Basic SEISAN for volcano monitoring

Version 0.9

April 22, 2009

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Document conventions:
In this document, command lines from DOS/CMD screens are shown in `8-pt Courier New` font. Your input is shown as **`bold Courier New`**. SEISAN input files are shown in `10-pt Lucida console` to preserve the fixed formatting of the original files. Page numbers refer to the SEISAN 8.2.1 manual, Oct 2008.

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Introduction

These notes assume the user has a copy of the SEISAN 8.2.1 manual (October 2008), has downloaded and installed SEISAN onto a computer with a Windows operating system, and has used the SEISAN tutorial to acquire some understanding of how SEISAN works and how to operate it.

These notes are intended to augment the SEISAN tutorial and manual with techniques specific to processing continuous files of volcano seismic data derived from an Earthworm continuous record module.

Broadly, that process is to

1) create and regularly add data from Earthworm continuous waveform files to a SEISAN database of continuous data
2) Scroll through those data, identifying events, characterizing them by volcanic seismic event type by their appearance and registering them into an event database as event files (SEISAN S-files).
3) Processing events in that event database to determine phase arrivals, azimuths, spectral characteristics, particle motion, and amplitudes of ground motion to determine locations, magnitudes, and energy release.
4) Catalog time-series of numbers and energy-release of different types of volcano seismic event type.

In this manual steps 1 and 2 are organized under the section Routine Processing 1: registration. Steps 3 and 4 are organized under the section Routine Processing 2: EEV.

Some SEISAN quirks:

SEISAN comprises a large and comprehensive suite of powerful seismic analysis tools that is used world-wide. Yet SEISAN is open-source, largely written and maintained by a few people. It should not be surprising to the user to encounter problems with SEISAN modules from time to time. In addition, SEISAN, especially one of it's main programs MULPLT, has some inconvenient quirks that can make processing difficult for the unwary. Here are a few important ones.

MULPLT freezes:
MULPLT may freeze up when the user makes erroneous or unexpected keystrokes. Sometimes the only solution is to kill the programs from Task Manager.

Last trace in MULPLT single-trace mode:
In MULPLT, you can scroll down through the traces in single trace mode using the 'next' key. However, if you select the 'next' key while you are on the last trace, the waveform screen will disappear and you will be ignominiously returned to the MULPLT command prompt.

Case dependency:
In MULPLT as well as other SEISAN programs, commands are case-dependent. For a given command, upper and lower case mean different things. Be careful.

MULPLT screen size:
The MULPLT window can be resized to full-screen, but it will return to it's default size when it repaints.

There are other quirks you may encounter. Be patient.

In case of problems with SEISAN

The best first step is always to consult the SEISAN manual for guidance on the correct procedure. Usually, problems are due to user error or mis-understanding of the manual. Be patient.

If the problem persists despite patient reading and investigation of the manual and procedure, the next step is to consult the on-line repository of communiqués among the SEISAN global user community at http://mailman.uib.no/listinfo/seisan. We strongly recommend you subscribe to the users group in the first place, if you are going to use SEISAN. Remember, there is no cost.

If there is no relevant posting to the repository, try emailing the SEISAN users group (seisan@geo.uib.no) with your problem. Be sure to provide as much detail as you can. The postings must be in English, but few of the users group speak English as a first language, so be precise. Normally, you will get a reply from someone within a day or so, especially if the problem appears to be a program bug. I will try to answer the posting if I can. You can write to me in Spanish.

Configure SEISAN

Configuration of SEISAN to facilitate basic processing for volcano monitoring consists of four one-time tasks:

- Install SEISAN
- Create the continuous and event folders
- Modify key SEISAN input files
- Generate instrument response files

Install SEISAN

Follow the SEISAN procedure for installation using Seisan_8.2.1.exe. Download and unzip EPIMAP map files for your region:

SOAM_BO.MAP
SOAM_CO.MAP
SOAM_RI.MAP
NOAM_BO.MAP
NOAM_CO.MAP
NOAM_RI.MAP
ASIA_BO.MAP
ASIA_CO.MAP
ASIA_RI.MAP

If you are simply copying an existing SEISAN directory structure onto a new computer, do the following two modifications to the Environmental parameters:

1) modify the Path command to include the locations ;e:\Seismo\Com; e:\Seismo\Pro; assuming you are loading the \seismo\ directory onto the e: drive.

2) add the system variable SEISAN_TOP e:\seismo\ (again assuming you are loading the \seismo\ directory onto the e: drive.

Note: If you are using SEISAN on an external drive, the drive letter may change depending on how the operating system assigns names when other disks are present. If this happens, your SEISAN external drive may be assigned a new letter, rendering your path modifications and SEISAN_TOP variable incorrect. However, you can rename your external drive using the DISKPART command from the DOS prompt as follows.

In this example, we change drive F: to drive E:.

Open a DOS window and type the command **DISKPART**.
At the DISKPART> command prompt, type **list volume** to get a list of the active volumes.
View the list of volumes, and determine which volume number corresponds to the drive letter you want to change. Then,
Type **select volume n**, where n is the volume number corresponding to your drive letter. Then,
Type **assign letter = x**, where x is the drive letter that corresponds to the drive in the path name to \seismo\.

Here is the terminal session.

```
C:\Documents and Settings\ablock>diskpart

Microsoft DiskPart version 5.1.3565

Copyright (C) 1999-2003 Microsoft Corporation.
On computer: MAXIMO

DISKPART> list volume

  Volume ###  Ltr  Label        Fs     Type        Size     Status     Info
  ----------  ---  -----------  -----  ----------  -------  ---------  --------
  Volume 0     D                       DVD-ROM        0 B
  Volume 1     C                NTFS   Partition    112 GB  Healthy    System
  Volume 2     F   ABLOCK       FAT32  Partition    298 GB  Healthy

DISKPART> select volume 2

Volume 2 is the selected volume.

DISKPART> assign letter =E

DiskPart assigned the drive letter, but your computer needs to be rebooted
before the changes take effect.

DISKPART>
```

Then close the DOS window. You may need to reboot. You may have to rename your external drive back to e: from time to time if you swap multiple external drives.

Build the continuous database and the event database.

Some fundamentals.

Seismic waveform files produced by the Earthworm (EW) continuous record CONTRECORD, or by SCREAM® are fixed-length records (for example 10 minutes; 1 hour) of data from all stations. These files will be archived somewhere in the system, and are copied temporarily into the SEISAN directory structure (usually \seismo\wor) for processing. The original archival waveform files are usually stored apart from the SEISAN structure are not modified.

To process the waveform files as continuous data, a SEISAN s-file for each waveform file is written into a ‘continuous’ database directory using AUTOREG. S-files for the continuous databases only serve as pointers to each of the waveform files generated by Earthworm; they contain no parametric data.

Thus the continuous waveform files may remain in the earthworm archives, and also may be stored in the \wav directory (ie \wav\CVC). Waveform files corresponding to manually selected and registered events are kept in the \wav\CVE directory. Admittedly this results in some duplication of data, but it speeds subsequent processing and is a fairly efficient system.

Once AUTOREG has added files to the continuous database, the user manually scrolls through the continuous database using MULPLT to identify events and window in on them, ‘register’ each event into the ‘events’ database and manually assign it a volcanic event type.

After each event is registered, the reader continues paging through the continuous files to find the next event, repeating the process.

Later, (Routine processing 2: EEV), events are processed interactively, through EEV (and MULPLT within EEV), to determine phase arrivals, coda length, amplitude, spectra, particle motion and location.

Parametric files and waveform files: when an event is registered, either through AUTOREG or manually in MULPLT or EEV, a new parametric file is automatically created and named according to the start time of the corresponding waveform file. The parametric file is called an s-file; it contains the parameters determined by the reader, and the name of a new waveform file consisting of the waveforms displayed in the MULPLT window at the time of the registration. An s-file created during registration of an event is placed in an events database directory distinct from the s-files representing the continuous waveforms and the new waveform file is written to the corresponding event wav directory. There are separate directories for the parametric s-files and the waveform files.

The example SEISAN implementation has a database directory labeled CVC for the s-files from the Cascades Volcano continuous data, and CVE for s-files from events registered during processing. These are both located in the \rea\ directory, ie \rea\CVC\ and \rea\CVE\. The waveform files are stored in corresponding directories under the \wav\ directory, ie \wav\CVC\ and \wav\CVE\. Here is the SEISAN directory structure. Note the \rea and \wav directories for the parametric s-files and waveform files, respectively.

```
E:\seismo
        \cal
        \com
        \dat
        \inc
        \inf
        \iso
        \lib
        \maps
        \pic
        \pro
        \rea
                \CVC
                \CVE
        \sup
        \tmp
        \wav
                \CVC
                \CVE
        \wor
```

Sample SEISAN directory structure for Mt. St. Helens. (CV = Cascades Volcano)

Build the Continuous and Event databases

Make the REA and WAV directories for S -files and the waveform files that correspond to them, for both the continuous database and the event database.

1) Open a dos command window and type **wo** to move to the working directory seismo\wor. (wo.cmd is a .cmd file located in the \com directory)
2) Use the MAKEREA command to build the database directory structure for the continuous database, here named CVC for ‘Cascades Volcano Continuous’. MAKEREA makes the directories, if they don’t already exist. Follow the example in the terminal session below, substituting your continuous database name, start time and end time. You only need to do this once per time period, but note that you will need to do it for future time periods as time goes by.

```
C:\Documents and Settings\ablock-pr>wo

C:\Documents and Settings\ablock-pr>cd /d E:\seismo\\wor

E:\seismo\WOR>makerea
 Give 1-5 letter base name, UPPER CASE
CVC
 Give start time, year month, e.g. 198302
200801
 Give end time, year month, e.g. 198303, blank for one month
200812
 Create REA or WAV structure or BOTH
BOTH
```

3) Now, run MAKEREA again, this time building an equivalent directory structure for a database named ‘CVE’ for your evens file, here ‘Cascades Volcano Events’. You will place files for specific events processed at your observatory in this directory..
4) Copy the continuous event files from their archive location into the /WOR directory. In this example, we have 10-minute files from Cascades Volcano, named as 2008-07-24-1210-00S.CC____009.
5) Run ‘Dirf’ to make a file containing a list of all the waveform files in /wor/ with ‘CC’ in the extent:

```
E:\seismo\WOR>dirf *.CC*
   1  2008-07-24-1200-00S.CC____009
   2  2008-07-24-1210-00S.CC____009
   3  2008-07-24-1220-00S.CC____009
   4  2008-07-24-1230-00S.CC____009
   5  2008-07-24-1240-00S.CC____009
   6  2008-07-24-1250-00S.CC____009
   7  2008-07-24-1300-00S.CC____009
   8  2008-07-24-1310-00S.CC____009
   9  2008-07-24-1320-00S.CC____009
  10  2008-07-24-1330-00S.CC____009
  11  2008-07-24-1340-00S.CC____009
  12  2008-07-24-1350-00S.CC____009
.
.
.
```

6) Dirf shows the numbered list of files corresponding to the file name & wildcards. (The file is called ‘filenr.lis’. it is placed in \wor\.
7) Run AUTOREG (p137) which generates and s-file for each waveform file, and puts the s-files into the REA\CVC database for continuous data. NOTE: YOU MUST MANUALLY TRANSFER THE WAVEFORM FILES FROM \WOR TO THE APPROPRIATE \WAV DIRECTORY FOR THE CONTINUOUS DATA. In this example that directory would be E:\seismo\WAV\CVC__\2008\07\

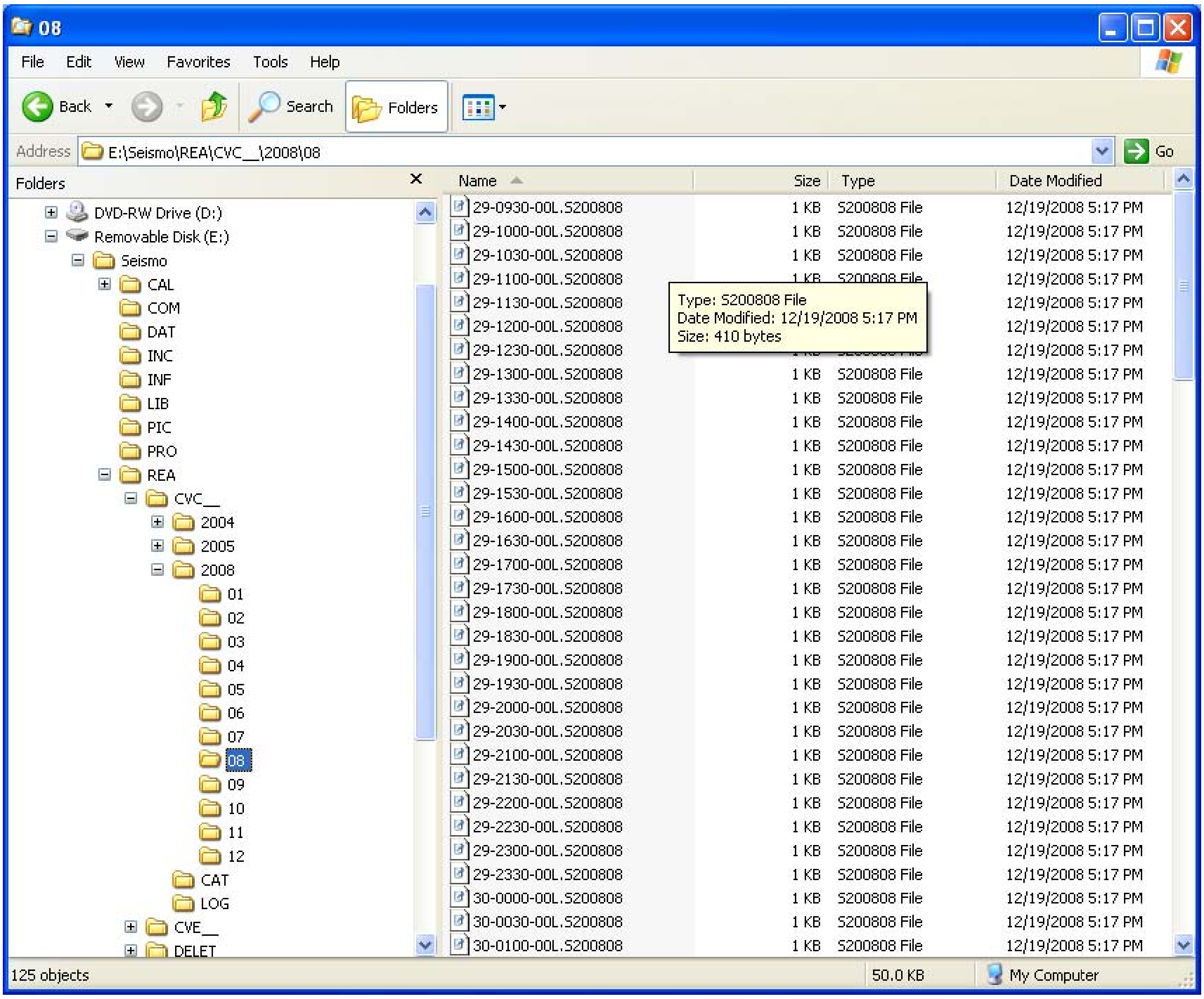
```
E:\seismo\WOR>autoreg
 Event type for all events: Local:    L (default)
                            Regional: R
                            Distant:  D
L
 1-5 letter base name, return for standard base, ,, for local base
CVC
 Operator, max 4 chars
ANDY
```

The last part of the command output looks something like this:

```
.
.
.
2008-07-25-1510-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1510-00L.S200807

2008-07-25-1520-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1520-00L.S200807

2008-07-25-1530-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1530-00L.S200807

2008-07-25-1540-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1540-00L.S200807

2008-07-25-1550-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1550-00L.S200807

2008-07-25-1600-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1600-00L.S200807

2008-07-25-1610-00S.CC____009
E:\seismo\\REA\CVC__\2008\07\25-1610-00L.S200807

Stop - Program terminated.

E:\seismo\WOR>
```

Now your \REA directory has the CVC database, with folders for each month. Here the 07 folder is highlighted to show the new S-files just created.

Remember to manually move the waveform files from the \wor directory to the appropriate \wav continuous waveform directory after running AUTOREG.



Screen shot of the \REA\CVC\2008\08 directory with s-files of s-files created for the continuous database.

The new S-files for the continuous waveforms all look like this:

Example of an s-file created for the continuous database. See SEISAN manual for details of format.

Open the S-files with Wordpad. (Other word processers will work, but Wordpad is simple. Use it now, and then change later if you prefer something else.) Refer to the SEISAN manual's Appendix 1 –The Nordic Format for the s-file format.

Multiple Continuous databases, Event databases for multiple individual volcanoes

It is convenient to have a continuous database for each independent source of a continuous datafile. For example, the files from ContRecord at an Earthworm node that receives some stations and writes them all to a single continuous data file would all be gathered under one continuous database. Likewise, data files from a remote node that collected data from a single broadband with SCREAM! would be stored in their own continuous database.

Event databases should be configured for each volcano monitored by an observatory. For example, an observatory might collect data locally on an earthworm system, and remotely from several remote nodes running SCREAM!® or Earthworm. Data from each of these would be registered into a continuous database. Those databases would be specified in SEISAN.DEF (see below). Routine processing of the continuous data into event data would consist of opening all the appropriate continuous databases, selecting events associated with a specific volcano, and registering those events into the event database for that volcano.

Note that an event waveform file for a small event at an individual volcano does not have to include traces from stations that did not see the event. In MULPLT, it is easy to select only those traces of interest to be saved into the waveform file generated when the event is registered. Note that MULPLT.DEF can list 'DEFAULT CHANNELS' to be displayed, ignoring other traces that are known or expected to not have seen events at the volcano.

If you have a separate event database for each volcano, the most straightforward technique for processing continuous data is to process one volcano at a time. If the DEFAULT CHANNELs in MULPLT .DEF are used, they would have to be changed depending on the volcano being processed. Obviously, there should also be an events database for regional tectonic events in addition to the volcanic events, if they are of interest.

Modify the important SEISAN initialization files

SEISAN.DEF (p18), MULPLT.DEF (p 107), STATION0.HYP (p66) and VOLCANO.DEF (p227) are the four key SEISAN parameter files that require modifications for routine volcano seismic processing. They list parameters that should be modified for each observatory. The most important ones are described here. In addition to the parameters described here, there are many others that may be modified for one application or another. While they may be useful, they are not described here. For a more complete listing, see the page references in the SEISAN 8.2.1 manual.

SEISAN.DEF

SEISAN.DEF (p18) lists general parameters used in SEISAN. Note that the parameters must be aligned with the 'Par 1' and 'Par 2' markers since the file is read by Fortran, which reads a fixed format statement. There are several parameters in SEISAN.DEF that should be modified for use in a particular observatory.

The parameters to be modified are:

> <u>WAVEFORM_BASE</u>: the name of your event database; here, CVE.
>
> <u>CONT_BASE</u>: the name(s) of your continuous database(s) to be searched for trace data when starting MULPLT in continuous (CONT) mode. In our example, it is CVC.

COPY_WAVE DIR: the name of your event database, for use when registering events. Again here, CVE

MERGE_WAVEFORM: the 2-character network ID used to name the waveforms when registering. Here, CC.

CONT_BEFORE: when using MULPLT in CONT mode, the number of minutes of waveform data to be read into memory before the required start time. CONT_BEFORE must be at least as long as the waveform file. Here, 10.

CONT_AFTER: when using MULPLT in CONT mode, the number of minutes of waveform data to be read into memory after the data that is plotted. Here, 10.

MAP_LAT_BORDER: , MAP_LON_BORDER: Used with MAP in EEV, which plots a map around the current epicenter. These 2 parameters give the distance in degrees from the epicenter to the edges of the map

EPIMAP_STATIONS: Indicator for EPIMAP to plot stations, ‘A’ will plot the stations.

EPIMAP_MAP_FILE: the names of the maps to use with MAP option in EEV.

Here is an example of part of a SEISAN.DEF file. Note the fixed formatting.

```
This file is for defaults for SEISAN and called SEISAN.DEF. The name must
be in upper case on Sun. The following shows the parameters which can be set.
The file can contain any lines in any order, only the lines with
recognized keywords and a non blank field under Par 1 will be read. The
comments have no importance. VDAP modifications.

KEYWORD............Comments.............Par 1.....Par 2

WAVEFORM_BASE      Waveform base name   CVE

CONT_BASE          REA continuous base  CVC
CONT_BASE          REA continuous base  KKC

COPY_WAV_DIR       copy when register   CVE

MERGE_WAVEFORM     Code for merging wa  CC

CONT_BEFORE        start min before     60.
CONT_AFTER         start min after      60.
CURSOR             0: default, 1: cross 1.
FOCMEC MAXSOL      max solutions        125.

MAP_LAT_BORDER     dist from center       1.0
MAP_LON_BORDER          "                 1.0

EPIMAP_STATIONS    plot stations        A
EPIMAP_MAP_FILE    name of map          NAME_CO
EPIMAP_MAP_FILE    name of map          NAME_BO
EPIMAP_MAP_FILE    name of map          NAME_RI
EPIMAP_MAP_FILE    name of map          SOAM_CO
EPIMAP_MAP_FILE    name of map          ASIA_RI
EPIMAP_MAP_FILE    name of map          ASIA_CO
```

MULPLT.DEF

MULPLT.DEF (p107) lists parameters used in the MULPLT program. Note that the parameters must be aligned with the 'Par 1' and 'Par 2' markers since the file is read by Fortran, which reads a fixed format statement. None of these parameters need to be modified, although it is usually convenient to modify some of the '<u>FILTER X</u>' settings to frequencies useful in band-passing data for spectral analysis, particle motion and magnitude determination. There are some suggested filter settings in the MULPLT.DEF example listed below.

Normally it is not useful to list '<u>DEFAULT CHANNELS</u>'. One exception is when the continuous database contains traces from many volcanoes but the events database is specific to one volcano. In that case, it is convenient to only list as DEFAULT CHANNELS those traces that would be useful to the event files for that volcano. In the example below, only RIN, SOP and EMP are listed as DEFAULT CHANNEL. All the other 13 traces in the continuous waveform file are left out of the displayed data. Another case is if a trace is dead, and therefore does not need to be included in an event waveform file. If no DEFAULT CHANNELS are listed, MULPLT.DEF lists all the channels in the waveform files.

Here is an example of a MULPLT.DEF file. Note the fixed format.

```
This file is for defaults for MULPLT and called MULPLT.DEF. The name must
be in upper case on Sun. The following shows the parameters which can be set.
The file can contain any lines in any order, only the lines with
recognized keywords and a non blank field under Par 1 will be read. The
comments have no importance.

KEYWORD............Comments.............Par 1.....Par 2
X_SCREEN_SIZE      Size in pixels       100.0
PHASE NAME KEY     Phase key and phase
PHASE NAME KEY
PHASE WEIGHT KEY   Weight key and weight
PHASE MOUSE KEY    Mouse key character
SPECTRAL Q0        Q0                    440.0
SPECTRAL QALPHA    Q = Q0**Qalpha        0.70
SPECTRAL KAPPA
SPECTRAL P-VELOCITY P velocity            6.2
SPECTRAL S-VELOCITY P velocity            3.6
SPECTRAL DENSITY   Density
3COMP VELOCITY     velocity for 3 comp
RESOLUTIONX        # points pl. screen  2000.0
RESOLUTIONHC       # points pl. hc      3000.0
NSORT_DISTANCE     0: no sort, min ph.   1.0
SPECTRAL F-BAND                          0.01     20.0
AUTO_LOCATE        0,1,2       0,1,2     0.0      0.0
AUTO_PROCESS       0,1,2       name      0.0      ls
SPECTRAL OUTPUT                          1.0
WOOD ANDERSON HIGH CUT                  20.0
BANDPASS FILTER
AUTOCODA FILTER                          0.1      10.0
AUTOCODA STA                             3.0
AUTOCODA RATIO                           1.2
CODA AUTO                                0.0
PHASE NAME KEY
PHASE MOUSE KEY
SPECTRAL Q0
SPECTRAL QALPHA
### Set Filter type 0 for bndpas 1 for recfil routine
FILTER TYPE                             0.0
### Setup user-defined filters
FILTER 1                                1.0       20.0
FILTER 2                                0.1       20.0
FILTER 3                                0.5       20.0
FILTER 4                                5.0       10.0
FILTER 5                                10.0      15.0
FILTER 6                                15.0      25.0
FILTER 7                                2.0       4.0
### Magnitude filters
ML LOW CUT AND POLES
ML HIGH CUT AND POLES
MS LOW CUT AND POLES
MS HIGH CUT AND POLES
MB LOW CUT AND POLES
MB HIGH CUT AND POLES
###
#DEFAULT CHANNEL                         TRO       S  Z
DEFAULT CHANNEL                         RIN       EH Z
DEFAULT CHANNEL                         RIN       EH E
DEFAULT CHANNEL                         RIN       EH N
DEFAULT CHANNEL                         SOP       EH Z
DEFAULT CHANNEL                         EMP       EH Z
```

STATION0.HYP

STATION0.HYP (p66) lists parameters used in the location program HYP. There are many important parameters here to modify, including parameters for the

- coda magnitude calculation,
- station locations,
- velocity model and

- network code.

Coda duration magnitude parameters TEST(7), TEST(8) and TEST(9):

These parameters are the duration magnitude coefficients used for calculating the coda magnitude, as

MAG = TEST(7) +TEST(8) * LOG(T) + TEST(9) * DELTA

where

T is the coda length in seconds,
DELTA is the hypocentral distance in km.

The default SEISAN values for the coda magnitude parameters are those determined by Richter for Northern California.

Default values: 7: 0.087,
8: 2.0,
9: 0.0035 (Lee, 1972)

So default MAG = 0.087 +2.0 * LOG(T) + 0.0035 * DELTA

Values for these parameters are often different at volcanoes. Here, we use the coda magnitude parameters determined for Mt. St. Helens, or
RESET TEST(07)=-2.46
RESET TEST(08)=2.82
RESET TEST(09)=0.00

See the section below on M_c for more information.
See the document "Processing Seismic Data" for more information on determining Mc parameters for your volcano.

Station locations:

Follow the format of the examples in STATION0.HYP for station location.

Velocity structure:

The velocity structure is given as shown in this example, from the example file below:

```
  4.6      0.0
  5.10     2.2
  6.0      3.4
  6.2      6.0
  6.6     10.0
  6.8     18.0
  7.1     34.0      N
  7.8     43.0
```

This velocity structure is used at Mt. St. Helens. Use this, or your own velocity structure, following this format. The letter 'N' indicates the moho.

S/P velocity ratio

S/P velocity radio in the example below is given by the value 1.74 in the line:

```
33.0 1000.3300. 1.74   15  1.0 00.5
```

Use this value or your own.

<u>Network code</u>:

In the example below, CC is the network code used when a location is reported in the event's s-file. Replace it with your own 2-digit network code.

Other parameters are given in the SEISAN 8.2.1 manual starting on page 66. It is useful to review them.

Here is an example of part of a STATION0.HYP file.

```
RESET TEST(02)=500.0
RESET TEST(07)=-2.46
RESET TEST(08)=2.82
RESET TEST(09)=0.00
RESET TEST(11)=99.0
RESET TEST(13)=5.0
RESET TEST(34)=1.5
RESET TEST(35)=2.5
RESET TEST(36)=0.0
RESET TEST(41)=20000.0
RESET TEST(43)=5.0
RESET TEST(51)=3.6
RESET TEST(50)=1.0
RESET TEST(56)=1.0
RESET TEST(57)=2000.0
RESET TEST(58)=99990.0
RESET TEST(40)=0.0
RESET TEST(60)=0.0
RESET TEST(71)=1.0
RESET TEST(75)=1.0
RESET TEST(76)=0.420
RESET TEST(77)=0.0050
RESET TEST(78)=-1.35
RESET TEST(79)=1.0
RESET TEST(80)=3.0
RESET TEST(81)=1.0
RESET TEST(82)=1.0
RESET TEST(83)=1.0
RESET TEST(88)=1.0

  PUS 0732.30S11027.24E2625
  KLA 0732.08S11025.68E1918
  KLB 0731.93S11025.96E1890
  DEL 0733.61S11027.68E1487
  PLA 0735.14S11025.89E1276
  LBH 0733.43S11026.74E1730
  PAS 0732.22S11026.97E2650
  PUN 0732.18S11026.78E2925
  EMP 0122.10N12448.02E1177
  MAH 0121.30N12451.67E1319
  MHW 0120.94N12451.37E1143
  RIN 0107.97N12444.85E1500
  SEA 0122.20N12448.00E1202
  SOP 0107.35N12444.50E1570
  TTW 0121.67N12447.63E1177
  KIN 0122.01N12448.99E 937
  KLA 0126.31N12459.69E 800
  AUCH4302.18S 7251.58W 002
  STAB4251.36S 7247.53W 106
  PILL4233.50S 7229.49W
  PUMA4241.42S 7248.42W   2
  BARC4253.08S 7328.30W  60
  DOMO4250.16S 7238.94W 100
  BOLM4612.92N12210.48W1859
  BLIS4611.84N12211.19W2116
  EDM 4611.83N12209.07W1609
  ELK 4618.32N12220.52W1270
```

```
  HSR 4610.45N12210.83W1720
  HUO 4407.17N12150.96W2037
  JRO 4616.50N12213.06W1280
  JUN 4608.82N12209.14W1049
  FRIS4412.72N12206.10W1642
  FMW 4656.48N12140.26W1859
  IRO 4400.30N12215.32W1642
  LEL 4027.85N12131.08W2414
  LSI 4023.79N12125.38W1857
  MOON4403.09N12140.16W2240
  MBW 4847.03N12154.05W1676
  MB2 4847.04N12153.98W1676
  PRLK4412.58N12157.75W1283
  PRL 4650.07N12200.97W1494
  RAFT4611.74N12211.17W2132
  SHW 4611.60N12214.18W1425
  SHWZ4611.60N12214.18W1425
  SEP 4612.01N12211.43W2116
  SEND4611.61N12211.12W9999
  STD 4614.25N12213.43W1268
  STDZ4614.25N12213.43W1268
  SWFL4611.32N12212.12W2268
  TIM 4613.59N12209.35W1317
  TIMB4520.13N12142.60W1901
  TDH 4517.38N12147.49W1541
  VALT4612.85N12211.35W1681
  WIFE4403.57N12149.04W1955
  STAR4651.05N12147.57W3365
  SUG 4612.93N12210.57W1859
  REM 4611.94N12211.12W2102
  PAYL4711.55N12218.84W0009
  YEL 4612.57N12211.34W1750

  4.6       0.0
  5.10      2.2
  6.0       3.4
  6.2       6.0
  6.6      10.0
  6.8      18.0
  7.1      34.0      N
  7.8      43.0

33.0 1000.3300. 1.74   15  1.0 00.5
CC
```

VOLCANO.DEF

The VOLCANO.DEF file (p227) is a numbered list of volcano-seismic event types. The number of volcano sub-classes is limited to 10. VOLCANO.DEF can be modified as needed for a particular observatory, volcano and eruption. Here is a version for Mt. St. Helens.

```
Current volcano sub-classes:
1  vt     volcano-tectonic
2  lf     low frequency
3  hy     hybrid
4  tr     volcanic tremor
5  rf     rockfall
6  ex     explosion
7  er     eruption
8  unk    unknown
9         QUIT
```

As a general principal, for event subclasses to be useful in the long run, they should be descriptive of the waveform, rather than assigned general terms like LP and A- and B-type.

Generate instrument response files

Response file for a USGS-VDAP analog 1-Hz Sercel L4.

The SEISAN program RESP.EXE allows four different response file formats; SEISAN F&P, SEISAN PAZ, GSE2 F&P, GSE2 PAZ. In this example we will generate a GSE2-format poles-and-zeros response file.

This example is for station STDZ SH Z at Mt. St. Helens. The sensor is a short-period 1-Hz Sercel L-4C, sn 1934. The L-4 is connected to a McVCO (McChesney, 1999) whose subcarrier output tone is transmitted over an analog radio link to a USGS J120D discriminator. The discriminator output is digitized by a National Instruments PCI-MIO-16E4 12-bit ADC.

The parameters that must be entered into RESP are as follow.

- Seismometer natural period
- Seismometer damping ratio
- Sensor loaded generator constant
- Recording media gain
- Digitizer sample rate
- Amplifier gain (total system gain)
- Number of filters
- Corner frequency and number of poles for each filter.

Seismometer natural period:

The natural period of a typical 10Hz L-4 is 1 sec. SN 1934 is old; it's natural period (recalculated by Sercel) is 0.974sec. The natural period is usually written on the side of the sensor.

Seismometer damping ratio and loaded generator constant:

The damping ratio and loaded generator constant for a passive seismometer are determined by electrical sensor characteristics of mechanical damping (B_0) and unloaded generator constant G, as they are modified by the electrical resistances of the sensor, interfacing circuitry and the pre-amp impedance. The standard VDAP installation 'fixes' the damping ratio =0.8 and the loaded generator constant of a L4 =100v/m/sec and of an L22 =25v/m/sec.

The loaded generator constant (or *effective* motor constant) G_{eff} is described by the relation:

$$G_{eff} = G * \frac{R_s * R_{amp}}{(R_{seis} + R_t) * (R_s + R_{amp}) + R_s * R_{amp}}$$

or,

$G_{eff}=G*R_s*R_{amp} / \{(R_{seis}+R_t)*(R_s+R_{amp})+R_s*R_{amp}\}]$

where

G= seismometer motor constant (v/cm/sec)

R_t=series resistance of the VCO L-pad (ohms)
R_s=parallel resistance of the VCO L-pad (ohms)
R_{amp}=input impedance of the VCO preamp, U1 (ohms)
R_{seis}=resistance of the seismometer coil (ohms)

The damping B is the sum of the mechanical damping B_0 and the electromagnetic damping B_1,

$B=B_0 + B_1$.

B_1 is calculated as:

B_1=electromagnetic damping of geophone

$$B_1 = \frac{1}{2M * (2\Pi f_0)} * \frac{[G(10^2)]^2}{R_{seis} + R_t + R_s * \frac{R_{amp}}{R_s + R_{amp}}}$$

where
M=seismometer mass (kg)
G is multiplied by 10^2 to give units of
(v/m/sec)

Recording media gain:

The recording media gain depends on the digitizer used. For a standard VDAP installation using the National Instruments PCI-MIO-16E-4 digitizer, the recording media gain is 819.6. (For a PSN/Webtronics digitizer, the recording media gain is 6,558.)

Amplifier gain (total system gain):

Amplifier gain in RESP is actually the sum of several values: the gain (a fraction, since it is an attenuation) through the VCO interfacing resistances + the VCO gain + (VCO voltage to frequency conversion * discriminator frequency to voltage conversion).

<u>VCO gain and voltage-frequency conversion:</u>

In USGS J-model, Kinemetrics, Sprengnether and Eentec (basically a Sprengnether design), the VCO gain = preamp gain + amplifier gain – attenuation, where the attenuation is the value set by the Attenuation switch.

For the <u>USGS J-model</u>, the preamp gain = 300, or ~50dB. Amplifier gain = 162, or 44 dB. Total VCO gain for the USGS J-model then is 94dB – attenuation. The voltage-frequency conversion of the USGS-J-series VCO is +/-4.04v for +/-115Hz, or 28.46Hz/V. (This odd conversion is due to historical reasons. An early USGS J-series VCO used mercury cells as a power supply and constant voltage (4.04v) source.

The <u>Kinemetrics AM-1</u> preamp gain= either 0dB, 36dB or 54dB and the amplifier gain = 36dB Maximum total gain for the AM-1 then is =90dB – attenuation. The AM-1 output typically feeds the Kinemetrics OM-1 VCO, which has no additional gain. The voltage-frequency conversion of the OM-1 is +/-2.5v for +/-125Hz deviation.

In McVCO, the VCO gain is simply the gain set by switches 1,2 and 3. The voltage-frequency conversion of the McVCO as configured by VDAP is +/-4.04v for +/-115Hz or 28.46Hz/V, for backward compatibility with USGS J-series VCOs. (This odd conversion is due to historical reasons. An early USGS J-series VCO used mercury cells as a power supply and constant voltage (4.04v) source.

Discriminator frequency to voltage conversion:

The USGS J-120 discriminator frequency to voltage conversion factor is +/-125Hz per +/-2.500v or 0.02Hz/V.

The Kinemerics DM-2 Discriminator has a switch-selectable frequency-voltage conversion factor but it is usually set to +/-125Hz per +/-2.500v, or 0.02Hz/V.

The Eentec TC-20DS discriminator frequency to voltage conversion factor is +/-125Hz per +/-5.000v, or 0.04Hz/V

Number of filters; Corner frequency and number of poles for each filter:

USGS J-series VCOs, as well as most of the legacy analog VCOs by Kinemetrics, Sprengnether (including Eentec), Teledyne have high-pass filters on the inputs. The high-pass filters on the USGS J-series have two poles and corner frequencies at about 0.1Hz. The low-pass filters on the USGS J-series have 2 poles at about 44Hz. The legacy analog VCOs have similar high- and low-pass filters.

The low-pass filter on McVCO is a 4-pole filter at a corner frequency of 30Hz. There is no high-pass filter on McVCO, but feedback circuitry begins to affect low frequency response below about 0.03Hz. Mathematical evaluation of the effect is complex, and not worthwhile for short-period analog seismic systems. For purposes of SEISAN calibrations, we ignore this effect.

The USGS J120 discriminator has a 4-pole low-pass filter at about 20Hz.

Table: VCO parameters for calibration calculations

VCO	Input impedance	high-pass f_0/poles	low-pass f_0/poles	hz/volt
USGS J-series	10,000	0.1: 2	30Hz, 4 poles	28.46
Kinemetrics AM-1 amplifier/filter plus OM1 VCO Or AOM-1 amp/filter-VCO	100,000	Switch-selectable f_0, 2 pole	Switch-selectable f_0, 2 pole	Usually 50, switch-selectable
Eentec AS-110DG-SE amplifier/filter plus TC-10XV VCO	100,000	0.05Hz:2 poles	Switch-selectable f_0, 5 poles	25
McVCO	10,000	na	30Hz, 4 poles	28.46

Table: Discriminator parameters for calibration calculations

Discriminator	high-pass f_0/poles	low-pass f_0:poles	volt/hz
USGS J120		20Hz, 4 poles	0.02
Kinemetrics DM-2		Normally 25Hz, 3 poles, switch-selectable f_0.	0.02
Eentec TC-20DS	0.1Hz : ? poles	25 Hz, 5 poles	0.04

Significant digits: Precision of the resistors used to interface the seismometer to the amplifier are typically 1%, but may be 10%. Based on tests done at CVO, the L-4 mass M and coil resistance R_{seis} are generally assumed to vary by 5% to 10% from stated values. Generator constant G and center frequency F_o are generally taken to vary by 5%.

Here is an example of a terminal session with RESP for a short-period analog telemetry system. Responses are in **bold**.:

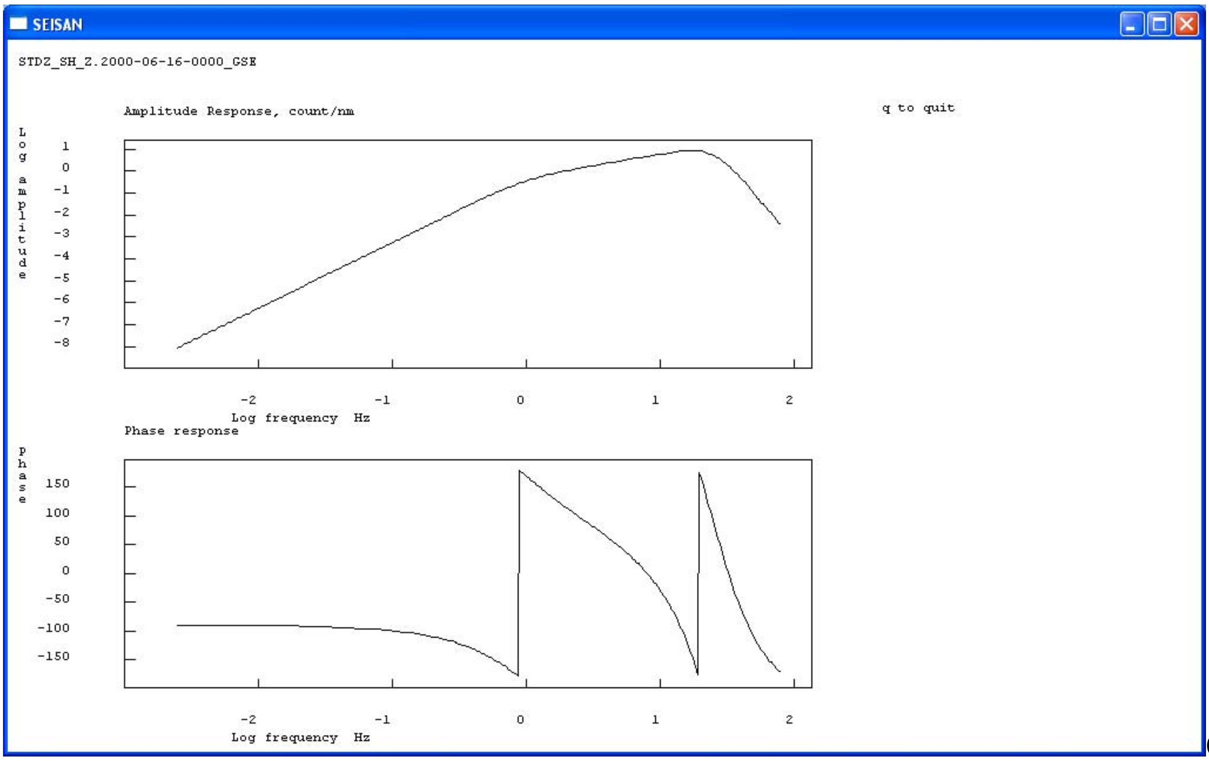
```
E:\seismo\WOR>RESP
 RESP - PROGRAM TO CREATE RESPONSE FILES IN SEISAN
        OR GSE FORMAT. THE RESPONSE CAN BE CREATED
        AS POLES AND ZEROS (PAZ) OR FREQUENCY
        AMPLITUDE AND PHASE (FAP). THE SAME
        TRANSFER FUNCTION AND FILTERS ARE USED
        IN BOTH CASES.

 CHOSE OUTPUT FORMAT: 0: NO OUTPUT FILE
                      1: SEISAN FAP
                      2: SEISAN PAZ
                      3: GSE2 FAP
                      4: GSE2 PAZ
4
 TYPE OF SENSOR:       1: NONE
                       2: SEISMOMETER
                       3: ACCELEROMETER
2
 SEISMOMETER NATURAL PERIOD ?
0.974
 SEISMOMETER DAMPING RATIO ?
0.8
 SENSOR LOADED GENERATOR CONSTANT (V/M/S OR V/G) ?
134.9
  INSTRUMENT TYPE FROM LIST BELOW

  Akashi, 23900, BB-13V, CMG-3, CMG-3N, CMG-3T, CMG-3E,
  FBA-23, GS-13, GS-21, KS3600, KS360i, KS5400, MK II,
  Oki, Parus2, S-13, S-500, STS-1, STS-2, TSJ-1e
 CHOICE
L4
 RECORDING MEDIA GAIN (COUNT/V OR M/V) ?
819.6
 DIGITIZER SAMPLE RATE (BEFORE POSSIBLE FIR FILTER)
100
 DIGITIZER MODEL
PCIMIO16E4
 AMPLIFIER GAIN (DB) ?
58.5
 NUMBER OF FILTERS (0-10), RETURN FOR NONE ?
2
 FREQUENCY AND NUMBER OF POLES FOR EACH FILTER,
 POLES NEGATIVE FOR HIGH PASS
20 4
30 4
 FILE NAME FOR FILE WITH POLES AND ZEROS, RETURN FOR NO FILE
```

```
 NUMBER OF FIR FILTER STAGES

0
 FILE NAME FOR MEASURED VALUES, RETURN FOR NO FILE


           AMPLITUDE RESPONSE   SEISMOMETER       DISPLACEMENT
 AMPL      ---------------------------------------------------------------
  24.2     I.         .         .         .         .     ++++++        .I
  8.60     I                                  ++++++      ++            I
  3.05     I.         .         .         .    +++++.         .   +     .I
  1.08     I                                +++                    +    I
 0.385     I. . . . . . . . . . . . . . ++.+. . . . . . . . . . . . + . .I
 0.137     I                           ++                               I
 0.485E-01 I.         .         .   ++    .         .         .      +  .I
 0.172E-01 I                      ++                                  +  I
 0.612E-02 I.         .         ++        .         .         .        +.I
 0.217E-02 I. . . . . . . . . ++. . . . . . . . . . . . . . . . . . . . +I
 0.772E-03 I.         .     ++  .         .         .         .         .I
 0.274E-03 I              ++                                            I
 0.973E-04 I.         . ++      .         .         .         .         .I
 0.345E-04 I          ++                                                I
 0.123E-04 I. . . . ++. . . . . . . . . . . . . . . . . . . . . . . . . .I
 0.435E-05 I     +++                                                    I
 0.155E-05 I.   +     .         .         .         .         .         .I
 0.549E-06 I  ++                                                        I
 0.195E-06 I++        .         .         .         .         .         .I
           ---------------------------------------------------------------
 FREQ      0.01      0.03      0.14      0.71      3.68     19.19    100.00
GAIN FACTOR AT 1 HZ: 0.356E+09     RETURN FOR PHASE RESPONSE
           PHASE RESPONSE   SEISMOMETER       DISPLACEMENT
 PHAS DEG  ---------------------------------------------------------------
  177.     I.         .         .         . +       .         .         .I
  157.     I                                 +                         +I
  138.     I.         .         .         .  ++     .         .+        .I
  118.     I                                   ++                       I
  98.0     I. . . . . . . . . . . . . . . . . . . + . . . . . . . . . . .I
  78.1     I                                      ++          +         I
  58.3     I.         .         .         .         .+        .         .I
  38.5     I                                         ++                 I
  18.7     I.         .         .         .         .  +      .  +      .I
 -1.16     I. . . . . . . . . . . . . . . . . . . . . . .+. . . . . . . .I
 -21.0     I.         .         .         .         .     +   .         .I
 -40.8     I                                             +      +       I
 -60.6     I.         .         .         .         .         .         .I
 -80.4     I                                              +       +     I
 -100.     I+++++++++++++++++++++++. . . . . . . . . . . . . . . . . . . .I
 -120.     I                       ++++                    +      +     I
 -140.     I.         .         .     +++ .         .         .      +  .I
 -160.     I                             + +                          +  I
 -180.     I.         .         .         .         .         +        +.I
           ---------------------------------------------------------------
 FREQ      0.01      0.03      0.14      0.71      3.68     19.19    100.00
GSE RESPONSE FILE (Y/N=default)?y
Enter station code. e.g. BERGE, max 5 chars
STDZ
Enter component (4 chars) e.g. SL Z
  First character is type, must be one of the following:
  S: Short period, L: Long period
  B: Broad band,   A: Accelerometer
Last character must be Z,N or E
Character 2 and 3 can be anything
SH Z
Enter date as YYYYMMDDHHMMSS, at least up to the day  (e.g. 19880123):20000616
No gsesei.def file, will use internal information for channel codes
Channel # and name not defined in def file:   1 STD   SHZ
 Constants used:

1: SEISMOMETER PERIOD=         0.97
2: GENERATOR CONSTANT=       134.90
3: DAMPING RATIO     =         0.80
4: AMPLIFIER GAIN(DB)=        58.50
5: RECORDING GAIN=             820.
6: STATION AND COMP=  STDZ SH Z
7: DATE AND TIME=     2000 616 0 0 0
8: FILTER CONSTANTS
 F= 20.00   POLES=  4
 F= 30.00   POLES=  4
 Run again: Enter number to change value, enter to end
```

```
 End: Enter

Response file name is: STDZ_SH_Z.2000-06-16-0000_GSE
 RESPONSE CURVE IS IN FILE resp.out
Stop - Program terminated.

E:\seismo\WOR>
```

The resulting GSE2 PAZ output file should be moved to the \CAL directory. Here it is STDZ_SH_Z.2000-06-16-0000_GSE.

```
CAL2 STDZ   SH Z      L4        0.28E+01       1.   100.00000 2000/06/16 00:00
PAZ2  1 V  0.42467426E+11                    10    3 Laplace transform
 -0.51607275E+01  0.38705454E+01
 -0.51607275E+01 -0.38705454E+01
 -0.48089428E+02  0.11609813E+03
 -0.11609813E+03  0.48089413E+02
 -0.11609812E+03 -0.48089432E+02
 -0.48089405E+02 -0.11609814E+03
 -0.72134140E+02  0.17414719E+03
 -0.17414720E+03  0.72134117E+02
 -0.17414719E+03 -0.72134148E+02
 -0.72134109E+02 -0.17414720E+03
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
DIG2  2  0.68960744E+06   100.00000 PCIMIO16E4
```



Q

The response curve generated by RESP.

GSE2 response file for a 30-sec Guralp CMG-6TD sensor

This is an example of running the RESP program for a Guralp CMG-6TD 30-second broadband, serial number T6330, z axis. This approach uses a file containing Poles and Zeros information and a normalization constant prepared as per the SEISAN manual. That preparation is repeated here for completeness. Refer to the CMG-6TD calibration file in Appendix 1 for values given here.

Digitizer:
The sensitivity of the digitizer (labeled 'Digitizer output' in the Guralp response document) is given as 0.2609uV/ct. the SEISAN gain is in counts/volt so
SEISAN recording media gain = 1,000,000/0.2609 = 3,832,000 ct/V.

Sensor:

Sensitivity (labeled 'Velocity Response' in the Guralp response document) is 1125.1 V/m/s.

Make response file with Poles and Zeros:

The Poles and Zeros velocity response in units of Hz is given by Guralp as:

Poles

-23.65e-3 + 23.65e-3j
-23.65e-3 - 23.65e-3j
-393.011
-7.4904
-53.5979 - 21.7494j
-53.5979 + 21.7494j

Zeros

-5.03207
0
0

SEISAN units are radians/sec so the Guralp Poles and Zeros values in Hz must be multiplied by 2pi. The Normalizing factor at 1Hz is given as:

$1.983(10)^6$.

To convert the normalizing factor to radians, multiply by $(2pi)^{(Poles-Zeros)}$ or, since there are 6 Poles and 3 Zeros,

$1.983(10)^6$ X $(2pi)^3$ or

$4.918(10)^8$ (at 2pi radians?)

SEISAN uses units of displacement, whereas Guralp gives Poles and Zeros of the velocity response. To convert Poles and Zeros of the velocity response to the displacement response, add one zero to the three Zeros of the velocity response for four Zeros total. (Note that in this response only one Zero is a non-zero number)

Converting from Hz to Rad/sec and velocity to displacement, the Poles and zeroes are then:

Poles (rad/sec)	
-1.486E-01	1.486E-01
-1.486E-01	-1.486E-01
-2.469E+03	0.000E+00
-4.706E+01	0.000E+00
-3.368E+02	-1.367E+02
-3.368E+02	1.367E+02

Zeros(rad/sec)	
-3.162E+01	0
0	0
0	0
0	0

Summarizing the conversion between the Guralp Poles and Zeros in Hz to the SEISAN Poles and Zeros in rad/sec:

Guralp Poles (Hz)		SEISAN Poles (rad/sec)	
-23.65E-03	23.65E-03	-1.486E-01	1.486E-01
-23.65E-03	- 23.65E-03	-1.486E-01	-1.486E-01
-393.011	0.0	-2.469E+03	0.0
-7.4904	0.0	-4.706E+01	0.0
-53.5979	- 21.7494	-3.368E+02	-1.367E+02
-53.5979	- 21.7494	-3.368E+02	1.367E+02

GuralpZeros (Hz)		SEISAN Zeros(rad/sec)	
-5.03207		-3.162E+01	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
		0.0	0.0

To get the total normalization constant (gain X normalization constant), multiply the sensor sensitivity (in V/m/s) by the SEISAN recording media gain (in ct/V) by the normalization constant or

1125 V/m/s X 3,496,000 ct/V X $4.918(10)^8$ or

$2.121(10)^{18}$

From these values the input file to RESP is:

```
6 4 2.121E+18
-0.1486 0.1486
-0.1486 -0.1486
-2469.36 0.0
-47.064 0.0
-336.766 -136.656
-336.766 136.656
-31.6174 0.0
0.0 0.0
0.0 0.0
0.0 0.0
```

Where the first line indicates 6 Poles, 4 Zeros and total gain constant $2.121(10)^{18}$

The inputs to the RESP program are then:

Output Format **4**	GSE2 PAZ
Type of sensor **1**	No sensor; sensor response is in the Poles and Zeros file
Recording media gain **1**	Gain is included in total gain constant, in file
Digitizer sample rate **50**	This CMG-6TD is set to 50sps
Digitizer model **CMG-6TD**	
Amplifier gain (dB) **0**	All gain included in total gain constant, in file

Number of filters **0**
File name for file with Poles and Zeros **T6330Z.txt**
Number of FIR filter stages **0**
File name for measured values, return for none **<return>**

The terminal session running RESP is shown below. Responses are in **bold**.

```
E:\seismo\WOR>RESP
 RESP - PROGRAM TO CREATE RESPONSE FILES IN SEISAN
        OR GSE FORMAT. THE RESPONSE CAN BE CREATED
        AS POLES AND ZEROS (PAZ) OR FREQUENCY
        AMPLITUDE AND PHASE (FAP). THE SAME
        TRANSFER FUNCTION AND FILTERS ARE USED
        IN BOTH CASES.

 CHOSE OUTPUT FORMAT: 0: NO OUTPUT FILE
                      1: SEISAN FAP
                      2: SEISAN PAZ
                      3: GSE2 FAP
                      4: GSE2 PAZ
4
 TYPE OF SENSOR:       1: NONE
                       2: SEISMOMETER
                       3: ACCELEROMETER
1
 RECORDING MEDIA GAIN (COUNT/V OR M/V) ?
1
 DIGITIZER SAMPLE RATE (BEFORE POSSIBLE FIR FILTER)
50
 DIGITIZER MODEL
cmg-6td
 AMPLIFIER GAIN (DB) ?
0
 NUMBER OF FILTERS (0-10), RETURN FOR NONE ?
0
 FILE NAME FOR FILE WITH POLES AND ZEROS, RETURN FOR NO FILE
t6330z.txt
```

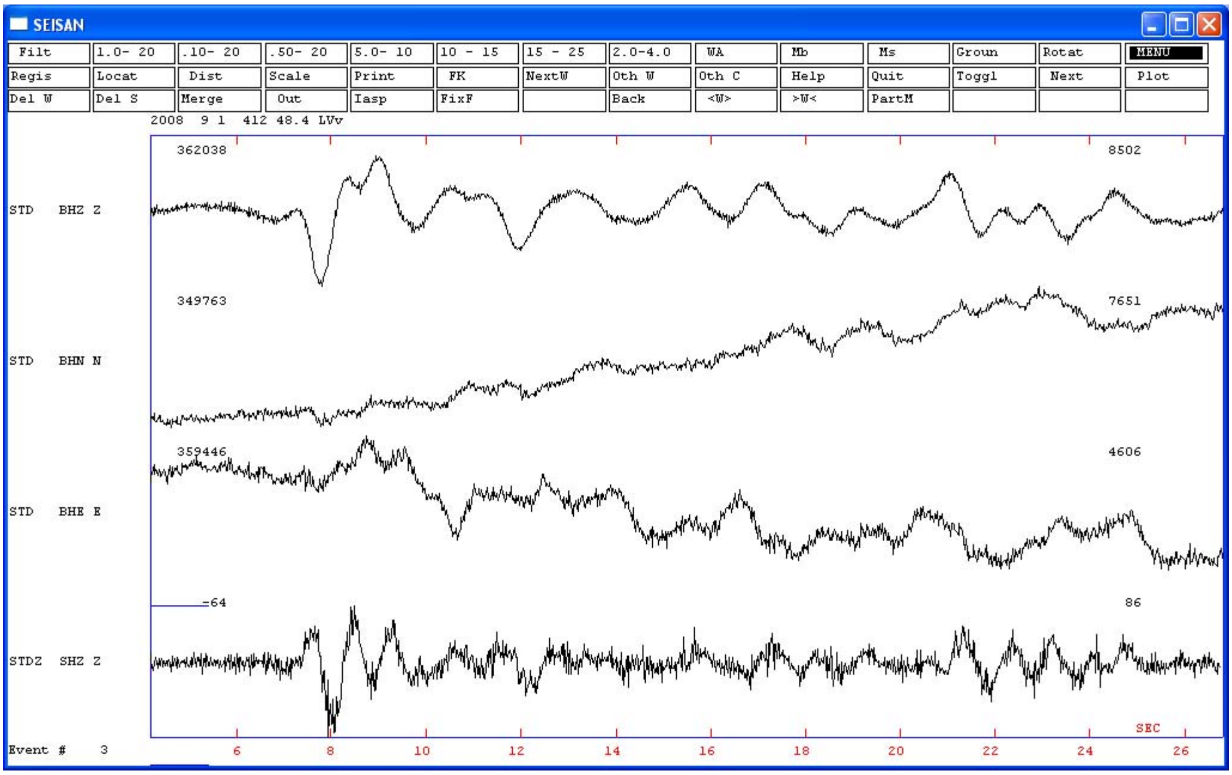
```
           10 poles and zeros
 NUMBER OF FIR FILTER STAGES
0
 FILE NAME FOR MEASURED VALUES, RETURN FOR NO FILE


            AMPLITUDE RESPONSE   NO SENSOR         DISPLACEMENT
 AMPL      ---------------------------------------------------------------
  45.2     I.         .         .         .         .         . +++++++++I
  22.1     I                                                ++++         I
  10.8     I.         .         .         .         .   ++++  .         .I
  5.25     I                                        ++++                 I
  2.56     I. . . . . . . . . . . . . . . . . . ++++. . . . . . . . . . .I
  1.25     I                                ++++                         I
 0.609     I.         .         .      +++.+        .         .         .I
 0.297     I                       ++++                                  I
 0.145     I.         .        ++++       .         .         .         .I
 0.707E-01 I. . . . . . . .++++ . . . . . . . . . . . . . . . . . . . . .I
 0.345E-01 I.         . +++     .         .         .         .         .I
 0.168E-01 I          ++                                                 I
 0.821E-02 I.       ++.         .         .         .         .         .I
 0.400E-02 I       +                                                     I
 0.195E-02 I. . .++ . . . . . . . . . . . . . . . . . . . . . . . . . . .I
 0.953E-03 I    +                                                        I
 0.465E-03 I.  +      .         .         .         .         .         .I
 0.227E-03 I ++                                                          I
 0.111E-03 I+         .         .         .         .         .         .I
           ---------------------------------------------------------------
 FREQ      0.01      0.03      0.14      0.71      3.68     19.19    100.00
GAIN FACTOR AT 1 HZ: 0.277E+11     RETURN FOR PHASE RESPONSE
            PHASE RESPONSE   NO SENSOR         DISPLACEMENT
 PHAS DEG  ---------------------------------------------------------------
  172.     I.         . +       .         .         .         .         .I
  153.     I             ++                                              I
  133.     I.         .    ++   .         .         .         .         .I
  114.     I                 +++++                                       I
  94.5     I. . . . . . . . . . . ++++++++.+++++++++++++++. . . . . . . .I
  75.2     I                                              ++++           I
  55.8     I.         .         .         .         .         ++        .I
  36.5     I                                                    ++       I
  17.1     I.         .         .         .         .         .   ++    .I
 -2.22     I. . . . . . . . . . . . . . . . . . . . . . . . . . . . ++. .I
 -21.6     I.         .         .         .         .         .       + .I
 -40.9     I                                                           ++I
 -60.3     I.         .         .         .         .         .         .I
 -79.6     I                                                             I
 -99.0     I+++ . . . . . . . . . . . . . . . . . . . . . . . . . . . . .I
 -118.     I   ++++                                                      I
 -138.     I.      ++ .         .         .         .         .         .I
 -157.     I         ++                                                  I
 -176.     I.         .+        .         .         .         .         .I
           ---------------------------------------------------------------
 FREQ      0.01      0.03      0.14      0.71      3.68     19.19    100.00
GSE RESPONSE FILE (Y/N=default)?y
Enter station code. e.g. BERGE, max 5 chars
STD
Enter component (4 chars) e.g. SL Z
  First character is type, must be one of the following:
  S: Short period, L: Long period
  B: Broad band,   A: Accelerometer
Last character must be Z,N or E
Character 2 and 3 can be anything
BH Z
Enter date as YYYYMMDDHHMMSS, at least up to the day  (e.g. 19880123):20080103
No gsesei.def file, will use internal information for channel codes
Channel # and name not defined in def file:   1 STD   BH Z
 Constants used:

1: SEISMOMETER PERIOD=         0.00
2: GENERATOR CONSTANT=         1.00
3: DAMPING RATIO     =         0.00
4: AMPLIFIER GAIN(DB)=         0.00
5: RECORDING GAIN=               1.
6: STATION AND COMP=  STD  BH Z
7: DATE AND TIME=     2008 1 3 0 0 0

 Run again: Enter number to change value, enter to end
 End: Enter
```

```
Response file name is: STD__BH_Z.2008-01-03-0000_GSE
 RESPONSE CURVE IS IN FILE resp.out
Stop - Program terminated.
```

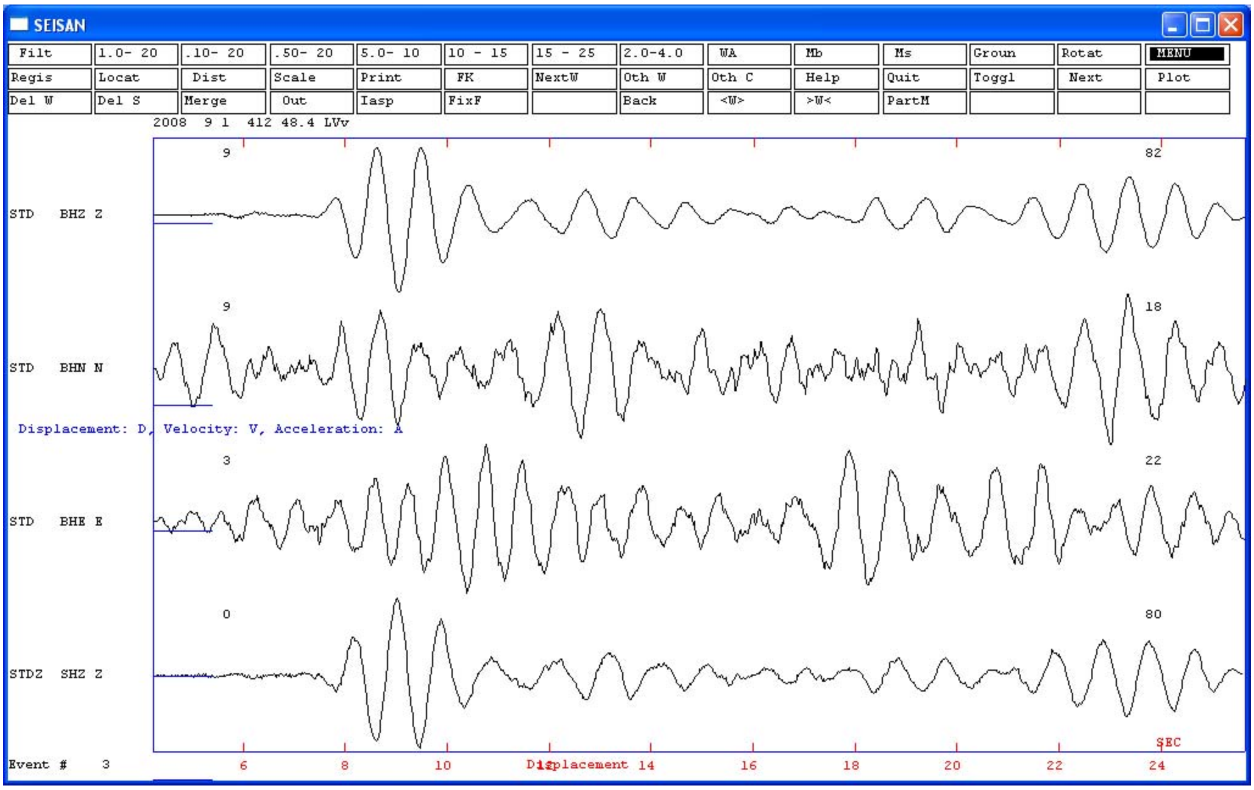
The resulting response file STD__BH_Z.2008-01-01-0000_GSE is

```
CAL2 STD   BHZ                0.36E-01      1.    50.00000 2008/01/03 00:00
PAZ2  1 V  0.21209999E+10                  6    4 Laplace transform
 -0.14860000E+00  0.14860000E+00
 -0.14860000E+00 -0.14860000E+00
 -0.24693601E+04  0.00000000E+00
 -0.47063999E+02  0.00000000E+00
 -0.33676599E+03 -0.13665601E+03
 -0.33676599E+03  0.13665601E+03
 -0.31617399E+02  0.00000000E+00
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
DIG2  2  0.10000000E+01    50.00000 cmg-6td
```

The Guralp CMG-6TD sn T6330 used in this example is co-located with a short-period vertical seismometer at Studebaker Ridge near Mt. St. Helens. The broadband vertical component is STD BHZ CC. The short-period vertical is STDZ SHZ CV (yes, the naming is inconsistent and the CV network code now is reserved for Cabo Verde). The response of STDZ SHZ is well-understood and can be used to check the calibrated response of STD BHZ.



MULPLT display of STD broadband and STDZ SHZ traces of a small low-frequency volcanic event at Mt. St. Helens, unfiltered. (Polarity of STDZ SHZ is inverted.)



The same event as above, filtered at 1.0-20hz band pass, showing ground displacement values. Note the close agreement between STD BHZ and STDZ SHZ.

Routine processing 1: add data to continuous database with AUTOREG; identify & register events with MULPLT

The first stage in the routine processing procedure is to:

- Put data into the continuous database with AUTOREG
- Use MULPLT to page through those data to identify events
- Window out each event and register it into the events database for further processing.

These are housekeeping and event identification tasks that are only done one time. They set the stage for any additional processing, done in the second stage, Routine Processing 2; EEV

To put data into the continuous database, run MULPLT (p 75)

```
E:\seismo\WOR\mulplt
```

You will see this DOS screen:

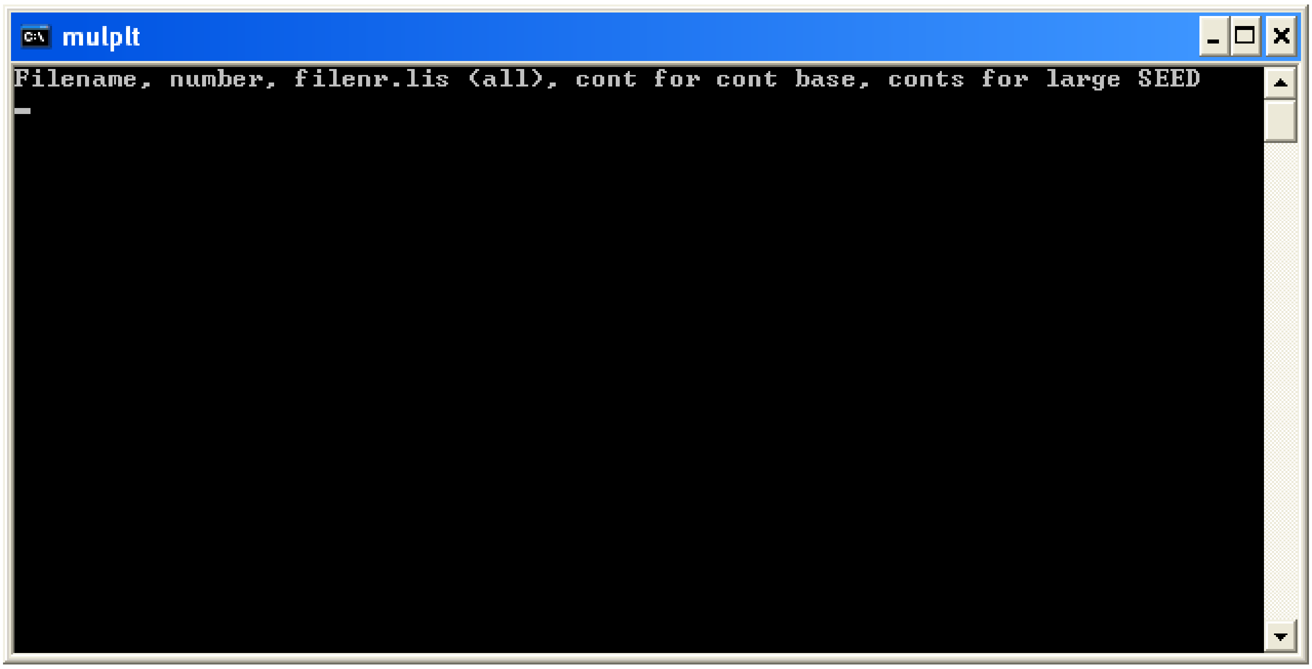


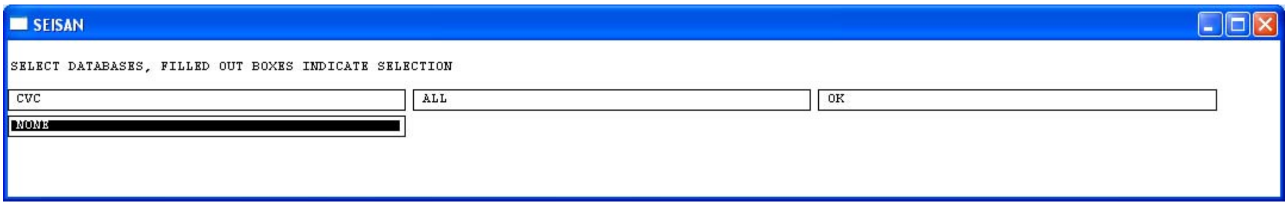
Figure: screenshot of DOS screen with MULPLT response.

Type ‘cont’ (Note: ‘cont’ must be lowercase) for continuous database, then start time and interval as follow:

```
Filename, number, filenr.lis (all), cont for cont base, conts for large SEED
cont
Give start time, yyyymmddhhmmss
20080900
Interval in min
10
```

Data are reviewed one interval at a time; here, 10 minutes. The windows have a 20% overlap, or 2 minutes for a 10-minute window. Despite the overlap, occasionally an events may start in one window and end in the next. Note however that the window length and start of the continuous data can be changed at any time in MULPLT by using the >w< button to reduce the time displayed in the window or the <w> button to increase it.

You will see this screen:



Screenshot of SEISAN window with MULPLT request for cont database selection. Here the only continuous database is CVC.

Click the ‘CVC’ button then ‘OK’.

Now, the previous DOS command screen labeled MULPLT will reappear with the plot options, similar to this one:

```
Filename, number, filenr.lis (all), cont for cont base, conts for large SEED
cont
Give start time, yyyymmddhhmmss
2008090
Interval in min
10
2008  8  Reading events for base CVC__          125

 Plot options: Interactive picking          Return
              Multi trace plot on screen, def (0)
              Multi trace plot on screen      (1)
              Multi trace plot on screen+laser(2)
              Multi trace plot on laser       (3)
              Continuoues on screen           (4)
              Continuoues on screen + laser   (5)
              Continuoues on laser            (6)
              Stop                            (q)
0
 Low and high cut for filter, return for no filter
```

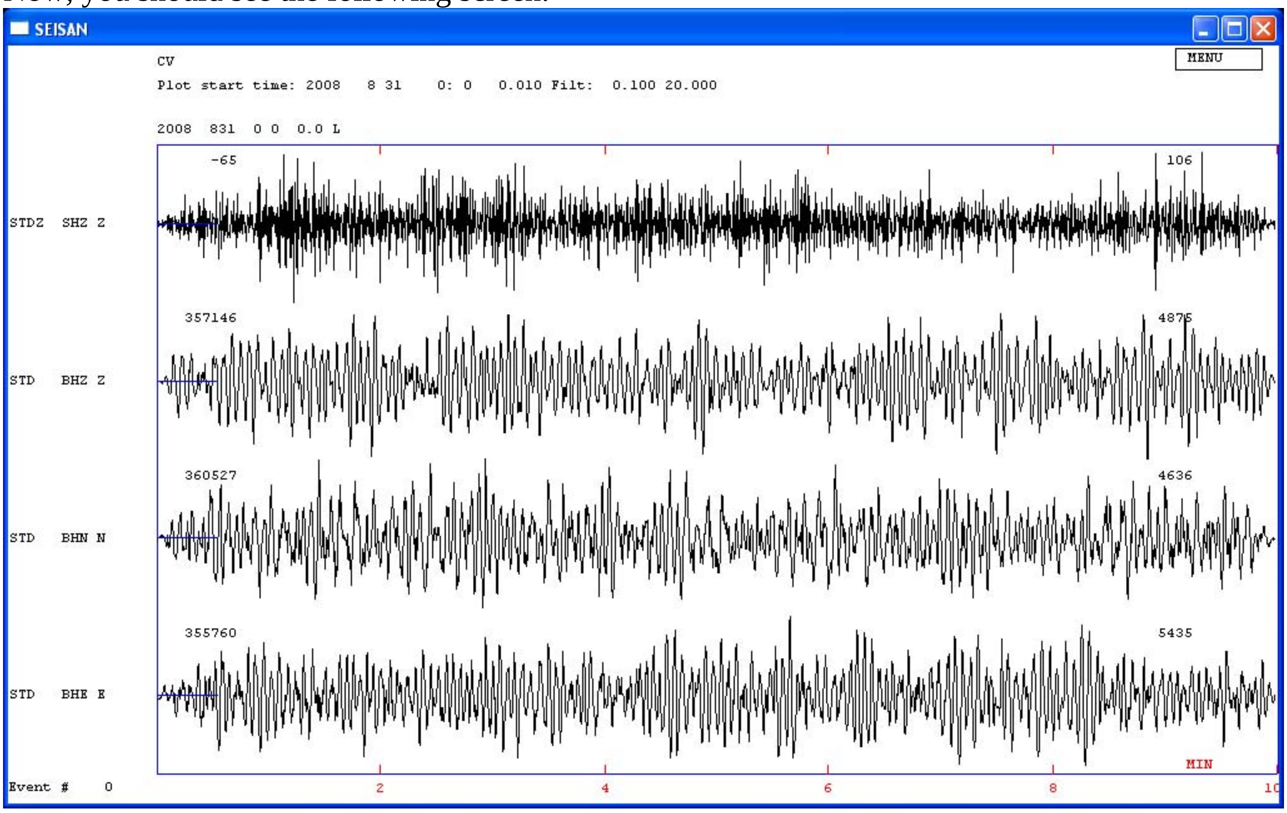
Type ‘0’ for the Multi-trace on screen, def (0) option.
Then ‘.1 20’ for the high and low-pass filters, if you have broadband data. These filter settings allow you to view the broadband data as if it were SP data, and more easily identify events. It is not a permanent filter, only for viewing purposes.

```
…
 Plot options: Interactive picking          Return
              Multi trace plot on screen, def (0)
              Multi trace plot on screen      (1)
              Multi trace plot on screen+laser(2)
              Multi trace plot on laser       (3)
              Continuoues on screen           (4)
              Continuoues on screen + laser   (5)
              Continuoues on laser            (6)
              Stop                            (q)
0
 Low and high cut for filter, return for no filter
.1 20
```

Blank white SEISAN screen that may appear when MULPLT is started.

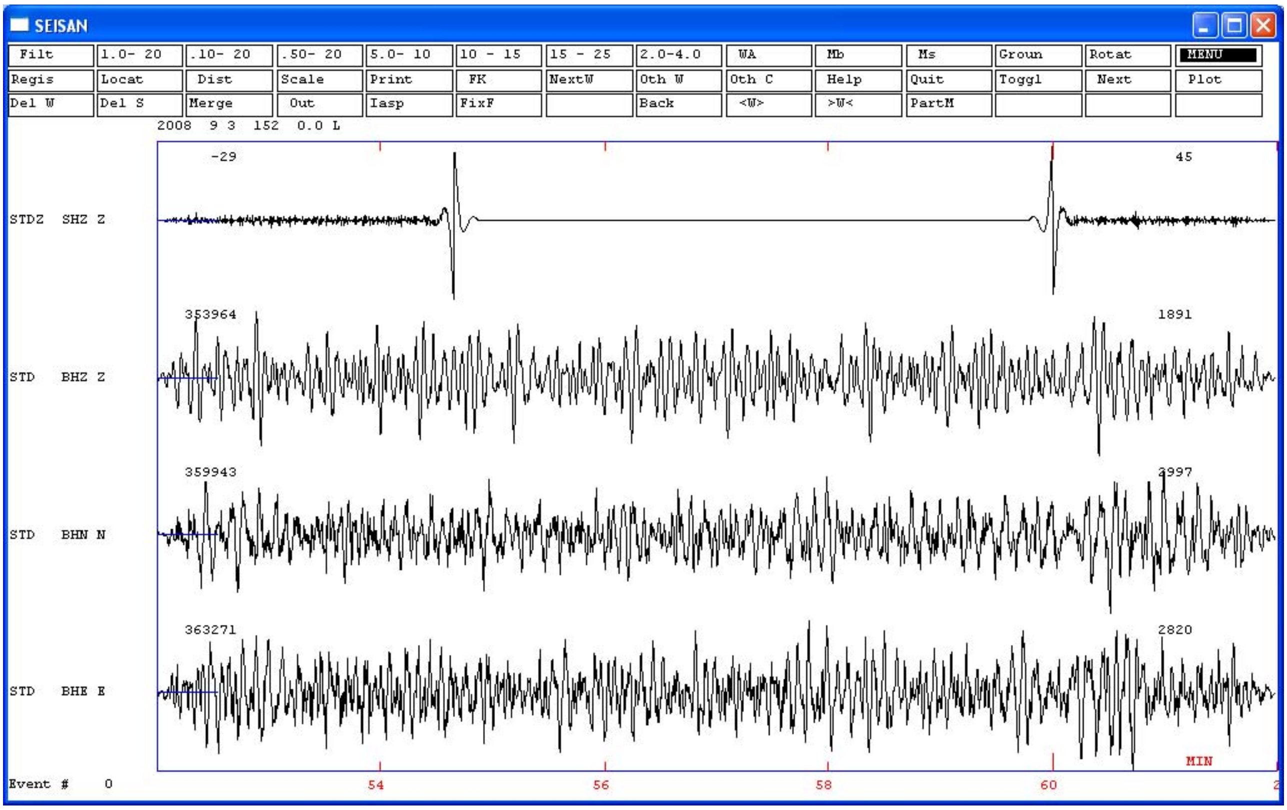
Then this blank white SEISAN screen may appear. Usually, you must move it for it to refresh and display the contents

Now, you should see the following screen:

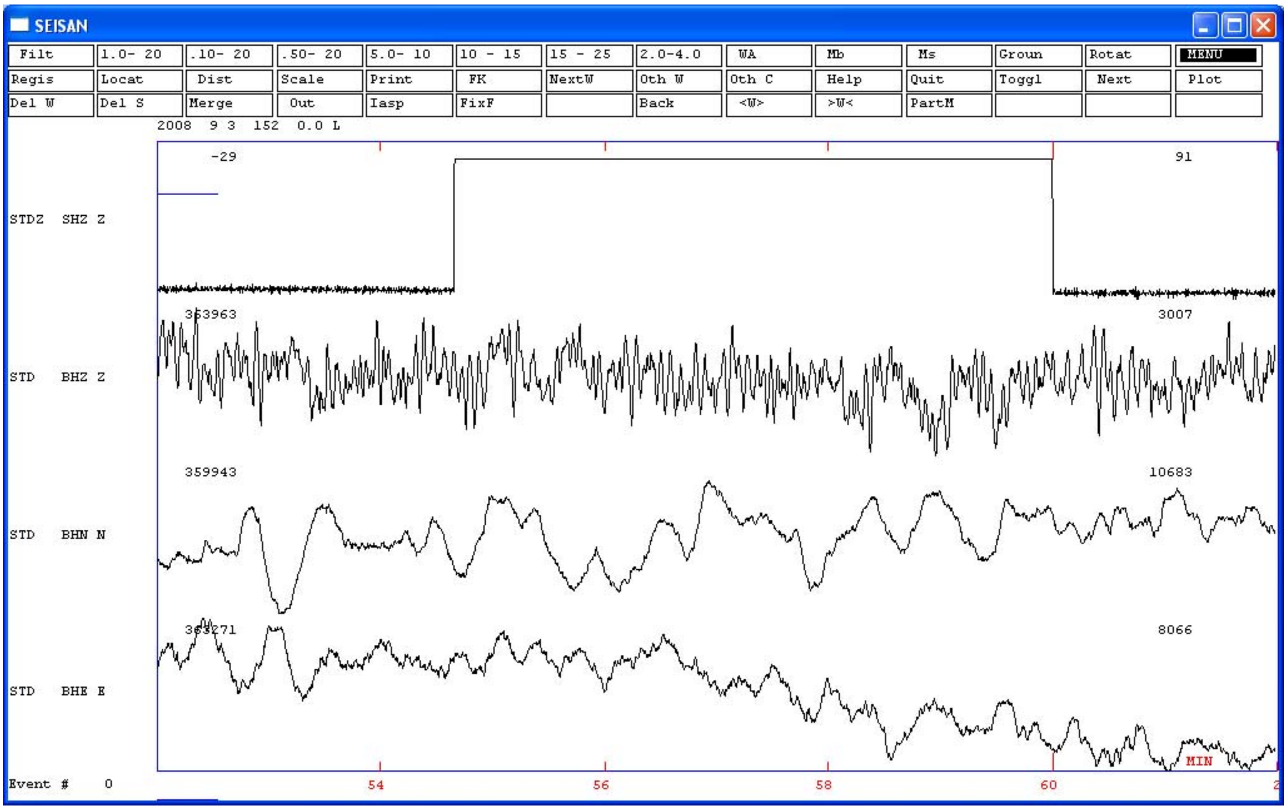


MULPLT screen in multi-trace mode.

Note that the high-pass filter will make the DC offsets caused by discriminator squelching look like waveforms. See the two screenshots below.

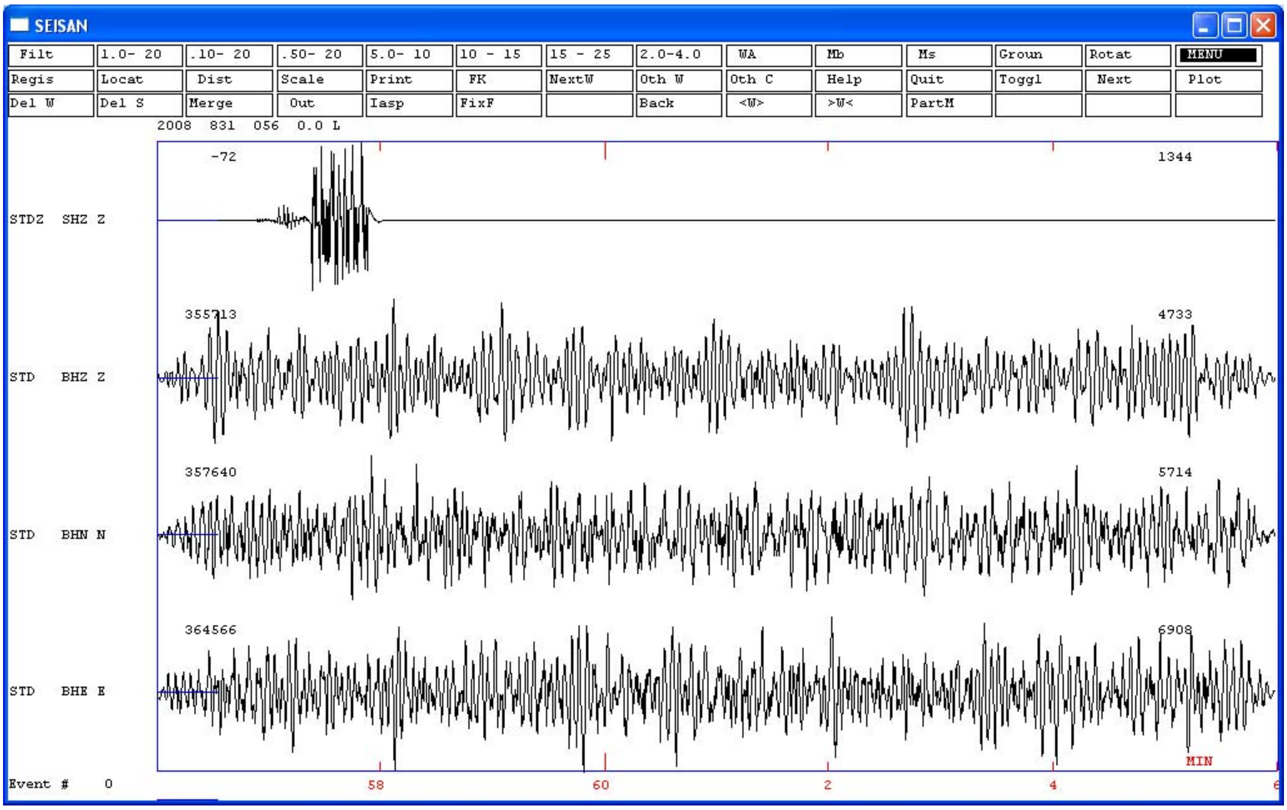


Screenshot of a 0.1Hz – 20Hz filtered data showing distortion of a discriminator squelch on STD SHZ. Compare to the following screenshot of the unfiltered traces.

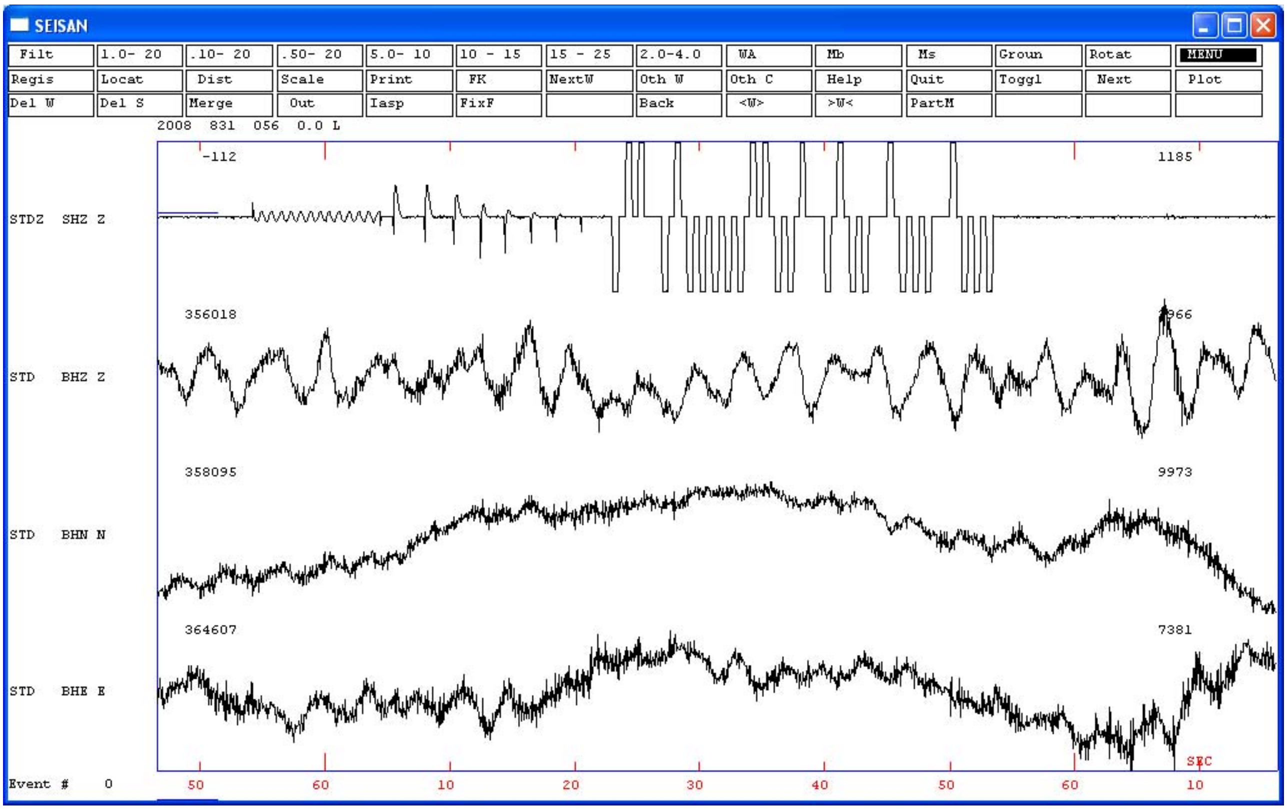


Screenshot; same as above but unfiltered. Note the DC offset of the STD SHZ trace.

Note also that the 10-minute time base, while convenient for detecting events, compresses the waveform too much to accurately identify an event, without further windowing. Here is a McVCO Cal pulse.



McVCO Cal pulse on a filtered, 10-minute trace.



The same cal pulse, in an expanded window for clarity.

Don’t bother increasing the size using the box in the upper right corner as normal with a windows application, since the window will resize itself back down to the original size when you replot. Click the ‘menu’ button to display the menu.

Note that in this example the timing marks are colored red. That is controlled by the \dat\color.def file. The default is black. Note that the time base for each screen is 10 minutes, in this example.

Scroll though the continuous data with the ‘Next’ key. When you see an event you want to extract and register, choose a window around the event, then select ‘Regis’ button to register the event. This will make an s-file for the event, place it in the \rea directory and place the windowed waveform file in the \wav directory. See the following terminal session for an example. Here are the selections made for this event.

Select event type **LV** for ‘Local Volcanic’.

Then you see the contents of the VOLCANO.DEF file, listing possible event types and corresponding numerical codes. Note – you can customize VOLCANO.DEF to suit your own observatory.)

Select sub-class number **3** for hybrid (for example)

Give operator code **andy** (substitute your name/4-char code)

Give database **CVE** for Cascades Volcano events (this example)

Then MULPLT registers the event. You will see many lines of informational output…

GO AHEAD? Type **y** to continue with the default s-file name

Continue Plot? Type **y** to return to the MULPLT multi-trace screen.(Beware. This ‘y’ must be lower case. If you type an upper case ‘Y’, or any other non-‘y’ character, MULPLT will terminate.) Then, window backwards (right to left) to restore the full 10-minute screen that existed before you windowed down to the event.

If there are additional events in the MULPLT window that you want to register, repeat this process for each of them. Then select the ‘Next’ button to move to the next 10 minutes of continuous data.

Here is the terminal session:

```
ENTER EVENT TYPE L,R OR D LV


Current volcano sub-classes:

-------------------------------------
Number Sub-Class Description
-------------------------------------
    1 vt        volcano-tectonic
    2 lf        low frequency
    3 hy        hybrid
    4 tr        volcanic tremor
    5 rf        rockfall
    6 ex        explosion
    7 er        eruption
    8 unk       unknown
    9           QUIT
-------------------------------------
Please enter number for sub-class :
```

```
(Negative number to add to sub-class)
3
Sub-class hy     selected.
 Give operator code (max 4 char)
Andy
 Give 2-5 letter data base, ,, for local dir, return for default base
CVE

wavetool -start 20080831062400 -cwav -duration      600.0 -chansel extract.inp
 -wav_out_file SEISAN -cbase cbase.inp
Databases are:
    CVC
2008  8  Reading events for base CVC__           125
 Total duration:   600.0100
 1 STDZ  SH Z  2008  8 31  6 24  0.010 60000  100.000    0.000  600.000    0.000
    0.000    0. N
 2 STD   BH N  2008  8 31  6 24  0.020 30000   50.000    0.010  600.000    0.000
    0.000    0. N
 3 STD   BH E  2008  8 31  6 24  0.020 30000   50.000    0.010  600.000    0.000
    0.000    0. N
 4 STD   BH Z  2008  8 31  6 24  0.020 30000   50.000    0.010  600.000    0.000
    0.000    0. N
                                4108 244  8 31  6 24  0.010   600.010

 STDZSH Z    0.00   600.00 STD BH Z    0.01   600.00 STD BH N    0.01   600.00
 STD BH E    0.01   600.00




STDZ SHZZ108 244  8 31  6 24  0.010  100.00  60000                          4
STD  BHZZ108 244  8 31  6 24  0.020   50.00  30000                          4
STD  BHNN108 244  8 31  6 24  0.020   50.00  30000                          4
STD  BHEE108 244  8 31  6 24  0.020   50.00  30000                          4
 Output waveform file name is 2008-08-31-0624-00S.CC____004

Stop - Program terminated.


S-file name:   E:\seismo\\REA\CVE__\2008\08\31-0624-00L.S200808
GO AHEAD (Y/N)
y
copy 2008-08-31-0624-00S.CC____004 E:\seismo\\WAV\CVE__\2008\08\

        1 file(s) copied.

 File transferred to WAV **********

 Continue plot(y/n=default)
 y
```

Go through the continuous data screen by screen. At each worthwhile event, size the window to include the entire event, decide what event type it is, register it, and move on through the continuous data to the next event. (After finding and registering all the worthwhile events in the continuous data, you will move to Routine Processing 2, quit MULPLT and start EEV to manually select phase arrivals, amplitudes, and azimuths, look at spectra and particle motion plots.)

After processing through all the continuous waveform files you've temporarily placed in \wor, verify that the waveform files created during the registration were placed in the appropriate monthly directory under \wav\cve. Then, delete the continuous waveform files and the event files from \wor.

During this stage of processing, it is possible to do other tasks within MULPLT before registering the event. Although this might appear to offer the possibility of saving time when processing large amounts of volcano-seismic data, I do not recommend this since some MULPLT functions can perform in an unexpected manner, such as failing to record phase arrivals, when MULPLT is used in stand-alone mode, outside EEV.

Routine processing 2: processing event files in EEV

At this point in routine processing, event files have been culled from the continuous files. The event files reside in an Event directory such as CVE. The next step is to process the event files to determine phase arrivals, coda length, particle motion, spectral parameters, and to verify the event type that was used to identify the event upon registration. All these tasks will be done interactively within EEV, many of them using MULPLT within EEV.

Basic EEV:

EEV is the primary seismic data processing tool in SEISAN. All of the processing tasks shown here can be done within EEV. Several of the important programs such as MULPLT and HYP are run within EEV.

The basic EEV interface shows the name of an event file, numbered from 1 to the number of events in the one-month time period (here, 12), and a question mark prompt. See the terminal session below. EEV commands are entered at the question mark. An 'enter' at the question mark moves to the next event.

Here is a partial listing of EEV commands. The complete set is listed by typing a '?' at the EEV question mark prompt.

```
E:\Seismo\WOR>eev 200809 cve

2008  9  Reading events for base cve__           12
    1  1 Sep 2008  0:31 51  D                                        1  ? ?
----------------------------------------------------------------------
Help on EEV
-----------------------------------------------------------------------

?         Print this help file
#xx:      Go to event # xx, also works without the #
Axx:      Append event # xx to current event, original event
          remains
AA:       Append current event to next event, original event remains
AUTOSIG:  Automatic processing
B:        Back one event
BOUCH:    Run Bouchon's modeling program
BOUSEI:   Make SEISAN file from Bouchon synthetic file
C:        Copy event to another data base or to current directory
COMMENT:  Write comment lines in S-file
D:        Delete current event, you will be prompted to confirm
DUP:      Duplicate current event in data base, different id
Dxxxxxx:  Go to first event on date xx, hour xx, min xx
 Return for next page
E:        Edit
EXP:      Enter explosion information
Eyyyymm:  Let EEV session end with year yyyy and month mm
F:        Make a fault plane solution
GRID:     Locate by grid search
GMAP:     Make epicenter maps with Google Map or Google Earth
GMTMAP:   Makes a GMT map  like the MAP commnad
HERRMANN: Run Herrmann's modelling program (not PC)
HERSEI:   Make SEISAN file from Herrmann synthetic file (not PC)
H:        Locate with Hypoinverse
HYPO71:   Locate with Hypo71
IASP:     Generate arrival times using IASPEI91 tables
IL:       ISC location program (unix only)
INPUTEPI: Input hypocenter and origin time in S-file from st. input
INPUTONE: Input an additional type one line (hypocenter line)
INVRAD:   Make moment ternsor inversion with Invrad
Jyyyymm BAS:Jump to year yy and month mm in base BAS
L:        Locate event, will also calculate magnitude if not
          locatable but distance is present, Hypocenter
 Return for next page
```

```
LL:       Locate current and next event together
Lxx:      Locate current and event xx together
MAC:      Input macroseismic information
MACROMAP: Make a GMT based map of felt information, Unix only
MAP:      Make a map of current location
MODELS:   List MODEL.DEF file in DAT
MOM:      Make moment ternsor inversion with Invrad
NEW:      Add a new event to data base
WKBJ:     Make synthetic seismograms with WKBJ program
O:        Operating system command, e.g. ols is ls, ocd test is cd test
          do not currently work on command with prompt input like epimap and
          collect
P:        Plot event, also make hard copies and pic phases
PO:       Plot event with defaults
PF(IT):   Get back azimuth and app. Velocity for network P-arrival
PITSA:    Start Pitsa program (not on PC)
PRINT:    Print S-file on printer
PMAC:     Macroseismic Windows program
PUT:      Register event
 Return for next page
Q:        Quit EEV
R:        Rename event type, must be L, R or D
REG:      Register event
RMSDEP:   Calculates and plots RMS as a function of depth
SAC:      Run SAC
Sxxxxxx:  Search for next two events which are within xxxxxx seconds. If time
          blank, a default of 180 secs is used
SS:       Find next unprocessed event in base
SYNT:     Make parameters for synthetic modelling
T:        Type event
TT:       Type only header line of event
TTPLOT:   Make travel time plot
UPDATE:   Updates S-file with hypocenter etc.
USERCOM:  Start user defined command as 'usercom -sfile <sfile-name> '
WAD:      Make a wadati diagram
U:        Update list of S-files
W:        Show location of waveform files
Z:        Auto pic current event, if readings available, new pics
          will be added with a flag
```

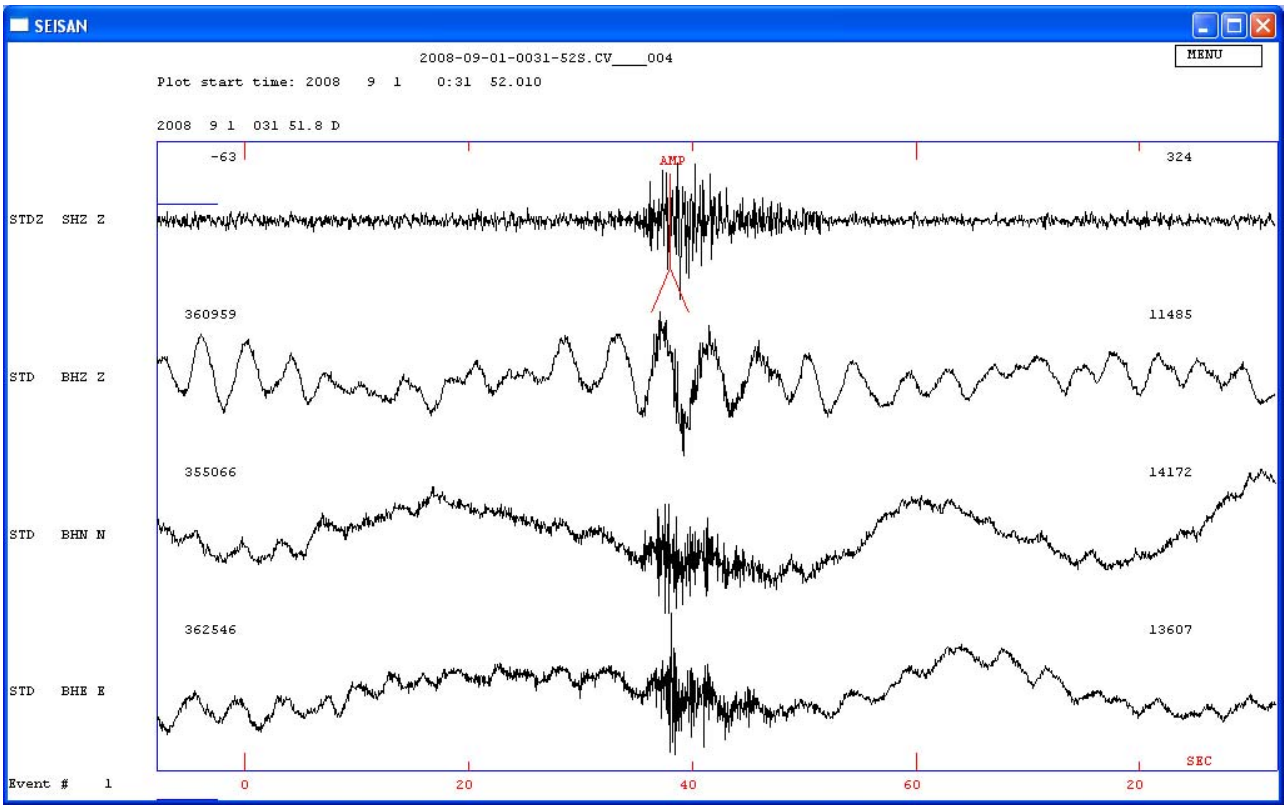
Of these events, the most important to start with are:

```
PO:       Plot event with defaults
L:        Locate event, will also calculate magnitude if not
          locatable but distance is present, Hypocenter
MAP:      Make a map of current location
GMAP:     Make epicenter maps with Google Map or Google Earth
UPDATE:   Updates S-file with hypocenter etc.
E:        Edit
#xx:      Go to event # xx, also works without the #
?         Print this help file
Q:        Quit EEV
```

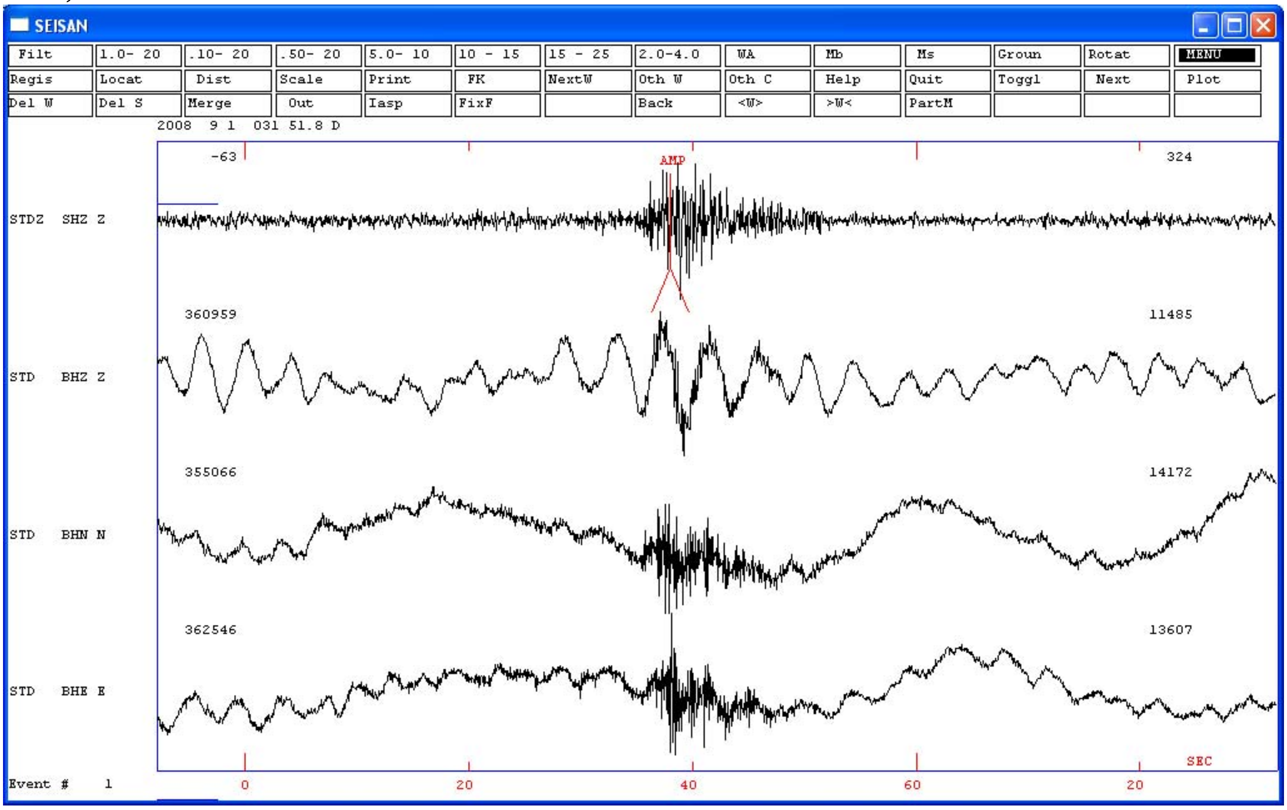
EEV is designed to work with registered events in a specific database within a specific time, usually one month. There are several ways to start EEV (p33). The following is an example from the data used here, in which we select one month (yyymm) of the event database for our volcano:

```
E:\Seismo\WOR>eev 200809 cve

2008  9  Reading events for base cve__          12
    1  1 Sep 2008  0:31 51  D                                      1  ?
```

Type ‘po’ (‘p’ and letter ‘o’, not number ‘0’) to start MULPLT with defaults. Get the MULPLT screen as below.



Now, hit the ‘MENU’ button to see the MULPLT functions available in multitrace mode.



MULPLT is intended to function within EEV, and works better within EEV than in stand-alone mode.

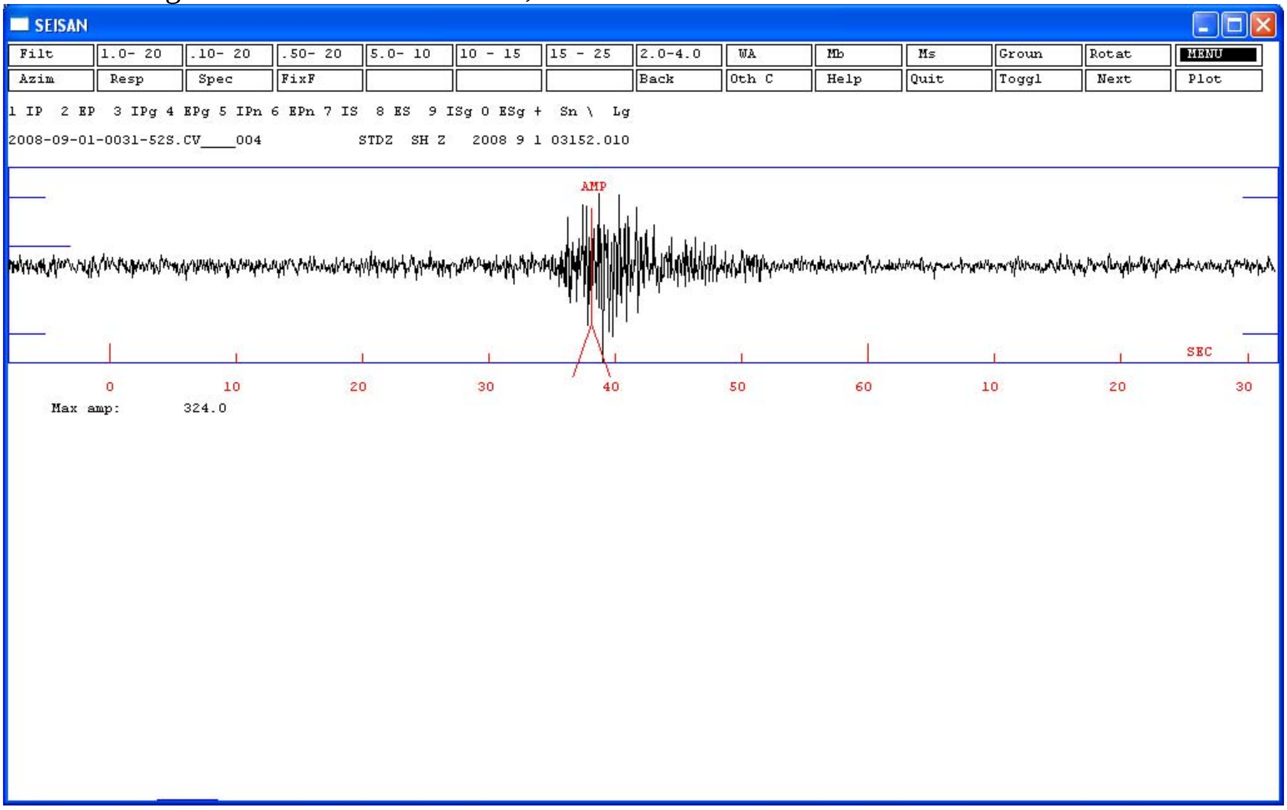
.

Event type determination:

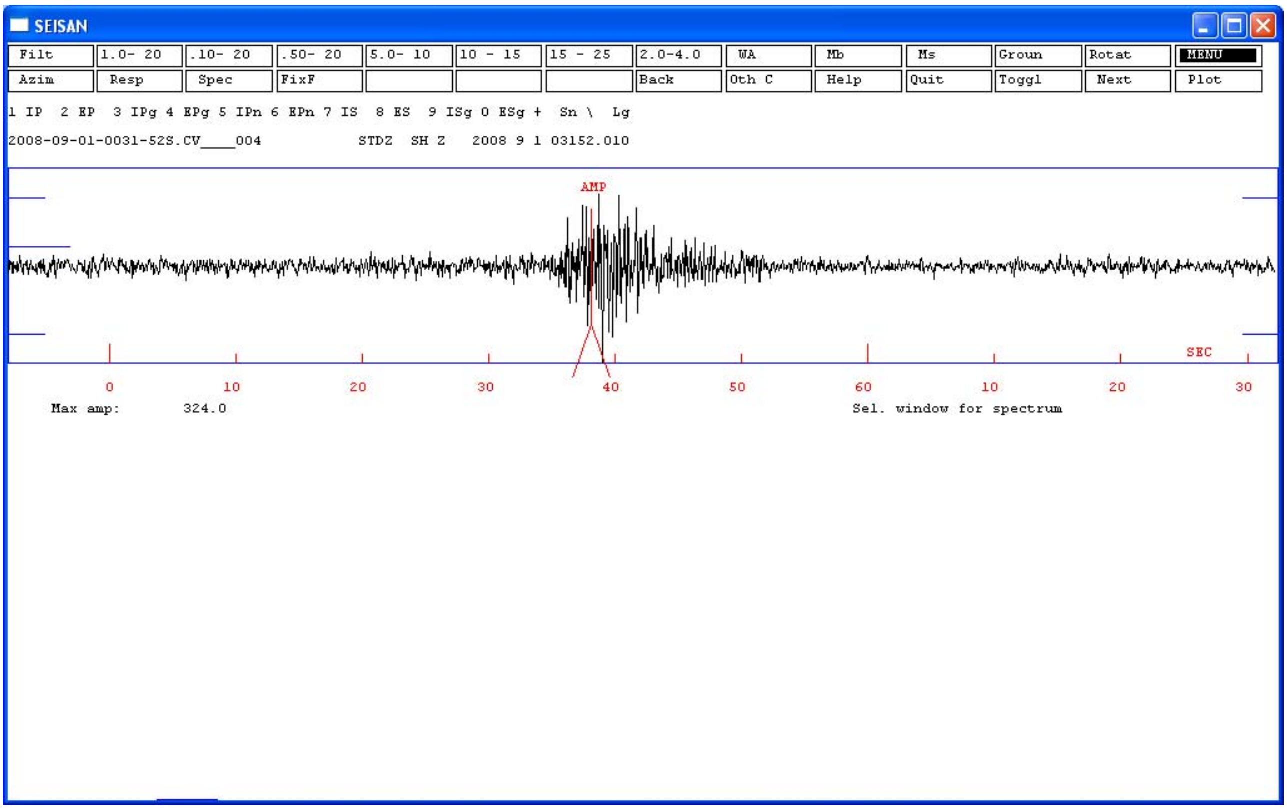
Event type determination may be done by eye as a first pass when registering events into the event database (ie CVE). Normally the frequency content and pattern must be recognized to determine the event type. This work is rapidly done with SWARM, but can also be done in SEISAN. Particle motion can be used in SEISAN as well.

Viewing event spectrum:

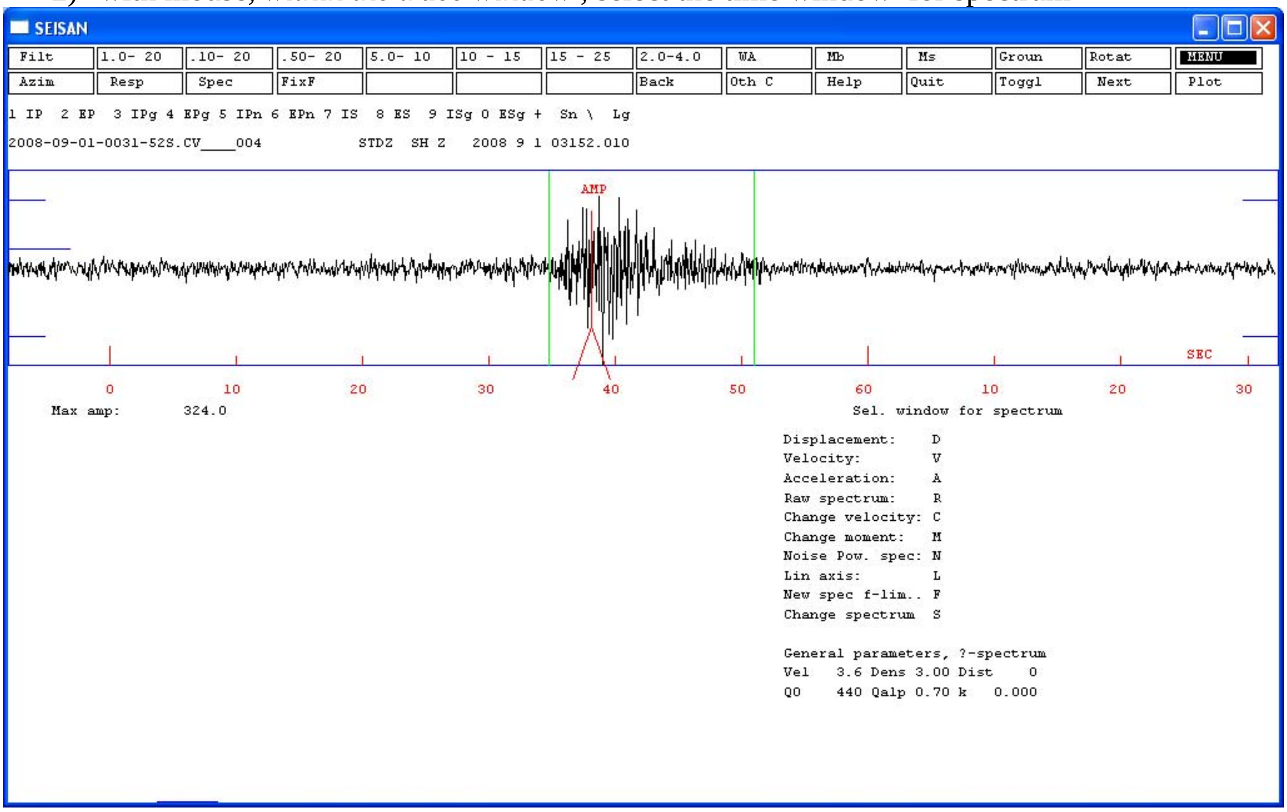
From the multitrace mode in MULPLT, Select the ‘Toggl’ button to toggle to single-trace mode. From the single-trace mode in MULPLT,



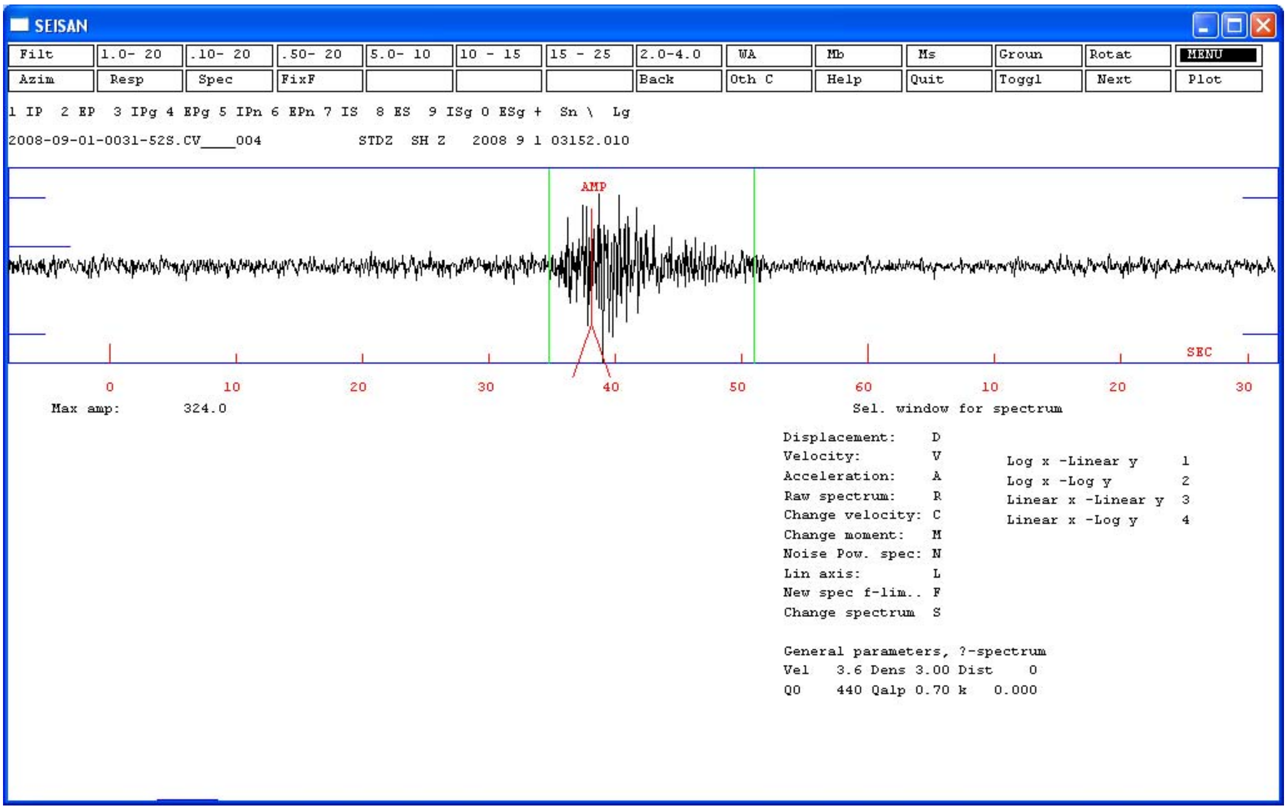
1) type upper-case ‘S’. If you select the ‘Spec’ button or type lower-case ‘s’, the plot shows the noise spectrum as well, which just clutters it up.



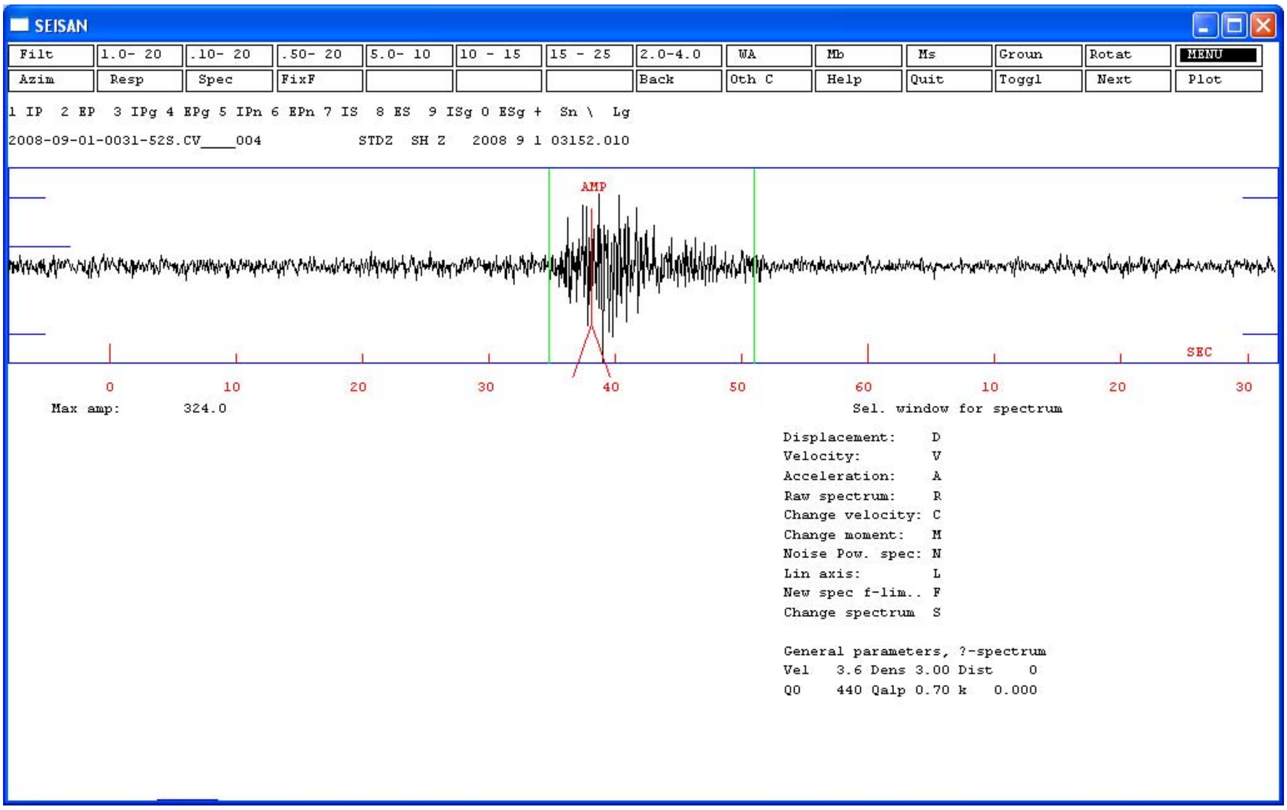
2) with mouse, *within the trace window* , select the time window for spectrum



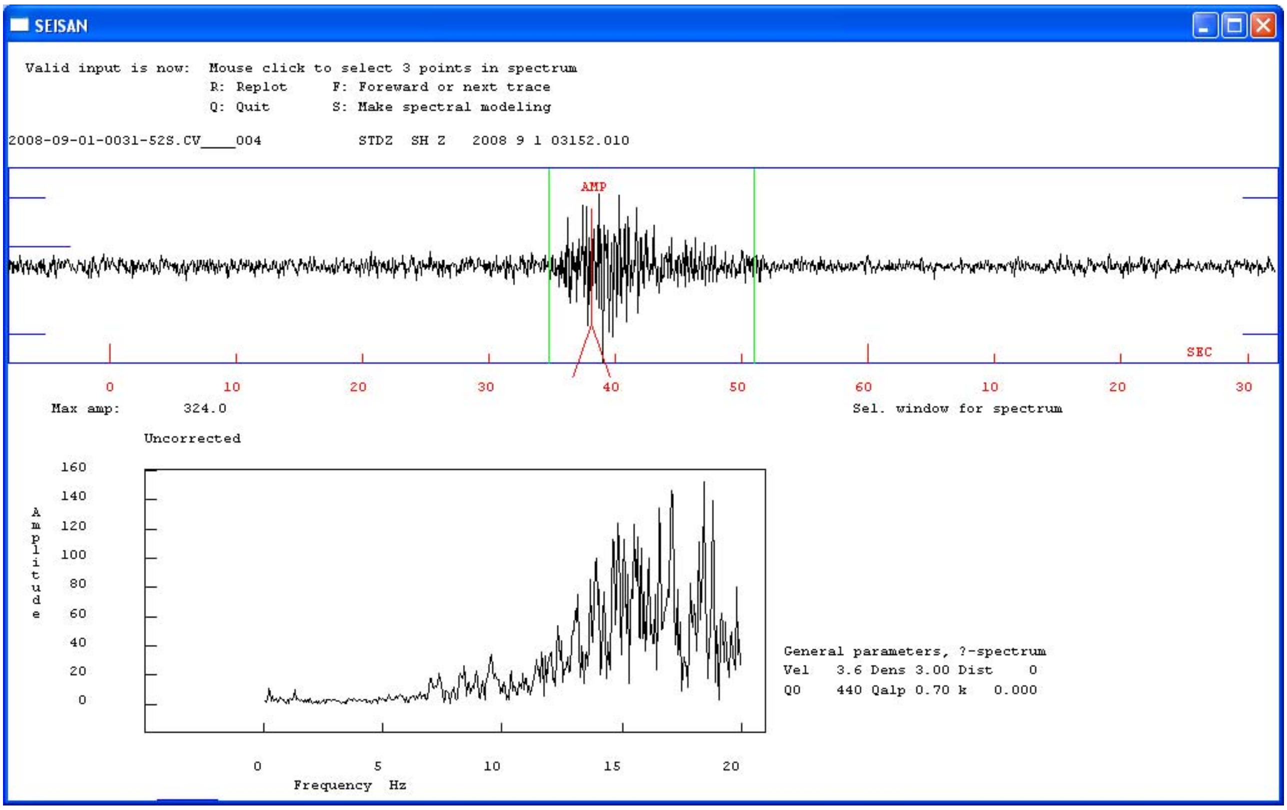
3) type lower-case ‘l’ for ‘linear axes’



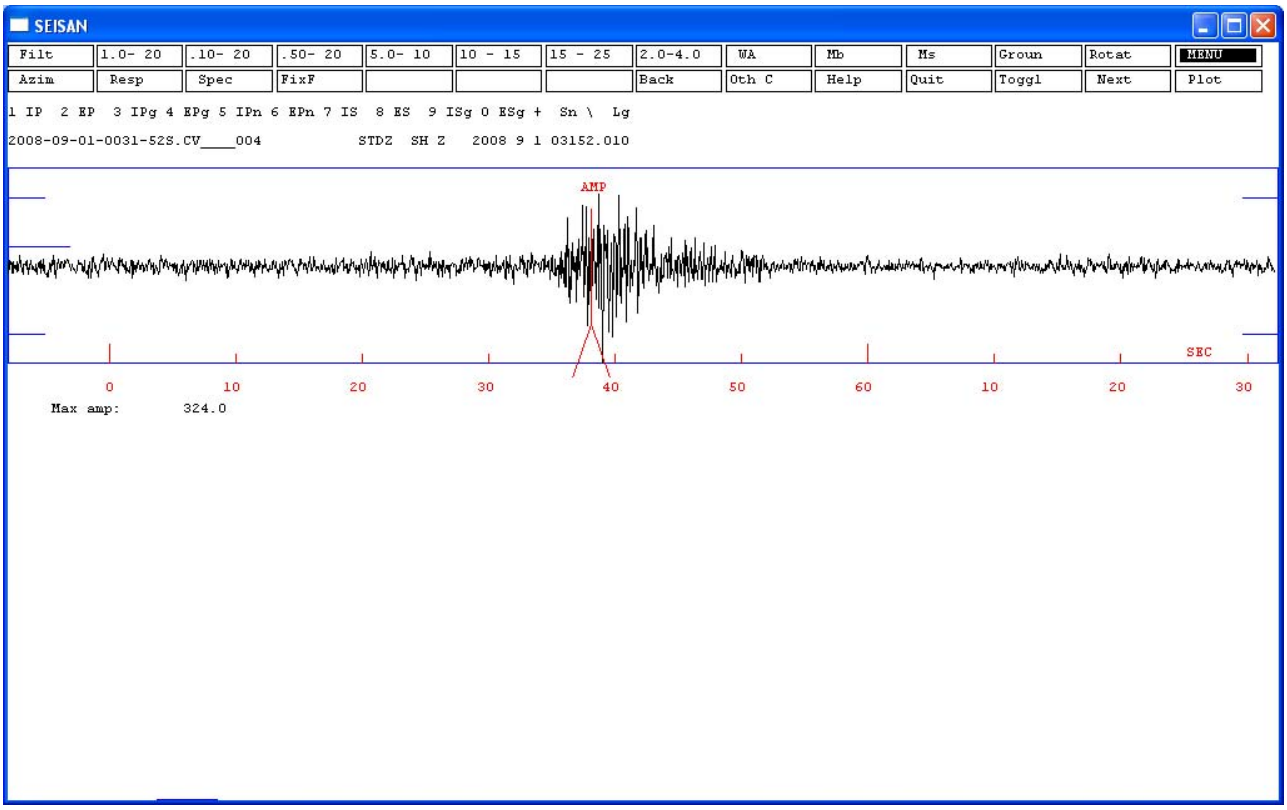
4) type '3' for linear scales on x & y axes



5) type lower-case 'r' for 'raw spectrum'

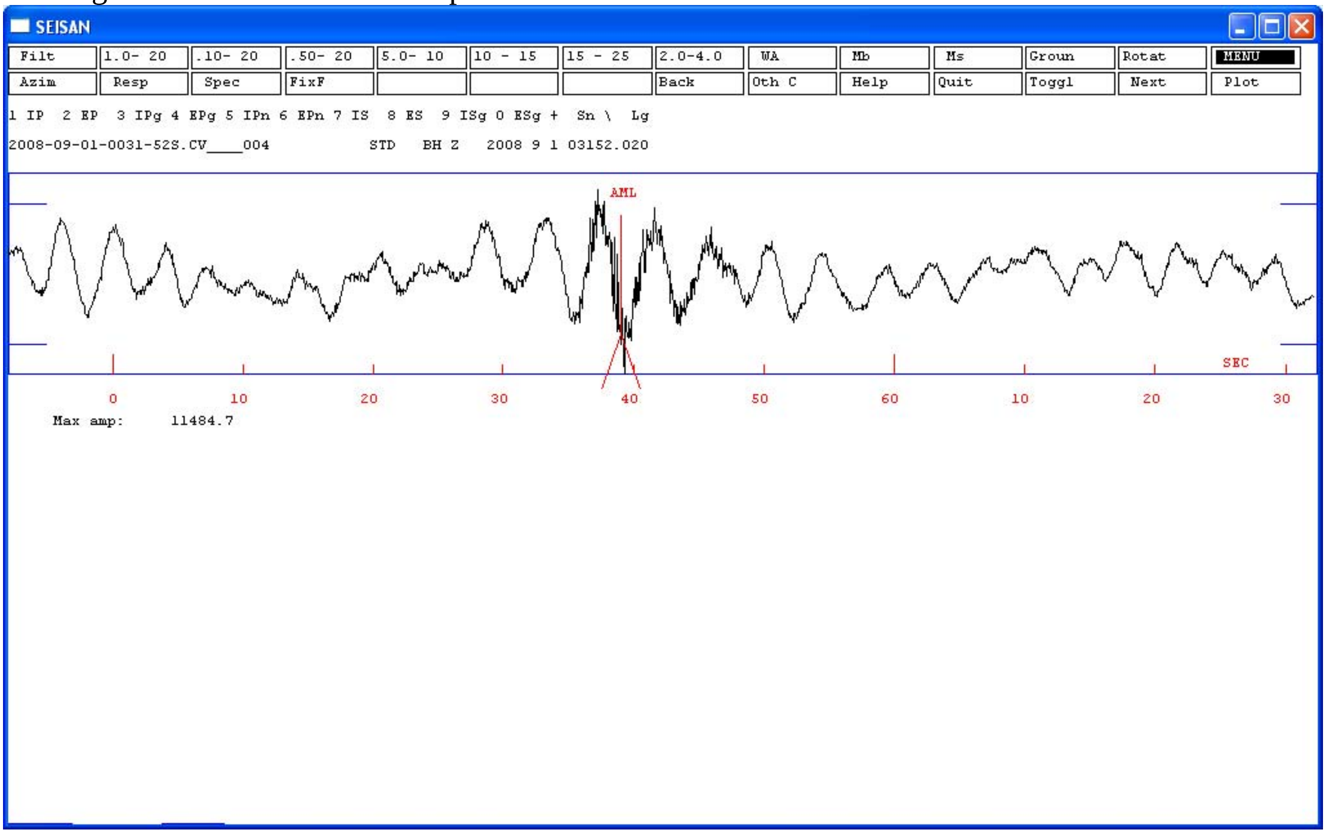


6) note the peak frequency plus the upper and lower half-power points for event characterization. This example shows a high-frequency event, with a peak frequency of approximately 17Hz and half-power points at 12 and 19Hz.
7) type R (upper or lower-case) to replot the single-trace.

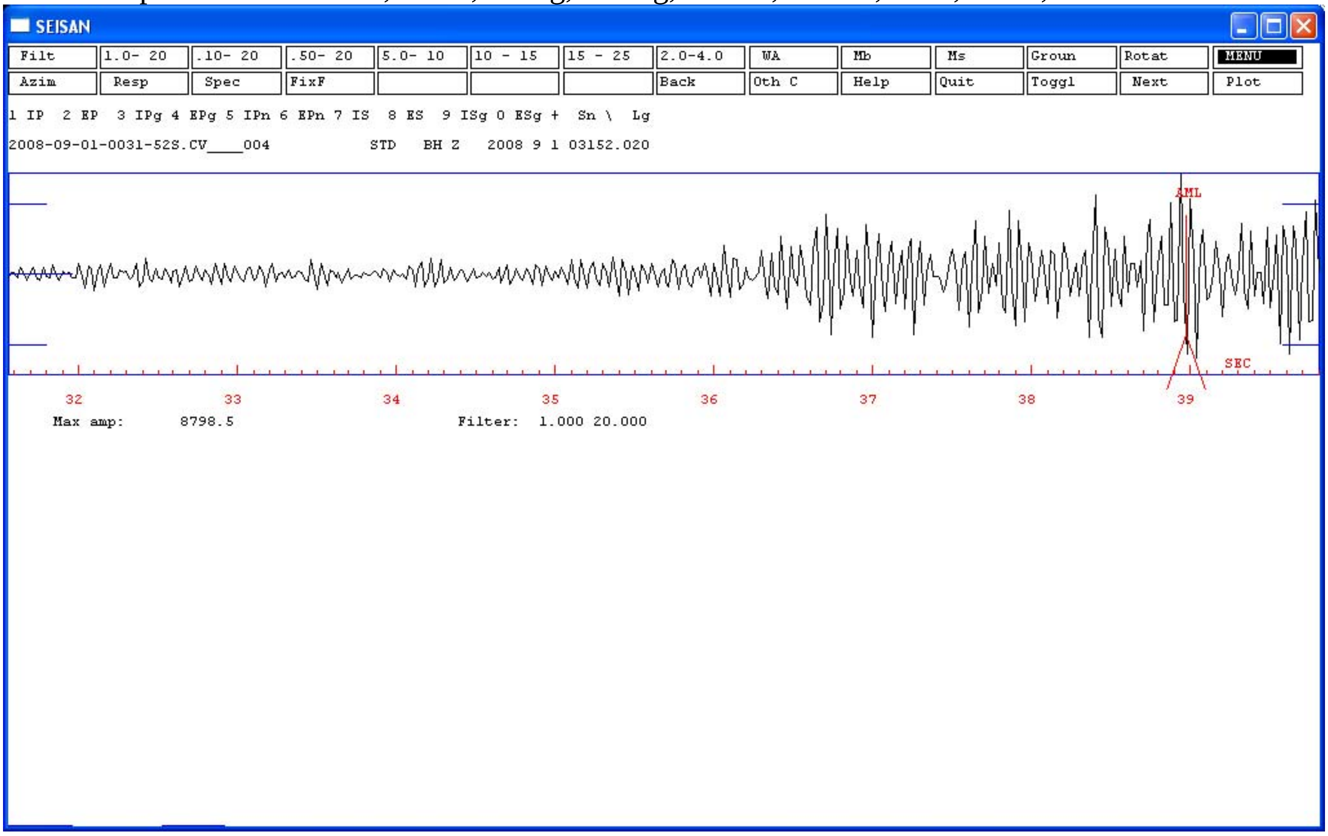


Phase arrivals and coda selection

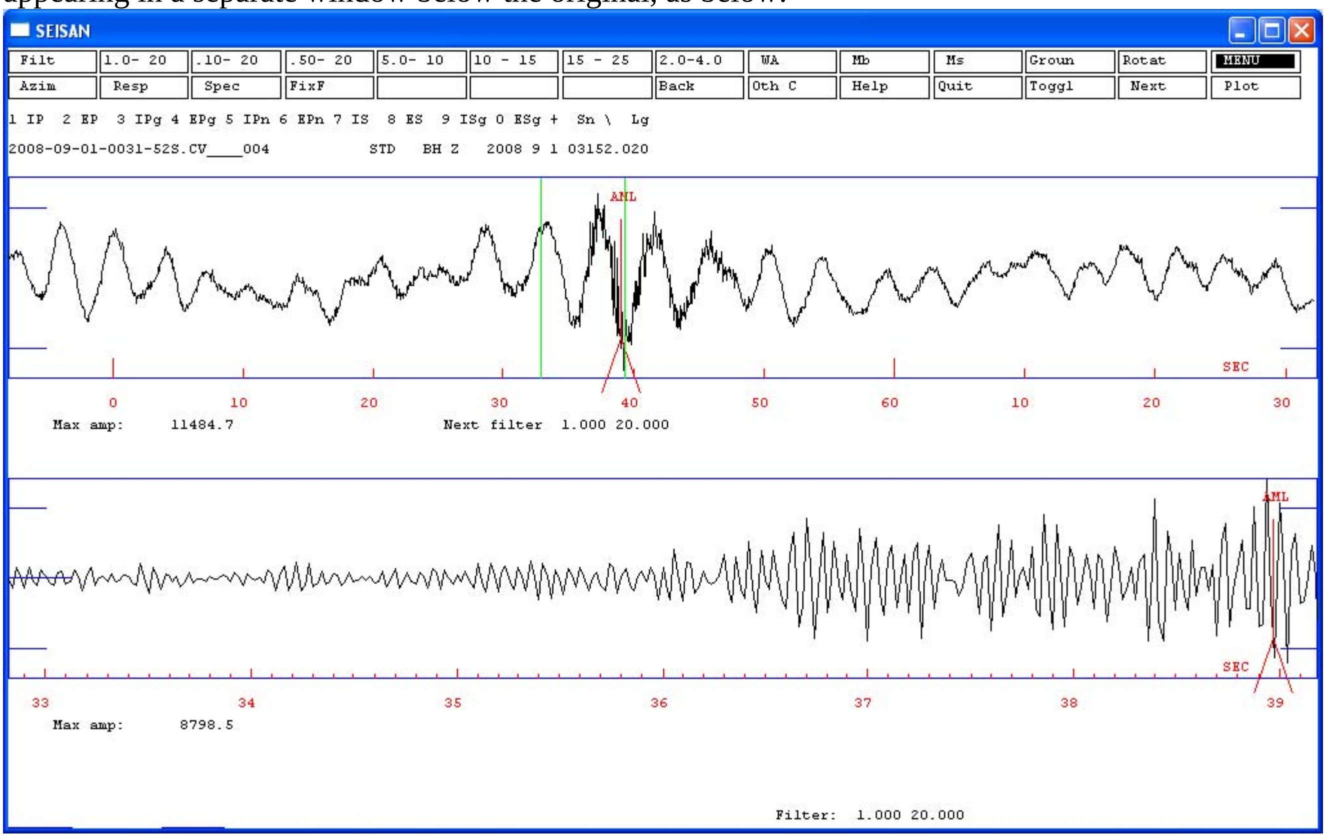
Phase arrivals and coda selsction can be done in both multitrace and single trace modes. Here, we use single trace mode to select the p-arrival of the STD BZ trace:



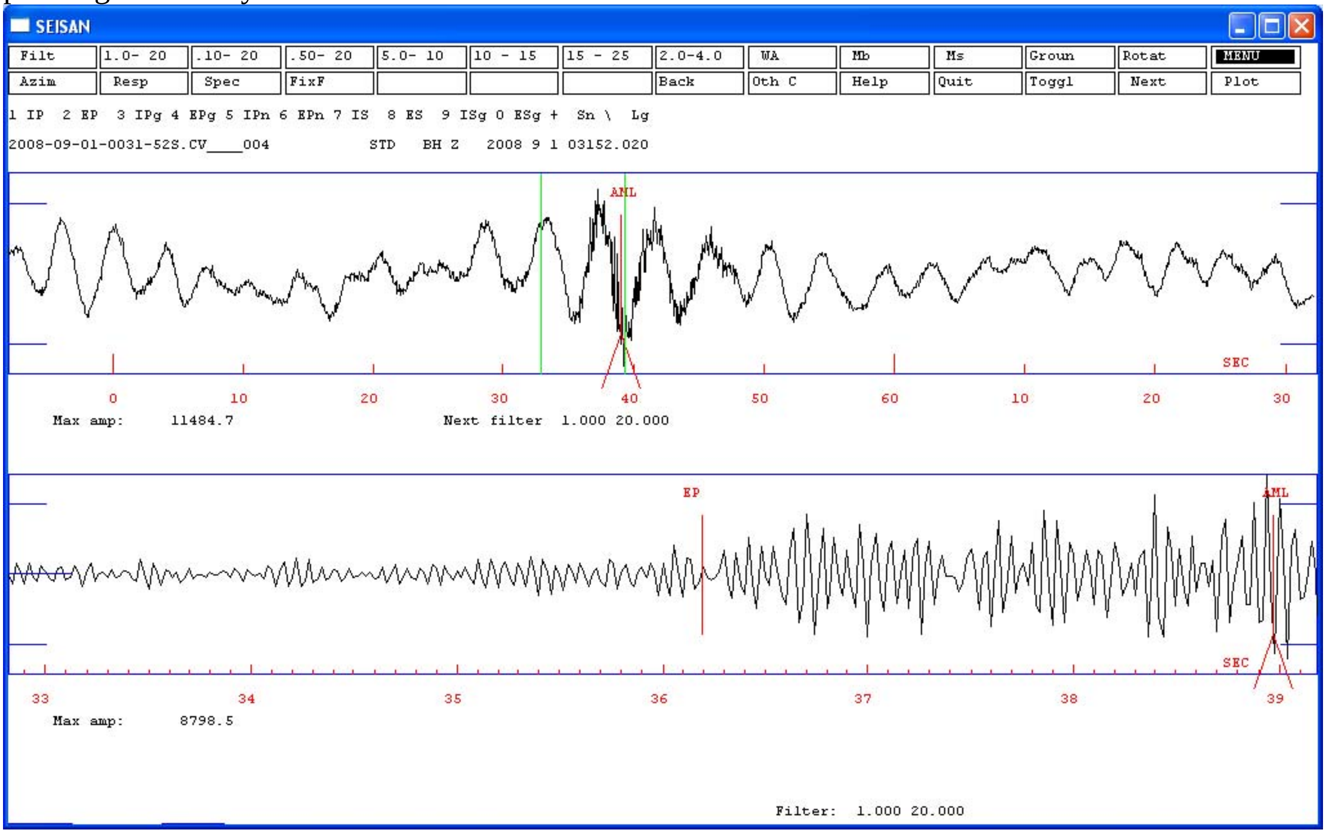
First, select the 1.0-20Hz filter to remove the long-period portion of the broadband trace by pressing the '.10- 20' button. The text 'next filter 1.000 20.000' will appear at the bottom of the MULPLT window. Then, select a window around the start of the event, clicking *above* the trace window, to get the screen here. Note the text on the single-trace screen designating the number key to select a phase arrival: 1=IP, 2=EP, 3=IPg, 4=EPg, 5= IPn, 6=EPn, 7=IS, 8=ES, etc.



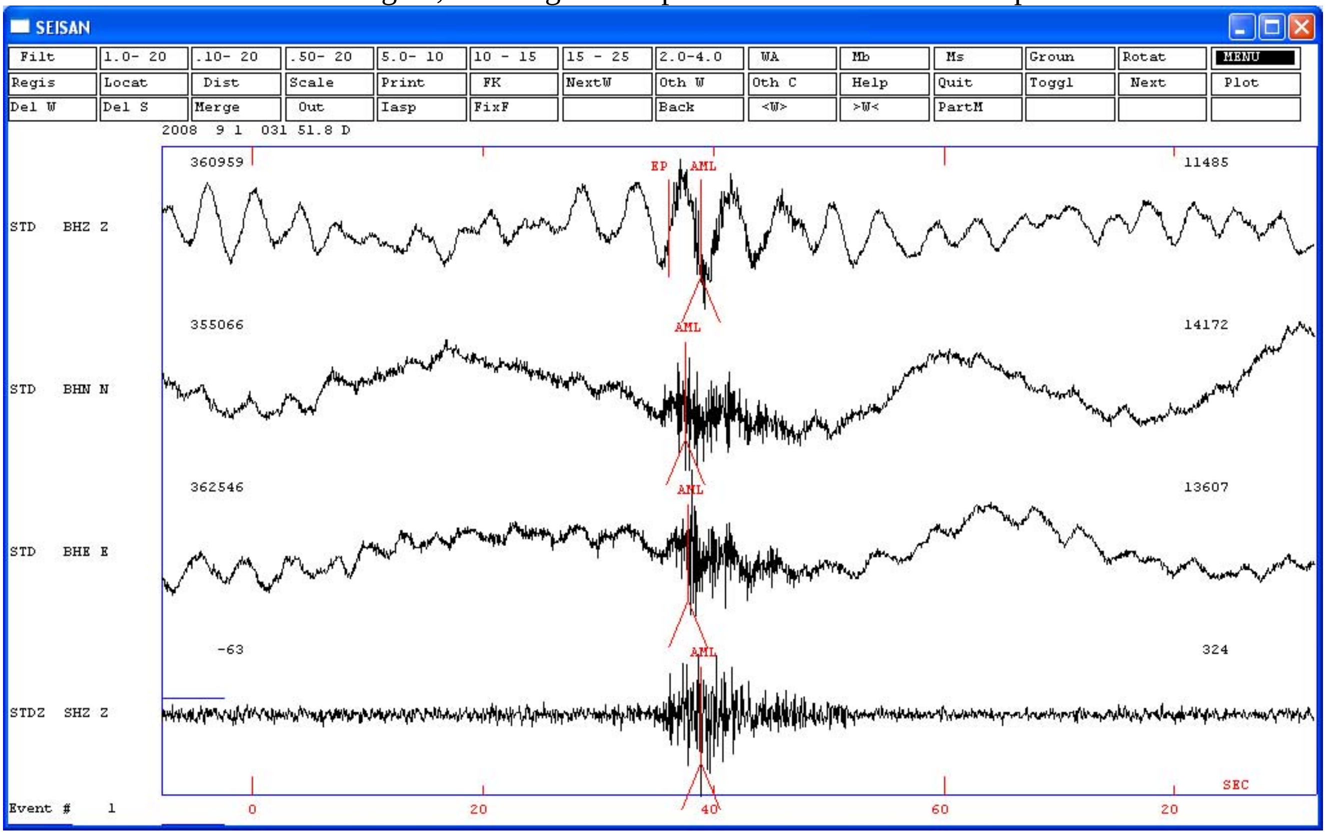
Note that selecting a window by clicking inside the trace window results in the windowed trace appearing in a separate window below the original, as below:



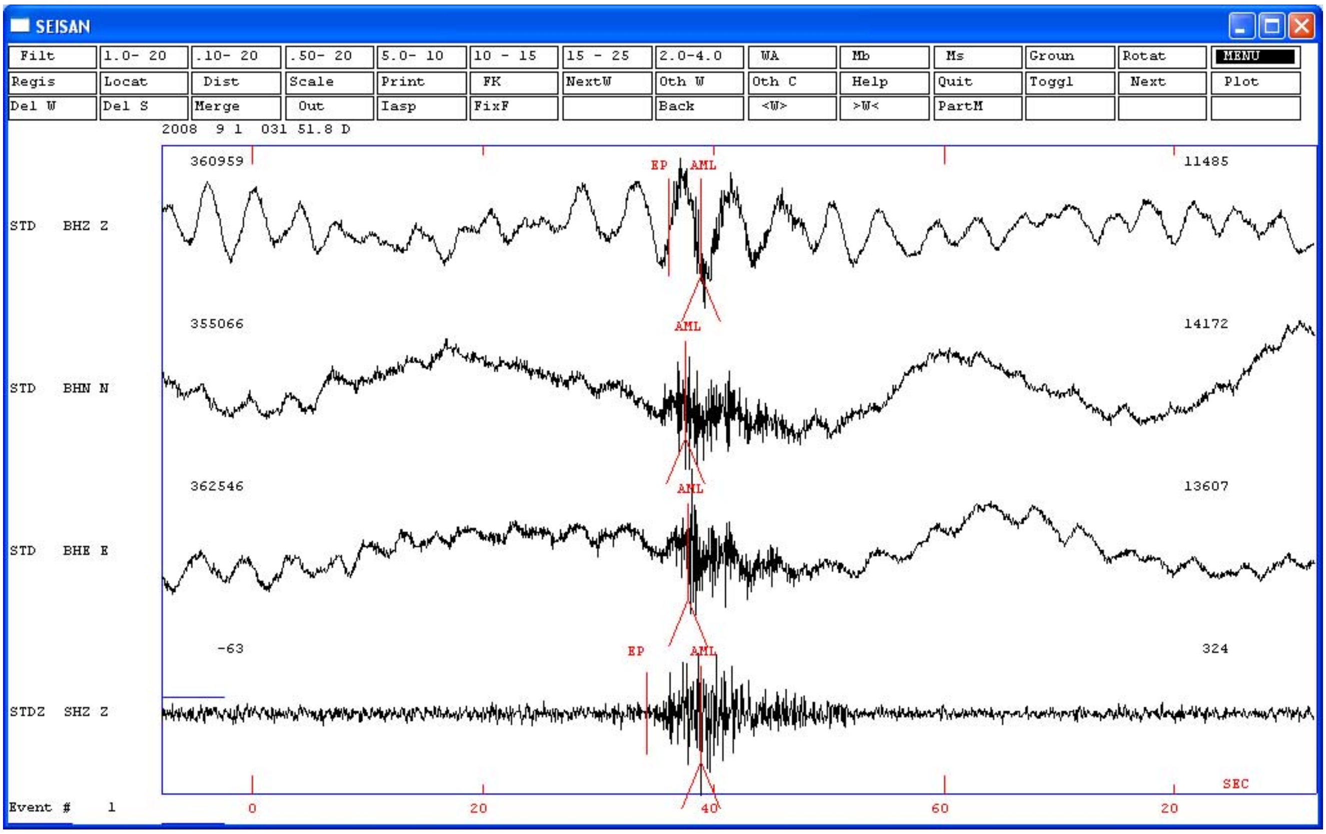
Here, I have picked an emergent P wave EP by placing the pointer over the lower waveform and pressing the '2' key:



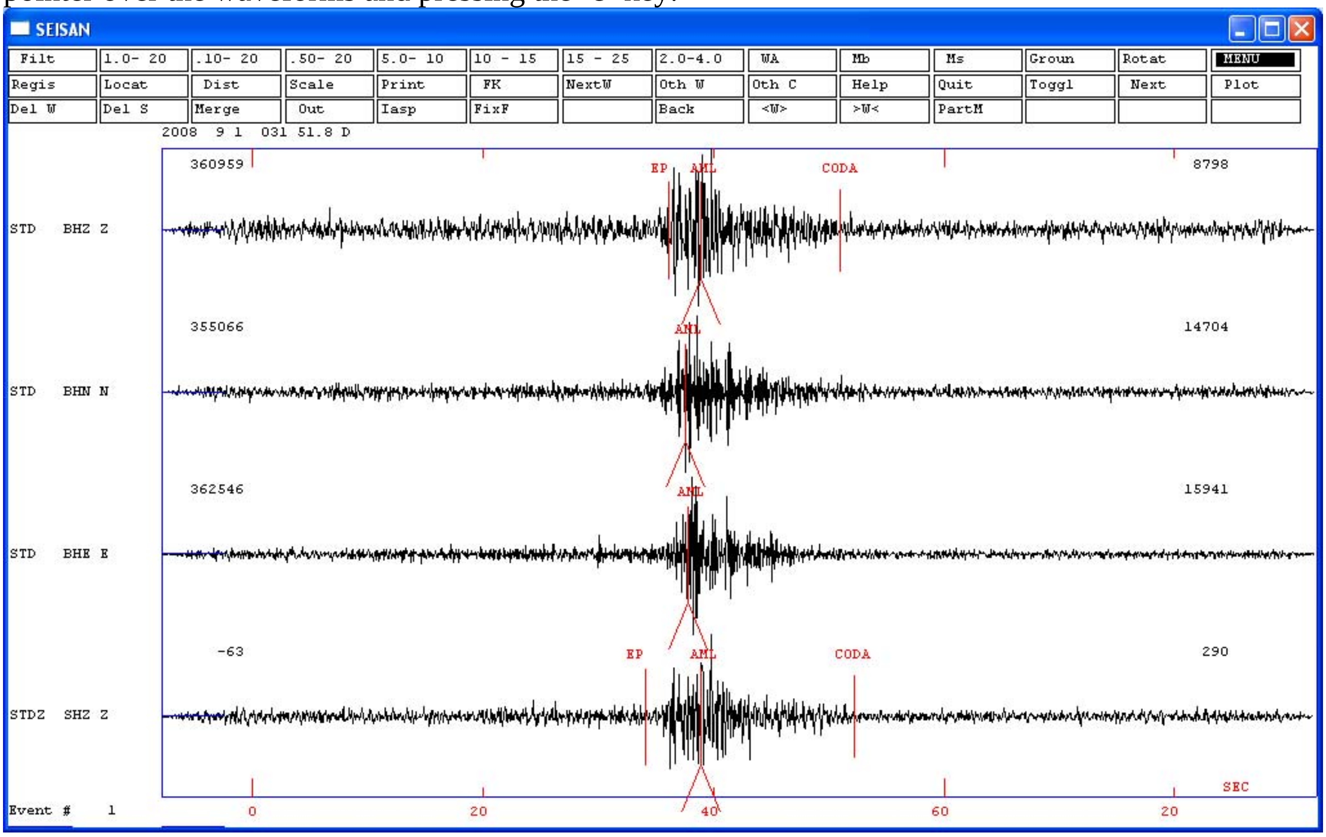
Here is the multitrace mode again, showing the EP picked on the STD BZ component



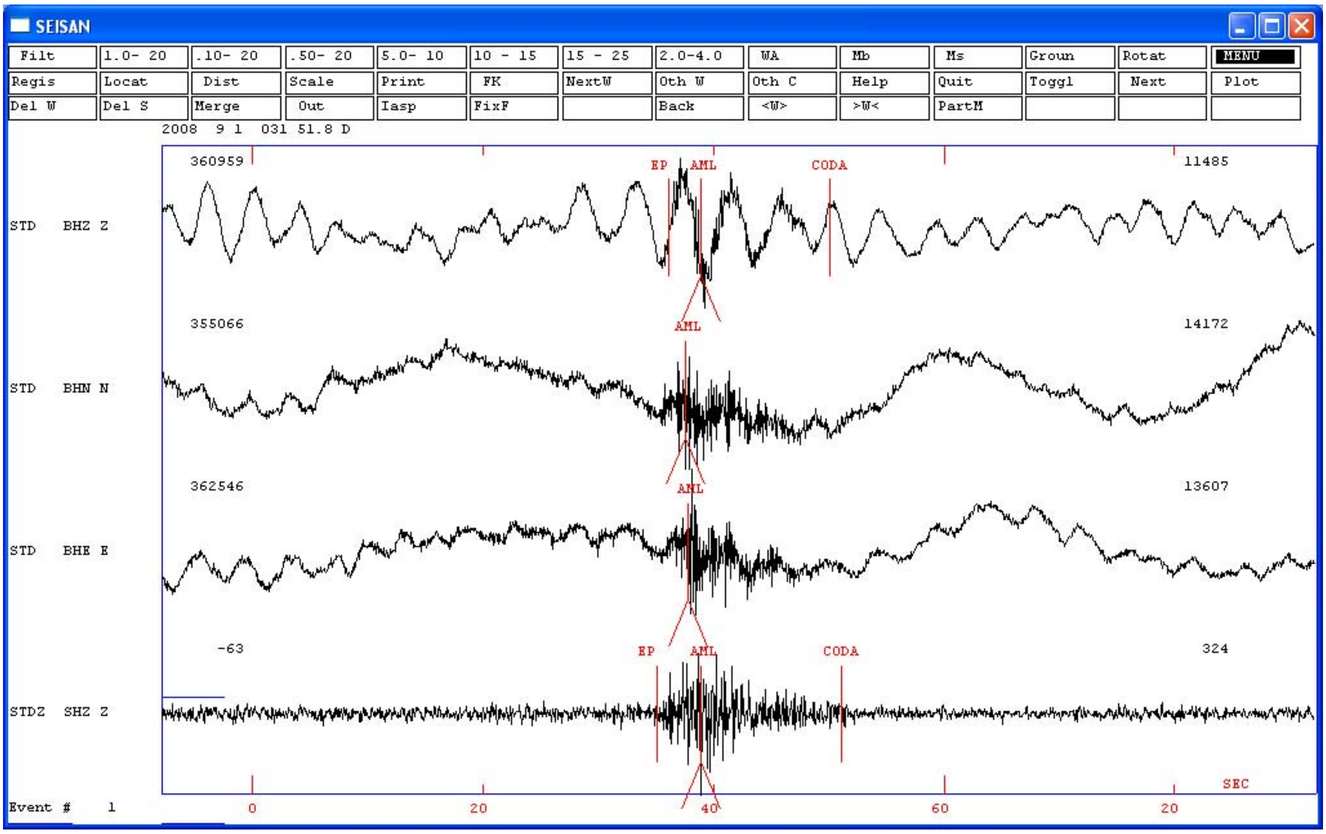
And here is an EP picked from the multitrace screen on the STD EHZ trace:



Here, I have selected codas on STD SHZ and STD BHZ by filtering at 1-20Hz, hovering the pointer over the waveforms and pressing the ‘c’ key.



Here, I have changed the P arrival on STDZ SHZ. Delete the unwanted phase by moving the cursor over the EP line and pressing ‘d’, then move the cursor to the desired phase arrival time and pressing ‘2’.


SEISAN
Filt
1.0- 20
.10- 20
.50- 20
5.0- 10
10 - 15
15 - 25
2.0-4.0
WA
Mb
Ms
Groun
Rotat
MENU
Regis
Locat
Dist
Scale
Print
FK
NextW
Oth W
Oth C
Help
Quit
Toggl
Next
Plot
Del W
Del S
Merge
Out
Iasp
FixF
Back
<W>
>W<
PartM
2008 9 1 031 51.8 D
360959
EP
AML
CODA
11485
STD BHZ Z
355066
AML
14172
STD BHN N
362546
AML
13607
STD BHE E
-63
EP
AML
CODA
324
STDZ SHZ Z
SEC
Event # 1
0
20
40
60
20

Magnitude determination

MULPLT allows you to calculate magnitudes in most standard techniques; M_l, M_c, M_s, M_b, M_w. Local magnitude Ml, coda magnitude Mc, and moment magnitude Mw are the most useful magnitudes in volcano monitoring. This document sketches the techniques for determining M_c and M_l since they are the most common. The document 'Processing Earthquake Data' Havskov & Ottemoller, 2008 has a very good treatment of the different magnitude estimations, and practical applications.

Local Magnitude, M_l

M_l is determined by measuring maximum ground motion in data filtered to simulate the response of a Wood Anderson seismometer. There must be a response file for the station, dated before the event whose magnitude is to be determined.

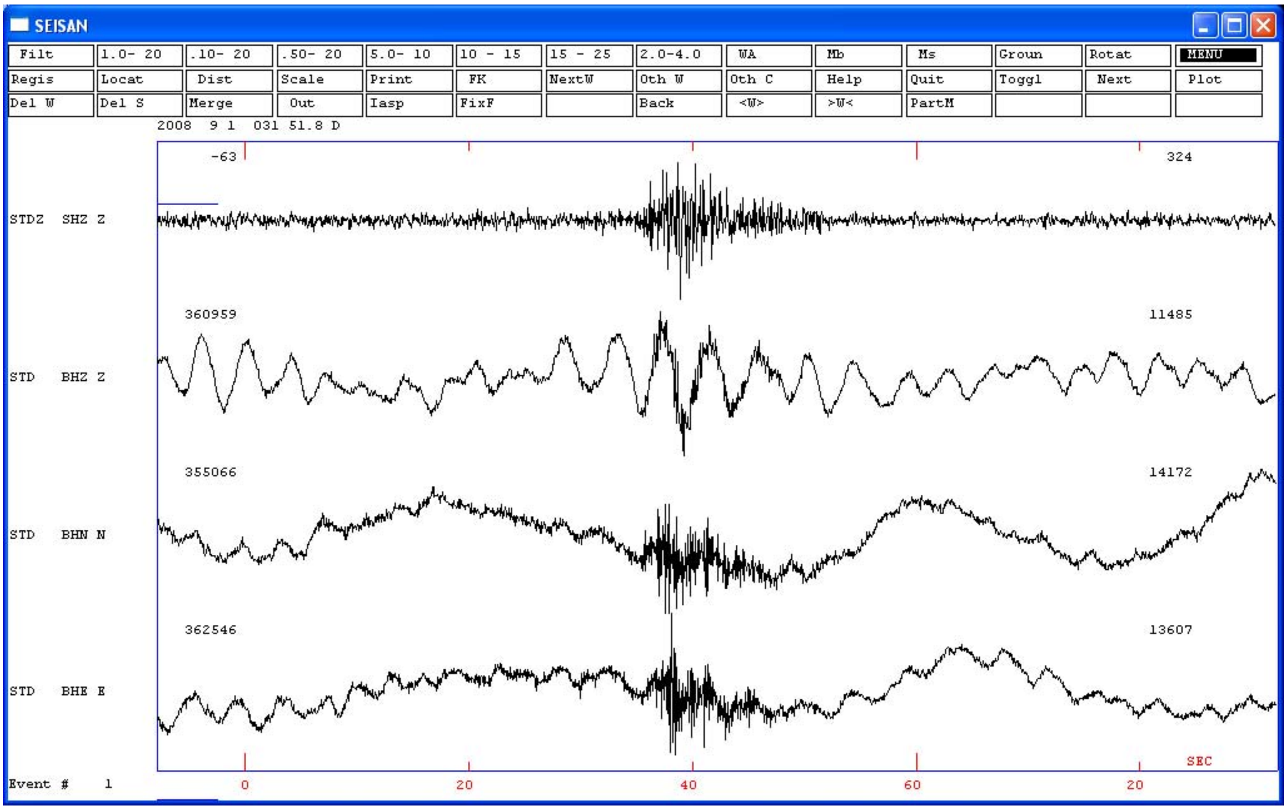
Once the event is displayed in MULPLT, the steps are:

- Window into the event.
- Select the WA (Wood Anderson) option to display a ground-motion seismogram and filter the trace between 1.25Hz and 20 Hz.
- Pick the maximum peak to peak amplitude by placing the cursor at one peak , press 'a', place the cursor at the other extreme, press 'a' again. Note that 'a' is lowercase.

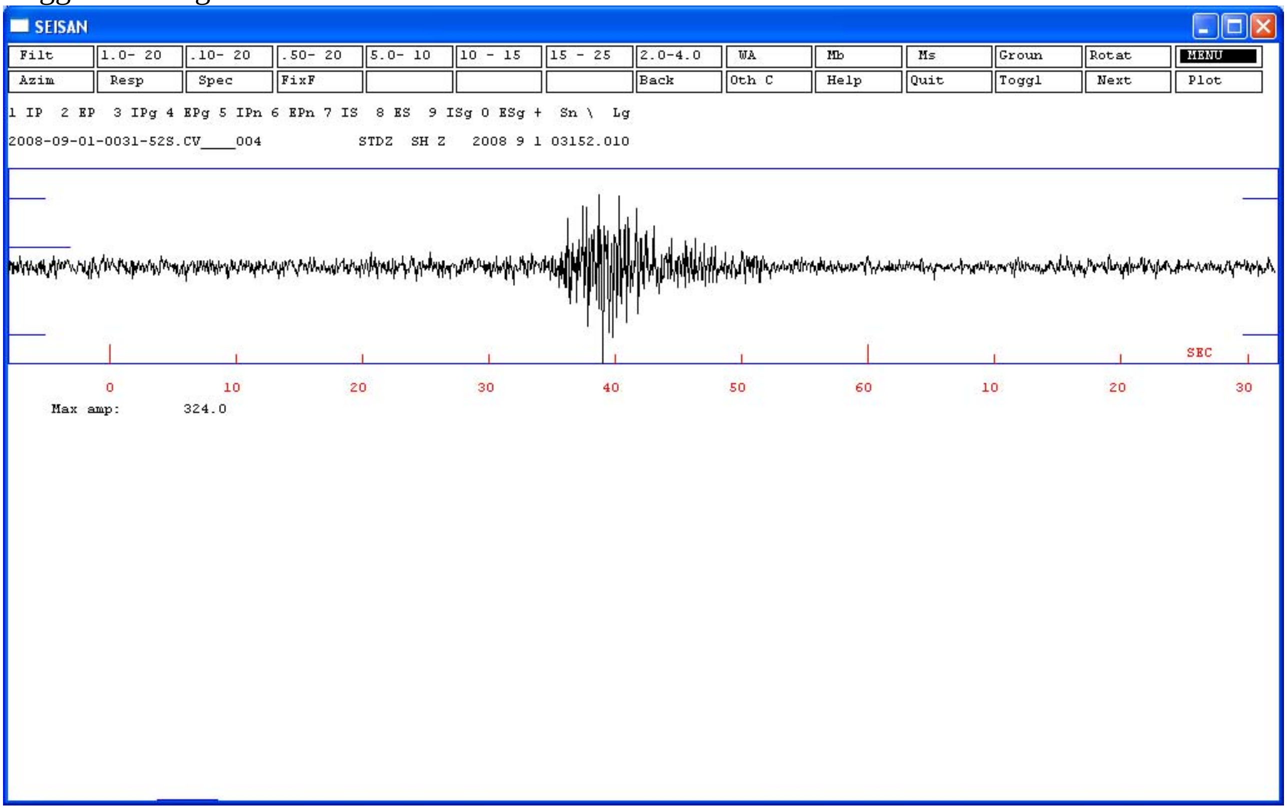
MULPLT will associate the amplitude and period with the amplitude reading label AML.

Screen shots detailing the procedure follow:

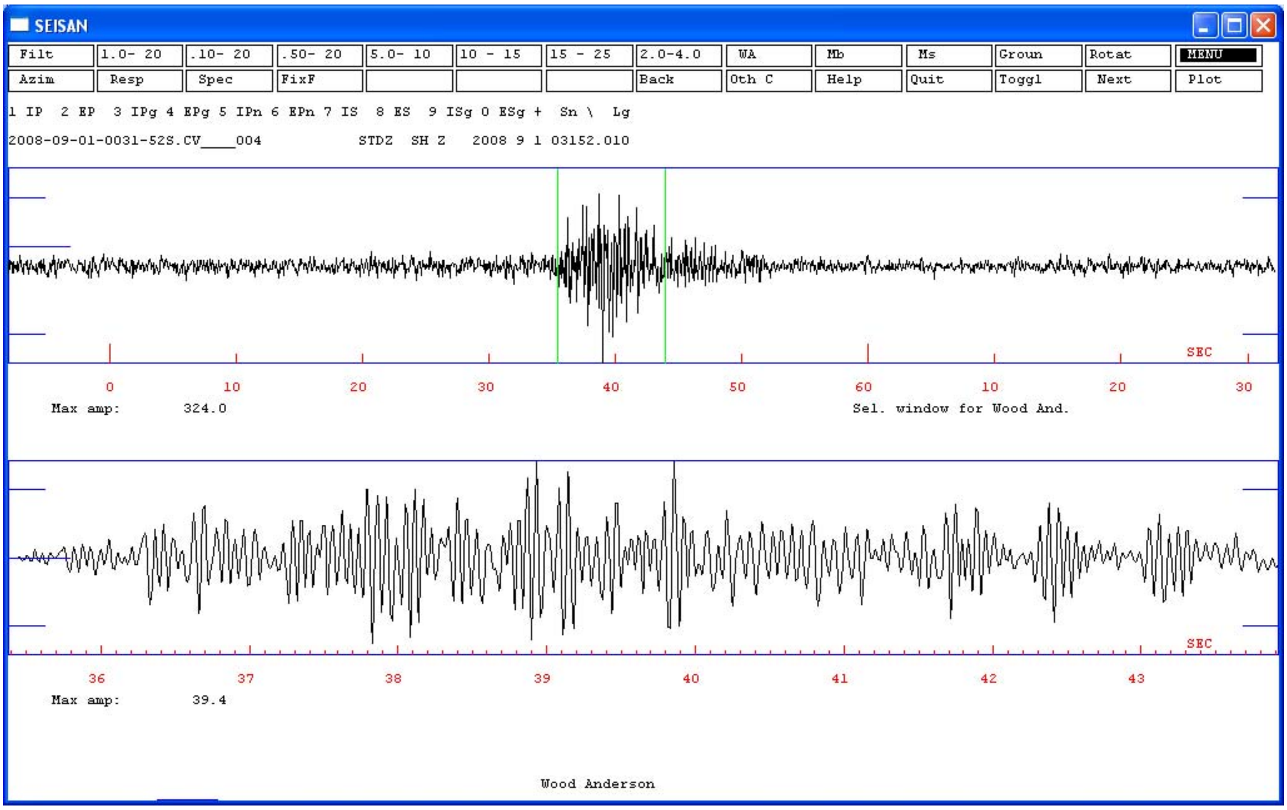
Multitrace screen



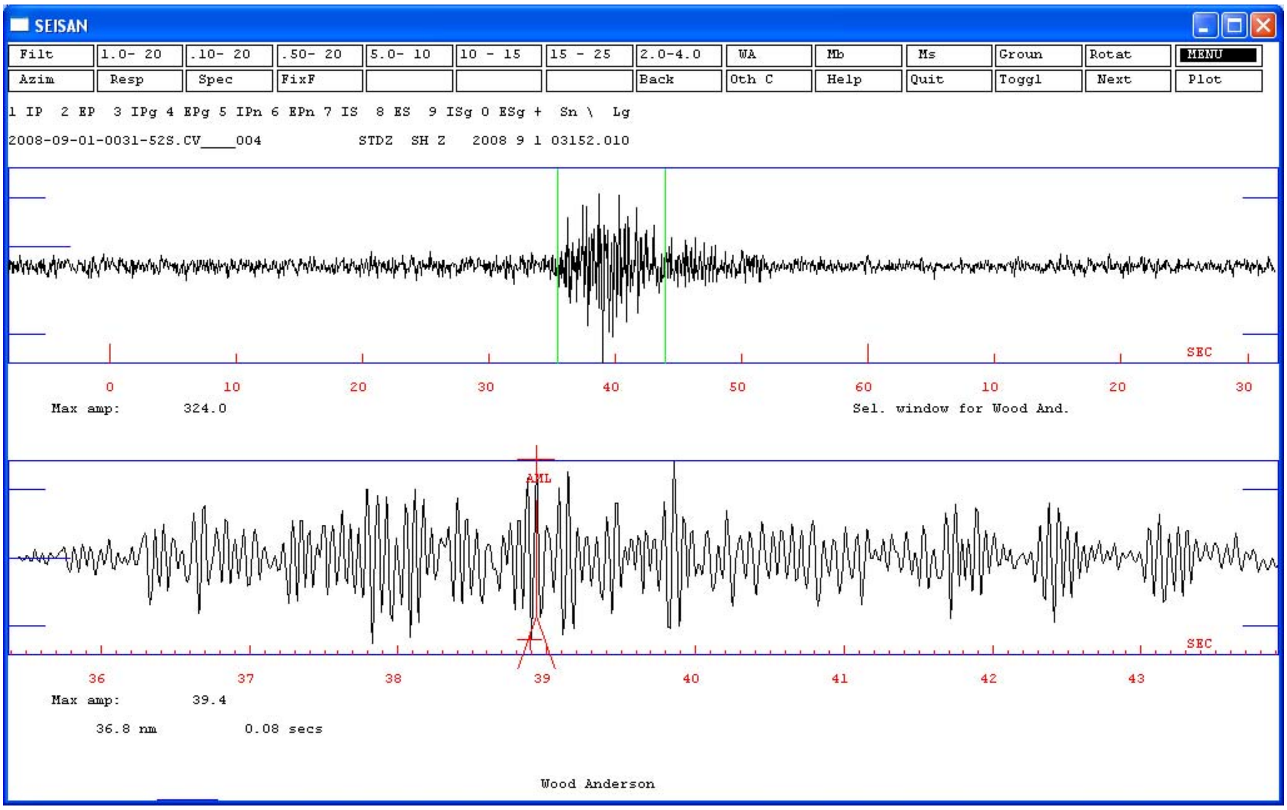
Toggle to a single-trace screen



Select the WA button and a window around the event.



Pick the maximum Peak-peak amplitude. Place the cursor at one peak, press ‘a’, place the cursor at the other extreme, press ‘a’ again.



Note the max amp reading and period listed.

Next, repeat the process for each of the other traces in the waveform file. For each trace, MULPLT will write the max amp in nm and the period in sec to the s-file. Each amp/period pair will be associated with a phase called AML, as shown in the printout of the s-file below. To see this file, type ‘e’ at the EEV ? prompt.

```
2008  9 1  031 51.8 D                                                      1
 ACTION:REG 08-12-20 15:35 OP:andy STATUS:               ID:20080901003151
I
 2008-09-01-0031-52S.CV____004
6
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS
CAZ7
 STD  BN  AML      032 37.63        29.7 0.12
 STD  BE  AML      032 37.82        39.8 0.06
 STDZ SZ  AML      032 38.93        36.8 0.08
 STD  BZ  AML      032 38.97        13.5 0.08
```

.

Coda Magnitude, M_c

The M_c parameters are set in Station0.def, as noted above:

MAG = TEST(7) +TEST(8) * LOG(T) + TEST(9) * DELTA

where

T is the coda length in seconds,
DELTA is the hypocentral distance in km.
Default values: 7: 0.087,
8: 2.0,
9: 0.0035 (Lee, 1972)

So the default formulation for M_c is

$$M_c = 0.087 + 2.0 * LOG(T) + 0.0035 * DELTA$$

This is the original Richter formulation for Northern California.

Other M_c calculations are:

Pacific Northwest Seismic Network (Mt. St. Helens)

$$M_{c\ PNSN} = -2.46 + 2.82*LOG(T)$$

This is the M_c formulation used in the example version of STATION0.HYP.

Coda Magnitude determination is determined in the location process, when both a P-arrival and a coda length have been selected.

Event location

The precise location of volcanic events is usually difficult, given the emergent phase arrivals of many of the events, the complex velocity structure and the topography. In addition, most volcanoes have too few seismic stations for good locations.

However, in the experience of VDAP seismologists, precise event locations have not been shown to be of much monitoring value. VT events do not tend to reflect the actual location of the magma as much as the zone of weakness where stress from the deformation of an intrusion is being released, such as along nearby faults. Other events like shallow hybrids associated with dome growth may demonstrate some shoaling, but not early enough in the extrusive process to provide prognostic value. Shallow LPs are too emergent to locate well and generally just indicate groundwater boiling. Most volcanic events just locate under the volcano anyway.

Therefore we in VDAP focus our seismic monitoring effort less on the precise locations of events than on the temporal evolution of different types of seismicity and energy release. The locations are of interest only broadly; it is of value to know if they are located either under the vent area or off to the side of the edifice. If they are located off to one side, if they form distinct families of swarms.

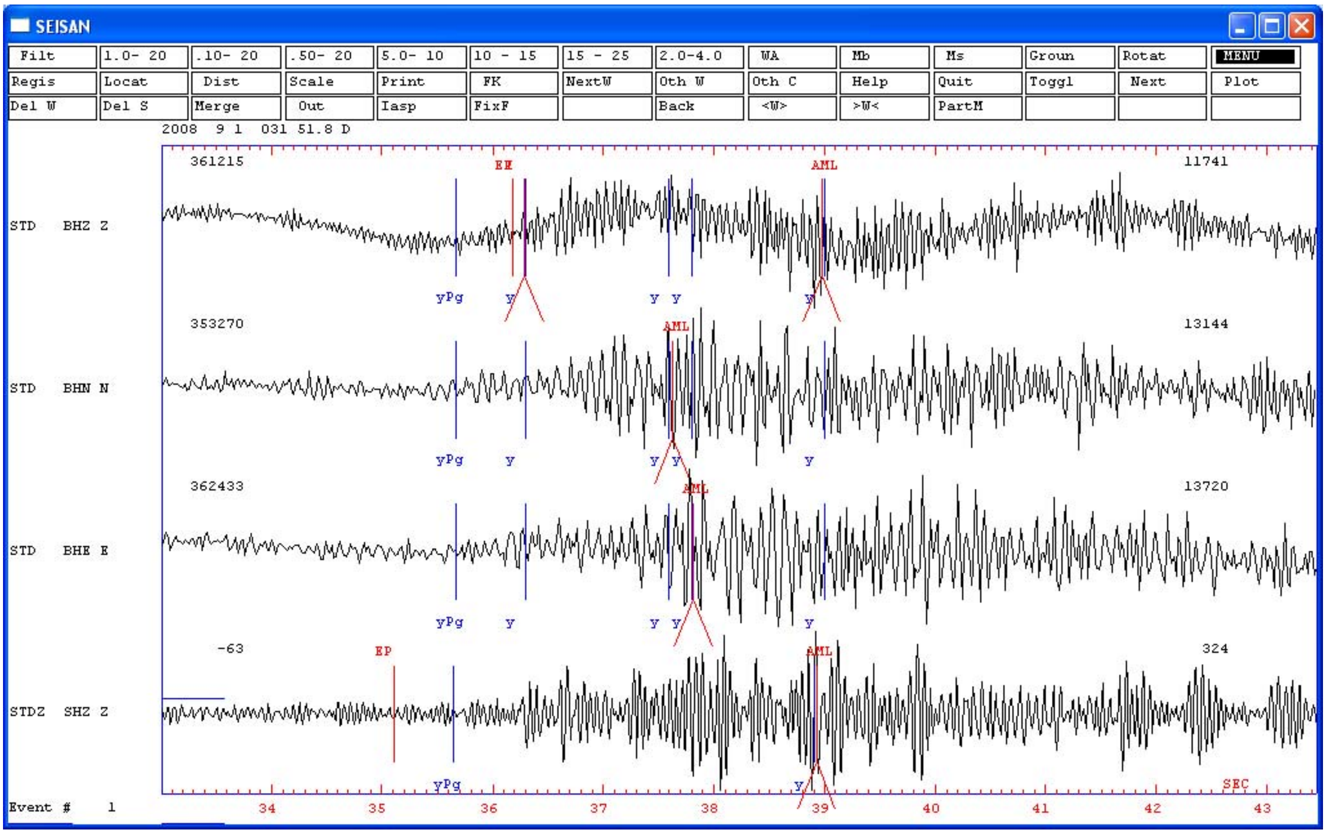
The location technique outlined here is sufficient to broadly locate events, to a degree of precision sufficient for VDAP seismic-monitoring techniques.

3-comp azimuth and event location with one 3-comp station:

MULPLT permits the use of a single 3-comp station for event location. (For this capability to be implemented, the RESET TEST(56) variable in STATION0.HYP must be set =1, the default setting) In this technique, the p-arrival, s-arrival and back-azimuth are used to give a general location. The azimuth reading calculated by MULPLT is from the station back to the hypocenter, with reference to True North (not Magnetic North; note that many 3-comp sensors are oriented with respect to magnetic north. The local magnetic declination must be taken into account to get the true azimuth.)

1) select the p arrival.
2) display any one of the three components – if you picked the p-arrival on the z-component display that one.
3) Select a time window around the p-arrival by clicking *above* the trace window. The window should be several seconds or tens of seconds before and after the p-arrival. If the 3-comp is a broadband, select a filter first (Try the 1Hz – 20Hz filter).
4) select the ‘Azim’ button and select a zoom window around the p-arrival of a few tenths of seconds duration.
5) The 3 components are now displayed in order along with calculated azimuth of arrival, apparent velocity and correlation co-efficient.
6) Repeat this procedure a few times, experimenting with different window lengths and filters. The azimuth should be reasonable, and the correlation coefficient should be as high as possible and positive. Sometimes the correlation coefficient cannot be made positive, despite heroic efforts. The ‘vel’ (apparent velocity) will usually be unrealistic. To refresh the screen between attempts, select the ‘plot’ button.
7) When you are satisfied with the azimuth, save it to the s-file by associating it with a phase. The usual way to do this is to pick an I or E phase (type ‘e’ or ‘i’). That phase must be picked on the single upper trace seen on the same screen.
8) Return to multitrace mode by selecting the ‘other c’ button, and selecting the ‘all’ and ‘ok’ button for all the traces.
9) Select the ‘Locat’ button to locate the event. The command screen appears as the location is calculated, and the results are written to the command window. The waveform plot shows both the manually-determined phases and the calculated phases.
10) If you are locating the event from secondary processing in EEV, after locating the event you must update the s-file to include the location by typing the ‘update’ command at the EEV command prompt. Update will run the location program again and write the results to the s-file.

Here is the multitrace screen showing manually-determined and calculated phases.



Here is a portion of the EEV terminal session showing the UPDATE process.

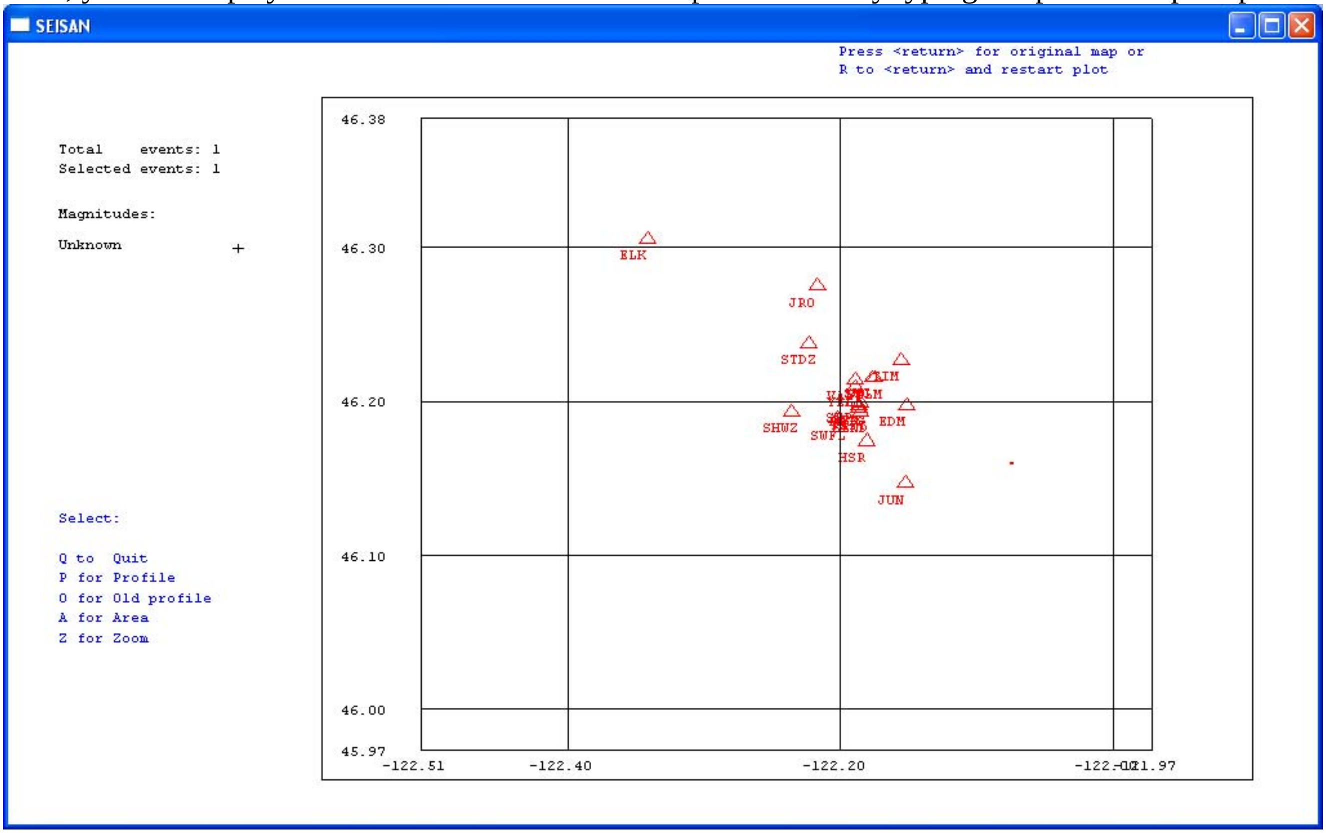
```
    1  1 Sep 2008  0:31 51   D                                       2  ? update

  date hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp i
 8 9 1  032 33.16 46 9.61N 122  4.5W   1.0    3 1   0.21 0.000  3.6999.9999.9
stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
STD     14 306.7      0 AML              032 37.6    4.5
STD     14 306.7      0 AML              032 39.0    5.8
STD     14 306.7 94.7 0 P       Pg       032 36.2   3.03   2.49   0.54 1.00* 0
STD     14 306.7      0                  032 36.3    3.1
STDZ    14 306.7      0 AML              032 38.9    5.8
STDZ    14 306.7 94.7 0 P       Pg       032 35.1   1.95   2.49  -0.54 1.00* 0
STD     14 306.7      0 AML              032 37.8    4.7
STD     14 306.7        AZ                         126.6  126.6   0.00 0.20 **

STD  BN   hdist:      14.4   amp:          29.7   ml =   0.7
STD  BE   hdist:      14.4   amp:          39.8   ml =   0.8
STDZ SZ   hdist:      14.4   amp:          36.8   ml =   0.8
STDZ SZ   hdist:      14.4   coda:         16.0   mc =   0.9
STD  BZ   hdist:      14.4   amp:          13.5   ml =   0.3
STD  BZ   hdist:      14.4   coda:         14.0   mc =   0.8
2008  9 1 0032 33.2 D  46.160-122.074  1.0  CC    2 0.2 0.7LCC  0.9CCC
OLD:  9 1  031 51.8 D

Stop - Program terminated.
 You are now about to overwite the current event in the data base.
 with the solution just shown
 The catalog is not updated !!!!!
 Sure you want to update, (y/n) ?
y
        1 file(s) copied.
Give operator code, max 4 characters
Andy
    1  1 Sep 2008 00:32 33   D  46.160-122.074  1.0    0.2  0.7LCC    2  ?
```

Here is the resulting s-file:

```
01-0031-51D.S200809 - Notepad
File  Edit  Format  View  Help
 2008  9 1 0032 33.2 D  46.160-122.074  1.0  CC   2 0.2 0.7LCC  0.9CCC        1
 GAP=360        2.39       999.9     3.6999.9  0.0000E+00  0.0000E+00  0.0000E+00E
 ACTION:UP  09-04-21 15:03 OP:Andy STATUS:               ID:20080901003151     I
 2008-09-01-0031-52S.CV____004                                                 6
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 STD  BZ EP        032 36.19   14                          95     0.5410 14.4 307
 STD  BN  AML      032 37.63        29.7 0.12                           14.4 307
 STD  BZ  AML      032 38.97        13.5 0.08                           14.4 307
 STDZ SZ EP        032 35.11   16                          95    -0.5410 14.4 307
 STDZ SZ  AML      032 38.93        36.8 0.08                           14.4 307
 STD  BZ I         032 36.29                   126.6  5.8      0          14.4 307
 STD  BE  AML      032 37.82        39.8 0.06                           14.4 307
```

Note that Ml =0.7 (shown as 0.7LCC, where L indicates local magnitude and CC is the network code from STATION0.HYP) and Mc = 0.9, (shown as 0.9CCC where the first C indicates coda magnitude and CC is the network code from STATION0.HYP).

Now, you can display the location on an EPIMAP map from EEV by typing ‘map’ at the ? prompt.



Here the stations are shown as red triangles and the event location is a small ‘+’. The event is a hybrid that should have located under the Mt. St. Helens dome at the center of the cluster of stations. The calculated location is poor, as might be expected from a single station STD, an emergent p-arrival, and no s-arrival. This example is not intended to show a good location, only that HYP can obtain a location solution from very sparse, poor data.

A better location could be obtained from more stations, using the same techniques shown above for determining phase arrivals, and azimuths.

Use the technique below for particle motion to help determine phase arrivals within the event coda.

Particle motion:

After the azimuth has been determined (as per the instructions on ‘event location with one 3-comp station’), particle motion can be determined from the rotated components.

From the multi-trace mode:

1) Select the ‘Rotat’ button, followed by the ‘plot’ button to refresh the screen and show the rotated traces. The trace windows will now show the back azimuth, labeled, for example, ‘baz 148’ for a back azimuth of 148.
2) select the three components of a 3-comp sensor and select the ‘plot’ button
3) select the ‘PartM’ button.

Particle motion plots now appear under the three traces. Window the traces for the portion of the waveforms for which you want to view the particle motion. For a more detailed example, see Appendix 3.

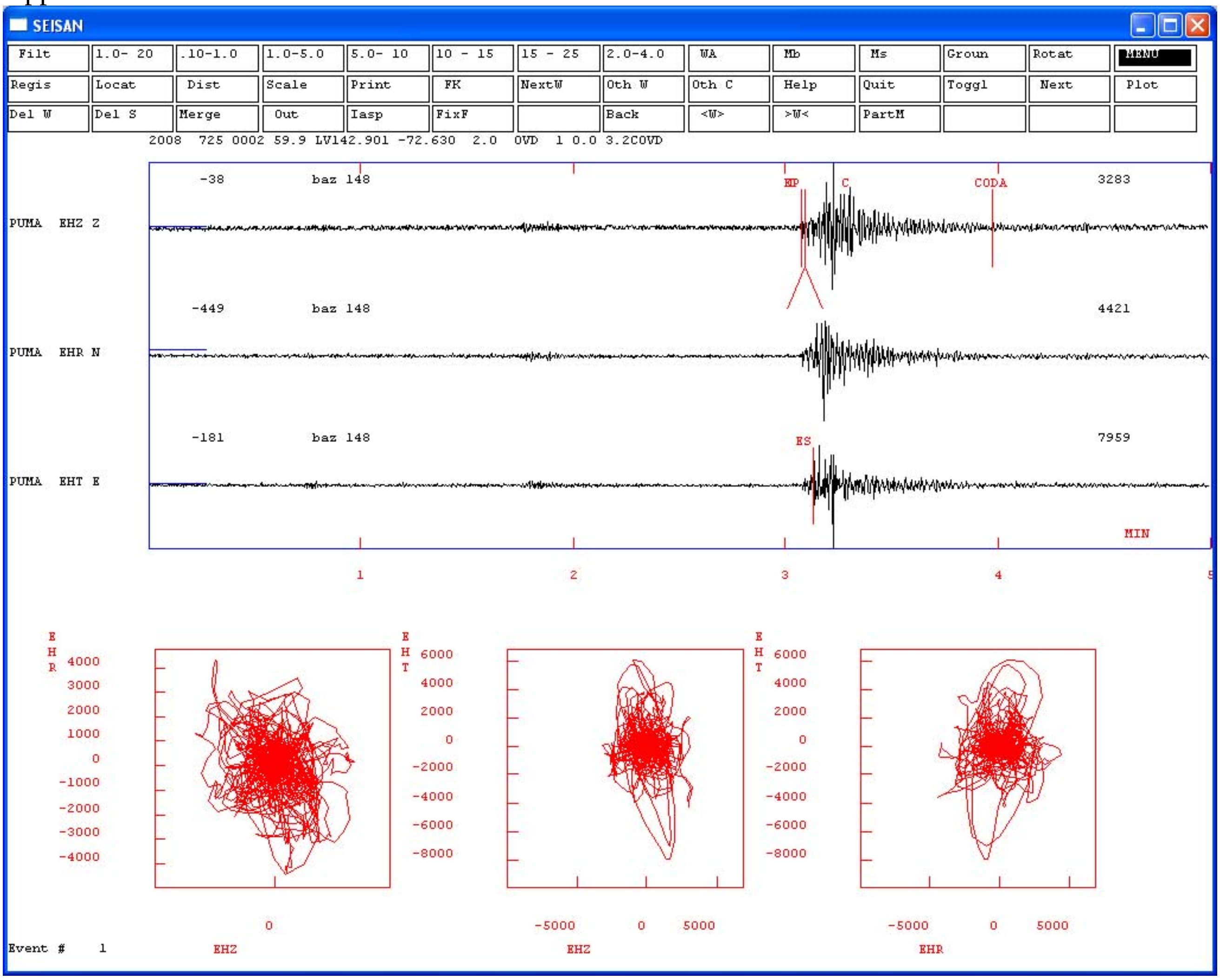


Figure: screenshot of MULPLT single-trace mode particle analysis results. Note that the whole window is used for the particle motion, so the result here is unreadable. In general, select a short time window to view particle motion. Filtering is often required to bring the particle motion trace onto scale and into the box.

Catalog the results: the SELECT command:

The SELECT command is used to extract information about the event files from the database. Here is an example of a SELECT session to extract a list of the hybrid event from the CVE event database for 2005-10:

```
E:\Seismo\WOR>select
 POSSIBLE INPUT IS:
    STANDARD CAT DATA BASE: RETURN
    ALTERNATIVE DATA BASE, GIVE 1-5 LETTER CODE:
    FILENAME FOR ONE FILE, MUST BE 6 OR MORE CHARACTERS OR HAVE A .
CVE
 Type of base: CAT (Return) or Sfiles (s):
s
 Start time (blank is 1980), yyyymmddhhmmss:200510
 End time, enter for end of month          :

            PARAMETERS

     1   - Fault Plane Solution
     2   - Earthquake Felt
     3   - Magnitude Type(s)
     4   - Distance ID(s)
     5   - Event ID(s)
     6   - Magnitude Limits
     7   - Latitude Limits
     8   - Longitude Limits
     9   - Depth Limits
     10  - RMS Limits
     11  - Number of Stations Limits
     12  - Hypocenter Errors Latitude Limits
     13  - Hypocenter Errors Longitude Limits
     14  - Hypocenter Errors Depth Limits
     15  - Minimum Number of Polarities
     16  - Hypocenter Agencies
     17  - Magnitude Agencies
     18  - Station Codes, components, distance range and phase
     19  - Polygon
     20  - Use all header lines
     21  - Look for wave form file names
     22  - Gap range
     23  - Phases
     24  - Volcanic subclasses


 SELECT NUMBER TO CHANGE PARAMETER, RETURN TO SEARCH: 24

 Volcanic subclasses, max 10 classes of 6 char, press enter after each type:
hy


            PARAMETERS

     1   - Fault Plane Solution
     2   - Earthquake Felt
     3   - Magnitude Type(s)
     4   - Distance ID(s)
     5   - Event ID(s)
     6   - Magnitude Limits
     7   - Latitude Limits
     8   - Longitude Limits
     9   - Depth Limits
     10  - RMS Limits
     11  - Number of Stations Limits
     12  - Hypocenter Errors Latitude Limits
     13  - Hypocenter Errors Longitude Limits
     14  - Hypocenter Errors Depth Limits
     15  - Minimum Number of Polarities
     16  - Hypocenter Agencies
     17  - Magnitude Agencies
     18  - Station Codes, components, distance range and phase
     19  - Polygon
     20  - Use all header lines
     21  - Look for wave form file names
     22  - Gap range
     23  - Phases
```

```
     24  - Volcanic subclasses               3


 SELECT NUMBER TO CHANGE PARAMETER, RETURN TO SEARCH:
2005 10  Reading events for base CVE__           82

 TOTAL NUMBER OF EVENTS IN TIME INTERVAL           82
 NUMBER OF DISTANT EVENTS   - - - - -               0
 NUMBER OF REGIONAL EVENTS  - - - - -               0
 NUMBER OF LOCAL EVENTS     - - - - -              82
 ---------------------------------------------------
 NUMBER OF EVENTS SELECTED *************            0
 NUMBER OF WAVEFORM FILES SELECTED                  0
 NUMBER OF INDEXES SELECTED                         0
 SELECTED EARTHQUAKES ARE IN FILE: select.out
 LOCAL INDEX FILE IN:              index.out
 NAMES FOR WAVEFORM FILES IN FILE: waveform_names.out
 SELECT COMMANDS IN FILE:          select.inp

Stop - Program terminated.

E:\Seismo\WOR>
```

Now the file ‘index.out can be used as input to EEV for further processing. The file ‘select.out’ contains all the s-files with the selected parameters. It can be searched, and further information extracted with a PERL script….(examples and further techniques to come once we finish our research…)

The next steps, as of April 21, 2009…

This document is no more than a primer to help bridge the space between the wide-ranging and complex SEISAN documents and a limited, well-understood set of thorough but efficient seismic processing techniques suitable for volcano monitoring.

There is a lot more that can be done with SEISAN in seismic volcano monitoring. The next steps may be to

- Determine how to use PERL scripts or some other tool to make use of data extracted from the event databases with the SELECT tool
- Determine how to do automated event detections on the continuous data using CONDET.
- Experiment with the capabilities of the automatic processing tools such as AUTOSIG and AUTOPIC.

In addition, there are many other powerful and subtle SEISAN tools that might be brought to bear on seismic volcano monitoring and data processing. This primer has only scratched the surface. The interested user is encouraged to dig deeper into the SEISAN manual for more tools.

Appendix 1: calibration file for T6330 from Guralp.

CMG-6TD CALIBRATION

WORKS ORDER: 2576 DATE: 17 September 2004

SERIAL NUMBER: T6330 TESTED BY: ENS

	Velocity Response V/m/s	Digitiser Output uV/count	Digital Output m/s/count
VERTICAL	1125.10	0.2609	2.319E-10
NORTH/SOUTH	1089.64	0.2628	2.412E-10
EAST/WEST	1084.50	0.2735	2.522E-10

	Coil Constant $A/m/s^2$	Mass Position Response $V/m/s^2$	Mass Position Digital Output uV/count	Mass Position Digital Output m/s^2/count
VERTICAL	0.0028	8.44	0.5829	6.907E-08
NORTH/SOUTH	0.0027	8.17	0.5868	7.180E-08
EAST/WEST	0.0027	8.13	0.5861	7.206E-08

Current Consumption: @12V (±10 mA) 89mA

This sensor operates from 10 to 36 Volts only.

POLES AND ZERO TABLE

WORKS ORDER NUMBER: 2576

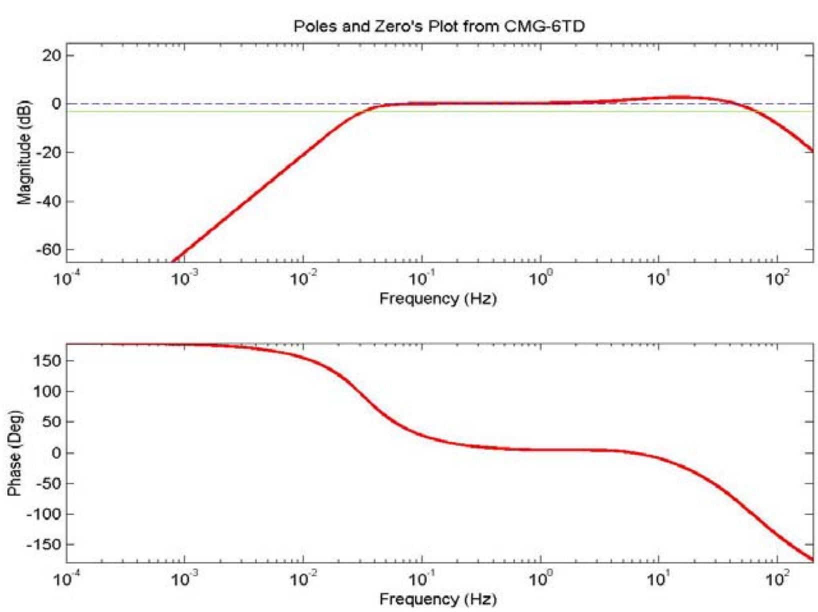
SENSOR SERIAL NO: **T6330**

Velocity response output:

POLES (HZ)	**ZEROS HZ**
-23.65e-3 + 23.65e-3j	-5.03207
-23.65e-3 - 23.65e-3j	0
-393.011	0
-7.4904	
-53.5979 - 21.7494j	
-53.5979 + 21.7494j	

Normalizing factor at 1 Hz: A =1.983*10^6

Sensor Sensitivity: See Calibration Sheet.



NOTE: The above poles and zeros apply to the vertical and the horizontal sensors and are given in units of Hz. To convert to Radian/sec multiply each pole or zero with 2π The normalizing factor A should also be recalculated.

Appendix 2 'resp.out' for a USGS-VDAP analog 1-Hz Sercel L4

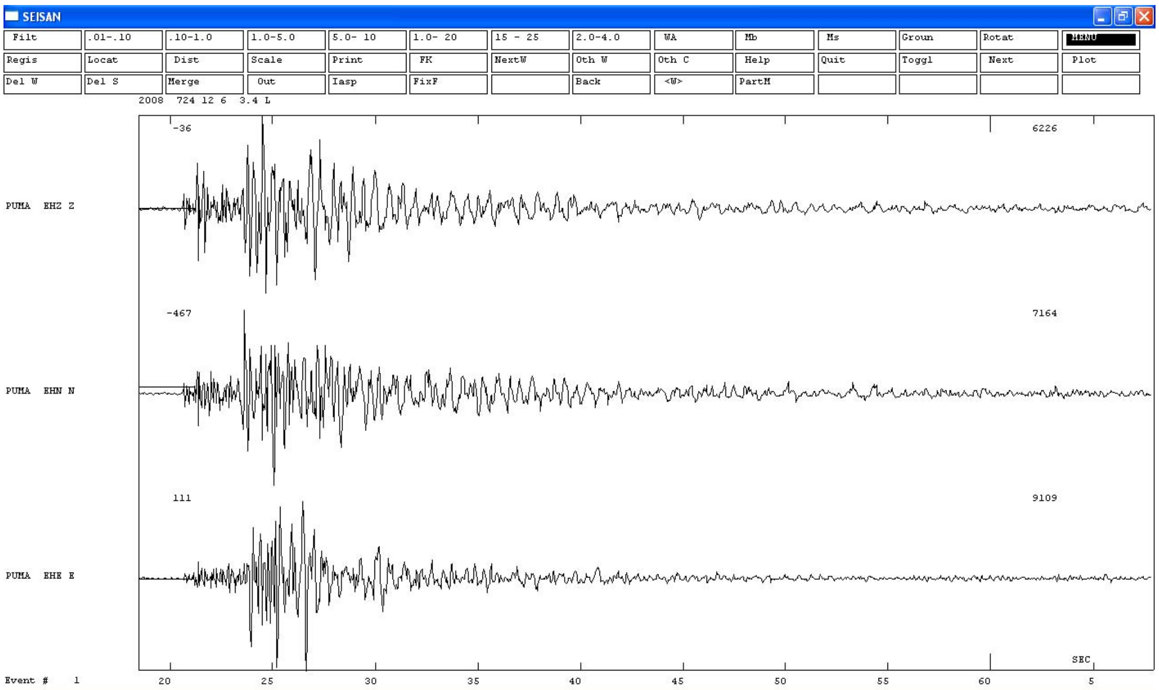
```
 SENSOR TYPE: SEISMOMETER       RESPONSE: DISPLACEMENT
  SEISMOMETER PERIOD=  0.9740000
  GENERATOR CONSTANT=   134.9000
  DAMPING RATIO     =  0.8000000
  AMPLIFIER GAIN(DB)=   58.50000
  RECORDING GAIN=       819.6000
  FILTER CONSTANTS
  F= 20.00   POLES=  4
  F= 30.00   POLES=  4
  GAIN AT 1 HZ=        3.5562915E+08

F=  0.0050   T=  200.00    AMP=      0.000000    AMPDB=-134.2    PHAS=   -90.5
F=  0.0059   T=  169.49    AMP=      0.000000    AMPDB=-129.9    PHAS=   -90.6
F=  0.0070   T=  142.86    AMP=      0.000001    AMPDB=-125.4    PHAS=   -90.7
F=  0.0083   T=  120.48    AMP=      0.000001    AMPDB=-121.0    PHAS=   -90.8
F=  0.0098   T=  102.04    AMP=      0.000001    AMPDB=-116.7    PHAS=   -91.0
F=  0.0120   T=   83.33    AMP=      0.000003    AMPDB=-111.4    PHAS=   -91.2
F=  0.0140   T=   71.43    AMP=      0.000004    AMPDB=-107.4    PHAS=   -91.4
F=  0.0160   T=   62.50    AMP=      0.000006    AMPDB=-103.9    PHAS=   -91.6
F=  0.0190   T=   52.63    AMP=      0.000011    AMPDB= -99.4    PHAS=   -91.9
F=  0.0230   T=   43.48    AMP=      0.000019    AMPDB= -94.4    PHAS=   -92.3
F=  0.0270   T=   37.04    AMP=      0.000031    AMPDB= -90.3    PHAS=   -92.7
F=  0.0320   T=   31.25    AMP=      0.000051    AMPDB= -85.8    PHAS=   -93.3
F=  0.0370   T=   27.03    AMP=      0.000079    AMPDB= -82.1    PHAS=   -93.8
F=  0.0440   T=   22.73    AMP=      0.000133    AMPDB= -77.5    PHAS=   -94.5
F=  0.0520   T=   19.23    AMP=      0.000219    AMPDB= -73.2    PHAS=   -95.3
F=  0.0620   T=   16.13    AMP=      0.000371    AMPDB= -68.6    PHAS=   -96.3
F=  0.0730   T=   13.70    AMP=      0.000606    AMPDB= -64.4    PHAS=   -97.4
F=  0.0870   T=   11.49    AMP=      0.001025    AMPDB= -59.8    PHAS=   -98.9
F=  0.1000   T=   10.00    AMP=      0.001555    AMPDB= -56.2    PHAS=  -100.2
F=  0.1200   T=    8.33    AMP=      0.002684    AMPDB= -51.4    PHAS=  -102.2
F=  0.1400   T=    7.14    AMP=      0.004256    AMPDB= -47.4    PHAS=  -104.3
F=  0.1700   T=    5.88    AMP=      0.007600    AMPDB= -42.4    PHAS=  -107.4
F=  0.2000   T=    5.00    AMP=      0.012335    AMPDB= -38.2    PHAS=  -110.4
F=  0.2400   T=    4.17    AMP=      0.021202    AMPDB= -33.5    PHAS=  -114.6
F=  0.2800   T=    3.57    AMP=      0.033449    AMPDB= -29.5    PHAS=  -118.7
F=  0.3300   T=    3.03    AMP=      0.054208    AMPDB= -25.3    PHAS=  -124.0
F=  0.3900   T=    2.56    AMP=      0.088123    AMPDB= -21.1    PHAS=  -130.3
F=  0.4600   T=    2.17    AMP=      0.141360    AMPDB= -17.0    PHAS=  -137.6
F=  0.5500   T=    1.82    AMP=      0.232679    AMPDB= -12.7    PHAS=  -147.1
F=  0.6500   T=    1.54    AMP=      0.363841    AMPDB=  -8.8    PHAS=  -157.5
F=  0.7700   T=    1.30    AMP=      0.557330    AMPDB=  -5.1    PHAS=  -169.6
F=  0.9100   T=    1.10    AMP=      0.819239    AMPDB=  -1.7    PHAS=   177.2
F=  1.1000   T=    0.91    AMP=      1.206175    AMPDB=   1.6    PHAS=   161.3
F=  1.3000   T=    0.77    AMP=      1.620594    AMPDB=   4.2    PHAS=   147.2
F=  1.5000   T=    0.67    AMP=      2.025292    AMPDB=   6.1    PHAS=   135.4
F=  1.8000   T=    0.56    AMP=      2.606783    AMPDB=   8.3    PHAS=   121.0
F=  2.1000   T=    0.48    AMP=      3.162730    AMPDB=  10.0    PHAS=   109.6
F=  2.5000   T=    0.40    AMP=      3.877639    AMPDB=  11.8    PHAS=    97.1
F=  2.9000   T=    0.34    AMP=      4.574036    AMPDB=  13.2    PHAS=    86.7
F=  3.5000   T=    0.29    AMP=      5.599074    AMPDB=  15.0    PHAS=    73.4
F=  4.1000   T=    0.24    AMP=      6.610917    AMPDB=  16.4    PHAS=    61.8
F=  4.9000   T=    0.20    AMP=      7.948905    AMPDB=  18.0    PHAS=    47.8
F=  5.8000   T=    0.17    AMP=      9.445530    AMPDB=  19.5    PHAS=    33.2
F=  6.8000   T=    0.15    AMP=     11.101945    AMPDB=  20.9    PHAS=    17.9
F=  8.1000   T=    0.12    AMP=     13.247005    AMPDB=  22.4    PHAS=    -1.4
F=  9.5000   T=    0.11    AMP=     15.541428    AMPDB=  23.8    PHAS=   -21.9
F= 11.0000   T=    0.09    AMP=     17.957018    AMPDB=  25.1    PHAS=   -44.1
F= 13.0000   T=    0.08    AMP=     20.984226    AMPDB=  26.4    PHAS=   -74.6
F= 16.0000   T=    0.06    AMP=     24.227942    AMPDB=  27.7    PHAS=  -123.7
F= 19.0000   T=    0.05    AMP=     23.885962    AMPDB=  27.6    PHAS=  -176.1
F= 22.0000   T=    0.05    AMP=     19.579336    AMPDB=  25.8    PHAS=   132.7
```

```
F= 26.0000   T=    0.04    AMP=     12.293935    AMPDB=  21.8    PHAS=    72.3
F= 31.0000   T=    0.03    AMP=      5.733468    AMPDB=  15.2    PHAS=    10.2
F= 37.0000   T=    0.03    AMP=      2.051783    AMPDB=   6.2    PHAS=   -44.3
F= 43.0000   T=    0.02    AMP=      0.761585    AMPDB=  -2.4    PHAS=   -81.3
F= 51.0000   T=    0.02    AMP=      0.235585    AMPDB= -12.6    PHAS=  -114.5
F= 60.0000   T=    0.02    AMP=      0.075932    AMPDB= -22.4    PHAS=  -139.7
F= 71.0000   T=    0.01    AMP=      0.023407    AMPDB= -32.6    PHAS=  -161.0
F= 85.0000   T=    0.01    AMP=      0.006643    AMPDB= -43.6    PHAS=  -179.6
F=100.0000   T=    0.01    AMP=      0.002130    AMPDB= -53.4    PHAS=   166.6
```

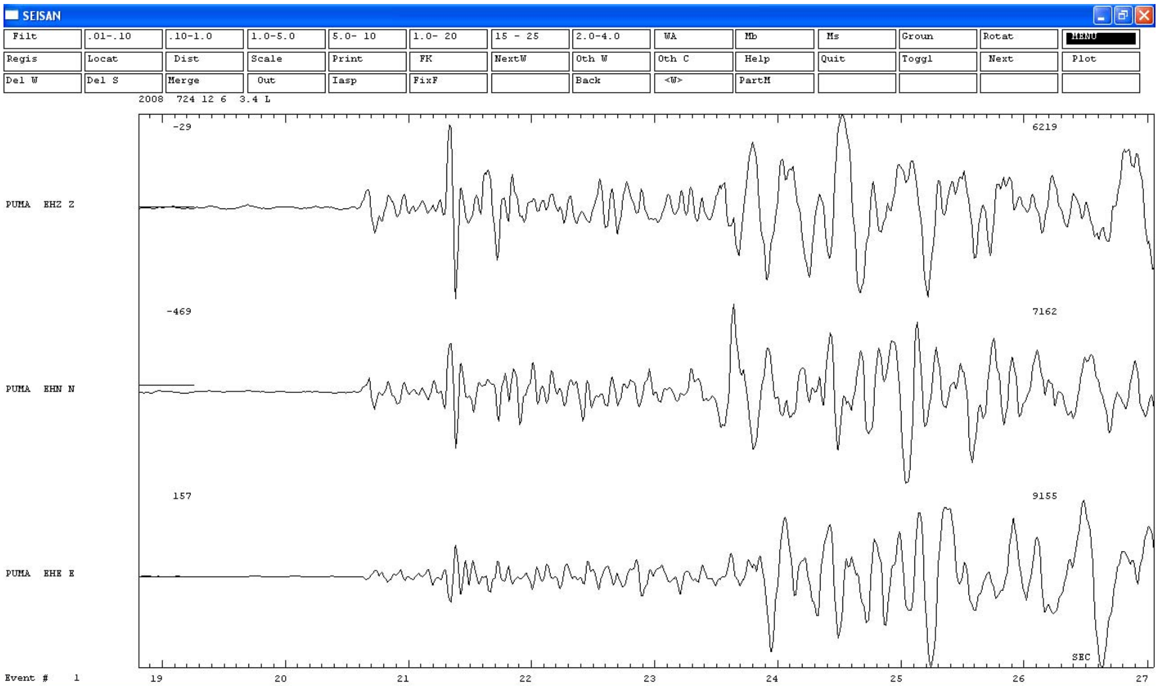
Appendix 3: Particle motion of event 200807241206

This is a more detailed display of a MULPLT session to determine particle motion and event location of this event.

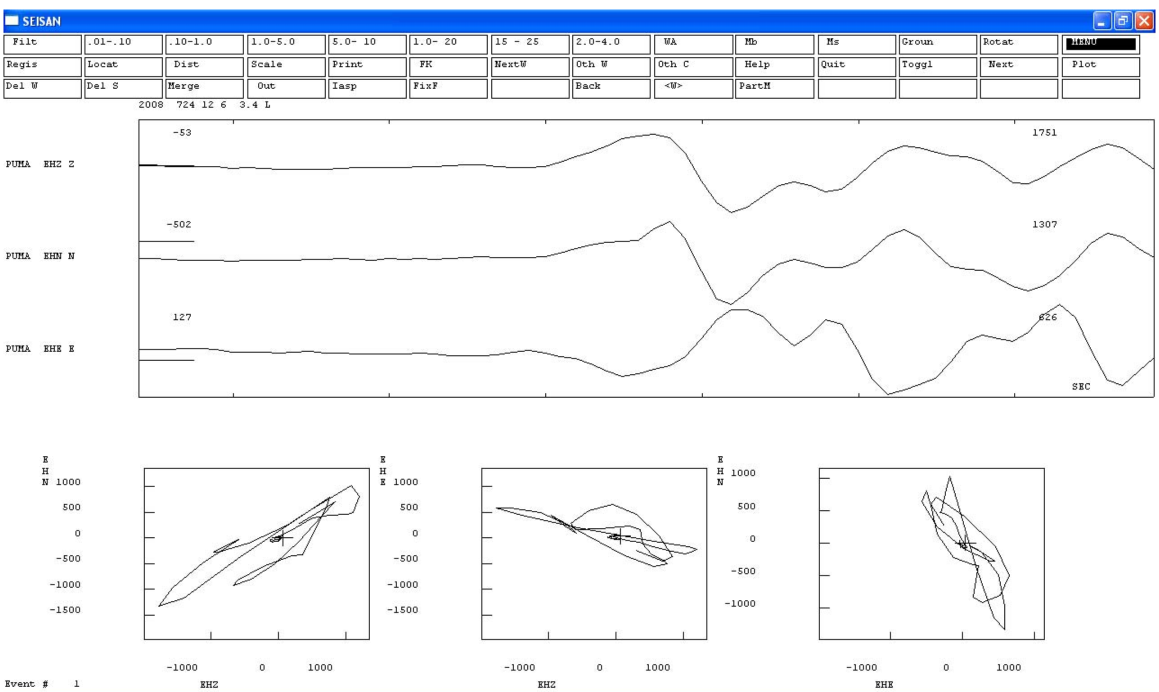
Screen shots of the event & particle motion.



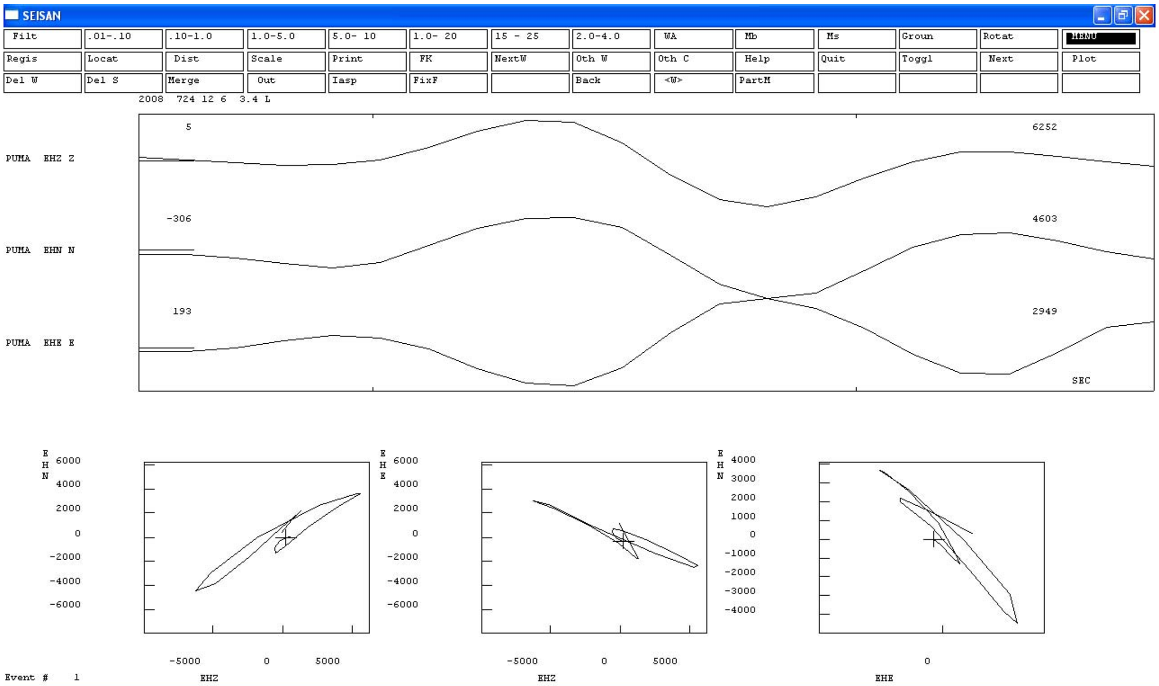
The event.



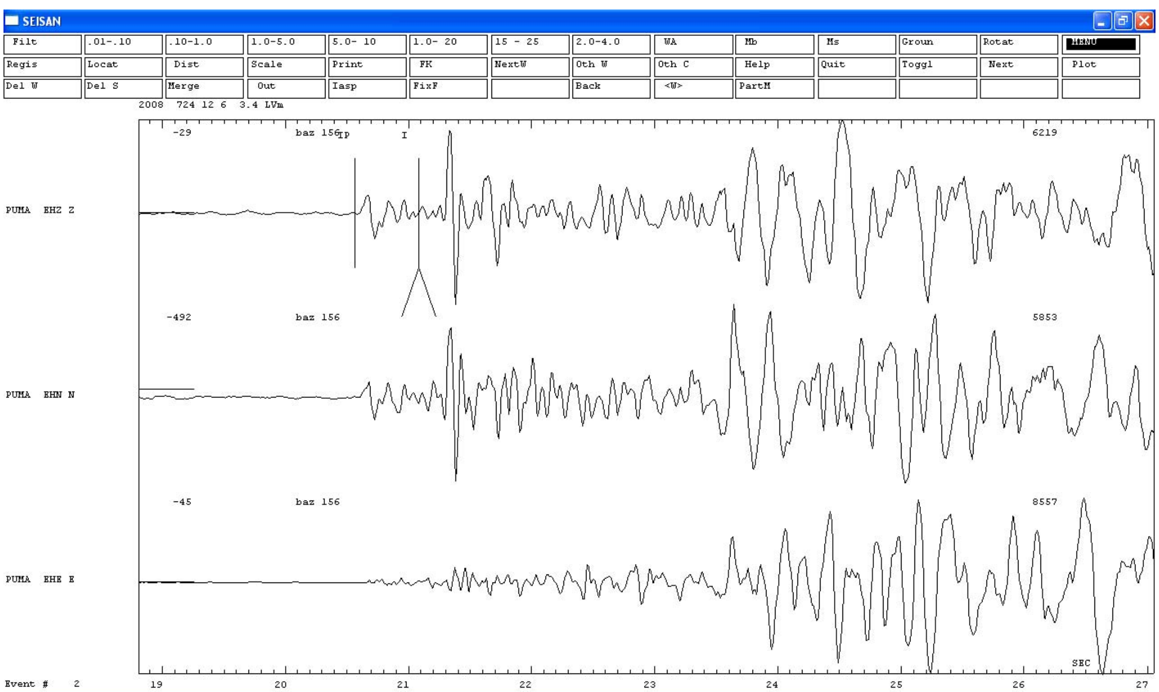
An expanded view of the early part of the coda. Note the interesting waveform at ~21.3 seconds.



The p arrival ~20.7sec. note in the particle motion plots that X marks the beginning.



The wave at 21.3 seconds looks like another p.



The same waveform rotated into the azimuth to the source. Components are not correctly named as R and T: I don't know why not. R is the middle trace. Disregard the I arrival on the Z component at ~21 seconds.

23.6 – 23.9 sec.