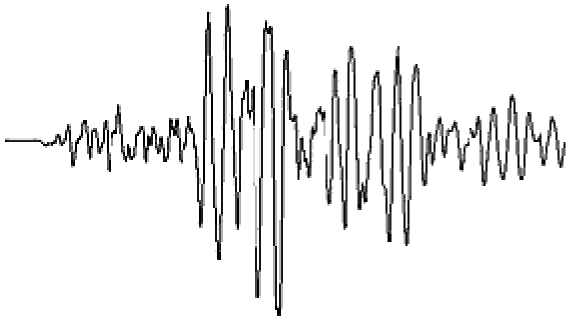

Interpreting Seismograms - A Tutorial for the AS-1 Seismograph [1]

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Objective: This tutorial is intended as a resource for the interpretation of seismograms recorded by educational seismographs. The tutorial provides a description of the main features of the Earth that affect seismic wave propagation and therefore controls the character of seismic signals recorded on seismographs. A catalog of selected seismograms is also presented to illustrate the variation in signal properties with distance, magnitude, and depth of focus. After initial visual analysis of an earthquake seismogram, one can often determine additional information about the event by identifying phases (individual arrivals on the seismogram that travel a distinct path through the Earth) and measuring amplitudes to estimate the magnitude of the earthquake.

This tutorial is available for viewing with a browser (html file) and for downloading as an MS Word document or PDF file at the following locations:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/InterpSeis.htm
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/InterpSeis.doc
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/InterpSeis.pdf
A PowerPoint presentation for the Interpreting Seismograms document is available for download at:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/InterpSeis.ppt

[1] Explorations in Earth Science

Last modified January 15, 2007

The web page for this document is:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/InterpSeis.htm
Partial funding for this development provided by the National Science Foundation.

Contents (click on topic to go directly to that section; use the red up arrows to return to the list of contents):

1. Introduction: Interpreting earthquake seismograms generally requires considerable experience and study of seismology. However, there are some fundamental principles that provide a basic understanding of seismic wave propagation and seismogram characteristics. Furthermore, some experience can be quickly obtained by systematic study of selected seismograms illustrating variations in amplitude and signal character related to source-to-station distance, the magnitude of the earthquake, and the earthquake's depth of focus.

This tutorial utilizes seismograms recorded over the last six years at the WLIN station in West Lafayette, Indiana. The data were recorded using an AS-1 seismograph (http://www.amateurseismologist.com/) attached to a Windows computer running the AmaSeis software (http://www.geol.binghamton.edu/faculty/jones/). Seismogram analysis and displays shown here also used the AmaSeis software. A tutorial on the use of AmaSeis for data collection (earthquake monitoring), processing and analysis is available at: http://web.ics.purdue.edu/~braile/edumod/as1lessons/UsingAmaSeis/UsingAmaSeis.htm. Although the examples shown here are for data recorded with the AS-1 seismograph, the software can be used to display and analyze seismograms from other sources (downloaded from SpiNet, IRIS, PEPP, etc.) that can be stored in SAC (Seismic Analysis Code, http://www.llnl.gov/sac/) format (http://www.passcal.nmt.edu/software/sac.html). The seismograms displayed in this tutorial can also be downloaded (SAC format) from the Internet for analysis on another computer with AmaSeis. AS-1 seismograph station operators are also encouraged to maintain a station log and catalog of earthquakes that are recorded by their seismograph. A description of station log and earthquake catalog information is contained in the PowerPoint presentation available for download at: http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/StationLog.ppt.

An earthquake catalog (Excel file) for the WLIN station can be downloaded at: http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/EqList.xls. Sample AS-1 seismic data for the WLIN station for the years 2004 and 2005 (data for days that have no significant events have been deleted from the files to reduce the total file size; files are compressed and are zip files; the 2004 file is 17.2MB; the 2005 file is 46.4MB; files must be unzipped [extracted] and placed in your AmaSeis folder to view with the AmaSeis software as folders named "2004" and "2005") are available at: http://web.ics.purdue.edu/~braile/new/2004.zip and http://web.ics.purdue.edu/~braile/new/2005.zip. You can use these data with the AmaSeis software to view and analyze seismograms, determine the epicenter-to-station distance using the S minus P method and calculate magnitudes.

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2. Seismic Wave Propagation in the Earth: Four main types of seismic waves propagate in elastic materials including the Earth. A simplified model of Earth's interior structure is illustrated in Figure 1. A hands-on Earth structure activity is available at: http://web.ics.purdue.edu/~braile/edumod/earthint/earthint.htm. Two types of body waves, compressional or P-waves and shear or S-waves, travel through the Earth's interior. S-waves do not travel through fluids so they are not present in the Earth's liquid outer core. The two types of surface waves are Rayleigh waves and Love waves. Surface waves travel approximately parallel to the Earth's surface and their particle motions decrease in amplitude with depth below the surface. Additional information of seismic waves can be found in standard seismology and Earth science reference books including Bolt (1993, 2004) and Shearer (1999). Hands-on activities for exploring seismic waves and seismic wave propagation using the slinky are available at: http://web.ics.purdue.edu/~braile/edumod/slinky/slinky.htm and http://web.ics.purdue.edu/~braile/edumod/slinky/slinky4.htm.
Seismic wave animations and related hands-on activities are be found at: http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm.

Seismic waves in the Earth can be represented by specific raypaths and wave types that result in distinct arrivals, called phases, on seismograms (Figure 2). Several raypaths for seismic phases and the concept of geocentric angle (angular distance) and distance along the Earth's surface are illustrated in Figures 2, 3 and 4.

Travel times for seismic waves are well known from many years of recording seismograms all over the world from earthquake and explosive sources. Examples of standard travel time curves are shown in Figures 5, 6 and 7. These curves can be used to estimate the epicenter-to-station distance from the S minus P time (Figures 7 and 8) and for identifying phases (arrivals) on recorded seismograms. Examples of using the AmaSeis software and AS-1 seismograms for the S minus P distance estimation and epicenter location method are given at:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/UsingAmaSeis/UsingAmaSeis.htm
http://web.ics.purdue.edu/~braile/edumod/eqdata/eqdata.htm
http://web.ics.purdue.edu/~braile/edumod/as1lessons/EQlocation/EQlocation.htm.

The magnitudes (mb, MS and mbLg) of earthquakes recorded on the AS-1 seismograph can also be estimated using methods described at:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/EQlocation/EQlocation.htm
http://web.ics.purdue.edu/~braile/edumod/as1lessons/magnitude/CalcMagnElect.htm
http://web.ics.purdue.edu/~braile/edumod/as1mag/as1mag.htm
and the AS-1 online magnitude calculator:

http://web.ics.purdue.edu/~braile/edumod/MagCalc/MagCalc.htm. Magnitudes can also be calculated directly with the AmaSeis software.
Results of many magnitude calculations for WLIN seismograms are illustrated at: http://web.ics.purdue.edu/~braile/edumod/MagCalc/AS1Results.htm.

Additional raypath diagrams for seismic wave propagation through the Earth are shown in Figures 9-12.

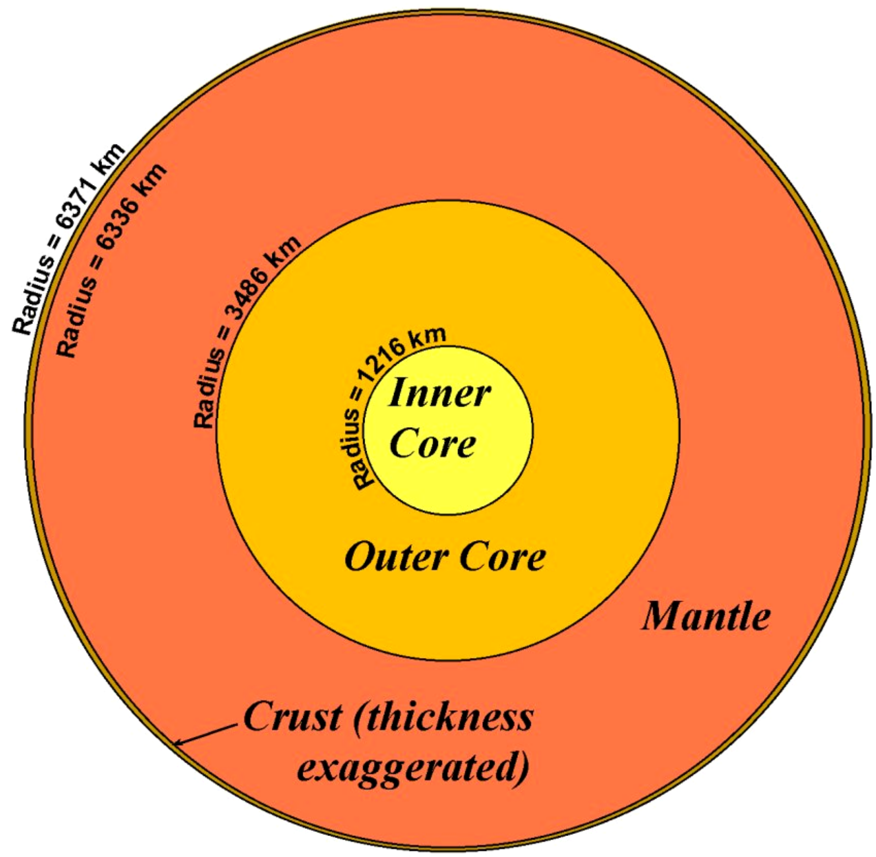


Figure 1. Schematic diagram illustrating the major spherical shells of the Earth's interior structure. The circles (representing spherical shells in the 3-D model) are drawn at true scale except for the circle representing the base of the crust. The thickness of the crustal layer is exaggerated so that a distinct layer is visible at this scale (the scale of this diagram is approximately 1:120 million). In the real Earth, the crust is also of variable thickness with significant differences between the crustal thickness of oceanic and continental regions and increased crustal thickness beneath mountainous areas.

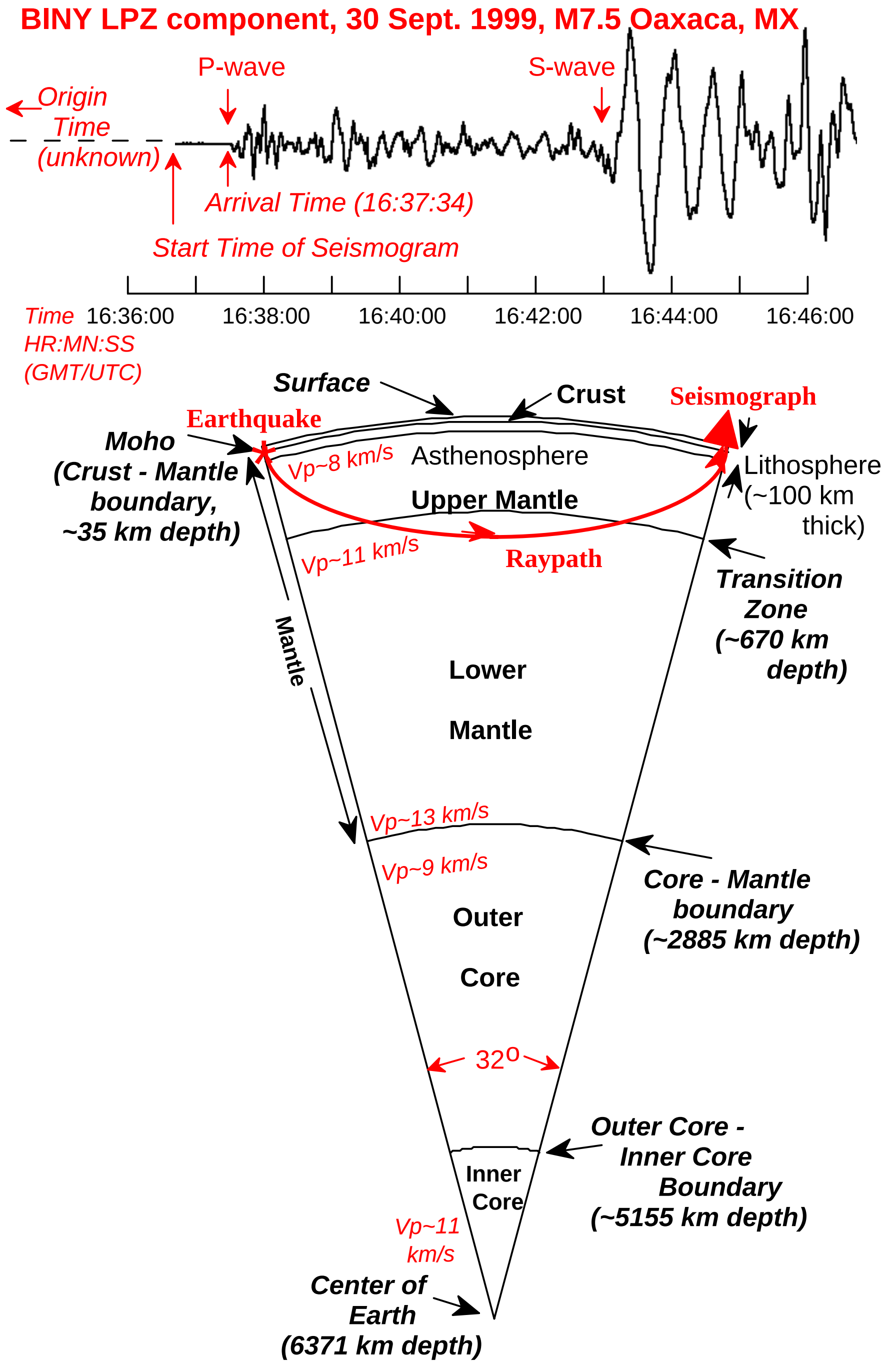


Figure 2. Segment of Earth model showing main boundaries and layers, and approximate compressional- or P-wave velocity with depth. Raypath shows approximate travel path for the first arriving P-wave (and the S-wave) for the seismogram shown above. The seismogram was recorded by the Binghamton, NY (BINY) station and is the record of the long period, vertical component (LPZ) of motion. The source was the M7.5, Oaxaca, Mexico earthquake of September 30, 1999. The distance from the earthquake epicenter to the seismograph station is approximately 32 degrees geocentric angle, corresponding to a distance of about 3560 km along the Earth's surface.

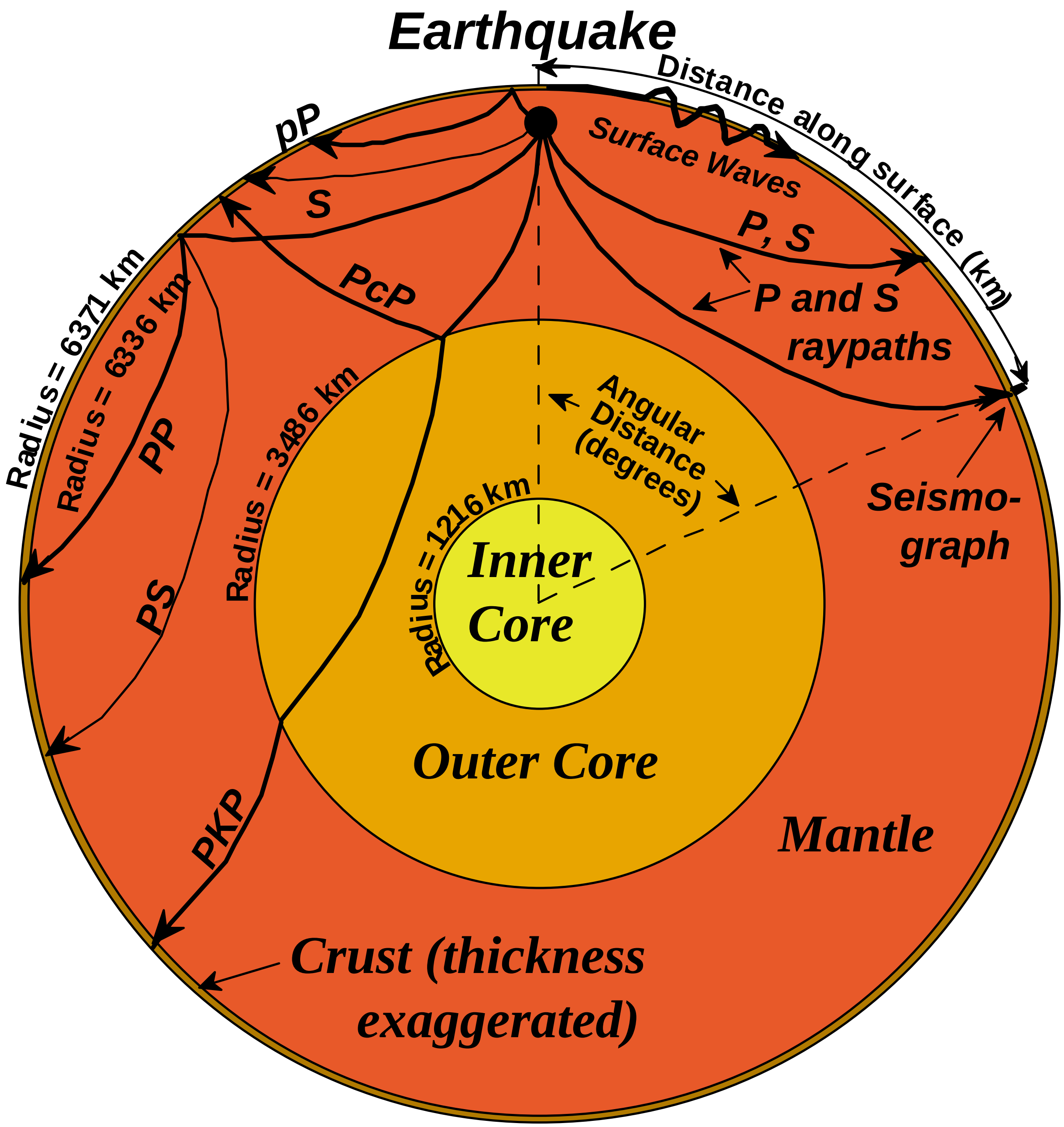


Figure 3. Cross section through the Earth showing important layers and representative raypaths of seismic body waves. Direct P and S raypaths (phases), including a reflection (PP and pP), converted phase (PS), and a phase that travels through both the mantle and the core (PKP). P raypaths are shown by heavy lines. S raypaths are indicated by light lines. Additional information about raypaths for seismic waves in the whole Earth and illustrations of representative raypaths are available in Bolt (1993, p. 128-142) and Shearer (1999, p. 49-60). Surface wave propagation (Rayleigh waves and Love waves) is schematically represented by the heavy wiggly line. Surface waves propagate away from the epicenter, primarily near the surface and the amplitudes of surface wave particle motion decrease with depth.

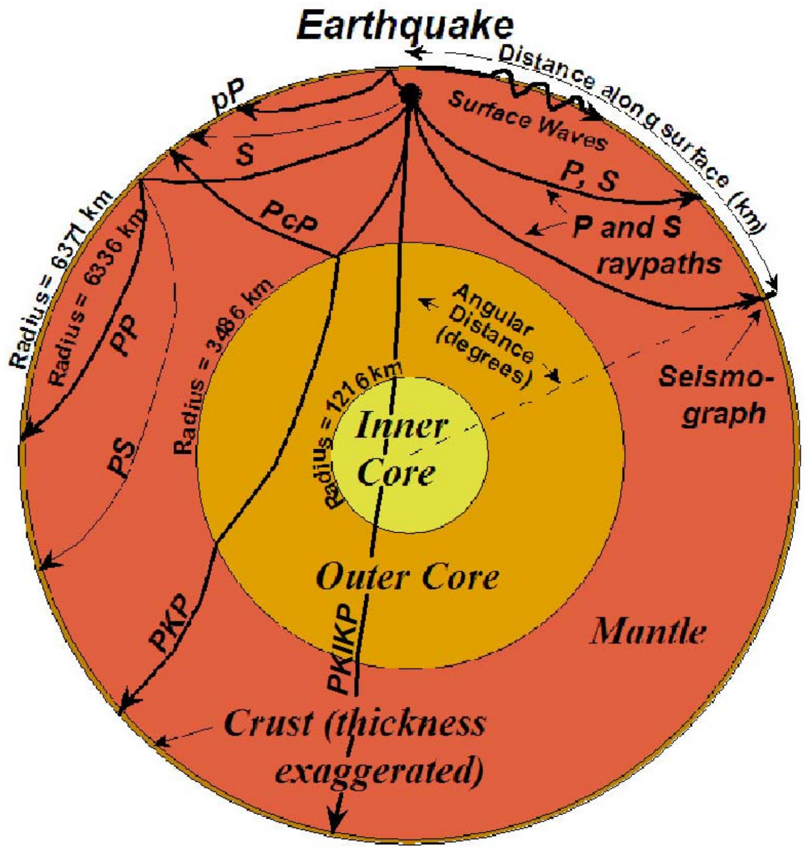


Figure 4. Earth structure and raypaths (Figure 3) with the addition of a raypath for the seismic phase PKIKP that travels through the Earth's inner core.

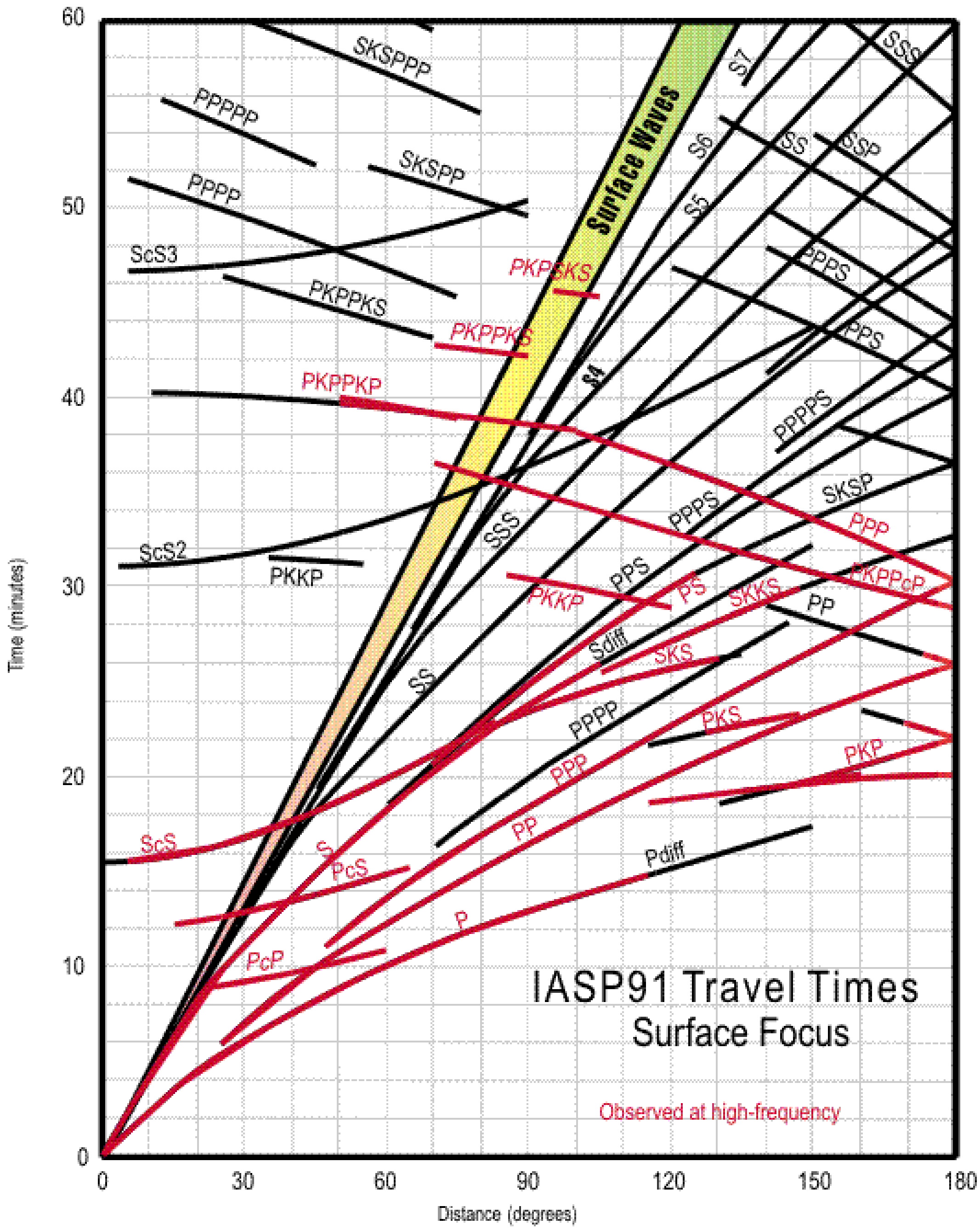


Figure 5. Standard Earth travel time curves for a source depth of 0 km (can be used for shallow focus earthquakes at distances of ~20 to 120 degrees). Travel times for many different phases (types of seismic waves and paths through the Earth) are shown. Note that the ***difference*** *between the S and the P times increases smoothly with distance. Therefore, a seismogram with a given S minus P time will only match the travel time data at one specific distance. This diagram is available at: http://neic.usgs.gov/neis/travel_times/ttgraph.html.*

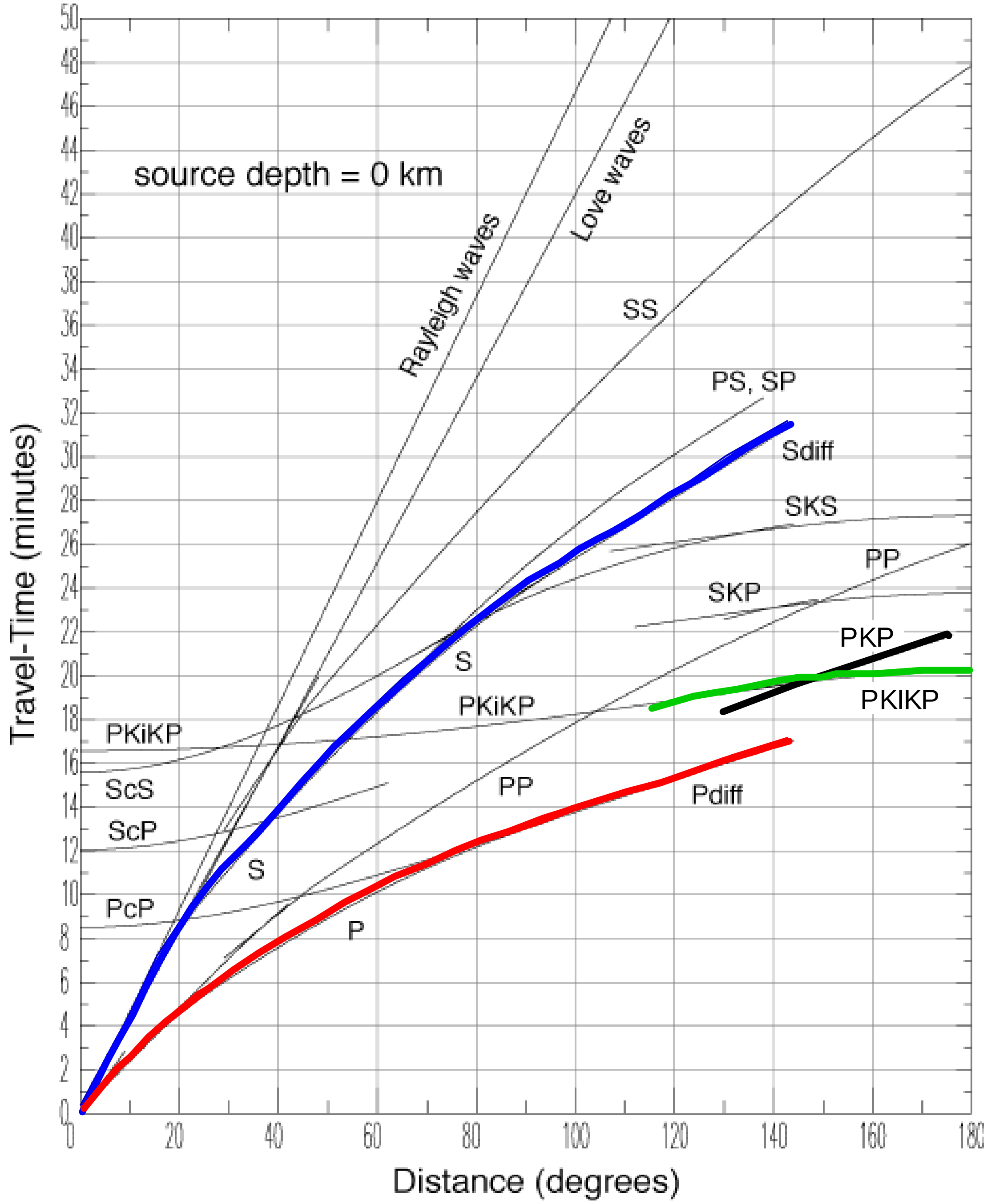


Figure 6. Standard travel time curves for the Earth for several seismic phases. Travel times for some primary phases are highlighted.

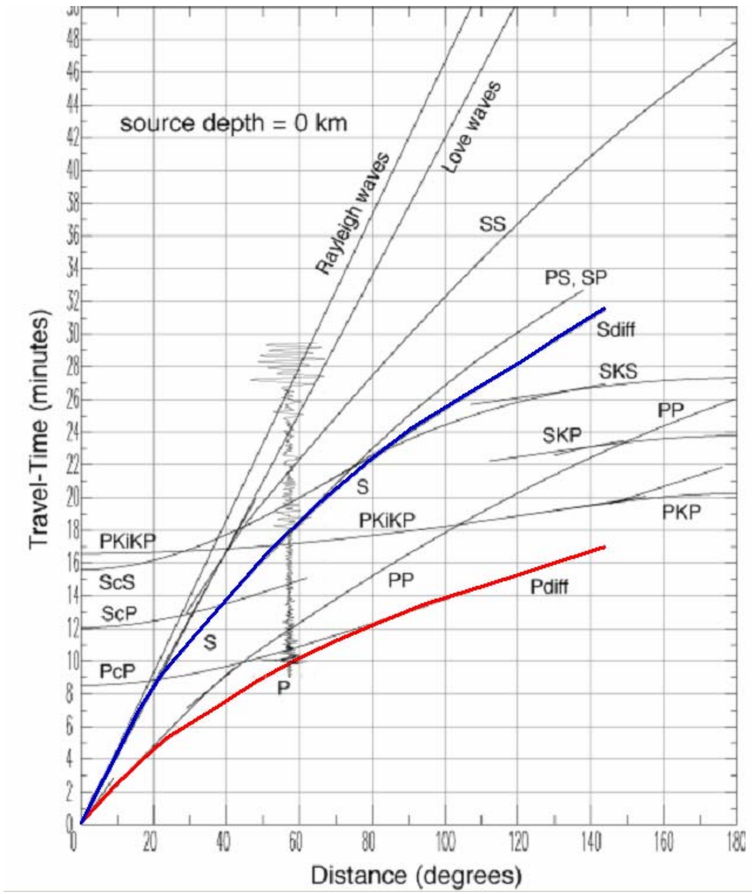


Figure 7. Overlaying a seismogram (station KIP, M7.5, 1999 Oaxaca earthquake) on the standard Earth model travel time curves. This diagram shows that the S minus P arrival times indicate an epicenter-to-station distance of about 58 degrees. The AmaSeis travel time curve tool provides a similar display (Figure 8) although the graph is rotated so that the seismograms are plotted horizontally.

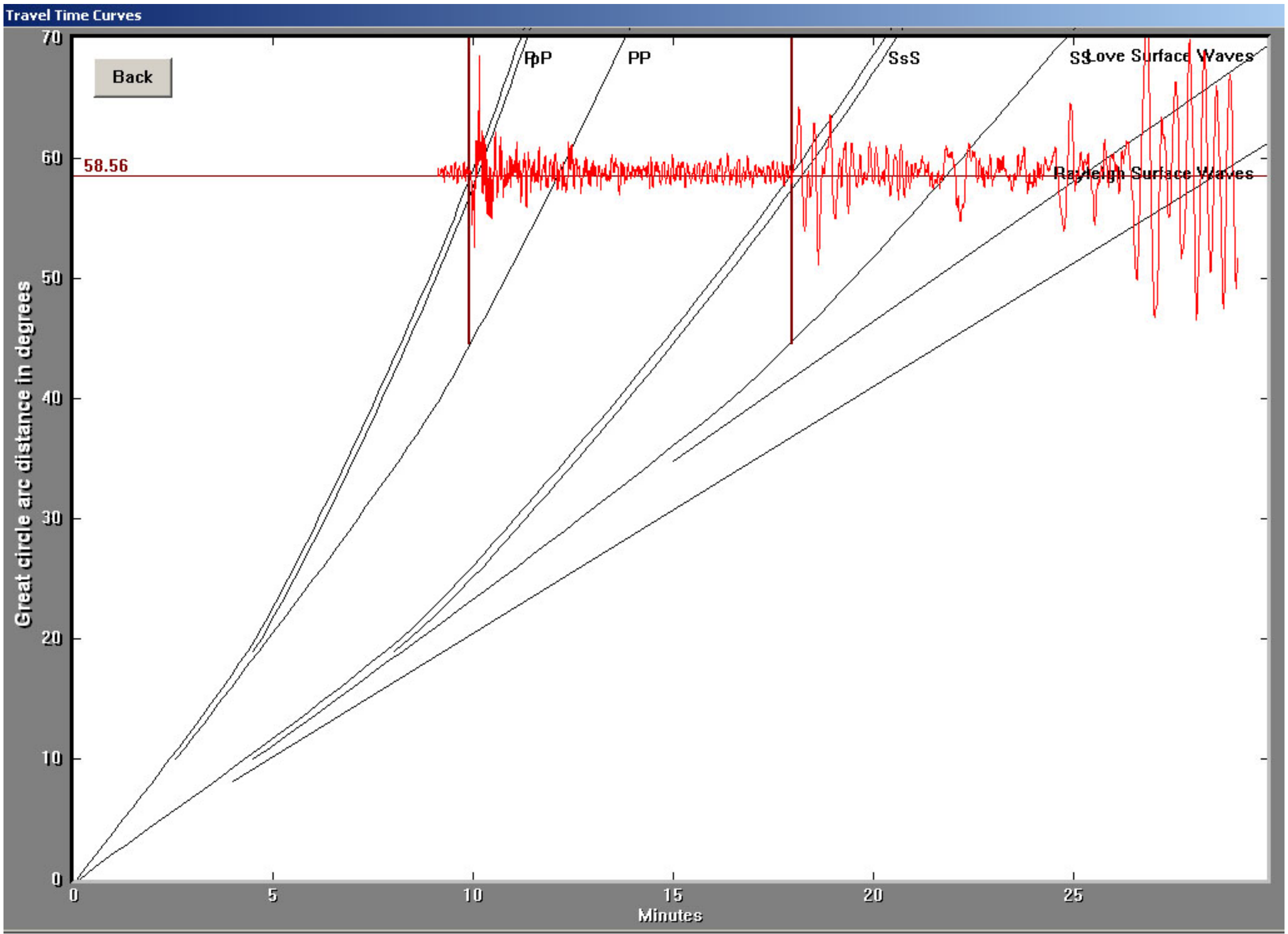


Figure 8. KIP seismogram for the Oaxaca earthquake displayed in the AmaSeis travel time curves window. The seismogram is moved in the AmaSeis software (by dragging with the mouse cursor) until the P and S arrival times match the travel time curves. The epicenter-to-station distance that corresponds to the interpreted S minus P time is displayed to the left of the seismogram.

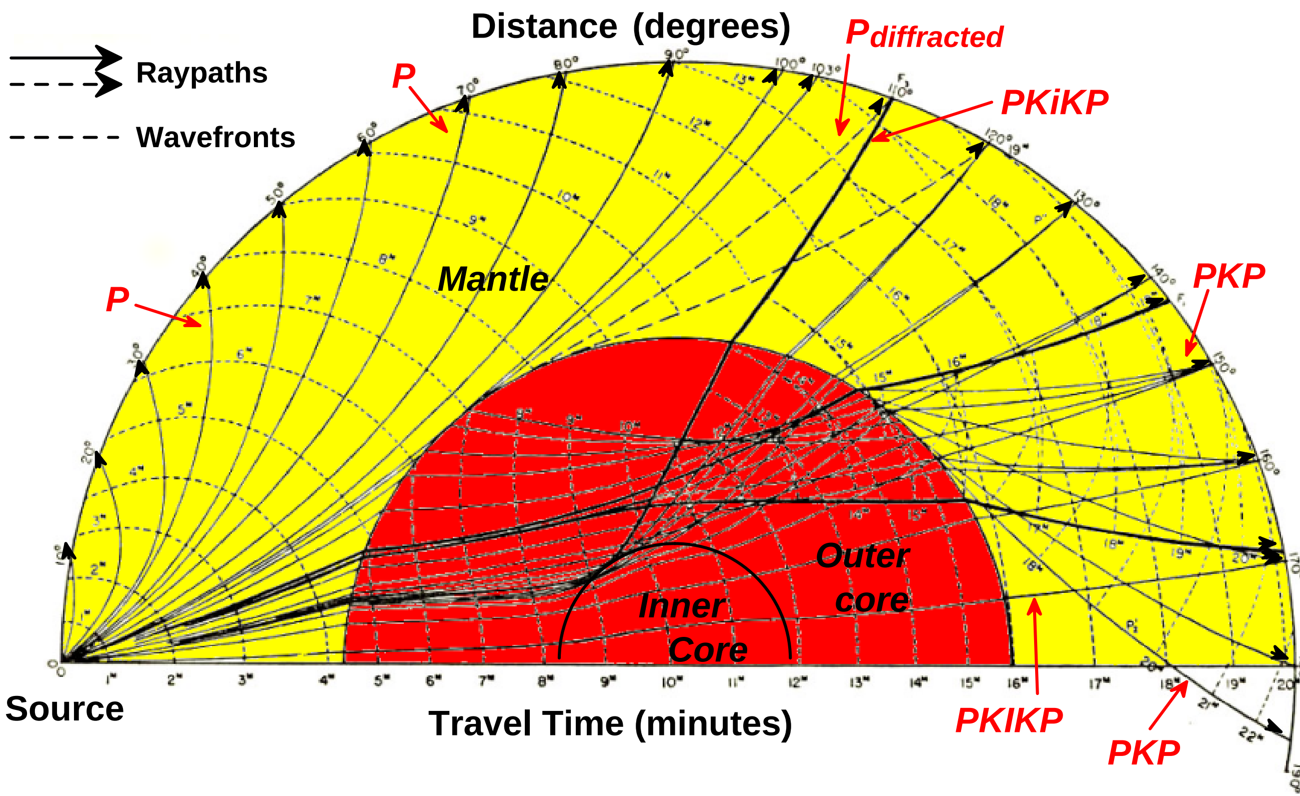


Figure 9. Raypaths and wavefronts for selected primary (compressional) wave phases which travel through the Earth. The travel times (in minutes) along the raypaths and the corresponding wavefronts (short dashed lines; lines or surfaces of equal travel time) are given by the small numbers adjacent to the wavefronts. The raypaths are perpendicular to the wavefronts and represent the direction that a specific point on the wavefront is propagating. The raypaths in this real Earth model are curved because the seismic wave velocity varies with depth. Note the strong refraction (bending) of the raypaths and wavefronts caused by the velocity change across the core-mantle boundary. The primary wave types (phases) illustrated in this diagram are:

P	*Raypaths for waves which travel through the mantle with a relatively direct path; 0°-103° distance range.*
Pdiffracted	*Raypaths for waves which travel through the mantle and are diffracted at the core-mantle boundary by the reduced outer core velocity; 103°-150° distance range.*
PKP	*Raypaths for waves which travel through the mantle, are strongly refracted at the core-mantle boundary and travel through the outer core; 110°-187° distance range.*
PKIKP	*Raypaths for waves which travel through the mantle, the outer core and the inner core; 110°-180° distance range.*
PKiKP	*Raypaths for waves that are reflected from the inner core. In more recent models of the Earth's interior, the PKiKP arrivals are observed for distances less than about 120°.*

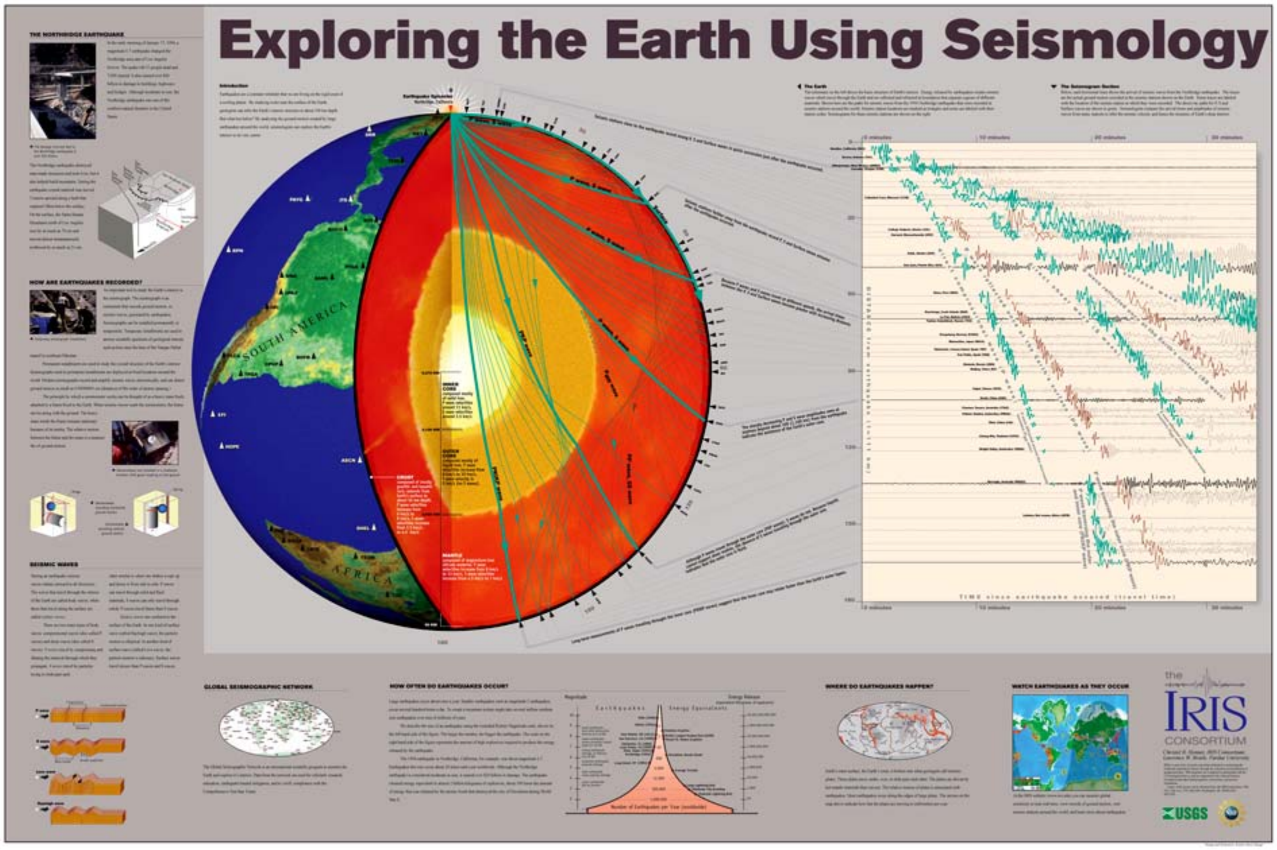


Figure 10. IRIS "Exploring the Earth Using Seismology" poster illustrating seismic wave propagation through the Earth (http://www.iris.edu/about/publications.htm#p).

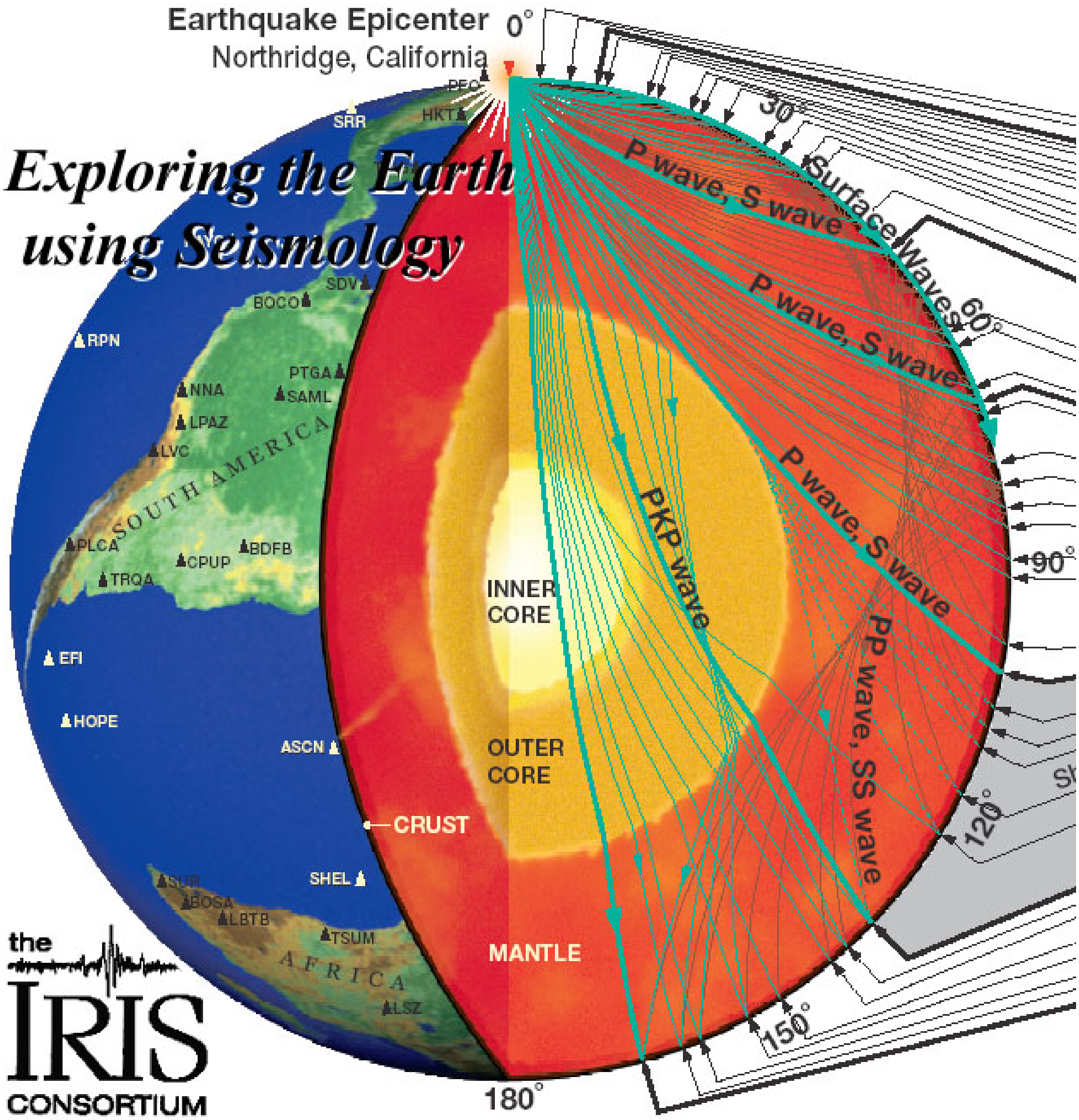


Figure 11. Close-up diagram of a portion of the IRIS poster (Figure 10) showing raypaths through the Earth's interior for several seismic phases. Distances in geocentric angle are noted using the degrees scale.

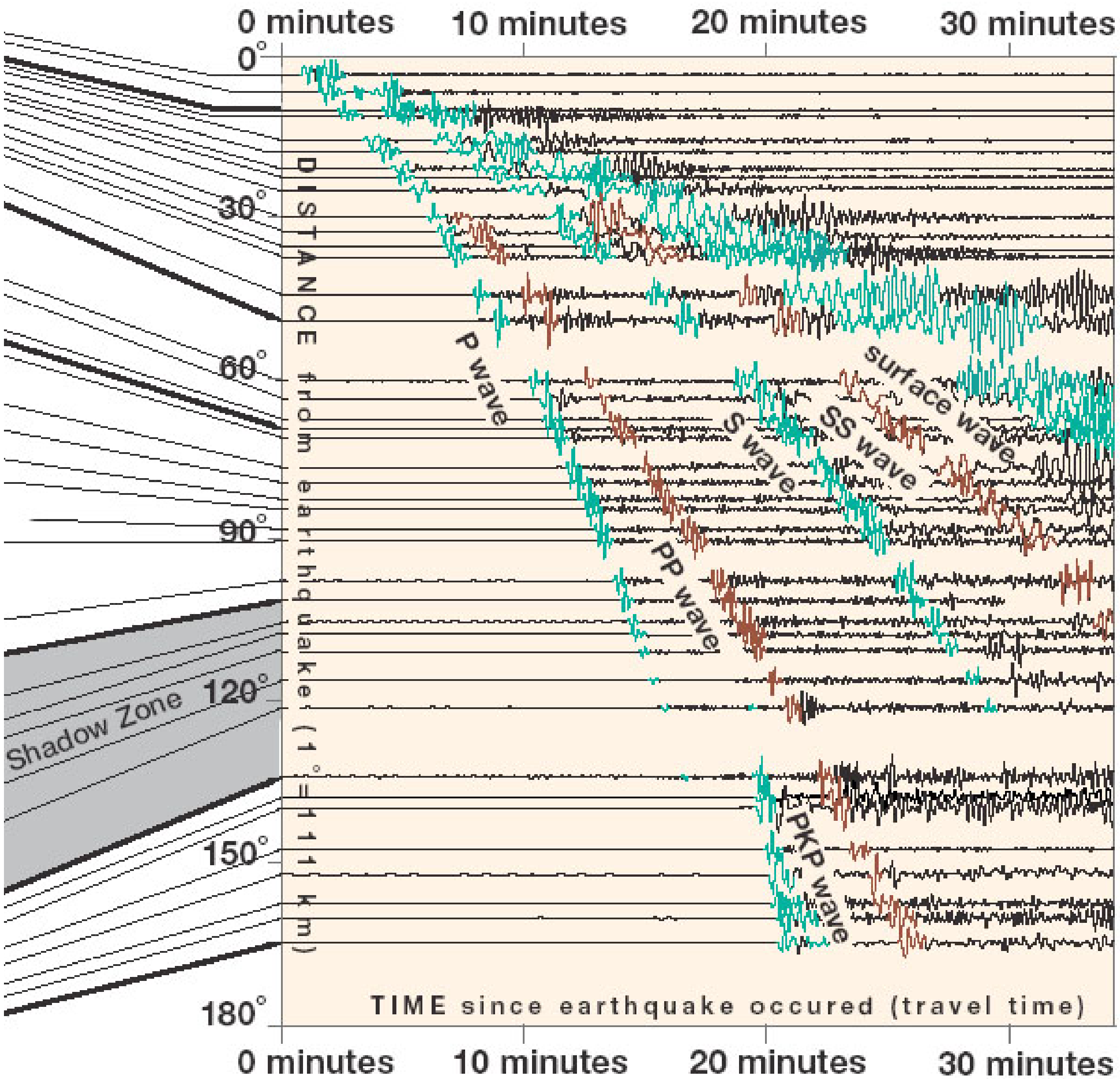
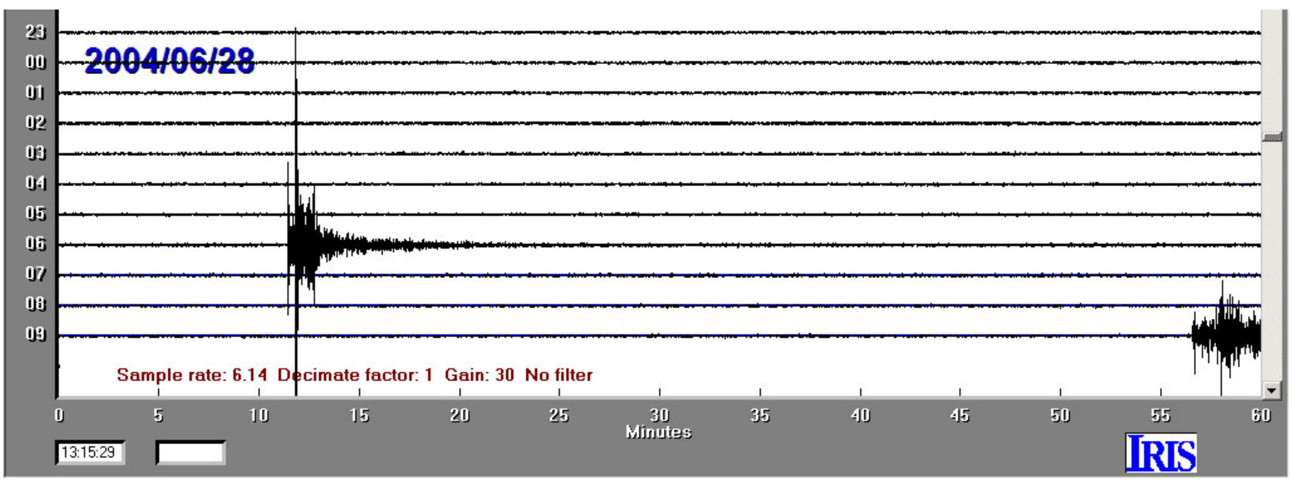


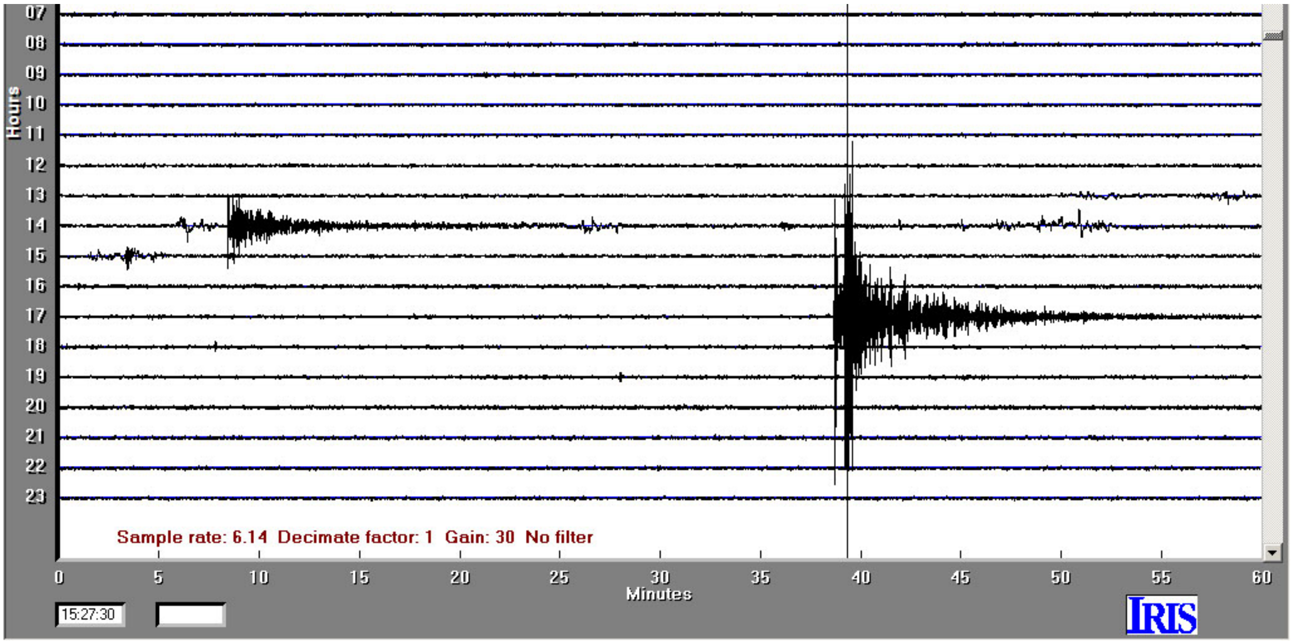
Figure 12. Close-up diagram of a portion of the IRIS poster (Figure 10) showing a seismogram record section with several phases identified.

3. Catalog of Seismograms at Various Distances – Screen Images: The partial screen images (from the 24-hour display in AmaSeis for station WLIN) included below and labeled **A** through **R** show seismograms from shallow focus earthquakes at epicenter-to-station distances from 1.81 degrees to 143.49 degrees. All screen displays have the same gain factor of 30. The selected seismograms illustrate the change in character of seismic signals with increasing source-to-station distance. It is immediately clear that as the distance increases, the seismograms have longer time duration. This feature is caused be the fact that different wave types travel at different velocities which causes the difference in time between phases to increase with distance. An example is the S minus P times as illustrated in Figures 6 and 7. Also, surface waves travel slower than S waves and are dispersive (velocity is a function of frequency) further increasing the duration of the seismogram with increasing distance of travel. Furthermore, greater source-to-station distance tends to result in many phases representing different wave types and travel paths to have similar amplitudes so that the seismograms are often long and complex. Seismograms also often show a relatively abrupt first arrival (P wave energy), a small number of distinct arrivals, and then a slow "tapering off" of amplitudes as time increases. This last part of the seismogram is called the "coda." Some of the records shown below also include signals from other events and several noise sources.

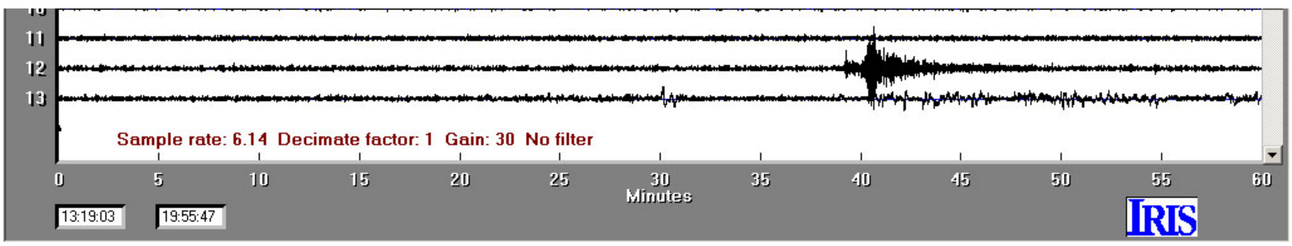
Additional information about the events represented by the seismograms can be found in the Excel spreadsheet station catalog (http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/EqList.xls).



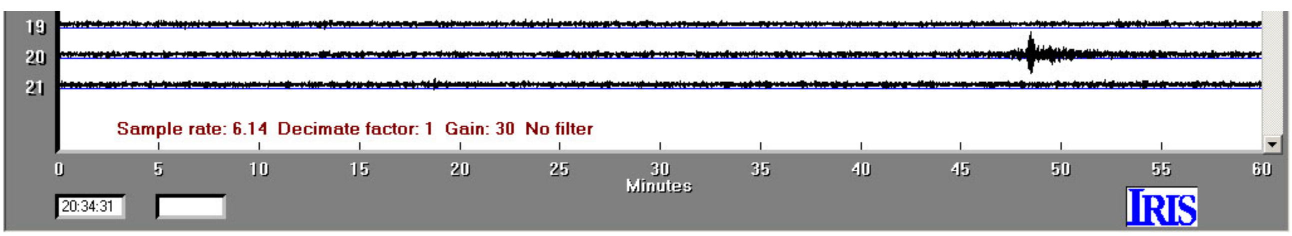
A. D = 1.81°, 2004 6/28, N. Illinois, M4.2.



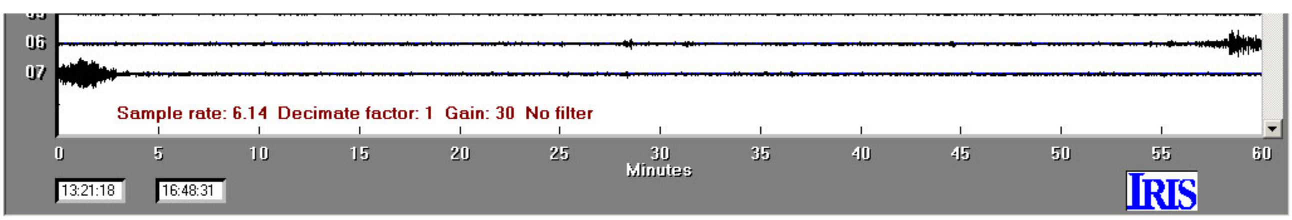
B. **D = 2.59°**, **2002 6/18, Near Evansville, IN, M4.4.**



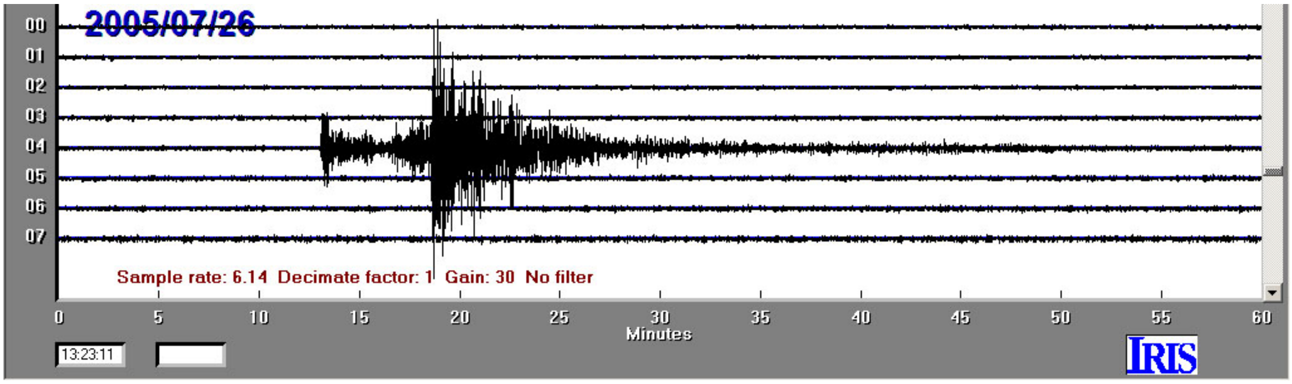
C. **D = 5.31°**, **5/1/05, Arkansas, M4.2.**



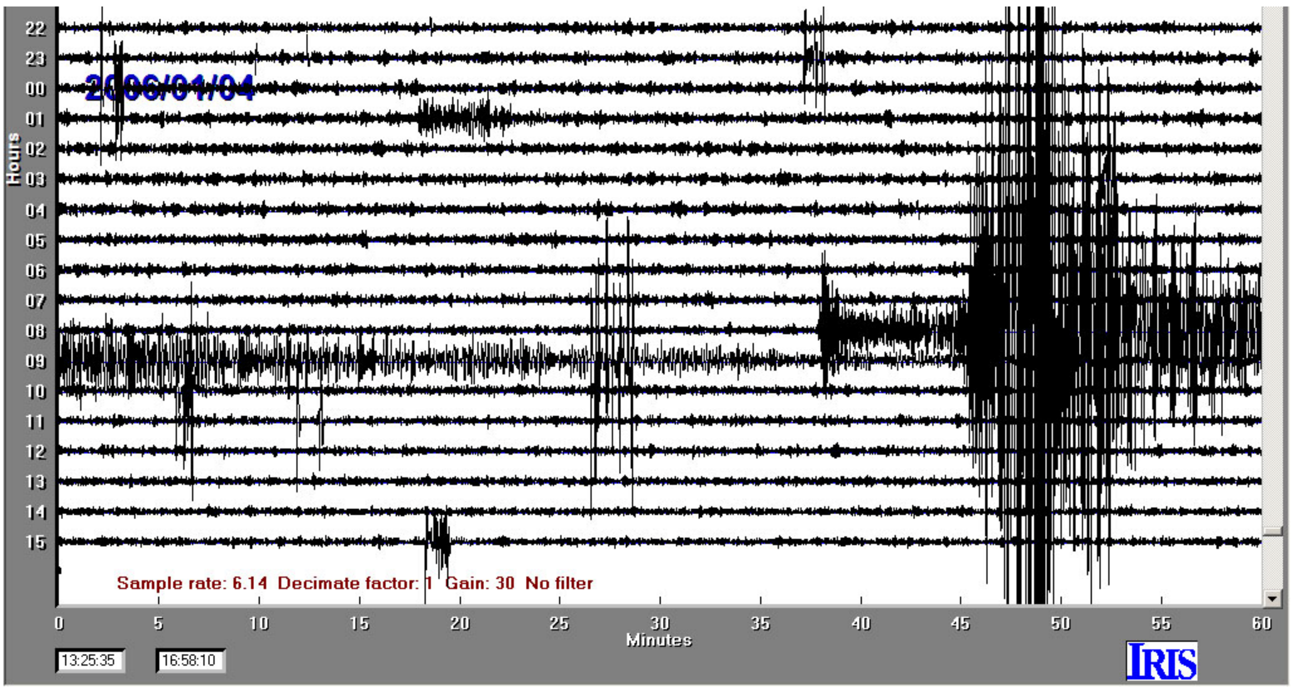
D. **D = 9.30°**, **2002 11/3, Nebraska, M4.3.**



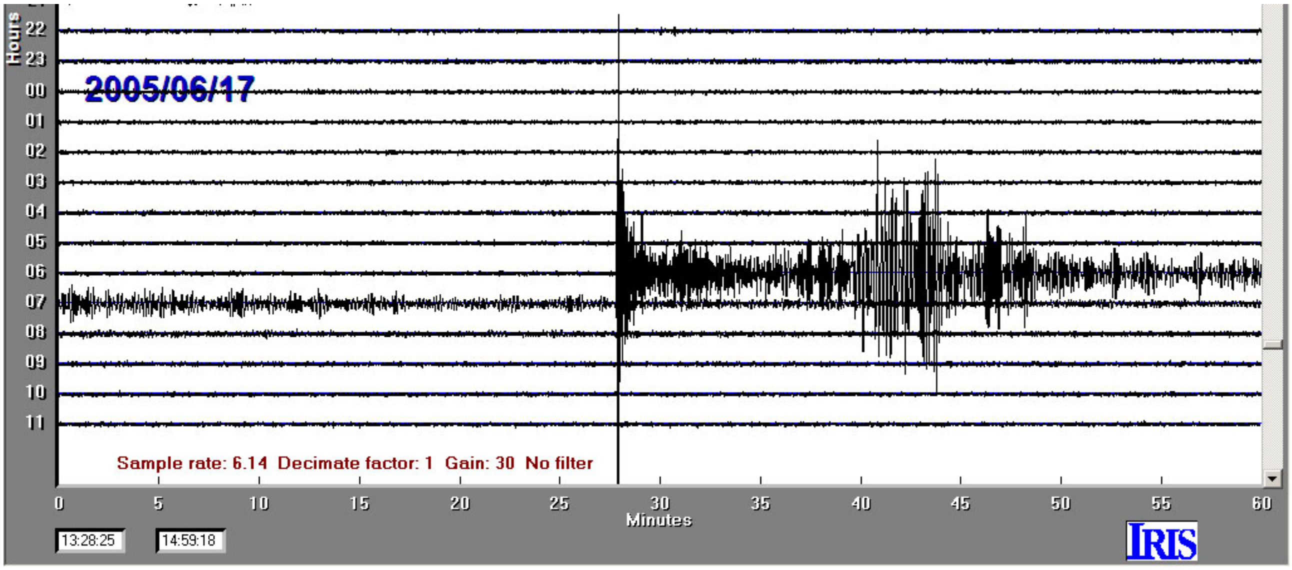
E. **D = 14.68°**, **2004 8/1, N. New Mexico, M4.3.**



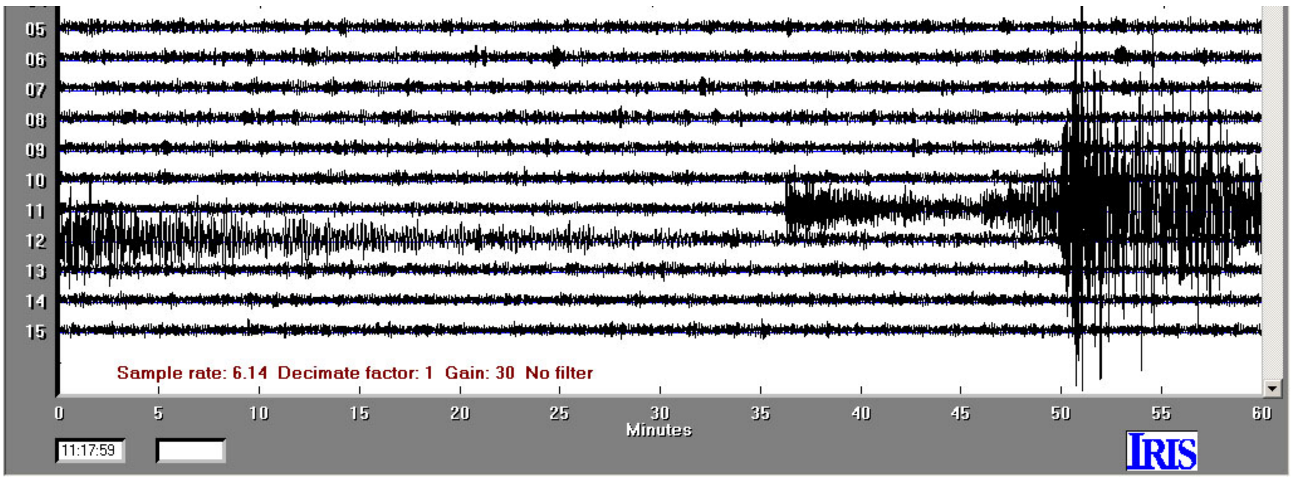
F. D = 19.39°, 2005 7/26, W. Montana, M5.6.



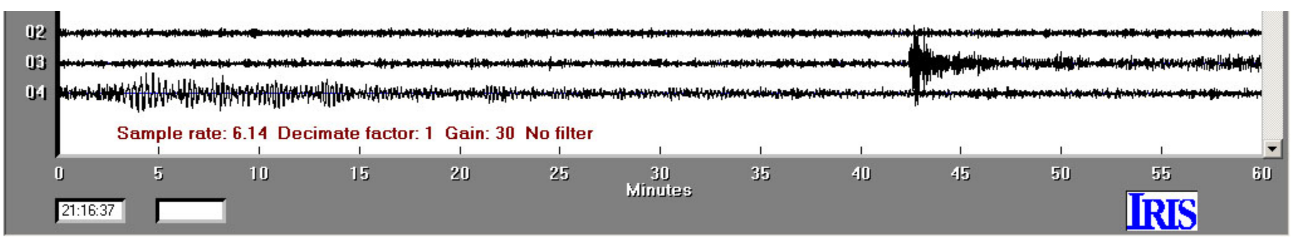
G. D = 24.10°, 2006 1/4, Gulf of California, M6.5.



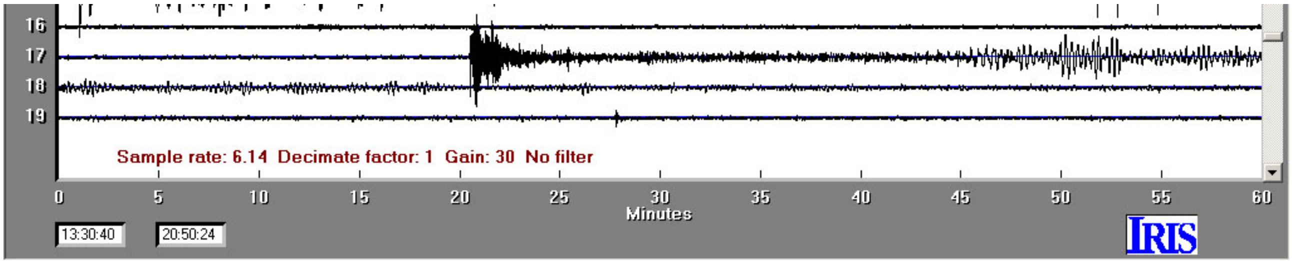
H. D = 29.97°, 2005 6/17, Off Coast of N. California, M6.7.



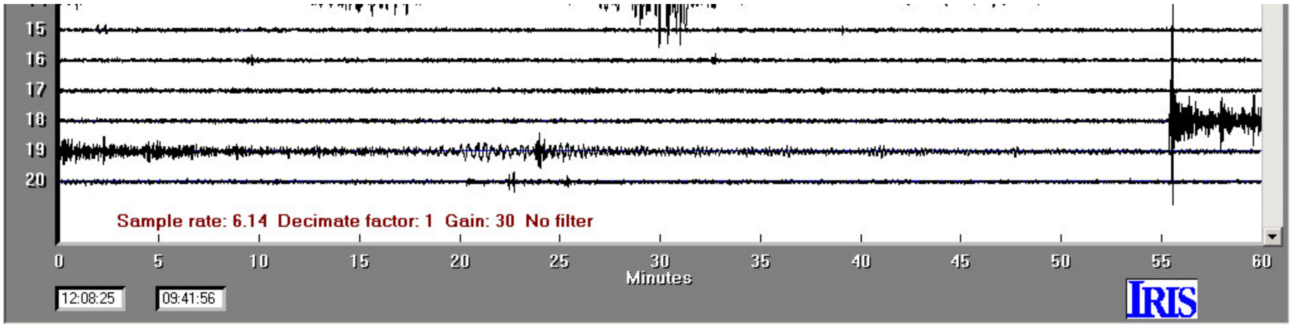
I. D = 42.04°, 2002 10/23, Central Alaska, M6.7.



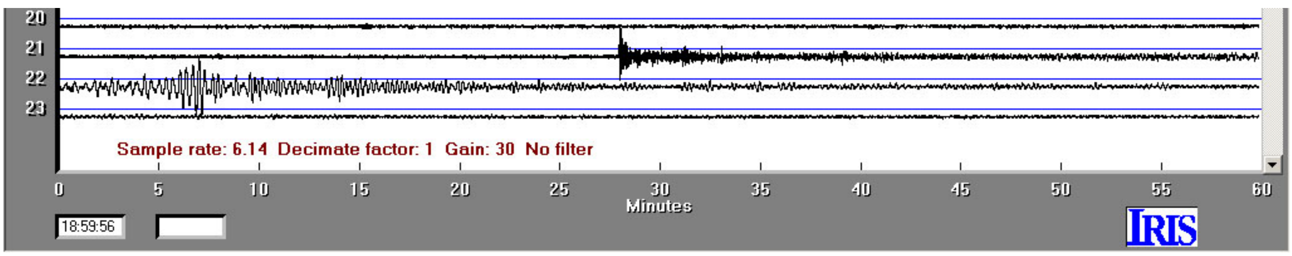
J. D = 51.92°, 2003 2/19, Unimak Island Region, Alaska, M6.6.



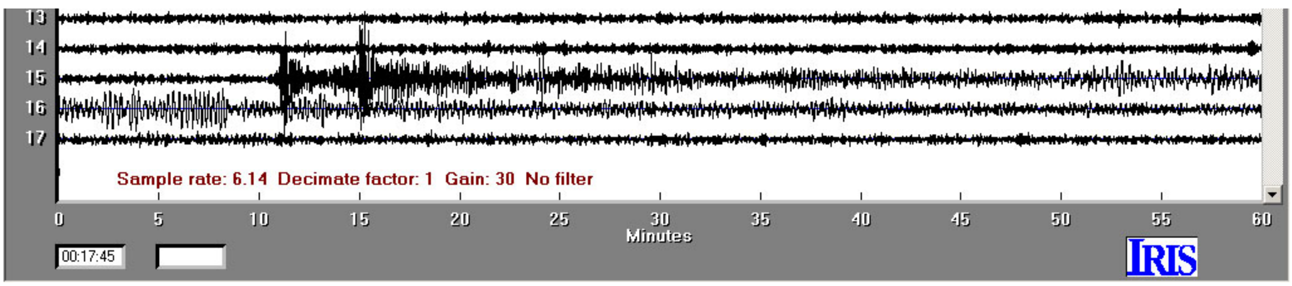
K. D = 61.17°, 2005 6/14, Rat Islands, Aleutians, Alaska, M6.8.



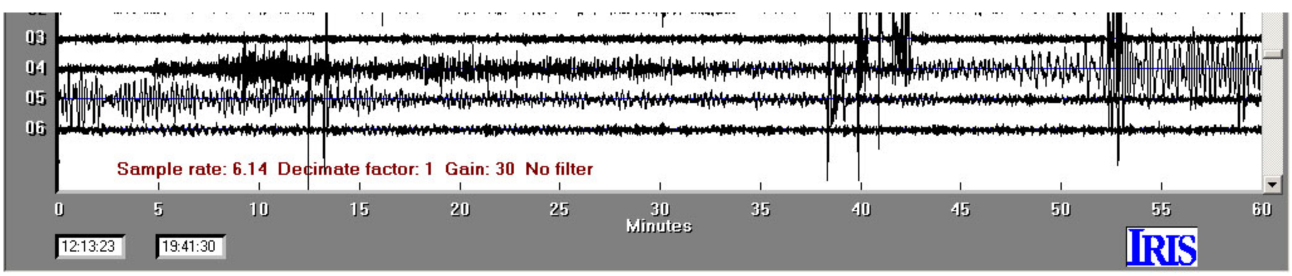
L. D = 67.70°, 2003 5/21, N. Algeria, M6.8.



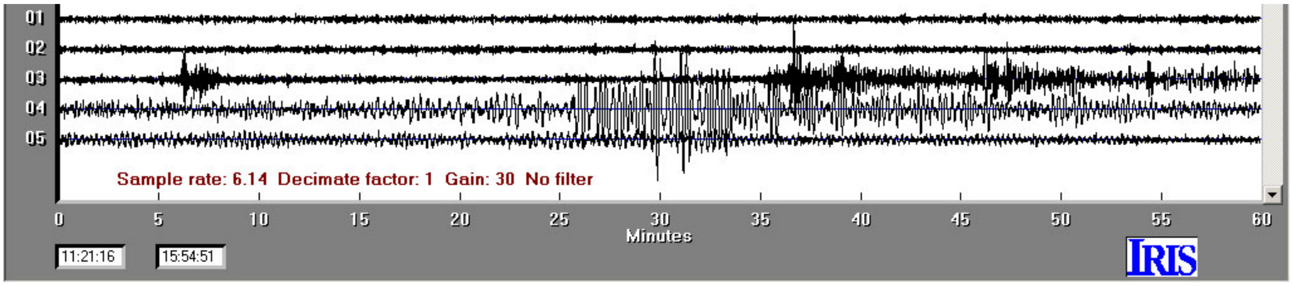
M. D = 81.08°, 2000 8/4, Sakhalin, Island, M7.1.



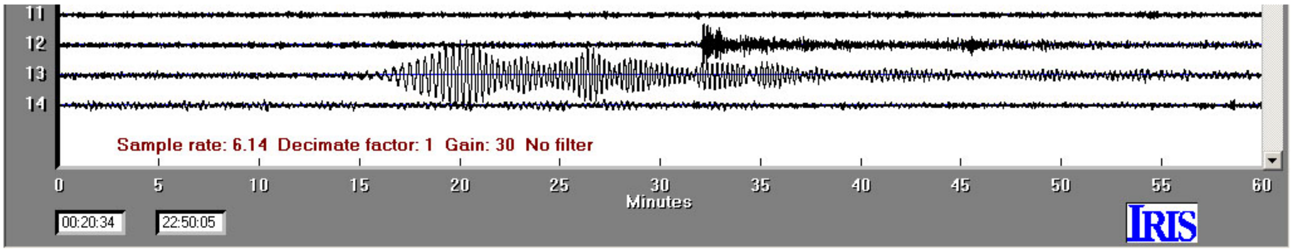
N. D = 96.20°, 2004 9/5, Near Honshu, Japan, M7.4.



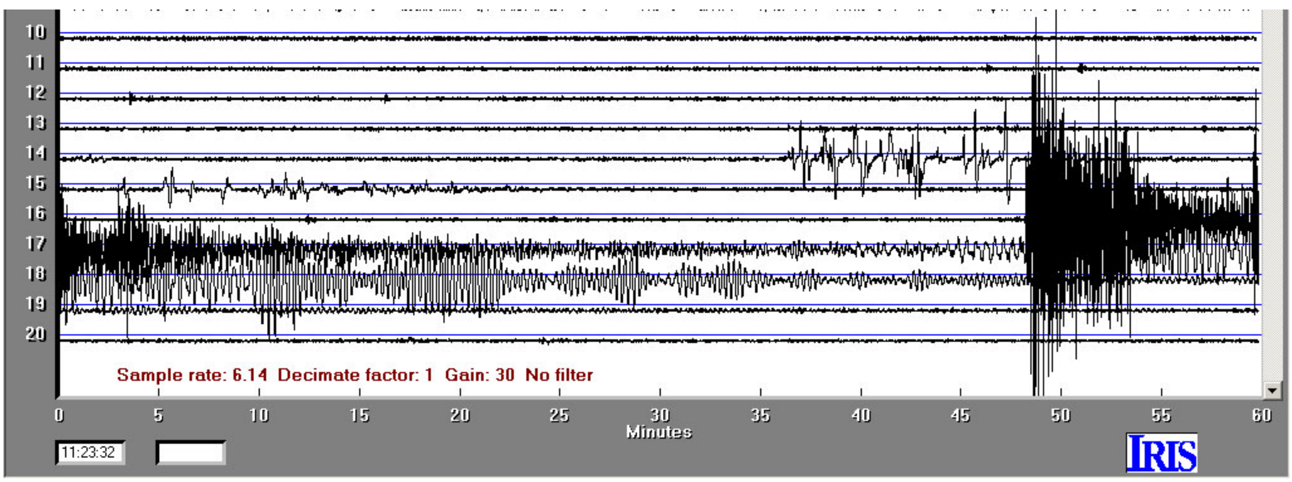
O. D = 103.21°, 2005 10/8, Pakistan, M7.8.



P. D = 112.99°, 2001 1/26, S. India, M7.7.

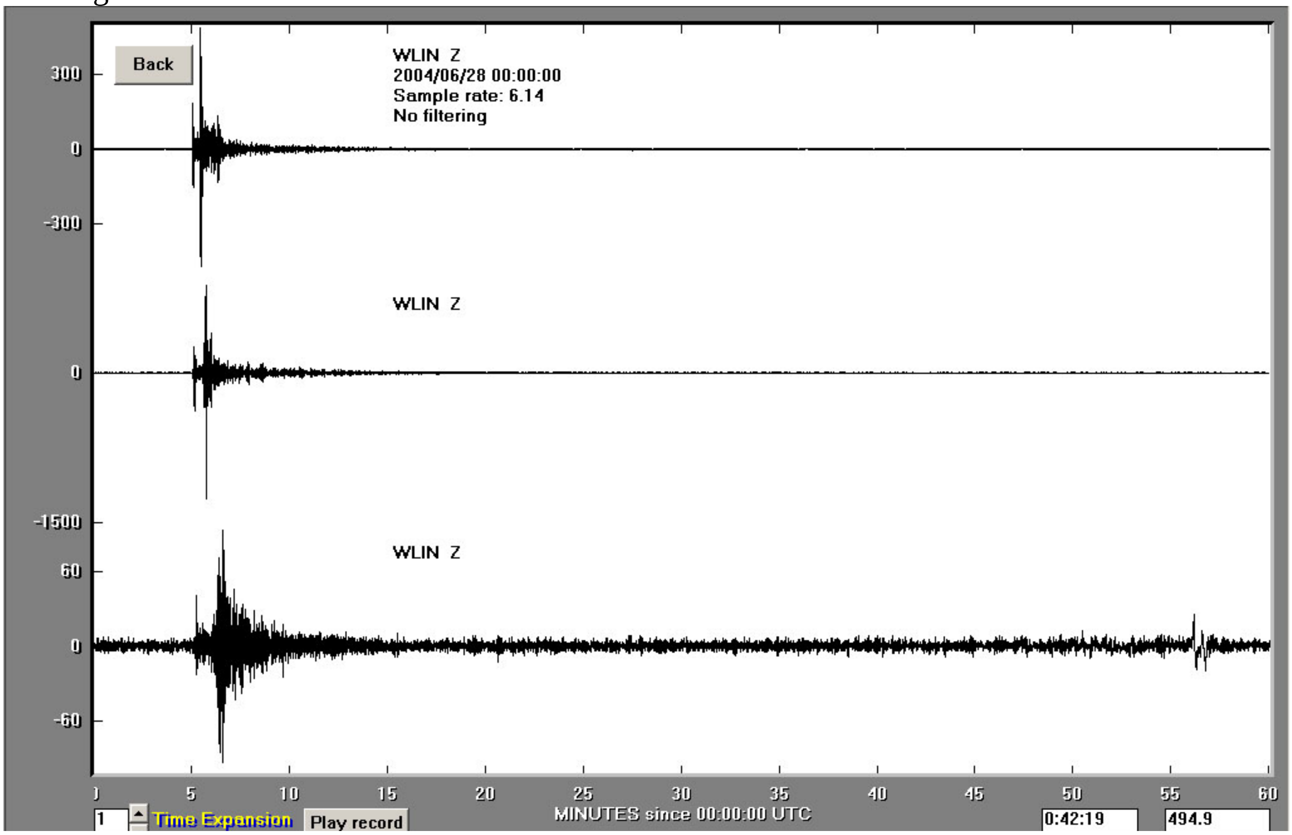


Q. D = 127.24°, 2003 8/21, S. Island, New Zealand, M7.2.

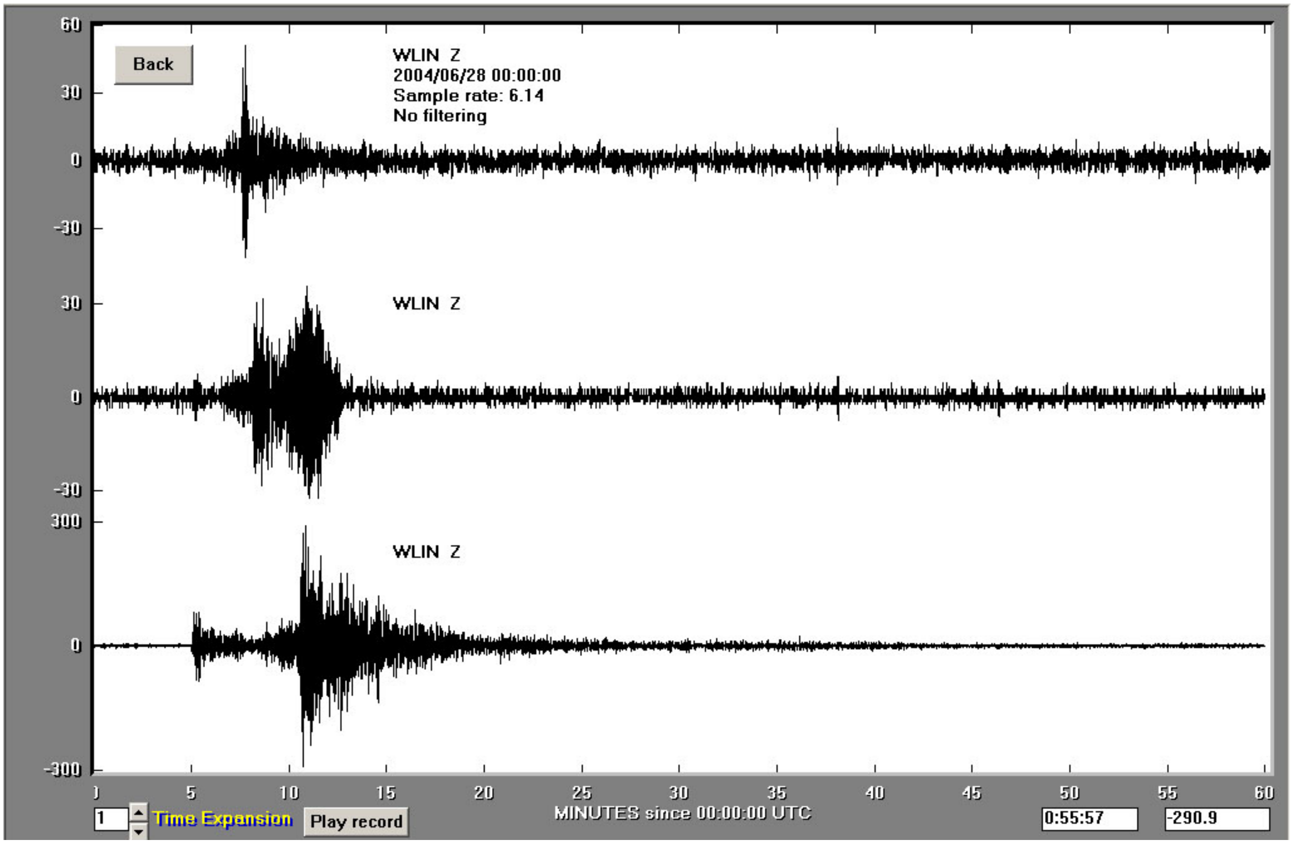


R. D = 143.49°, 2000 6/4, S. Sumatra, M7.6.

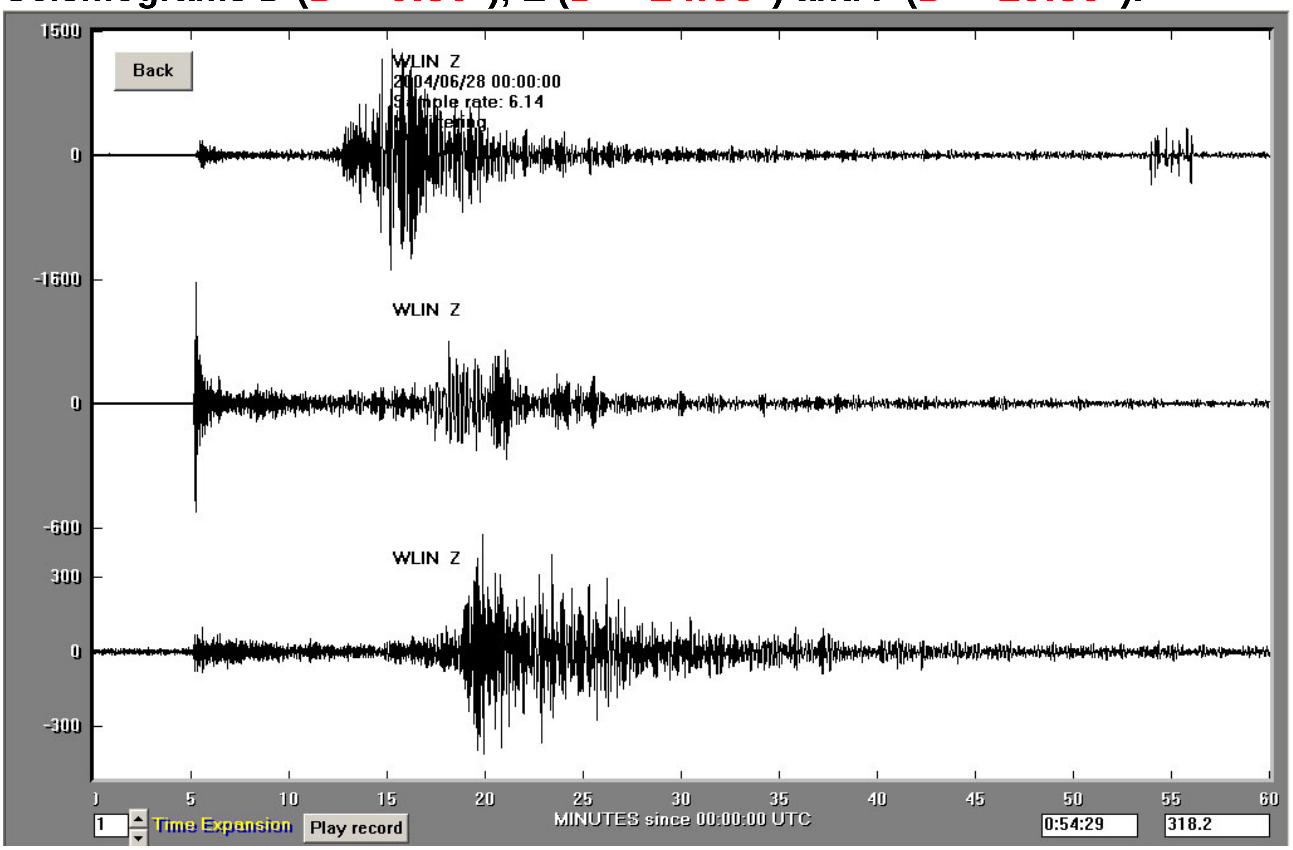
4. Catalog of Seismograms at Various Distances – 60-minute Seismograms: In the following 3-trace plots (extracted using AmaSeis), the **A** through **R** seismograms shown above are displayed as 60-minute records (with different amplitude scales – note the vertical scales on the left) to see a direct comparison of the signals at various distances and the same time scale. For some of the seismograms, one could "zoom in" further using the AmaSeis extract seismogram tool to see more detail. The digital, SAC-format seismograms are listed (with Internet links) in Table 1 so that one can change the view by "zooming in" and perform additional analysis and display the results. Seismograms **P**, **Q** and **R** are also shown in 2-hour records because of the duration of these records due to the large source-to-station distances. The increase in duration with distance, characteristic phases and seismogram complexity are apparent from the comparison of these seismograms.



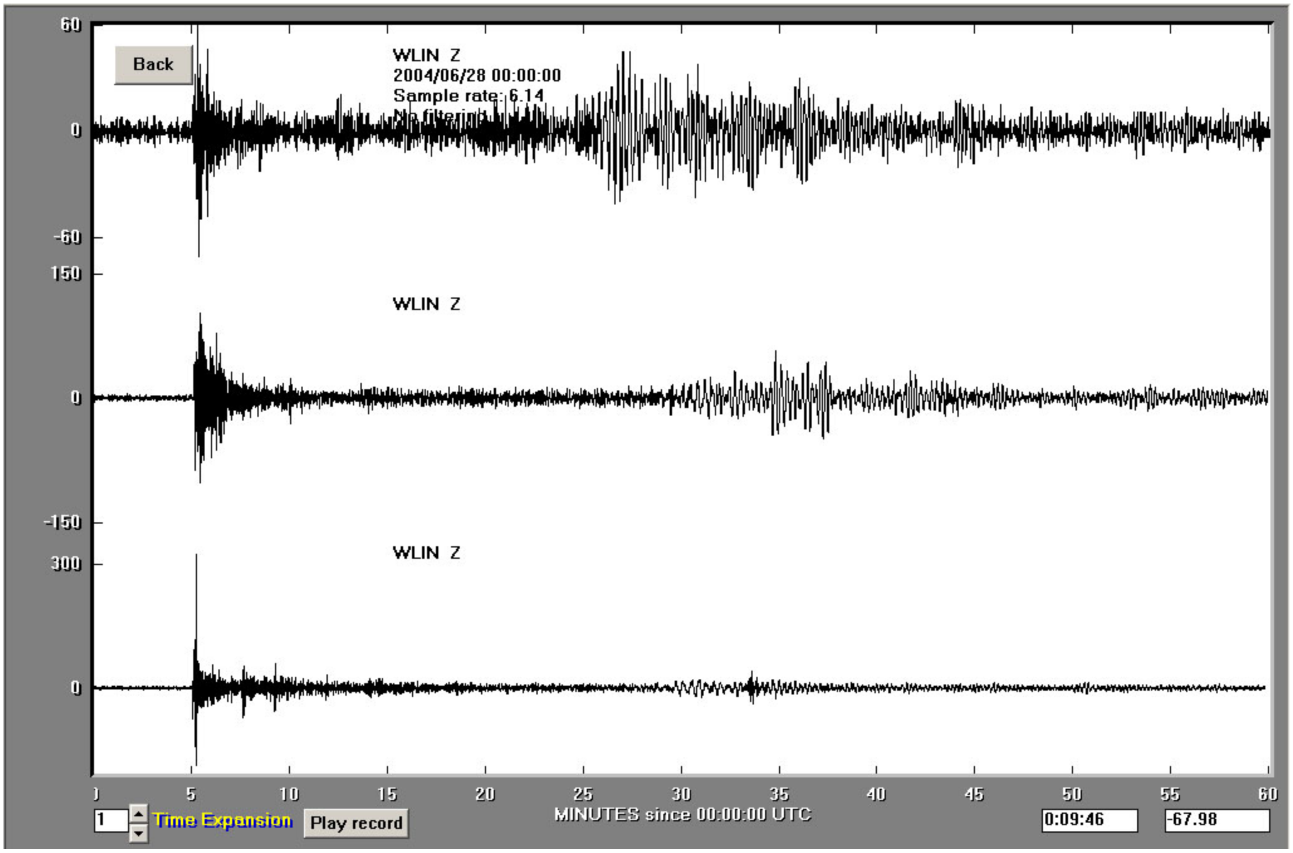
Seismograms A (D = 1.81°), B (D = 2.59°) and C (D = 5.31°).



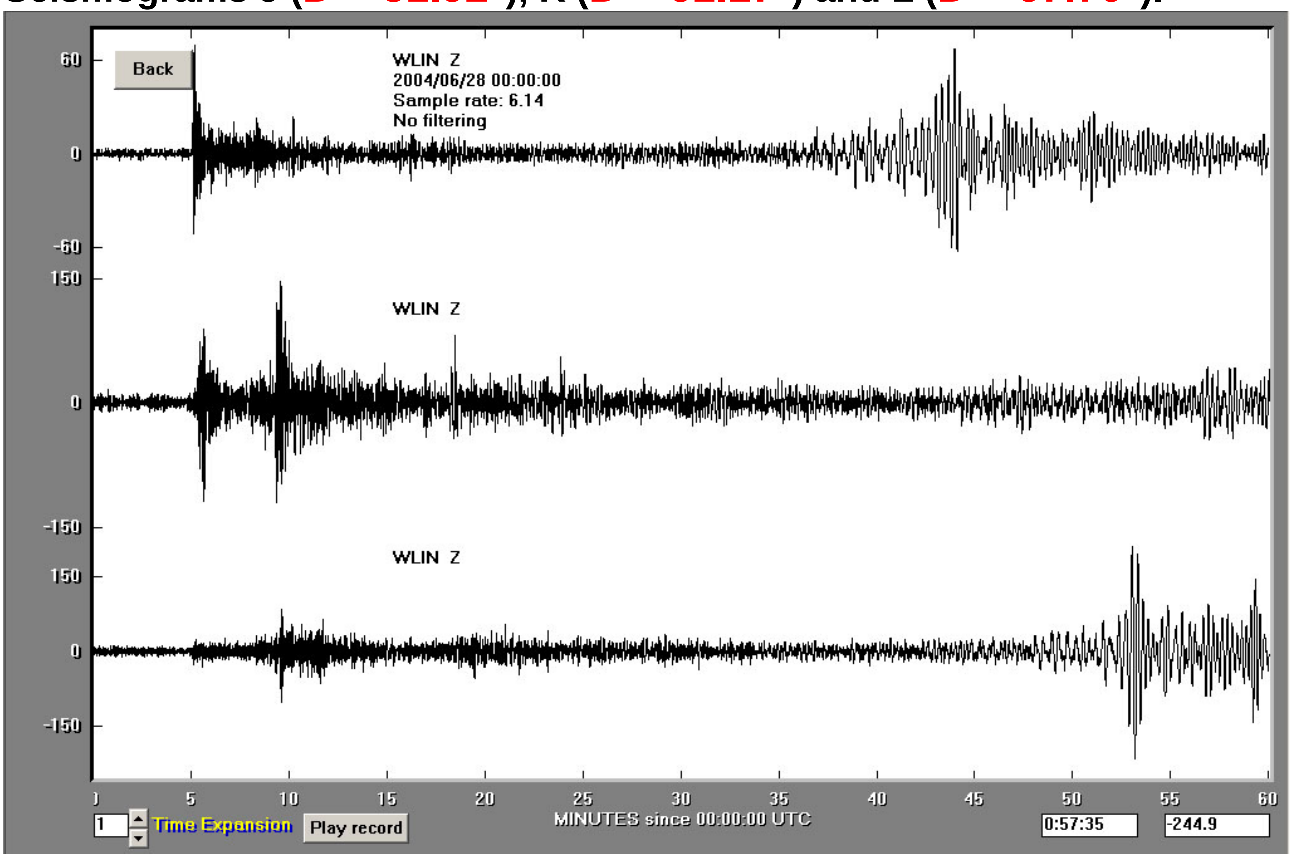
Seismograms D (D = 9.30°), E (D = 14.68°) and F (D = 19.39°).



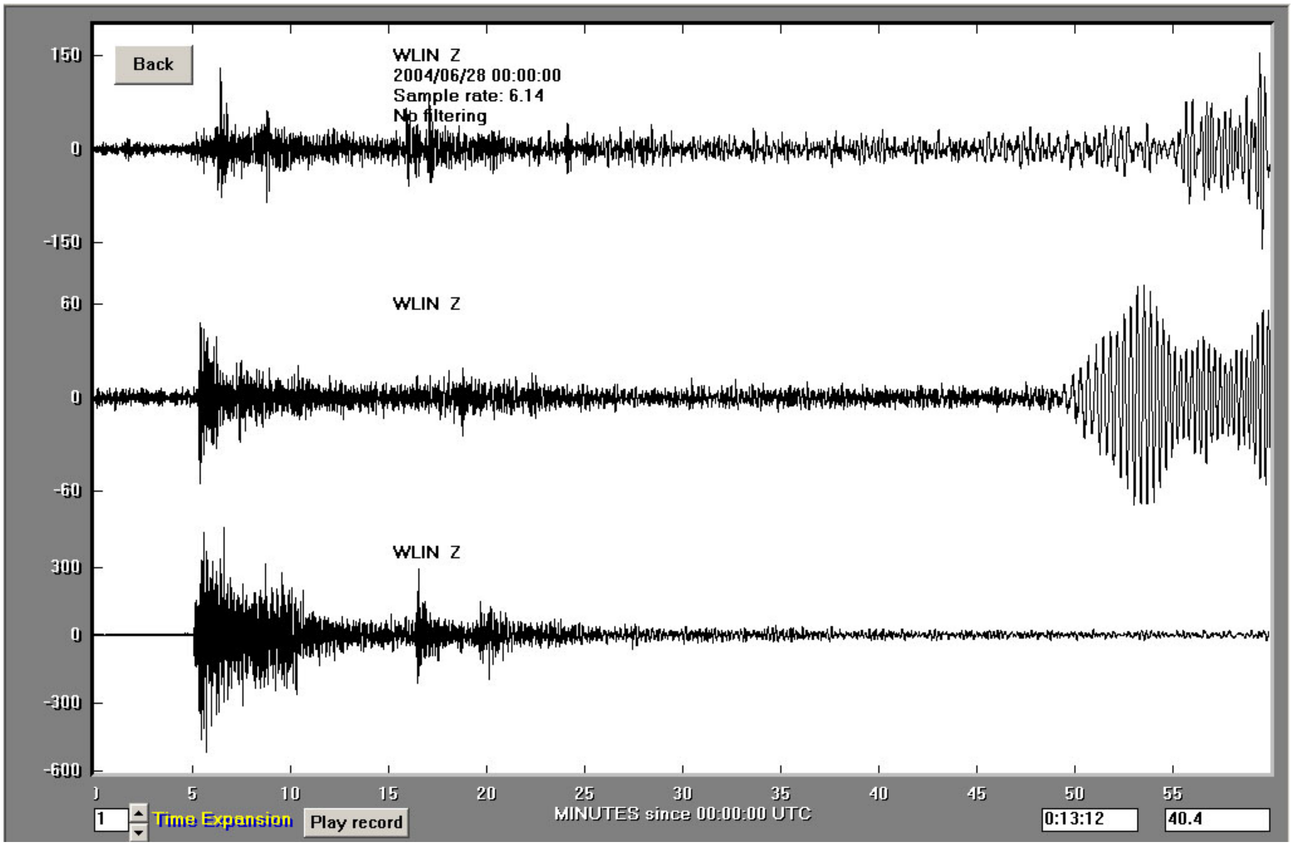
Seismograms G (D = 24.10°), H (D = 29.97°) and I (D = 42.04°).



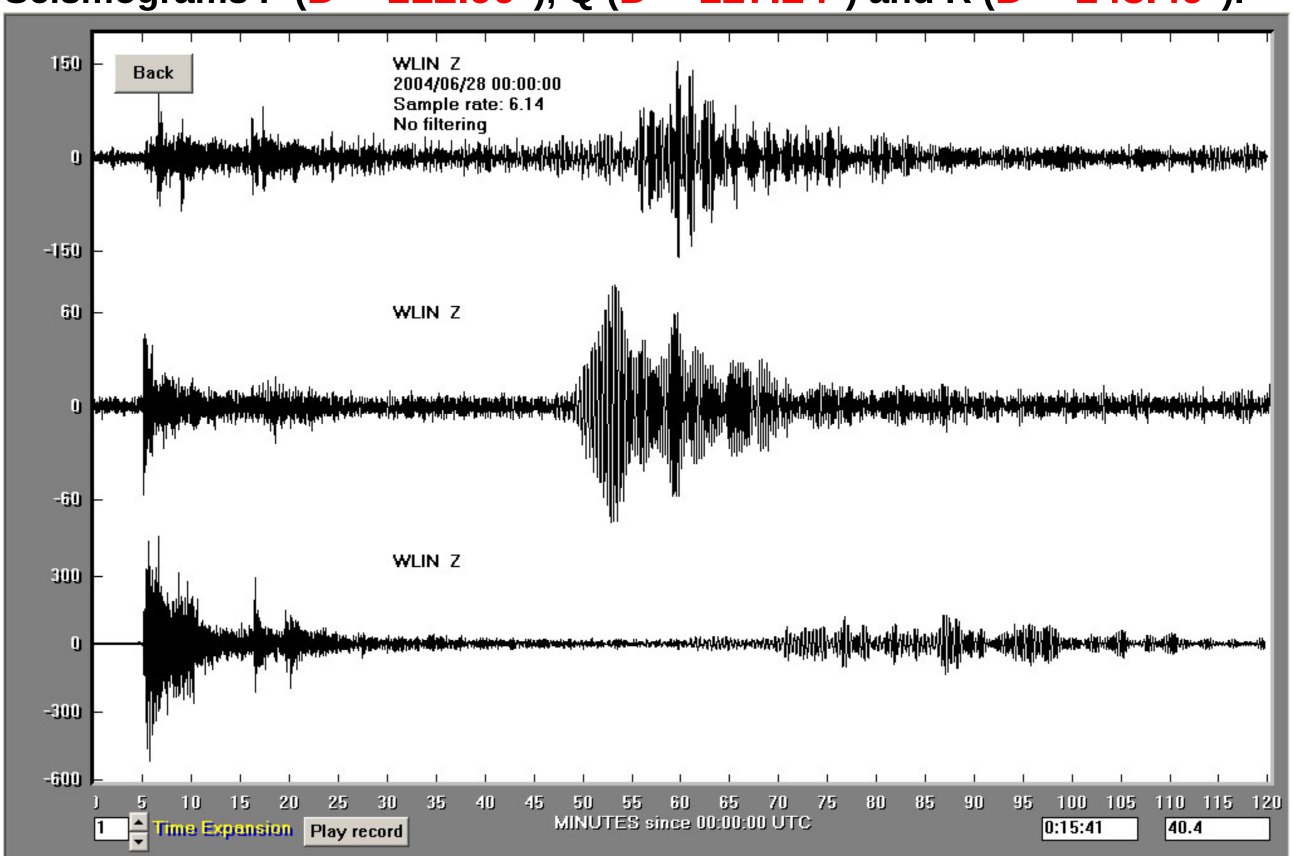
Seismograms J (D = 51.92°), K (D = 61.17°) and L (D = 67.70°).



Seismograms M (D = 81.08°), N (D = 96.20°) and O (D = 103.21°).



Seismograms P (D = 112.99°), Q (D = 127.24°) and R (D = 143.49°).

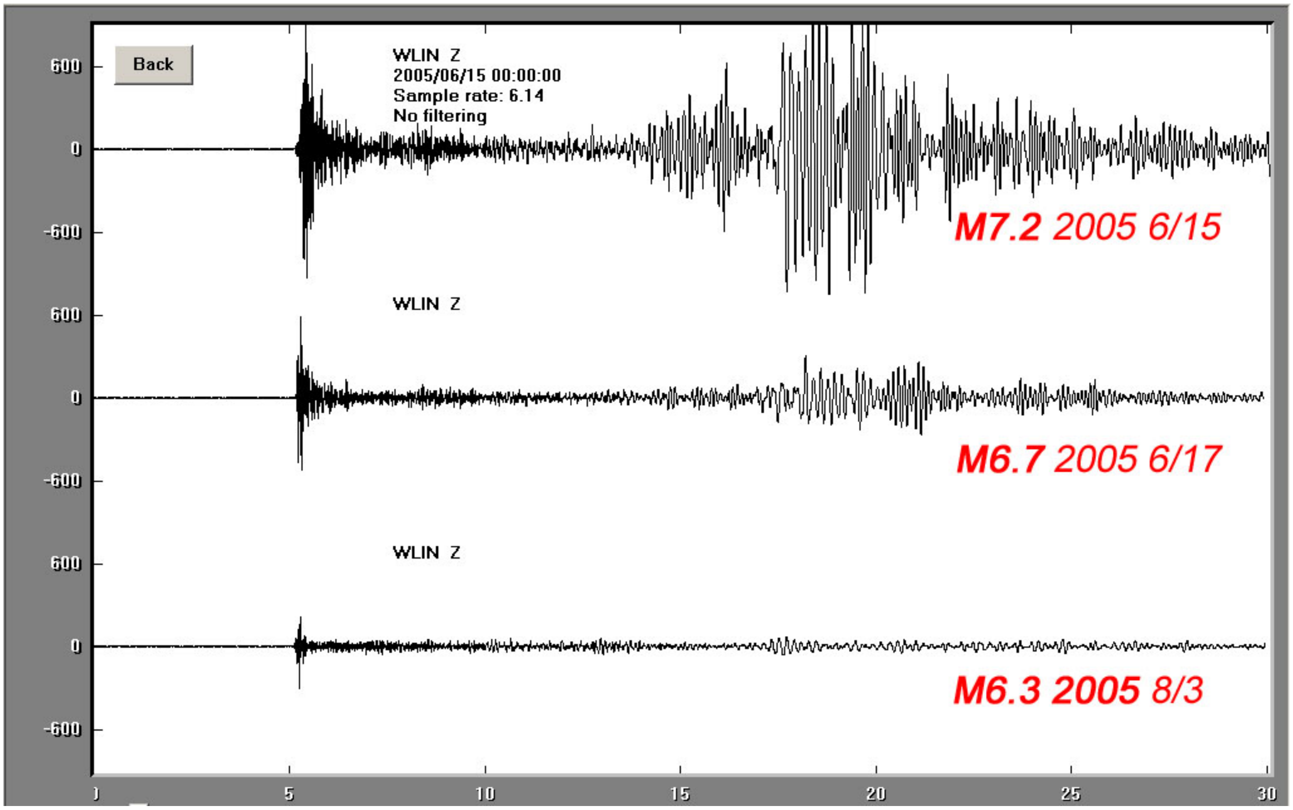


Seismograms P (D = 112.99^o), Q (D = 127.24^o) and R (D = 143.49^o) (2-hour seismograms).

Table 1. Seismogram download files for events at various distances.

Code	Dist (Deg.)	Seismogram
A	1.81	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0406280612WLIN.sac
B	2.59	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0206181733WLIN.sac
C	5.31	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0505011239WLIN.sac
D	9.30	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0211032041WLIN.sac
E	14.68	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0408010655WLIN.sac
F	19.39	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0507260412WLIN.sac
G	24.10	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0601040837WLIN.sac
H	29.97	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506170628WLIN.sac
I	42.04	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0210231131WLIN.sac
J	51.92	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0302190337WLIN.sac
K	61.17	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506141720WLIN.sac
L	67.70	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0305211850WLIN.sac
M	81.08	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0008042123WLIN.sac
N	96.20	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0409051511WLIN.sac
O	103.21	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0510080400WLIN.sac
P	112.99	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0101260330WLIN.sac
Q	127.24	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0308211232WLIN.sac
R	143.49	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0006041643WLIN.sac
P2	112.99	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0101260330.2hrWLIN.sac
Q2	127.24	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0308211232.2hrWLIN.sac
R2	143.49	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0006041643.2hrWLIN.sac

5. Catalog of Seismograms for Different Magnitudes – Distance ~30°: To illustrate the effects of different magnitudes of the earthquake on the seismogram, several seismograms from different magnitude events but with a source-to-station distance of about 30° are shown in 3-trace plots below (amplitude scale factor is the same for all traces). The seismograms are listed in Table 2 along with links to the digital files. It is clear that the general shape of each seismogram is similar (because of similar distances) but the amplitudes become significantly smaller with decreasing magnitude of the earthquake.


Back
WLIN Z
2005/06/15 00:00:00
Sample rate: 6.14
No filtering
M7.2 2005 6/15
WLIN Z
M6.7 2005 6/17
WLIN Z
M6.3 2005 8/3
600
0
-600
5
10
15
20
25
30

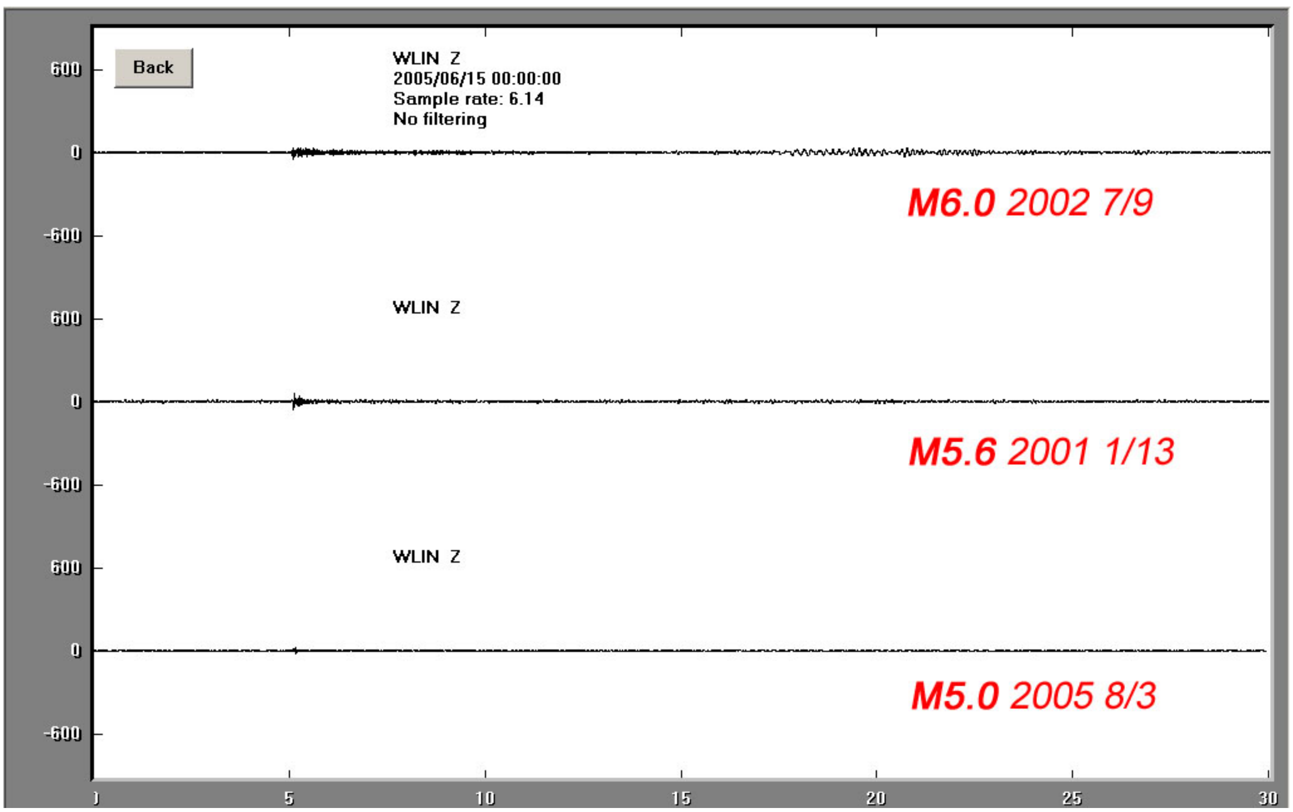
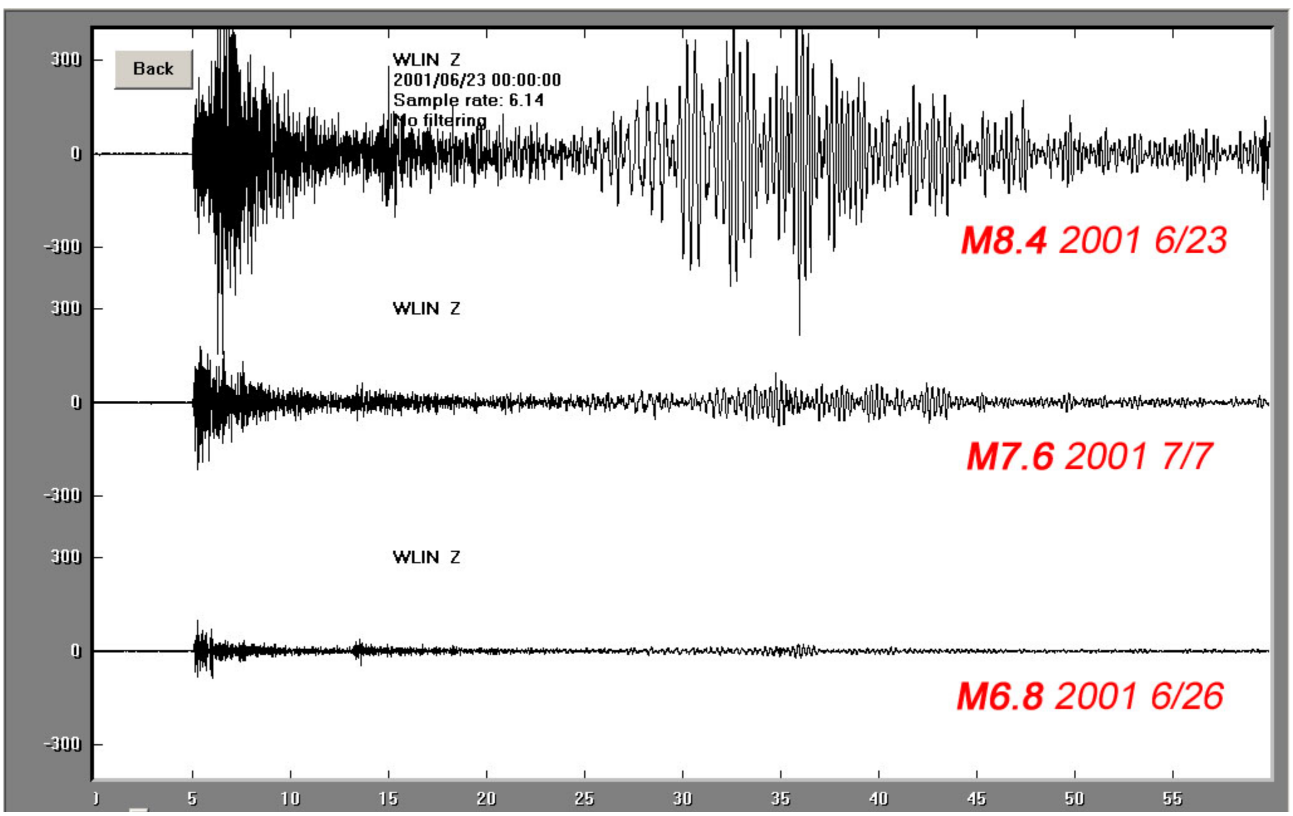

Back
WLIN Z
2005/06/15 00:00:00
Sample rate: 6.14
No filtering
M6.0 2002 7/9
WLIN Z
M5.6 2001 1/13
WLIN Z
M5.0 2005 8/3
600
0
-600
5
10
15
20
25
30

Table 2. Seismogram download files for magnitude comparison for distance ~30°.

Code	Dist (Deg.)	Seismogram
M7.2	29.31	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506150257WLIN.sac
M6.7	29.97	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506170628WLIN.sac
M6.3	29.08	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0508031109WLIN.sac
M6.0	29.93	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0207091843WLIN.sac
M5.6	29.04	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0101131315WLIN.sac
M5.0	29.20	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0508030933WLIN.sac

6. Catalog of Seismograms for Different Magnitudes – Distance ~60°: To illustrate the effects of different magnitudes of the earthquake on the seismogram, several seismograms from different magnitude events but with a source-to-station distance of about 60° are shown in 3-trace plots below (amplitude scale factor is the same for all traces). The seismograms are listed in Table 3 along with links to the digital files. It is clear that the general shape of each seismogram is similar (because of similar distances) but the amplitudes become significantly smaller with decreasing magnitude of the earthquake.



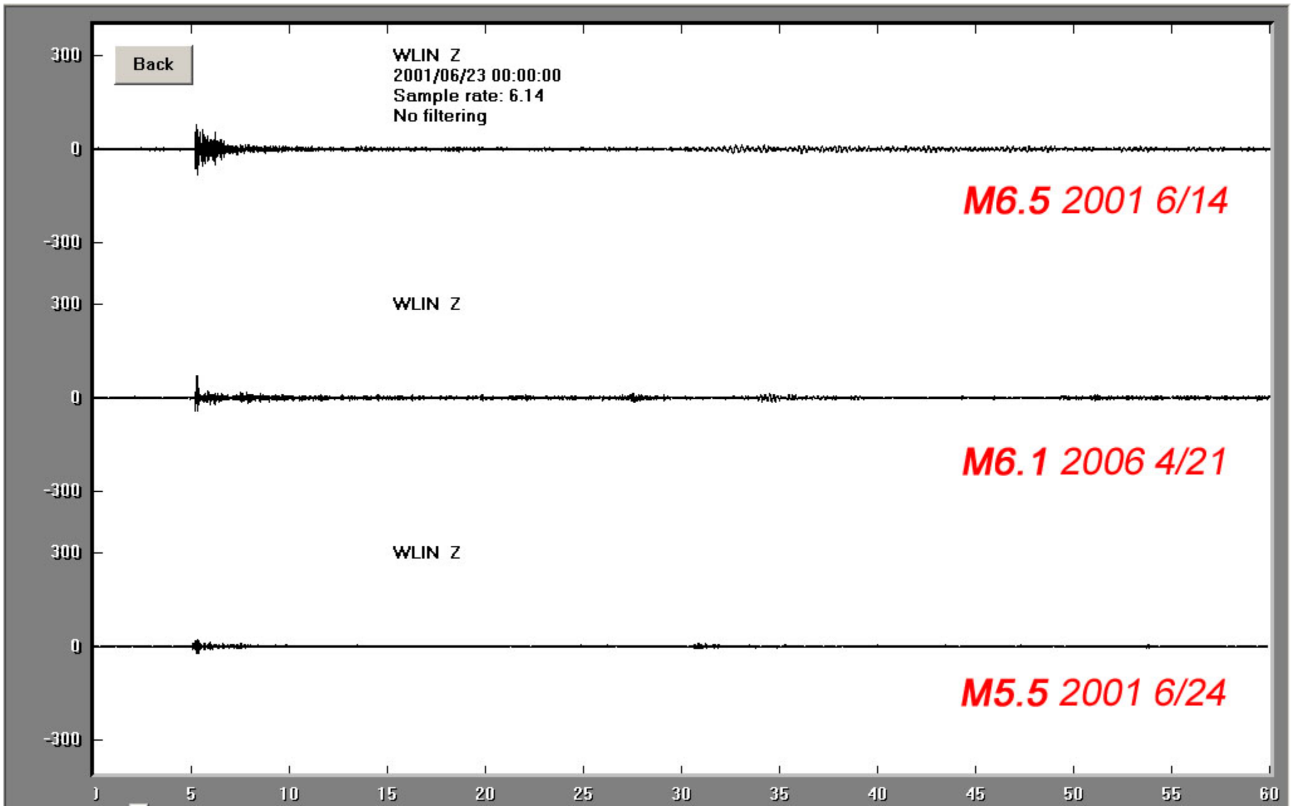
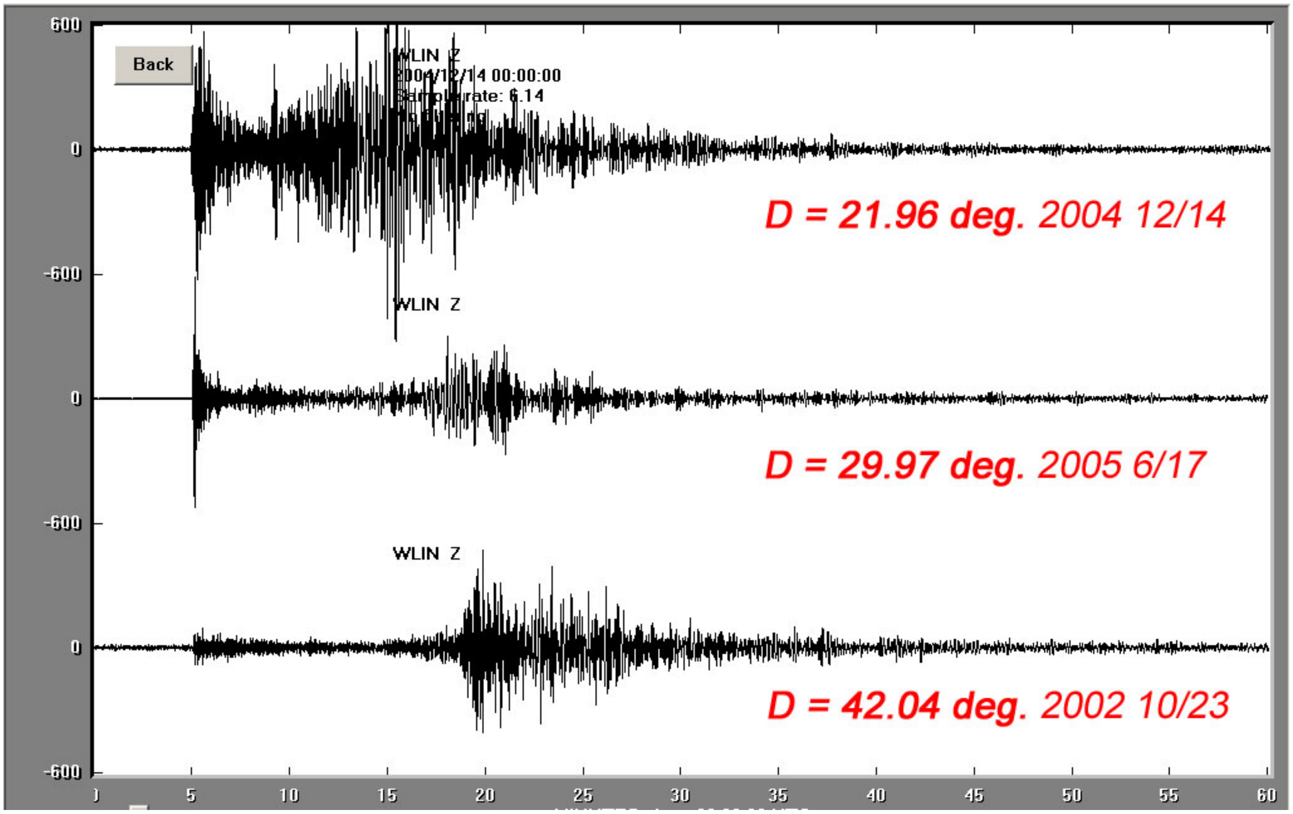
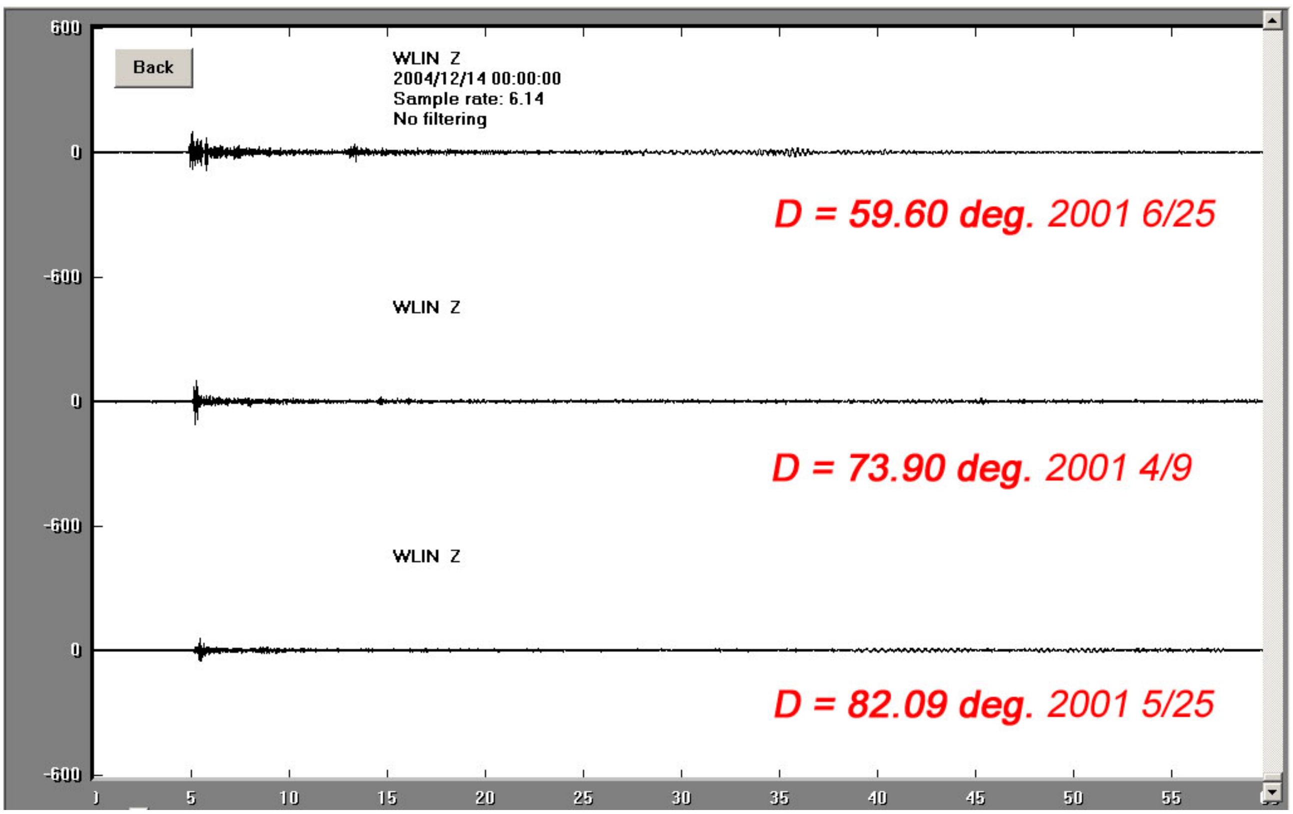


Table 3. Seismogram download files for magnitude comparison for distance ~60°.

Code	Dist (Deg.)	Seismogram
M8.4	57.74	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106232044WLIN.sac
M7.6	59.31	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0107070951WLIN.sac
M6.8	59.60	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106260429WLIN.sac
M6.5	61.49	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106142002WLIN.sac
M6.1	63.24	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0604210443WLIN.sac
M5.5	59.37	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106240133WLIN.sac

7. Catalog of Seismograms for the Same Magnitude (~6.7) at Different Distances: To illustrate the effects of magnitude and distance of the earthquake on the seismogram, several seismograms from the same magnitude events but with different source-to-station distances are shown in 3-trace plots below (amplitude scale factor is the same for all traces). The seismograms are listed in Table 4 along with links to the digital files. For the same magnitude earthquake the amplitudes of the seismograms become significantly smaller with increasing distance. One can also observe differences in the character of the seismograms with increasing distance similar to what was observed with seismograms **A** through **R**. The seismograms are listed in Table 4 along with links to the digital files.





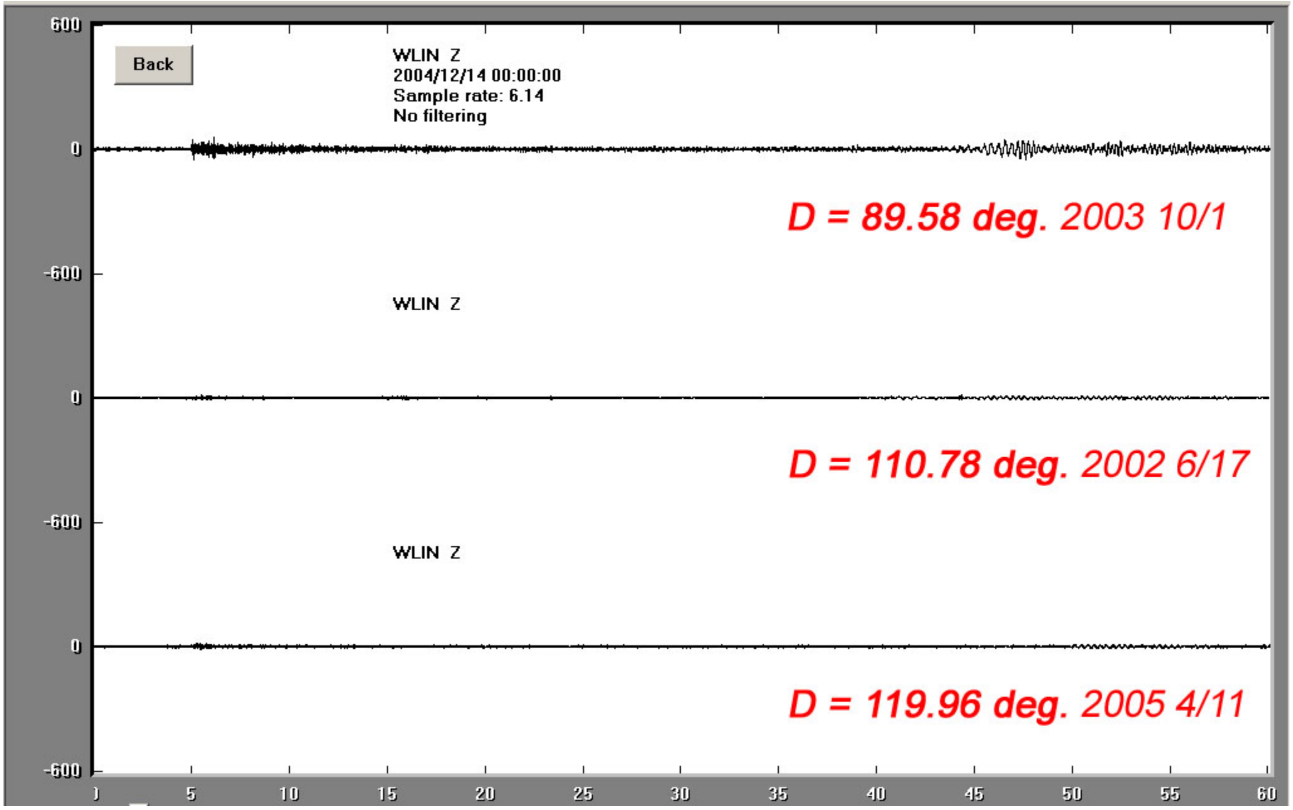


Table 4. Seismogram download files for magnitude comparison for various distances, M ~6.7.

Magn.	Dist (Deg.)	Seismogram
M6.7	**21.96**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0412142325WLIN.sac
M6.7	**29.97**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506170528WLIN.sac
M6.7	**42.04**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0210231131WLIN.sac
M6.8	**59.60**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106260429WLIN.sac
M6.7	**73.90**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0104090913WLIN.sac
M6.7	**82.09**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0105250054WLIN.sac
M6.7	**89.58**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0310010116WLIN.sac
M6.7	**110.78**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0206172141WLIN.sac
M6.7	**119.96**	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0504111241WLIN.sac

8. Catalog of Seismograms for Large Earthquakes at About the Same Distance:

Seismograms for 3 large earthquakes from a source-to-station distance of about 130° are illustrated in the 3-trace plot below (amplitude scale factor is the same for all traces). The seismograms are listed in Table 5 along with links to the digital files.

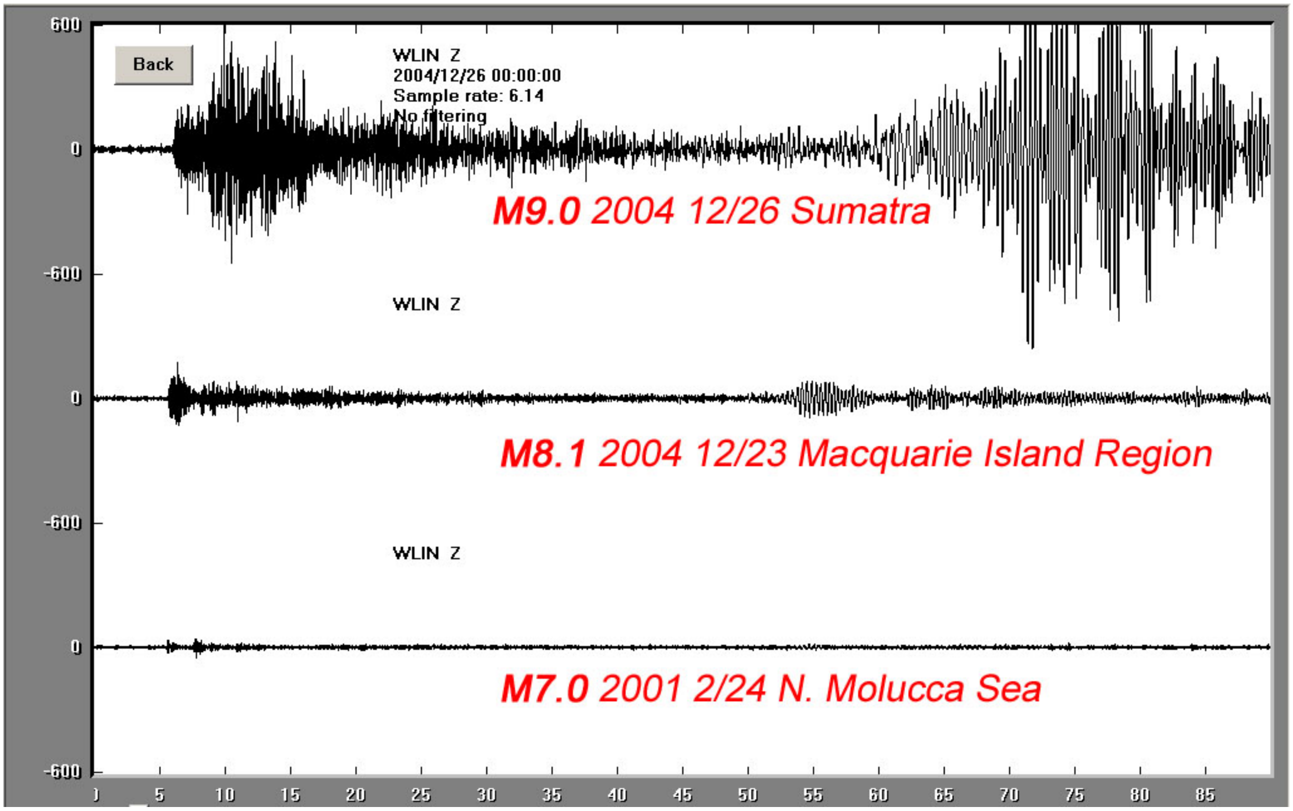


Table 5. Seismogram download files for magnitude comparison for distance ~130°.

Magn.	Dist (Deg.)	Seismogram
M9.0	136.34	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0412260113WLIN.sac
M8.1	133.39	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0412231513WLIN.sac
M7.0	128.45	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0102240749WLIN.sac

Examination of many seismograms from various magnitude earthquakes recorded at different distances allows one to generalize the "detectibility" of events for the AS-1 seismograph. Figure 13 illustrates the approximate relationship between earthquake magnitude and maximum distance of detection (relatively clear seismogram visible on the record) for the WLIN AS-1 station.

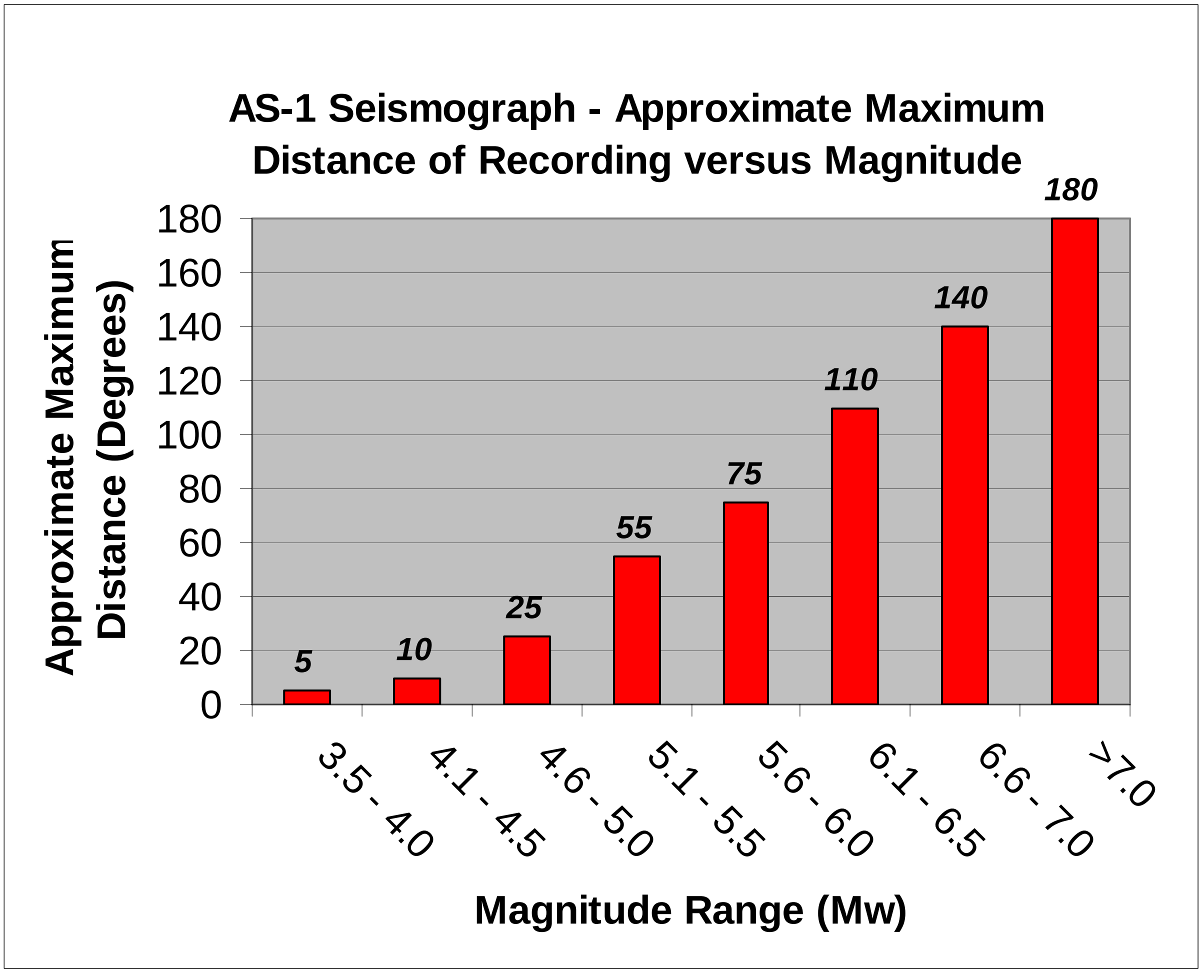
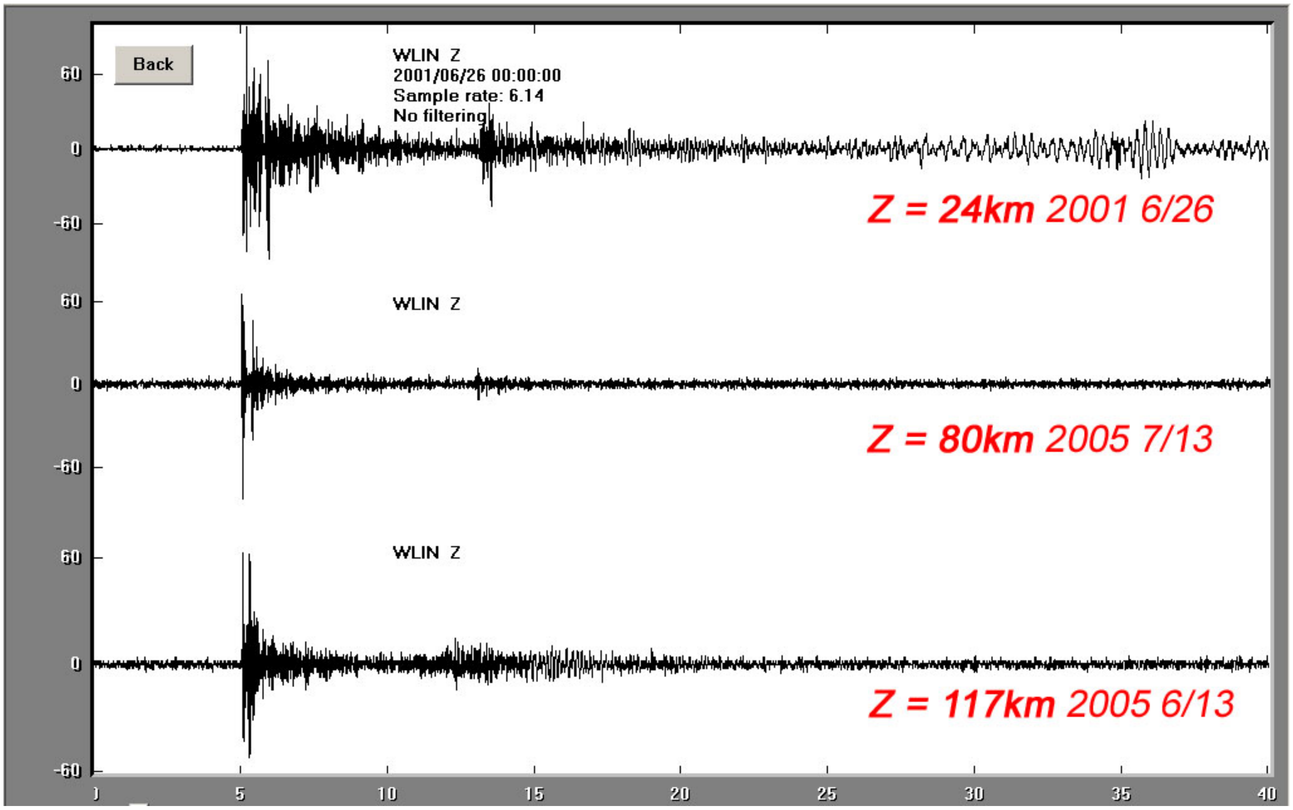


Figure 13. Approximate maximum distance of recording for the AS-1 seismograph as a function of the magnitude of the source. Variation in the actual distance will occur due to noise levels, depth of focus of the earthquake, site response at the sensor and other factors.

9. Catalog of Seismograms for the Same Distance (~65°) for Different Depths of Focus: To illustrate the effects depth of focus of the earthquake on the seismogram, several seismograms from about the same source-to-station distance but different focal depth are shown in 3-trace plots below (amplitude scale factor is the same for all traces in the first set of seismograms but is different in the second set). The seismograms are listed in Table 6 along with links to the digital files. The major difference in the seismograms is the reduction of the surface waves for deeper earthquakes. Also, a prominent "depth phase" (pP) is visible on the seismograms just after the first P arrival. The pP minus P time can be used to accurately determine the depth of focus of the event.


Back
WLIN Z
2001/06/26 00:00:00
Sample rate: 6.14
No filtering
Z = 24km 2001 6/26
WLIN Z
Z = 80km 2005 7/13
WLIN Z
Z = 117km 2005 6/13
60
0
-60
0
5
10
15
20
25
30
35
40

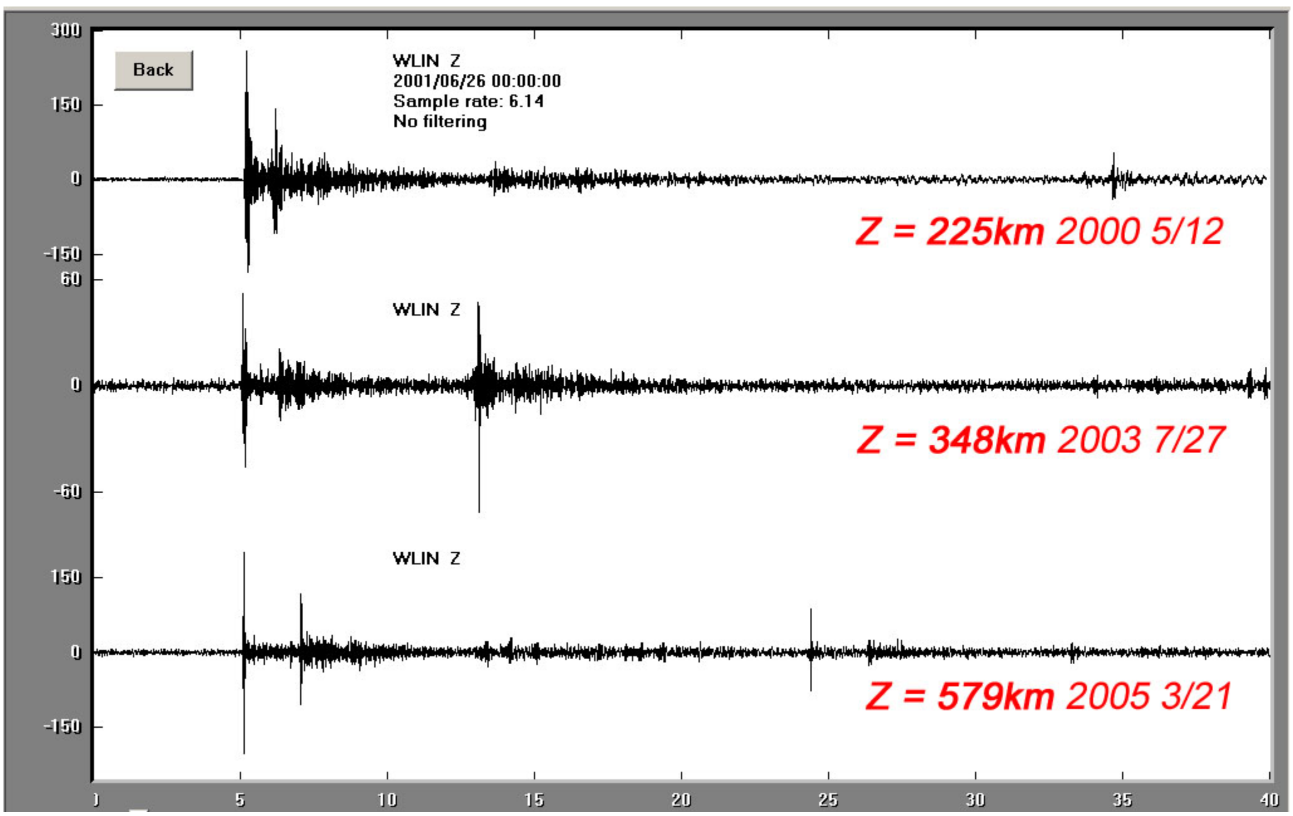

Back
WLIN Z
2001/06/26 00:00:00
Sample rate: 6.14
No filtering
Z = 225km 2000 5/12
WLIN Z
Z = 348km 2003 7/27
WLIN Z
Z = 579km 2005 3/21
300
150
0
-150
60
-60
0
5
10
15
20
25
30
35
40

Table 6. Seismogram download files for depth of focus comparison for distance ~65°.

Depth (km)	Dist (Deg.)	Seismogram
24	59.60	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0106260429WLIN.sac
80	60.09	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0507131215WLIN.sac
117	62.36	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0506130358WLIN.sac
225	66.48	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0005121849WLIN.sac
348	63.39	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0307271151WLIN.sac
579	68.68	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/0503211234WLIN.sac

The P, pP and S phases for two of these earthquakes are illustrated on the seismograms shown in Figures 14 and 15 using the AmaSeis travel time curve display tool. The pP – P time (difference in arrival time of the pP phase and the P phase) can be used to accurately determine the depth of focus of the earthquake. Table 7 shows the pP – P times for various depths for an epicentral distance of 65 degrees.

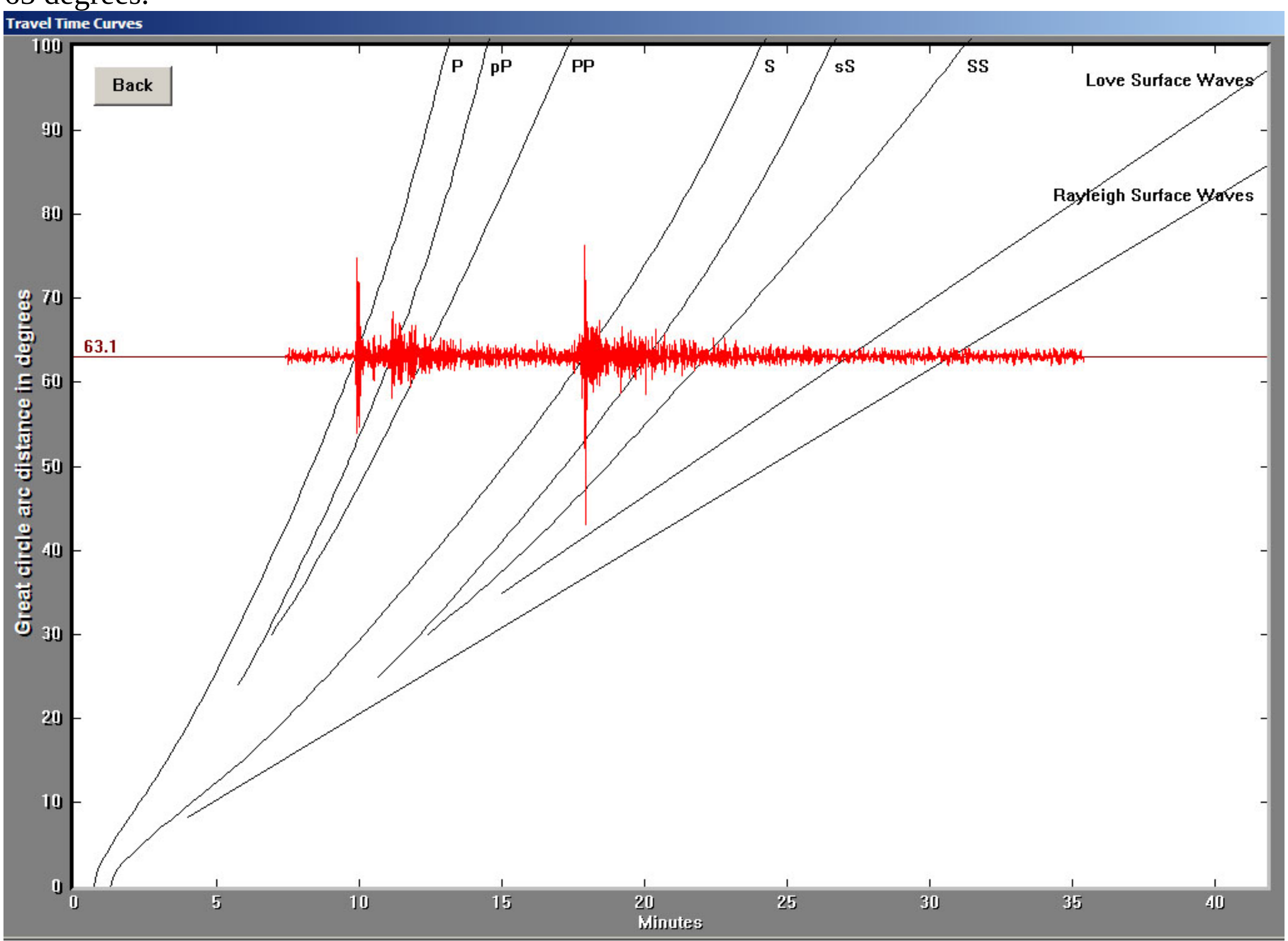


Figure 14. Seismogram for the 7/27/03 earthquake displayed using the AmaSeis travel time curve tool. A depth of 348 km was entered for this event to produce the travel time curves. The match of the pP – P time indicates that the depth of focus determined from this seismogram is approximately correct.

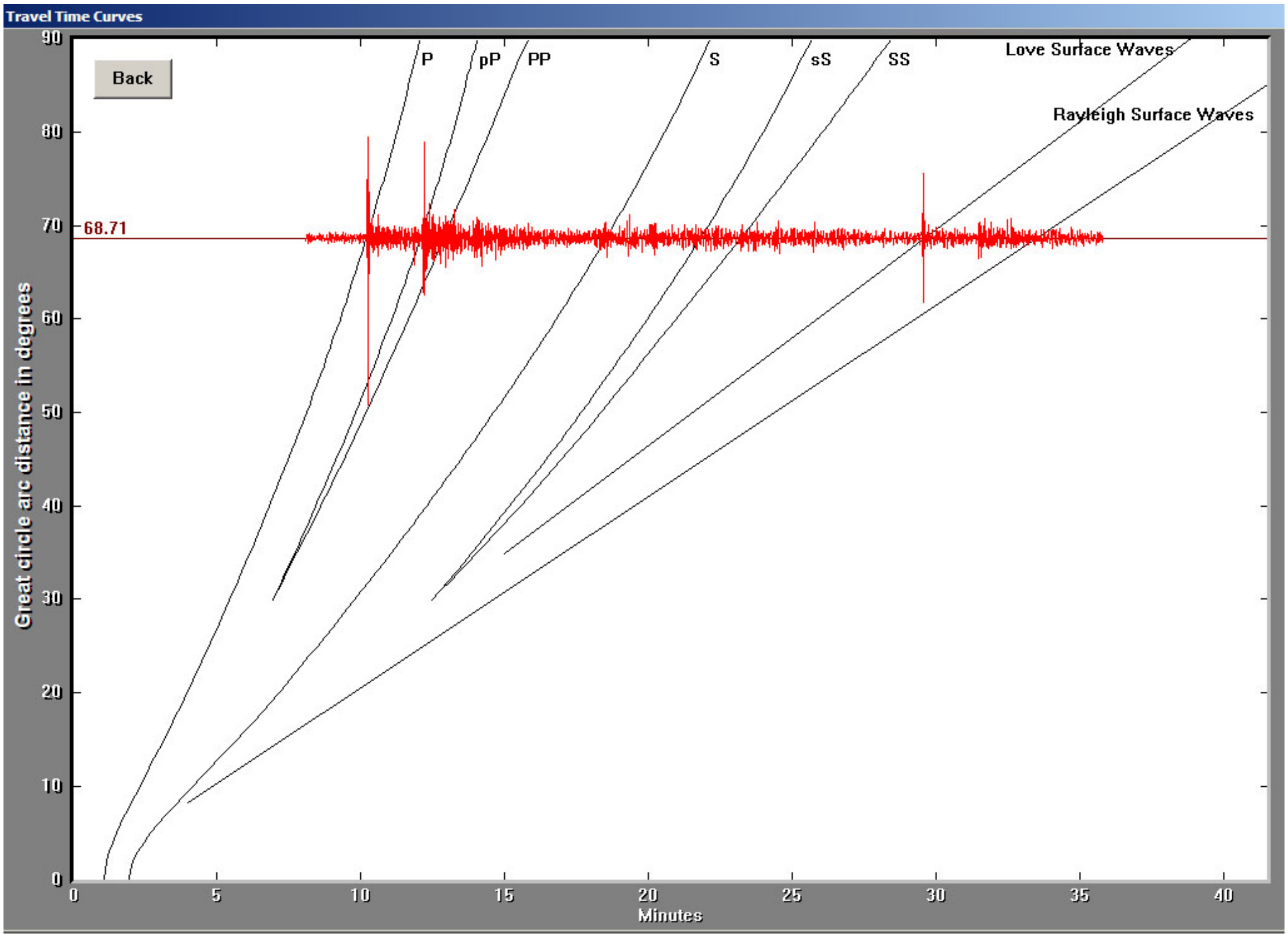


Figure 15. Seismogram for the 3/21/05 earthquake displayed using the AmaSeis travel time curve tool. A depth of 579 km was entered for this event to produce the travel time curves. The match of the pP – P time indicates that the depth of focus determined from this seismogram is approximately correct.

Table 7. pP minus P times for the pP phase (depth phase) for an epicenter-to-station distance of 65 degrees and various depths of focus (hypocentral depths).

Depth (km)	pP - P Time (seconds)
0	0
50	14
100	25
200	46
300	67
400	86
500	102
600	118
700	133

10. Analysis of Noise on Seismograph Records: Signals are commonly visible on a seismograph that are not caused by earthquakes or other seismic sources such as explosions. These signals are often referred to as “noise” and come from many possible sources. Noise on the seismograph record can significantly affect the ability to detect or recognize an earthquake signal. Also, it is necessary to consider how one can distinguish a seismogram signal from noise. Some of the characteristics of earthquake seismograms have previously been illustrated in the catalog sections above. In this section, we will consider what factors affect the signals that are visible on the seismograph and the characteristics of earthquake seismograms and noise. A very distinctive seismogram is illustrated on the AmaSeis partial screen display shown in Figure 16. A list of factors that affect the characteristics of the seismogram is given in Figure 17 and schematically illustrated in Figure 18.

What factors affect the seismogram that you see on the screen?

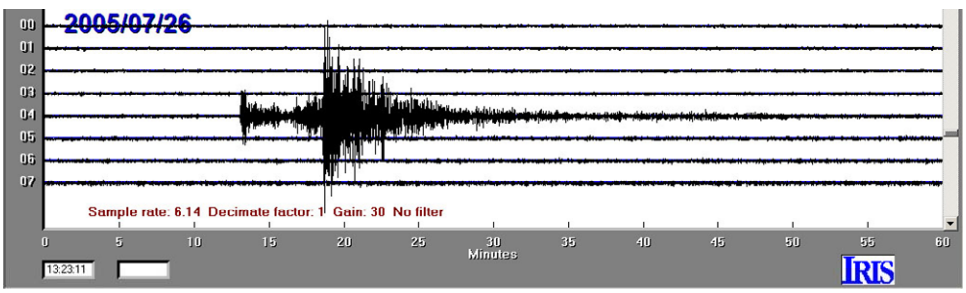


Figure 16. Example of a distinctive seismogram characteristic of an earthquake generated signal. No large amplitude noise sources are visible.

What factors affect the seismogram that you see on the screen?

- EQ epicenter to station distance
- EQ magnitude
- EQ depth (surface waves small or not visible for deep focus events; depth phases)
- EQ mechanism (radiation pattern, freq. range)
- Propagation path (oceanic, continental, mixed)
- Instrument response, filtering
- Noise level
- Seismograph sensitivity and gain
- Site response

Figure 17. List of factors that affect the seismic signals that are visible on the seismograph.

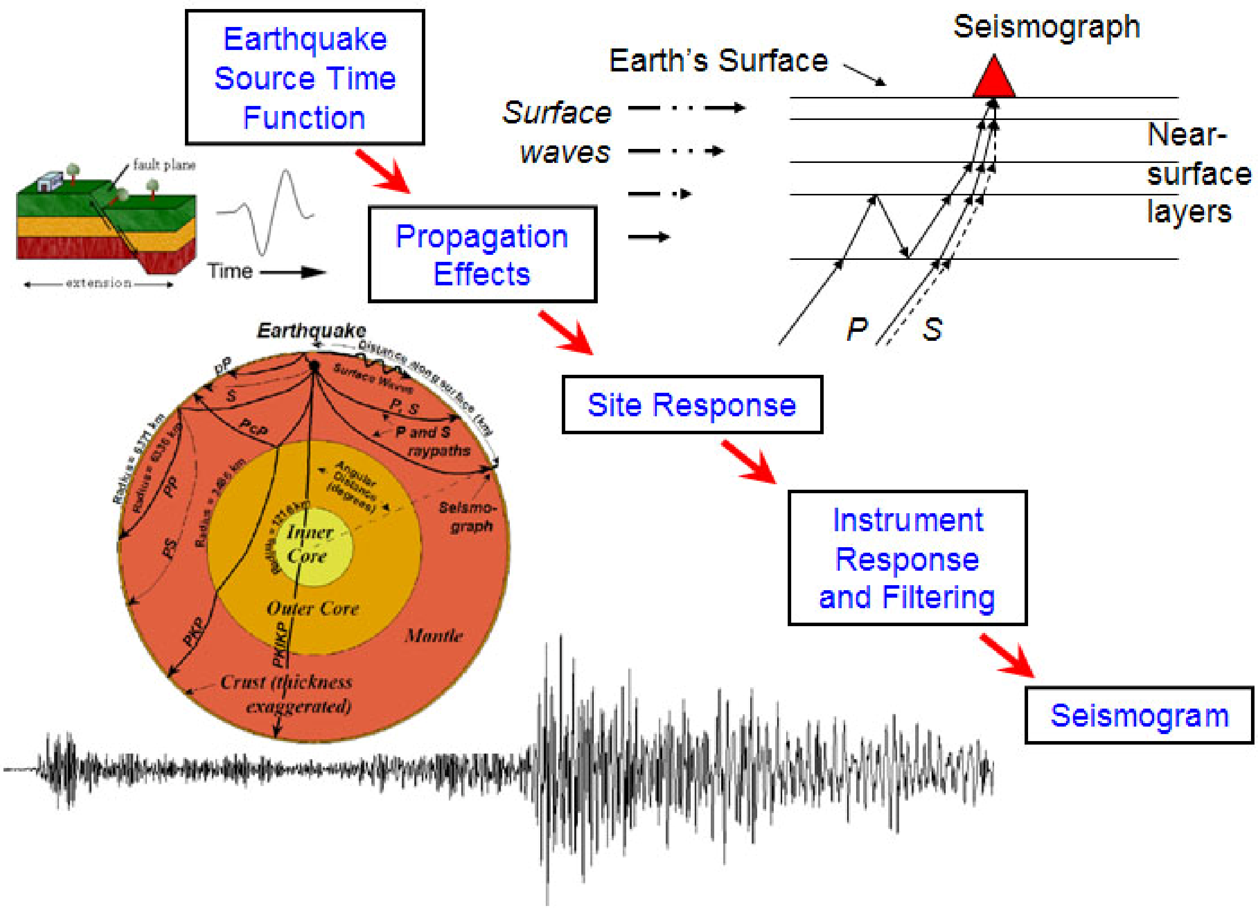


Figure 18. Schematic illustration of the factors that control the character of the recorded seismogram. Differences in magnitude of the earthquake are included in the source time function. Both the amplitude and the duration of the source time function increase with larger magnitude. Depth of focus also significantly affects the seismogram. For example, as shown previously, deep focus earthquakes do not generate strong surface waves. Propagation effects are primarily controlled by source-to-station distance but can also include variability of Earth structure between the source and the seismograph station.

Earthquake seismograms can usually be recognized by fairly distinctive characteristics that result from the effects of the source, propagation path and seismograph response. A list of several of these characteristics is shown in Figure 19. Many of these distinctive characteristics are visible on the seismograms included in the catalogs above. With some experience, it is generally fairly easy to recognize earthquake or explosion seismic sources from background noise or other noise sources (Figure 20). Recognition becomes more challenging if the seismic signal is small (small magnitude event or distant event) and the noise is large (often called small signal-to-noise ratio or S/N).

Some common noise sources are listed in Figure 21. Examples of seismograph records illustrating these noise sources are shown in Figures 22 to 30. Microseisms (Figure 24) are almost always present on seismographs although on relatively quiet days the microseismic noise can have very small amplitudes. For small or distant events, large microseisms can make the identification of the first arrival on a seismogram uncertain. An example of this effect is seismogram P in sections 3 and 4 above. For local and regional events, a high pass filter can be used to enhance the S/N for microseismic noise.

What are the distinctive characteristics of a seismogram?

- Duration of signal
- Impulsive first arrival (P-wave)
- Usually 2 or more “separate” arrivals
- Distinct shape
- Change in frequency of the signal (often seen with S wave and surface waves)
- Signal amplitude “tapers off” at end (the “coda”)
- Complexity (can’t explain every wiggle!)

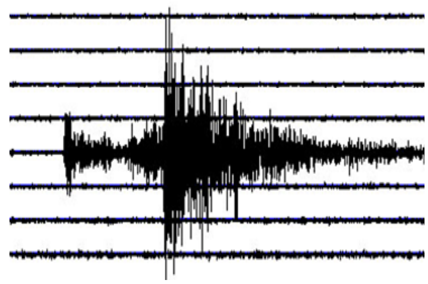
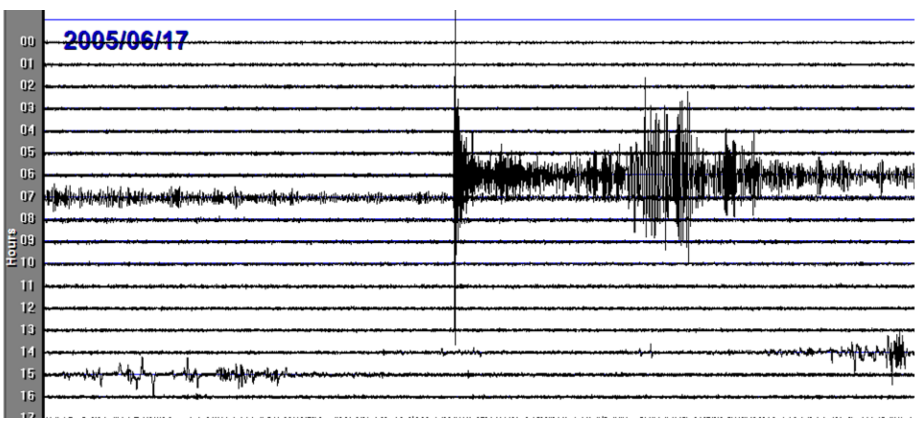


Figure 19. Distinctive characteristics of seismograms.

What are some commonly recorded Noise Sources?



(6/17/05 Earthquake and noise)

Figure 20. An earthquake seismogram and noise signals.

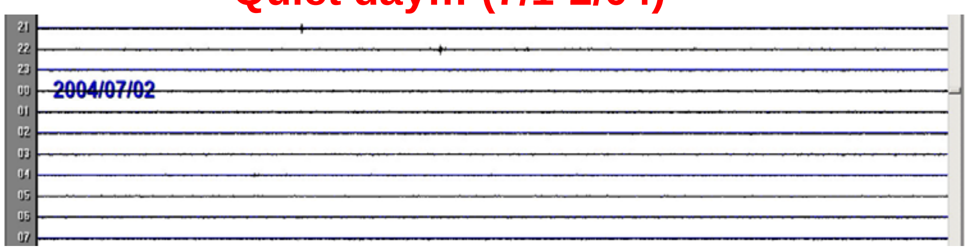
What are some commonly recorded Noise Sources?

- Wind
- Microseisms
- Hurricanes (large microseisms)
- Local noise (trucks, machinery, walking)
- Electronic
- Spikes
- Dropouts

Figure 21. Some common noise sources. ("Microseisms are weak, almost continuous background seismic waves or Earth "noise". They can only be detected by seismographs. They are often caused by surf, ocean waves, wind, or human activity,"[Bolt, 2004]. Microseisms usually look very sinusoidal and have a characteristic period of about 4-6 seconds.)

Noise Examples…

Quiet day… (7/1-2/04)



Noisy day… (9/29-30/04)

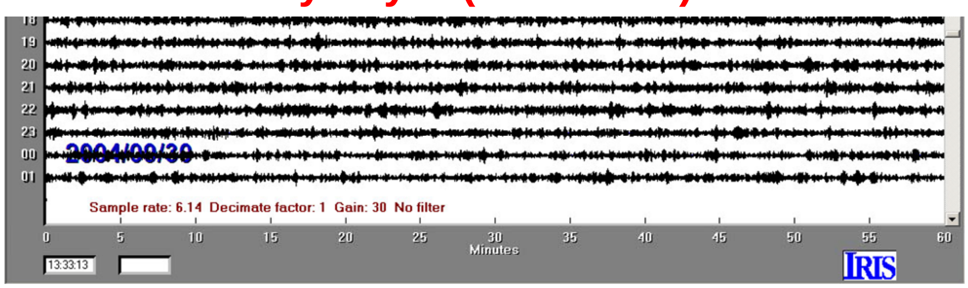


Figure 22. Comparison of quiet day and noisy day background noise levels. Both records were plotted with a gain factor of 30.

Noise Comparison – Quiet Day vs. Noisy Day (Same scale; 10 minute seismograms)

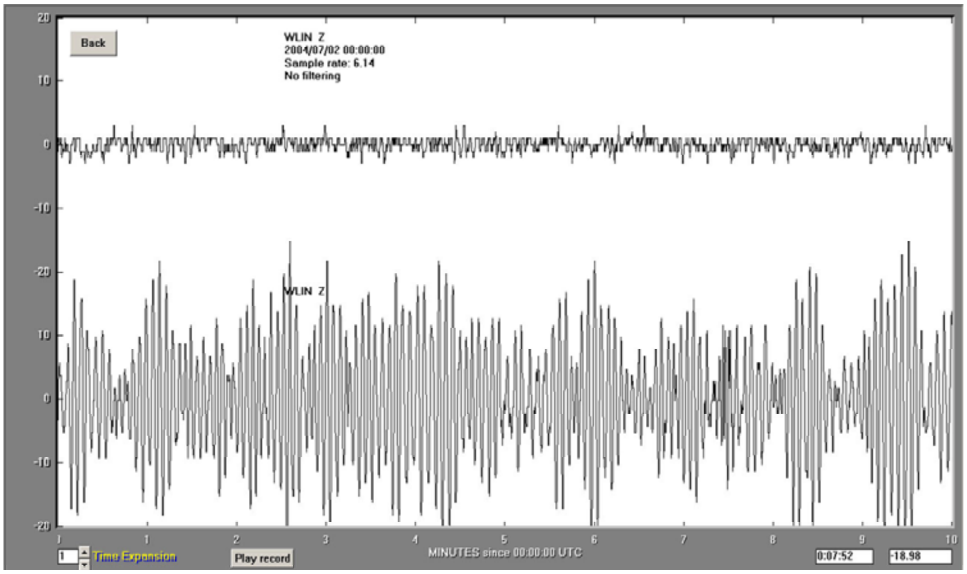
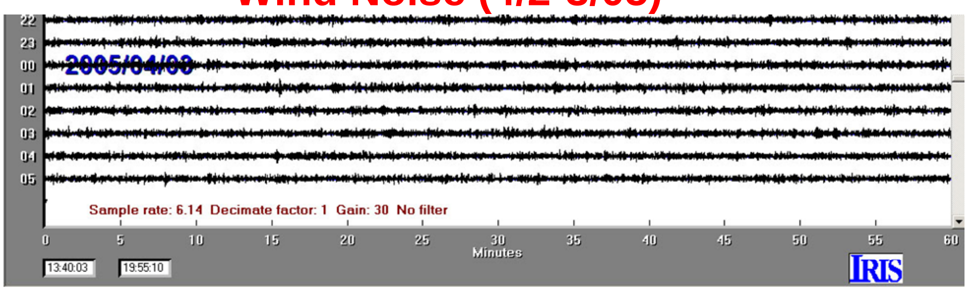


*Figure 23. Comparison of background noise levels for a seismically quiet day (upper trace, 7/2/04, Figure 22) and a noisy day (lower trace, 9/29/04, Figure 22) for WLIN AS-1 records. The seismograms are plotted with the same amplitude scale. The quiet day seismogram has maximum amplitudes of about 3 digital units. The noisy day seismogram has maximum amplitudes of about 20 digital units. Background noise amplitudes as large as 60 digital units (**twenty times the quiet day noise levels**) have been observed demonstrating the significance of the noise level on detection and quality of the recorded signals, particularly from small or distant earthquakes.*

Wind Noise (4/2-3/05)



Microseismic Noise (8/12-13/05)

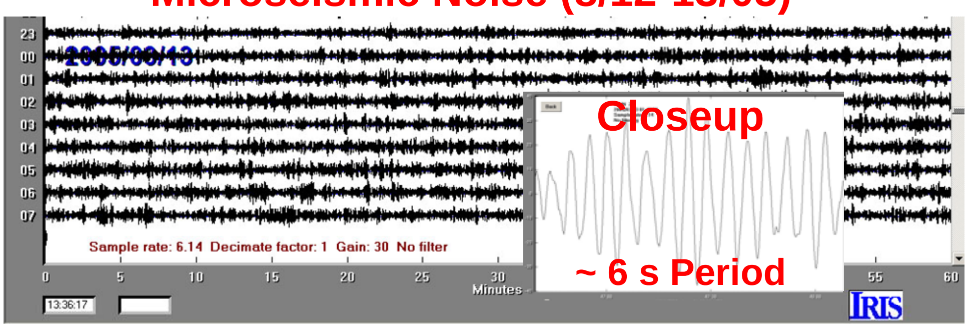
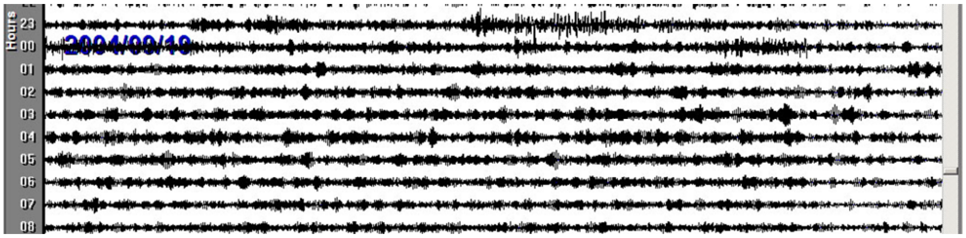


Figure 24. Local high winds (upper record) can generate fairly large noise signals on the seismograph. Wind noise generally is of higher frequency (shorter periods) than microseismic noise. Microsesimic noise (lower record) is usually in the 4-6 s period range.

Hurricane Ivan (9/18-19/04)



Electronic Noise

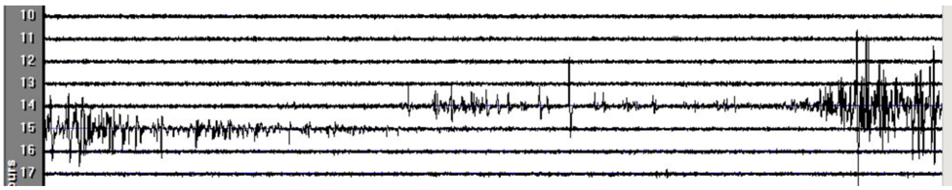
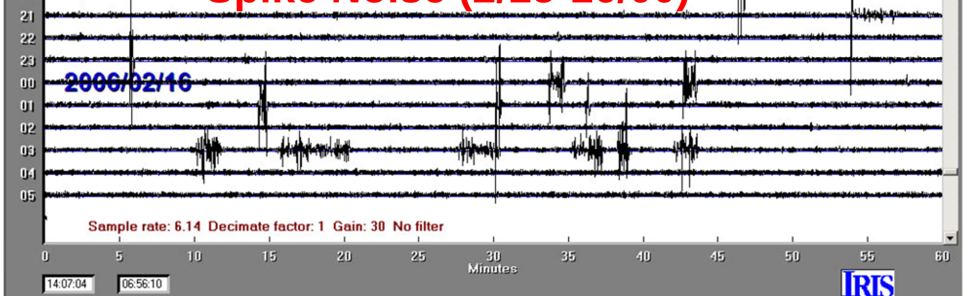


Figure 25. Microseismic noise generated by Hurricane Ivan (upper record) and local electronic noise (lower record). Note that although the electronic noise signals have long duration in this case, the other characteristics of the signal are not similar to an earthquake seismogram.

Spike Noise (2/15-16/00)



Foot Steps (rectangle; 5/27/05)

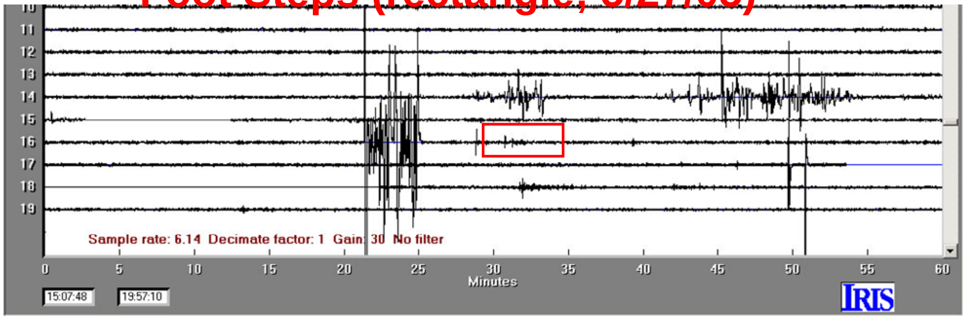


Figure 26. Spike noise (upper record) and footstep noise (lower record; walking with about 2 meters of the seismometer).

Foot Steps (Close-up)

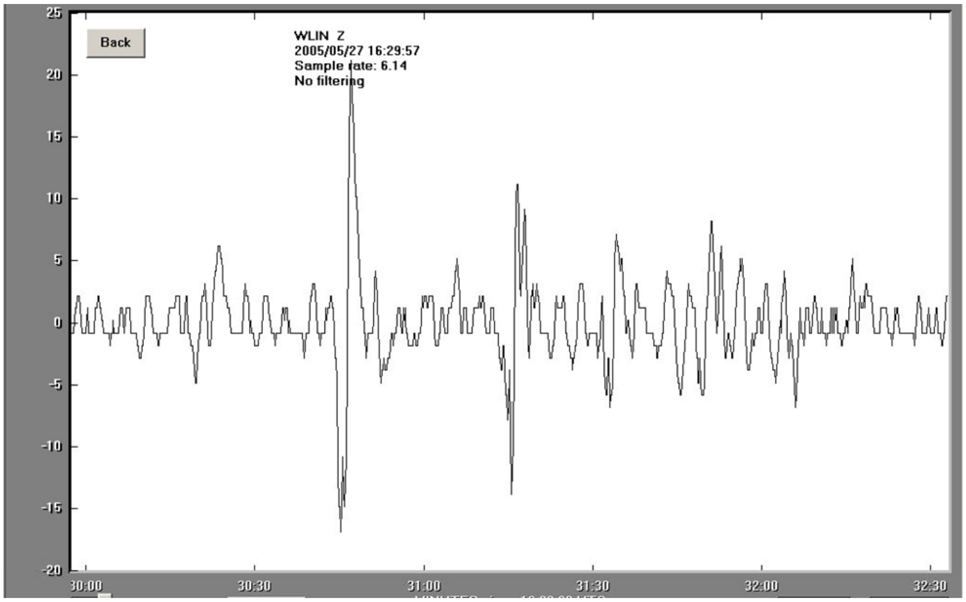


Figure 27. Close-up of footstep noise.

Dropout (spike at one point usually at one hour breaks; 2/24/01)

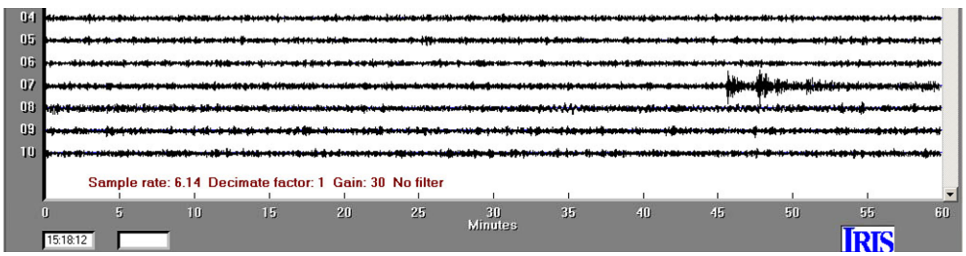


Figure 28. Partial AmaSeis screen image showing an earthquake on 2/24/01.

Dropout (spike at one point usually at one hour breaks; Extracted seismogram) 2/24/01

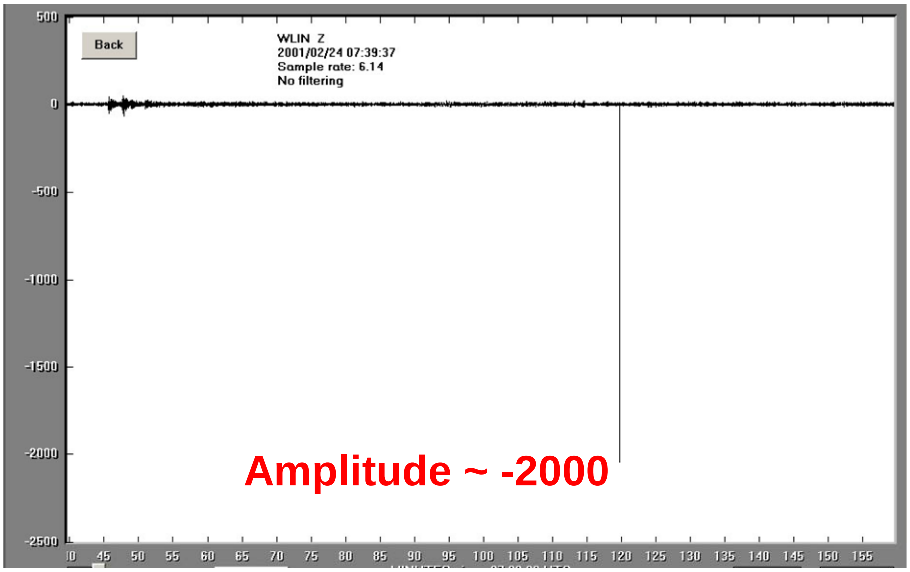


Figure 29. Extracted seismogram from the record shown in Figure 28. The "dropout" is a single point with an amplitude of about -2000 that distorts the scaling of the seismogram.

Dropout (after median filter; 2/24/01)

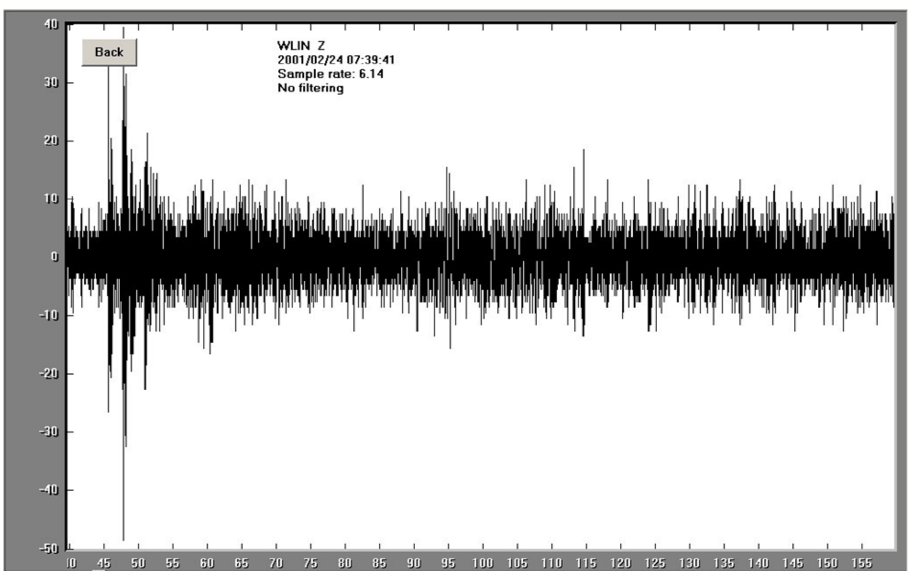
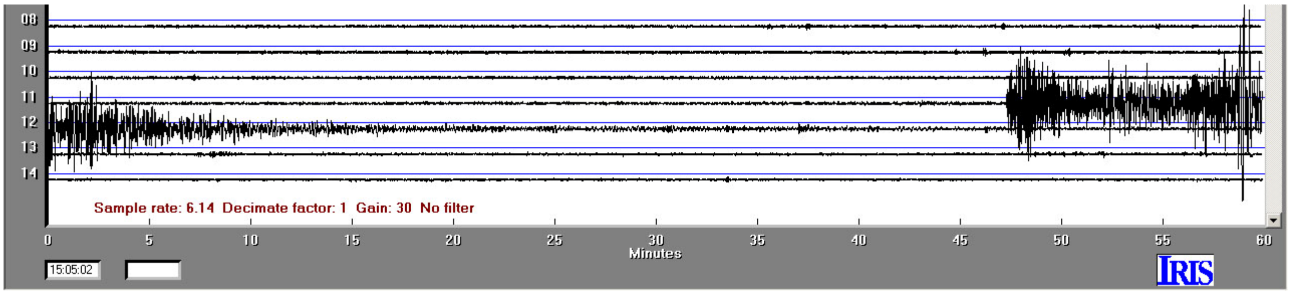
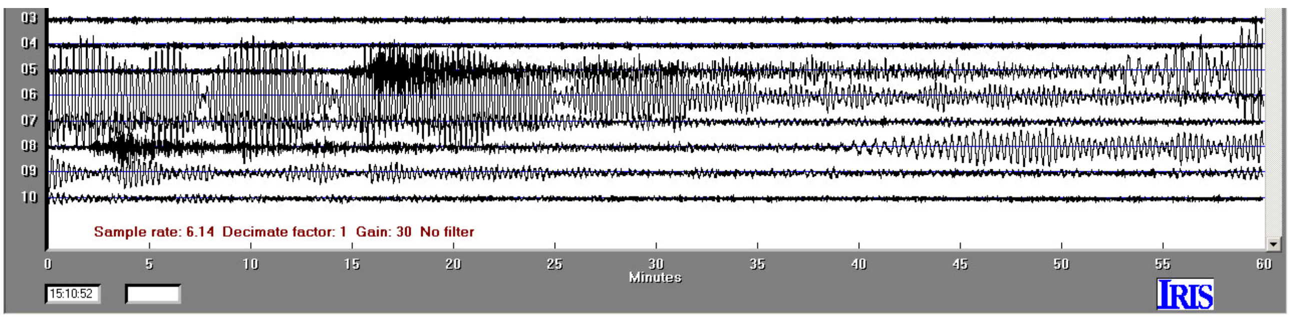


Figure 30. Extracted seismogram shown in Figure 29 after median filter was applied using the AmaSeis filter tool. The dropout spike has been removed without significantly distorting the seismogram (in this case, a fairly noisy seismogram).

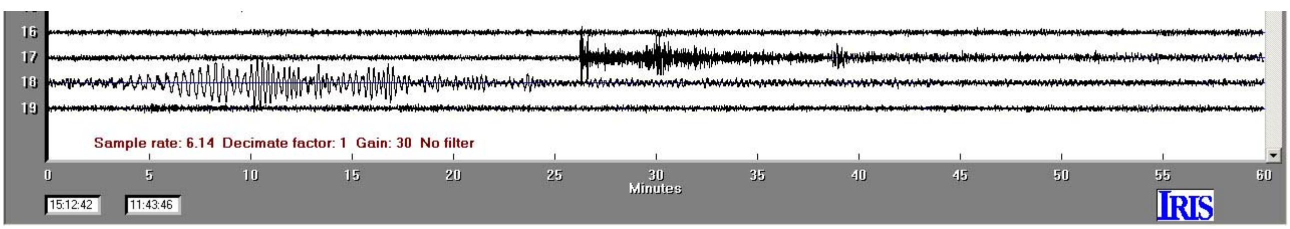
11. Mystery events: Below are twelve "mystery events" (labeled M1 through M12) that are selected to provide experience in recognizing earthquake seismograms on the AmaSeis 24-hour screen, making a rough estimate of epicenter-to-station distance (local, regional, distant or very distant events – these last two descriptors are sometimes called "teleseisms"), determining distance more accurately using the S minus P method, and calculating magnitudes. For each event, there is a partial screen display so that one can see what the seismogram looks like on the "standard" 24-hour AmaSeis screen. All screen displays have a gain of 30.



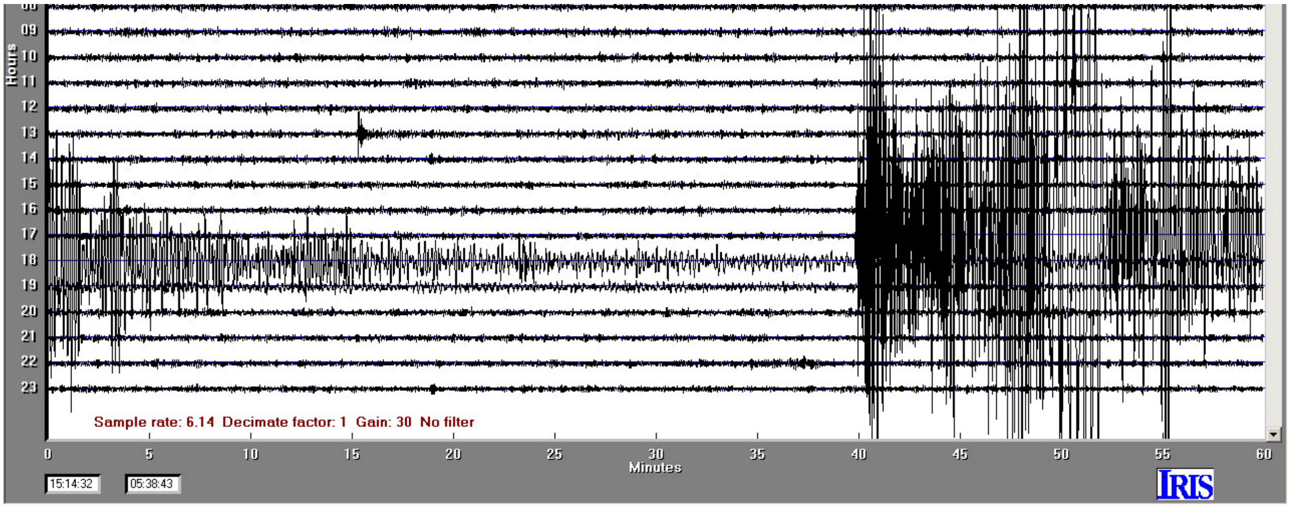
M1 Event.



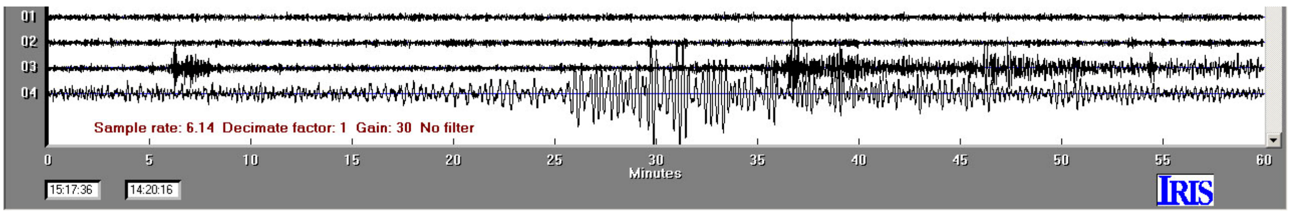
M2 and M3 Events.



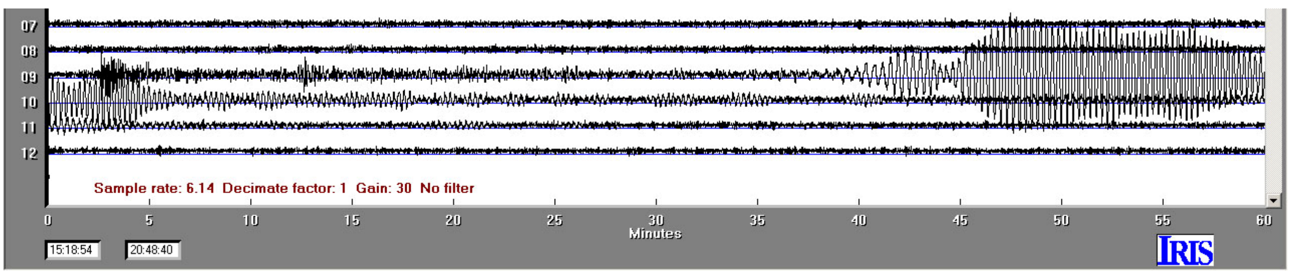
M4 Event.



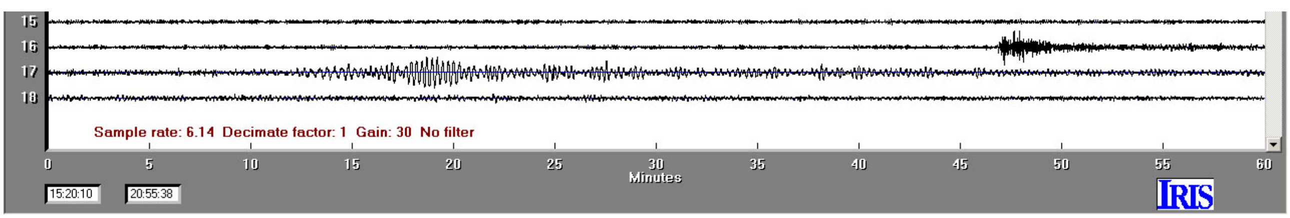
M5 Event.



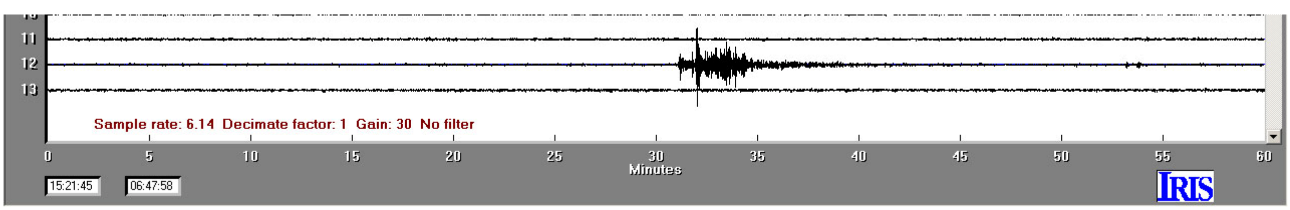
M6 Event.



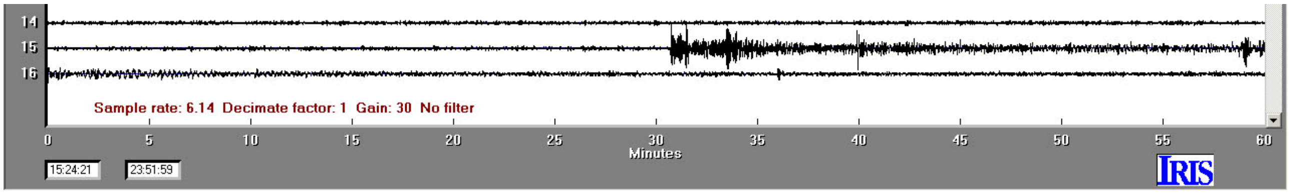
M7 Event.



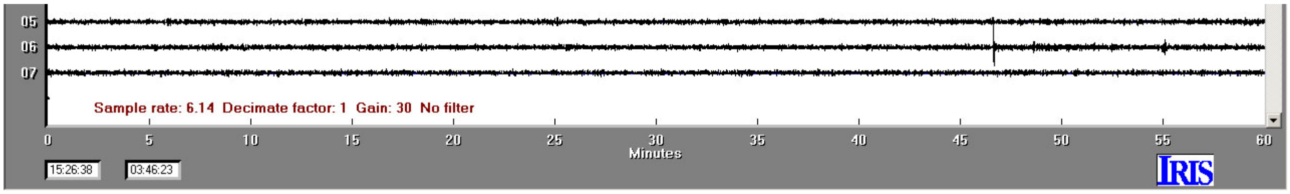
M8 Event.



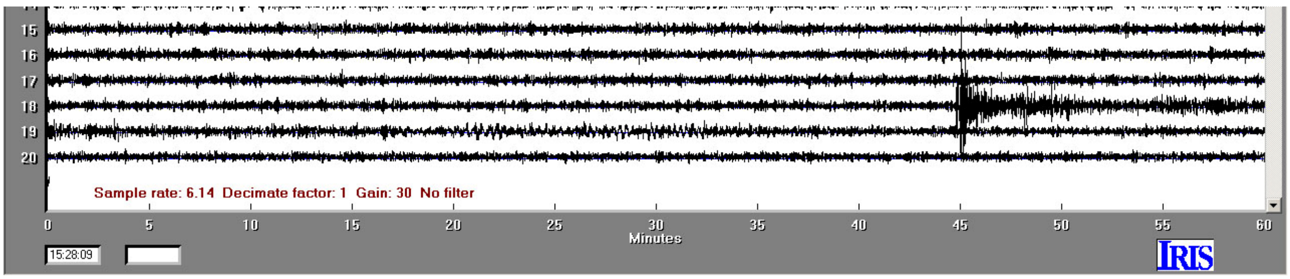
M9 Event.



M10 Event.



M11 Event.

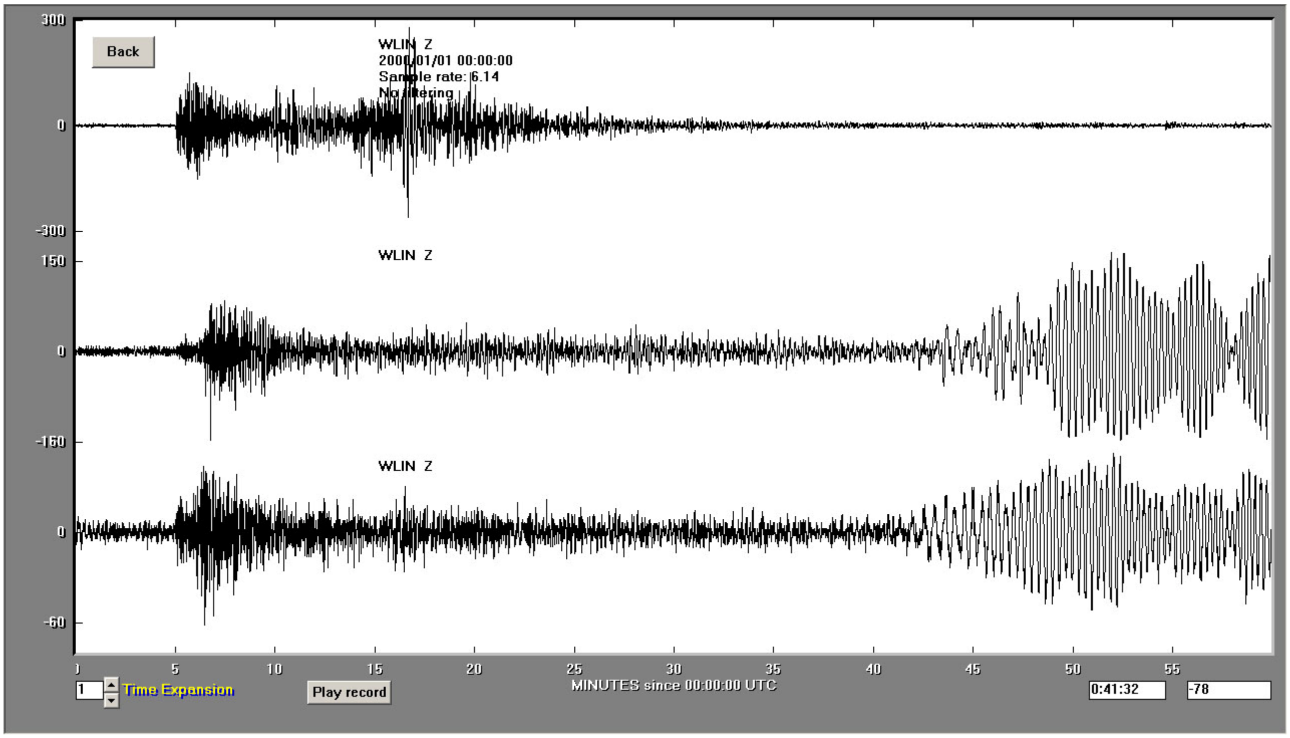


M12 Event.

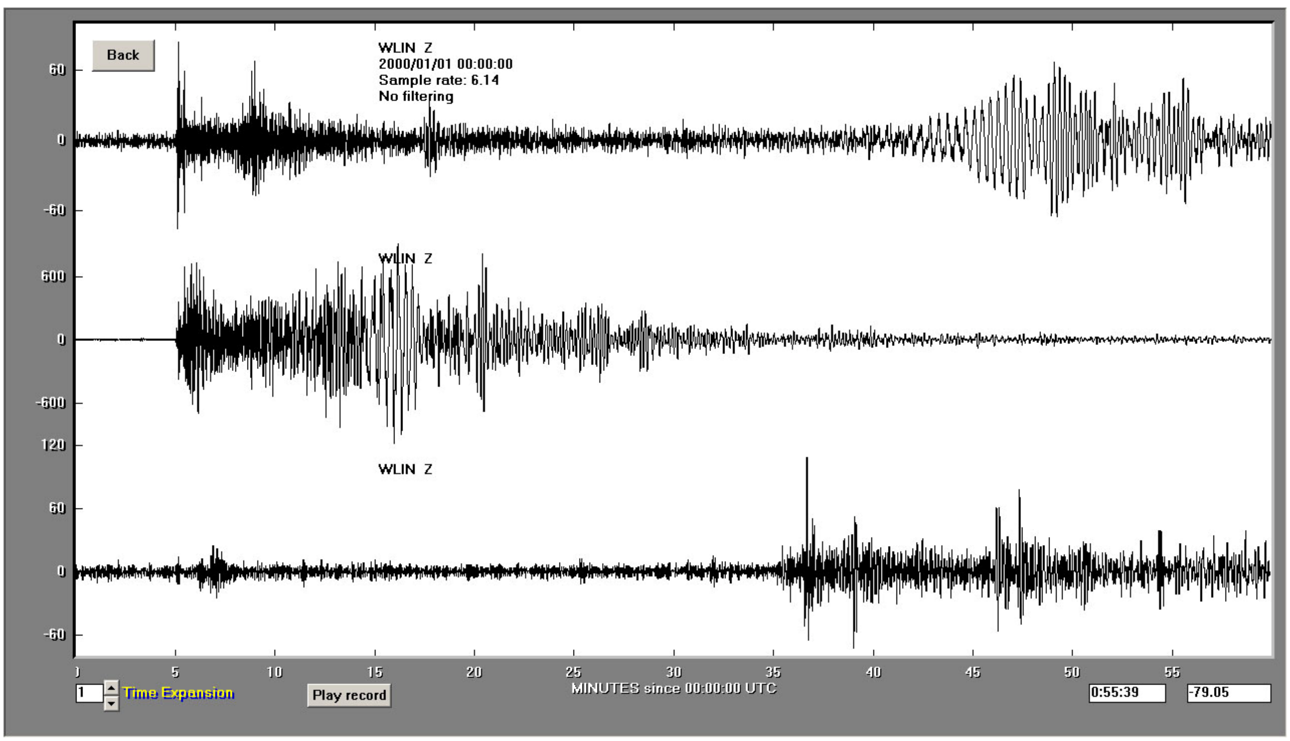
In the figures below, the twelve mystery events are displayed as individual 60-minute seismograms using the 3-trace plotting capability in AmaSeis. Each trace is scaled individually and the amplitude scales on the left display the AS-1 amplitudes for each trace. Individual seismograms for each mystery event are available for download (sac format) using the links given in Table 8.

For each event, one can examine the screen display and the extracted seismograms and try to determine as much about the event as possible by simple visual analysis. To gain experience with this skill, a useful approach is to compare the mystery event with the seismograms in the catalogs (by distance, by depth and by magnitude) that are provided above. For example, one can make a rough estimate of the distance from duration and signal character and observe whether prominent surface waves are present or not which could suggest the depth of focus of the event.

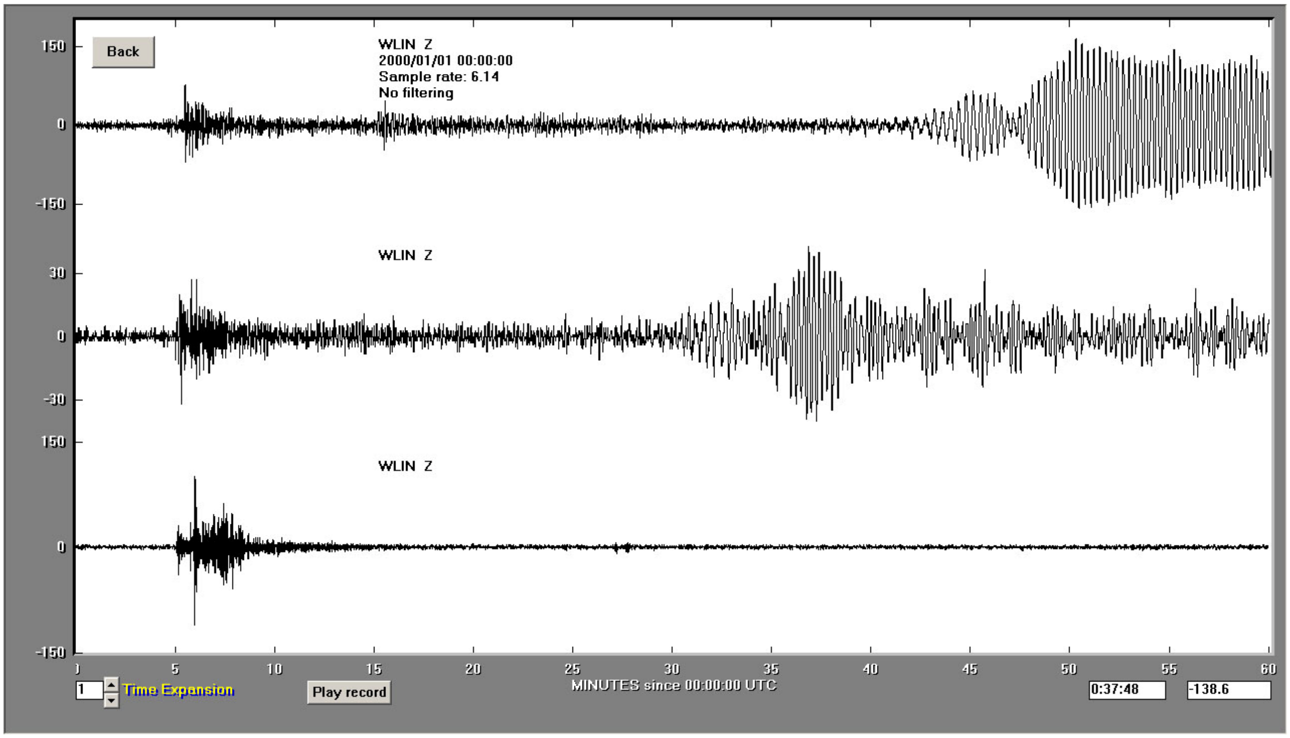
Next, use the seismograms downloaded from Table 8 to further analyze the event. In this step, one can filter the seismogram and use the AmaSeis tools such as the travel time tool to determine the distance from the S minus P times and measurements of amplitudes to calculate magnitude estimates. In some cases, it is also possible to further identify additional phases in the seismograms that are of interest for understanding seismic wave propagation in the Earth or estimating the depth of focus of the earthquake. The parameters column in Table 8 suggests the most prominent seismogram or earthquake attributes that can be determined from analysis of the seismograms.



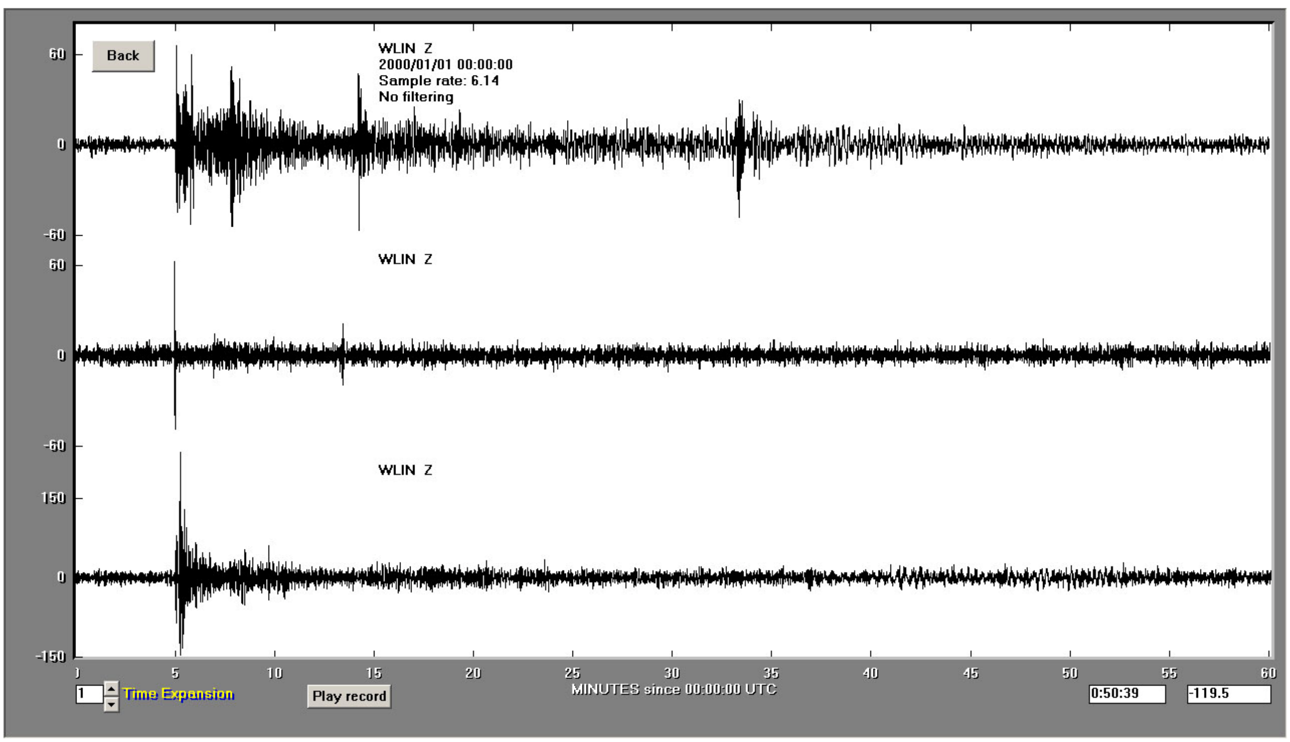
M1, M2 and M3 (top to bottom) Seismograms.



M4, M5 and M6 (top to bottom) Seismograms. Seismogram M6 is the smaller event near the beginning of the lower trace.



M7, M8 and M9 (top to bottom) Seismograms.



M10, M11 and M12 (top to bottom) Seismograms.

Table 8. Seismogram download files for mystery events.

EQ	Parameters	Seismogram
M1	mb, S-P[1]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M1WLIN.sac
M2	MS	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M2WLIN.sac
M3	MS	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M3WLIN.sac
M4	mb, MS, S-P[2]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M4WLIN.sac
M5	mb, MS, S-P	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M5WLIN.sac
M6	mbLg, S-P[3]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M6WLIN.sac
M7	MS	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M7WLIN.sac
M8	mb, MS, S-P[4]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M8WLIN.sac
M9	mbLg, S-P[3]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M9WLIN.sac
M10	mb, S-P, pP[5,6]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M10WLIN.sac
M11	mb, S-P, pP[6]	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M11WLIN.sac
M12	mb, MS, S-P	http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/M12WLIN.sac

[1] In general, low pass filtering (suggested cutoff periods are 2, 5, or 10 s) of teleseismic (distant) seismogram helps enhance the S arrival and allows one to see the change in frequency that is often associated with the S phase. Therefore, accurate determination of the S minus P (S-P) time for many of these seismograms is improved by low pass filtering (LP).

[2] Correctly identifying the S arrival for this seismogram is challenging. Try the 10 s period LP filter. Challenge question: What are the strong arrivals ~3 min. and 45 s after P and ~12 min. and 26 s after P? (Hint: Examine the travel time curves shown in Figures 5 or 6.)

[3] For this seismogram, try using a High Pass (HP) filter with a cutoff of 1 s to better see the phases.

[4] For this seismogram, try using a LP filter with a cutoff of 2 s to better see the phases.

[5] For this seismogram, try using a LP filter with a cutoff of 5 s to better see the phases. What is the strong arrival ~2 min. and 45 s after P?

[6] For this seismogram, the pP depth phase is present and can be used to estimate depth of focus using the AmaSeis travel time curve tool.

12. References:

Bolt, B.A., *Earthquakes and Geological Discovery*, Scientific American Library, W.H. Freeman, New York, 229 pp., 1993.

Bolt, B.A., *Earthquakes*, (5th edition; similar material is included in earlier editions), W.H. Freeman, New York, 378 pp., 2004.

Shearer, P. M., *Introduction to Seismology*, Cambridge University Press, Cambridge, UK, 260pp, 1999.

Mystery event information (Excel file of hypocenter information and links to correct time seismograms) is available for viewing with a browser (html file) and for downloading as an MS Word document or PDF file at the following locations:
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/MysteryEqs.htm
http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/MysteryEqs.doc

http://web.ics.purdue.edu/~braile/edumod/as1lessons/InterpSeis/MysteryEqs.pdf.

Information on the early history of seismographs can be found at:
http://earthquake.usgs.gov/learning/topics/seismology/history/history_seis.php.

Additional references on Seismogram interpretation:

Kulhanek. O., *Anatomy of Seismograms* 1990 Elsevier.

Manual of Seismological Observatory Practice (1979 edition):
http://www.seismo.com/msop/msop79/rec/rec.html#aa30 and
http://www.seismo.com/msop/msop79/msop.html.

Ruth B. Simon, *Earthquake Interpretations, A manual for reading seismograms*, William Kaufmann Inc. 1981