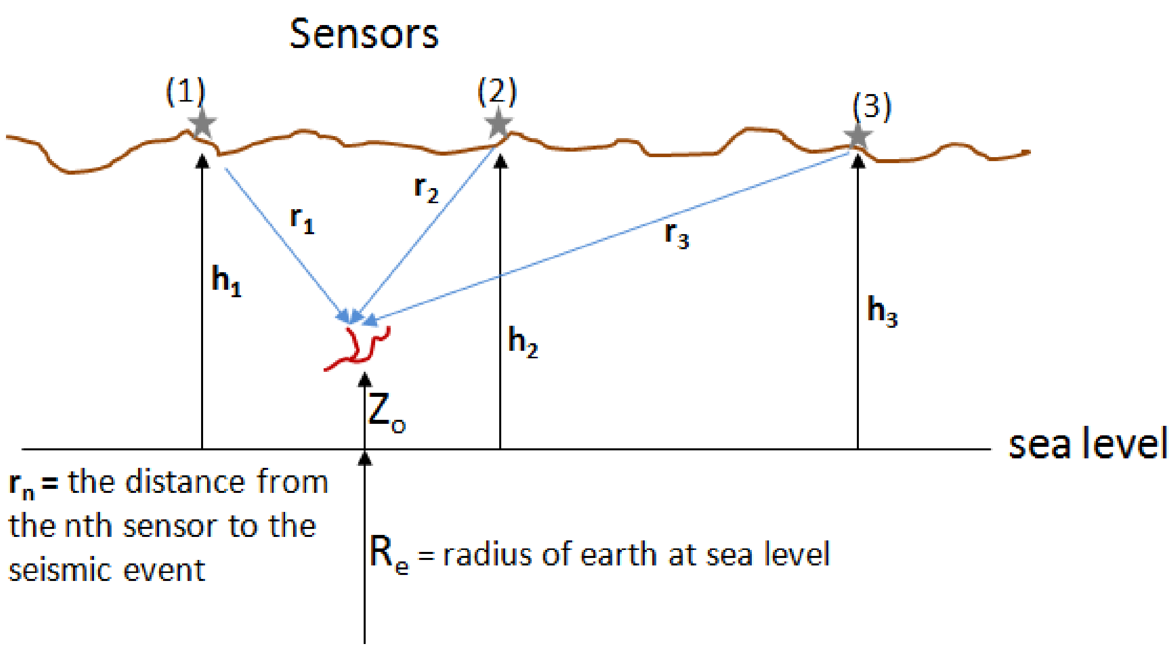
LoQuake Java Applet

by John R. Victorine

Introduction

The LoQuake web app was designed to implement the equations that will predict the location of shallow seismic events below a 15-sensor array, located around the Wellington KGS 2-32 Mississippian Injection Well[1]. The analysis is designed to predict the location of any seismic event using three sensors to triangulate the position of the event. The solution to predicting the location of the seismic event is to translate from an earth coordinate system to a shallow event coordinate system, using simple algebraic equations and trigonometry to create a series of equations that will give the location of the seismic event as latitude, longitude, and depth with respect to the elevation of the sensors.

Using our sensor array, it should be possible to predict the depth of the seismic event using simple algebraic equations from three seismic sensors around and above the seismic event. The algebraic equations are three equations of a sphere, which theoretically can be reduced to give you latitude, longitude and depth of the seismic event.

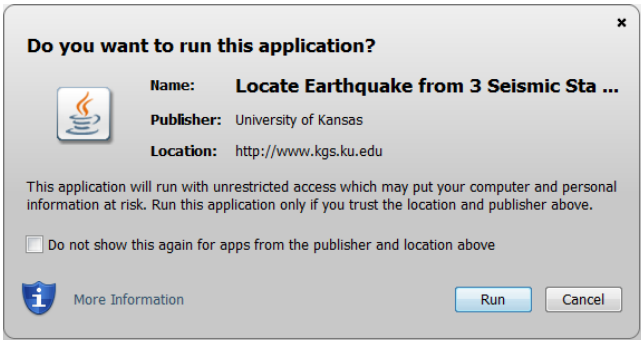


Reference: (1) **Computing the Location of a Shallow Seismic Event** by John R. Victorine, KGS Open File Report 2015-18, July 2015
http://www.kgs.ku.edu/Publications/OFR/2015/OFR15_18/index.html

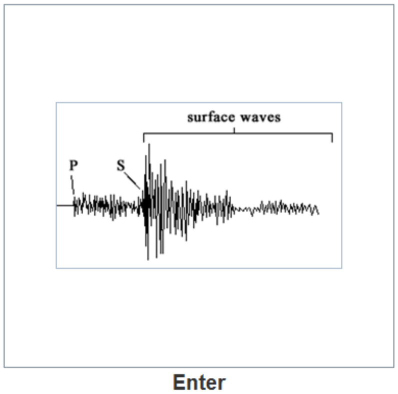
This web app requires a Velocity model the predicts the average shear and compression wave velocities. A Comma Separated Values (CSV) File was created to represent the subsurface Average Vs & Vp Velocity model. This file was created from the PSWave web app using Litho-density and Seismic Well Log Data from the Wellington KGS 1-28. Download the file at:

http://www.kgs.ku.edu/PRS/Ozark/Software/LoQuake/PSWave-Wellington_KGS-1-28.zip

To access Profile go to **http://www.kgs.ku.edu/PRS/Ozark/Software/LoQuake/index.html**. At the top of the web page there is a menu "Main Page|Description|Applet|Help|Copyright & Disclaimer|". Select the "Applet" menu option a "Warning - Security" Dialog will appear.



The program has to be able to read and write to the user's PC and access the Kansas Geological Survey (KGS) Database and File Server. The program does not save your files to KGS, but allows you to access the KGS for well information that may be missing in your Kansas logs. The program does **NOT** use Cookies or any hidden software it only reads the CSV files for the LoQuake Session and writes a CSV or SQL script file to your PC to save data. The blue shield on the warning dialog is a symbol that the Java web app is created by a trusted source, which is the University of Kansas. Select the "Run" Button, which will show the LoQuake "Enter" Panel illustrated below,



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Enter Seismic Information Frame

Click on the LoQuake Seismic Image Icon Button in the "Enter" Panel to display the “Enter Seismic Information” Frame. This frame allows the user to compute the location of seismic events under the 15 sensor array in the Wellington Field, which will monitor the Injection of CO_2 in the Mississippian Formation in the Wellington KGS 2-32 well.

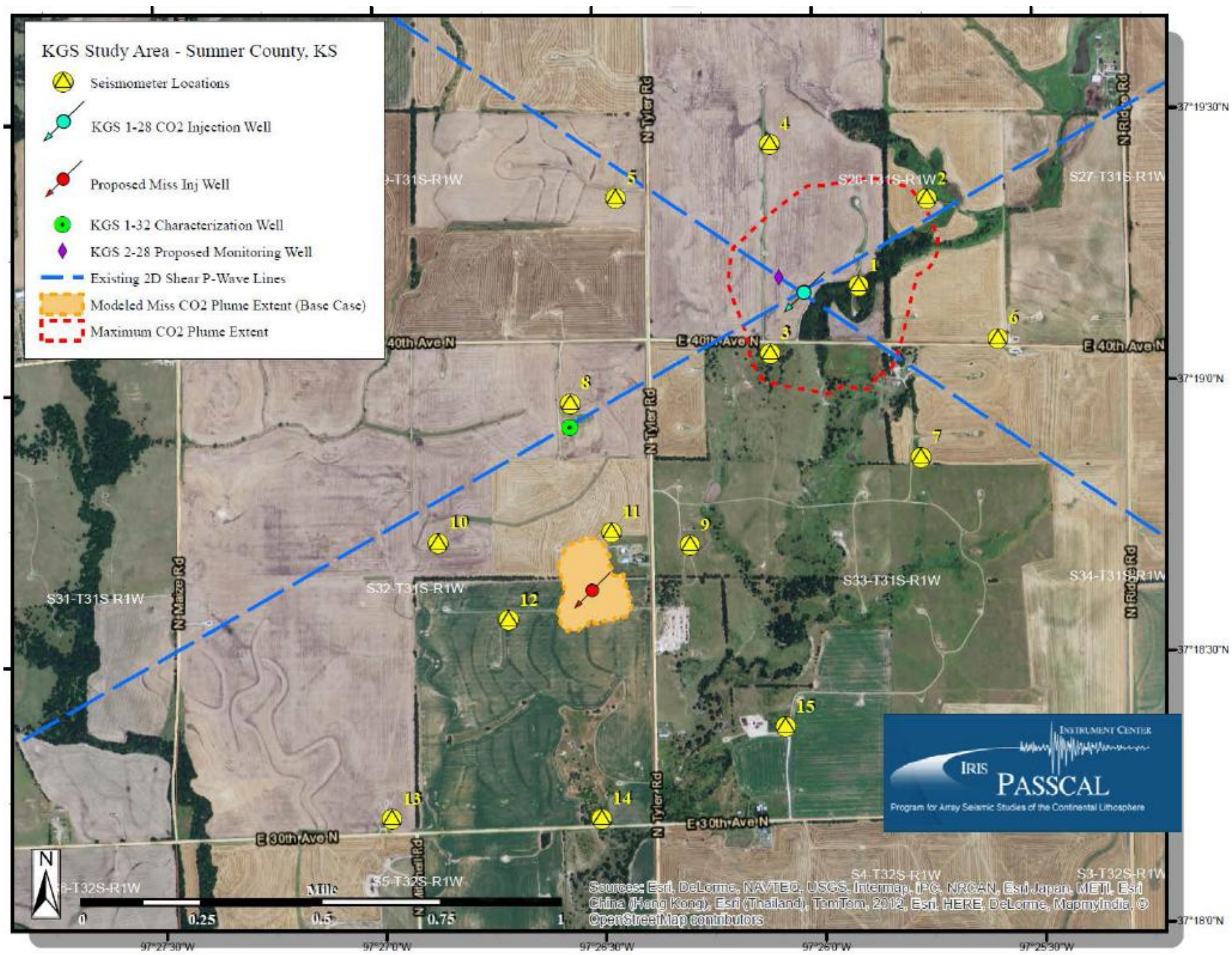


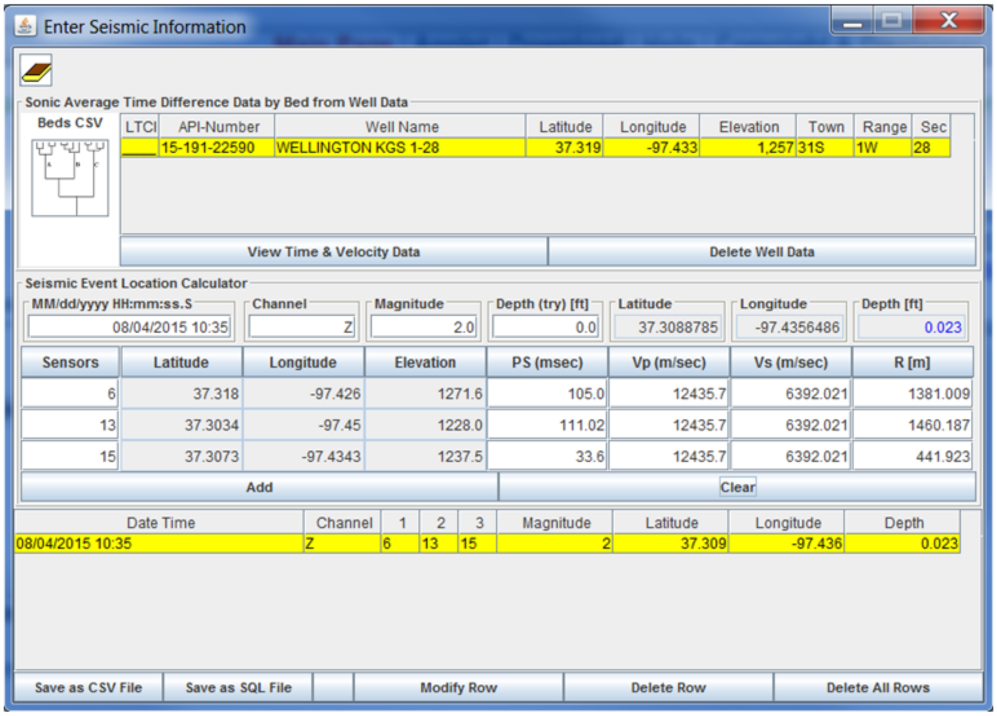
Image take from “Small scale field test demonstrating CO2 sequestration in Arbuckle saline aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas”, presentation given at DOE Carbon Storage R&D Project Review Meeting, August 21-23, 2012 by W. Lynn Watney & Jason Rush (Joint PIs).

The program is designed around these 15 sensors and assumes that the seismic events of interest will be in subsurface below and within the sensor array. The Latitude and Longitude and Elevation of the 15 sensors are fixed and the user is inputting either SP time differences in milliseconds or distances from each sensor to the event in meters in order to predict the location of the event. The accuracy of position of the event is very dependent on the velocity model as well as determining the SP time difference of the event from each sensor. The challenge will be distinguishing low magnitude events from background, since the sensor arrays are set up in an active well producing area, i.e. pump jacks, trucks traveling on the roads, etc.

Velocity Model
Vs & Vp Velocity Model PSWave Comma Separated Values (CSV) File using the Wellington KGS 1-28 Well Log Data.

Calculator
Seismic Event Calculator computes the Latitude, Longitude and Depth (Elevation) of the Seismic Event below the 15 seismic array.

Computed Events
List of computed seismic events location to be saved either as Comma Separated Values (CSV) or as a SQL Script for insert into ORACLE Database.



The "Enter Seismic Information" Frame has 3 sections,

(1) The Velocity model for the Compression & Shear Wave. This model is first created in the PSWave web applet which can be found in the PS Wave Web App Web Site; **http://www.kgs.ku.edu/PRS/Ozark/Software/PSWave/index.html**. The PS Wave Web App will import Log data, Zonation Web App Output Comma Separated Values (CSV) File, Tops and Geologist Cuttings Report/Core Description and compute the average compression and shear wave velocities and times by "Beds". This program then allows the user to save this data as a Comma Separated Values (CSV) File that can be imported into the LoQuake Web App.

(2) The Calculator. This section allows the user to enter the number of sensor 1 through 15 in the "Sensors" Column and the program will automatically insert the location of the sensor. The Average Vp and Vs velocities are inserted for each sensor using the "Depth (try) [ft]" text field. This section assumes that the event falls below and within the 3 selected sensors to compute the location of the event.

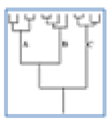
(3) The Computed Events. This section allows the user to save successful computed event locations in either a Comma Separated Values (CSV) File for future reference or as a SQL script to insert into the Seismic Events Database Table in the KGS Database. This data will be accessed by other Java Web Apps to visualize the events within a 3D plot.

Import Velocity Model PSWave Comma Separated Values (CSV) File

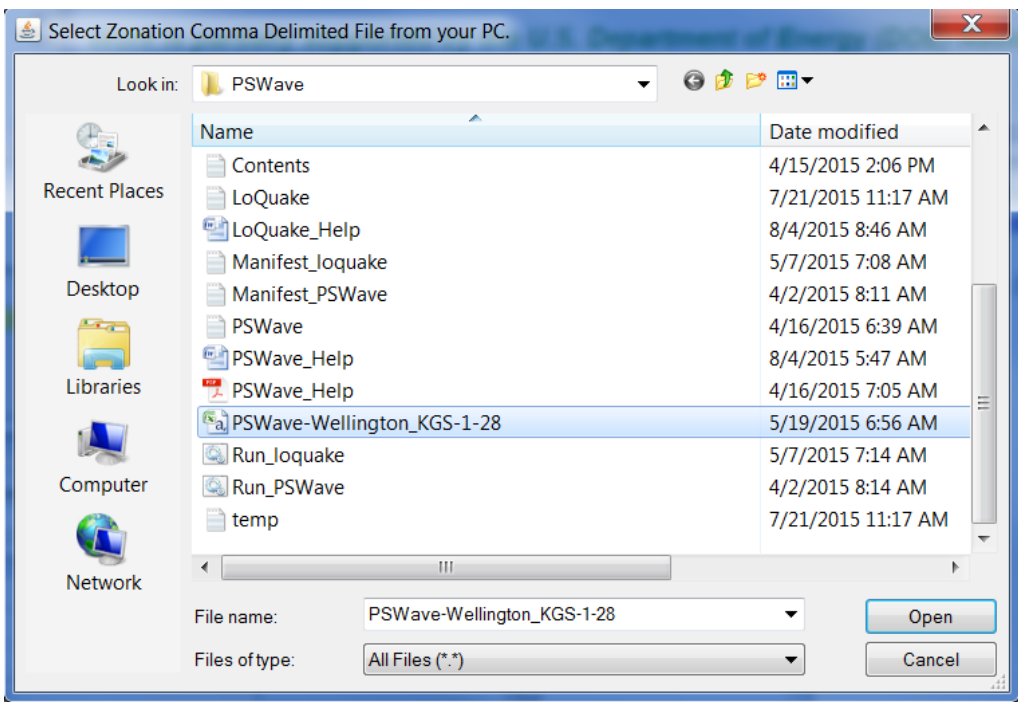
Download the PSWave Wellington KGS 1-28 Zip file containing the Comma Separated Values (CSV) File from the following URL,

http://www.kgs.ku.edu/PRS/Ozark/Software/LoQuake/PSWave-Wellington_KGS-1-28.zip

Save the file anywhere on your PC. Unzip the File so the CSV File can be imported into the LoQuake Program. Click on the Beds CSV Icon Image Button



which will display the "Select Zonation Comma Delimited File From your PC" Frame. Select the "PSWave-Wellington_KGS-1-28.csv" file and select the "Open" button,

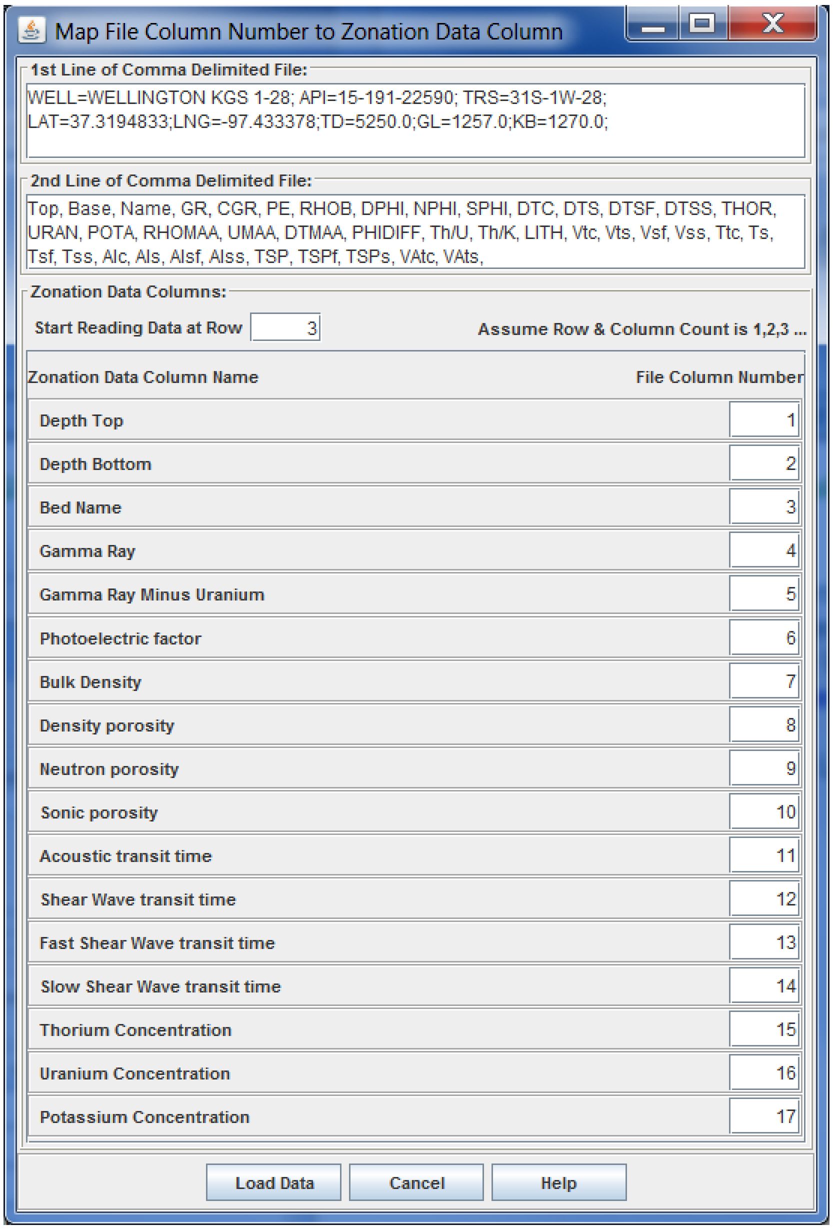


This will display the "Map File Column Number to Zonation Data Column" Dialog, which allows the user to map selected curves in the CSV file to "Zonation Data Column Name" The PS Wave web app creates a mnemonics line to help the program automatically identify what type of curve it is. Like the PS Wave web app requires both the Acoustic Transit Time (DTc) and Shear (DTs) log curves to work or the Acoustic Transit Time (DTc) and Litho- Density Logs, i.e. Gamma Ray (GR), Neutron Porosity (NPHI) and Density Porosity (NPHI) computed in a Limestone Matrix or Bulk Density (RHOB) as a minimum from which the Shear (DTs) log curve can be computed from defined Velocity Ratio (Vp/Vs) for specific lithologies, i.e.

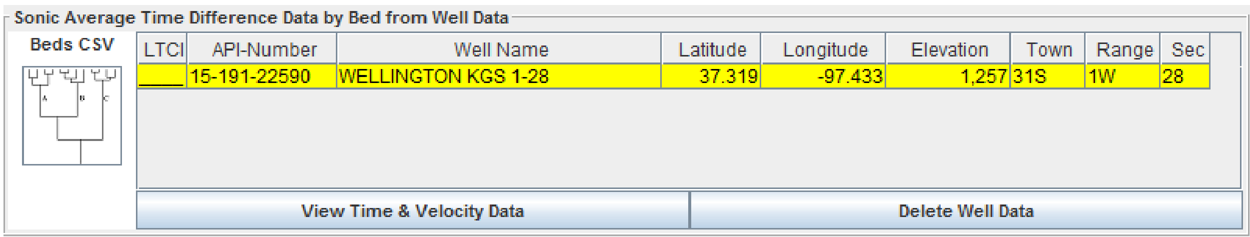
Vp/Vs	Lithology
1.55	Very Clean Sandstone
1.6	Clean Sandstone
1.68	Shaly Sandstone
1.7	Compact Shale
1.9	Limestone
1.8	Dolomite
1.75	Salt
1.85	Anhydrite
1.59	Coal

Pickett (1963)

The “Map File Column Number to Zonation Data Column” Frame will read the PS Wave Comma Separated Values (CSV) file showing the available data columns mapped to the

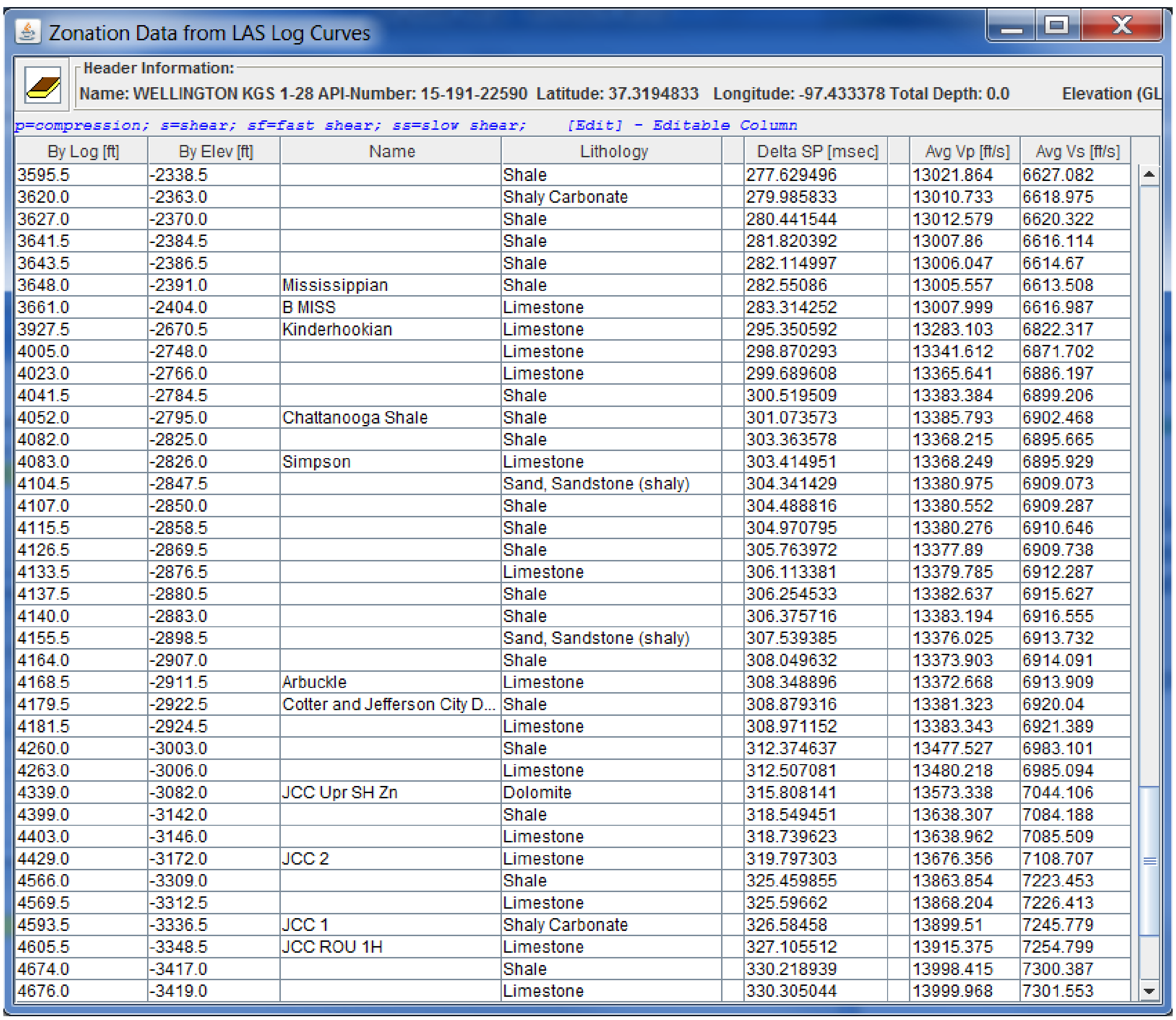


"Zonation Data Column Name". The 1st and 2nd line of the CSV file is displayed, where the second line is the mnemonics variable list used to automatically map the data columns. Since this program was created by the PS Wave web app the necessary columns should all be mapped correctly, the user only needs to select the "Load Data" button to import the contents of the CSV file into the LoQuake web app and compute the average times and velocities for the shear and compression waves by "bed".



LTCI	API-Number	Well Name	Latitude	Longitude	Elevation	Town	Range	Sec
	15-191-22590	WELLINGTON KGS 1-28	37.319	-97.433	1,257	31S	1W	28

To view the file click on the "View Time & Velocity Data" button in the "Sonic Average Time Difference Data by Bed from Well Data" Panel, this will display the "Zonation Data from LAS



By Log [ft]	By Elev [ft]	Name	Lithology	Delta SP [msec]	Avg Vp [ft/s]	Avg Vs [ft/s]
3595.5	-2338.5		Shale	277.629496	13021.864	6627.082
3620.0	-2363.0		Shaly Carbonate	279.985833	13010.733	6618.975
3627.0	-2370.0		Shale	280.441544	13012.579	6620.322
3641.5	-2384.5		Shale	281.820392	13007.86	6616.114
3643.5	-2386.5		Shale	282.114997	13006.047	6614.67
3648.0	-2391.0	Mississippian	Shale	282.55086	13005.557	6613.508
3661.0	-2404.0	B MISS	Limestone	283.314252	13007.999	6616.987
3927.5	-2670.5	Kinderhookian	Limestone	295.350592	13283.103	6822.317
4005.0	-2748.0		Limestone	298.870293	13341.612	6871.702
4023.0	-2766.0		Limestone	299.689608	13365.641	6886.197
4041.5	-2784.5		Shale	300.519509	13383.384	6899.206
4052.0	-2795.0	Chattanooga Shale	Shale	301.073573	13385.793	6902.468
4082.0	-2825.0		Shale	303.363578	13368.215	6895.665
4083.0	-2826.0	Simpson	Limestone	303.414951	13368.249	6895.929
4104.5	-2847.5		Sand, Sandstone (shaly)	304.341429	13380.975	6909.073
4107.0	-2850.0		Shale	304.488816	13380.552	6909.287
4115.5	-2858.5		Shale	304.970795	13380.276	6910.646
4126.5	-2869.5		Shale	305.763972	13377.89	6909.738
4133.5	-2876.5		Limestone	306.113381	13379.785	6912.287
4137.5	-2880.5		Shale	306.254533	13382.637	6915.627
4140.0	-2883.0		Shale	306.375716	13383.194	6916.555
4155.5	-2898.5		Sand, Sandstone (shaly)	307.539385	13376.025	6913.732
4164.0	-2907.0		Shale	308.049632	13373.903	6914.091
4168.5	-2911.5	Arbuckle	Limestone	308.348896	13372.668	6913.909
4179.5	-2922.5	Cotter and Jefferson City D...	Shale	308.879316	13381.323	6920.04
4181.5	-2924.5		Limestone	308.971152	13383.343	6921.389
4260.0	-3003.0		Shale	312.374637	13477.527	6983.101
4263.0	-3006.0		Limestone	312.507081	13480.218	6985.094
4339.0	-3082.0	JCC Upr SH Zn	Dolomite	315.808141	13573.338	7044.106
4399.0	-3142.0		Shale	318.549451	13638.307	7084.188
4403.0	-3146.0		Limestone	318.739623	13638.962	7085.509
4429.0	-3172.0	JCC 2	Limestone	319.797303	13676.356	7108.707
4566.0	-3309.0		Shale	325.459855	13863.854	7223.453
4569.5	-3312.5		Limestone	325.59662	13868.204	7226.413
4593.5	-3336.5	JCC 1	Shaly Carbonate	326.58458	13899.51	7245.779
4605.5	-3348.5	JCC ROU 1H	Limestone	327.105512	13915.375	7254.799
4674.0	-3417.0		Shale	330.218939	13998.415	7300.387
4676.0	-3419.0		Limestone	330.305044	13999.968	7301.553

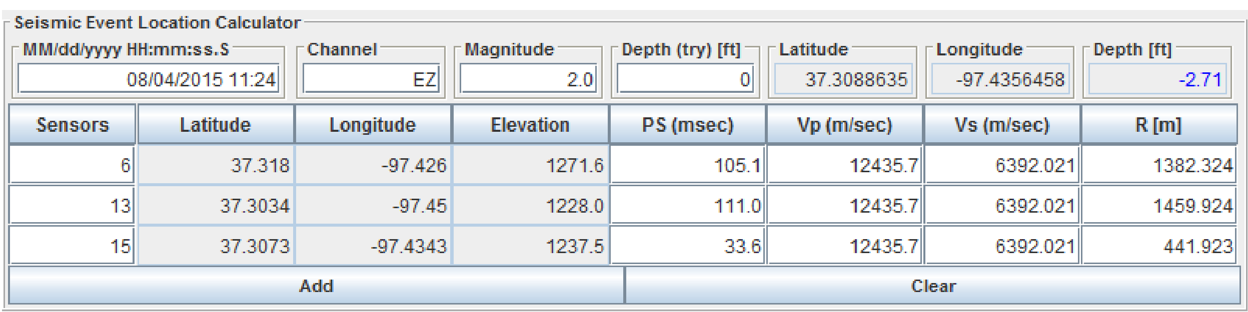
Log Curves" Table Frame. This frame is a lookup that will assist the user to select an elevation depth as a first guess to load the Vs and Vp at that depth into the calculator section of the "Enter Seismic Information" Frame, i.e. the Mississippian is at -2391.0 feet below sea level of elevation. This value can be entered into the "Depth (try) [ft]" assuming the seismic events will come from this depth during the Injection of CO_2.

Seismic Event Location Calculator

This example assumes an event has occurred at a 0.0 sea level elevation at latitude 37.309547 and longitude -97.4367. Three sensors will be used to compute the location of the event, i.e. sensor numbers 6, 13 and 15. The Shear (s) and Compress (p) wave time difference in milliseconds are listed as follows,

Sensor Number	PS Wave Time Difference [msec]
6	105.00
13	111.02
15	33.60

Enter the Sensor Number in the "Sensor" Column, which will automatically file the "Latitude", "Longitude" and "Elevation" Columns. Insert the respective PS Wave Time Difference [msec] values in the "PS (msec)" Column, which will automatically load the "Vp (m/sec) " and the "Vs (m/sec)" Columns using the "Depth (try) [ft]" text field value as the depth to retrieve the velocities from the Velocity Model data set. As each field is filled the "R [m]" Column is computed. When all the "R [m]" Column data is filled the web app will automatically compute



Seismic Event Location Calculator

MM/dd/yyyy HH:mm:ss.S	Channel	Magnitude	Depth (try) [ft]	Latitude	Longitude	Depth [ft]
08/04/2015 11:24	EZ	2.0	0	37.3088635	-97.4356458	-2.71

Sensors	Latitude	Longitude	Elevation	PS (msec)	Vp (m/sec)	Vs (m/sec)	R [m]
6	37.318	-97.426	1271.6	105.1	12435.7	6392.021	1382.324
13	37.3034	-97.45	1228.0	111.0	12435.7	6392.021	1459.924
15	37.3073	-97.4343	1237.5	33.6	12435.7	6392.021	441.923

Add | Clear

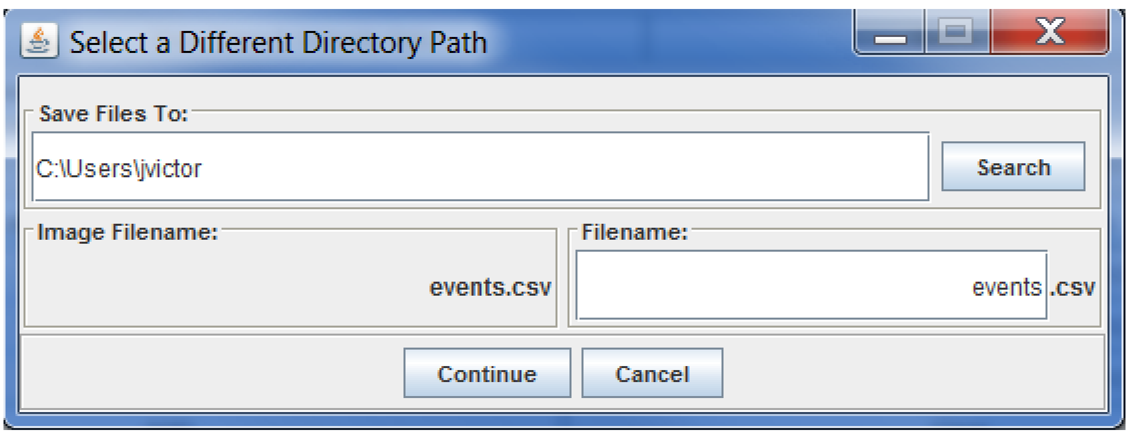
the latitude, longitude and depth of the event. If the computation is computed, i.e. the 3 PS wave time difference can compute a point, then the elevation depth will be entered in the "Depth [ft]" text field in a blue color, if not the value in the text field will be red and have the same value as the first row sensor's elevation value. The "Latitude" and "Longitude" values will also be inserted. In this example the computed latitude is 37.3088635, longitude is -97.4356458 and the elevation depth is -2.71 feet. The example event values we were looking for was latitude 37.309547 and longitude -97.4367 and an elevation depth of 0.0 feet.

Saving the results

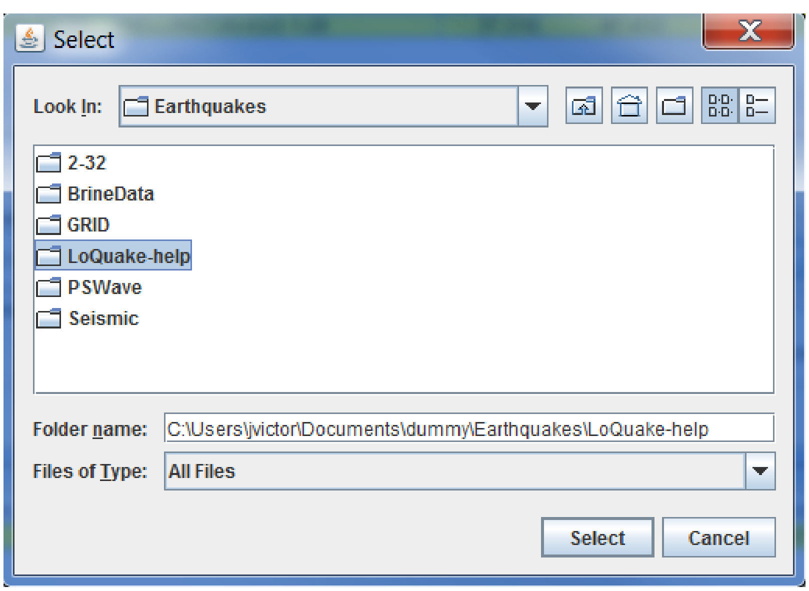
If this above example was a real event and you wanted to save the data, click on the “Add” button in the “Seismic Event Location Calculator” Panel, which will be displayed in the Computed Events Panel. This program was basically designed to compute the seismic events and save the input data as well as the calculated seismic event location in the CO2 Seismic Events Database Table. The user can also save the data to a Comma Separated Values (CSV) file for future reference.

- **Comma Separated Values (CSV) File**

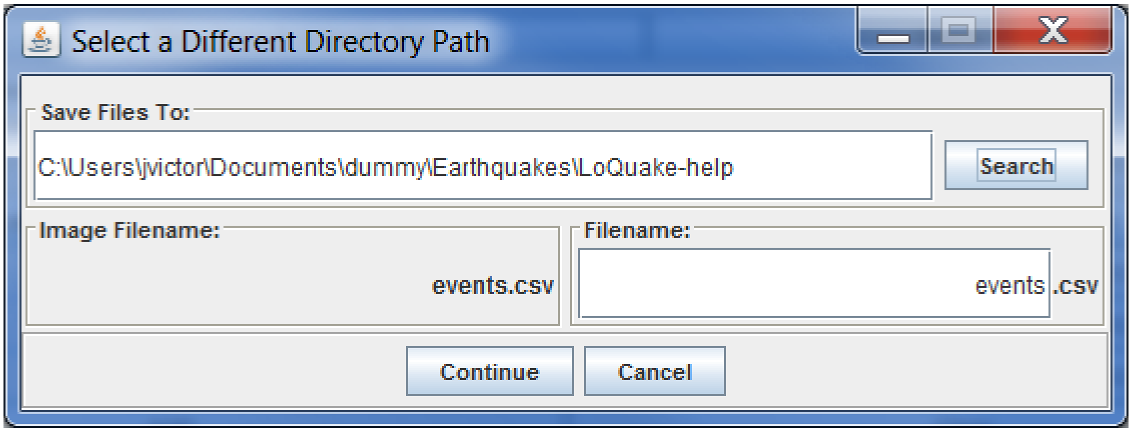
Click on the “Save as CSV File” Button at the bottom of the “Enter Seismic Information” Frame, white will display the “Select a Different Directory Path” Dialog. This dialog allows the user to select the directory & filename of the CSV file that will be saved on the user’s PC.



Click on the “Search” button to display the “Select” Directory frame. This dialog allows the user to search their PC for the correct directory path.



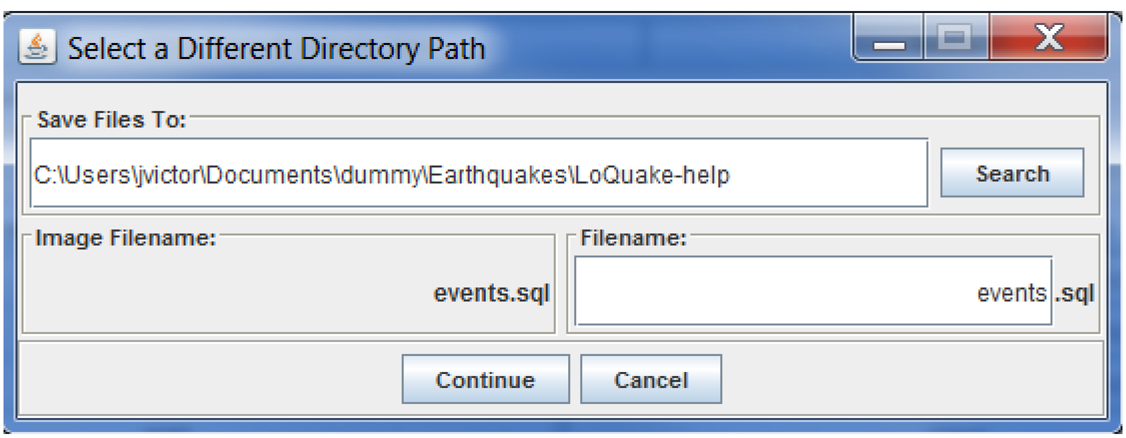
Once the user identifies the path then click on the “Select” button to transfer the directory path to the “Select a Different Directory Path” Dialog and automatically enter the path in the “Save Files To” text field.



The “Filename” holds the default filename, i.e. events.csv. The user can change the name to any name they wish. Click on the “Continue” button to save the CSV file.

- **ORACLE SQL script File**

Click on the “Save as SQL File” button at the bottom of the “Enter Seismic Information” Frame, white will display the “Select a Different Directory Path” Dialog. This dialog allows the user to select the directory & filename of the CSV file that will be saved on the user’s PC. The same steps are done for the SQL as the CSV. Once the user identifies the path then click on the “Select” button to transfer the directory path to the “Select a Different Directory Path” Dialog and automatically enter the path in the “Save Files To” text field.



The “Filename” holds the default filename, i.e. events.sql. The user can change the name to any name they wish. Click on the “Continue” button to save the SQL script file.

```
INSERT INTO co2_event_location
 ( KID, event_time, event_magnitude,
   nad27_latitude, nad27_longitude, depth, depth_units)
 VALUES
 (1045059088, TO_DATE('08/04/2015 10:35', 'MM/DD/YYYY HH24:MI'), 2.0,
  37.3088785, -97.4356486, 0.023, 'ft');
COMMIT;

INSERT INTO co2_sensor_raw
 ( KID, sensor_KID,
   channel,
   event_time,
   event_magnitude,
   sensor_order,
   sp_time_diff, sp_time_units,
   Vp, Vs, velocity_units,
   distance, distance_units
 ) VALUES
 (1045059089, 1045035827, 'Z',
  TO_DATE('08/04/2015 10:35', 'MM/DD/YYYY HH24:MI'),
  2.0, 0, 105.0, 'msec', 12435.7, 6392.021, 'm/sec', 1381.009, 'm' );
COMMIT;

INSERT INTO co2_sensor_raw
 ( KID, sensor_KID,
   channel,
   event_time,
   event_magnitude,
   sensor_order,
   sp_time_diff, sp_time_units,
   Vp, Vs, velocity_units,
   distance, distance_units
 ) VALUES
 (1045059090, 1045035834, 'Z',
  TO_DATE('08/04/2015 10:35', 'MM/DD/YYYY HH24:MI'),
  2.0, 1, 111.02, 'msec', 12435.7, 6392.021, 'm/sec', 1460.187, 'm' );
COMMIT;

INSERT INTO co2_sensor_raw
 ( KID, sensor_KID, channel,
   event_time,
   event_magnitude,
   sensor_order,
   sp_time_diff, sp_time_units,
   Vp, Vs, velocity_units,
   distance, distance_units
 ) VALUES
 (1045059091, 1045035836, 'Z',
  TO_DATE('08/04/2015 10:35', 'MM/DD/YYYY HH24:MI'),
  2.0, 2, 33.6, 'msec', 12435.7, 6392.021, 'm/sec', 441.923, 'm' );
COMMIT;
```

There are 4 INSERT statements the first one is the location of the seismic event. The last three are the raw data for calculating the seismic event for reference.