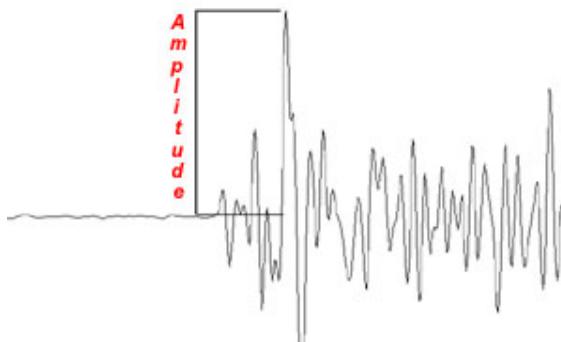


# The AS-1 Seismograph – Magnitude Determination

L. W. Braile<sup>©</sup>, November, 2002  
Updated April 30, 2006



**Estimating Earthquake Magnitude from AS-1 Seismograms:** Magnitude is an estimate of the energy release or size of an earthquake. Magnitude estimates are calculated from the amplitude of wave energy on a seismograph adjusting for the distance of the seismograph station from the earthquake (seismic waves spread out and are absorbed during propagation and thus generally become smaller at greater distances from the earthquake epicenter) and the amplification of the signal by the seismograph. Magnitude formulas have been developed for different types of seismographs (usually dependent on the frequency response of the seismograph) and different type of seismic arrivals (body waves and surface waves). Usually, the formulas are valid for a certain range of epicenter to station distances or region (for example, Richter magnitude was developed for California) and for earthquakes of particular depths (for example, surface wave magnitudes are only valid for shallow focus earthquakes) or magnitude (body wave formulas are inaccurate for very large earthquakes). Additionally, magnitude formulas have been developed over time as instruments have changed and more data have become available. Generally, magnitudes should be determined from amplitudes measured on unfiltered seismograms. If large noise levels necessitate filtering the seismogram before measuring amplitudes, one should select cutoff frequencies for the filter that place the typical frequency for the magnitude determination (about 0.5 – 1 Hz for body waves [mb], and 0.05 Hz (20 s period) for surface waves [MS]) near the center of the filter “passband” (approximately midway between the cutoff frequencies). Information on magnitudes and intensity (magnitude and intensity are often confused – magnitude is a measure of the size of the earthquake, intensity is the level of ground shaking at a specific location) can be found in Bolt (1993, 1999) and at the following web sites:

[neic.usgs.gov/neis/general/handouts/general\\_seismicity.html](http://neic.usgs.gov/neis/general/handouts/general_seismicity.html)  
[www.seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html](http://www.seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html)

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[lasker.princeton.edu/ScienceProjects/curr/eqmag/eqmag.htm](http://lasker.princeton.edu/ScienceProjects/curr/eqmag/eqmag.htm)

[http://www.eas.slu.edu/People/CJAmmon/HTML/Classes/IntroQuakes/Notes/earthquake\\_size.html](http://www.eas.slu.edu/People/CJAmmon/HTML/Classes/IntroQuakes/Notes/earthquake_size.html)

<http://www.seismo.com/msop/nmsop/03%20source/source4/source4.html>

Currently, in an effort to reduce confusion about earthquake magnitudes and use the most reliable measure of earthquake size, most magnitudes reported by the US Geological Survey (<http://earthquake.usgs.gov>) are labeled “Magnitude” or “M” and are *moment magnitude* (sometimes referred to as Mw) determinations (when available). However, traditional magnitude determinations such as body wave magnitude (mb), surface wave magnitude (MS) and Lg wave magnitude (mbLg) are also reported in USGS earthquake catalogs. Determinations of magnitude for these magnitude definitions can be made using data from the AS-1 seismograph.

The procedure for determining magnitude from seismograms recorded by the AS-1 seismograph is:

From the AmaSeis software, determine the approximate arrival time of the earthquake. If possible, pick the P and S arrivals (filtering the seismogram may help in the identification of the S wave) and estimate the distance using the travel time curve tool. Using the selection tool, zoom in on the P wave (extract the early part of the seismogram; the time expansion tool at the bottom left of the screen may also be useful for zooming in on the P arrival) and determine the maximum amplitude (zero to peak, in counts) and the approximate period of the P wave. Use the largest amplitude of the P wave. The P arrival may include energy that occurs during the first approximately 10 s of the record. Often, a distinct secondary P phase (such as pP or PP) will be present after the first P arrival. Estimate the period by measuring the time in seconds between two successive peaks or troughs of the signal. A millimeter scale held up to the screen is useful to this measurement. Next, using the selection tool, extract the early (usually largest) part of the surface wave signal (the surface waves will usually be distinguished by their much lower frequency) on the seismogram and determine the maximum amplitude (zero to peak, in counts) of the surface wave arrival that is near 20 s period. Note the period of the surface wave where your amplitude measurement is made.

1. Go to the USGS earthquake search web site ([neic.usgs.gov/neis/epic/epic.html](http://neic.usgs.gov/neis/epic/epic.html)) or the IRIS earthquake search site (<http://www.iris.washington.edu/>), select Event Search under the Quick Links menu at left side of screen) or, for recent events, to the USGS earthquake site (<http://earthquake.usgs.gov>, select Latest Quakes and then NEIC Current Earthquake Information) or the IRIS Seismic Monitor tool, [www.iris.edu](http://www.iris.edu)) and find and record the “official” origin time, location (latitude and longitude; note S latitudes and W longitudes are negative; and depth) and magnitude. Several magnitude estimates may be available (for events that occurred at least a week earlier, the IRIS event search tool can be used to find

different magnitude estimates; for example, the primary magnitude reported may be Mw (moment magnitude) which cannot be estimated from AS-1 record, but mb and MS magnitude may be reported later). The IRIS sites also provide a brief geographic description of the earthquake location that is often useful.

2. Go to the USGS travel time and distance calculation site ([http://neic.usgs.gov/neis/travel\\_times/](http://neic.usgs.gov/neis/travel_times/)) and calculate the distance from your seismograph station to the earthquake epicenter by entering the latitudes and longitudes of the event and the station into the web site form. If you don't know the latitude and longitude of your station, you can view a topographic map and use the tools to find a specific location at [www.maptech.com](http://www.maptech.com) (click on Online Maps select the Map Server, then enter city and state in the boxes and click go; select correct map from list if list of possible maps appears; choose DD.DD in coordinates window to the left of the displayed topographic map; place cursor on location of interest; read the latitude and longitude of the cursor location from the display to the left of the map). For interest, you can compare the calculated distance (in degrees, geocentric angle) with the distance that you determined from the P and S arrivals (S – P time) in AmaSeis.
3. Using the Amplitude, distance, period and displacement amplification (read from the table provided in the computer code below) data, calculate the magnitude estimate(s) for the earthquake. The calculations can easily be made with a hand calculator or one can write a simple computer program such as the Matlab code shown below. Note that valid data from the magnitude formulas will usually be restricted to certain distance ranges. Compare the magnitudes determined from your AS-1 seismogram with the official magnitude estimates.

Magnitude formulas, a table of amplification information for the AS-1 seismograph (amplification versus period) and a sample Matlab computer code that uses the amplitude, distance, period, displacement amplification data and the magnitude formulas to calculate magnitude estimates is shown below:

```
% Calculate magnitudes for AS-1 Seismograms
% L Braile, Purdue University, 12/28/00, revised 01/17/01
%-----
%
% a = amplitude (zero to peak) in counts of the arrival on AS-1
% seismogram
% D = distance in degrees (geocentric angle; one degree = 111.19 km on
% surface)
% T = period (s) of the arrival (measure by distance between two peaks)
% Velamp = velocity amplification of AS-1 in counts/micron/s
% Disamp = displacement amplification of AS-1 in counts/micron
% Disamp = Velamp*2*pi/T
% A = displacement amplitude = a/Disamp (microns)
%
```

```
% Table of amplification versus period for the AS-1 seismograph
%-----
% Period, T      Frequency   Vel. Amplification   Displ. Amplification
% (s)           (Hz)        (counts/micron/s)     (counts/micron)
%-----
%
%    1            1           12                  75
%    1.5          0.667       22                  92
%    2            0.5          28                  88
%    3            0.333       28                  59
%    5            0.2          22                  28
%   10            0.1          9                   5.7
%   15           0.0667       4                   1.7
%   20            0.05         2                   0.63
%   30            0.333        0.7                 0.15
%   50            0.02         0.15                0.019
%  100           0.01         0.02                0.0013
%-----
%
% Change a, D, T, and Disamp for each calculation.
% Read Disamp from table above for appropriate period, T.
% Use magnitude estimate (mb, MS, mbLg1, or mbLg2) appropriate to data.
% Note distance ranges and approximate period information for each
% magnitude formula. Magnitude equations are from Bolt (1999) for mb
% and USGS/NEIC for MS and mbLg. Amplification factors are
% from AS-1 calibration data provided by Tim Long (Georgia Tech;
% http://quake.eas.gatech.edu/MagWeb/CalReptAS-1.htm.
% Bob Hutt (USGS, Albuquerque) clarified the use of the amplification
% factors in the magnitude formulas.
%-----
a=28;
D=45.07;
T=20;
Disamp=0.63;
A=a/Disamp;
mb = log10(A/T) + 0.01*D + 5.9 % 25 deg < D < 90 deg; T~1-3 s
MS = log10(A/T) + 1.66*log10(D) + 3.3 % 20 deg < D < 160 deg; T~20 s
mbLg1 = log10(A/T) + 0.90*log10(D) +3.75 % 0.5 deg < D < 5 deg; T~1 s
mbLg2 = log10(A/T) + 1.66*log10(D) +3.3 % 5 deg < D < 30 deg; T~1 s
%-----
```

**Magnitude Calculator:** A new online magnitude calculator for the AS-1 seismograph is available at: <http://web.ics.purdue.edu/~braile/edumod/MagCalc/MagCalc.htm>. The calculator can be used to calculate mb, MS and mbLg magnitudes from AS-1 amplitude data. The calculator uses the same equations that are programmed in the Matlab code shown above. It is also possible to use these equations to perform the calculations with a simple electronic calculator “by hand”.

**AmaSeis Updates:** A new version of AmaSeis (<http://www.geol.binghamton.edu/faculty/jones/>) includes the ability to easily determine time and amplitude on an extracted seismogram. For example for the September 25, 2003 M8.0 Hokkaido, Japan earthquake (Figure 1), the extracted seismogram (after

selection with the cursor on the 24-hour screen display or from opening a previously saved .sac file) is shown with an actual (UTC) time scale below the seismogram. In addition two small windows appear in the lower right hand corner of the screen. The first of these windows displays the actual UTC time (assuming that the computer's clock has been synchronized with UTC time) of the position of the cursor (horizontal position on the screen) and the second window shows the amplitude (in digital units) of the cursor position (vertical position on the screen). These tools can be used to easily measure times of arrivals on the seismogram and amplitudes of the arrivals for magnitude calculation. When measuring amplitudes, it is necessary to note the position of the approximate zero line on the seismogram. If the recorded signals are centered on the zero line, then no adjustment is necessary. If signals are offset from the zero line, then the amplitude of the peak used for the magnitude measurement should be measured from the position of the signal zero line and needs to be adjusted by the amount of the zero line offset (usually a small number of digital units).

Examples of magnitude calculations using the AS-1 online magnitude calculator and the AmaSeis time and amplitude measuring tool are shown in Figures 1, 2 and 3.

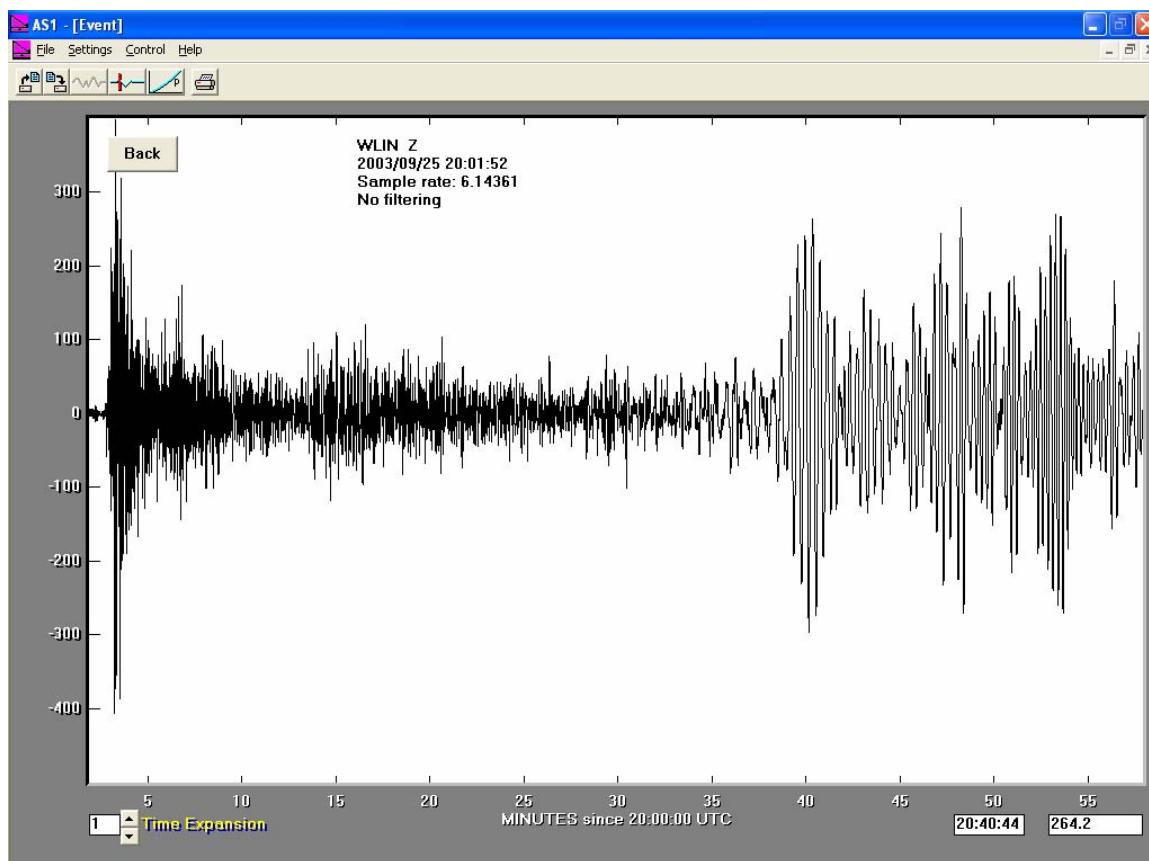


Figure 1. AmaSeis seismogram for the M8.3 September 25, 2003 Hokkaido, Japan earthquake. The SAC file for this event recorded at WLIN can be downloaded from the [SpiNet](#) site.

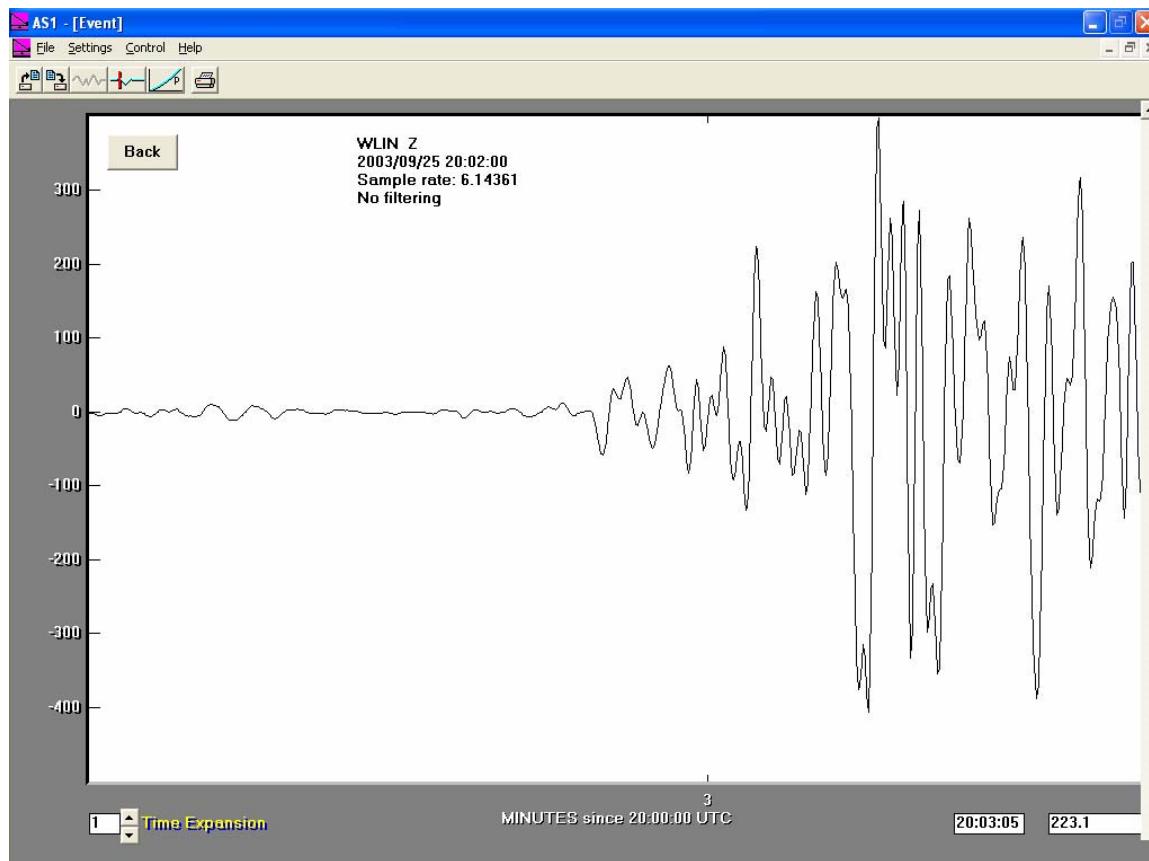


Figure 2. Enlarged (selected in AmaSeis) seismogram for the P wave arrival for the M8.3 September 25, 2003 Hokkaido, Japan earthquake recorded at West Lafayette, Indiana. For the mb magnitude calculation, the maximum amplitude of the first 10-15 seconds of the first arrival, in this case at about 20:03:05 is measured. For distant events, the first arriving energy is often spread out over 10-15 seconds. For closer events, the maximum amplitude of the first arriving P phase is often within the first 2-3 seconds of the arrival. For this event, an amplitude of 223 digital units is measured using the cursor in the AmaSeis software. The wave period is 2 s and the epicenter-to-station distance is 86.07 degrees. Using these values, the AS-1 magnitude calculator returns a calculated mb magnitude of 6.9, the same as the official USGS mb magnitude for this event determined from an average of many seismograph stations.

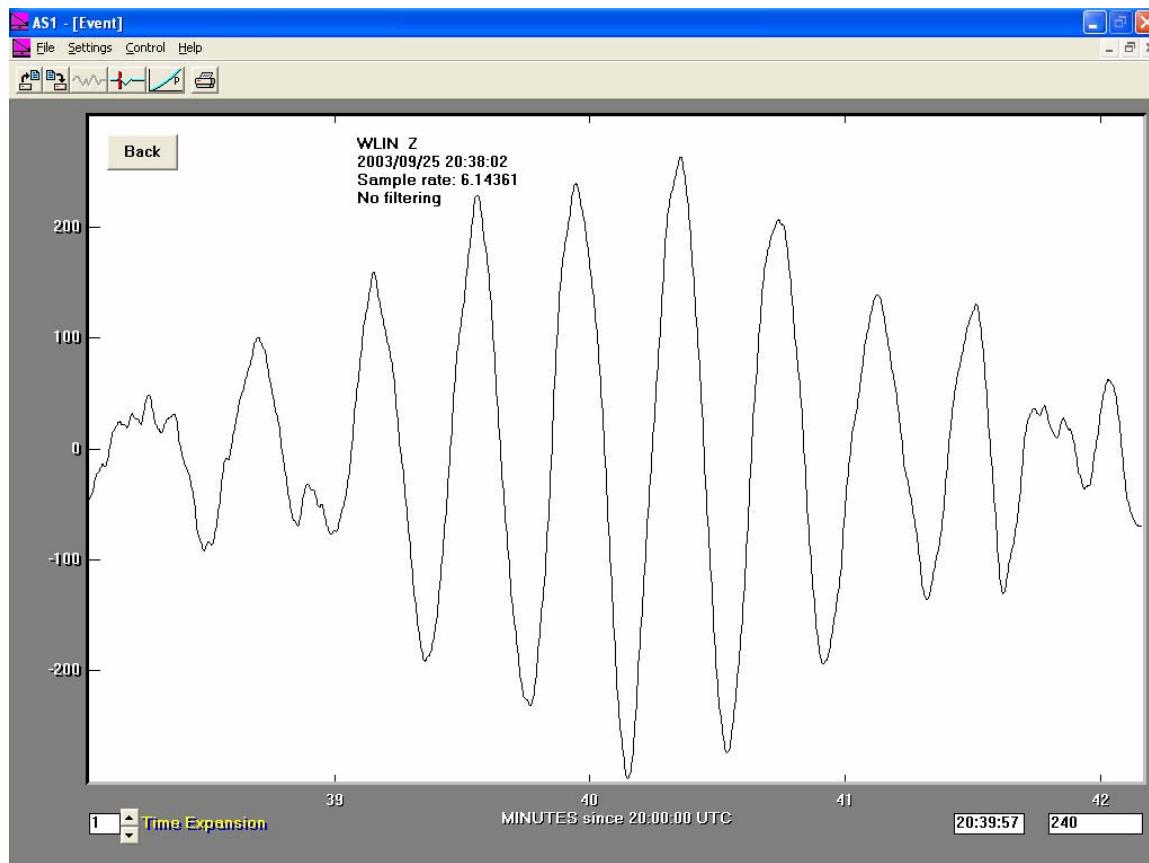


Figure 3. Enlarged (selected in AmaSeis) seismogram for the ~20 s surface wave arrivals for the M8.3 September 25, 2003 Hokkaido, Japan earthquake recorded at West Lafayette, Indiana. For the MS magnitude calculation, the maximum amplitude of the 18-22 second surface waves is measured. In this case the amplitude is 240 digital units at about 20:39:57 measured using the cursor in the AmaSeis software. The epicenter-to-station distance is 86.07 degrees. Using these values, the AS-1 magnitude calculator returns a calculated MS magnitude of 7.8, compared to the official USGS MS magnitude of 7.5 for this event determined from an average of many seismograph stations.

**Example Magnitude Calculations for AS-1 Seismograms:** Examples of AS-1 seismograms and magnitude calculations are given below. Figure 4 shows a 24 hour AS-1/AmaSeis screen display of seismic data including the August 4, 2000 Sakhalin Island earthquake recorded in West Lafayette, Indiana. Prominent first arriving P waves and surface waves are visible. The extracted seismogram for the Sakhalin Island event is shown in Figure 5. A close-up view of the P wave arrival is shown in Figure 6. The maximum amplitude of the P wave is about 70 counts and the period of the wave energy is about 2 s. The distance from the epicenter to the seismograph (determined from the latitudes and longitudes of the epicenter and station using the [http://neic.usgs.gov/neis/travel\\_times/](http://neic.usgs.gov/neis/travel_times/) site) is 81.08 degrees. The displacement

amplification of the AS-1 seismograph for a 2 s period is 88 counts/micron (one micron is one millionth of a meter). So, for the following data:

$$a = 70 \text{ counts},$$

$$T = 2 \text{ s},$$

$$D = 81.08 \text{ degrees},$$

$$\text{Dispamp} = 88 \text{ counts/micron}, (\text{so } A = a/\text{Dispamp} = 70/88 \text{ microns}),$$

and the body wave formula:  $mb = \log_{10}(A/T) + 0.01*D + 5.9$ ,

the magnitude is  $mb = 6.3$ . This magnitude is the same as the official, USGS magnitude of  $mb = 6.3$ .

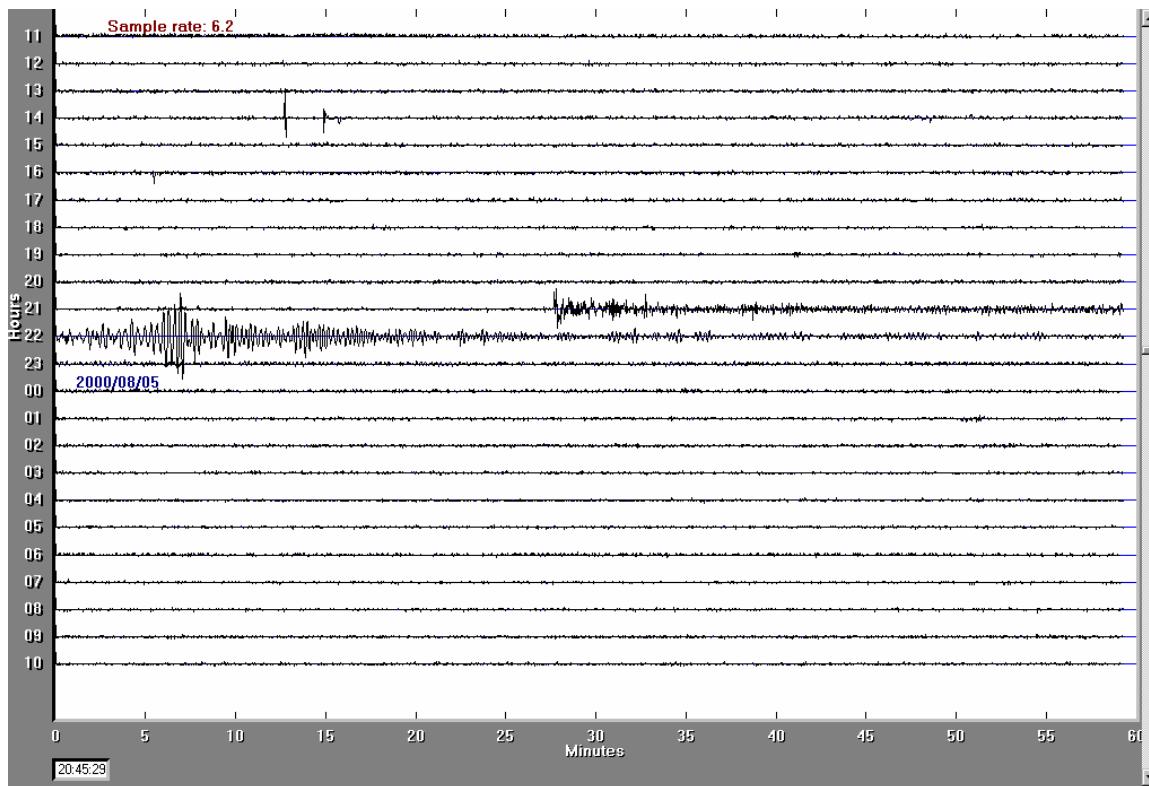


Figure 4. AmaSeis 24 hr. record including the Aug.t 4, 2000 Sakhalin Island earthquake.

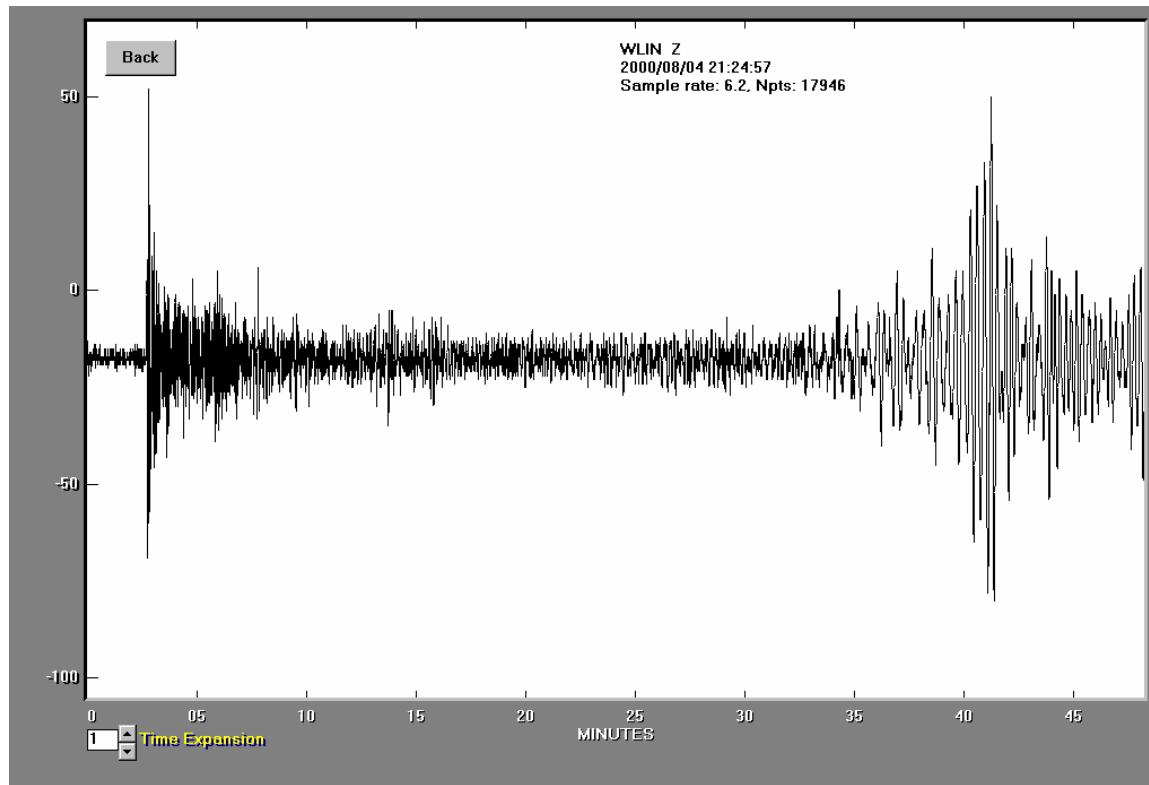


Figure 5. Seismogram for the Sakhalin Island earthquake.

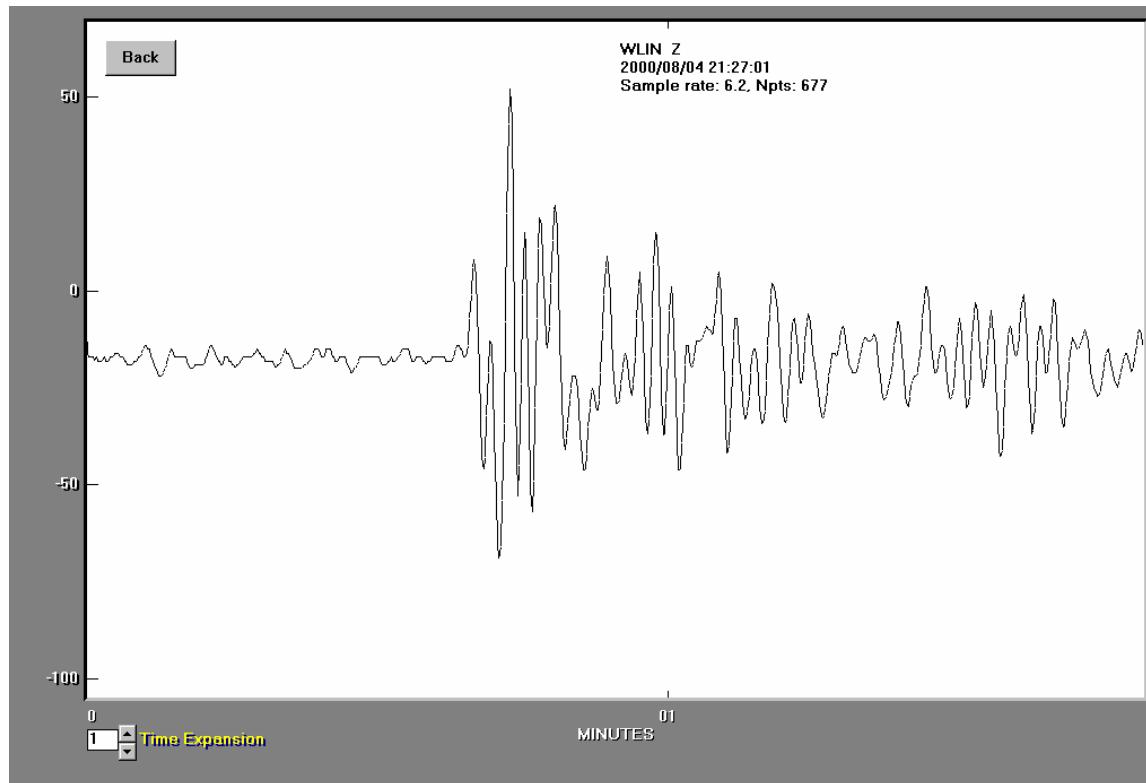


Figure 6. Seismogram for the Sakhalin Island earthquake, close-up of the P arrival.

A close-up view of the surface waves for the Sakhalin Island event is shown in Figure 7. Using the following data for the surface wave arrival:

$$a = 60 \text{ counts},$$

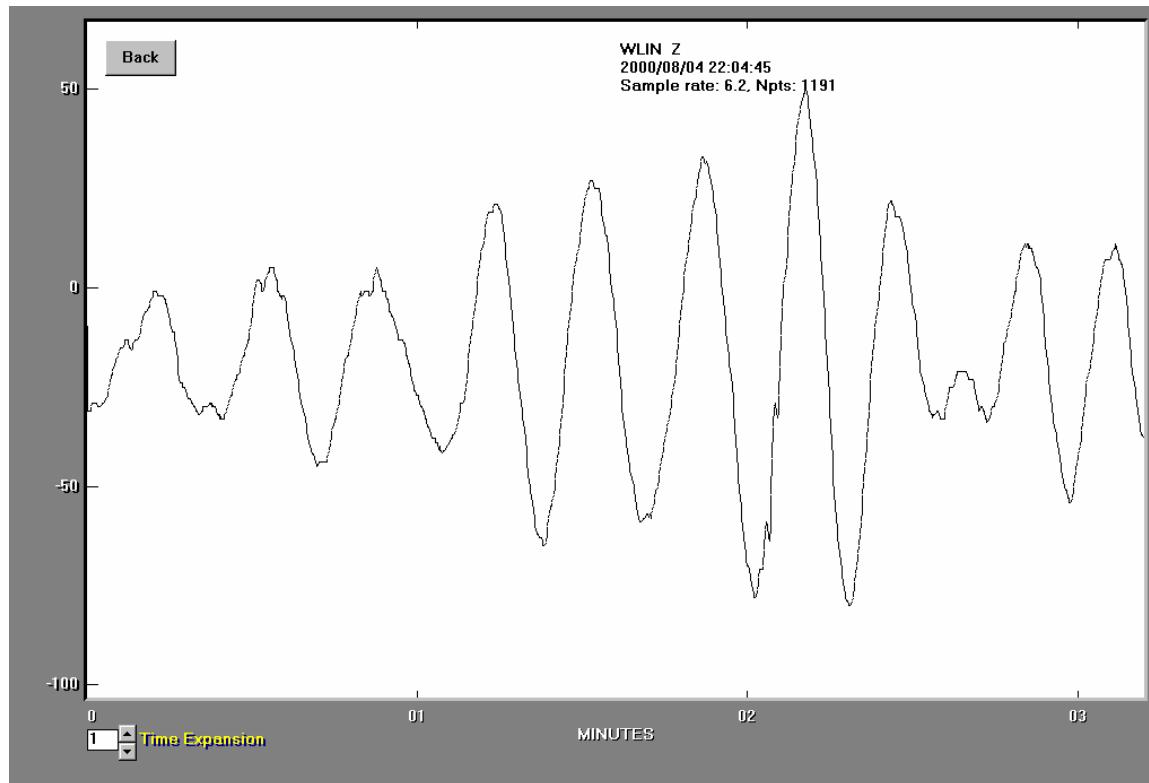
$$T = 20 \text{ s},$$

$$D = 81.08 \text{ degrees},$$

$$\text{Disamp} = 0.63 \text{ counts/micron}, (\text{so } A = a/\text{Disamp} = 60/0.63 \text{ microns}),$$

and the surface wave formula:  $MS = \log_{10}(A/T) + 1.66 * \log_{10}(D) + 3.3$ ,

the calculated magnitude is  $MS = 7.1$ , the same as the USGS magnitude of  $MS = 7.1$ .



*Figure 7. Seismogram for the Sakhalin Island earthquake, close-up of the surface wave arrivals.*

An additional example of body wave and surface wave magnitude calculations is provided by the seismograms for the June 21, 2000, Iceland earthquake (Figures 8 and 9).

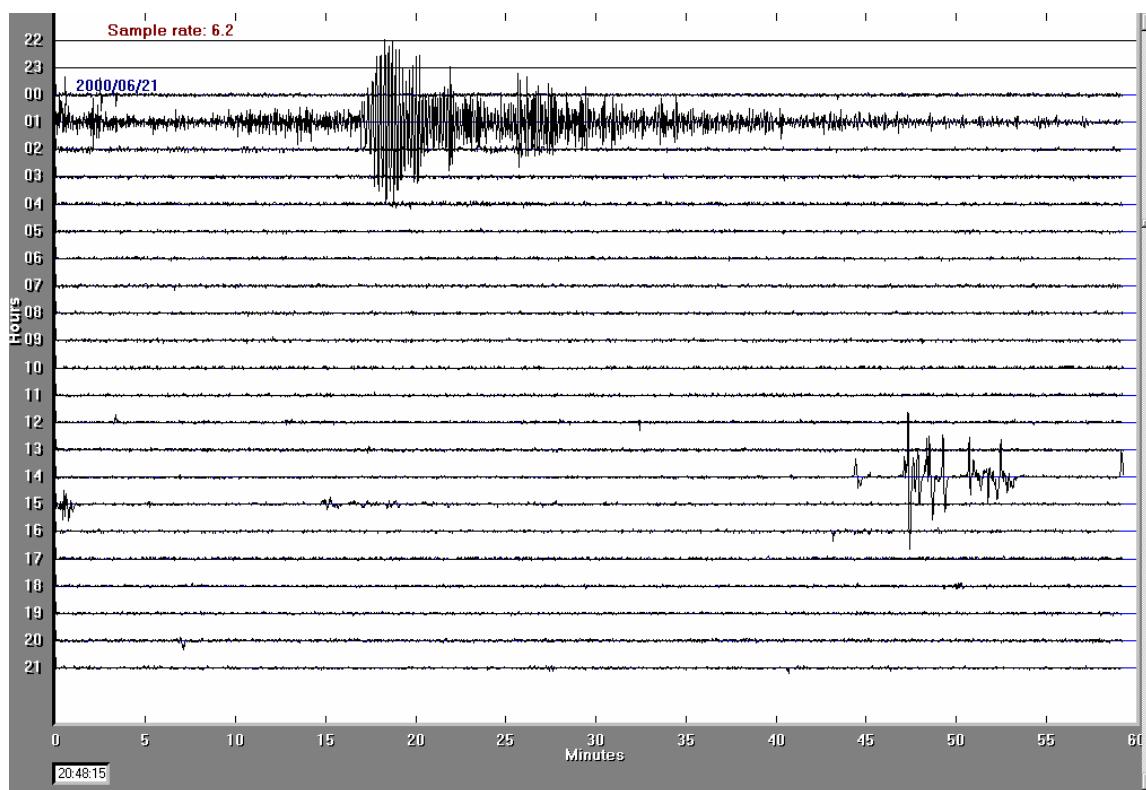


Figure 8. AmaSeis 24 hour seismic record including the June 21, 2000 Iceland earthquake.

A close-up view of the P wave for the Iceland event is shown in Figure 10. Using the following data for the P wave arrival:

$$a = 60 \text{ counts},$$

$$T = 1.5 \text{ s},$$

$$D = 44.23 \text{ degrees},$$

$$\text{Disamp} = 92 \text{ counts/micron}, (\text{so } A = a/\text{Disamp} = 60/92 \text{ microns}),$$

and the body wave formula:  $mb = \log_{10}(A/T) + 0.01*D + 5.9$ ,

the magnitude is  $mb = 6.0$  compared to the USGS magnitude of  $mb = 6.1$ .

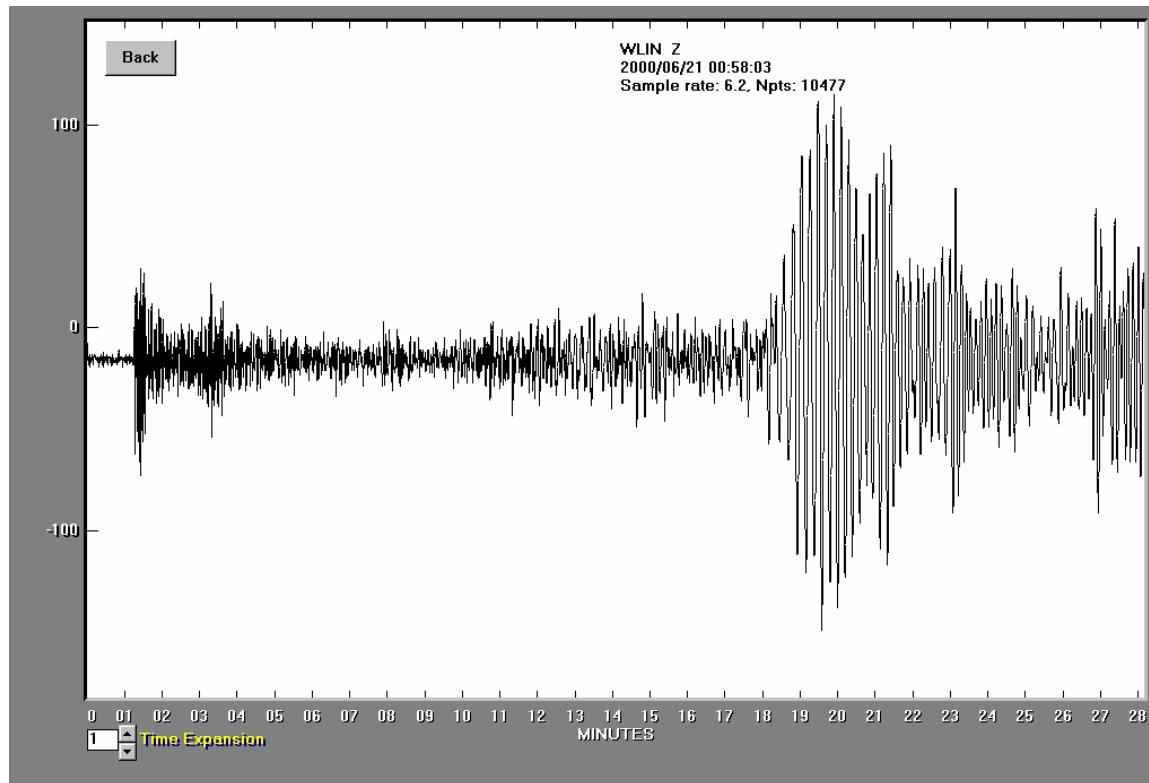


Figure 9. Seismogram for the Iceland earthquake.

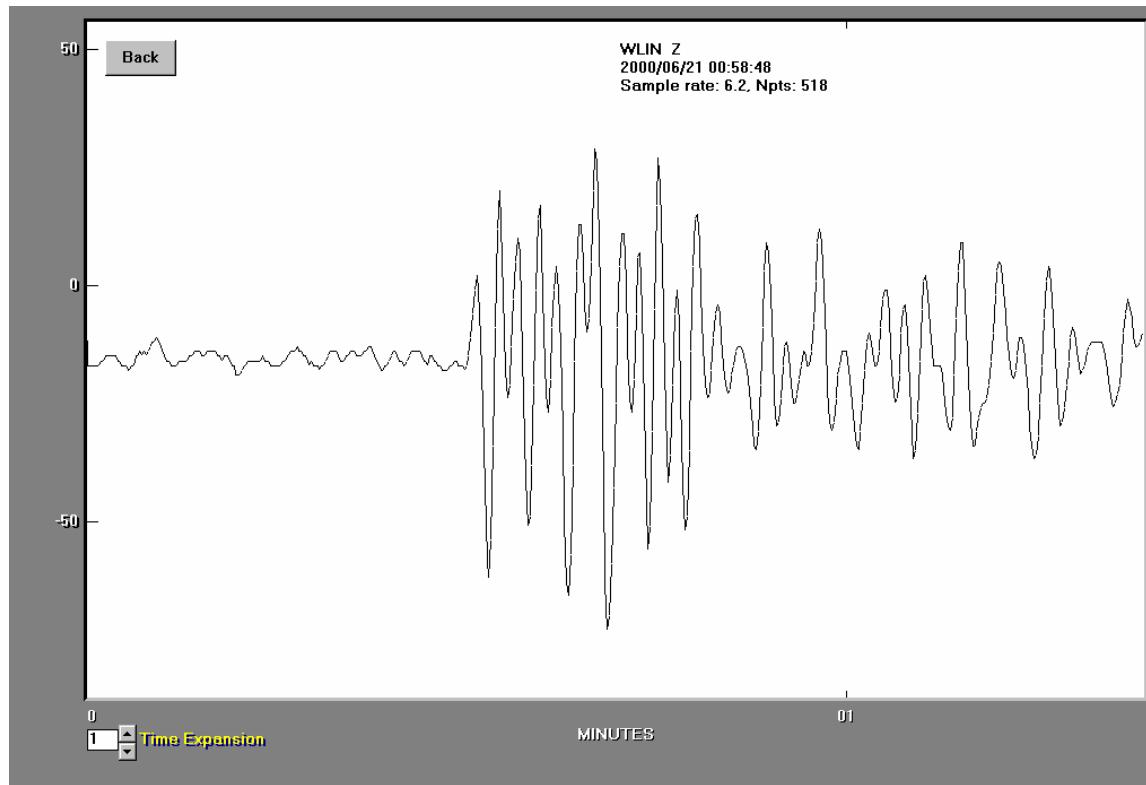


Figure 10. Seismogram for the Iceland earthquake, close-up of the P arrival.

A close-up view of the surface waves for the Iceland event is shown in Figure 11. Using the following data for the surface wave arrival:

$$a = 120 \text{ counts},$$

$$T = 15 \text{ s},$$

$$D = 44.23 \text{ degrees},$$

$$\text{Disamp} = 1.7 \text{ counts/micron}, (\text{so } A = a/\text{Disamp} = 120/1.7 \text{ microns}),$$

and the surface wave formula:  $MS = \log_{10}(A/T) + 1.66 * \log_{10}(D) + 3.3,$

the calculated magnitude is  $MS = 6.7$  compared to the USGS magnitude of  $MS = 6.6$ .

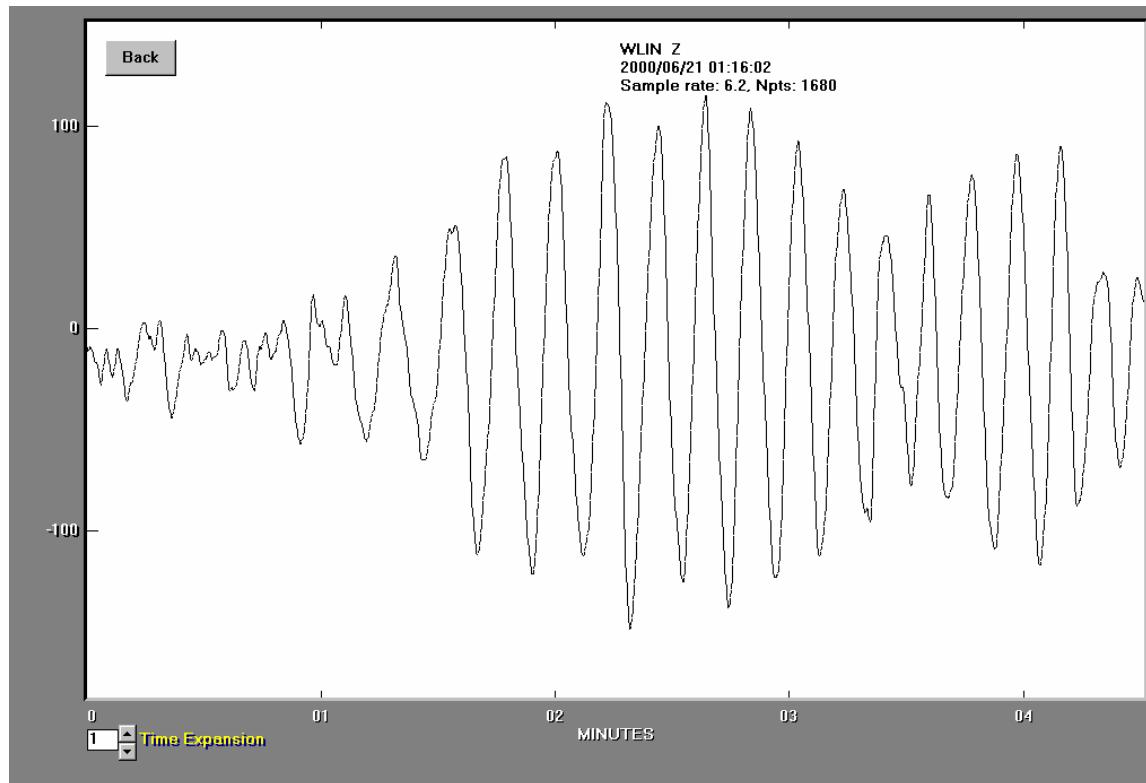


Figure 11. Seismogram for the Iceland earthquake, close-up of the surface wave arrivals.

An example of calculating magnitude for a deep focus earthquake (in which surface waves are generally very small so that the surface wave magnitude formula cannot be used) is shown in Figures 12, 13 and 14. The formula used here and in the Matlab code above is a simplified formula in which no correction is made for the depth of the earthquake. Often (including the USGS magnitude calculations), mb calculations for deeper earthquakes include a correction for the effect of depth. A description of this procedure and the graph showing correction factors is given at: <http://www.seismo.com/msop/nmsop/03%20source/source4/source4.html>. Figure 12 shows an AmaSeis screen display for the May 12, 2000 seismic data. The record includes a seismogram for a deep focus earthquake from the Jujuy Province of Argentina. The extracted seismogram for this event is shown in Figure 13. Notice that although there are very strong P waves near the beginning of the signal, the surface waves (which should begin about 17 minutes after the first arrival for this distance) are absent. A close-up view of the P wave for the Argentina

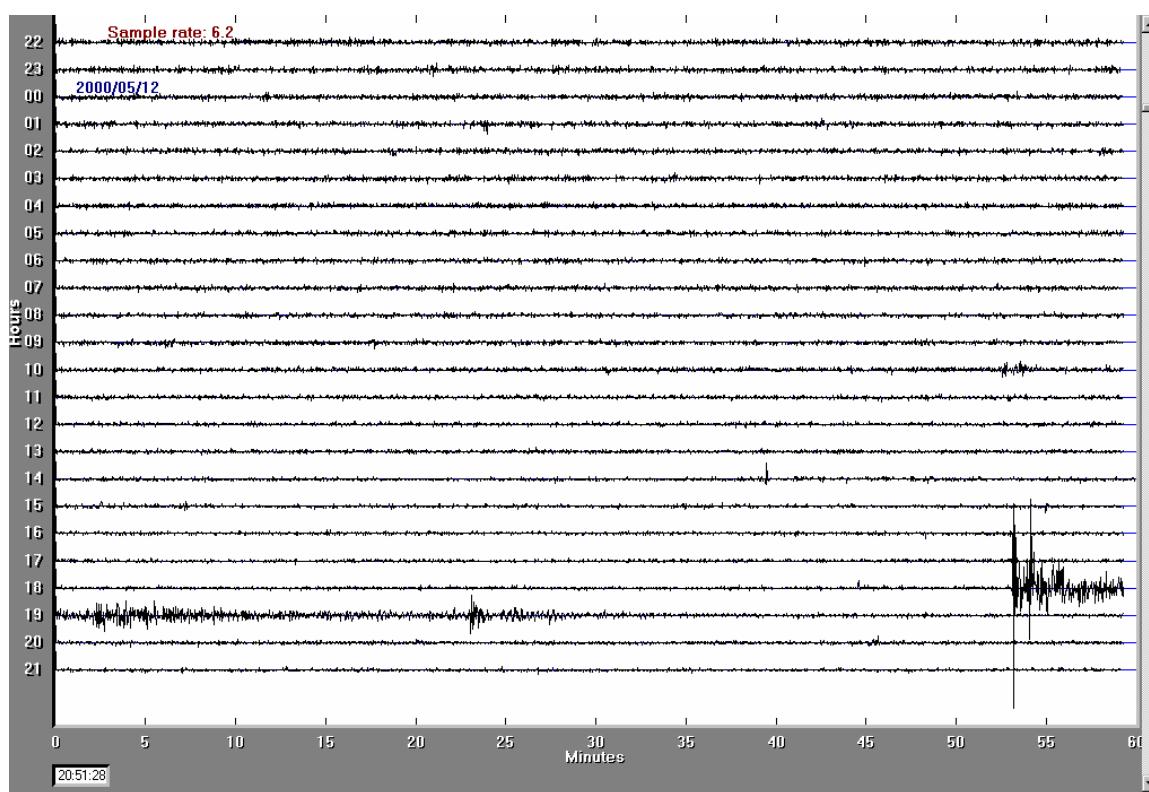


Figure 12. AmaSeis 24 hour seismic record including the May 12, 2000 Argentina earthquake.

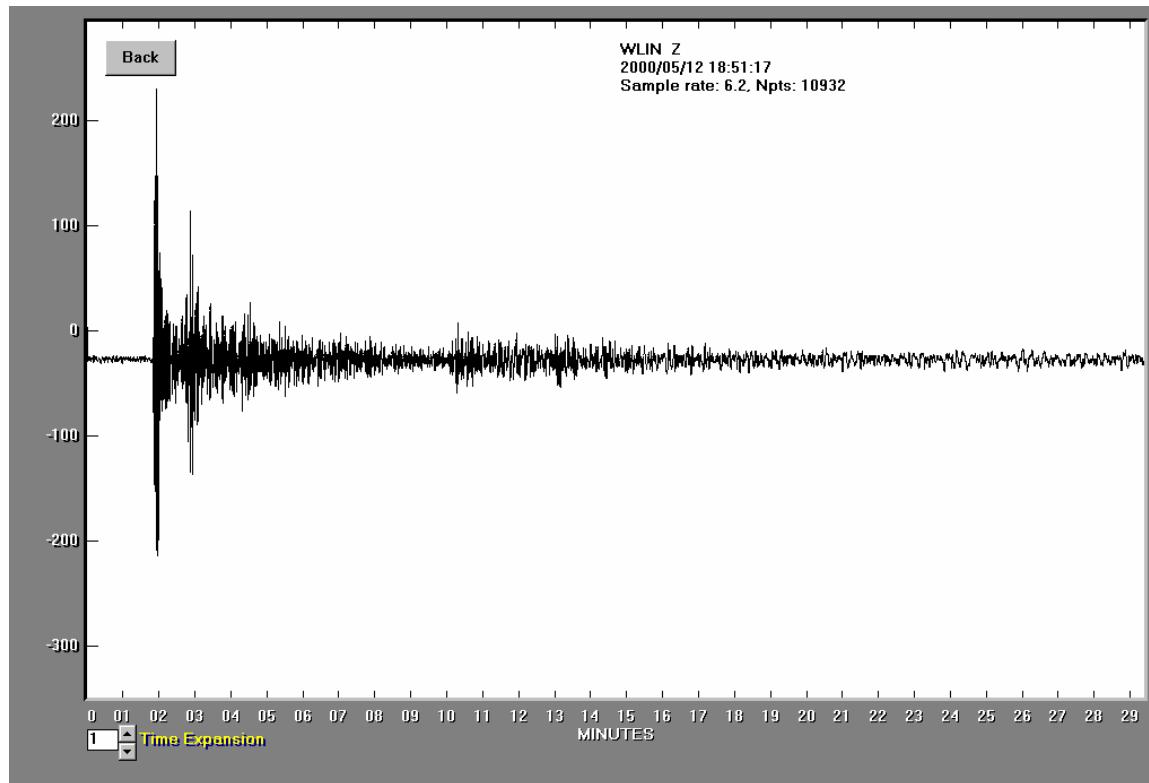


Figure 13. Seismogram for the deep-focus Argentina earthquake.

event is shown in Figure 14. Using the following data for the P wave arrival:

$a = 150$  counts,

$T = 2$  s,

$D = 66.48$  degrees,

Disamp = 88 counts/micron, (so  $A = a/\text{Disamp} = 150/88$  microns),

and the body wave formula:  $mb = \log_{10}(A/T) + 0.01*D + 5.9$ ,

the magnitude is  $mb = 6.5$  compared to the USGS magnitude of  $mb = 6.2$ .

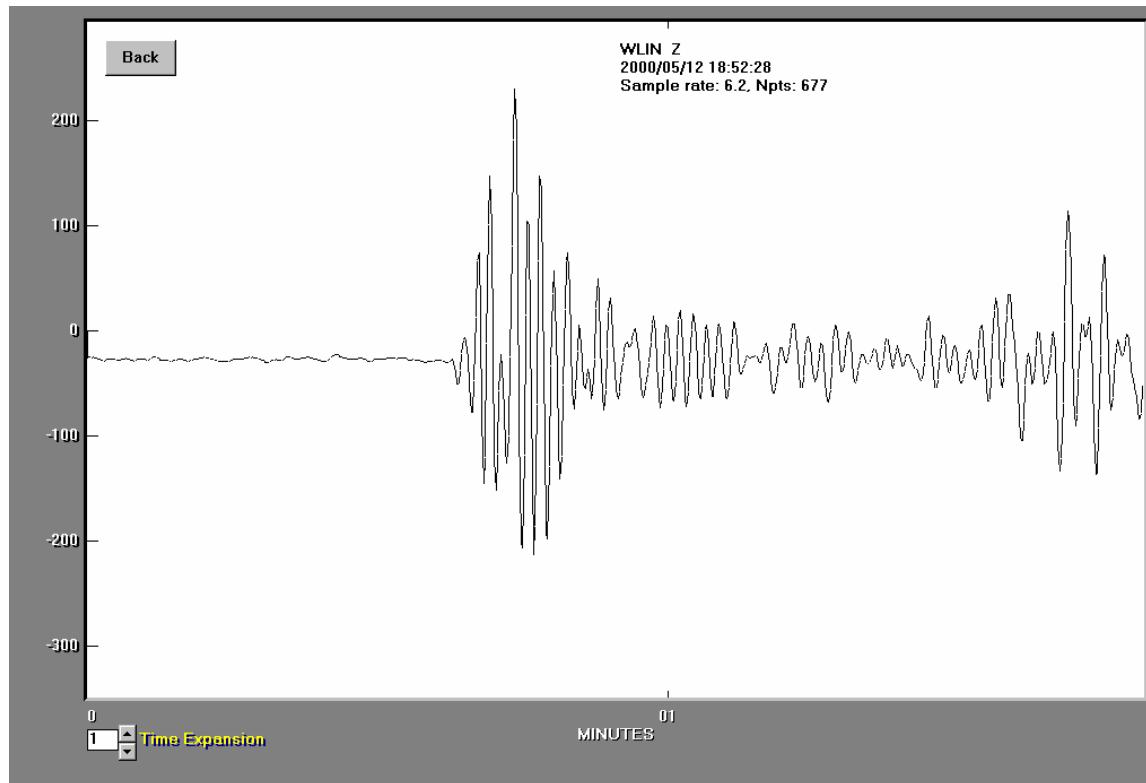


Figure 14. Seismogram for the Argentina earthquake, close-up of the P arrival.

The calculation of the mbLg magnitude can be illustrated with the regional event from Figure 15 (Evansville, IN earthquake). The mbLg magnitude is used most often for regional distance events (distances less than about 30 degrees) in the eastern part of North America. In this case, the maximum amplitude of the shear and surface wave arrivals (near 1.75 minutes relative time in the seismogram in Figure 15) is used. Using the following data for the Lg (shear and surface wave arrivals; originally defined for use with horizontal component observations) arrival:

$$a = 25 \text{ counts},$$

$$T = 1.0 \text{ s},$$

$$D = 2.63 \text{ degrees},$$

$$\text{Disamp} = 75 \text{ counts/micron}, (\text{so } A = a/\text{Disamp} = 25/75 \text{ microns}),$$

$$\text{and the mbLg formula: } mbLg = \log_{10}(A/T) + 0.90 * \log_{10}(D) + 3.75,$$

the magnitude is mbLg = 3.7 compared to the USGS magnitude of mbLg = 3.9.

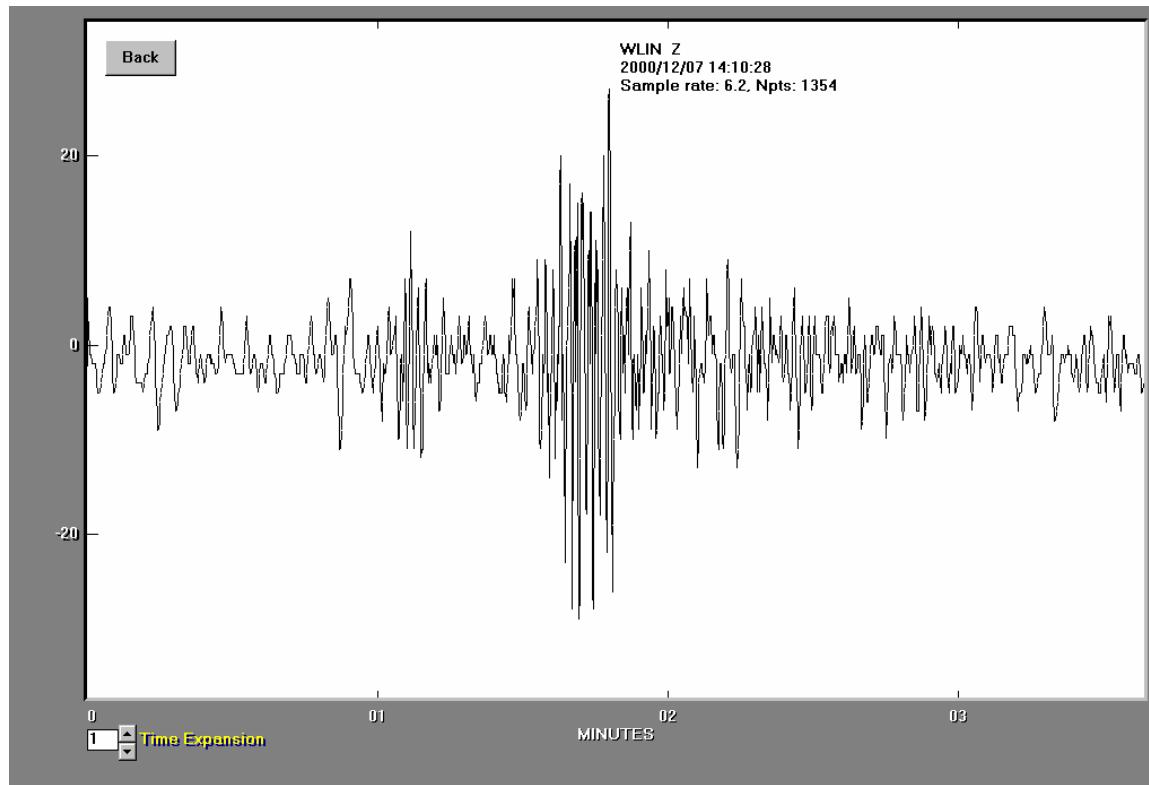


Figure 15. AS-1 seismogram recorded at West Lafayette, Indiana from an earthquake located near Evansville, Indiana, December 7, 2000. The earthquake epicenter was about 292 km away from the seismograph and had a magnitude of about 3.9 (mbLg). Microseisms of about 3-6 second period are visible before the first arrival (the compressional or P wave) that is located at about 1.1 minutes (relative time). The S (Shear) wave and surface waves are the largest arrivals following the P wave.

A comparison of magnitudes calculated from AS-1 seismograph data using the procedures described here with USGS magnitudes is shown in Figure 16. If the magnitude estimates agreed perfectly, the data would plot on the diagonal line. This comparison suggests that earthquake magnitudes can be determined from AS-1 seismograph records with an accuracy of about +/- 0.5 magnitude units (95% confidence limits). Some variation in magnitude estimates is expected because: seismograph stations are located on different geological materials (variation in site response); the radiation pattern of seismic waves generated by earthquakes (because seismic waves are caused by release of energy associated with slip along a fault plane with a specific orientation, energy is not propagated equally in all directions); there is variation in the amplification of seismographs; and amplitude and period measurement on the seismogram is subject to some interpretation and error.

Although we cannot calculate moment magnitude (Mw or simply, M) from AS-1 seismograms, the AS-1 magnitudes (mb, MS and mbLg) provide reasonably accurate estimates of Mw (Figure 17).

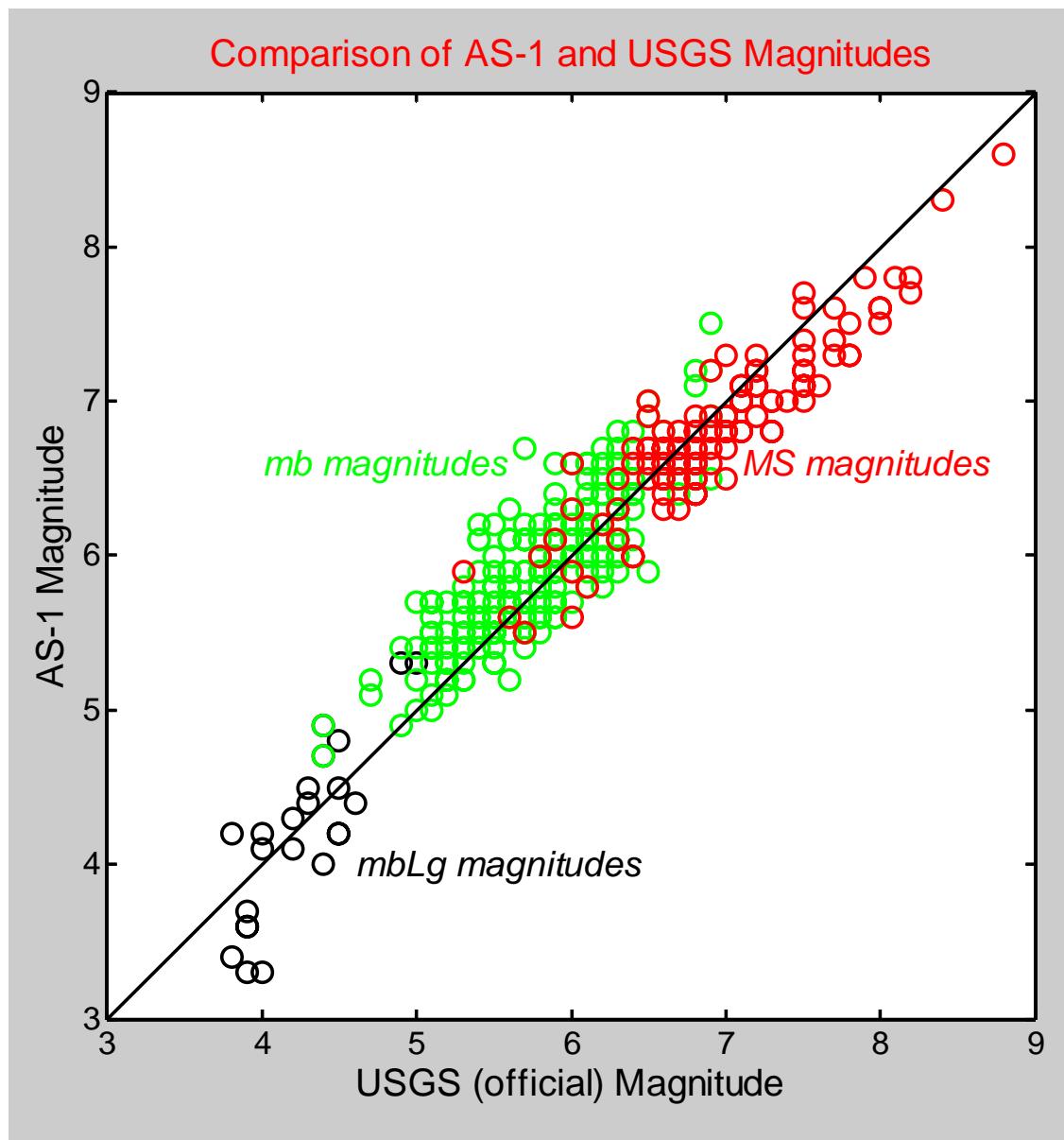


Figure 16. Comparison of magnitudes for earthquakes recorded by an AS-1 seismograph (calculated using the procedures and formulas given in the text) and the USGS magnitude determinations for the earthquakes. Data from January 1, 2000 to March 31, 2006.

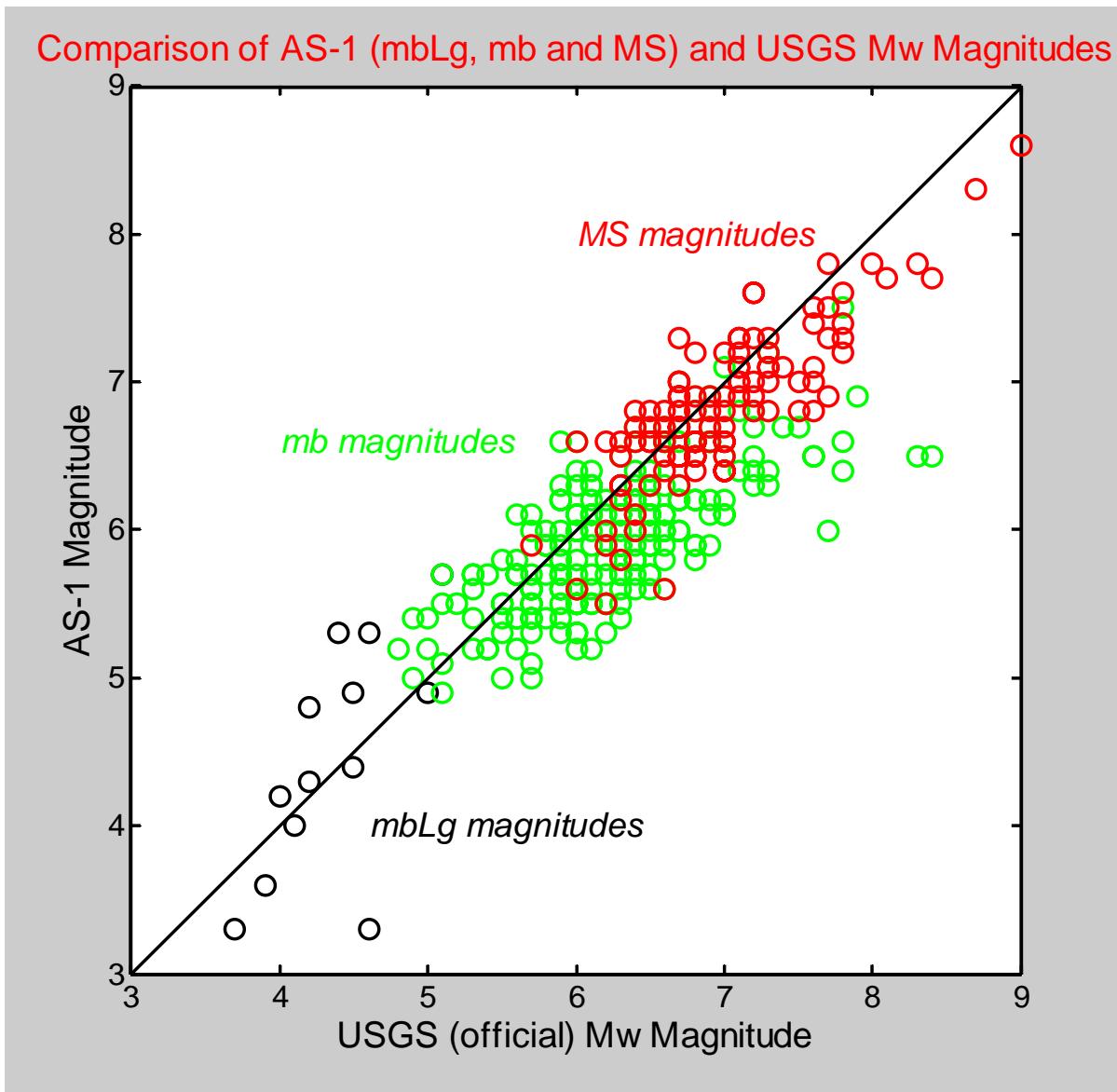


Figure 17. Comparison of AS-1 magnitudes (mbLg, mb and MS) with USGS Mw magnitudes.

### References:

- Bolt, B.A., *Earthquakes and Geological Discovery*, Scientific American Library, W.H. Freeman, New York, 229 pp., 1993.
- Bolt, B.A., *Earthquakes*, (4<sup>th</sup> edition), W.H. Freeman & Company, New York, 364 pp., 1999.

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