A Relationship between Earthquake Magnitude/Distance and Visibility on the Seismometer in Locy Hall, Northwestern University, with an analysis of the correlation between the signal amplitude on the seismometer and the reported M_w by the USGS

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Abstract

The seismometer at Northwestern University has the ability to detect many earthquakes from around the world, however, several questions remain surrounding the data produced by the seismometer. Two of these such questions are addressed in this paper, specifically, which earthquakes should produce a signal given a certain distance and magnitude, and what is the correlation between the signal produced on the seismometer and the M_w reported by the USGS. Using mathamatical analysis and manipulation, results to these questions were found providing two distinct results. The first is a model which can determine which earthquakes should produce a signal on the seismometer given a certain magnitude and distance. For example a magnitude 4.5 earthquake that occurs 1000 km away from Northwestern University would produce a signal on the seismometer on a day with normal seismic noise. The second result is a numerical multiplier, which when multiplied by the signal amplitude will produce a rough estimate of the M_w which is consistent with the USGS reported M_w.

Introduction

For this independent study, I was tasked with determining the minimum magnitude that could be seen on the Locy seismometer at varying distances, as well as developing a rough calculation with which a correlation between the amplitude on the Locy seismometer measured in counts and the reported M_w by the USGS could be determined. In order to accomplish this project, it was necessary for me to learn Generic Mapping Tools (GMT), Seismic Analysis Code (SAC), and GNU Octave to produce data as well as results. The data for the study was provided through analysis of several earthquakes picked up by the Locy seismometer. For each earthquake, the M_b, M_s, M_w, M_0, Distance (Δ), Q, T, and relative P and S wave amplitudes were determined, and from these values, SAC calculations, and USGS data (Table 1), results were procurred. The minimum P and S wave amplitudes were determined based on seismic noise data from the Locy seismometer for both days with normal seismic noise, as well as days with extreme seismic noise (Table 1). The minimum P and S wave amplitudes were then plugged into the equations for M_b and M_s to produce minimum M_b and M_s magnitudes at varying distances (Table 2). Through calculations, these values were then related to M_w, producing a minimum M_w at varying distances (Table 2). These data can be seen graphically in Figures 1-4. This independent study allowed me to broaden my knowledge base of seismic data and analysis, leaving me with more tools with which to analyze and produce data in the future.

Methods

Data for P and S wave amplitudes as well as P wave period (T) were determined from SAC calculations to determine the maximum of each peak measured in counts relative to this particular siesmometer, as shown by figures six and seven. Distance was calculated in a Microsoft Excel spreadsheet using the haversine formula. The exact M_w was provided through USGS data, while the M_s, M_b, and M_0 were determined through the following calculations using P and S wave amplitude, T, Distance, and Q (which is a globally varying factor and was estimated for this study using data from the Tonga region):

$$M_s = log(\frac{A}{T}) + 1.66log(\Delta) + 3.3 \quad (1)$$

$$M_b = log(\frac{A}{T}) + Q(h, \Delta) \quad (2)$$

$$M_0 = 10^{1.5(M_w+10.73)} \quad (3)$$

A relation between M_s and M_w was then calculated using the total energy of the earthquake (E) and M_0 as common factors between the two values as seen in the following set of equations:

$$M_s = \frac{Log(E) - 11.8}{1.5} \quad (4)$$

$$Log(E) = 1.5M_s + 11.8 \quad (5)$$

$$M_0 = \frac{E}{(2 * 10^4)} \quad (6)$$

$$M_0 = 10^{1.5(M_w+10.73)} \quad (7)$$

Using these calculated data, results were then input into Graphical formats via GMT (Sections 5). These GMT images provide a model of the maximum distance for which an earthquake will produce a signal on the seismometer on days with both normal seismic noise as well as extreme seismic noise.

Several plots were created using GNU Octave to analyze the relationship between the amplitude recorded on the Locy seismometer and the M_w reported by the USGS. The plot of $M_w - Q * log(D) + log(T)$ versus $log(A)$ where A is some constant C multiplied by the amplituded on the Locy seismometer. By calculating a linear regression of these data, an equation was derived ($y = 0.44x + 15.77$) which allowed for a calculation of the average C value for estimates.

Conclusions

These data derived a relationship between the amplitude in counts measured at the Locy seismometer and the USGS reported M_w giving the constant C a value of 0.0316. When the estimated M_w is compared with the USGS M_w, it can be seen that there is a significant relationship, although when the raw data is viewed, it is noted that the estimates have a greater error for earthquakes at greater distances.

The analysis of these data provided a model with which the minimum magnitude earthquake visible on the seismometer can be determined. The Locy seismometer is able to record earthquakes that occur at any distance given a minimum magnitude of 6.5. As expected, the closer the earthquake occurs to Locy, the smaller the minimum magnitude will be in order to be recorded on the Locy seismometer. For example, at 1000 Km distance, the minimum magnitude that will be recorded on the Locy seismometer is 4.73.

The seismometer at Locy is more accurate in dealing with P-waves rather than S-waves, and therefore in order to produce better results, a study using M_b and P- wave magnitude analysis, rather than M_s and S-wave magnitude analysis, to correlate the Locy seismometer with the

USGS data should be done, including as many data points as were picked up by the Locy seismometer to give more precise data. Since seismic waves travel at varying speeds determined by the material the waves are traveling through, the directionality of the earthquake source could skew data in these results. Therefore I suggest that an analysis of the earthquake source direction be done using a graph similiar to a rose plot to display these data as well as to provide more precise results for this study.

References

Kanamori, H.; 1982 "Magnitude scale and quantification of earthquakes" Tectonophysics,93 (1983)185-199 Stein, S.;

Wysession, M.; 2010 "An introduction to seismology, earthquakes, and earth structure" Blackwell Publishing, 350 Main Street, Malden, MA. Van der Lee, S. 2011

Wysession, M.E.; 1996 "Large-scale

structure at the core-mantle boundary from core-diffracted waves," Nature, 382 244-8.

Figures

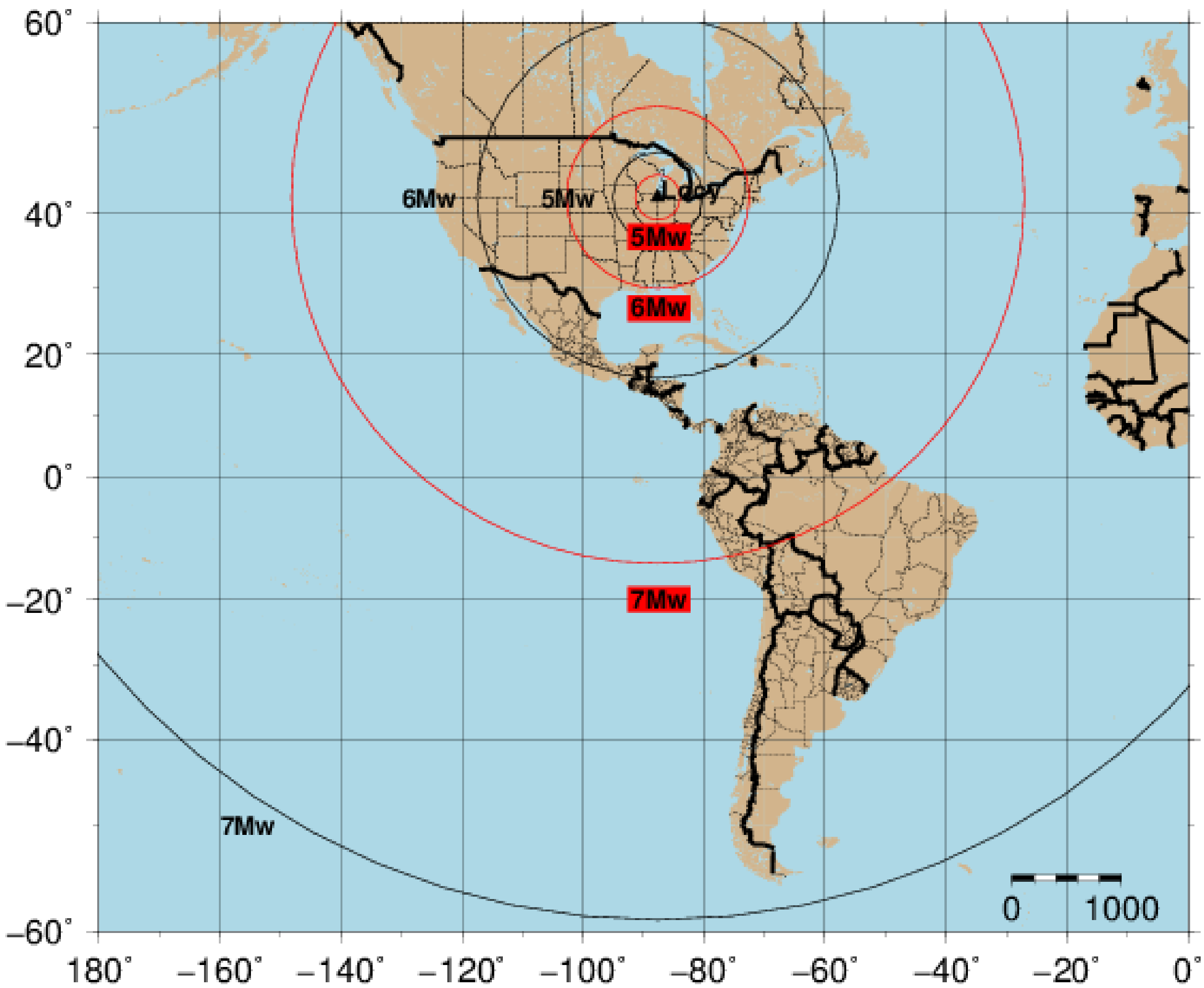

Figure 1: Minimum magnitude visible on the Locy seismometer. Magnitudes in Black are from days with normal seismic noise, while the data in red are from days with heavy siesmic noise.

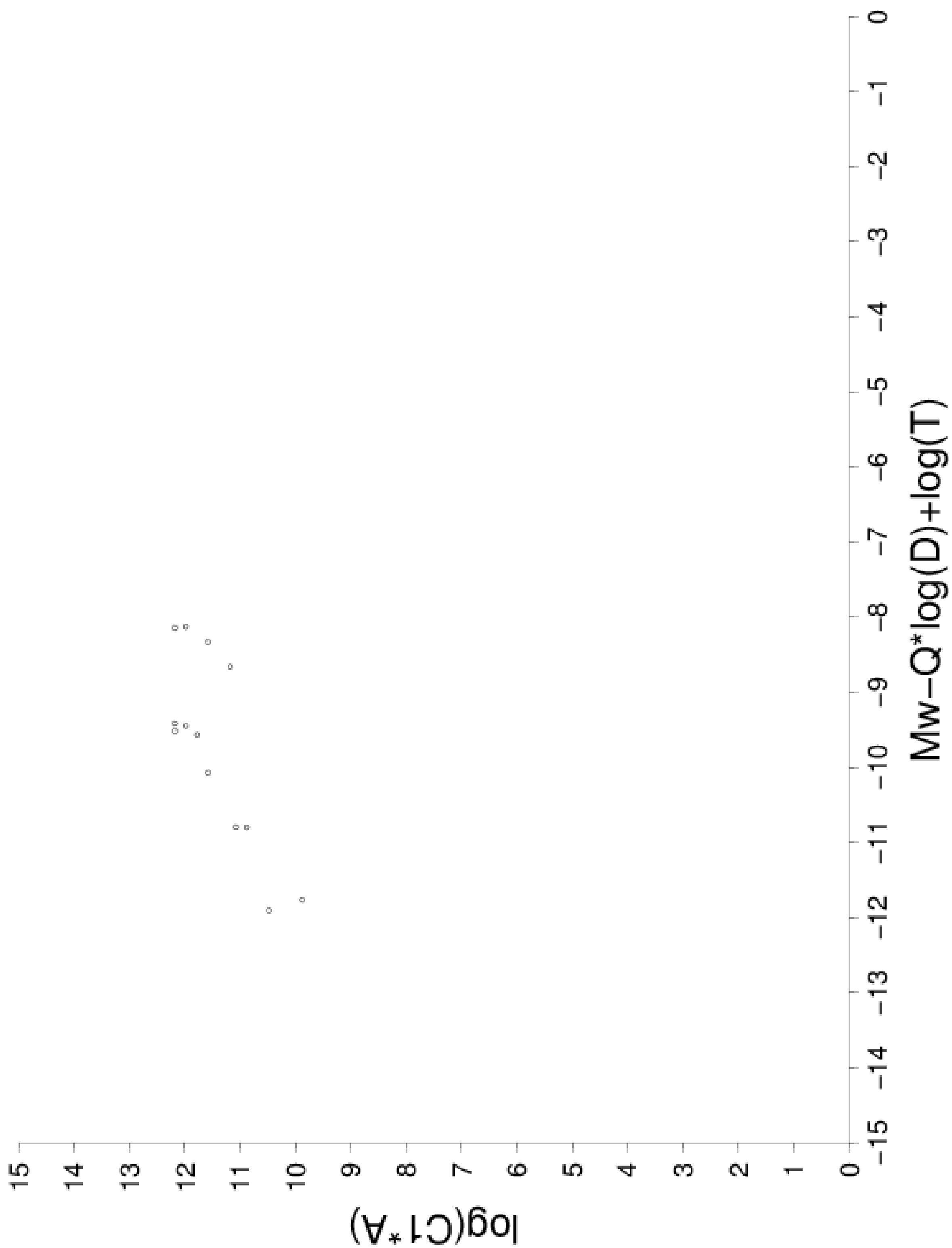

Figure 2: Plot of $log(C * A)$ versus $M_w - Q * log(D) + log(T)$ where the linear regression calculated from these data provided a means to calculate the constant C with which it is possible to determine and estimate M_w from the amplitude of the seismograms on the Locy seismometer.

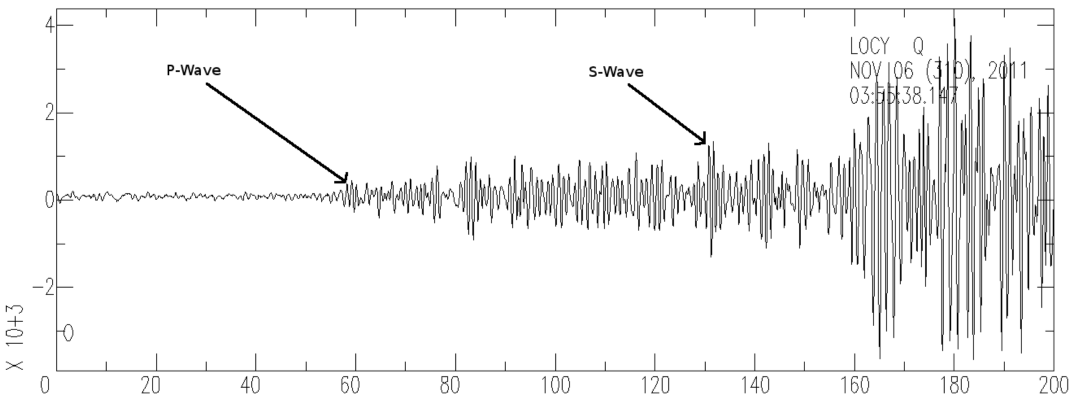

Figure 3: Sesimograph from the Oklahoma Earthquake on November 8, 2011 with P and S wave arrivals labeled.

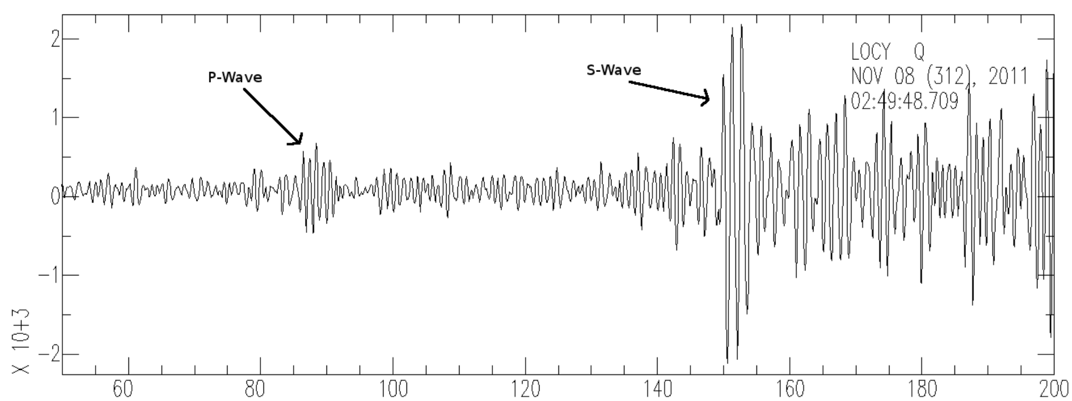

Figure 4: Sesimograph from the Virginia Earthquake on August 23, 2011 with P and S wave arrivals labeled.

Appendix

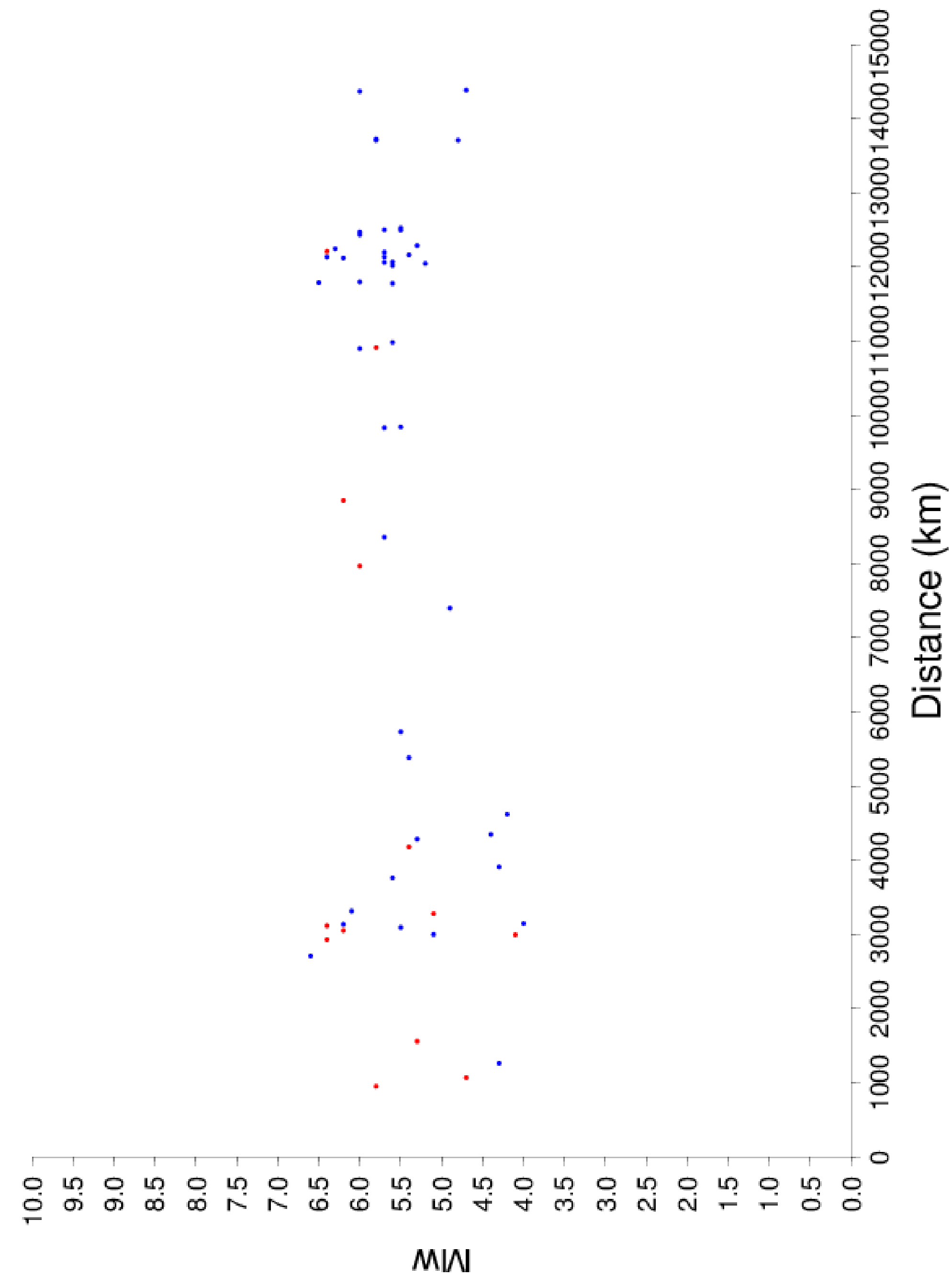

Figure 5: Plot of $log(C * A)$ versus $M_w - Q * log(D) + log(T)$ where the linear regression calculated from these data provided a means to calculate the constant C with which it is possible to determine and estimate M_w from the amplitude of the seismograms on the Locy seismometer.

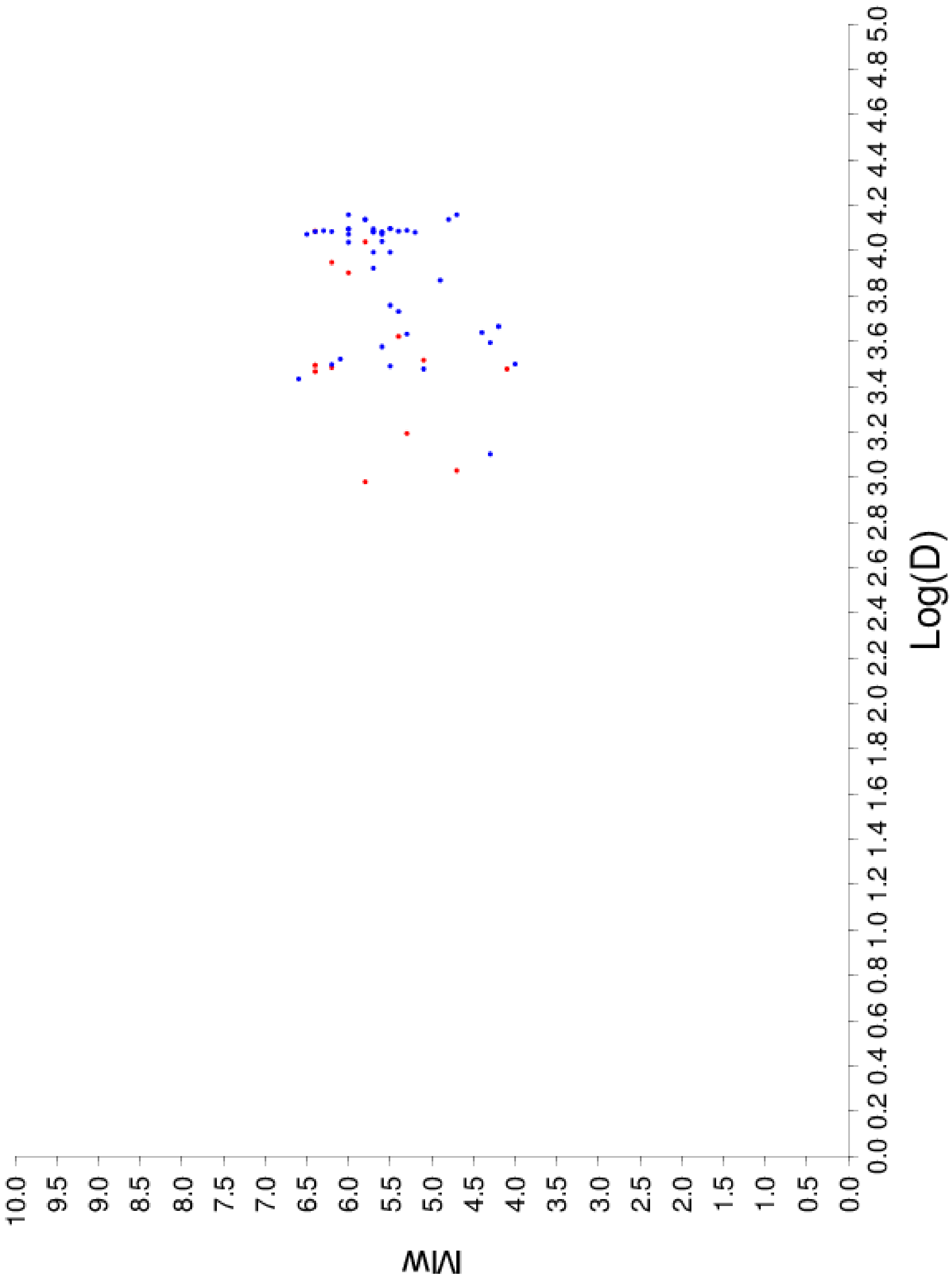

Figure 6: Plot of $log(C * A)$ versus $M_w - Q * log(D) + log(T)$ where the linear regression calculated from these data provided a means to calculate the constant C with which it is possible to determine and estimate M_w from the amplitude of the seismograms on the Locy seismometer.

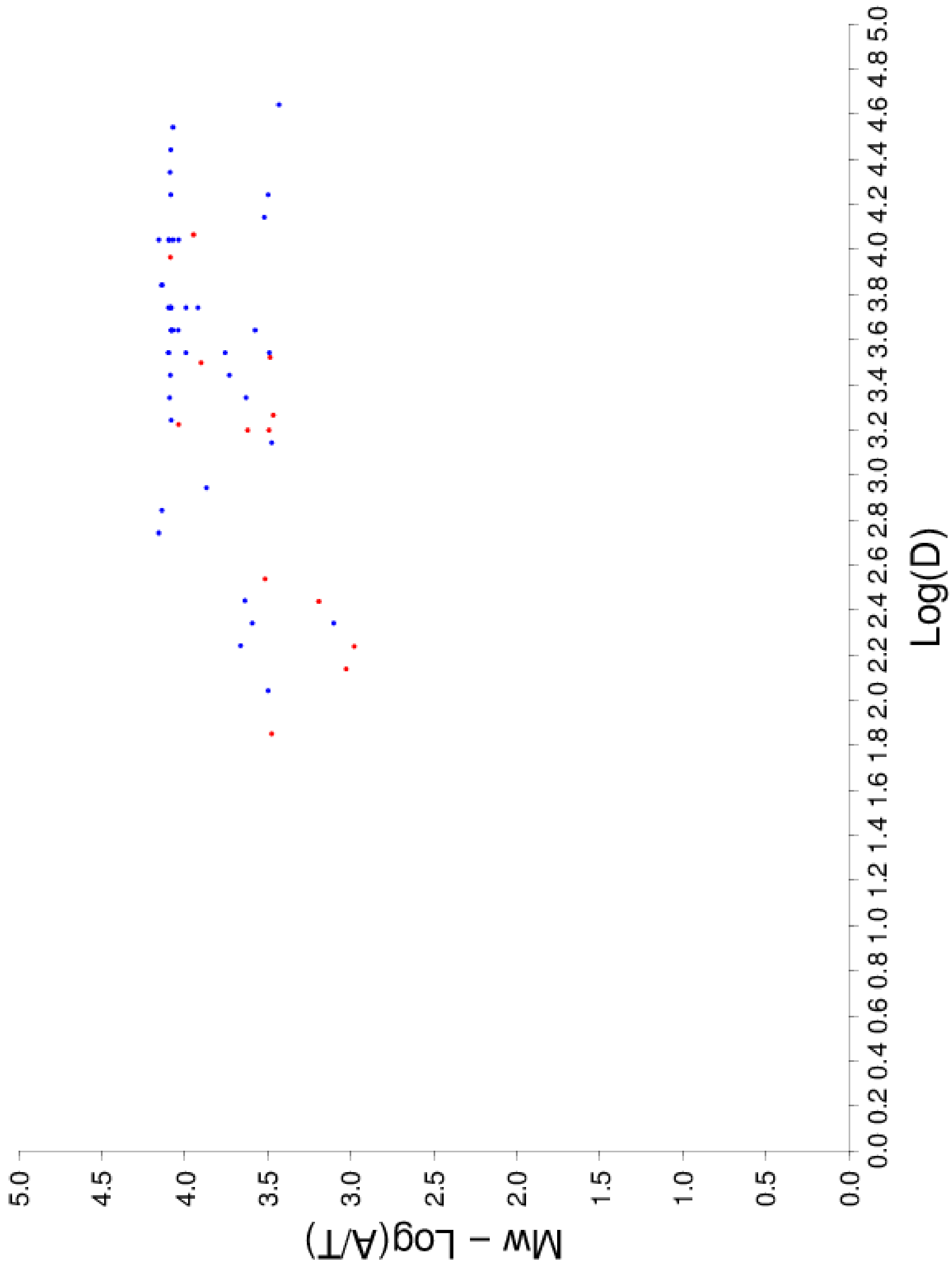

Figure 7: Plot of $log(C * A)$ versus $M_w - Q * log(D) + log(T)$ where the linear regression calculated from these data provided a means to calculate the constant C with which it is possible to determine and estimate M_w from the amplitude of the seismograms on the Locy seismometer.

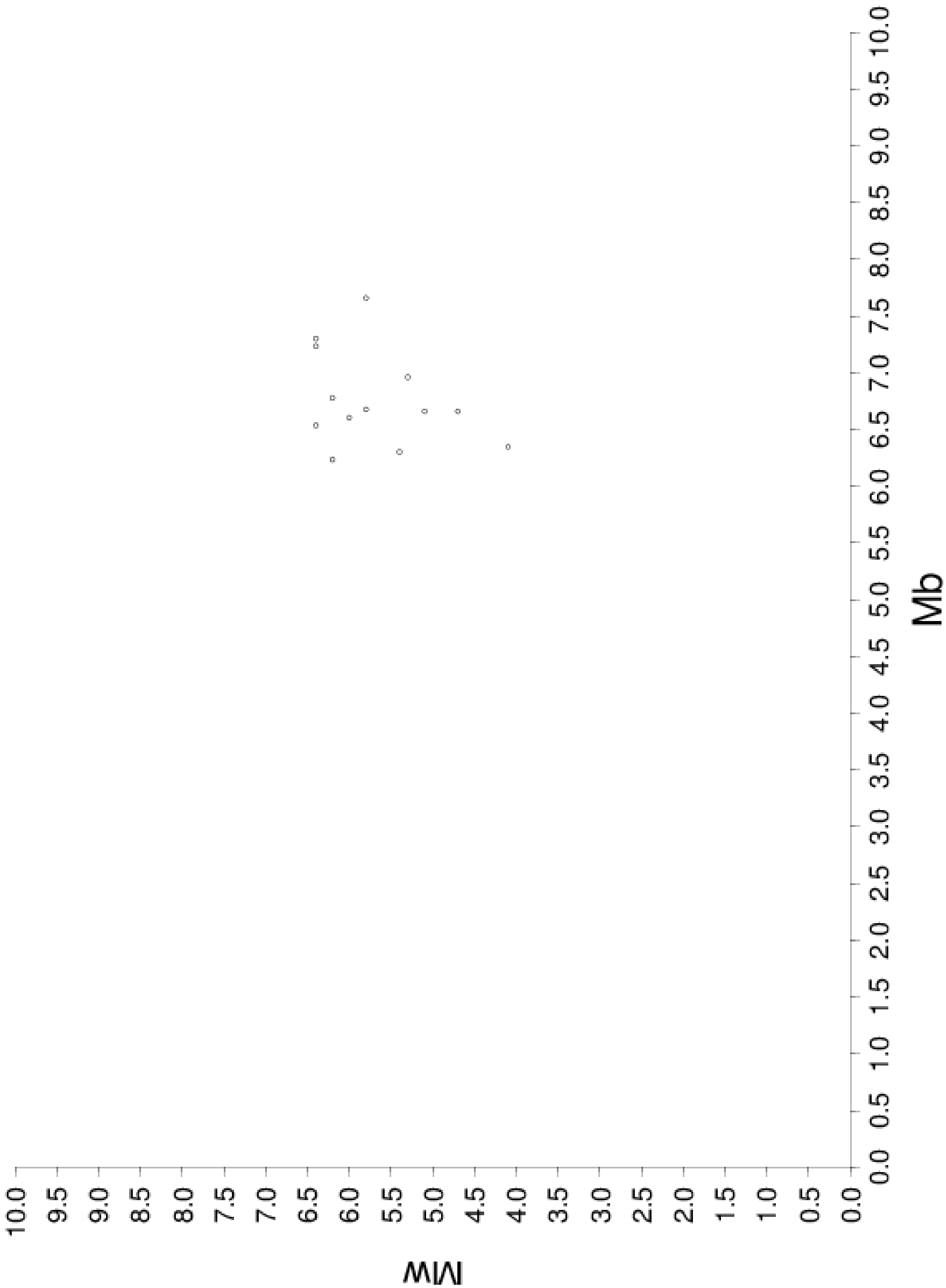

Figure 8: Plot of $log(C * A)$ versus $M_w - Q * log(D) + log(T)$ where the linear regression calculated from these data provided a means to calculate the constant C with which it is possible to determine and estimate M_w from the amplitude of the seismograms on the Locy seismometer.

The following are GMT scripts used to produce the above images

```
#!/bin/bash
# Script to Plot Minimum Magnitude Visible on the Locy Seismometer at a Given Distance

#Set Variables
  SCALE=18                           # make plot 15 cm across
  LONMIN=-180. ; LONMAX=0.         # Longitude range of plots
  LATMIN=-60.  ; LATMAX=60.          # Latitude range of plots
  LATLOCY=42.  ;LONGLOCY=-87.        #Latitude and Longitude of the Locy Seismometer

#Set ps file and remove if already exists
ps=minmag+.ps

rm $ps

#Plot map with coast, country, and state lines
pscoast -R$LONMIN/$LONMAX/$LATMIN/$LATMAX -JM$SCALE -P -B10a20WSen \
-Lf-20/-55/$LATMIN/1000k --LABEL_FONT_SIZE=10 -N2/a -N1/Thickest \
-Gtan -Slightblue -Bg20 -K > $ps

#Plot Locy on the map
psxy -: -R -JM$SCALE -P -O -K -G0 -W2 -St << END >> $ps
42.05 -87.67 0.25c
END

#Plot Distances from Locy for normal noise
psxy -: -R -JM$SCALE -P -O -K -W2 -Sc << END >> $ps
42.05 -87.67 1.49c
42.05 -87.67 5.97c
42.05 -87.67 23.9c
END

#Plot Distances from Locy for high noise
psxy -: -R -JM$SCALE -P -O -K -W2,red -Sc << END >> $ps
42.05 -87.67 0.75c
42.05 -87.67 3.02c
42.05 -87.67 12.1c
END

#Plot text stating the smallest magnitude visible on the Locy seismometer
pstext -: -R -JM$SCALE -P -N -O -K<< END >> $ps
42.05 -107 12 0 1 5 5Mw
42.05 -130 12 0 1 5 6Mw
-50 -160 12 0 1 5 7Mw
```

```
43 -87 12 0 1 5 Locy
END

#Plot text stating the smallest magnitude visible on the Locy seismometer
pstext -: -R -JM$SCALE -P -N -O -Wred<< END >> $ps
37 -92 12 0 1 5 5Mw
27 -92 12 0 1 5 6Mw
-20 -92 12 0 1 5 7Mw
END

#View output in GhostScript

gs $ps

exit 0
```

```
#!/bin/bash
# Practice Script to plot data

#Set Variables
  X_MAX=0 ; X_MIN=-15          # Maximum and Minimum X values
  Y_MAX=15; Y_MIN=0           # Maximum and Minimum Y values


ps=plot5.ps

rm $ps

/usr/lib/gmt/bin/psxy Plot5_Data.txt -R$X_MIN/$X_MAX/$Y_MIN/$Y_MAX -JX9.5i/7i \
-B1:"Mw-Q*log(D)+log(T)":/1:"log(C1*A)":WS -L -Sc.1 -K > $ps

gs $ps

exit 0
```