Fun With Travel Times

Earthquakes generate two kinds of motions, forward and back along the direction of travel, compressing and stretching the rock, much like sound waves in the air. These are compression waves. Quakes also start vibrations that are side to side, perpendicular to the direction they are traveling. These are called shear waves. As they travel through the earth, their paths are both bent and also reflected from interior layers at depths where the nature of the earth suddenly changes.

When these waves travel through the earth they are called body waves and when they reach your seismograph, they get named based on which layers they have been reflected from or passed through before they got there.

There are also surface waves, both up and down (Rayleigh waves) and side to side (Love Waves). They are slower and travel farther, so they generally arrive well after the body waves. Surface waves from distant quakes vibrate quite slowly, taking 10 to 30 seconds for each complete oscillation. At those low frequencies, the Raspberry Shake has little sensitivity, from 1/25 to 1/225 of what it has in the middle of its frequency response band, so it will only see surface waves from the largest quakes, such as the Dec., 2016 M7.8 quake in the Solomon Islands.

Body waves generally vibrate faster and can be in a frequency range that the Shake will see well. By observing the times that the various body phases arrive, relative to the time of the quake, it will usually be possible to identify them by name.

Figure 1 is a very complete graph of the various phases, showing their travel times vs distance. Many of those phases will rarely be seen by anyone, so Figure 2 is a condensed version which plots the phases that are most likely to be seen.

To use these curves to identify the phases in your seismometer trace, you need to know two things, the time after the quake that a particular wave arrived, and your distance from the quake. To simplify the computation, if you have Excel on your computer, you can use the Excel worksheet at:
http://bnordgren.org/seismo/GC_Distance.xls The first time you use the worksheet, you should enter your own latitude and longitude and then save it. Then, you should find the latitude and longitude and the time of the quake from the USGS, starting on http://earthquake.usgs.gov/earthquakes/

In the worksheet, enter that information along with the times of any phases you are trying to identify. The worksheet will compute your distance from the quake and the travel times of each phase. Then you can look at the travel time curves and get a good idea of which phases you might be seeing.

Figure 4, from IRIS plots actual data from many stations, a wave envelope stack, mapping the recorded intensity as plot darkness for various travel times, vs their distances from the quake. These plots can be found for each significant quake, with the Solomon Island quake being shown in the Event Plots section of http://ds.iris.edu/spud/event/9912119 When compared with the travel time curves, it is clear which phases are being recorded.

Figure 5 is an overlay of the travel time plot and the wave envelope stack, with the distance of my station shown by the vertical line at 123 degrees. From that, I can tell that I won't see the P wave since I am in its shadow zone. From my Swarm recording, the first thing I see is at 17:57:38, then something at 17:59:15, 18:07:35 and 18:11:02, with the surface wave starting up at around 18:40.

Using the travel time data from the spreadsheet in Figure 6 and using the travel time curves, I am guessing that I may be seeing first the PKP, then PP, S diffracted, PPS and finally the LR surface wave.

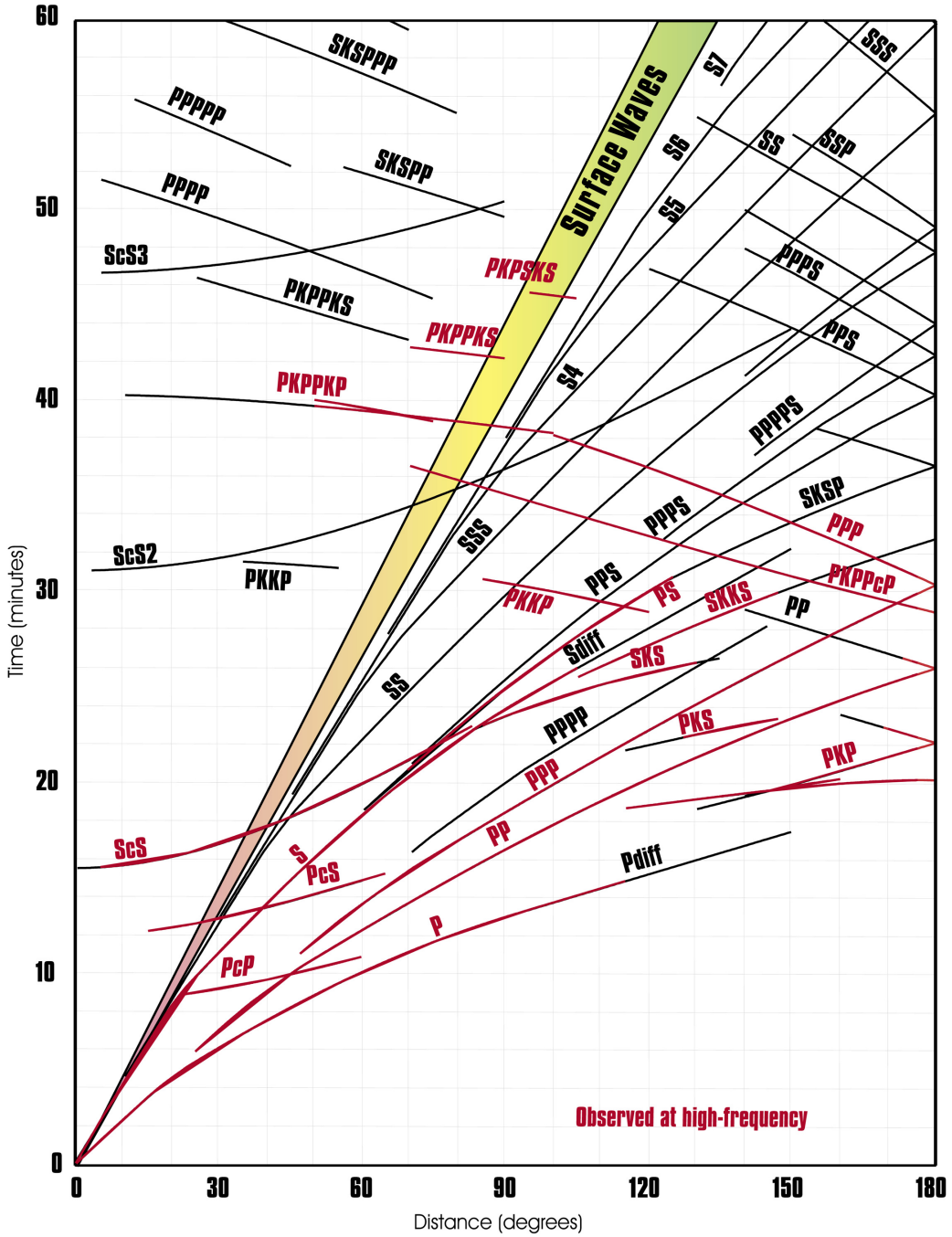

Figure 1 USGS Travel time curves
http://earthquake.usgs.gov/learn/topics/images/ttgraph.pdf

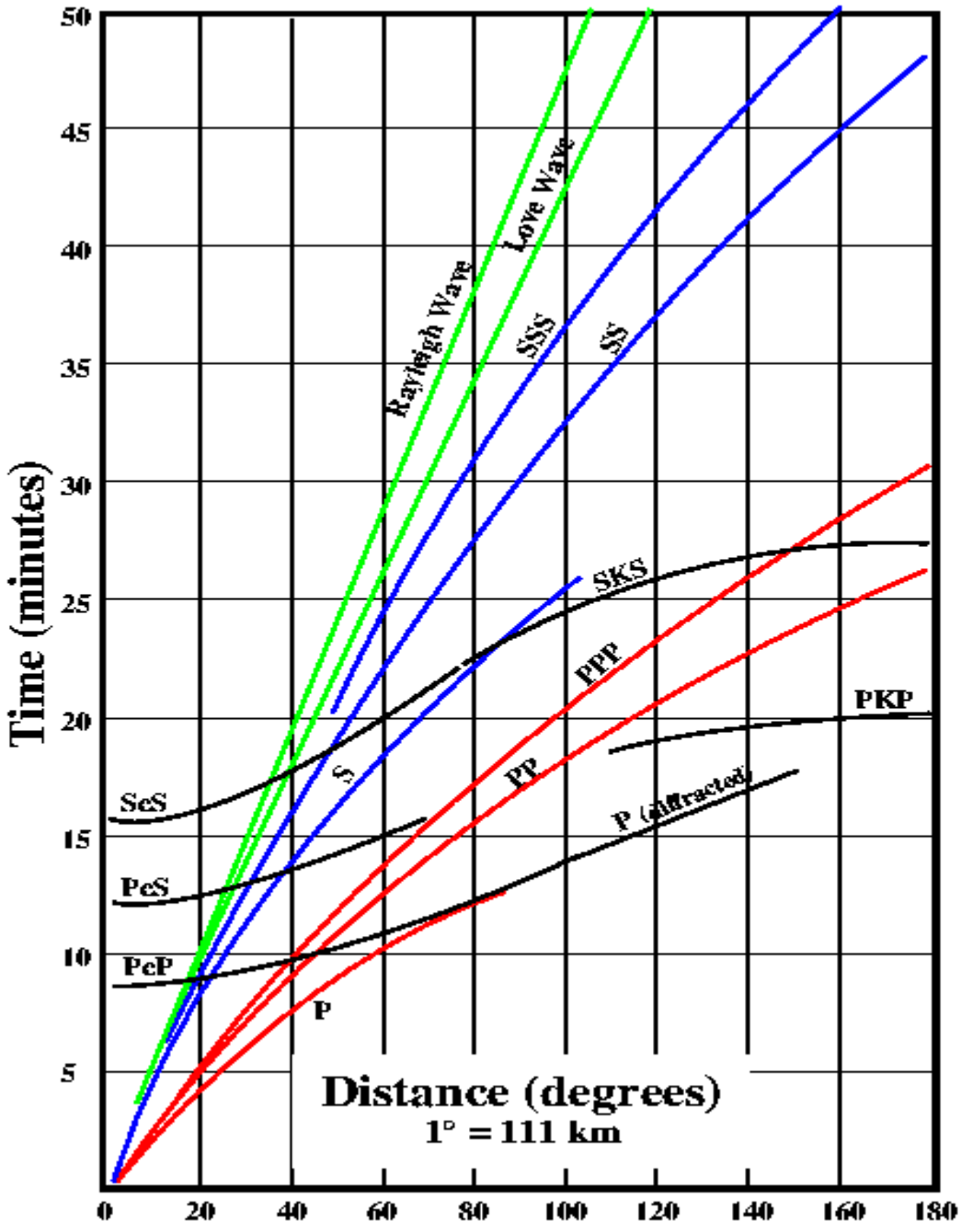

Figure 2 Simplified Travel time curves
http://www.geo.arizona.edu/saso/Earthquakes/Recent/ttc.gif

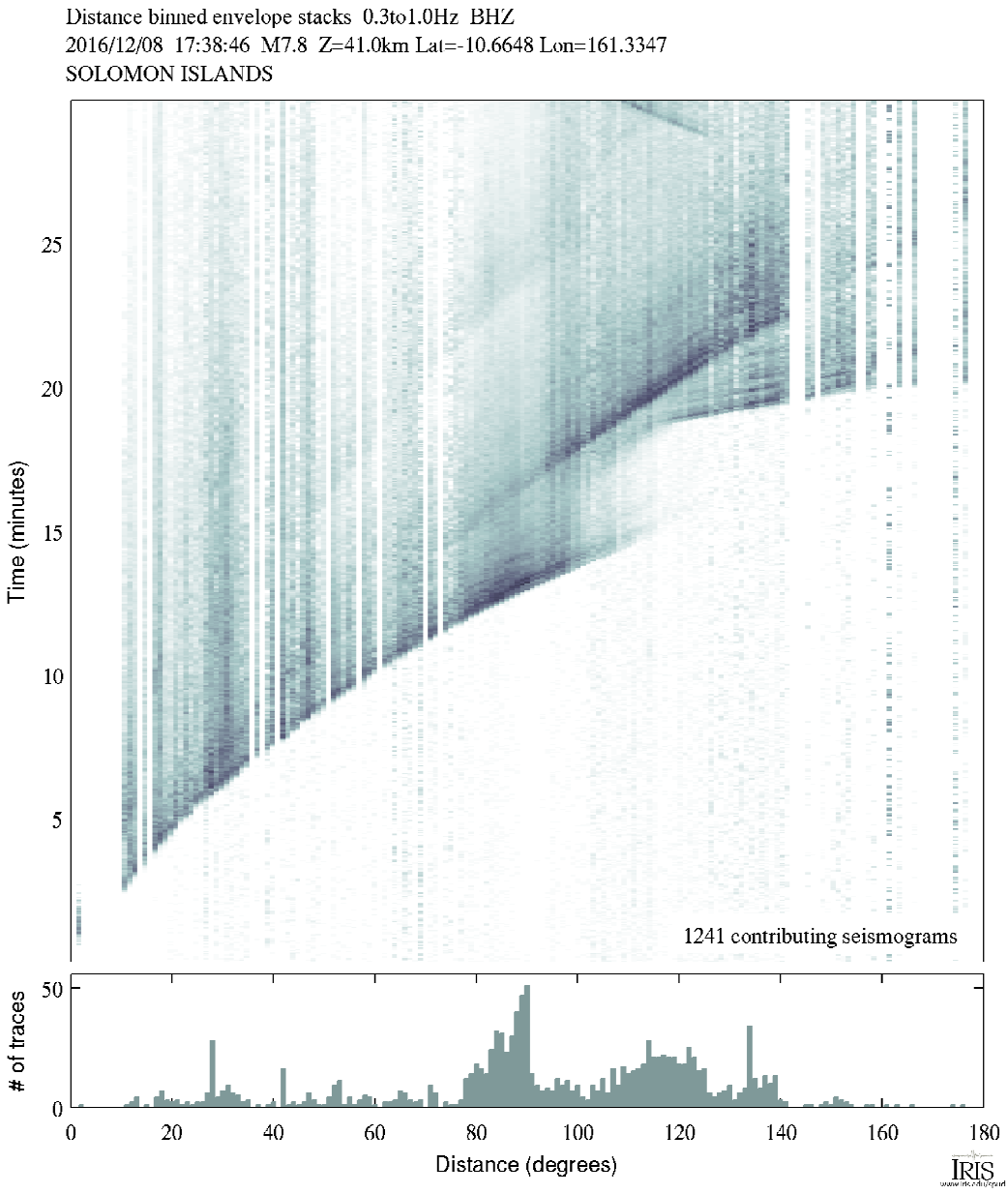

Figure 3 Wave envelope stack Travel time vs Distance
Dec 8, 2016 Solomon Islands M 7.8 Quake

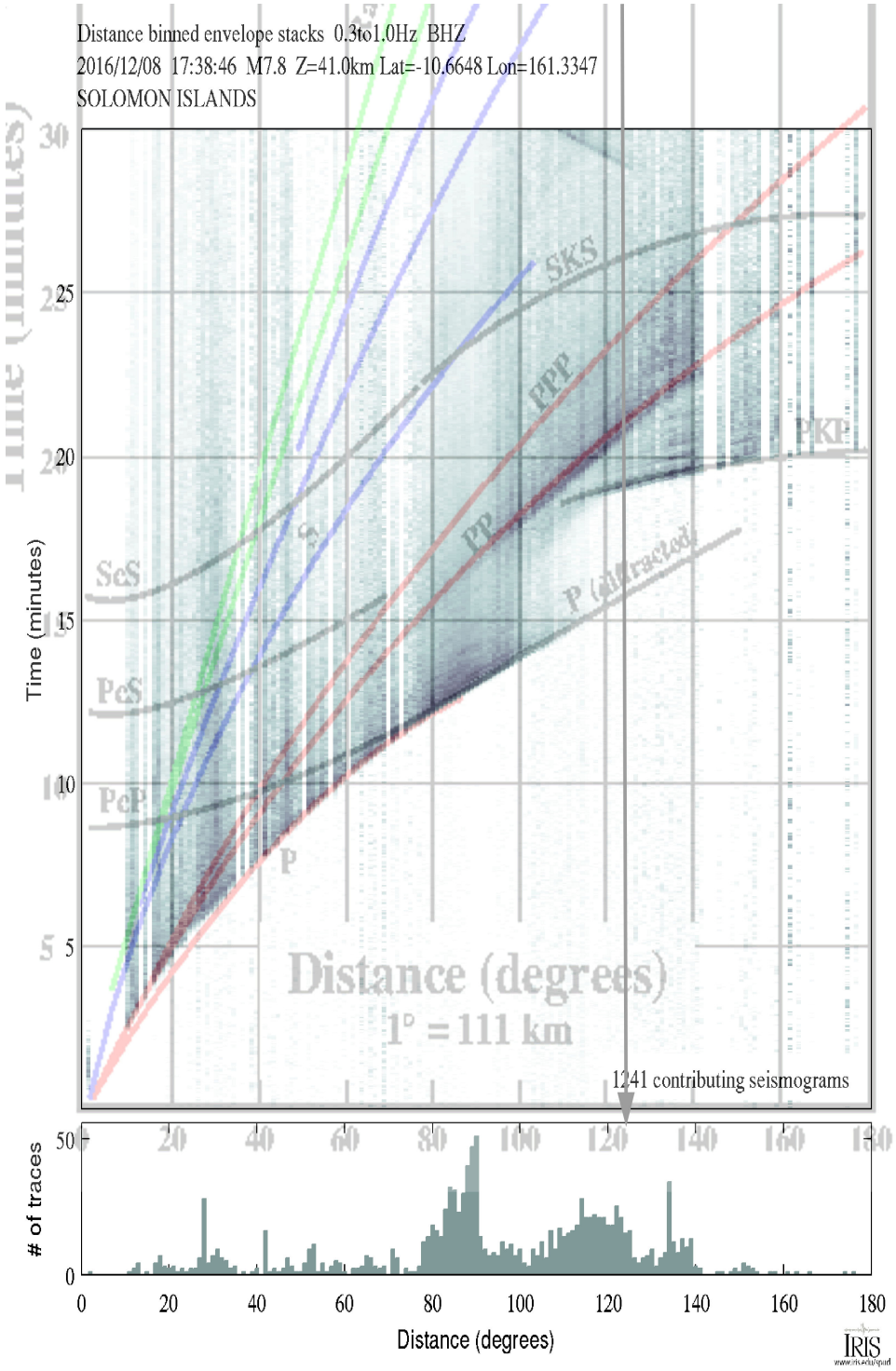

Figure 4 Envelope stack overlaid with Travel Time curves.
Vertical line at 123° is my location

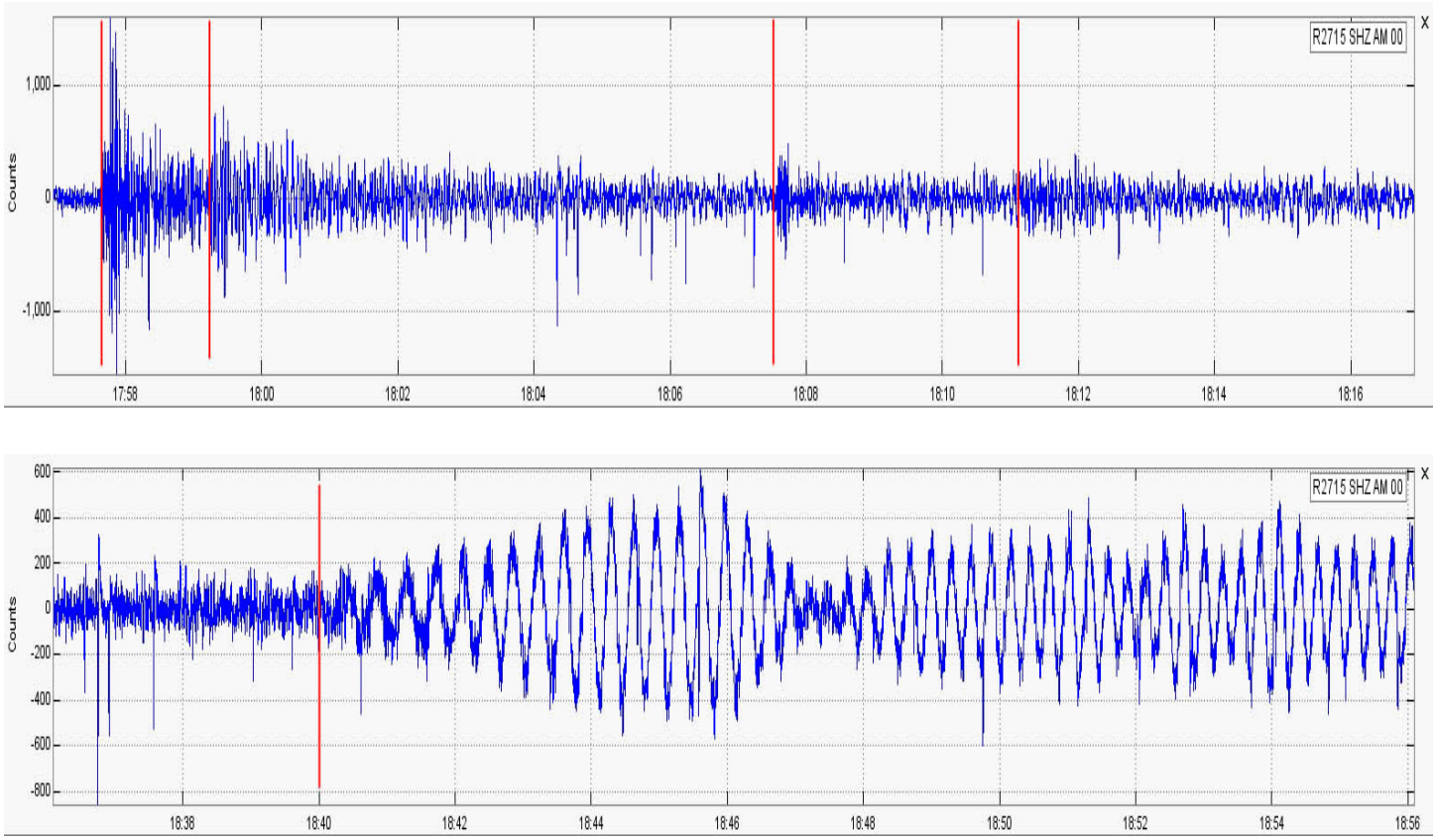

Figure 5 Phase picks used in the Excel worksheet

EQ Time UTC	17:38:46	Travel time minutes	Phase	
Arv. Time 1	17:57:38	18.87	PKP	
Arv. Time 2	17:59:14	20.47	PP	
Arv. Time 3	18:07:35	28.82	Sdiff	
Arv. Time 4	18:11:02	32.27	PPS	
Arv. Time 5	18:40:00	61.23	LR	

Figure 6 Excel worksheet results