Study of Earthquake Source and Crustal Structure in the New Madrid Seismic Zone

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Investigation Undertaken

We first measure the arrival time differences between the direct S and converted Sp waves at each of the CERI regional seismic stations in the NMSZ. 3-dimensional Vp model for the sediments is determined from linear interpolation or extrapolation from nearby well-logs data. Along with some shallow Vp and Vs information, Vs profile beneath each station can be obtained from a simple linear inversion of Vp/Vs values from the travel time differences between the direct S and converted Sp arrivals. Thus, 3-dimensional Vp and Vs for the sedimentary basin in the NMSZ can be determined. The PANDA velocity model and the sedimentary basin model are merged into an initial velocity grid model. 3-dimensional upper crustal Vp and Vs structural model can be determined from a tomographic velocity inversion of P- and S-arrival time data from PANDA experiment (1989-1992) and CERI regional seismic network data (1995-2000). During the velocity inversion, earthquakes are relocated simultaneous using the resultant 3-D Vp and Vs model. Since 3-D tomographic inversion is very time consuming and requires large amount of high quality P- and S-arrival time data, it is not practical to be applied for routine single earthquake location. We also developed a new program for a single earthquake location using 3-dimensional Vp and Vs structural model for the NMSZ. Results of single event location using 3-D Vp and Vs model are compared with those relocated simultaneously from the tomographic inversion.

Results

Lateral variations of thickness and velocity of sediments beneath CERI seismic network stations have a very significant impact on earthquake location. Epicenters and depths of earthquakes can easily be mislocated in the ranges from a few tenth km to a few km when the lateral variations of velocity structure, especially the sediments, is not properly taken into account. Travel time differences between the direct S and converted Sp waves is a constant at any CERI network station but is different between different stations which can be correlated with the thickness of sediments beneath each station (Figure 1). 3-dimensional Vp and Vs model for the sediments will provide structural information important for the calculation of predicted strong ground motion in the Upper Mississippi Embayment. A 3-dimensional initial velocity grid model can be constructed by including the 3-dimensional Vp and Vs model of the sediments and the PANDA model. From a 3-dimensional tomographic inversion using

the initial model and selected high quality data, 3-dimensional crustal Vp and Vs structure model as well as earthquake relocation were determined simultaneously. Although there are no clear correlations between velocity anomalies and the relocated hypocenters, it seems that most earthquakes are either located in regions of lower velocity or in transition regions between the high and low velocity anomalies. Since simultaneous velocity structure inversion and earthquake relocation requires a large volume of hiqh quality arrival time data and is also very time-consuming, it is not practical to be applied for a routine single earthquake location. We have developed a new program utilizing the newly available 3-dimensional Vp and Vs velocity model in the NMSZ region for a reliable single earthquake location. Because the velocity model will remain unchanged during earthquake location, travel time parameters from every grid points to all surface stations can be calculated and stored in disk files for a later usage. Travel time calculation for any ray path can be easily determined from a linear interpolation of that from ray paths of adjacent grid points. Test results using the selected data from the NMSZ indicate that the single event location using a well-determined 3-dimensional velocity model can be as reliable as the earthquake relocations obtained during a simultaneous velocity inversion. Discrepancies on traditional local earthquake location due to the improperly represented lateral variations of crust structure can be taken care by the application of 3-dimensional velocity structure in travel time calculation.

Figure 1 shows a map view of selected epicenters in the NMSZ from the PANDA experiment (1989-1992) and from the CERI regional seismic network (1995-2000). The along the strike cross-sectional views of the preliminary earthquake location, the relocated hypocenters from the simultaneous velocity inversion, and the single event location using a 3-dimensional Vp and Vs model are shown in Figures 2, 3, and 4. It is apparent that thickness of the sediments in the northern embayment is in general overestimated in the PANDA model and therefore depths of the relocated hypocenters are consistently shifted toward deeper depths when the lateral velocity variations and thickness of sediments are properly taken care either from the simultaneous tomographic inversion and relocation or from the single earthquake relocation using a 3-dimensional velocity model (Figure 2). On the contrary, thickness of the sediments in the southern NMSZ is in general under-estimated in the PANDA model that the relocated hypocenters are consistently shifted toward shallower depths (Figure 4). In the central NMSZ where thickness of sediments is roughly around 650 m, the relocated hypocenters are very similar to the original locations using the PANDA model (Figure 3) which is what we would expect. Thus, we have demonstrated in this report that a reliable earthquake location is possible only when the lateral variations of seismic velocity and thickness of sedimentary basin and crust are properly taken into account. When a 3-dimensional Vp and Vs structural model for a region is properly determined, single earthquake location using the resultant 3-dimensional velocity model can produce reliable hypocentral information as well as those obtained from a simultaneous velocity inversion and earthquake relocation.

Non-Technical Summary

The New Madrid seismic zone is the most active seismic region in the U.S. east of the Rocky Mountains. Assessment of strong ground motion on the surface and image of active faults in the region have been hindered by overlooking details on sedimentary basin structure

and lateral variations of seismic velocity structure in the upper crust. In this research, we combine all the available geological and geophysical information together with additional analysis of high resolution earthquake data from a previous seismic array experiment and from the new regional seismic network in the New Madrid seismic zone to first determine a 3-dimensional Vp and Vs structure model for the sedimentary basin, and then a 3-dimensional crustal Vp and Vs model for the New Madrid seismic zone. We then develop a new program to local local earthquake by using the newly determined 3-D velocity model. Thus, a well-determined 3-D sedimentary basin structure model will allow a successful prediction of strong ground motion in the Upper Mississippi Embayment from any potential future earthquake source along the active faults. A reliable image of active fault zone from the linear distribution of hypocenters will allow us to understand about the mode of fault movement and what to expect from any future big earthquake rupture.

Reports

Results of this project will be summarized into two papers which include

1. 3-D Upper Crustal V_p and V_s Structures in the New Madrid Seismic Zone using PANDA and Regional Seismic Network Data Authors : H. Chen(1,4), J.M. Chiu(1), J. Pujol(1), E. Schweig(1,2) R. Street(3), S.C. Chiu(1), and M. Withers(1)

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2. Local Earthquake Locations in the New Madrid Seismic Zone using a 3-Dimensional Vp and Vs Velocity Model. Authors : H. Chen(2), J.M. Chiu(1), J. Pujol(1), S.C. Chiu(1) M. Withers(1)

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Availability of Data

3-component digital seismic data from PANDA and CERI regional seismic network will be available upon request. AH, and other standard data format will be available for PANDA and regional network data. Final earthquake locations will be implemented into CERI earthquake catalog to be released via Web or upon request. Contact Jer-Ming Chiu at chiu@ceri.memphis.edu or (901)-6784839 for PANDA data. Contact Mitch Withers at withers@ceri.memphis.edu or (901)-6784940 for CERI regional seismic network data.

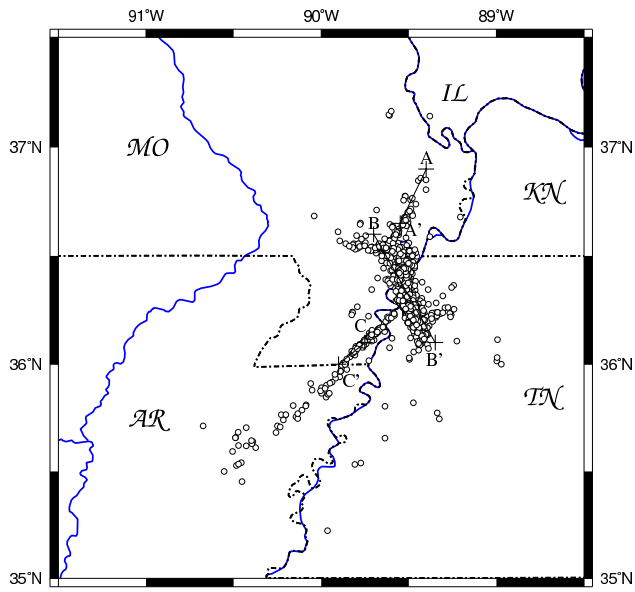

Figure 1: Epicenter distribution of the events recorded by CERI stations from May, 1995 to April, 2001 and by PANDA stations from October, 1989 to August, 1992. These events were relocated by the newly developed earthquake location/relocation program using a 3-D velocity model in which the 3-D velocity and depth variations of the sediments have been taken into account (Gao et al. 2001a; Chen et al. 2001a)

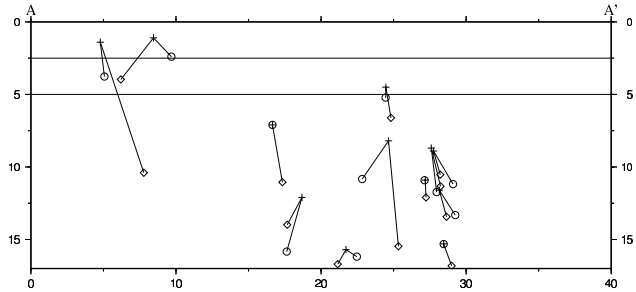

Figure 2: A cross-sectional view of the earthquake hypocenters along the profile A-A'. The crosses, diamonds, and open circles are denoted as earthquake hypocenters located preliminarily using the PANDA model (Chiu, et al., 1992), those inversed simulotaneously with the velocity structure, and those relocated using the newly developed earthquake location/relocation program using a 3-D velocity model (Gao, et al., 2001a; Chen et al., 200a) respectively.

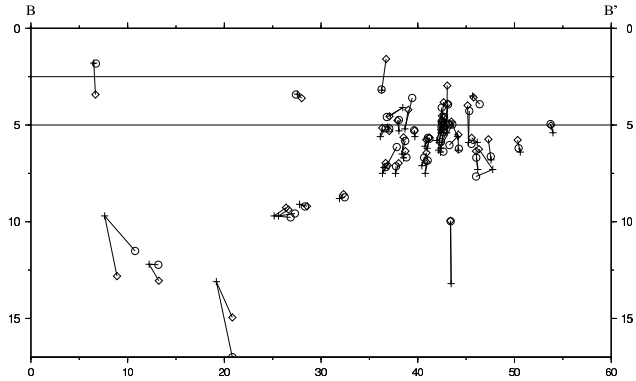

Figure 3: A cross-sectional view of the earthquake hypocenters along the profile B-B'. The crosses, diamonds, and open circles are denoted as earthquake hypocenters located preliminarily using the PANDA model (Chiu, et al., 1992), those inversed simulotaneously with the velocity structure, and those relocated using the newly developed earthquake location/relocation program using a 3-D velocity model (Gao, et al., 2001a; Chen et al., 200a) respectively.

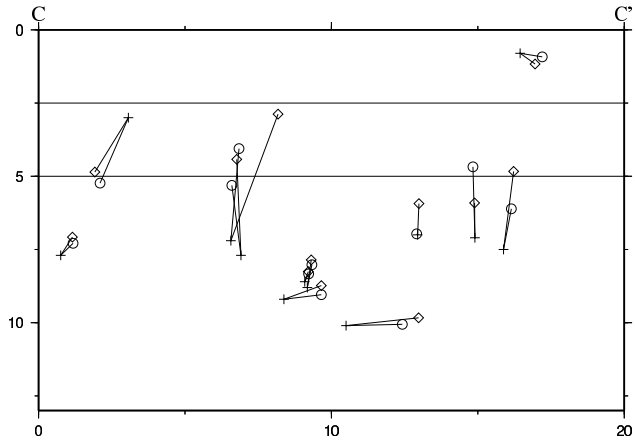

Figure 4: A cross-sectional view of the earthquake hypocenters along the profile C-C'. The crosses, diamonds, and open circles are denoted as earthquake hypocenters located preliminarily using the PANDA model (Chiu et al., 1992), those inversed simultaneously with the velocity structure, and those relocated using the newly developed earthquake location/relocation program using a 3-D velocity model (Gao, et al., 2001a, Chen et al., 2001a) respectively.