Appendix 2.5CC Updated Characterization of the Maximum Magnitude Wabash Valley/Southern Illinois Seismic Zone Earthquake Model

The following description of the updated characterization of the maximum magnitude distribution for the Wabash Valley/Southern Illinois seismic zone is excerpted from the EGC ESP SSAR. [Tables, Figures, and References cited in the following text is from the excerpt and are not associated with Fermi 3 citations]

2.1.5.2.2 Wabash Valley/Southern Illinois Seismic Zone

Table 2.1-6 provides a summary of recent publications pertinent to the identification and characterization of seismic sources in the WVSZ. These data have been incorporated into recent source characterizations for seismic hazard analyses (e.g., Frankel et al., 1996, 2002; Toro and Silva, 2001; Wheeler and Cramer, 2002).

Within the source region for the earthquake that paleoliquefaction studies indicate occurred 6,100 yr BP, candidate thrust faults have been identified at depth (McBride et al., 2002a). It has been postulated that a broad flexure (restraining bend or kink) in bedrock structure results in a concentration of stress in this region (Hildenbrand and Ravat, 1997) (Figures 2.1-6 and 2.1-28). This kink lies near the northern terminus of a 360 mile-long magnetic and gravity lineament, referred to as the Commerce geophysical lineament (CGL), that extends from Vincennes, Indiana, far into Arkansas (see Section 2.1.2.3.1). Late Quaternary faulting that displays major offsets recently has been identified near this lineament, close to the Missouri-Illinois border (Langenheim and Hildenbrand, 1997). The new paleoliquefaction data suggests the existence of a source of repeated large-magnitude (~**M** = 7.0-7.8) earthquakes in the Wabash Valley region (Attachment 1 to this Appendix). McBride and Kolata (1999) also note a possible relationship between the most deformed region of the Precambrian basement yet to be identified beneath the Illinois basin (the anomalous Enterprise subsequence) and some of the largest twentieth-century earthquakes in the central Midcontinent (figure 2.1-7). This region roughly coincides with the area of the broad flexure (kink) in the CGL. Morphometric analysis of the land surface, detailed geologic mapping, and structural analysis of bedrock also indicate westward-dipping surfaces in the Wabash Valley region along the western edge of the CGL in the restraining bend region (Fraser et al., 1997) (Figure 2.1-28).

Evaluation of recently acquired industry seismic-reflection profile data from southern Illinois provides additional insights regarding the causative structures for recent earthquakes. McBride et al. (1997, 2002a) reprocessed industry seismic-reflection profiles, integrating the results with those from potential field analysis to evaluate structural features in southern Illinois basin (Figures 2.1-5 and 2.1-8). They report a northeast-trending zone of dipping reflectors and diffractions that they interpret as a zone of intrusions, a zone of deformation, or both. This zone lies along the CGL. McBride et al. (2002b) suggest that the zone may represent thrust faults deep within crystalline basement, faults that may be subject to reactivation. The largest instrumentally recorded earthquake in the Illinois basin, which occurred in 1968, had a moment magnitude of **M** 5.4 (Johnston, 1996) (*mbLg 5.5,* McBride et al., 2002a). Its focal mechanism has a nodal plane that is subparallel to the zone of dipping reflections, a mid-crustal hypocenter that is located within the zone, and a seismic moment that corresponds to a rupture zone approximately the same size as one of the reflectors (Figure 2.1-9). McBride et al. (1997 and 2002a) note that earthquakes may be nucleating along compressional

structures in crystalline basement and thus may occur in parts of the basin where there are no obvious surface faults or folds. McBride et al. (2002a) note that dipping reflector patterns in the Precambrian crust are not collinear, in that fault surfaces are updip in the Paleozoic sedimentary section. They conclude that shallow Paleozoic structures are "decoupled" from deeper, possibly seismogenic, structures. The results of their study suggest that the seismogenic source just north of the New Madrid seismic zone consists, in part, of a pre-existing fabric of thrusts in the basement localized along pre-existing igneous intrusions that are locally coincident with the CGL.

Maximum-magnitude distribution for the Wabash Valley-southern Illinois source zones are based on recent analysis of paleoliquefaction features in the vicinity of the lower Wabash Valley of southern Illinois and Indiana (see Attachment 1 to this Appendix). The magnitude of the largest paleoearthquake, which occurred 6,011 ± 200 yr BP, was initially estimated to be ≥ **M** 7.5 using the magnitude-bound method (Obermeier, 1998). Subsequent estimates based on a suite of approaches (magnitude–bound, cyclic stress, and energy-stress methods) ranged from **M** 7.5 to 7.8 (summarized in Obermeier et al., 1993, 2001, and 2002). The highest value of **M** 7.8 from Pond and Martin (1997) based on the magnitude-bound approach (assuming an **M** 8.3 for the largest event in the 1811-1812 New Madrid earthquake sequence) and geotechnical studies using the energy-acceleration method likely is too high. Use of a more recently developed magnitude-bound curve for the CEUS based on a value of **M** ~7.6-7.7 for the largest of the 1811-1812 New Madrid earthquakes (reduced from the higher **M** 8 used in the older curve) and review of other historical events gives a lower estimate of **M** 7.3 (Olson et al., 2005, in press). A re-analysis of this earthquake by Green et al. (2004a, 2004b) using more recent ground motion attenuation relationships for the central United States; review of boring logs presented by Pond to select appropriate SPT values for the re-analysis; and 2001 NEHRP site amplification factors gives lower results. Based on this analysis, Green et al. (2004a, 2004b) estimate the magnitude of the Vincennes earthquake was approximately **M** 7.5. The more recent evaluations by Green et al. have considered the influence of aging effects on liquefaction susceptibility and concluded that for moderately susceptible sites such as those in southern Illinois, the small changes expected (given the types of sediments) would have little influence on the interpretation of paleomagnitude (Obermeier et al., 2001, 2002; Green et al., 2004a, 2004b).

The next largest earthquake, the Skelton-Mt Carmel event, occurred 12,000 ± 1,000 yr BP (Hajic et al., 1995; Munson et al., 1997; and Obermeier, 1998). This earthquake is estimated to be an **M** 7.1 to 7.2 by Munson et al. (1997) or **M** 7.3 by Pond and Martin (1997). Obermeier et al. (2002) report magnitudes of **M** 7.2, **M** 7.4, and **M** 7.3 based on magnitude bound, cyclic stress and energy stress methods, respectively. Olson et al. (2005, in press) give a best estimate of **M** 6.7 based on the revised magnitude-bound curve. Both of these earthquakes were in proximity to one another and took place in the general vicinity of the most numerous and strongest historic earthquakes (**M** 4 to 5.5) in the lower Wabash Valley of Indiana-Illinois (Obermeier, 1998).

Su and McBride (1999) suggest that all paleoliquefaction features in south-central Illinois and southeastern Missouri may have been induced by the paleoearthquakes that occurred near the potential seismogenic sources identified by the re-analysis of industry seismicreflection data (i.e., the Louden anticline, Centralia fault zone, and Du Quoin monocline). Based on the dimensions of basement-involved faults that may be associated with these structures, they estimate the maximum

possible moment magnitude for an earthquake nucleating in the basement in this region to be between 6 to a little more than 7.

The WVFS is a zone of northeast-trending, high-angle, normal and strike-slip faulting that occurs within the WVSZ (Plate 1). As described in more detail above (Section 2.1.2.2.12), faults within this system lie within and form the borders of the northeast-trending Grayville graben. Recent analysis of industry reflection data across the fault system (Bear et al., 1997) indicates Cambrian fault movements as well as early Paleozoic dextral strike slip along some of the faults. The age of faulting in Paleozoic rocks is post-Pennsylvanian and pre-Pleistocene (Bristol and Treworgy, 1979; Nelson and Lumm, 1987). There is no indication of any recent faulting (Heigold and Larson, 1994).

CHAPTER 6

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TABLE 2.1-6

SUMMARY OF NEW INFORMATION FOR WABASH VALLEY SEISMIC ZONE (WVSZ)
Seismic Hazards Report for the EGC ESP Site

AUTHOR(S); YEAR	TITLE	SIGNIFICANCE OF WORK
GEOPHYSICAL AND SEISMOLOGIC DATA—WABASH VALLEY SEISMIC ZONE		
McBride et al. (2002a)	"Interpreting the Earthquake Source of the Wabash Valley Seismic Zone (Illinois, Indiana, and Kentucky) from Seismic Reflection, Gravity, and Magnetic Intensity"	Reprocessing of seismic-reflection data provides new images of upper- to middle-crustal structures beneath the WVSZ. A series of moderately dipping crustal reflectors are identified below the western flank of the WVFS and locally following the Commerce geophysical lineament (CGL). Association of dipping crustal reflectors and gently arched Paleozoic strata also hint at a limited degree of Phanerozoic reactivation. The *mbLg* 5.5 1968 earthquake (focal mechanism—moderately dipping reverse fault) is correlated to reflectors in basement (inferred reactivated thrust in basement).
SEISMOGENIC FAULTS		
Fuller, Mossbarger, Scott & May Engineers (2001)	"J.T. Myers Locks and Dam Seismological Study, Summary of Deterministic and Probabilistic Seismic Hazard Analyses and Generation of Time Histories Report"	Identifies late Pleistocene displacement on Wabash Island fault within the Wabash Valley fault system.
Heigold and Larson (1994)	"Geophysical Investigations of Possible Recent Ground Deformation and Neotectonism in White County, Illinois"	Evaluates escarpment along projection of Herald-Phillipstown fault zone and concludes that it formed as a result of erosion, possibly along the fault zone. Vertical electric soundings, seismic-refraction profiling, resistivity profiling, and boreholes are used to evaluate the depth to Pennsylvanian bedrock. The study finds no evidence to support recent movement along pre-existing or newly formed faults.

TABLE 2.1-6

SUMMARY OF NEW INFORMATION FOR WABASH VALLEY SEISMIC ZONE (WVSZ)

Seismic Hazards Report for the EGC ESP Site

AUTHOR(S); YEAR	TITLE	SIGNIFICANCE OF WORK
Nelson et al. (1997)	"Tertiary and Quaternary Tectonic Faulting in Southernmost Illinois"	Documents Tertiary and/or Quaternary tectonic faulting in three areas: the Fluorspar area fault complex (FAFC); the Ste. Genevieve fault zone (SGFZ); and the Commerce fault zone(CFZ). In the FAFC, faults displace Mounds Gravel (late Miocene to early Pleistocene) and locally Metropolis terrace gravel (Pleistocene; pre-Woodfordian). Deformed Quaternary sediments are not observed along the SGFZ. The CFZ displaces Mounds Gravel and units as young as Peoria Silt (Woodfordian) in Missouri. Only the CFZ exhibits slip that conforms to the current stress field.
SEISMOGENIC FAULTS		
Odum et al. (2002)	"Near-Surface Faulting and Deformation Overlying the Commerce Geophysical Lineament in Southern Illinois"	Structural features interpreted from the Tamms, Illinois, high-resolution seismic-reflection survey and supporting microgravity data correlate with anomalous changes in drainage patterns, strikingly linear topographic blufffront scarps, and the complex faulting and folding of Paleozoic rock. Several faults are traceable to the PaleozoiX/Quaternary interface, and, at one site, deformed Quaternary strata may have been faulted upward 16 to 30 feet.
McBride et al. (2002a)	"Interpreting the Earthquake Source of the Wabash Valley Seismic Zone (Illinois, Indiana, and Kentucky) from Seismic Reflection, Gravity, and Magnetic Intensity"	Results suggest that the seismogenic source just north of the New Madrid seismic zone consists, in part, of a pre-existing fabric of thrusts in the basement localized along pre-existing igneous intrusions, locally coincident with the CGL
Wheeler et al. (1997)	"Seismotectonic Map Showing Faults, Igneous Rocks, and Geophysical and Neotectonic Features in the Vicinity of the Lower Wabash Valley, Illinois, Indiana, and Kentucky"	Describes neotectonic features (defined as younger than Miocene) in the lower Wabash Valley (see Fraser et al., 1997; and Heigold and Larson, 1994).

TABLE 2.1-6

SUMMARY OF NEW INFORMATION FOR WABASH VALLEY SEISMIC ZONE (WVSZ)

Seismic Hazards Report for the EGC ESP Site

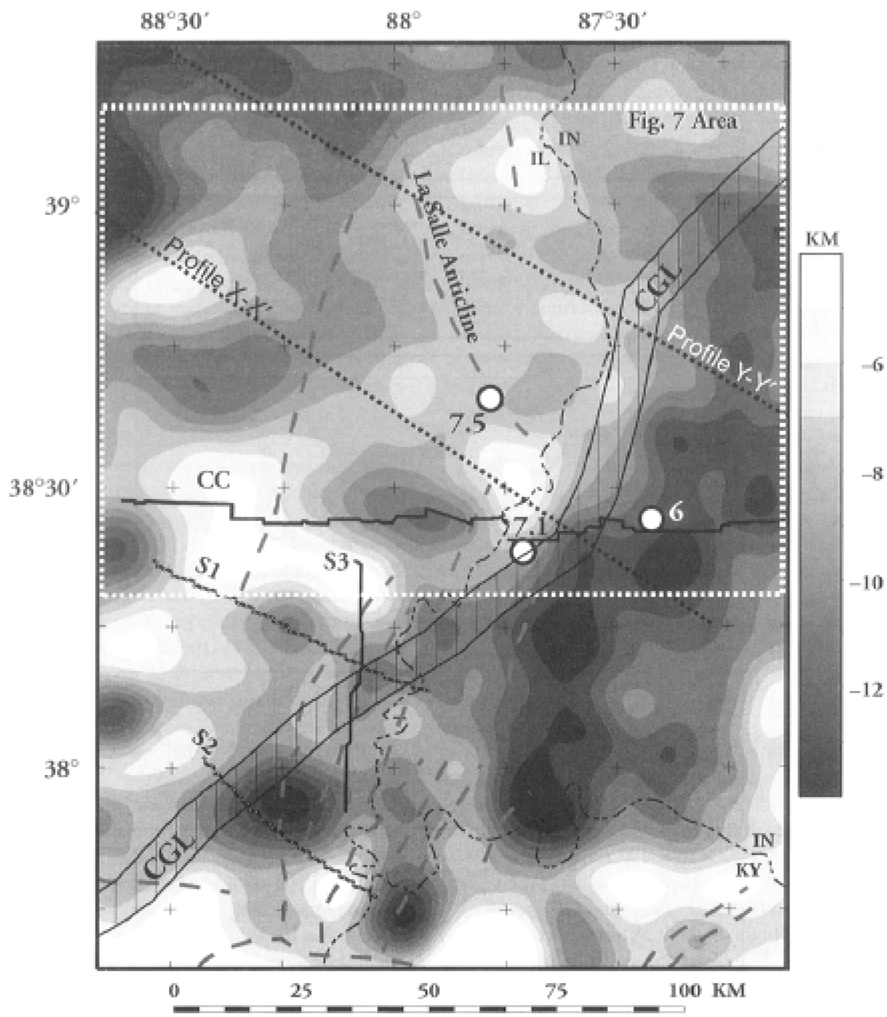
AUTHOR(S); YEAR	TITLE	SIGNIFICANCE OF WORK
Fraser et al. (1997)	"Geomorphic Response to Tectonically-Induced Ground Deformation in the Wabash Valley"	Morphometric analysis of the land surface, detailed geologic mapping, and structural analysis of bedrock indicate westward-dipping surfaces in the Wabash Valley region along the western edge of the Commerce deformation zone in the region of the restraining bend.
PALEOLIQUEFACTION STUDIES		
See Attachment 1 (Table B-1-1)		
SEISMIC SOURCE CHARACTERIZATION / SOURCE MODELS		
Frankel et al. (1996)	"National Seismic-Hazard Maps. Documentation June 1996"	1996 National Ground Motion Hazard Maps use a five-sided, ~ rectangular zone for the Wabash Valley source. Recurrence is based on historical seismicity; Mmax 7.5. This polygonal zone is based on the spatial association of the Wabash Valley fault system, paleoliquefaction energy centers, and historical seismicity. This zone was assigned the higher Mmax of 7.5 than assigned to the surrounding craton (M6.5) largely on the basis of the paleoliquefaction evidence.
SEISMIC SOURCE CHARACTERIZATION / SOURCE MODELS		
Frankel et al. (2002)	"Documentation for the 2002 Update of the National Seismic Hazard Maps"	The 2002 National Ground Motion Hazard Maps use the Tri-State zone for the Wabash Valley source. This zone is an oval larger than the polygonal source zone used for the 1996 maps. This zone is centered on the energy centers of the largest paleoearthquakes. Recurrence is based on historical seismicity; Mmax 7.5.
Wheeler and Cramer (2002)	"Updated Seismic Hazard in the Southern Illinois Basin—Geological and Geophysical Foundations for Use in the 2002 USGS National Seismic-Hazard Maps"	Develops alternative geometries for the Wabash Valley source, including a Tri-State source zone, Commerce geophysical lineament source zone, and Grayville graben. The latter two zones encompass the structures for which they are named.

TABLE 2.1-6

SUMMARY OF NEW INFORMATION FOR WABASH VALLEY SEISMIC ZONE (WVSZ)

Seismic Hazards Report for the EGC ESP Site

AUTHOR(S); YEAR	TITLE	SIGNIFICANCE OF WORK
Toro and Silva (2001)	"Scenario Earthquakes for Saint Louis, MO, and Memphis, TN, and Seismic Hazard Maps for the Central United States Region including the Effect of Site Conditions"	Develops alternative geometries for the Wabash Valley source. A large, extended zone is based on the extent of paleoliquefaction and diffuse historical seismicity.



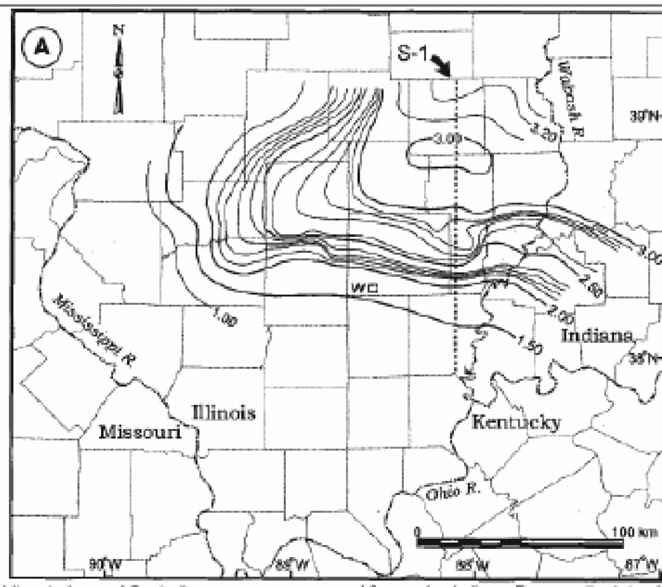
Calculated elevations of the top of a proposed dense igneous source (center) (with respect to sea level) based on inverted gravity data. The inversion results indicate that the igneous center lies near or at the Precambrian surface. Vertical line pattern shows the CGL, interpreted as a 3- to 6-mile-wide deformation zone bounding the igneous center on the southeast. Lines CC, S1, S2, and S3 are profiles analyzed by McBride et al. (2002a) to characterize this source of the CGL using seismic-reflection, gravity, and magnetic data. Dashed gray lines depict faults (one follow the La Salle anticline as labeled). Three white dots are the approximate locations of inferred epicenters of large prehistoric earthquakes (interpreted moment magnitudes of ~6, 7.1, and 7.5; McNulty and Obermeier, 1999).

From Hildenbrand et al. (2002)

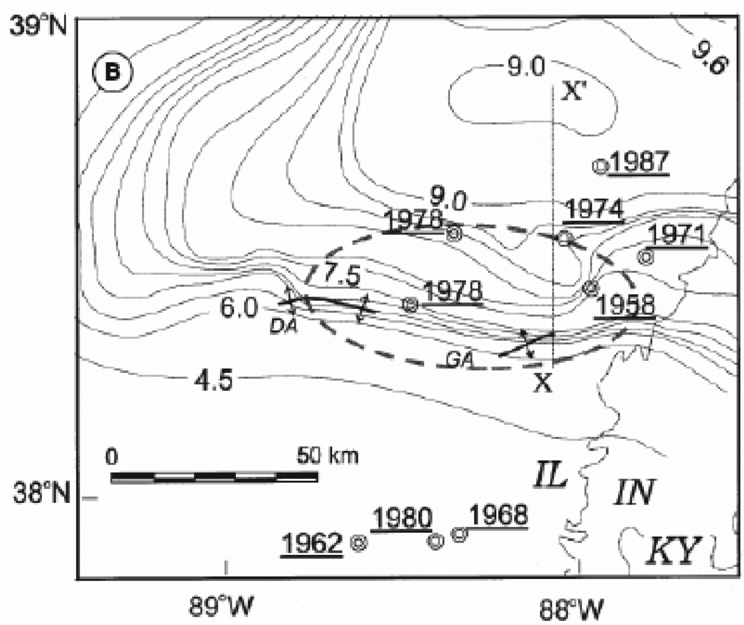
Seismic Hazards Report for the EGC ESP Site

Map Showing Inverted Gravity Data Along the Commerce Geophysical Lineament (CGL)

Figure 2.1-6



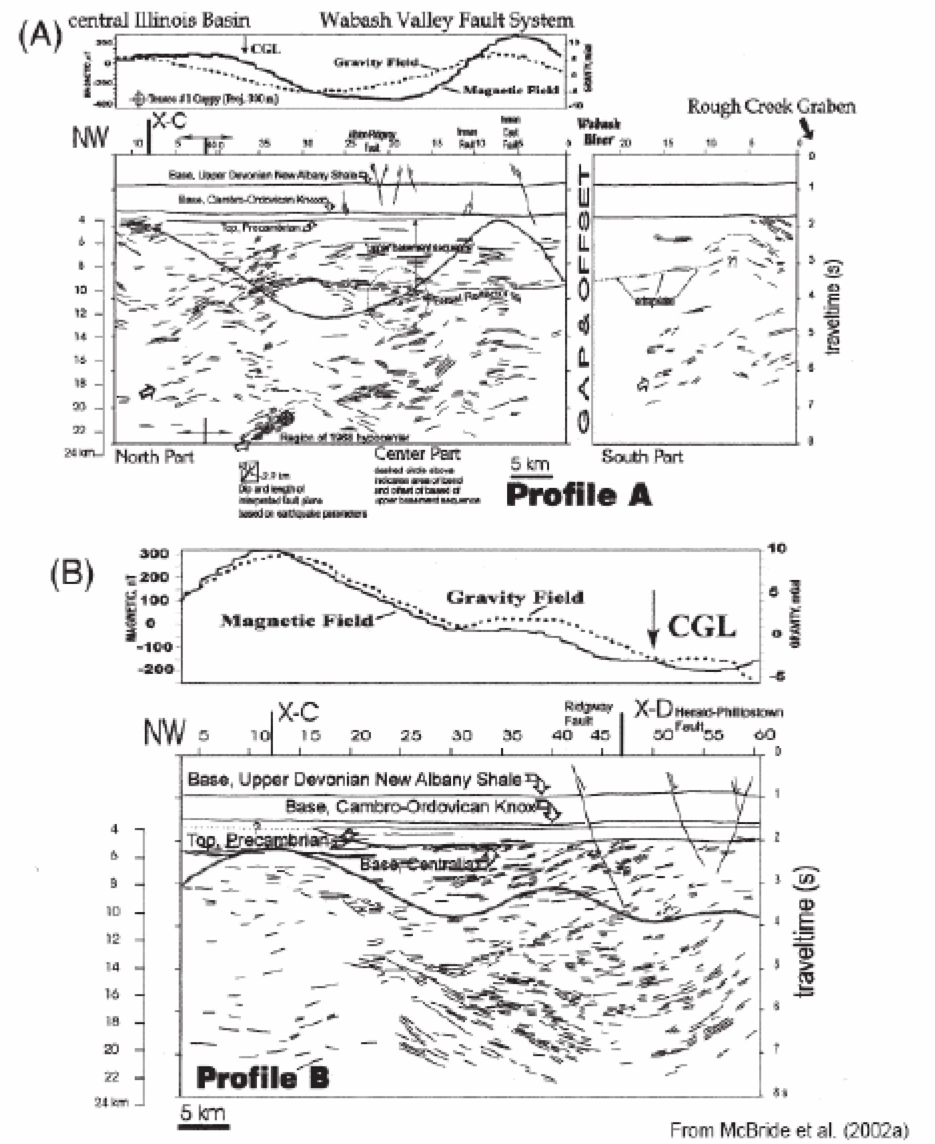
A.) Two-way isotravel time to base of Centralia sequence as mapped from seismic lines. Because the lateral change in seismic velocity for the Paleozoic section across the Illinois basin and the vertical change in velocity between the Paleozoic section and Precambrian basement are relatively small, little appreciable traveltime distortion of depth relations is expected. Contour interval is 100 ms (or 300 m at 6.0 km s^{-1}). For traveltimes less then 2 s, the contour interval is 500 ms.



B.) Epicenters of significant ($m_{bLg} \geq 3.0$) magnitude earthquakes in the southern part of the Illinois basin in Illinois, Indiana, and Kentucky (from Gordon, 1988; Langer and Bollinger, 1991). Contours are depth (converted from traveltime contours in A using a simple conversion velocity of 6.0 km s^{-1}) to base of the Centralia sequence marked by inward-dipping and disrupted reflectors. DA-Divide anticline; GA-Goldengate anticline.

From McBride and Kolata (1999)

Seismic Hazards Report for the EGC ESP Site **Maps Showing Correlation of Deformed Region of Precambrian Basement and Historical Earthquakes in the Southern Illinois Basin**	Figure **2.1-7**

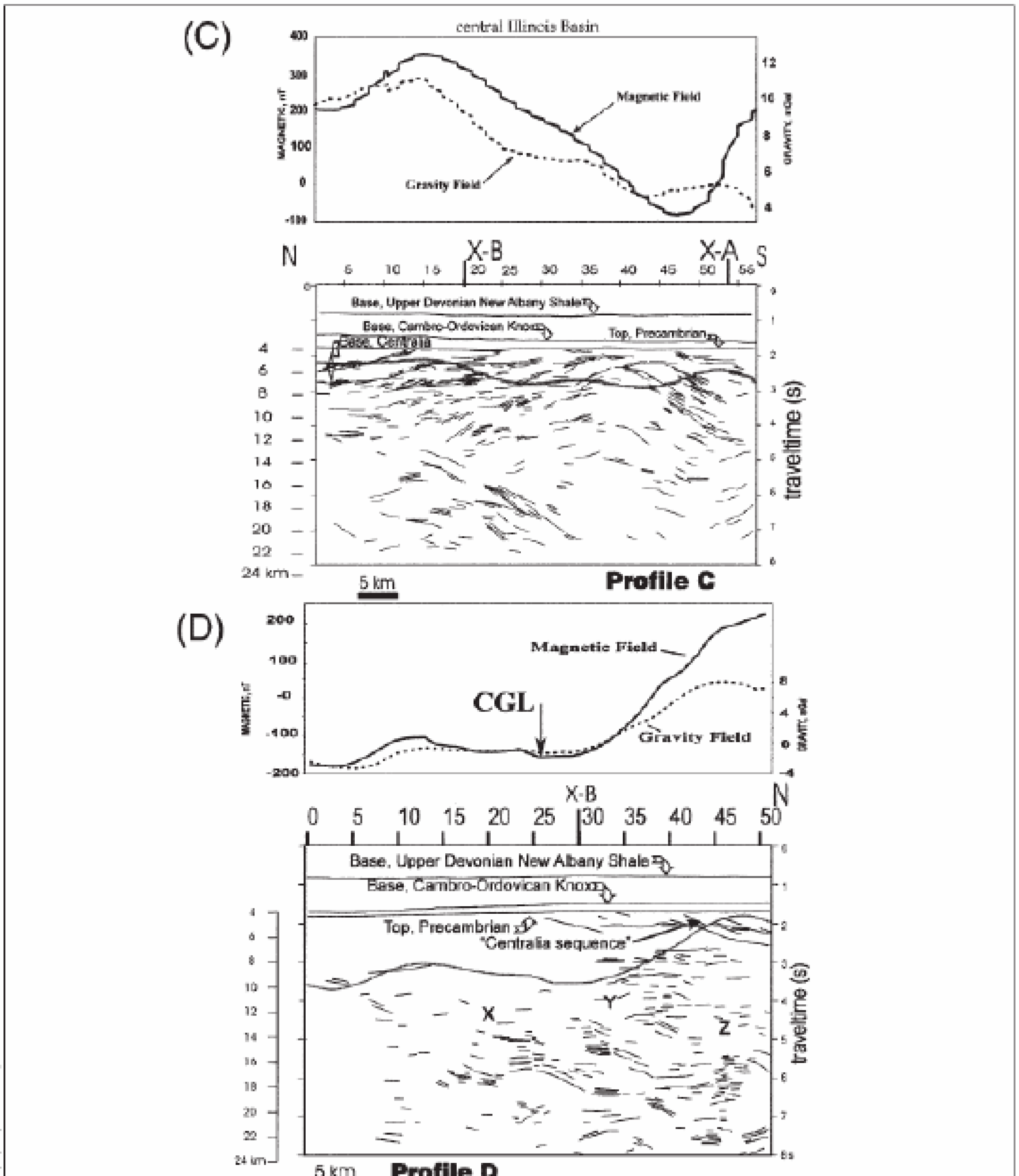


From McBride et al. (2002a)

Vertically exaggerated interpretive line drawings of profiles A, B, C, and D (based on reprocessed seismic reflection data. Only the principal stratigraphic markers are shown simplified for the mostly horizontal Illinois basin sequence. Cross sections of gravity and magnetic data are also shown, as well as the model density boundary superimposed on the reflection line drawing as a gray line. Small box for A shows apparent dip of west-dipping nodal plane for the 1968 event (interpreted as the fault plane) and its modeled rupture length. Position of m_b 5.5 1968 hypocenter is shown (Gordon, 1988); depth uncertainty is ± 5.4 km or ~-5.4-8.9s based on Gordon's (1988) estimate. Stratigraphic identifications from McBride et al. (1997). WVFS is Wabash Valley fault system.

Seismic Hazards Report for the EGC ESP Site
Interpretative Line Drawings of Reprocessed Reflection Profiles

Figure 2.1-8 (1 of 2)



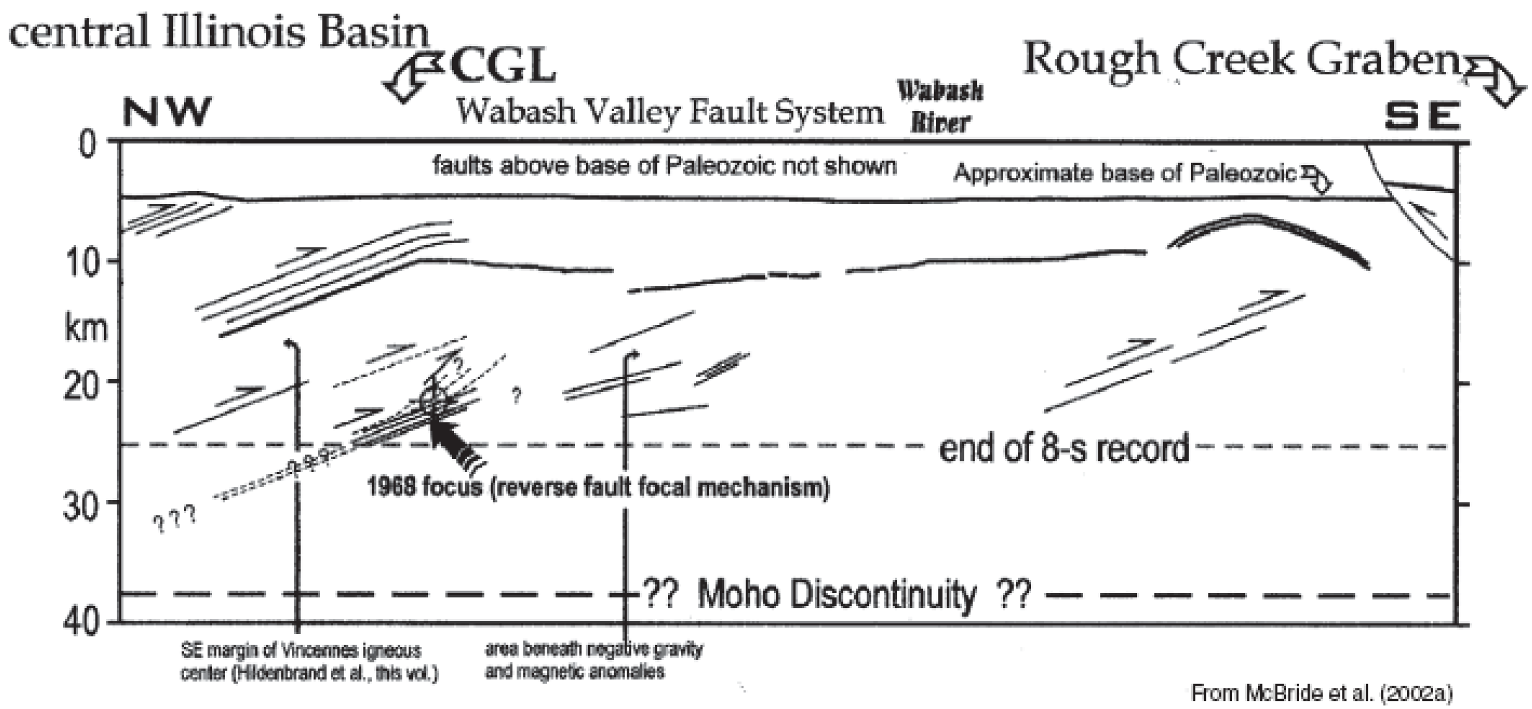
From McBride et al. (2002a)

Vertically exaggerated interpretive line drawings of profiles A, B, C, and D (based on reprocessed seismic reflection data). Only the principal stratigraphic markers are shown simplified for the mostly horizontal Illinois basin sequence. Cross sections of gravity and magnetic data are also shown, as well as the model density boundary superimposed on the reflection line drawing as a gray line. Small box for A shows apparent dip of west-dipping nodal plane for the 1968 event (interpreted as the fault plane) and its modeled rupture length. Position of m_b 5.5 1968 hypocenter is shown (Gordon, 1988); depth uncertainty is ± 5.4 km or ~-5.4-8.9s based on Gordon's (1988) estimate. Stratigraphic identifications from McBride et al. (1997). WVFS is Wabash Valley fault system.

Seismic Hazards Report for the EGC ESP Site

Interpretative Line Drawings of Reprocessed Reflection Profiles

Figure **2.1-8 (2 of 2)**

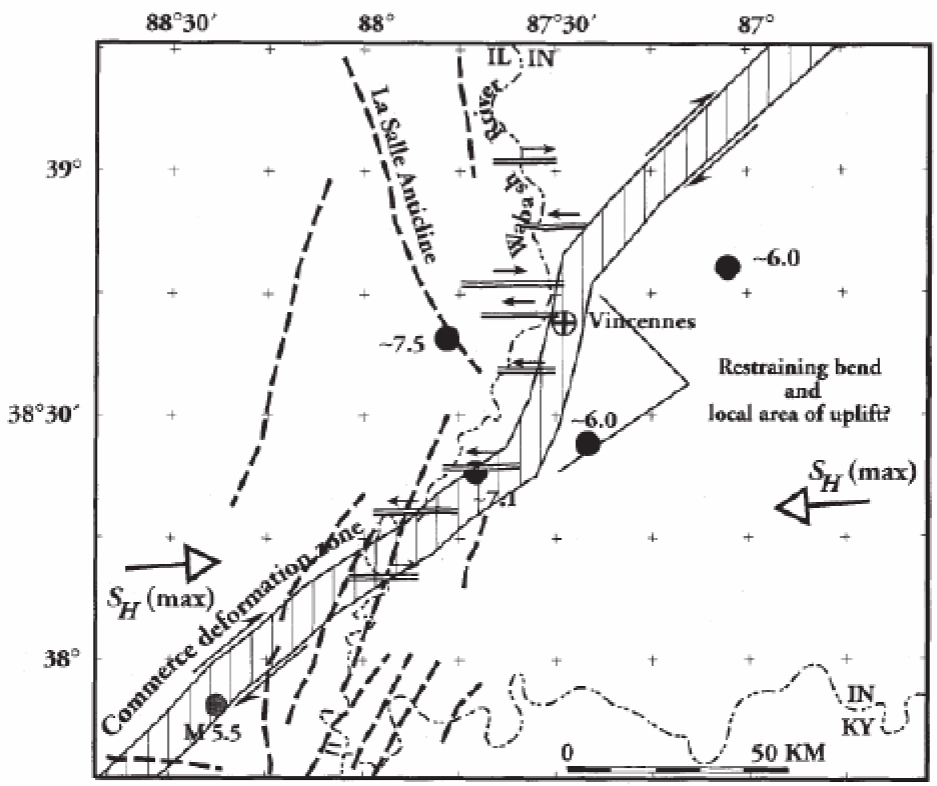


Interpretive model corresponding to area of Figure 2.1-8A. Dashed lines are speculative.
No Vertical exaggeration implied.

Seismic Hazards Report for the EGC ESP Site

Profile Showing Correlation of 1968 Earthquake Hypocenter to Postulated Reverse Fault in Precambrian Basement

Figure 2.1-9



Wabash Valley region highlighting the proposed restraining bend or left step in the Commerce deformation zone (Commerce geophysical lineament). Along eight east-west profiles in the Wabash River region (shown by double black lines), Fraser et al. (1997) carried out detailed morphometric analysis of the land surface, detailed geologic mapping, and structural analysis of bedrock. Arrows on these profiles show the tilt of bedrock and indicate that bedrock generally tilts to the west at the left step and to the east outside the step. Dashed lines are mapped faults based on the structural map of Illinois by Nelson (1995) and structural maps of the Illinois basin (Nelson, 1991). The direction of maximum horizontal compressive stress is shown by arrows and SH(max). Assuming right-lateral movement along the CDZ, thrust faults may have developed at the restraining bend, leading to a local uplifted block. The westward tilt of bedrock may suggest uplift in the vicinity of the proposed restraining bend. The four black circles are the approximate locations of epicenters of large prehistoric earthquakes (interpreted moment magnitudes of ~6, 7.1, and 7.5 and estimated radial location error of less than 20 km) discussed by McNulty and Obermeier (1999). Because these earthquakes occur near the proposed restraining bend, we suggest the possibility of a relationship between large earthquakes and stress build-up at the bend. Gray circle (M 5.5) identifies the epicenter of the November 1968 moment magnitude 5.5 earthquake in southern Illinois.

From Hildenbrand et al. (2002)

Seismic Hazards Report for the EGC ESP Site **Map Showing Restraining Bend In Commerce Geophysical Lineament**	Figure **2.1-28**