different from each other. Given the size of the events, this interpretation seems unlikely but cannot be ruled out. Although there are a few events with a poor signal to noise ratio in the frequency range modeled, for the most part the signal is clearly above the noise level suggesting it is not likely a factor. Any stations where the signal level was not visibly above the noise level were excluded from the inversion.

Magnitudes

While the attenuation relations for the M_L magnitude scale, originally developed for use in California, may not be appropriate for northern Canada, it is the default magnitude for earthquakes too small to be recorded teleseismically where the m_b or M_S magnitude scales could be used and when the earthquake locations are inappropriate for the m_N scale. The m_N scale was developed for continental crust. M_L is used in northern Canada in regions of oceanic crust or where the continental crust is thinning. The occurrence of a large number of earthquakes in the same location, many of which were large enough that m_b and, in some cases, M_S magnitudes could be calculated, allows for relations between various magnitude scales to be determined for this source region. While the results should be viewed as preliminary, they are one in a series of steps toward building a more uniform earthquake catalog for northern Canada and these events were included in a larger study to determine moment magnitude relations for eastern and northern Canada (Bent, 2010).

One observation of note is that the m_b values determined by the Geological Survey of Canada (GSC; National Earthquake Database, 2010) differ significantly from those determined by the United States Geological Survey (USGS, 2010) with the GSC values being generally smaller (Figure 5a). The m_b scale is defined for distances of 5° or greater but is more commonly used for teleseismic than regional distances. The m_b values determined by the GSC use Canadian data and therefore are based on data at predominantly regional distances (less than 2000 km) whereas those determined by the USGS employ primarily data from teleseismic distances. The difference between the magnitudes suggests that the m_b attenuation relation for regional distances does not reflect the average path for stations between this source region and the Canadian stations used in the calculations. The GSC m_b's are calculated from a large number of stations with as good an azimuthal coverage (due east to southwest) as is possible given the location of the earthquakes and the seismograph stations. It was noticed, however, that the m_b values calculated from stations of the Yellowknife array (YKA) were, on average, close to the USGS values (Figure 5b) suggesting that YKA m_b values might provide a better estimate of m_b for earthquakes in that source region than would an average of several stations. The average difference between M_L and the USGS m_b is 0.32 (Figure 5c), which is very close to the value of 0.38 for the Arctic as a whole (Bent, 2010) using m_b values from the International Seismological Centre (ISC, 2010).

Comparisons to other magnitude scales resulted in fewer surprises. The M_S and M_W magnitudes are consistently lower than the M_L magnitudes (Figures 5d and 5e). The mean difference between M_L and M_W is 0.56 with M_L being the larger of the two. This difference is more consistent with the relative values for eastern Canada (Bent, 2010) than for most regions of western Canada (Ristau et al, 2003, 2005).

Discussion

While the earthquakes of the 2008 swarm are similar to each other in terms of focal mechanism and stress orientation they differ in one or both respects from earthquakes in adjacent regions (Figure 6). To recap from the previous section most of the 2008 earthquakes show predominantly thrust faulting along northeast-southwest striking planes parallel to the continental margin and are indicative of a stress field dominated by northwest-southeast compression.

There are three focal mechanisms for events that occurred in 1999 and 2000 in the region just to the northeast of the 2008 swarm. All three have predominantly strike-slip mechanisms with one east-west striking nodal plane dipping to the south and a northwest-southeast striking nodal plane dipping steeply to the northeast. (Figure 6). These mechanisms are more consistent with northeast-southwest compression.

In the region further to the southeast of the 2008 swarm that includes the Byam Martin Channel strike-slip faulting also dominates (Figure 6). However, the majority of the focal mechanisms determined for this region are consistent with the stress orientations of the 2008 earthquakes and imply north-south to northwest-southeast compression.

The occurrence of thrust and strike-slip earthquakes in close proximity is not necessarily problematic to explain as the assumed stress fields based on the orientations of the stress axes can be compatible. The events in the 2008 swarm and the events in the Byam Martin Channel region have similarly oriented P axes and the difference in faulting styles may be explained by either differences in the relative strengths of the stress axes or by pre-existing structures whose orientation is more favorable to one type of faulting than another for a given stress field. The seemingly different P axis orientation between the 2008 swarm and the 1999-2000 events to the northeast is more problematic to explain. But could also be the result of pre-existing structures and/or differences in the relative strength of the stress axes over a regional scale.

Swarms occurred in regions near the 2008 swarm in 1972, 1974, 1978, 1984 and 2001 (Figure 7). There was also what may have been a swarm in 2006 but because of the location combined with the station distribution at the time fewer small earthquakes would have been recorded and it is not entirely clear whether this was a true swarm or simply the occurrence of a few larger earthquakes in close proximity in time and space. Of these only the 1972 Byam Martin Channel swarm was studied in detail (Hasegawa, 1977). Interestingly, it is similar to the 2008 swarm in that it started, stopped and resumed a couple of months later. There are a few additional periods of increased activity in this region but on closer inspection these appear to be typical mainshock-aftershock sequences rather than swarms.

There was also a swarm near the former station at Mould Bay (approximately 76.2ºN, 119.4ºW or just north of the southernmost 1999 event in Figure 6) in 1965. This swarm of over 2000 events in a 30 day period consisted entirely of events of magnitude less than 3.0 (Smith et al, 1968). Focal mechanisms could not be determined for these events but the available data were consistent with strike-slip faulting. It was interpreted as being tectonic in origin based on the b value of 0.68. Hasegawa (1977) interpreted the 1972 swarm as the result of the reactivation of intrusives, likely magma, in the presence of remanent tectonic stresses. The argument was based heavily on the observation that the stress axes orientations of the four largest events were not consistent with any known tectonic processes in the epicentral area or adjacent regions of the Arctic.

Conclusions

Regional moment tensor solutions determined for the eleven largest earthquakes of the October-November 2008 Arctic Ocean swarm indicate thrust faulting at mid-crustal depths on a plane (or planes) roughly parallel to the continental margin. The northwest-southeast trending P-axes are similar in orientation to those for earthquakes in the Byam Martin Channel region to the southeast although the latter are primarily strike-slip events. Events to the northeast of the 2008 swarm are primarily strike-slip but with northeast-southwest trending P-axes suggesting either regional variations in the stress field or that the faulting style is determined by the existence of pre-existing structures not favorably oriented with respect to the current stress field.

The occurrence of a large number of earthquakes in a very small volume allowed for some calibration of magnitude scales. The m_b-M_L data contributed to a larger study on magnitude relations for eastern and northern Canada. The m_b values determined using regional data were consistently smaller than those determined from teleseismic data suggesting that the attenuation relation used in the scale for regional distances is not representative of the average crust-upper mantle of northern Canada. The values determined from the Yellowknife array alone are more consistent with the teleseismic values. A comparison of M_L and M_W shows that the relation between the two is more similar to that observed in eastern Canada than in western Canada.

The reason for the occurrence of swarm activity in this region is not known. It was proposed (Hasegawa, 1977) that the 1972 swarm in the region to the southeast was magmatic in origin. However, a 1965 swarm in the region to the southwest was interpreted as tectonic in origin (Smith et al, 1968). The results of this study neither confirm nor refute either possibility. The high CLVD component found in the moment tensor inversion suggests that there may be a non-tectonic component to the source but some care must be taken not to over-interpret these values.

Acknowledgements

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Table 1
Summary of Focal Mechanisms

Date	Time (UT)	Lat. (° N)	Lon. (ºW)	M_L	M_W	Str_1	Dip_1	$Rake_1$	Str_2	Dip_2	$Rake_2$	Depth (km)	%CLVD
07.10.08	10:00:47	79.53	115.40	6.0	5.7	208	25	86	33	65	92	14	24
08.10.08	07:57:30	79.44	115.12	5.5	5.2	217	28	87	40	62	92	16	42
17.11.08	12:55:23	79.37	114.96	5.9	5.6	186	35	49	53	64	115	13	39
17.11.08	13:16:50	79.35	115.00	5.4	4.4	199	45	61	57	52	116	20	18
17.11.08	13:40:11	79.37	114.04	5.7	5.2	207	31	74	45	60	99	13	29
17.11.08	17:17:05	79.33	115.04	5.2	4.6	201	48	72	47	45	109	13	42
18.11.08	03:59:49	79.38	114.76	6.0	5.2	200	30	106	1	62	81	11	28
18.11.08	04:10:34	79.50	115.48	5.5	4.9	219	21	70	60	70	97	6	44
18.11.08	04:52:49	79.54	115.68	5.5	5.1	216	27	84	43	64	93	12	18
18.11.08	05:37:27	79.50	115.28	5.3	4.4	186	55	51	60	56	1 32	17	65
18.11.08	07:05:11	79.50	115.40	5.0	4.5	219	87	-171	128	81	-3	15	26

Figures

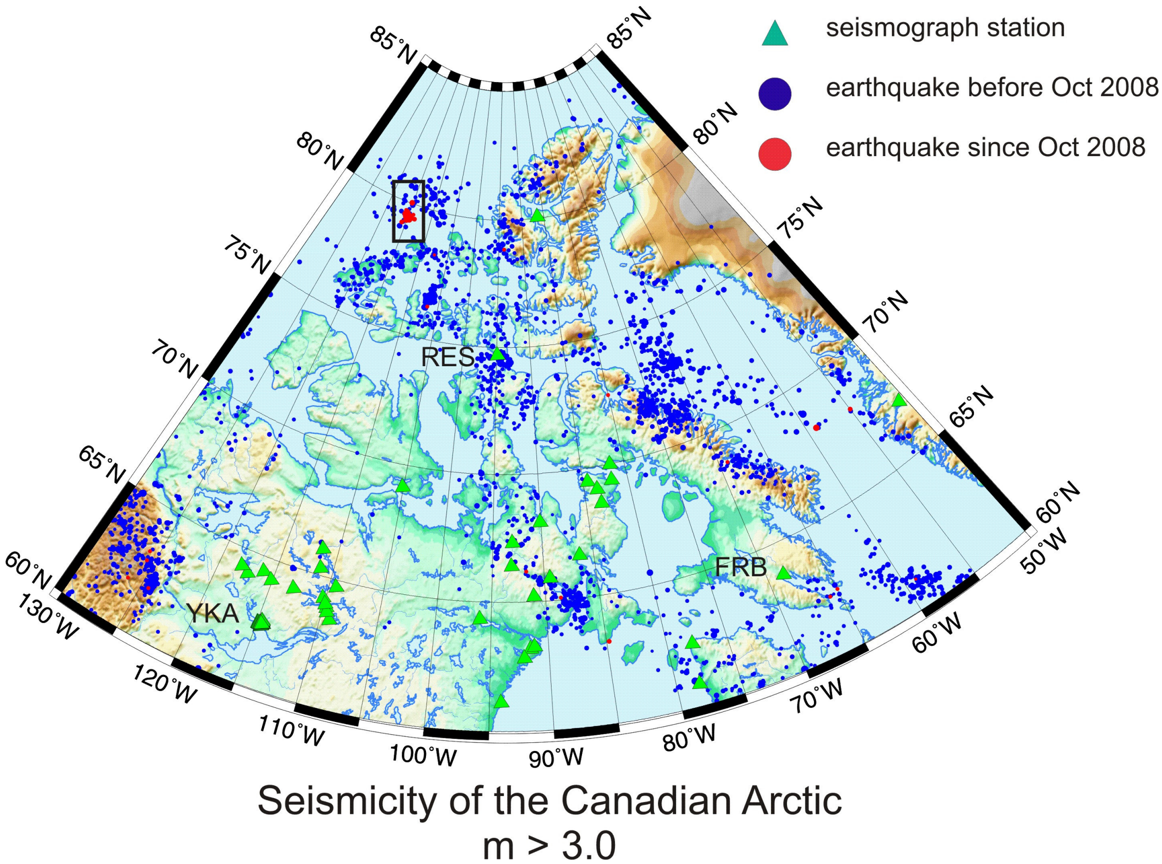


Figure 1. Seismicity of the Canadian Arctic from 1900 through April 2009. The blue symbols indicate earthquakes occurring before October 2008 and the red symbols indicate earthquakes occurring since October 2008. Only earthquakes of magnitude 3.0 and greater are shown. Note that prior to the 1950s it was rarely possible to locate any earthquakes smaller than magnitude 5.0. The swarm of interest is located near the northwest corner of the map in the region outlined in black. Green triangles indicate seismograph stations that were operating at the time of the swarm. For geographical reference FRB is Iqaluit, RES is Resolute and YKA is Yellowknife.

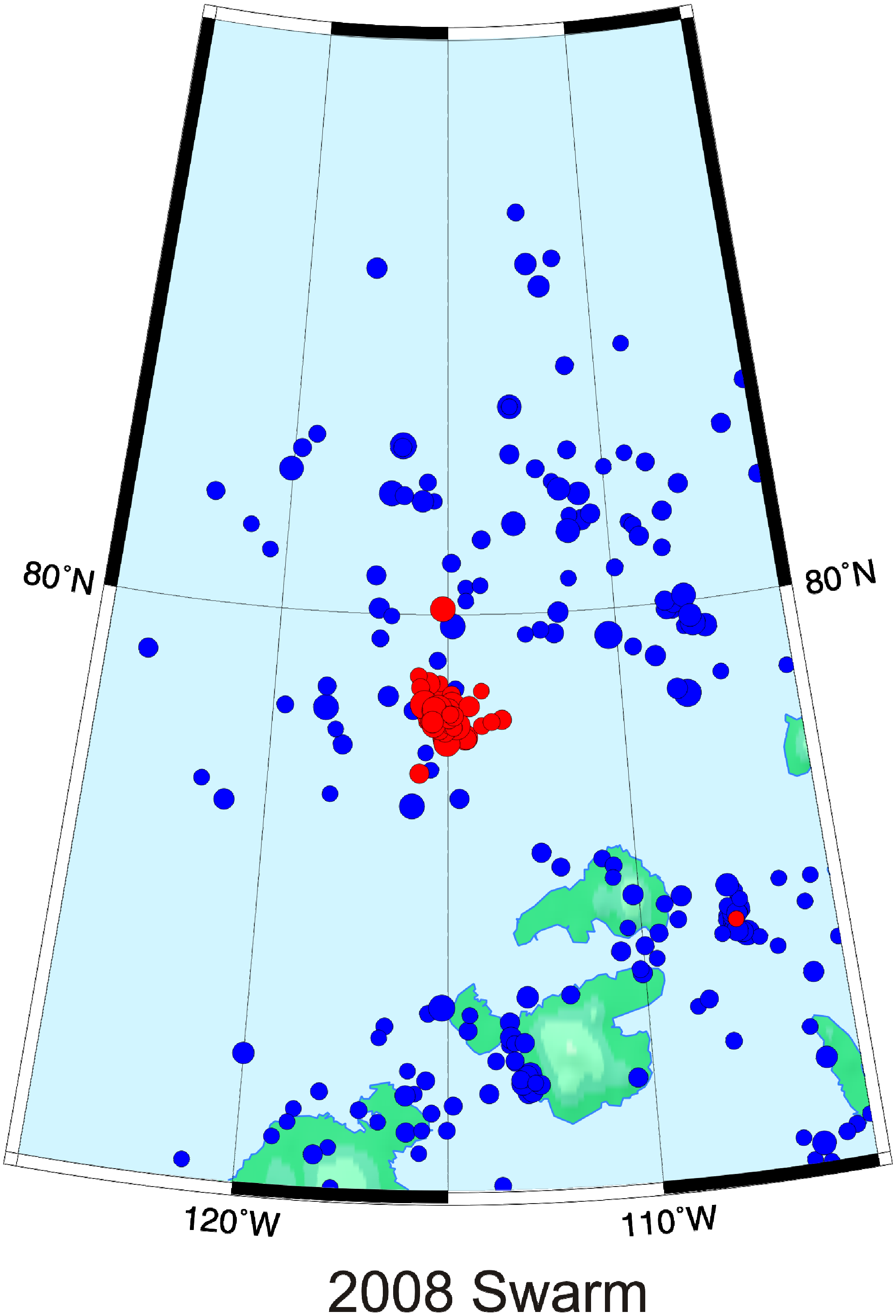


Figure 2. Close up map of the swarm region. The red symbols indicate earthquakes occurring since the swarm activity began in October 2008 and the blue symbols show the previous seismic activity in the region.

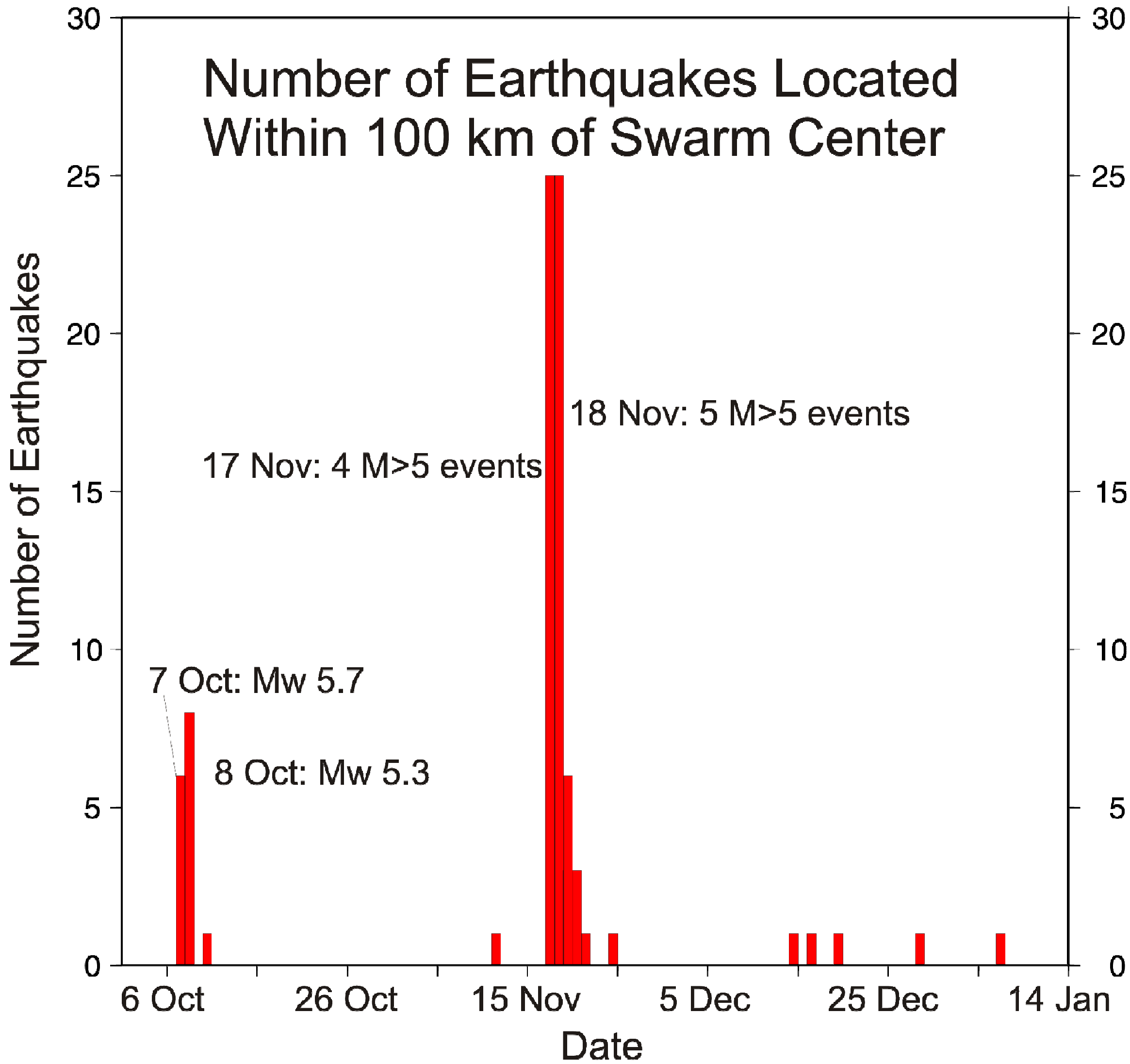


Figure 3. Number of earthquakes located in the swarm region as a function of time. Note that there may have been additional small earthquakes not well enough recorded to be located.

Figures 4a-k. Moment tensor solutions for the larger earthquakes of the swarm. The first header line for each station indicates the frequency range modeled, the second the station code, distance in km and azimuth in degrees, and the third the weighting of each component. The darker traces represent the data and the lighter ones the synthetic seismograms. The upper number indicates the amplitude relative to the largest component and the lower one the misfit. The complete solution is given to the right. The inset plots the misfit as a function of depth. Note that components with 0 weights are not used in the inversion but are shown on the plot and that the fit to these components is factored in to the overall misfit. In the focal mechanism plots, the shaded and white areas show the complete moment tensor solution and the dashed lines indicate the best fitting double couple. The events are shown in chronological order.

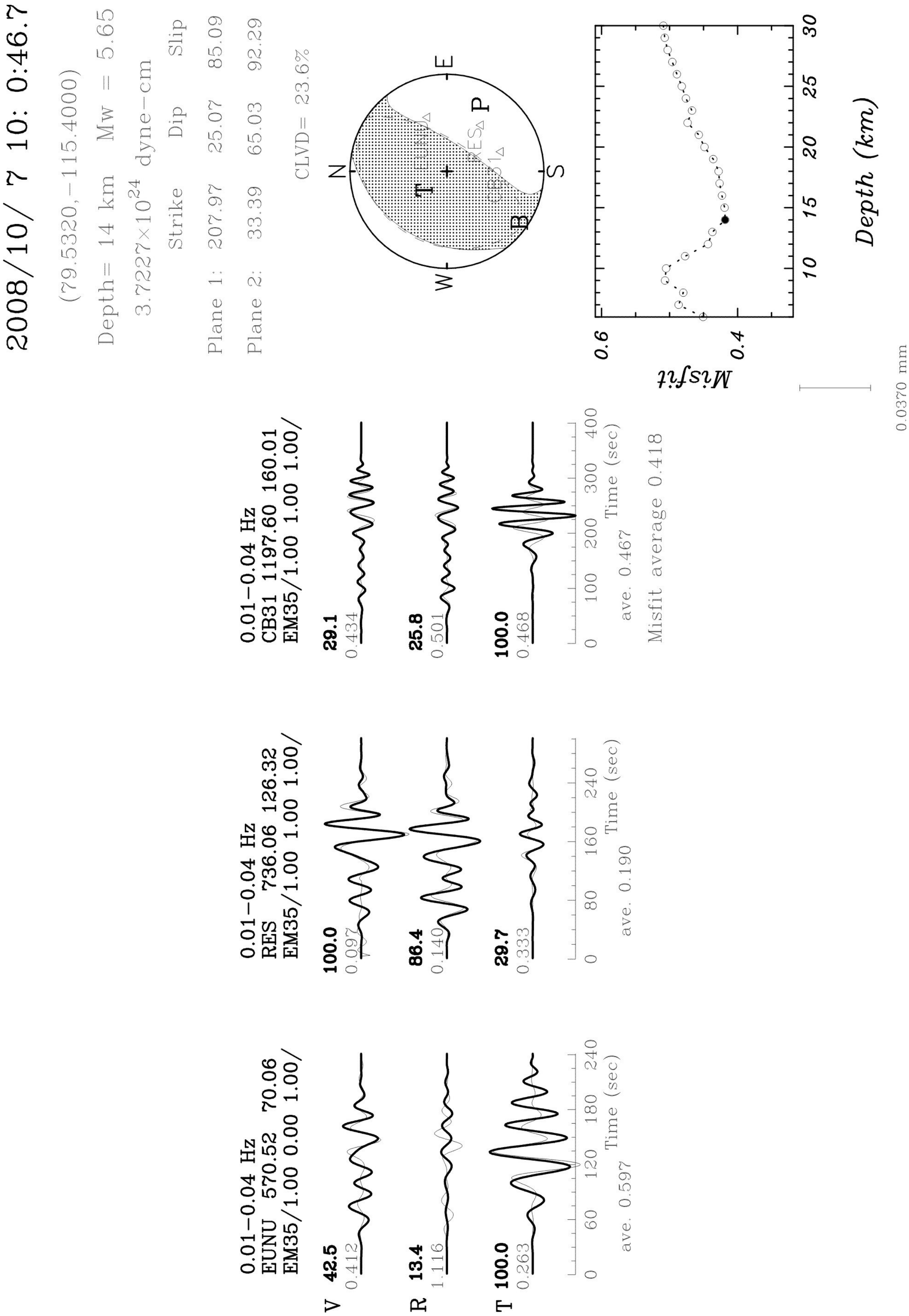

2008/10/ 7 10: 0:46.7
(79.5320,-115.4000)
Depth= 14 km Mw = 5.65
3.7227×10^24 dyne-cm
Strike Dip Slip
Plane 1: 207.97 25.07 85.09
Plane 2: 33.39 65.03 92.29
CLVD= 23.6%
N
E
S
W
T
P
B
Misfit
Depth (km)
0.0370 mm
0.01-0.04 Hz
EUNU 570.52 70.06
EM35/1.00 0.00 1.00/
V 42.5
0.412
R 13.4
1.116
T 100.0
0.263
Time (sec)
ave. 0.597
0.01-0.04 Hz
RES 736.06 126.32
EM35/1.00 1.00 1.00/
100.0
0.097
86.4
0.140
29.7
0.333
ave. 0.190
0.01-0.04 Hz
CB31 1197.60 160.01
EM35/1.00 1.00 1.00/
29.1
0.434
25.8
0.501
100.0
0.468
ave. 0.467
Misfit average 0.418

Figure 4a

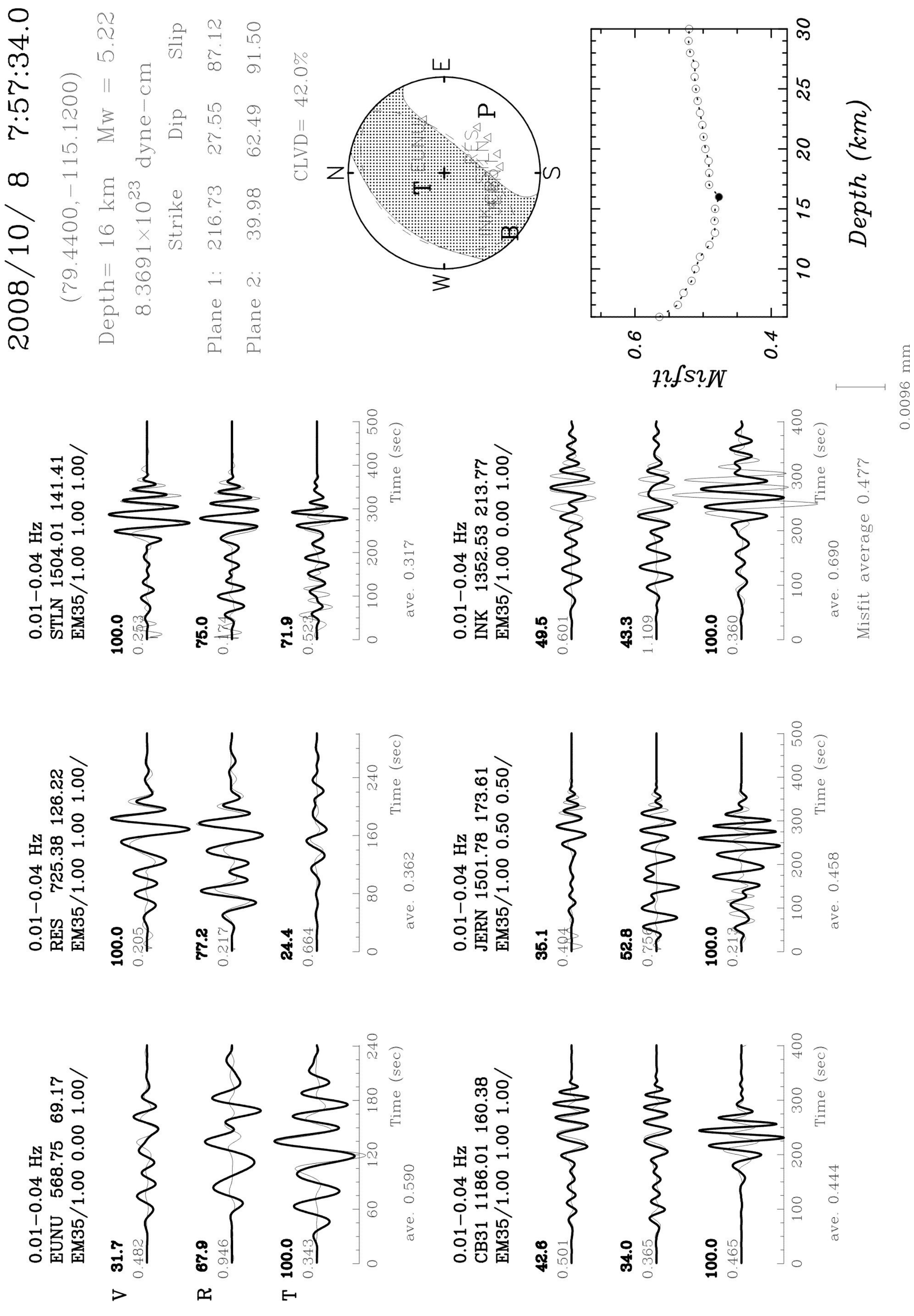
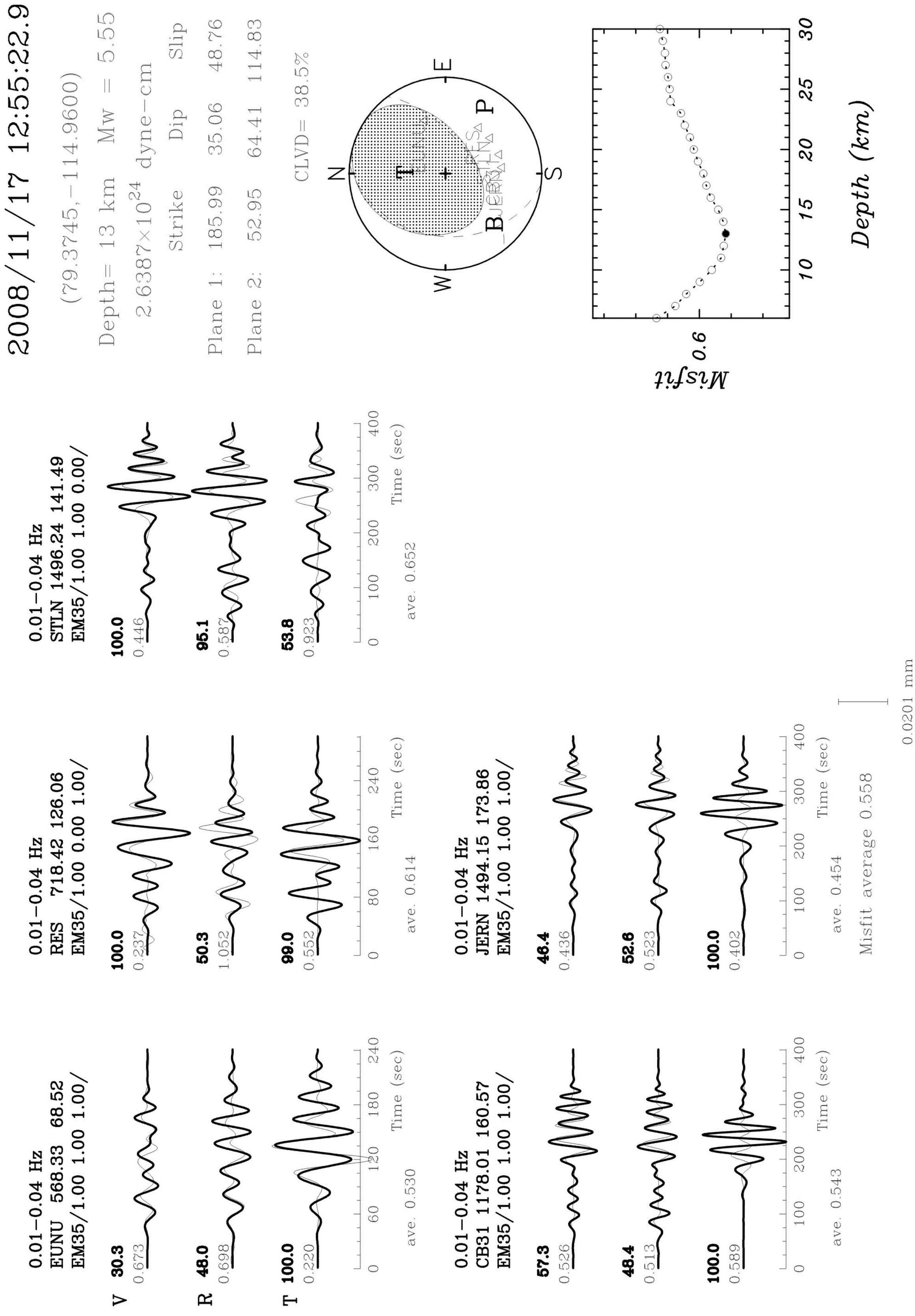

2008/10/ 8 7:57:34.0
(79.4400,-115.1200)
Depth= 16 km Mw = 5.22
8.3691×10^23 dyne-cm
Strike Dip Slip
Plane 1: 216.73 27.55 87.12
Plane 2: 39.98 62.49 91.50
CLVD= 42.0%
N
E
S
W
T
P
B
Misfit
Depth (km)
0.0096 mm
0.01-0.04 Hz
EUNU 568.75 69.17
EM35/1.00 0.00 1.00/
0.01-0.04 Hz
RES 725.38 126.22
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
STLN 1504.01 141.41
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
CB31 1186.01 160.38
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
JERN 1501.78 173.61
EM35/1.00 0.50 0.50/
0.01-0.04 Hz
INK 1352.53 213.77
EM35/1.00 0.00 1.00/
V
R
T
Time (sec)
ave. 0.590
ave. 0.362
ave. 0.317
ave. 0.444
ave. 0.458
ave. 0.690
Misfit average 0.477

Figure 4b



2008/11/17 12:55:22.9
(79.3745,-114.9600)
Depth= 13 km Mw = 5.55
2.6387×10^24 dyne-cm
Strike Dip Slip
Plane 1: 185.99 35.06 48.76
Plane 2: 52.95 64.41 114.83
CLVD= 38.5%
0.01-0.04 Hz
EUNU 568.33 68.52
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
RES 718.42 126.06
EM35/1.00 0.00 1.00/
0.01-0.04 Hz
STLN 1496.24 141.49
EM35/1.00 1.00 0.00/
0.01-0.04 Hz
CB31 1178.01 160.57
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
JERN 1494.15 173.86
EM35/1.00 1.00 1.00/
Time (sec)
Misfit average 0.558
0.0201 mm
Misfit
Depth (km)

Figure 4c

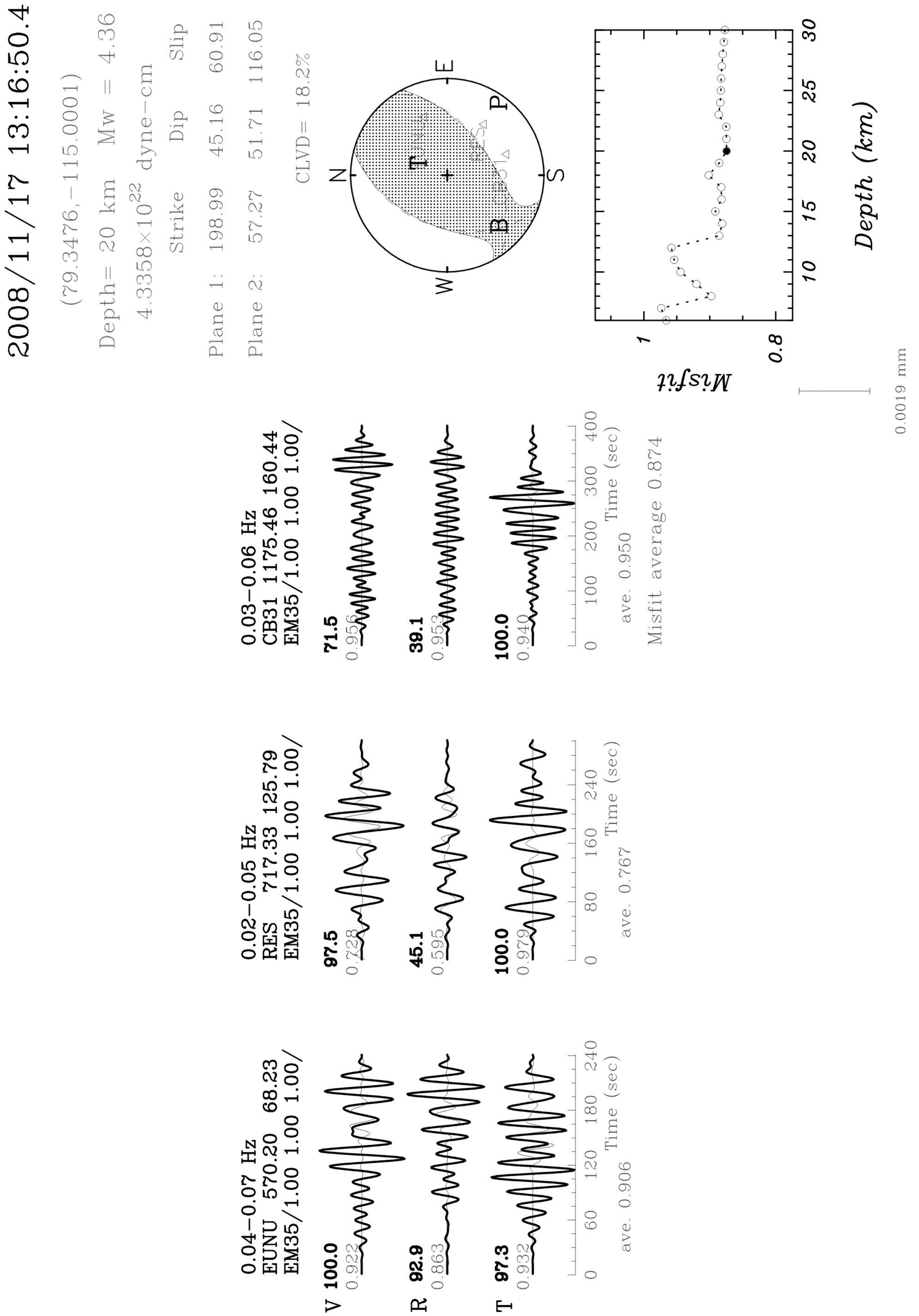
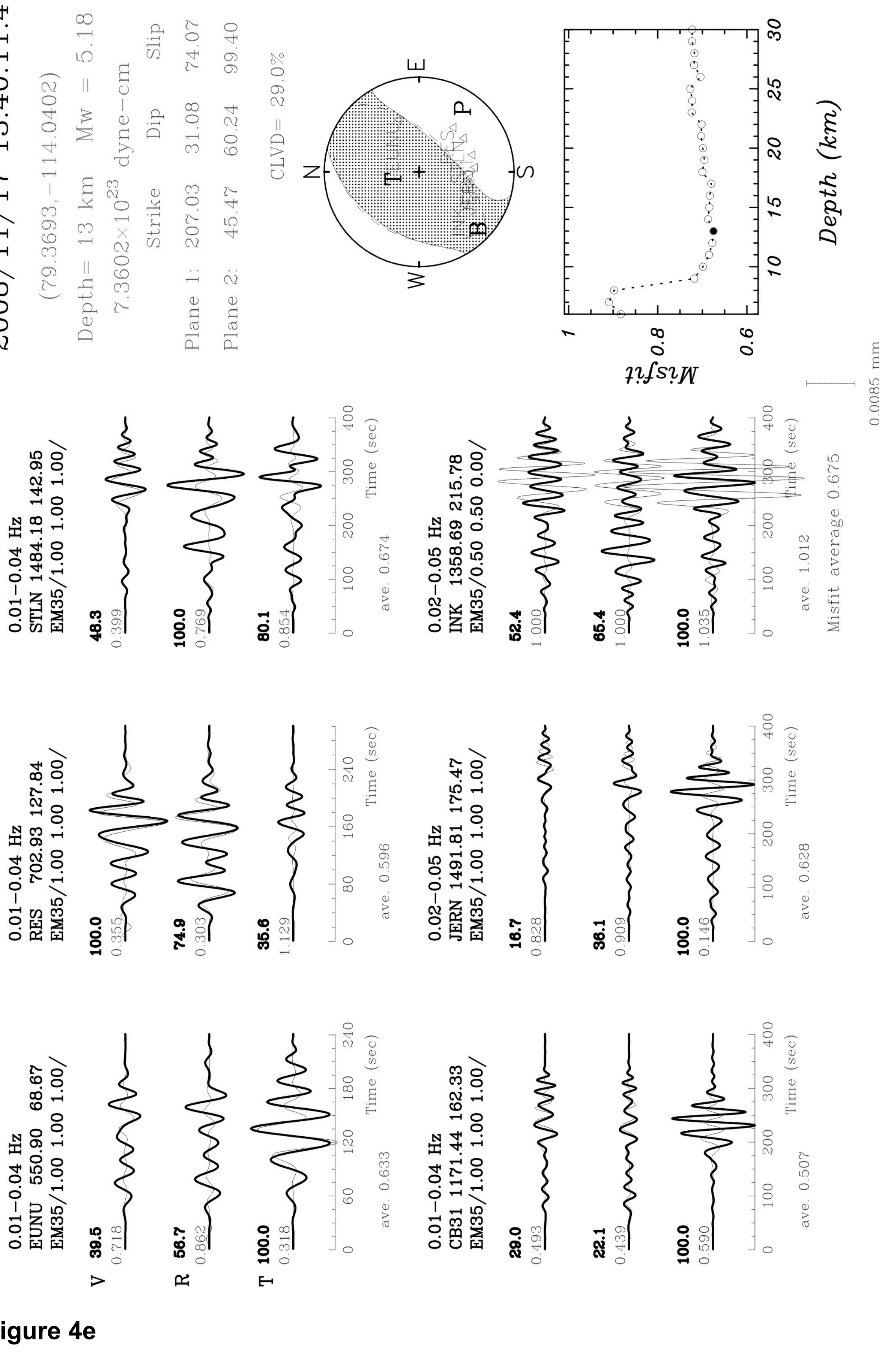

2008/11/17 13:16:50.4
(79.3476,-115.0001)
Depth= 20 km Mw = 4.36
4.3358×10^22 dyne-cm
Strike Dip Slip
Plane 1: 198.99 45.16 60.91
Plane 2: 57.27 51.71 116.05
CLVD= 18.2%
N
E
S
W
T
P
B
Misfit
Depth (km)
0.0019 mm
0.04-0.07 Hz
EUNU 570.20 68.23
EM35/1.00 1.00 1.00/
0.02-0.05 Hz
RES 717.33 125.79
EM35/1.00 1.00 1.00/
0.03-0.06 Hz
CB31 1175.46 160.44
EM35/1.00 1.00 1.00/
V
R
T
Time (sec)
ave. 0.906
ave. 0.767
ave. 0.950
Misfit average 0.874

Figure 4d

Figure 4e



2008/11/17 13:40:11.4
(79.3693,-114.0402)
Depth= 13 km Mw = 5.18
7.3602×10^23 dyne-cm
Strike Dip Slip
Plane 1: 207.03 31.08 74.07
Plane 2: 45.47 60.24 99.40
CLVD= 29.0%
0.01-0.04 Hz
EUNU 550.90 68.67
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
RES 702.93 127.84
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
STLN 1484.18 142.95
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
CB31 1171.44 162.33
EM35/1.00 1.00 1.00/
0.02-0.05 Hz
JERN 1491.81 175.47
EM35/1.00 1.00 1.00/
0.02-0.05 Hz
INK 1358.69 215.78
EM35/0.50 0.50 0.00/
Time (sec)
Misfit average 0.675
0.0085 mm
Misfit
Depth (km)

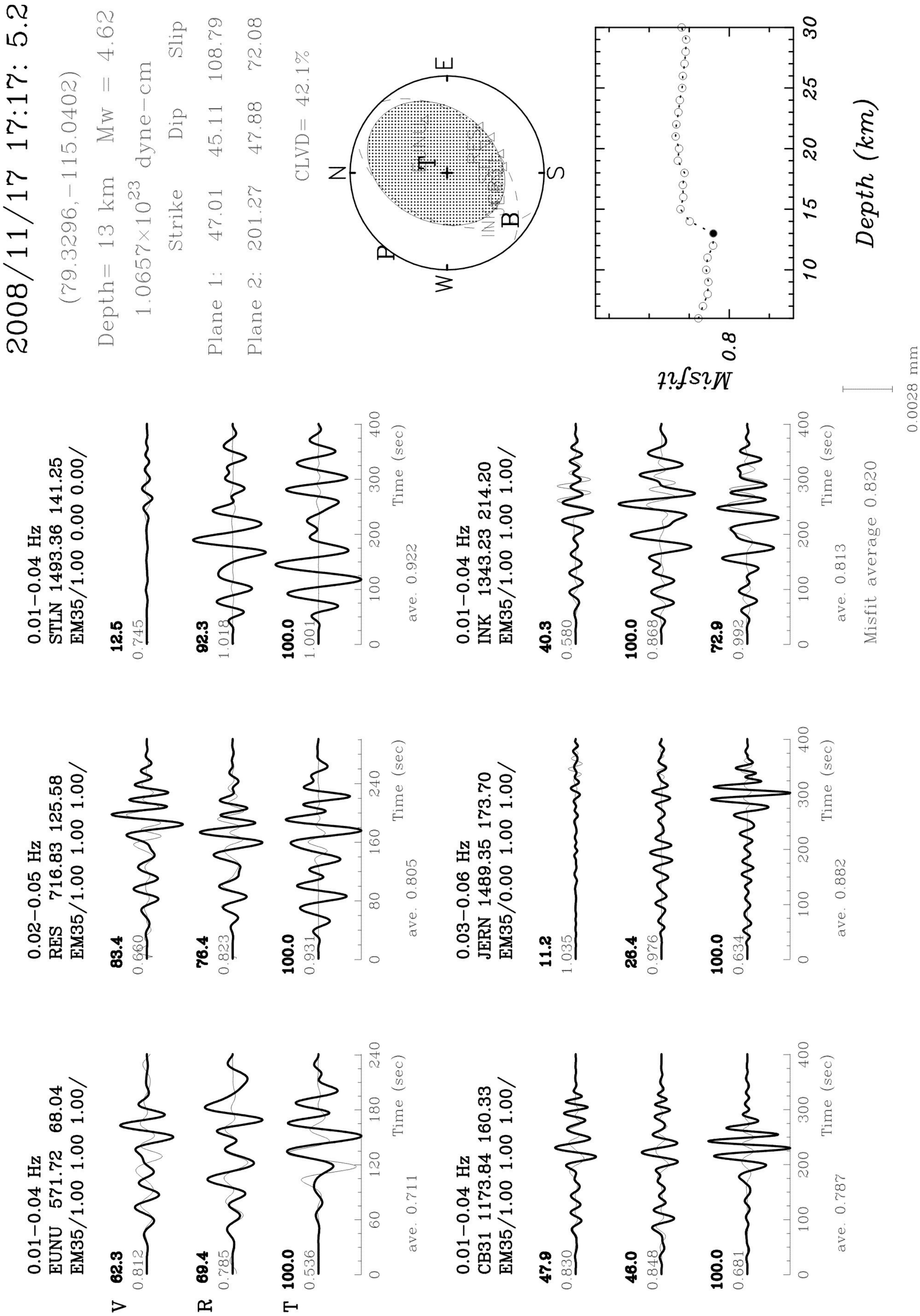

2008/11/17 17:17: 5.2
(79.3296,−115.0402)
Depth= 13 km Mw = 4.62
1.0657×10^23 dyne−cm
Strike Dip Slip
Plane 1: 47.01 45.11 108.79
Plane 2: 201.27 47.88 72.08
CLVD= 42.1%
N
E
S
W
P
T
B
Misfit
0.8
Depth (km)
10 15 20 25 30
0.0028 mm
Misfit average 0.820
0.01−0.04 Hz
EUNU 571.72 68.04
EM35/1.00 1.00 1.00/
V 62.3 0.812
R 69.4 0.785
T 100.0 0.536
ave. 0.711
0.02−0.05 Hz
RES 716.83 125.58
EM35/1.00 1.00 1.00/
83.4 0.660
76.4 0.823
100.0 0.931
ave. 0.805
0.01−0.04 Hz
STLN 1493.36 141.25
EM35/1.00 0.00 0.00/
12.5 0.745
92.3 1.018
100.0 1.001
ave. 0.922
0.01−0.04 Hz
CB31 1173.84 160.33
EM35/1.00 1.00 1.00/
47.9 0.830
46.0 0.848
100.0 0.681
ave. 0.787
0.03−0.06 Hz
JERN 1489.35 173.70
EM35/0.00 1.00 1.00/
11.2 1.035
26.4 0.976
100.0 0.634
ave. 0.882
0.01−0.04 Hz
INK 1343.23 214.20
EM35/1.00 1.00 1.00/
40.3 0.580
100.0 0.868
72.9 0.992
ave. 0.813
Time (sec)

Figure 4f

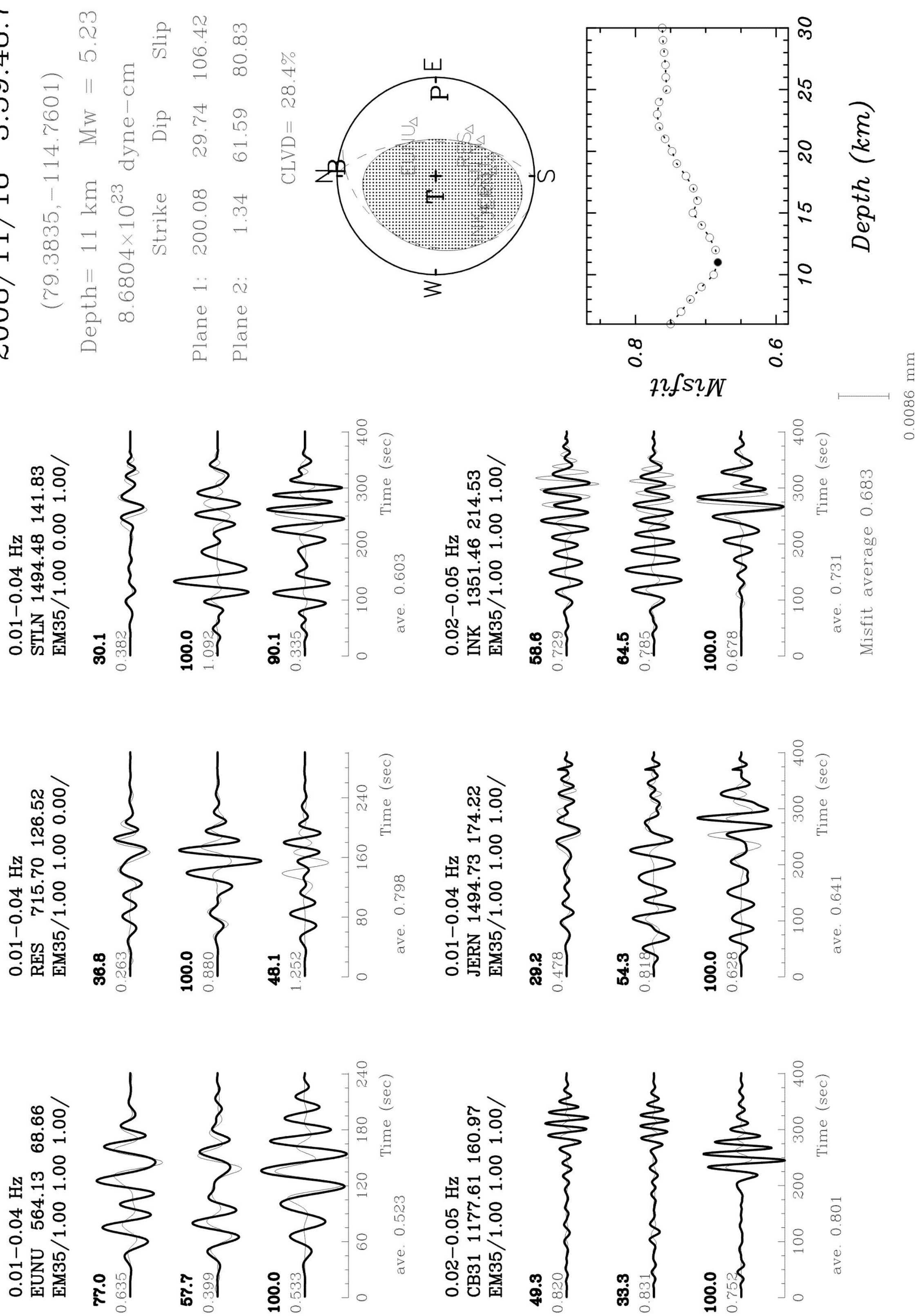

2008/11/18 3:59:48.7
(79.3835,-114.7601)
Depth= 11 km Mw = 5.23
8.6804×10^23 dyne-cm
Strike Dip Slip
Plane 1: 200.08 29.74 106.42
Plane 2: 1.34 61.59 80.83
CLVD= 28.4%
Misfit
Depth (km)
Misfit average 0.683
0.0086 mm
0.01-0.04 Hz
EUNU 564.13 68.66
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
RES 715.70 126.52
EM35/1.00 1.00 0.00/
0.01-0.04 Hz
STLN 1494.48 141.83
EM35/1.00 0.00 1.00/
0.02-0.05 Hz
CB31 1177.61 160.97
EM35/1.00 1.00 1.00/
0.01-0.04 Hz
JERN 1494.73 174.22
EM35/1.00 1.00 1.00/
0.02-0.05 Hz
INK 1351.46 214.53
EM35/1.00 1.00 1.00/
Time (sec)

Figure 4g

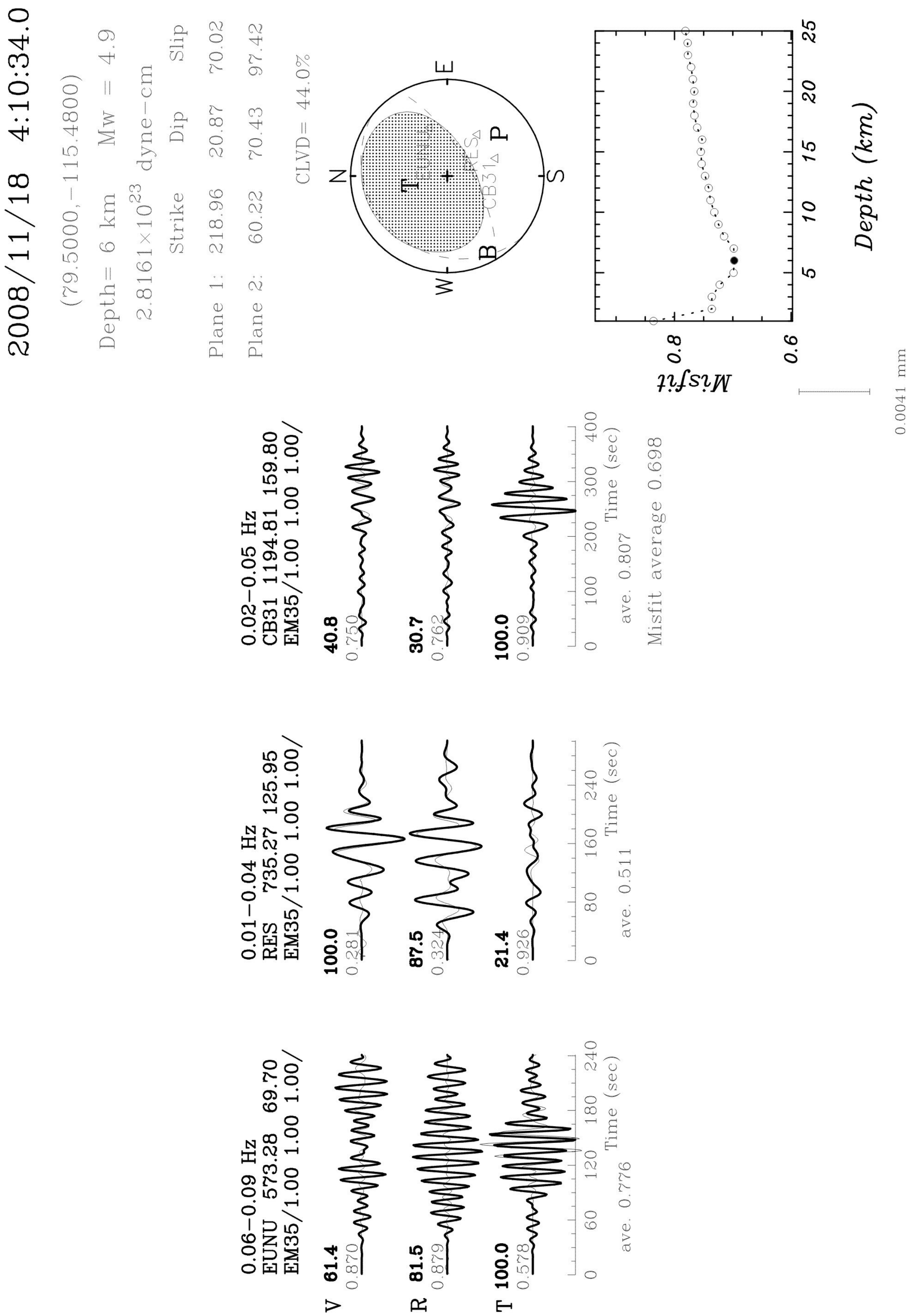

2008/11/18 4:10:34.0
(79.5000,-115.4800)
Depth= 6 km Mw = 4.9
2.8161×10^23 dyne-cm
Strike Dip Slip
Plane 1: 218.96 20.87 70.02
Plane 2: 60.22 70.43 97.42
CLVD= 44.0%
Misfit
Depth (km)
0.0041 mm
0.06-0.09 Hz
EUNU 573.28 69.70
EM35/1.00 1.00 1.00/
ave. 0.776
0.01-0.04 Hz
RES 735.27 125.95
EM35/1.00 1.00 1.00/
ave. 0.511
0.02-0.05 Hz
CB31 1194.81 159.80
EM35/1.00 1.00 1.00/
ave. 0.807
Misfit average 0.698
Time (sec)

Figure 4h

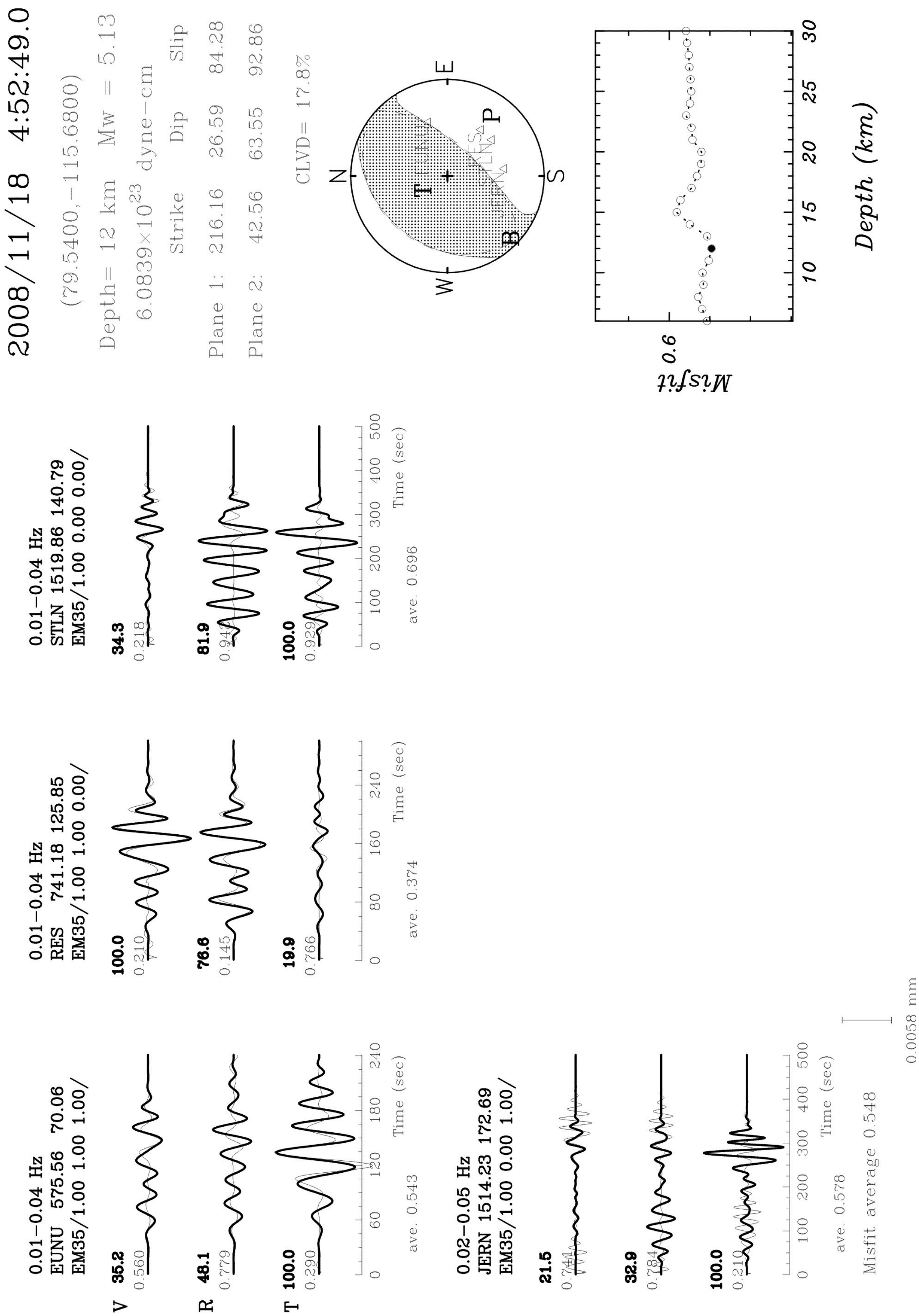

2008/11/18 4:52:49.0
(79.5400,-115.6800)
Depth= 12 km Mw = 5.13
6.0839×10^23 dyne-cm
Strike Dip Slip
Plane 1: 216.16 26.59 84.28
Plane 2: 42.56 63.55 92.86
CLVD= 17.8%
N
E
S
W
T
P
B
Misfit
0.6
Depth (km)
10 15 20 25 30
0.01-0.04 Hz
EUNU 575.56 70.06
EM35/1.00 1.00 1.00/
V 35.2 0.560
R 48.1 0.779
T 100.0 0.290
0 60 120 180 240
Time (sec)
ave. 0.543
0.01-0.04 Hz
RES 741.18 125.85
EM35/1.00 1.00 0.00/
100.0 0.210
76.6 0.145
19.9 0.766
0 80 160 240
Time (sec)
ave. 0.374
0.01-0.04 Hz
STLN 1519.86 140.79
EM35/1.00 0.00 0.00/
34.3 0.218
81.9
100.0
0 100 200 300 400 500
Time (sec)
ave. 0.696
0.02-0.05 Hz
JERN 1514.23 172.69
EM35/1.00 0.00 1.00/
21.5
32.9
100.0 0.210
0 100 200 300 400 500
Time (sec)
ave. 0.578
Misfit average 0.548
0.0058 mm

Figure 4i

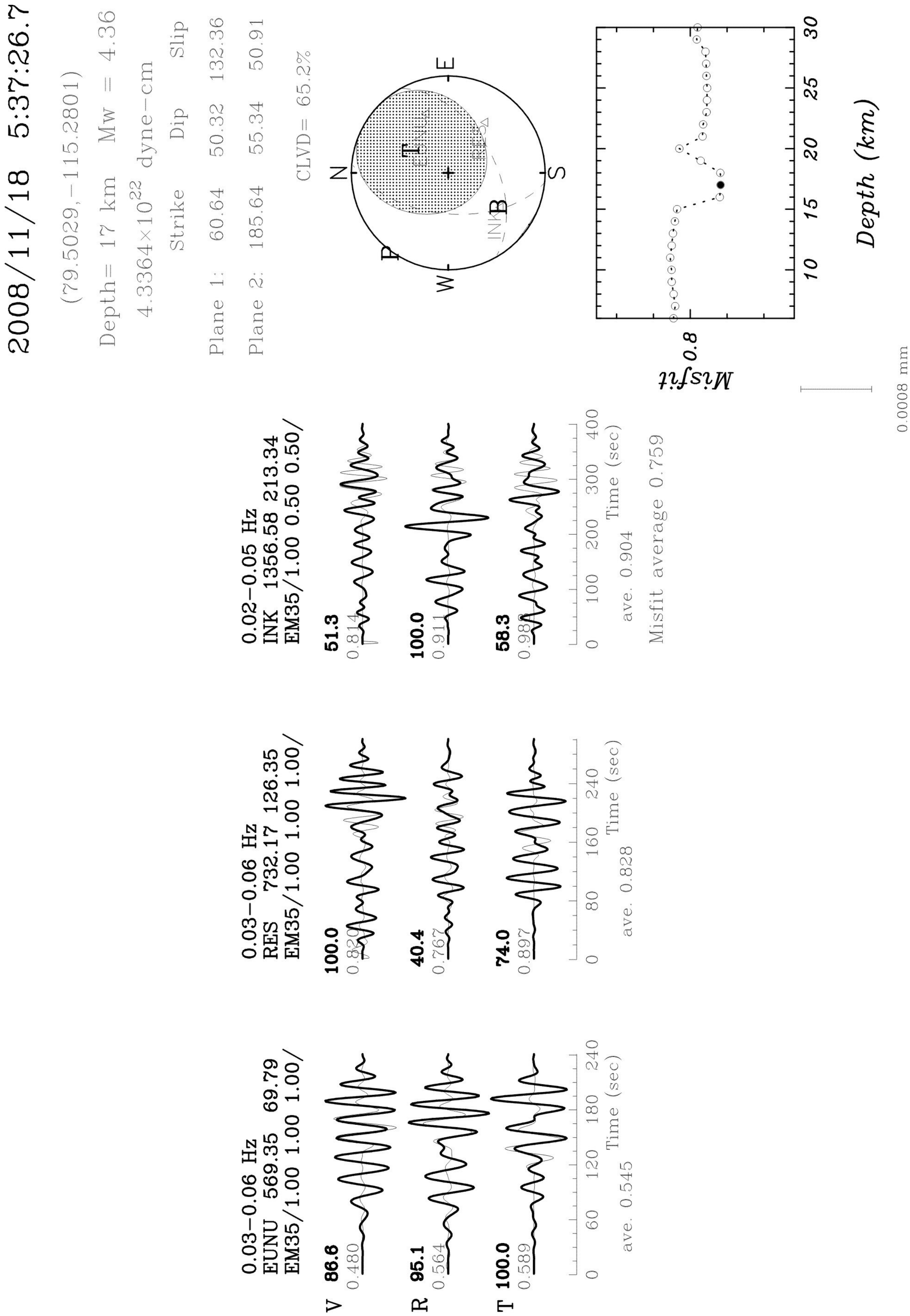
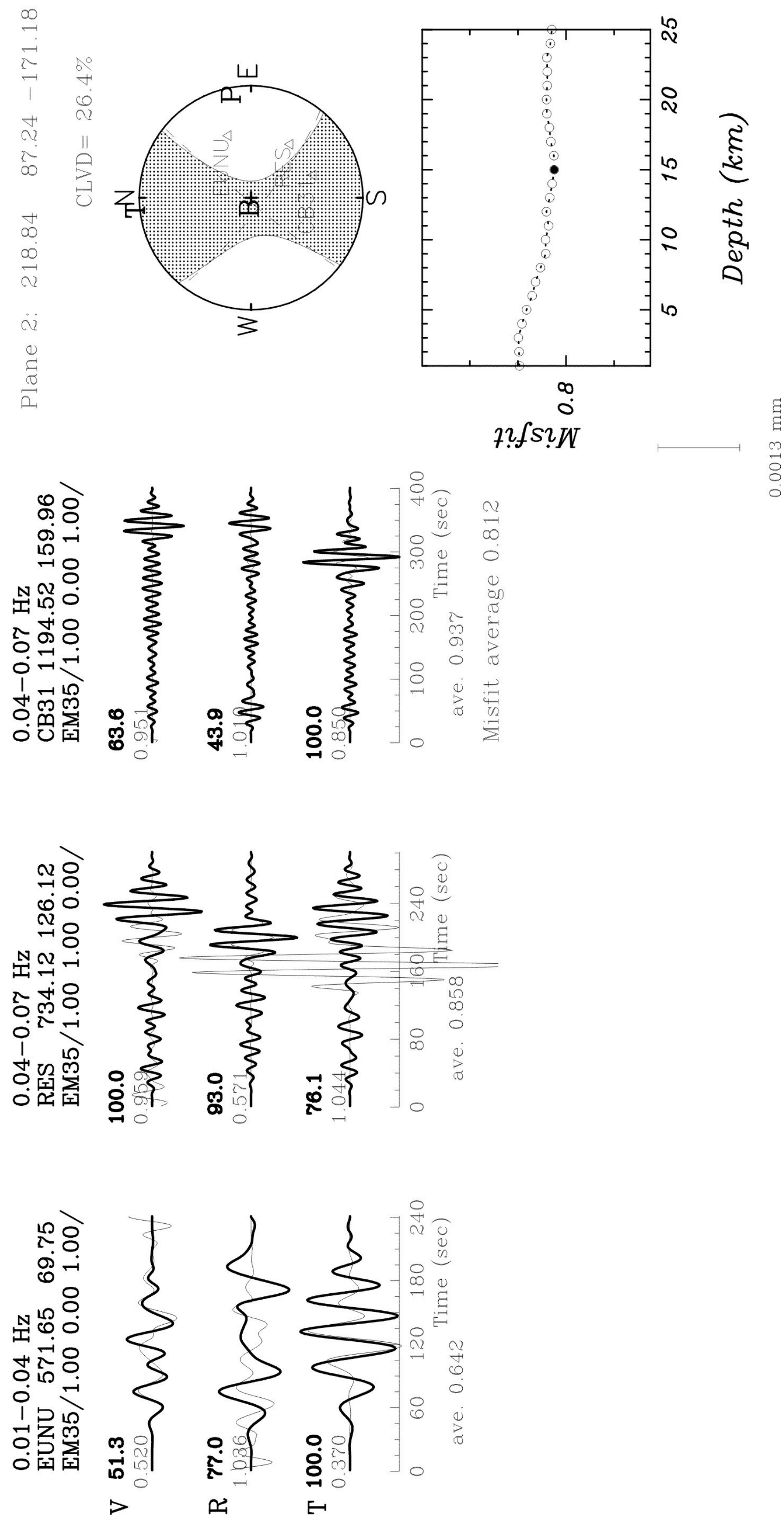

2008/11/18 5:37:26.7
(79.5029,-115.2801)
Depth= 17 km Mw = 4.36
4.3364×10^22 dyne-cm
Strike Dip Slip
Plane 1: 60.64 50.32 132.36
Plane 2: 185.64 55.34 50.91
CLVD= 65.2%
N
E
S
W
P
T
B
INK
Misfit
0.8
Depth (km)
10
15
20
25
30
0.0008 mm
0.03-0.06 Hz
EUNU 569.35 69.79
EM35/1.00 1.00 1.00/
V
R
T
86.6
0.480
95.1
0.564
100.0
0.589
Time (sec)
ave. 0.545
0.03-0.06 Hz
RES 732.17 126.35
EM35/1.00 1.00 1.00/
100.0
0.820
40.4
0.767
74.0
0.897
ave. 0.828
0.02-0.05 Hz
INK 1356.58 213.34
EM35/1.00 0.50 0.50/
51.3
0.814
100.0
0.911
58.3
0.988
ave. 0.904
Misfit average 0.759

Figure 4j



2008/11/18 7: 5:11.5
(79.5026,-115.4000)
Depth= 15 km Mw = 4.5
7.0203×10^22 dyne-cm
Strike Dip Slip
Plane 1: 128.41 81.19 -2.80
Plane 2: 218.84 87.24 -171.18
CLVD= 26.4%
0.01-0.04 Hz
EUNU 571.65 69.75
EM35/1.00 0.00 1.00/
V 51.3 0.520
R 77.0 1.036
T 100.0 0.370
ave. 0.642
0.04-0.07 Hz
RES 734.12 126.12
EM35/1.00 1.00 0.00/
100.0 0.959
93.0 0.571
76.1 1.044
ave. 0.858
0.04-0.07 Hz
CB31 1194.52 159.96
EM35/1.00 0.00 1.00/
63.6 0.951
43.9 1.010
100.0 0.850
ave. 0.937
Time (sec)
Misfit average 0.812
Misfit
Depth (km)
0.0013 mm

Figure 4k

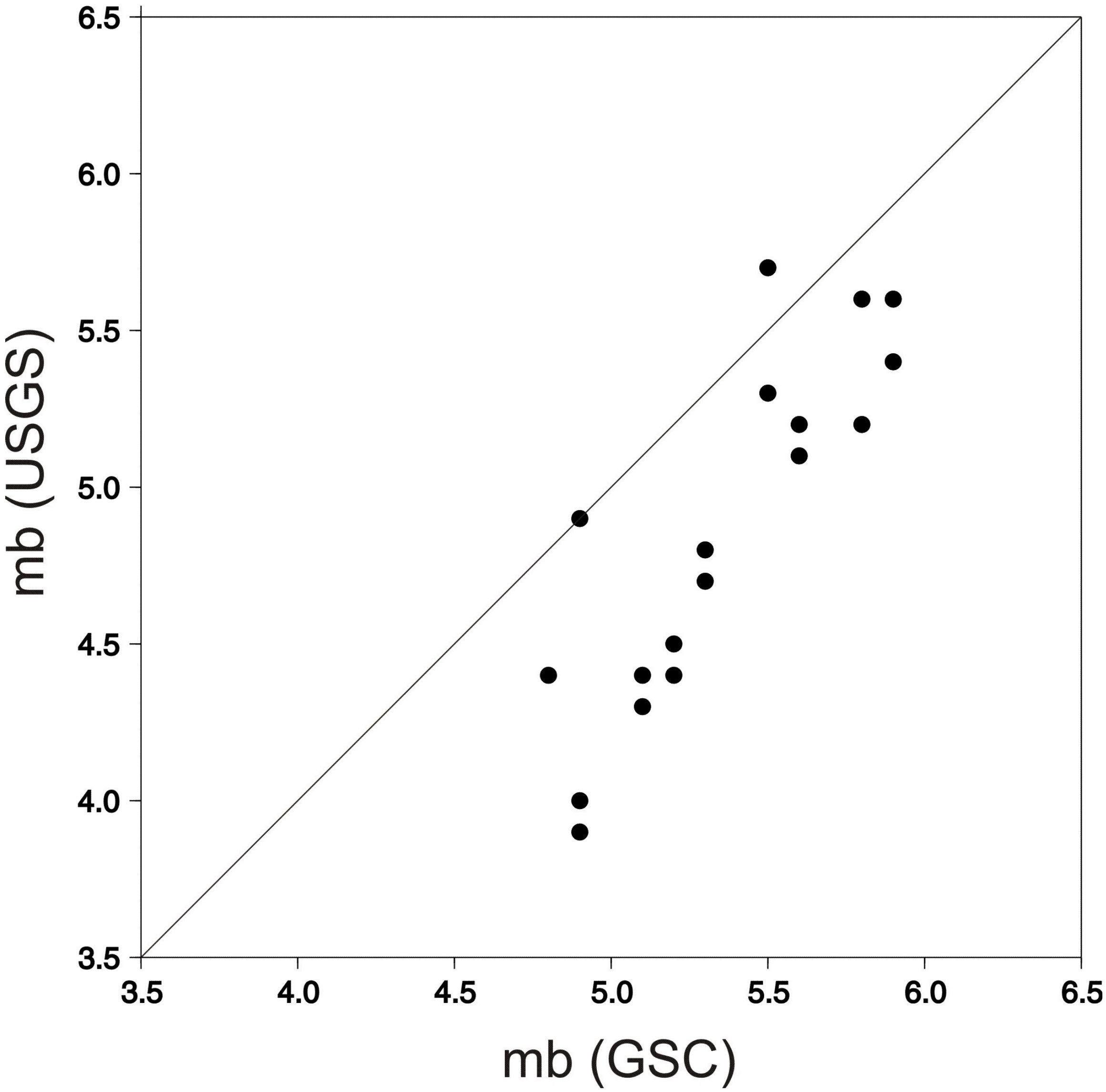


Figure 5a. Comparison of m_b (GSC) and m_b (USGS) scales. The diagonal line this figure and subsequent parts of Figure 5 indicates equal magnitudes.

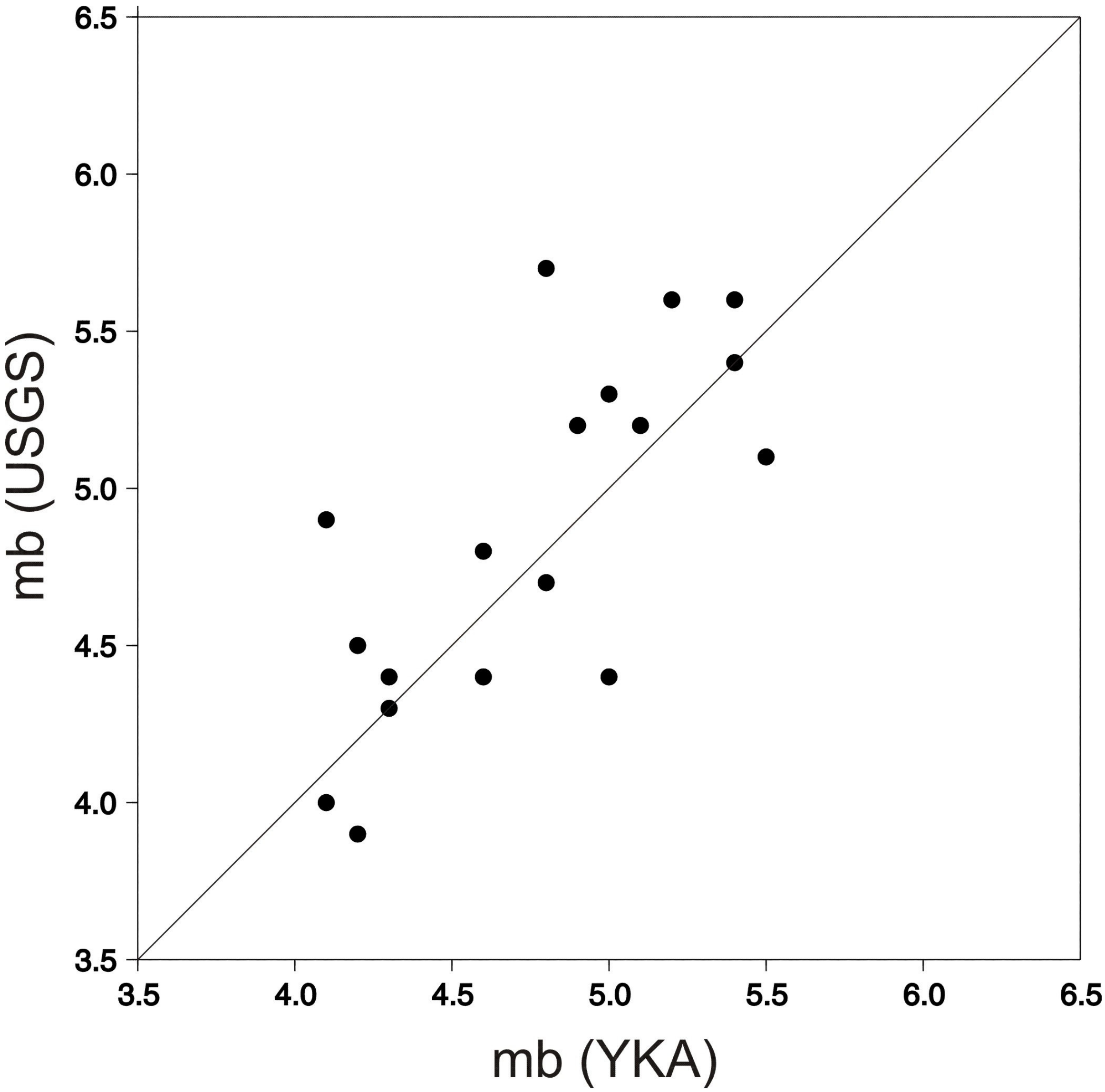


Figure 5b. Comparison of m_b (YKA) and m_b (USGS).

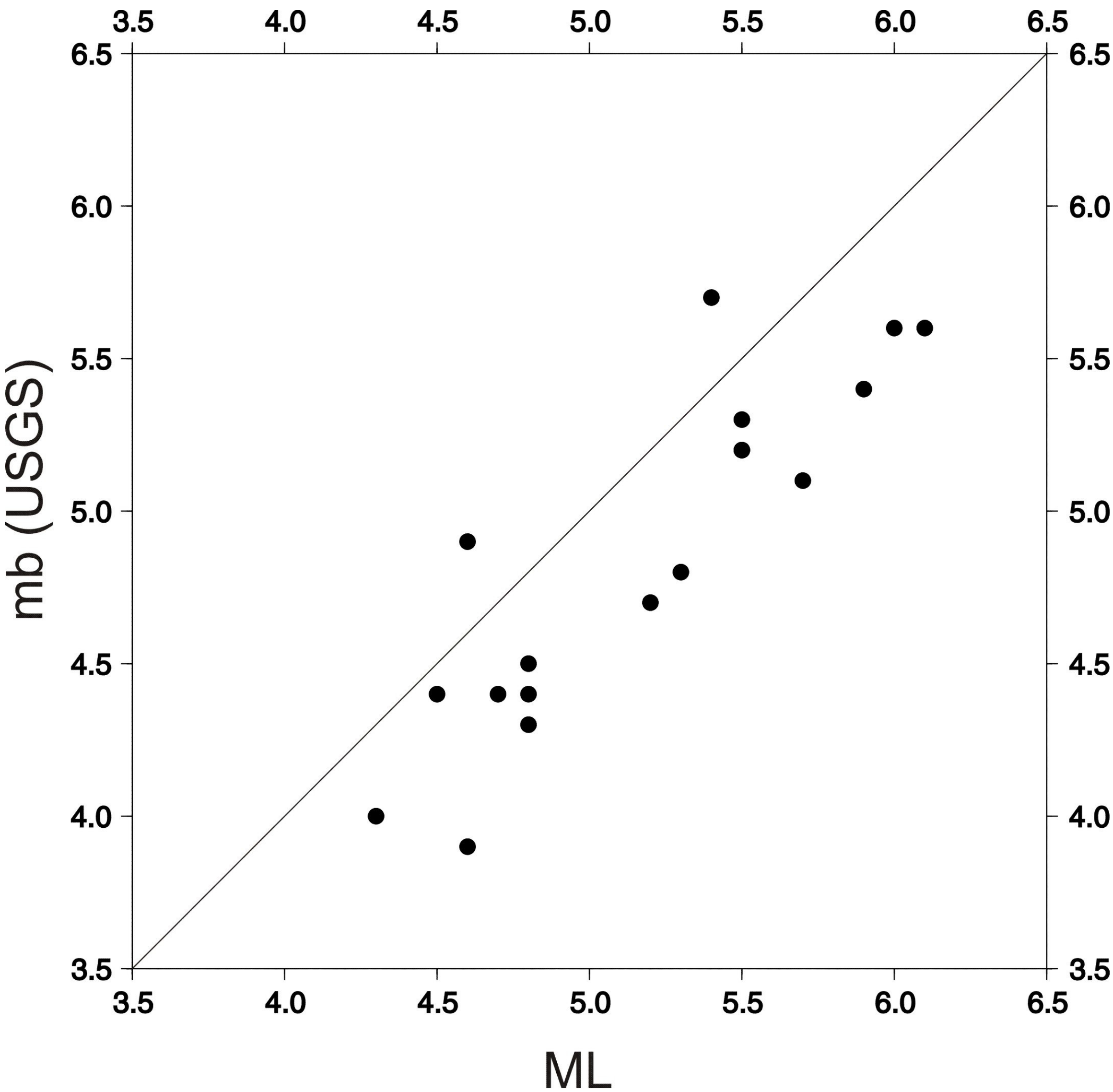


Figure 5c. Comparison of M_L and m_b (USGS).

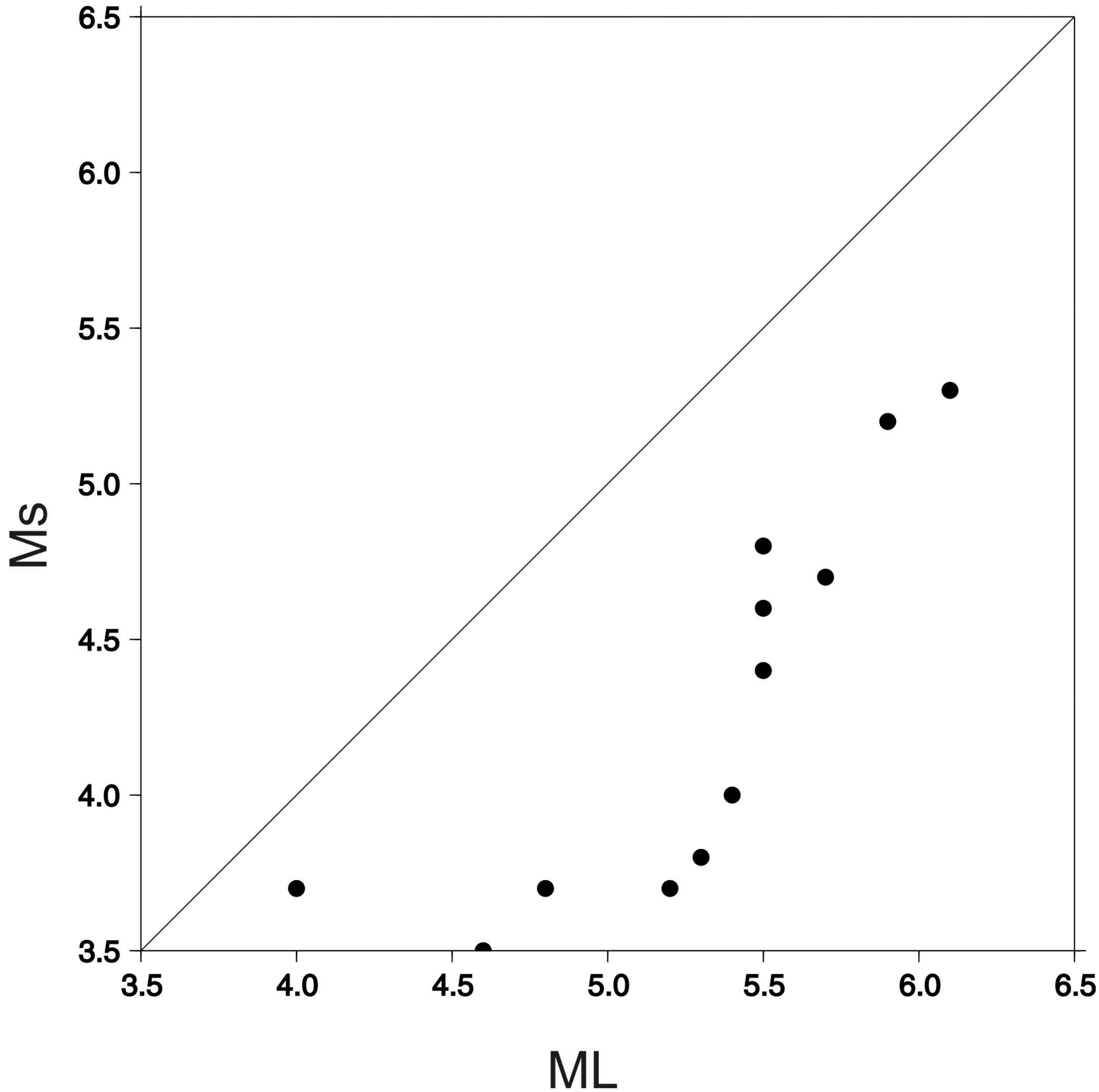


Figure 5d. Comparison of M_L and M_S.

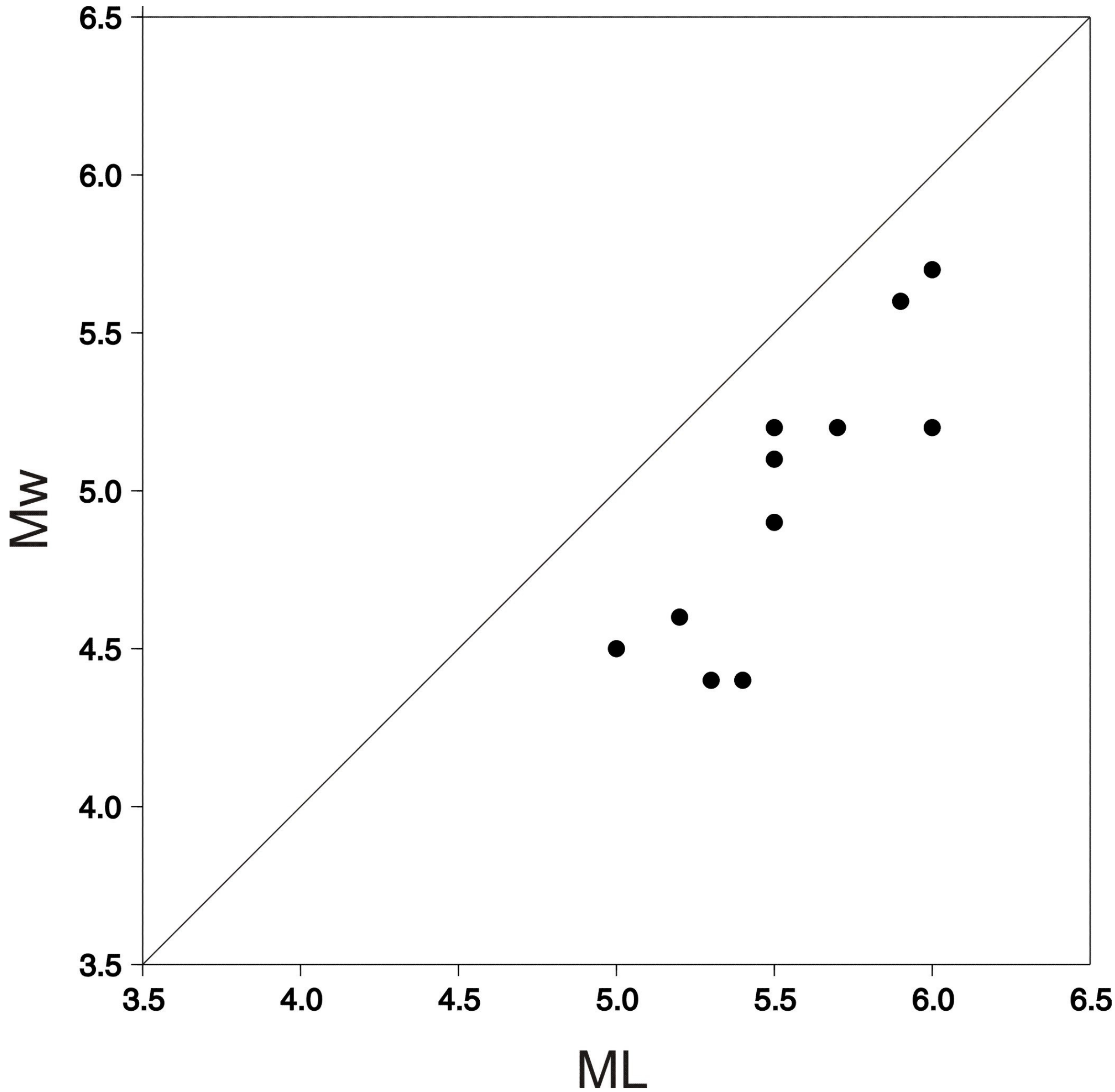


Figure 5e. Comparison of M_L and M_W.

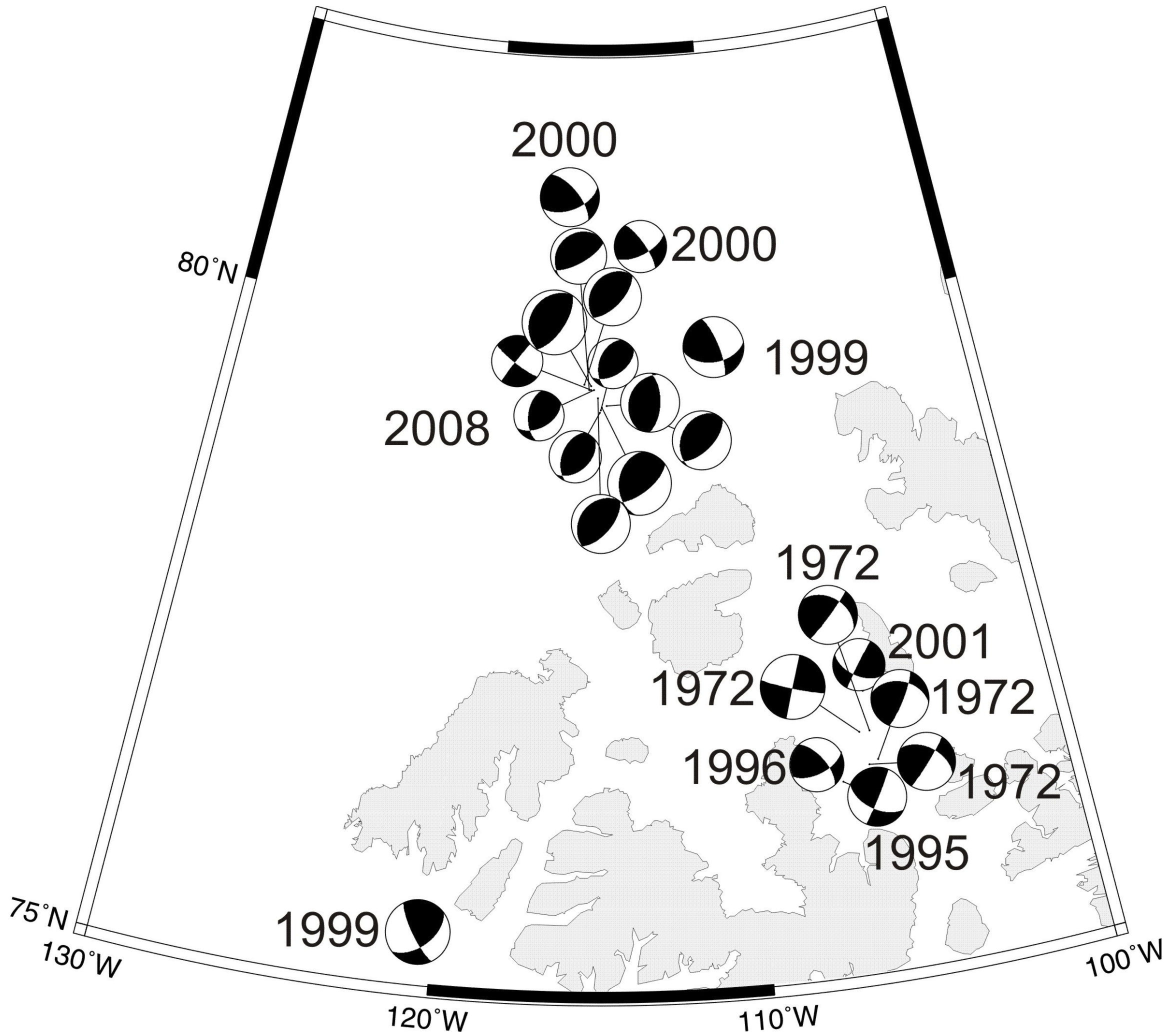


Figure 6. Focal mechanisms for earthquakes of the 2008 swarm determined in this study as well as those previously determined in adjacent areas. The focal mechanisms for 2008 were determined in this study, 2001 by Global CMT Project (2010), 1995-2000 by Bent et al (2003) and 1972 by Hasegawa (1977).

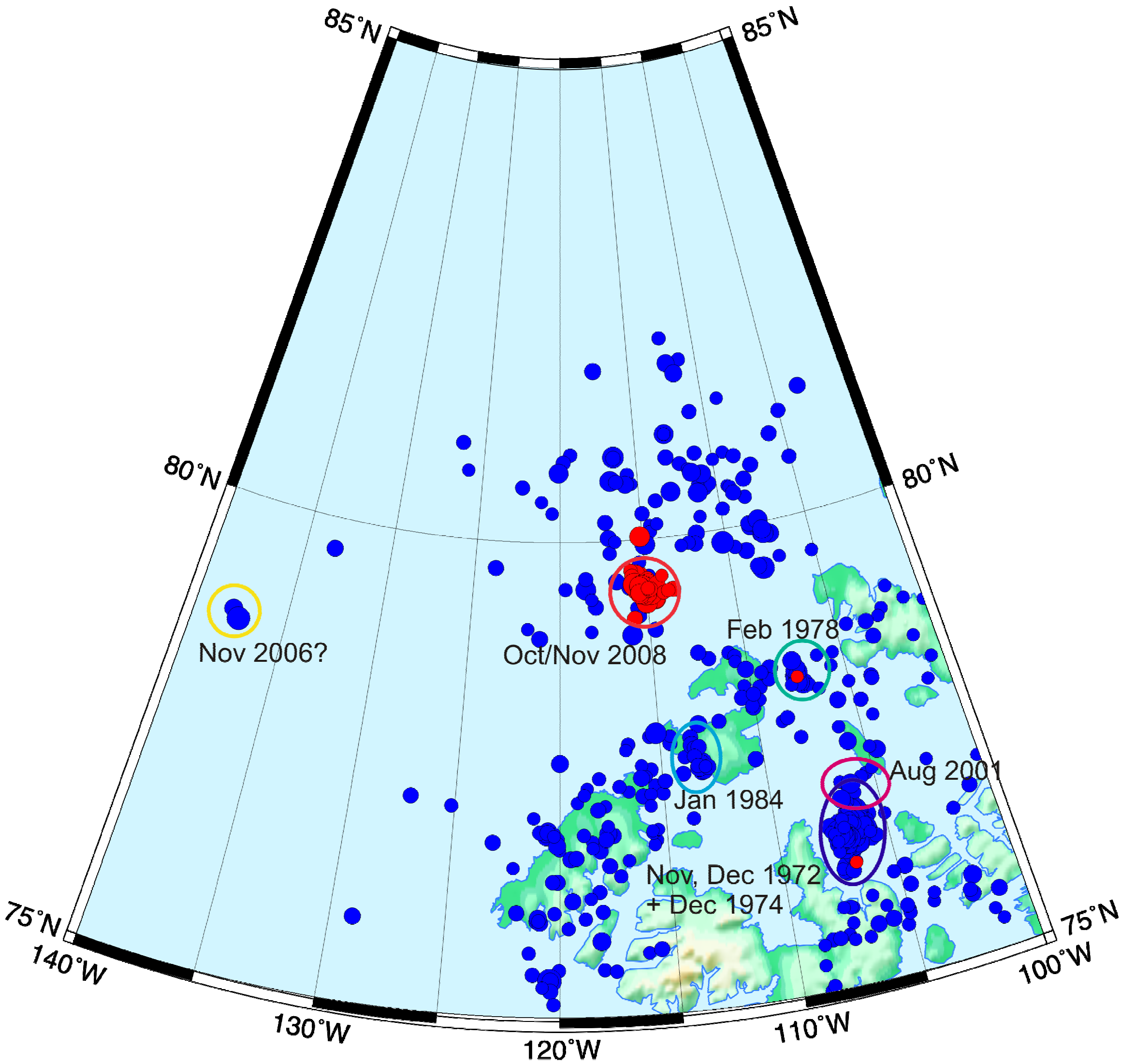


Figure 7. Map highlighting past swarm activity in the regions adjacent to the 2008 swarm. Of the previous swarms only the one occurring in 1972 has been studied in detail (Hasegawa, 1977).