Annual Project Summary
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Calculation and validation of a probabilistic seismic hazard assessment for the urban area of Evansville incorporating site effects

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Prof. Jennifer S. Haase, Prof. Robert L. Nowack and Yoon Seok Choi
Dept. of Earth & Atmos. Sci., Purdue University
550 Stadium Mall Dr
West Lafayette, IN 47907-2051
765-494-8677; 765-496-1210; jhaase@purdue.edu

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Non-technical Summary

The central US has a low rate of seismicity, but because of the occurrence of past earthquakes such as the 1811-1812 New Madrid events as well as prehistoric events in the Wabash Valley Fault Zone, there is a significant seismic hazard. Evansville, Indiana, is one of the closest large urban areas to both the New Madrid and Wabash Valley fault zones. For this reason, it has been targeted as a priority region for urban seismic hazard assessment and surficial geologic mapping, along with Memphis, TN, and St. Louis, MO. The probabilistic seismic hazard methodology that will be used in the Evansville, IN, region incorporates information on The work is taking place in coordination with surficial geologic mapping efforts on the part of the USGS and state geological surveys. A preliminary version of the probabilistic seismic hazard map for the Evansville, IN region has been calculated that incorporates information on the depth and properties of near surface soils and their uncertainties. Since then improved estimates of soil properties have been compiled using additional data to determine the depth dependent shear wave velocity for the major lithologic units. The impact of the new depth dependent model will be evaluated, but may reduce amplification by creating less of a contrast between bedrock and valley fill. The final surficial geologic mapping has recently been completed, and will now be used for a revised probabilistic hazard calculation.

Investigations undertaken

This project is designed to produce a probabilistic seismic hazard map for the nine quadrangle region surrounding Evansville that takes into account amplification due to near surface geologic structure. All available data are compiled from past seismic refraction studies, well logs, geotechnical borings, and cone penetrometer test (CPT) data to characterize the material properties at relatively high resolution. A preliminary site amplification and probabilistic seismic hazard calculation has been completed using geologic maps available before the surficial mapping component of the project was completed.

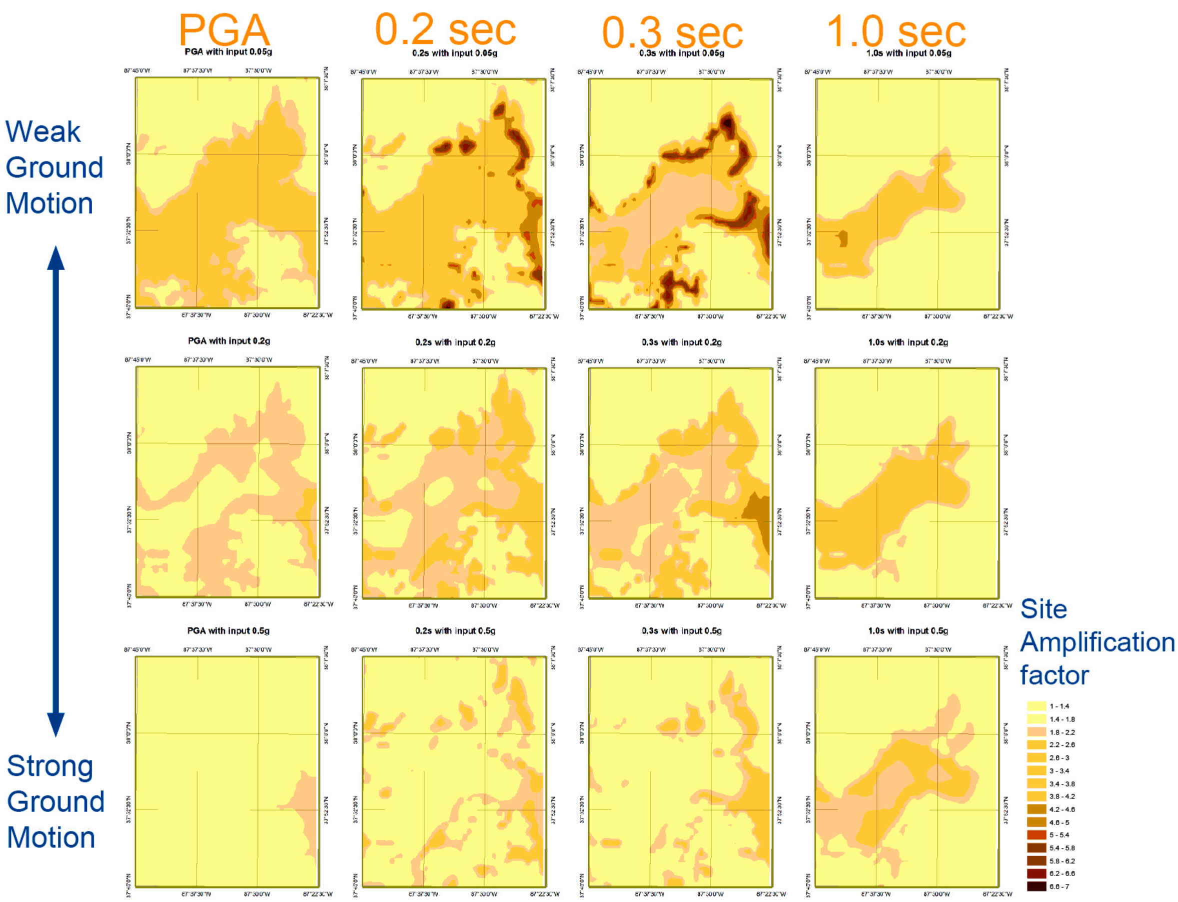

Figure 1 Preliminary results of the site amplification calculation, before final surfical mapping products were available. Note the higher amplification is concentrated along the edge of the underlying bedrock valley basin, with the distance from the edge varying with frequency. (greatest amplification factor is 7, dark red)

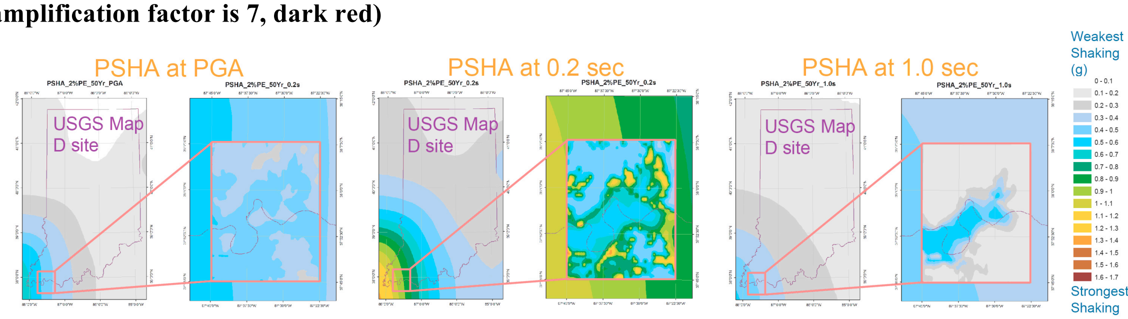

Figure 2 PSHA maps showing the level of ground motion with 2% probability of exceedence in 50 years including site effects. Maps are superimposed on the USGS 2002 PSHA maps adjusted for NEHRP class D site conditions.

The objective of the preliminary calculations was to demonstrate whether or not there is a clear correspondence between the properties of the bedrock valley fill and the amplification. The calculation showed a distinct amplification for regions where the depth to bedrock coincides with that which produces a resonant frequency, and the resulting probabilistic hazard is much higher in those regions.

A revised method has been developed to convert information on lithology from bore logs to approximate velocities that now includes variation with depth. This method has been tested with two data sets, cone penetrometer data (CPT) and borehole shear wave velocity data. Surficial geologic maps have recently been completed by the geological surveys involved in the Tri-state hazard mapping project. The United States Geological Survey, the Central US Earthquake Consortium (CUSEC) geologists and the state geological surveys in Indiana, Illinois and Kentucky have provided new maps for 6 quads of the study area, with much more detailed information and will be providing additional compiled data on bedrock depth.

Currently, we are evaluating the new information contained in the maps to verify that the lithologic velocity models are still consistent, and revising the method for assigning the shear wave velocity profiles to the new surficial map units. Some differences, in particular in the descriptions of the interleaved lacustrine and fluvial deposits at the edges of the river basin, may have a significant impact on the new amplification calculations. The final site amplification and probabilistic seismic hazard calculation using the new soil shear wave velocity model is currently underway in this phase of the project. The primary remaining tasks include:

1) Associate shear wave velocity with the new map units
2) Calculate site amplification with the improved soil profile model and apply it in the probabilistic seismic hazard calculation

Results

1) Analysis of local geology and CPT soil profile data

The CPT data is the primary dataset used to classify the soils within the lowland region surrounding Evansville. The soil profiles (Figure 3) show that there are distinctively different soil properties in the four geologic regions sampled.

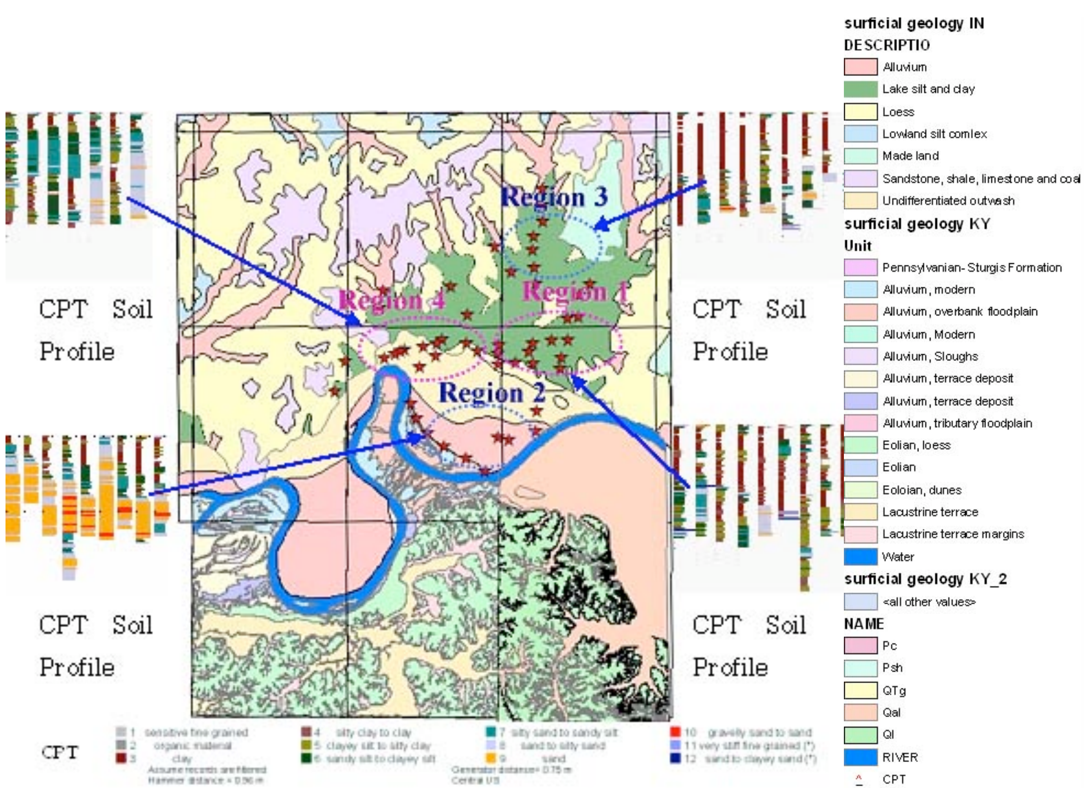

Figure 3 Map of surficial geology and soil profiles from the Cone Penetration Test Data from four different regions, ordered west to east (south to north for region 3).

Our preliminary calculation assigned a constant shear velocity for the material above bedrock, which was chosen based on the major textural constituent of the surficial unit. There was no systematic distinction that could be made by calculating the average shear wave velocity from samples collected in distinct surficial geologic units. However, there was some evidence for a simple correlation with sand and clay content. Therefore, the velocities were determined by averaging the CPT data for unit layers containing clay, and averaging the data for layer units containing sand. The mean value for units containing sand is 255.0 ± 43.5 (m/s) and for units containing clay 205.7 ± 32.3 (m/s), which are statistically distinct. The soil in the alluvium regions contain mainly sandy material, but clay-rich material occurs in the lacustrine regions.

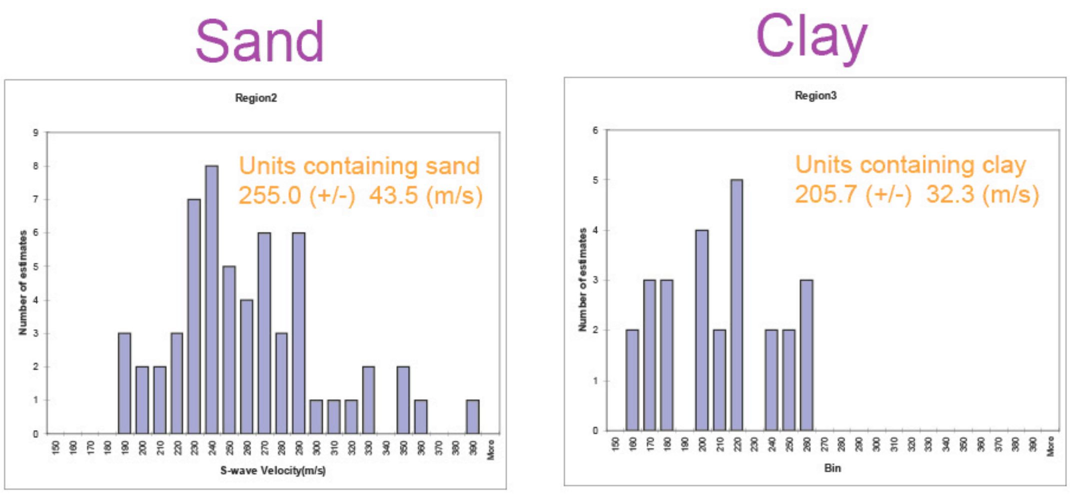

Figure 4 Shear wave velocity histograms for the sand and clay units in the CPT profiles

For the revised analysis, the depth dependence of velocity and lithologic units based on their predominant component of sand, clay or silt has been developed. By grouping the data carefully which show similar characteristics in terms of depositional environment, the distribution of velocities for each soil type is much narrower and it is possible to distinguish significantly different variations in shear wave velocities as a function of depth (**Error! Reference source not found.**). The sandy soil velocity depth dependence was calculated from profiles found in the river alluvium map unit where extensive thicknesses of these units permits accurate estimates. The clay soil velocity depth dependence was calculated from profiles found in the lacustrine map unit, and the silty soil velocity depth dependence was calculated from profiles where overbank deposits of silt are present overlapping lacustrine material at the edge of the river basin.

For the verification of the revised model, 33 independently measured borehole S-wave velocity profiles (Eggert, et al., 1994) are used to build a comparative model. First, average shear wave velocities were calculated at 5 meter depth intervals, then the differences between the average velocity model and the observations at each depth were calculated. The standard deviation is 63.9 m/s.

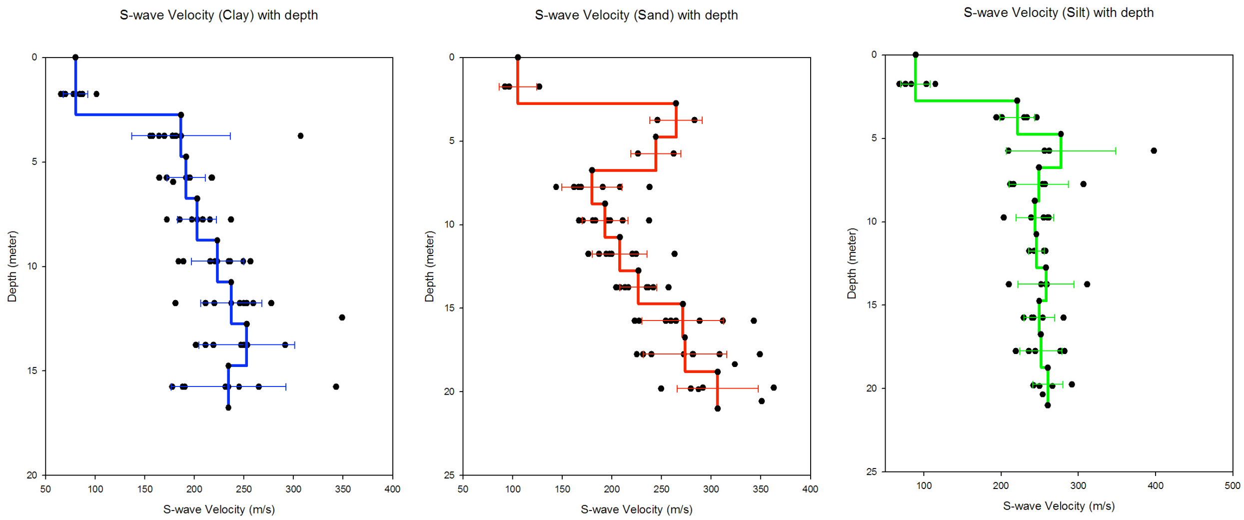

Figure 5 Depth dependent velocity characterization for sand, silt, and clay units determined from CPT profiles grouped by depositional environment.

The revised depth dependent shear wave velocity model determined from the grouped CPT data (Figure 5) is tested with the same method. The standard deviation of the differences between the borehole shear wave velocity observations and CPT determined model values is 59.3 (m/s). We can conclude that the soil type and depth dependent velocity model is an improvement over the simple depth averaged velocity model.

This model will be used for the final site effect amplification calculation. An important point to note about the model is that because it directly relates soil type to shear wave velocity, optimized for this environment, it is feasible to calculated shear wave velocity profiles from well log data where no direct observations of shear wave velocity are available.

2) Bedrock depth

Minor modifications have been made to the model of bedrock depth from the preliminary calculation. Previously existing bedrock topography contours [Indiana Geological Survey (1:500,000)] are not detailed enough to capture short range depth variability of the data. Development of detailed contours based on all available data is required to calculate the site response and amplification. 900 Indiana Geological Survey water well logs, 230 seismic P-wave refraction profiles, and new bedrock elevation points from Kentucky Geologic Survey oil, gas, water well logs were integrated to determine the depth to bedrock. IGS water well logs contain information of surface elevation, bedrock elevation and depth to bedrock, so the depth to bedrock can be obtained directly from these data.
The Indiana Geological Survey P-wave seismic refraction profiles also provide the depth of bedrock and depth of shallower interfaces as well. The Kentucky Geologic Survey provided a rich dataset of depths to bedrock in the Kentucky area [Ron Counts, 2005]

where all dataset of depths to bedrock from different sources are merged into one GIS attribute table. We create contoured depth to bedrock using local polynomial interpolation.

Table 1. Available data sets for the Evansville, Indiana, region used to constrain bedrock depth

Data type	Reference
48 CPT profile data collected by the USGS	[Holzer, 2003]
33 borehole S-wave velocity profiles	[Eggert et al., 1994]
570 SPT blow count data at over 60 geotechnical boring sites	[Choi and Hill, 2005]
230 P-wave seismic refraction profiles	[Rudman et al., 1973]
15 nearby S-wave refraction profiles	[Wang, 2004; CUSEC, 2004]
Indiana Geological Survey iLITH GIS database of approximately 900 water well logs	[Bluer, 2000]
Bedrock elevation points from Kentucky Geologic Survey oil, gas, water well logs	[Ron Counts, personal communication, 2005]

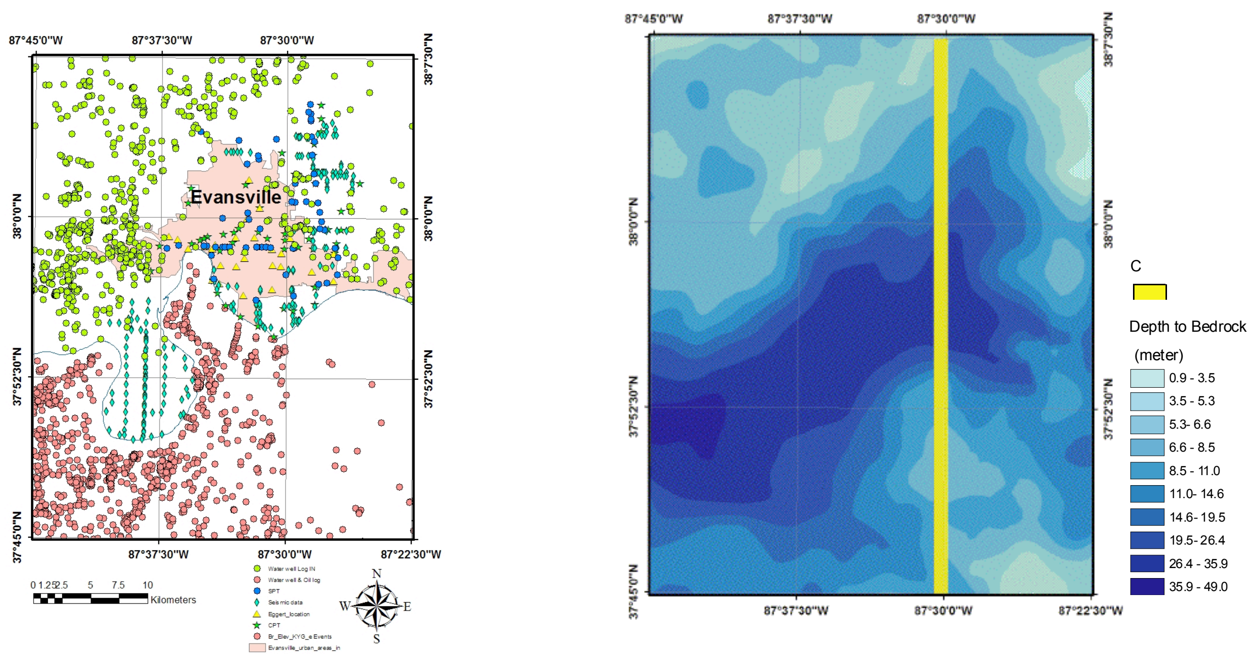

Figure 6 Location of bedrock depth points and contoured bedrock depth. Yellow line shows the north-south cross-section of Figure 7

The depth to bedrock or soil thickness is greater within the river area categorized as alluvium on the surficial geologic map (Figure 3). The depths to bedrock are as deep as 50 meters close to Ohio River. In contrast, soil thickness in the northern or southern upland areas is relatively thin, where residual soil above bedrock may or may not be covered with loess. There are rapid changes of soil thickness at the edges of river valley. The variation of depths to bedrock influences the resonant frequency of the site.

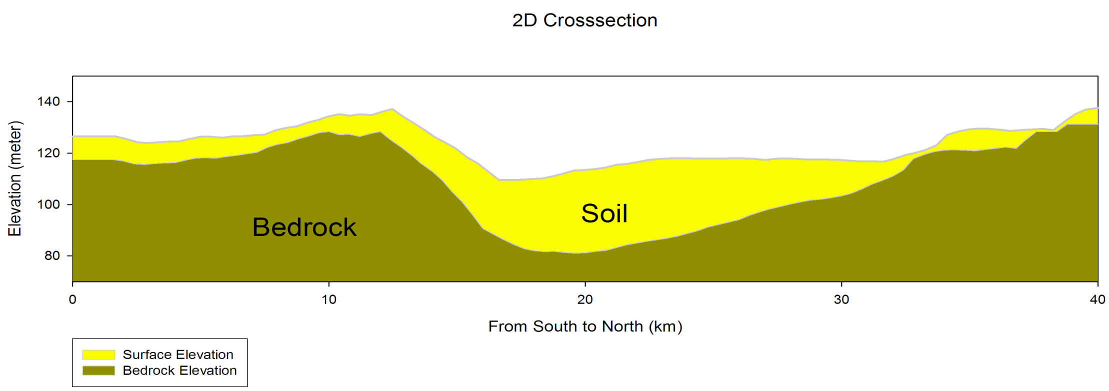

Figure 7 2D cross-section of bedrock elevation and soil depth.

Remaining work entails comparison and verification of these bedrock topography against the geological cross-sections currently being created by the collaborating members of the geological surveys. Then the final calculation using the new surficial geologic map units will be carried out.

Reports Published and data availability

No reports have been published. The intermediate GIS products as well as the final PSHA maps will be available at the end of the project in GIS shapefiles. Contact: Jennifer Haase, 765-494-8677, jhaase@purdue.edu

References

Eggert, Donald L. et al., Geologic Terrain Map of the Evansville Region, Indiana Geological Survey Open File Map 96-09, 1996.

USGS CPT Data, web site http://quake.wr.usgs.gov/prepare/cpt/, U.S. Geological Survey, Nov 2003.