ENCLOSURE 2
ATTACHMENT 24

SHINE MEDICAL TECHNOLOGIES, INC.

SHINE MEDICAL TECHNOLOGIES, INC. APPLICATION FOR CONSTRUCTION PERMIT RESPONSE TO ENVIRONMENTAL REQUESTS FOR ADDITIONAL INFORMATION

SEISMIC HAZARD ASSESMENT REPORT
JANESVILLE, WISCONSIN
REVISION 4, AUGUST 3, 2012

62 pages follow

SEISMIC HAZARD ASSESEMENT REPORT JANESVILLE, WISCONSIN

SEISMIC HAZARD
ASSESEMENT REPORT

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Project No. 113-81051

Report No. Golder Report 5, Rev 4, August 3, 2012

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Executive Summary

This report provides a summary of a seismic hazard assessment (SHA) completed by Golder Associates Inc. (Golder) for the site of the proposed SHINE medical isotope production facility in Rock County, Wisconsin. The SHA results include a summary of the geologic and tectonic history of a region within approximately 124 miles (200 km) of the SHINE site, a review of regional geologic structures to evaluate whether they are “capable” faults, a review of the historical record of felt and instrumentally-recorded earthquakes, estimation of the maximum earthquake potential, and the seismic parameters recommended for application of the 2009 International Building Code (2009 IBC) and American Society of Civil Engineers (ASCE) 7-05 standard.

The geologic history of the basement rocks and the development and growth of major tectonic structures indicate that the SHINE site is located in a region of relative tectonic stability. Several post-500 million year old geologic structures have been mapped near the site, including the Sandwich and Plum River fault zones, the La Salle anticlinorium, and the Wisconsin and Kankakee Arches. These geologic structures appear to have formed and been seismogenic under a tectonic regime different from the present-day. No seismogenic “capable” faults are recognized within the SHINE site—the closest known “capable” faults are part of the Wabash Valley liquefaction features located about 170 miles (274 km) south of the site, and the New Madrid seismic zone located about 400 miles (644 km) south of the site. Within 124 miles (200 km) of the SHINE site, available earthquake catalogs contain only 35 epicenters for small to moderate earthquakes up to expected moment magnitude (E[**M**]) 5.15 that have occurred since 1804. Interpretation of readily-available felt intensity records indicates that only moderate earthquake shaking (i.e., Modified Mercalli Intensity scale V) has probably been felt at the site four times in approximately the last 200 years.

Estimates of seismic hazard for the region from the U.S. Geological Survey 2008 national seismic hazard maps indicate that the SHINE site is located within one of the lowest earthquake hazard areas in the conterminous United States. For example, a peak ground acceleration (PGA) value of 0.19 g (a moderate to strong level of earthquake ground shaking) has a return period estimated at more than 19,900 years. We evaluated the 2,475- to 19,900-year return period deaggregations of the national seismic hazard model for the SHINE site. Based on this model, a magnitude 5.8 earthquake is an acceptable estimate of the maximum earthquake magnitude expected for the SHINE site. Seismic parameters required for application of the 2009 IBC-ASCE 7-05 seismic design procedures are shown in Table ES-1 below.

Table ES-1 2009 IBC-ASCE 7-05 Seismic Parameters for the SHINE Site

Parameter	**Value**
S_S	0.129 g
S_1	0.050 g
Site Class	D
S_{MS}	0.206 g
S_{M1}	0.119 g
F_a	1.6
F_v	2.4
T_L	12 seconds

Notes:
1. Parameters based on SHINE site location of 42.624136°N, 89.024875°W.
2. Parameters include: short period spectral response acceleration (S_S), 1-second spectral response acceleration (S_1), maximum considered earthquake spectral response for short period (S_{MS}), maximum considered earthquake spectral response for 1-second period (S_{M1}), site coefficient for short period (F_a), site coefficient for 1-second period (F_v) (IBC, 2009); long-period transition period (T_L) (ASCE, 2005).
3. S_S and S_1 are for Site Class B; S_{MS} and S_{M1} for Site Class D.

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1.0) Introduction

SHINE Medical Technologies (SHINE) proposes to construct a manufacturing plant for production of Molybdenum-99 (^{99}Mo) at a site located south of the community of Janesville in Rock County, Wisconsin (Figure 1.1-1). SHINE has contracted Golder Associates Inc. (Golder) to provide a range of technical services in support of the environmental impact assessment, site application process for the U.S. Nuclear Regulatory Commission (USNRC), and groundwater hydrology and geotechnical engineering analysis for engineering design. To date, Golder has completed a range of subsurface boreholes, soil testing, groundwater assessment, and geotechnical analyses at the SHINE site (Golder, 2012a; 2012b; 2012c). The geotechnical analyses are to support initial engineering design of manufacturing and related facilities proposed at the SHINE site.

One important aspect of both the site safety analysis process and engineering design is the assessment of seismic hazard at the site. While Wisconsin is not generally regarded as an area of high historical earthquake activity and seismic hazard, it remains necessary for engineering design to quantify the level of earthquake hazard at the site. Principal outputs of this seismic hazard assessment (SHA) are as follows:

- A description of the geologic, tectonic and seismic history of the region surrounding the SHINE site;
- An evaluation of the location and activity of any “capable” faults that could affect the SHINE site; and
- Seismic parameters recommended for structural analysis and design of both building and non-building structures as outlined in the 2009 IBC-ASCE 7-05 procedures.

1.1) Work Scope

The full extent of professional services and associated tasks SHINE contracted from Golder are set out in Golder’s proposal to Shine Medical Technologies on October 6, 2011 (Golder proposal P113-81051). For the SHA, Golder has undertaken the following office-based tasks:

- Acquire and review regional and site geology within the region of the SHINE site, including regional stratigraphy, regional geologic history and structural development, and location and seismic potential of any significant basement structures as indicated by the analysis of geophysical data such as magnetic and gravity anomalies, deep seismic reflection interpretations, and borehole measurements.
- Search online databases of historical seismicity to develop a project-specific historical epicenter catalog within the region of the SHINE site, including records of felt earthquake intensity (isoseismal maps) for the major historical earthquakes.
- Review available geologic information to evaluate the potential for seismically “capable” faults within the region of the SHINE site.
- Evaluate the seismic hazard at the site by obtaining estimates of peak ground acceleration (PGA) and spectral accelerations (S_a) from the 2008 U.S. Geological

Survey (USGS) national seismic hazard maps and associated ground motion estimation tools.

- Recommend seismic parameters for application of the 2009 IBC-ASCE 7-05 standard procedures.

- Evaluate the Maximum Earthquake Potential for the site by completing a deaggregation of the 2008 USGS seismic hazard model to evaluate source(s) of the seismic hazard at a range of return periods from 475 to 19,900 years.

- Prepare this report, including figures, maps, tables, and databases.

The principal purpose of this report is to summarize existing geologic and seismic information for the Shine site and surrounding region. The information is provided to contribute descriptions of the site geologic and seismic characteristics for the environmental impact assessment of the project. The seismic information contained in this report also forms part of the engineering analyses for the SHINE site. This report is not the Safety Analysis Report (SAR) for the site characteristics, which is at present in preparation. Golder has, however, reviewed the guidelines of NUREG 1537 Parts 1 and 2, Section 2.5 for non-power reactors so that information provided in this SHA is, wherever practical, compatible with the NUREG 1537 guidelines.

The preparation of this report was undertaken following the Golder Quality Assurance Program Description (QAPD) (Golder, 2012d). Golder's Geotechnical Engineering Report for Janesville, Wisconsin (Golder, 2012a) provides a description of the QAPD.

1.2) Definitions

For the purposes of this report we define the SHINE region as the area within a 124-mile (200 km) radius of the SHINE project site (SHINE site) near Janesville. For the assessment of the "capability" of the mapped faults, we use the definition of "capable" as set out in Appendix A of 10 CFR Part 100: a "capable" fault is a fault with at least one of the following:

1. Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

2. Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

3. A structural relationship to a capable fault according to characteristics above such that movement on one could be reasonably expected to be accompanied by movement on the other.

The 10 CFR Part 100 definition of "capable" identifies faults that are considered capable of being the source of moderate to large earthquakes in the future. Evidence for the existence of capable faults is based on a geomorphic expression of surface fault rupture in surficial sediments that range in age from present day to 35,000 and/or 500,000 years old, instrumental evidence for the alignment of hypocenters that could indicate a subsurface fault; and in the case where these types of evidence are lacking, a structural relationship with a known capable fault (i.e., a fault is parallel or offsets similarly aged rocks by the same amount as the capable fault).

1.3) Limitations

Seismic hazard assessment and geotechnical earthquake engineering are dynamic and fast-evolving fields of research and engineering practice. The standard of practice in this technical area will continue to develop. In keeping with the evolving standards, the seismic design parameters presented in this report should be reviewed and updated when new data and/or new practice standards become available.

2.0) Geologic Setting of the SHINE Site

In this section we summarize the regional geologic and tectonic setting of the SHINE site, and describe the site's earthquake-related hazards. The summary is based on a review of relevant, readily-available, peer-reviewed published reports and maps. We have not undertaken an exhaustive review of all information; additional information may be available in sources such as records and unpublished reports from federal and state agencies, and unpublished reports in theses, fieldtrip guides and conference papers.

This summary includes a description of the following major geologic characteristics within about 124 miles (200 km) of the SHINE site:

- Regional physiography and geomorphology
- Tectonic provinces and structures within the basement rocks
- Bedrock geology including stratigraphy, lithology and structure
- Magnetic and gravity geophysical anomalies
- Surficial geology and glacial history

Our analysis of these characteristics focuses on identifying the major geologic and geophysical structures in the region, and evaluating any evidence that these structures represent potential seismogenic sources for historical and future large earthquakes. The analysis is qualitative only. In Section *2.2 Site Geology*, the geologic setting, structural geology, and geologic history of the SHINE site with respect to the regional geologic and tectonic history are summarized in greater detail.

2.1) Regional Geology

The rocks and geologic structures that comprise the regional geology of Wisconsin record several phases of continent building and deformation, sedimentary deposition, and glacial and post-glacial processes. These are described in further detail below.

2.1.1) Physiography and Geomorphology

Wisconsin and the SHINE site are located within the Central Lowland Province of the Interior Plains Division of the United States (USGS, 2003)—one of many geomorphic, or physiographic regions of the United States as defined by terrain texture, rock type, and geologic structure and history. The regions represent a three-tiered classification of the United States by division, province, and section.

Figure 2.1-1 shows the boundaries of the three physiographic sections of the Central Lowland Province that surround and include the SHINE site. The south-central portion of Wisconsin is located within the Till Plains—a region of predominantly Illinoian-age glacial deposits (formed 310,000 to 128,000 years ago). To the west is the Wisconsin Driftless section—a region of unglaciated terrain. To the east is the Eastern Lake section containing the most recent topography associated with glacial advance deposits surrounding present-day Lake Michigan.

The present-day physiography of the Central Lowland Province and the three sections described above has been influenced strongly by processes associated with Pleistocene (1.8 million years to 10,000 years ago) glacial erosion and deposition, and the subsequent post-glacial erosional and deposition as described by Fullerton et al. (2003) and Attig et al. (2011). Glacial processes in this part of Wisconsin were part of the widespread glaciations that affected the entire northern portion of the continent. Although the most recent episode of widespread glacial advance in Wisconsin (late Wisconsin Glaciation) occurred from approximately 31,000 years ago to about 11,000 years ago, and covered much of the state, the immediate area of the SHINE site was not covered by glacial ice during this episode.

2.1.2) Tectonic Provinces and Major Structures

The tectonic provinces and structures surrounding the SHINE site preserve a record of major geologic events over about the last 2.6 billion years of geologic history. Figure 2.1-2 (left) is a generalized summary of the major older (Archean and Paleoproterozoic—2.6 to 1.6 billion years ago [Ga]) geologic provinces, structures and phases of major crustal deformation (orogens). Figure 2.1-2 (right) summarizes the same information but for the relatively younger Meso- to Neo-late Proterozoic time (1.6 to 0.542 Ga). In Wisconsin and the surrounding region, the geologic age of the tectonic provinces and structures generally decreases from north to south. These geologic provinces are inferred to represent several stages of continental expansion that occurred by processes of continental accretion and intrusions of igneous rock (e.g., granite); and continental rifting related to partial continental breakup. The tectonic chronological overview below is drawn from the studies of Charpentier (1987), Howell and van der Pluijm (1990), Sims and Carter (1996), Braschayko (2005), Sims et al. (2005), Schulz and Cannon (2007), Whitmeyer and Karlstrom (2007), Cannon et al. (2008), Garrity and Soller (2009), and Hammer et al. (2011).

The Superior or Southern Province of the Canadian Shield in northern Wisconsin forms part of the Archean craton that preserves rocks ranging in age from approximately 2.6 to 2.75 Ga. In the northern Wisconsin and Lake Superior region, the Superior Province (Figure 2.1-2) consists of gneiss, amphibolites, granite, and metavolcanic rock types.

The Penokean Orogen (Figure 2.1-2) in northern Wisconsin represents two phases of accretion to the southern margin of the Canadian Shield in this part of North America. Approximately 1.86-1.84 Ga ago, the Pembrine-Wausau Terrane, a volcanic arc, accreted to the Canadian Shield along an east-northeast-trending suture zone. Then approximately 1.84-1.82 Ga, the Marshfield Terrane, composed of Archean crust, accreted to the Pembrine-Wausau Terrane.

The processes of continental accretion continued as the Yavapai Province, included in the Central Plains Orogen (Figure 2.1-2) of southern Wisconsin, accreted to the Penokean Orogen terranes approximately 1.76-1.72 Ga. The Yavapai Province represents an assemblage of oceanic volcanic arc rocks as inferred by the abundance of rhyolite and granite rocks preserved within the Province. In southern Wisconsin, quartzite deposits with an approximate age of 1.7 Ga were deposited as the siliceous rhyolite and granite rocks were eroded and deposited in local sedimentary basins.

Following the accretion of the Yavapai Province, the Mazatzal Province of southern Wisconsin and northern Illinois accreted to the Yavapai Province approximately 1.69-1.65 Ga. Accretion occurred along a northeast-striking (northwest vergent) suture zone (Figure 2.1-2). The Mazatzal Province rocks, included in the Central Plains Orogen, represent volcanic and related sedimentary rocks that formed at the then-active continental margin. Intrusion of granite-rhyolite rocks into the Penokean Orogen terranes, and Yavapai and Mazatzal Provinces along the southern Wisconsin border region and in northern Wisconsin, occurred at approximately 1.48-1.35 Ga.

At approximately 1.1-1.2 Ga, a period of continental breakup resulted in the development of the Mid-Continent Rift (Figure 2.1-2). While the rifting ultimately failed to fully break up this part of North America, it left a major geologic and geophysical region known as the Mid-Continent Rift (MCR). The MCR can be traced north from Michigan up through Lake Superior, then southwest through northern Wisconsin and the Midwest of the United States (Figure 2.1-2). Rocks associated with the MCR include flood basalt, rhyolite, sandstone, and gabbroic assemblages. In addition, several northeast-striking normal faults developed in southern Wisconsin as part of intracontinental extension within the Marshfield Terrane, Yavapai and Mazatzal Provinces, 1.7 Ga quartzite deposits, and 1.48-1.35 Ga granite-rhyolite rocks.

During the Paleozoic Era, the Michigan Basin formed and accumulated substantial thicknesses of Cambrian to Pennsylvanian sedimentary deposits (540 to 300 million years [Ma] ago) (Figure 2.1-3). The Michigan Basin is one of several basins in the Midwest that contain predominantly Paleozoic sedimentary rocks underlain by Precambrian basement rock units. Models for the formation of the Michigan Basin include post-rifting thermal subsidence, tectonic reactivation of pre-existing crustal structures, and regional subsidence influenced by the active Appalachian Orogeny farther east. Three major structures that controlled the western margin of the Michigan Basin are present in Wisconsin—the Wisconsin Dome in northern Wisconsin, the north-trending Wisconsin Arch in the southern portion of the state and trending into northern Illinois, and the northwest-trending Kankakee Arch in northern Illinois and Indiana.

2.1.3) Bedrock Geology

The Proterozoic basement rocks beneath and surrounding the SHINE site are parts of the Marshfield, Penokean, Yavapai, Mazatzal Provinces/Terranes (Figure 2.1-2), as well as local quartzite and granite-rhyolite intrusive rocks that, in general, are overlain by Paleozoic marine sedimentary rocks. The following discussion of regional bedrock for the project region, including stratigraphy and lithology, is based on geological maps prepared by Mudrey et al. (1982) and Garrity and Soller (2009). Figure 2.1-4 shows the mapped bedrock geology of the project region.

The oldest rocks in the project region occur in the north (Figure 2.1-4), consisting of isolated Early Proterozoic quartzite and felsic volcanic rocks, and the Middle Proterozoic Wolf River Batholith. The oldest Phanerozoic sedimentary rocks generally occur in the northwest, but are also locally present where younger bedrock units have been eroded away, or where the older bedrock has been locally uplifted along major faults. Cambrian sedimentary rocks composed of sandstone, dolomite, and shale represent the oldest Phanerozoic bedrock units. Flanking the eastern and southern margins of the Cambrian bedrock units are Ordovician shale, dolomite, and sandstone, with additional limestone and conglomerate units. The Ordovician units are in turn flanked to the south and east by Silurian dolomite. Along the southern portion of the project area, upper Devonian and Pennsylvanian limestone, sandstone and clay rocks have been mapped. Upper Devonian and lower Mississippian carbonate, sandstone and shale rocks are preserved along the eastern portion of the project area.

2.1.4) Structural Geology

We summarize the structural geology of the SHINE site region in terms of major faults and folds. The summary commences with structures mapped in Wisconsin and then continues clockwise through Michigan, Indiana, Illinois, Iowa, and Minnesota (Figure 2.1-3). Additionally, we describe and discuss the development of regional structural basins and arches. Basement faults mapped in Rock County are discussed separately in Section 2.2.2. Faults are described in terms of "capable faults" per 10 CFR Part 100, Appendix A.

Several faults have been mapped in the Wisconsin portion of the SHINE project region. In Waupaca County, an unnamed, east-northeast-striking, approximately 19-mile-long (31 km) normal fault (south side down) was interpreted by Sims et al. (1992) to mark the contact between early Proterozoic rhyolite and Waupaca granite of the 1.470 Ga Wolf River Batholith (Figure 2.1-3). Mudrey et al. (1982) present an alternative interpretation that this fault offsets only Cambrian and Ordovician sedimentary units. Based on the similar length, strike, and mapped location of this fault with respect to faults discussed below, we conclude that this unnamed fault is not a "capable" fault.

The Waukesha fault of southeastern Wisconsin is a northeast-striking normal fault (southeast side down) mapped to occur with Silurian and possibly Ordovician sedimentary rock units (Mudrey et al., 1982) (Figure 2.1-3). Fault length estimates range from 38.5 miles (62 km) to 133 miles (214 km), with multiple strands or splays possible (see Braschayko, 2005). Based on the interpretation of Exelon (2006a), there is no evidence that the Waukesha fault or associated minor faults have Pleistocene or post-Pleistocene displacement. We conclude, therefore, that these faults are not "capable" faults.

The Madison fault is mapped as an east-striking, approximately 8-mile-long (13 km) fault by Mudrey et al. (1982) (Figure 2.1-3). From Exelon (2006a), two fault segments of the Madison fault are inferred: a northern segment with north side downthrown 40 to 75 feet (12.2 to 23 m), and a southern segment with south side downthrown 85 to 125 feet (26 to 38 m). Both fault segments lack evidence for Pleistocene or post-Pleistocene displacement. We conclude, therefore, that the Madison faults are not "capable" faults.

Located in the southwestern corner of Wisconsin, plus adjacent portions of Iowa and Illinois, the Upper Mississippi Valley mining district contains folds with southeast-, east- and northeast-trending fold axes. These folds include the Mineral Point and Meekers Grove anticlines, and Galena syncline (Exelon, 2006a; 2006b) (Figure 2.1-3). The northeast-striking Mifflin fault is approximately 10 miles (16 km) long and is located on the northeast limb of the Mineral Point anticline (DPC, 2010). The Mifflin fault has at least 65 feet (20 m) of vertical separation (northeast side down) and about 1,000 feet (305 m) of strike-slip separation, with the most recent fault movement estimated to have occurred from 330 Ma to 240 Ma (DPC, 2010). The last movement on the Mineral Point and Meekers Grove anticlines is estimated by Exelon (2006a) as Late Paleozoic in age. We conclude, therefore, that the Mifflin fault, and Mineral Point and Meekers Grove anticlines are not "capable" faults.

Major faults within the bedrock of Michigan have not been identified by Garrity and Soller (2009), or in northwestern Indiana by Nelson (1995). Thus, the potential for "capable" faults in these areas is not considered further.

In northeastern Illinois, a northwest-striking fault zone with Precambrian basement downthrown to the southwest 900 feet (274 m) has been mapped in the Chicago area by Exelon (2006a) and DPC (2010). The most recent fault offset may be pre-middle Ordovician in age. An additional interpretation by DPC (2010) suggests that the Precambrian basement is not offset and this fault may not be present. An additional 25 minor faults are identified in the subsurface of Cook County. The location and existence of these faults is based on the interpretation of subsurface seismic data. The interpretations indicate up to 55 feet (17 m) of vertical displacement at faults dated as post-Silurian and pre-Pleistocene in age (DPC, 2010) (Figure 2.1-3). None of these faults have evidence of displacement of the present-day ground surface. We conclude, therefore, that the Chicago area and Cook County faults are not “capable” faults.

The Sandwich fault zone in northern Illinois is a northwest-striking, approximately 85-mile-long (137 km), normal fault system with a generally down-to-the-northeast sense of vertical displacement, and up to approximately 330 feet (100 m) of vertical separation (Kolata et al., 2005; DPC, 2010) (Figure 2.1-3). There are also mapped anticlines with fold axes parallel to the fault system (Exelon, 2006b). The most recent movement is constrained to post-Silurian time and pre-Pleistocene (DPC, 2010), or post-Pennsylvanian and pre-Pleistocene (Exelon, 2006a). Based on felt intensities, the earthquakes of May 26, 1909 and January 2, 1912 may be related to the Sandwich fault zone within the Precambrian basement (Larson, 2002; Exelon, 2006a). However, the lack of surface rupture in the last 35,000 years, and lack of microearthquake activity associated with the fault suggests that the Sandwich fault is not a “capable” fault.

The La Salle anticlinorium is a northwest-trending, series of folds in northern Illinois, and is located on the eastern flank of the Illinois Basin (DPC, 2010) (Figure 2.1-3). Faults may be present on the west flank of the anticlinorium and exhibit pre-Cretaceous movement (DPC, 2010). The major movement of the fold belt is post-Mississippian (Exelon, 2006a). Larson (2002) suggested that three historic earthquakes in 1881, 1972, and 1999 may have been generated on faults associated with the northwest-trending Peru monocline that is part of the La Salle anticlinorium. Larson suggests that these moderate earthquakes may indicate that some faults within this larger Paleozoic structure could be in the process of reactivation within the present-day stress field. The lack of surface rupture in the last 35,000 years, and lack of microearthquake activity associated with the faults related to folds suggests that the faults associated with the La Salle anticlinorium are not “capable” faults.

In northern Illinois and eastern Iowa, the Plum River fault zone is an approximately 150-mile-long (241 km), east-northeast-striking fault and fold system (DPC, 2010; Witzke et al., 2010) (Figure 2.1-3). The faults have en-echelon segments with 100 to 400 feet (30 to 122 m) of vertical, down-to-the-north separation. Exelon (2006b) recognizes synclines and anticlines that are parallel to the fault system. The last movement on the fault zone is constrained between post-middle Silurian and pre-middle Illinoian (DPC, 2010). No evidence of Quaternary activity has been identified on the Plum River fault zone by Exelon (2006a). Based on the lack of confirmed Quaternary movements, we conclude that the faults associated with the Plum River fault zone are not “capable” faults.

To the south of the Plum River fault zone, the Iowa City-Clinton fault zone follows a similar east-northeast strike to that of the Plum River fault zone (Witzke et al., 2010) (Figure 2.1-3). The Iowa City-Clinton fault zone has a south-side-down sense of vertical separation. The Iowa City-Clinton fault zone has not been mapped in Illinois (Kolata et al., 2005). There is no known evidence for displacement during the Quaternary Period along mapped traces of the Iowa City-Clinton fault zone. Based on similar geometries and physiographic settings for both fault zones, we conclude that faults associated with the Iowa City-Clinton fault zone are not “capable” faults.

Located in the southeast corner of Minnesota, several northwest-to northeast-striking faults up to approximately 9 miles (14 km) long offset Cambrian to Ordovician sedimentary units in the Yavapai Province (Jirsa et al., 2011) (Figure 2.1-3). DPC (2010) completed a study of facility site characteristics at a boiling water reactor south of Genoa, Wisconsin. They concluded that faults within a 200-mile (322 km) radius of the site are at least pre-Pleistocene in age and, therefore, are not “capable” faults. They note that the closest mapped fault to the Genoa project site “... of any size…” is the Mifflin fault. While the faults of Jirsa et al. (2011) are not specifically mentioned in DPC (2010), we conclude based on DPC (2010) that the faults in the southeast corner of Minnesota are not “capable” faults.

The faults and folds described above have developed during the formation and development of a series of regional basins, arches and domes (Figure 2.1-3). The Michigan Basin contains Cambrian to Pennsylvanian sedimentary deposits (540 Ma to 300 Ma). The Illinois Basin is located to the southwest of the SHINE site. The last known major tectonic movements occurred in the Michigan Basin in the early to late Proterozoic (Exelon, 2006a). The Wisconsin Dome is located in the northern portion of Wisconsin, to the west of the Michigan Basin (Heyl et al., 1978). Separating the basins and domes are several structural arches. The Wisconsin Arch trends south from the Wisconsin Dome and had its last major tectonic movements in the early to late Paleozoic (Exelon, 2006a). The Kankakee Arch in northern Illinois forms the southwestern margin of the Michigan Basin (Howell and van der Pluijm, 1990), and had its last major tectonic movements in the Ordovician to Pennsylvanian (Exelon, 2006a). The Mississippi River Arch to the west of the Illinois Basin had its last major tectonic movements in the post-early Pennsylvanian (Exelon, 2006a).

2.1.5) Magnetic and Gravity Geophysical Anomalies

Maps and interpretations of geophysical magnetic and gravity anomalies have been used by others to summarize the geologic interpretations of geophysical anomalies for the project region. Much of the published literature focuses on areas in central and northern Wisconsin, such as the MCR, Penokean fold belt, and Wolf River Batholith (e.g., Klasner et al., 1985; Chandler, 1996).

We reviewed five principal sources of magnetic anomaly data: the magnetic anomaly map of North America (NAMAG, 2002); subsequent interpretation of Precambrian basement by Sims et al. (2005); the Earth magnetic anomaly grid (Maus et al., 2009); the Wisconsin composite aeromagnetic map of Daniels and Snyder (2002); and a magnetic anomaly map of Illinois from Daniels et al. (2008).

Figure 2.1-5 is the magnetic anomaly map from Maus et al. (2009) with interpretation of Precambrian basement structures from Sims et al. (2005). The magnetic anomalies have been interpreted by Sims et al. (2005) to illustrate the major tectonic features such as the MCR and major basement faults. Sims et al. (2005) also infer several northeast-striking ductile shear zones (faults in the mid to lower crust) and northwest-striking high-angle faults. They suggest that these basement structures are of late Paleoproterozoic-Mesoproterozoic age (1.76-1.70 Ga), and were the result of northwest-southeast shortening of the crust at that time. These shear zones probably bound the 1.76-1.65 Ga belt of rhyolite-quartz arenite to the north of the SHINE site. To the south of this belt of siliceous rocks, the Eastern granite-rhyolite province (1.5-1.4 Ga) is preserved and continues into Illinois. The SHINE site is located within the Eastern granite-rhyolite province. Figure 2.1-6 is a large-scale map of uninterpreted magnetic anomalies of Wisconsin and northern Illinois (Maus et al., 2009).

We reviewed three principal sources of gravity anomaly data for the region: the Bouguer gravity anomaly map of the conterminous United States presented by Kucks (1999), the Bouguer gravity anomaly map of Wisconsin prepared by Daniels and Snyder (2002), and a Bouguer gravity anomaly map of Illinois (Daniels et al., 2008). Interpretation of the gravity maps suggests that the southern margin of the central Wisconsin gravity low is possibly the northeast-trending shear zone that marks the boundary between the rhyolite-quartz arenite belt and Eastern granite-rhyolite province. Figures 2.1-7 and 2.1-8 are uninterpreted Bouguer gravity anomaly maps on the regional scale, and display Wisconsin and northern Illinois, respectively. These maps show the MCR as a strong positive anomaly because it is a region of dense volcanic and igneous rocks surrounded by lower-density sedimentary rocks. The Wolf River Batholith is interpreted by Chandler (1996) to be the source of the large negative gravity anomaly in central Wisconsin.

2.1.6) Surficial Geology and Glacial History

The surficial geology of the SHINE project region is controlled principally by processes associated with the advance and retreat of Pleistocene glaciers, and processes such as erosion and sedimentation that followed the retreat of glacial ice (post-glacial). Several major periods of Pleistocene ice advance are recognized in northern North America. These Pleistocene glaciations are known as the pre-Illinoian, Illinoian (also referred to as pre-Wisconsin), and Wisconsin (Roy et al. 2004) glaciations. Figure 2.1-9 is a map of the surficial geology of the SHINE project region as modified from Fullerton et al. (2003). Figure 2.1-10 indicates the estimated thickness of overburden and drift for Wisconsin and northern Illinois (Piskin and Bergstrom, 1975; WGNHS, 1983). The following summary is based on physiographic divisions from the USGS (2003), and summaries of the surficial geology and glacial history described by USDA SCS (1974), Fullerton et al. (2003), WGNHS (2004), Clayton and Attig (2007), and MLRA (2012).

The oldest known landform in the project region is the unglaciated Wisconsin Driftless section of the Central Lowland Province. The Wisconsin Driftless section contains relatively rugged, fluvially-dissected topography with about 600 feet (180 m) of topographic relief. Based on its geomorphology and lack preserved glacial deposits, the Wisconsin Driftless section has not been glaciated. In Dane County, Wisconsin, the Driftless section comprises near-horizontal Paleozoic sedimentary rocks that are locally mantled by Pleistocene deposits of windblown (eolian) and hillslope sediments.

Landforms composed of glacial deposits that formed during the Illinoian and Wisconsin Glaciations are present within the SHINE site region. During the Wisconsin Glaciations, the Laurentide Ice Sheet flowed south and comprised several ice lobes, including the Green Bay and Lake Michigan ice lobes that flowed over the SHINE site region. Glacial till was deposited from these ice lobes as basal and end moraines. Sand and gravel were transported from the edges of the glacial ice across to form extensive glacial outwash fan surfaces. Fine-grained sediments (silt and clay) were deposited within proglacial lakes near the ice margins and within the outwash plain. The maximum extent of the Wisconsin Glaciation ice occurred approximately 30,000 years ago. Ice was absent from the area of the state of Wisconsin by about 11,000 years ago (Attig et al., 2011). Alluvial and wind processes reworked the glacial deposits during the Holocene Epoch (last 10,000 years) during and following ice retreat.

With the retreat and almost complete melting of the Laurentide ice sheet, land surfaces of North America experienced a period of adjustment (known as glacial isostatic adjustment, or GIA) that continues to the present day. In GIA, slow movements occur in the highly viscous mantle, in response to the loading and unloading of the Earth's surface. In North America, GIA is still causing vertical movements of the land surface because of the removal of significant volumes of ice more than 10,000 years ago. Based on Global Positioning System (GPS) measurements, Sella et al. (2007) established a hinge line in the Great Lakes vicinity; north of the line, uplift from GIA is still occurring (e.g., 10 mm/yr of present day uplift at Hudson Bay, Canada), while south of the line subsidence of up to 2 mm/yr is ongoing. Based on the GIA model of Sella et al. (2007), Wisconsin has 0 to 2 mm/yr of ongoing subsidence. This subsidence is, however, regional in nature and not expected to result in any differential movements across the SHINE site.

2.1.7) Conclusion

Golder's review of the regional geological stratigraphy, structure, and tectonics found no positive evidence that the region's major geologic structures have experienced any significant tectonic movements in Quaternary time (over the last 1.8 million years). Geologic and geophysical structures are preserved in the pre-Phanerozoic basement rocks and appear related to major episodes of continent accretion and breakup before about 500 million years ago.

We identified several structures that appear to deform the Paleozoic rocks in the SHINE region: the Sandwich fault zone, the La Salle anticlinorium, several small and limited-length faults, and the regional Wisconsin and Kankakee Arches. The Wisconsin and Kankakee Arches are regional-scale, long wavelength tectonic features that appear related to crustal adjustment during and following the filling and development of the Michigan Basin more than 300 million years ago.

The bedrock faults such as the Sandwich and Plum River fault zones appear to have generated vertical offset of the Paleozoic rocks, indicating that the fault movements post-date the filling of the Michigan Basin. We found no evidence, however, that either of these faults has propagated upward into the Late Wisconsin sediments and/or to the ground surface. The lack of surface traces for these faults suggests that there has been no significant displacement of the faults at the ground surface for perhaps 35,000 years. The pattern of historical seismicity of the region does not demonstrate a positive alignment of the few known epicenters that might indicate ongoing seismic activity and reactivation of these older structures by the present-day stress field. The epicenter of the E[**M**] 5.15 earthquake in 1909 estimated by Bakun and Hopper (2004) is, however, close to the mapped trace of the Sandwich fault within the Paleozoic rocks of northern Illinois (Figure 3.1-1). It is not clear, however, whether the single, moderate-magnitude earthquake indicates reactivation of the Sandwich fault zone, or if it was generated by localized strain release on some other small-scale fault.

Based on our review of and interpretation of available literature and data, including USNRC documents for other sites, we have not found any evidence for "capable" faults within approximately 124 miles (200 km) of the SHINE site.

2.2) Site Geology

This section is a summary the geologic setting, stratigraphy and structure within about a 6 mile (10 km) radius of the SHINE site.

2.2.1) Geologic History of SHINE Site

As described in the previous Section *2.1 Regional Geology*, the Precambrian basement rocks originated as geologic terranes were accreted to the North American continent prior to about 1.48-1.35 Ga. During the Paleozoic Era, the region lay within a large continental marine area where shallow deposits of marine sediments accumulated within the Michigan Basin. Development of the Wisconsin Arch resulted in the formation of long wavelength, open regional folds within the Cambrian through Ordovician sedimentary rocks.

Based on the geologic maps by Mudrey et al. (1982) and Cannon et al. (1999), we infer that the bedrock beneath the SHINE site is Cambrian-age sandstone with some dolomite and shale (Figure 2.1-4). The sedimentary rocks of the Michigan Basin and Wisconsin Arch overlie Archean and Proterozoic volcanic and associated basement rocks that were intruded by a 1.48-1.35 Ga granite-rhyolite intrusive episode (Whitmeyer and Karlstrom 2007). These basement units are part of the Yavapai or Mazatzal Province/Terrane (Figure 2.1-2).

The mapped bedrock geology in the vicinity of the project site is composed of the Ordovician Period Prairie du Chien Group (dolomite with some sandstone and shale), Ancell Group (sandstone with minor limestone, shale, and conglomerate), and Sinnippee Group (dolomite with some limestone and shale). From Mudrey et al. (1982), the Ordovician sedimentary rock sequence is approximately 200 feet (60 m) thick, and underlain by an estimated 1,000 feet (300 m) of Cambrian sedimentary rock, that in turn overlies the Precambrian basement rocks.

The surficial geology of Rock County consists of the Wisconsin-age Jonestown moraine to the north. This moraine was formed at the margins of the Green Bay ice lobe. The remainder of the county contains Illinoian-age ground moraine deposits that in places were dissected by southward flowing Late Wisconsin outwash streams. The stream valleys now contain Late Wisconsin- and possibly Holocene-age glaciofluvial outwash deposits (Fullerton et al., 2003; RCGIS, 2012). The Green Bay ice lobe also produced paleo-lakes Yahara and Scuppernong with outflow that extended through the Rock River drainage basin (Clayton and Attig, 1997).

Soil mapping at and surrounding the project site shows Warsaw and Lorenzo well-drained, loamy soils underlain by stratified sand and gravel at depths of approximately 10 to 40 inches (0.25 to 1 m) (USDA SCS, 1974; RCGIS, 2012). The sand and gravel units represent outwash plains and terrace deposits.

Two estimates of depth to bedrock at the SHINE site are available: an estimate of 200-300 feet (60-90 m) from WGNHS (1983), and an estimate of 100 to 300 feet (30-90 m) from Mudrey et al. (1982). A third estimate is available from Winnebago County, Illinois at the Illinois-Wisconsin state border about 8.7 miles (14 km) south of the SHINE site. At this border, topographic contours to top of bedrock range from 500 feet to 700 feet (152 to 213 m) elevation in the Rock River Valley (McGarry, 2000).

Review of the borehole logs from the SHINE site (Golder, 2012a) indicates that the depth to bedrock at the site is more than 221 feet (67.4 m) below ground surface (bgs). Subsurface conditions include about 1 foot of topsoil and crop residue overlying a relatively clean, fine to coarse grained sand that extends to depths of 180 to 185 feet (54.9 to 56.4 m) bgs, followed by 10 to 18 feet (3.1 to 5.5 m) of sandy silt, and finally silty sand to 221 feet (67.4 m) bgs. The sediments underlying the site are predominantly sand derived from fluvial reworking of glacial outwash deposits. We interpret from the lack of weathering and near-surface sand density that the sediments are Late Wisconsin to Holocene in age.

2.2.2) Structural Geology

The SHINE project site is located near the axis of the Wisconsin Arch (Charpentier, 1987) (Figure 2.1-3). Despite the presence of the arch, cross sections from Mudrey et al. (1982), suggest that Cambrian and Ordovician sedimentary rock units beneath the site probably have shallow to horizontal dips. These data indicate little or no net deformation beneath the site over about the last 500 million years.

Two east-striking faults within Cambrian to Ordovician sedimentary bedrock are identified in Rock County by Mudrey et al. (1982). The Janesville fault (also named the Evansville fault) consists of an approximately 19-mile-long (31 km), east-striking fault with north side down (DPC, 2010) located approximately 6 miles (10 km) north of Janesville (Figure 2.1-3). This fault is identified as the predominant fault segment, with a second segment striking to the north (DPC, 2010). We assume that an estimated 70 feet (21.3 m) of displacement for the downthrown side (Exelon, 2006a) of the Janesville fault is associated with the primary east-striking fault segment. There is no evidence of Pleistocene or post-Pleistocene activity on the Janesville fault (Exelon, 2006a). We conclude that the Janesville fault is not a “capable” fault.

An unnamed, approximately 1.6-mile-long, (2.6 km) east-trending fault in Rock County is located approximately 1.9 miles (3.1 km) north of Janesville (Mudrey et al., 1982) (Figure 2.1-4). We are unable to identify the type or amount of fault displacement from our review of the available literature. Based on this unnamed fault’s similar orientation and location with respect to the Janesville fault, we conclude that this unnamed fault is also not a “capable” fault.

3.0) Historical Seismicity

This section describes the history of recorded and felt earthquakes in southern Wisconsin-northern Illinois based on online earthquake catalogs and databases, and peer-reviewed publications on specific earthquake events. These data are taken at face value because we have not undertaken any additional earthquake-specific studies, interpretations or reconciliation of any location or magnitude conflicts and errors within and between earthquake catalogs.

3.1) Historic Earthquakes

We developed a project-specific catalog of historic earthquakes for the SHINE site by searching several earthquake databases and published references on the location and intensity of historic earthquakes. Earthquake records were gathered for a search area extending from 40.5° to 45° north latitude, and 86° to 92° west longitude, and then filtered to include only those records located within a 124-mile (200 km) radius of the SHINE site at 42.624136° north latitude, 89.024875° west longitude. The following earthquake databases and references were reviewed in the initial phase of catalog development:

- Worldwide ANSS (Advanced National Seismic System) Composite Catalog (ANSS, 2012): The catalog is created by merging the master earthquake catalogs from contributing ANSS institutions and then removing duplicate solutions for the same event.

- USGS/NEIC 1973 to Present Preliminary Determination of Epicenters Catalog (PDE) (USGS, 2012d): The catalog includes earthquakes located by the U.S. Geological Survey National Earthquake Information Center (NEIC).

- Significant U.S. Earthquakes (USHIS) 1568-1989 (USGS, 2012d): The catalog is from the NEIC based on Stover and Coffman (1993).

- Eastern, Central, and Mountain States of the United States, 1350-1986 (SRA) (USGS, 2012d): The catalog is from the NEIC based on Stover et al. (1984).

- National Center for Earthquake Engineering Research (NCEER) Group (NCEER, 2012): Catalog of central and eastern United States earthquakes from 1627 to 1985 (Armbruster and Seeber, 1992).

- U.S. Geological Survey reports on central United States earthquakes and earthquake information by state: Bakun and Hopper (2004), Dart and Volpi (2010), Stover and Coffman (1993), Wheeler (2003), Wheeler et al. (2003), USGS (2012f).

- Review of significant Canadian earthquakes from 1600-2006 (Lamontagne et al., 2008) and Natural Resources Canada earthquake information (NRC, 2012).

- Centennial Catalog (Engdahl and Villaseñor, 2002): A global catalog of earthquakes from 1900 to 2008.

Because of numerous inconsistencies within and between various databases and references (e.g., different epicenter locations for a given earthquake), we conducted a second phase of review on the Central Eastern United States earthquake catalog (CEUS-SSC, 2012). This earthquake catalog was compiled as part of studies to develop a new characterization model for seismic sources in the Central and Eastern United States. The catalog contains records of earthquakes documented from 1568 to 2008. Earthquakes from various magnitude scales were recalculated to a uniform magnitude scale using moment magnitude (**M**). Based on the uncertainty of assessment, the recalculated magnitudes for historic earthquakes are termed expected moment magnitude (E[**M**]) in the CEUS-SSC (2012) catalog. The primary benefits of using the CEUS-SSC (2012) catalog to develop the project-specific SHINE catalog include a) using a single earthquake database that has been compiled and reviewed under uniform procedures, and b) obtaining uniform earthquake magnitudes for the project-specific database with E[**M**] values.

Based on the CEUS-SSC (2012) catalog, we developed the following project-specific catalog containing 35 records of historic earthquakes with epicenters located within about 124 miles (200 km) of the SHINE site. This project-specific catalog is presented in Table 3.1-1, and includes earthquake magnitudes ranging from E[**M**] 2.32 to 5.15. Four events are assigned depths of 5 or 10 km, with the remaining depths assigned a depth 0 km. We note that the October 22, 1909 and October 17, 1913 earthquake epicenters have the same latitude and longitude coordinates.

Table 3.1-1 Historic Earthquake Epicenters Located Within Approximately 124 Miles (200 km) of the SHINE Site

Year[1]	Month[1]	Day[1,2]	Latitude (°N)[1]	Longitude (°W)[1]	Depth[1] (km)	Expected Moment Magnitude (E[M])[1]	Approximate Distance from Epicenter to SHINE Site (km)[3]
1804	8	20	42.0	87.8	0	4.18	122
1804	8	24	42	89	0	4.12	69
1861	12	23	42.09	87.98	0	2.98	105
1869	8	17	41.56	90.60	0	2.32	176
1876	5	22	41.29	89.51	0	3.31	154
1881	5	27	41.3	89.1	0	4.44	147
1892	8	4	42.68	88.28	0	2.79	61
1895	10	7	41.1	89.0	0	3.31	169
1897	12	3	43.1	89.8	0	3.92	83
1897	12	3	42.4	90.4	0	3.31	116
1907	11	28	42.3	89.8	0	2.77	73
1909	5	26	41.6	88.1	0	5.15	137
1909	10	22	41.8	89.7	0	2.98	107
1911	7	29	41.8	87.6	0	2.98	149
1912	1	2	42.3	89.0	0	4.38	36
1912	9	25	42.3	89.1	0	2.32	37
1913	10	17	41.8	89.7	0	3.38	107
1914	10	7	43.1	89.4	0	2.65	61
1922	7	7	43.8	88.5	0	4.1	137
1928	1	23	42	90	0	3	106
1933	12	7	42.9	89.2	0	3.03	34
1934	11	12	41.5	90.5	0	3.73	175
1942	3	1	41.2	89.7	0	3.48	168
1944	3	16	42.0	88.3	0	2.61	92
1947	3	16	42.1	88.3	0	2.65	83
1947	5	6	43.0	87.9	0	3.53	101
1948	1	15	43.1	89.7	0	2.65	76
1956	7	18	43.6	87.7	0	2.65	153
1956	10	13	42.9	87.9	0	2.65	97
1957	1	8	43.5	88.8	0	2.32	99
1972	9	15	41.64	89.37	10	4.08	113
1981	6	12	43.9	89.9	0	2.65	159
1985	9	9	41.848	88.014	5	2.91	120
1999	9	2	41.72	89.43	5	3.41	106
2004	6	28	41.44	88.94	5	4.13	132

Notes:
1 Data from CEUS-SSC (2012) source file: CEUS_EQ_Catalog_R0.shp
2 Day is based on time with respect to Coordinated Universal Time (UTC), not local time.
3 Distance (ellipsoidal) estimated based on SHINE site location at 42.624136° N, 89.024875° W.

In the project-specific catalog, the largest earthquake is the May 26, 1909 E[**M**] 5.15 event located approximately 85 miles (137 km) southeast of the SHINE site. The largest earthquake since the 1970s is the June 28, 2004 E[**M**] 4.13 event located approximately 82 miles (132 km) south of the SHINE site. The closest earthquake epicenter to the SHINE site is the December 7, 1933 E[**M**] 3.03 event located approximately 21 miles (34 km) to the northwest.

The project-specific catalog indicates that in general, the region surrounding the SHINE site has an historic record of relatively infrequent, small to moderate earthquakes that is typical of much of the central and eastern United States.

3.2) Felt Intensities

In addition to recorded earthquake epicenters, information is also available on how earthquake shaking has been experienced by people located in Janesville and other communities near the SHINE site. The experience of earthquake shaking by people and a qualitative assessment of damage is measured on the Modified Mercalli Intensity scale (MMI). Table 3.2-1 provides a description of MMI levels of intensity from USGS (2000). While the quality of the measurements is highly variable depending on the skills of the observer and the quality of local engineered and non-engineered structures, the MMI scale nevertheless provides a reasonable estimate of the occurrence of moderate and large earthquakes before the development of a network of recording instruments.

Table 3.2-1 Modified Mercalli Intensity

Level	Abbreviated Description
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Notes:
Reference: USGS (2000).

The National Geophysical Data Center (NGDC) of the National Oceanic and Atmosphere Administration (NOAA) developed the National Earthquake Intensity Database (NEID), which is a collection of records of damage and felt reports from more than 23,000 U.S. earthquakes (NEID, 2012). The database contains information regarding earthquake epicentral coordinates, estimated magnitudes, and focal depths, names and coordinates of reporting cities (or localities), reported intensities, and the distance from a city (or locality) to the epicenter. Earthquakes listed in the NGDC database date from 1638 to 1985. From 1985 onward, the reports of earthquake shaking are maintained by the U.S. Geological Survey.

Earthquake shaking intensity records within approximately 124 miles (200 km) of the SHINE site from NEID (2012) contain reports from eight earthquakes that occurred from 1928 to 1985. We developed the composite dataset listed in Table 3.2-2, consisting of the earthquake location and expected moment magnitude from the CEUS-SSC (2012) database, plus the event MMI values from the NEID (2012) database and other sources cited in the table. The eight earthquakes listed in Table 3.2-2 are shown in Figure 3.1-1. An estimated MMI value of V at the SHINE site accompanied the 1909 E[**M**] 5.15 earthquake located approximately 85 miles (137 km) to the southeast, and accompanied the 1972 E[**M**] 4.08 earthquake located approximately 70 miles (113 km) to south-southwest (Table 3.2-2).

Table 3.2-2 Recorded Earthquake Intensities (Modified Mercalli Intensity – MMI) for Earthquakes Within Approximately 124 Miles (200 km) of the SHINE Site

Year[1]	Month[1]	Day[1,2]	Earthquake				Approximate Distance from Epicenter to SHINE Site (km)[4]	MMI at SHINE Site (Reported or Estimated)
			Lat (° N)[1]	Long (°W)[1]	MMI[3]	Expected Moment Magnitude (E[M])[1]		
1804	8	24	42	89	VI	4.12	69	-
1909	5	26	41.6	88.1	VII	5.15	137	V[5]
1912	1	2	42.3	89	III	4.38	36	Felt In Madison and Milwaukee[6]
1928	1	23	42	90	IV	3.00	106	-
1942	3	1	41.2	89.7	IV	3.48	168	-
1972	9	15	41.64	89.37	VI	4.08	113	V[7]
1985	9	9	41.848	88.014	V	2.91	120	-
1985	11	12	41.85	88.01	III	-	120	-

Notes:
1. Data from CEUS-SSC (2012) source file: CEUS_EQ_Catalog_R0.shp; except 11/12/1985 data from NEID (2012).
2. Day is based on time with respect to Coordinated Universal Time (UTC), not local time.
3. Maximum MMI for earthquake from NEID (2012) data.
4. Distance (ellipsoidal) estimated based on SHINE site location at 42.624136° N, 89.024875° W.
5. From Bakun and Hopper (2004).
6. From (USGS, 2012f), Wisconsin Earthquake History.
7. From NEID (2012) data for Janesville, Wisconsin (42.68° N, 89.02° W).

We also reviewed historic earthquake reports and isoseismal maps for the central United States from 1568 to 1989 (Stover and Coffman 1993), 1827 to 1952 (Bakun and Hopper, 2004), and United States earthquake information by state and territory (USGS, 2012f). In addition, we reviewed a summary of significant Canadian earthquakes from 1600 to 2006 (Lamontagne et al., 2008; NRC, 2012). Table 3.2-3 lists historic earthquakes with epicenters greater than 124 miles (200 km) from the SHINE site where earthquake shaking was reported as felt or inferred to have been felt in the SHINE site area. Similar to Table 3.2-2, we developed the composite dataset listed in Table 3.2-3 with event location and estimated moment magnitude from the CEUS-SSC (2012) database, earthquake MMI values from Stover and Coffman (1993), and estimated MMI values at the SHINE site from sources cited in the table. Depending on the level of detail in historical earthquake descriptions, we were able to estimate the MMI value at the SHINE site for some earthquakes, but only able to extract general felt intensity information for other earthquakes (e.g., “Felt in Wisconsin”). Isoseismal maps from Stover and Coffman (1993) and Bakun and Hopper (2004) representing some of the earthquakes listed in Table 3.2-3 are reproduced in Figures 3.2-1 through 3.2-6.

Table 3.2-3 Recorded Earthquake Intensities (Modified Mercalli Intensity - MMI) for Earthquakes with Epicenters farther than 124 Miles (200 km) of the SHINE Site

Year[1]	Month[1]	Day[1,2]	Earthquake					Approximate Distance from Epicenter to SHINE Site (km)[4]	MMI at SHINE Site (Estimated)
			Location	Lat (° N)[1]	Long (°W)[1]	MMI[3]	(E[M])[1]		
1811	12	16	Arkansas	36	90	X	7.17	740	V[3]
1877	11	15	Nebraska	41	97	VII	5.50	686	Felt in Wisconsin[3]
1886	9	1	South Carolina	33.0	80.2	X	6.90	1319	II-III to IV[3]; V[6]
1891	9	27	Illinois	38.3	88.5	VII	5.52	482	I-III[5] (site is may be outside this isoseismal)
1895	10	31	Missouri	37.82	89.32	VIII	6.00	534	IV[3]
1917	4	9	Illinois	37	90	VII	4.86	630	Felt in Wisconsin[3]
1925	3	1	Quebec	47.8	69.8	-	6.18	1611	III in Milwaukee and LaCrosse[7]
1935	11	1	Quebec	46.78	79.07	-	6.06	913	III[6]
1937	3	2	Ohio	40.488	84.273	VII	5.0M_{fa}	462	Felt in Milwaukee[7]
1937	3	9	Ohio	40.4	84.2	VIII	5.11	472	Felt in Milwaukee and Madison[7]
1939	11	23	Illinois	38.18	90.14	V	4.75	502	III[6]
1944	9	5	New York	45.0	74.7	VIII	5.71	1181	Felt in Wisconsin[7]
1968	11	9	Illinois	37.91	88.37	VII	5.32	526	I-III[3]; IV[6]
1974	4	3	Illinois	38.549	88.072	VI	4.29	460	I-III in southern Wisconsin[7]
1987	6	10	Illinois	38.713	87.954	VI	4.95	444	Felt in Wisconsin[3]

Notes:
1. Data from CEUS-SSC (2012) source file: CEUS_EQ_Catalog_R0.shp; except 3/2/1937 data from Stover and Coffman (1993), M_{fa} (body-wave magnitude calculated from earthquake felt area).
2. Day is based on time with respect to Coordinated Universal Time (UTC), not local time.
3. From Stover and Coffman (1993).
4. Distance (ellipsoidal) estimated based on SHINE site location at 42.624136° N, 89.024875° W.
5. From Bakun and Hopper (2004).
6. From NEID (2012) for Janesville, Wisconsin (42.68° N, 89.02° W).
7. From (USGS, 2012f), Wisconsin Earthquake History, New York Earthquake History.

The MMI values for historic earthquakes within an approximate 124-mile (200 km) radius of the SHINE site range from MMI III to MMI VII (Table 3.2-2). The largest MMI value (VII) recorded in the region was during the May 26, 1909 E[**M**] 5.15 earthquake. Figure 3.2-5 shows the isoseismal map from a detailed study of the 1909 earthquake by Bakun and Hopper (2004). The location of the estimated earthquake epicenter depends on the reference. For example, the 1909 event is located approximately 85 miles (137 km) southeast of the project site in CEUS-SSC (2012) and Stover and Coffman (1993); and 68 miles (109 km) south of the SHINE site according to the study of Bakun and Hopper (2004), and as depicted on Figure 3.2-5. For this report, we use the CEUS-SSC (2012) dataset as the primary dataset for epicenter locations for reasons discussed in Section 3.1. Thus, Figure 3.1-1 displays the felt intensity epicenter of the May 26, 1909 earthquake based on the location provided in CEUS-SSC (2012) and Stover and Coffman (1993).

Based on our review of felt intensity records for historic earthquakes (up to 1985), regional earthquakes have developed MMI values ranging from III to VII within approximately 124 miles (200 km) of the SHINE site. Greater than 124 miles (200 km) from the site, felt intensities of historic earthquakes (up to 1989) developed MMI values estimated from I to V at the SHINE site. We estimate that the maximum felt intensity experienced at the SHINE site in historical times is only moderate shaking (MMI V). MMI V intensity may have occurred at the SHINE site four times in approximately the last 200 years during earthquakes that occurred in 1811, 1886, 1909 and 1972.

3.3) Faults

We reviewed the U.S. Geological Survey Quaternary Fault and Fold Database of the United States, including the 2010 update (USGS, 2012c). This database contains no Quaternary faults or folds within an approximate 124-miles (200 km) radius of the SHINE site. Review of site aerial photographs and Google Earth™ images found no evidence for geomorphic features that indicate a Quaternary age fault within the SHINE site. Based on our review of USNRC projects in the project region, we conclude that no “capable” faults are present in Rock County, Wisconsin.

Two zones of “capable” faults are located hundreds of miles to the south of the SHINE site, the New Madrid seismic zone and the Wabash Valley region. The northern boundary of the New Madrid seismic zone is located about 400 miles (644 km) south of the SHINE Janesville site (Figure 2.1-7). The 1811-1812 earthquakes resulted in MMI V felt intensities (Figure 3.2-1). Recurrence intervals of paleoseismic events may be on the order of 400 to 1,100 years (Crone and Schweig, 1994)

The northern boundary of the Wabash Valley region is located approximately 170 miles (274 km) south of the SHINE Janesville site (Figure 2.1-7). Liquefaction studies indicate that at least seven Holocene earthquakes and one late Pleistocene earthquake may have generated on the order of moment magnitude 7.5 earthquakes (Obermeier and Crone, 1994).

3.4) Present-Day Stress Field

The World Stress Map database of Heidbach et al. (2008) contains data and interpretations for the orientation of maximum horizontal compressive stress (S_H) worldwide. For the Wisconsin-northern Illinois area, S_H has a generally northeast trend based on five measurements from five hydraulic fracture measurements and from available earthquake focal mechanism solutions. The earthquake focal mechanisms suggest that movements along reverse and strike-slip faults within the basement rocks are the source of the few historic earthquakes. There is no evidence that any of these faults have ruptured to the ground surface during the historic earthquakes.

4.0) Seismic Hazard Evaluation

Probabilistic seismic hazard analysis (PSHA) is commonly used to estimate expected levels of earthquake ground shaking for regions and for sites (e.g., McGuire, 2004). The PSHA method provides a probabilistic estimate (annual frequency of exceedance) for the specified levels of earthquake ground motion. The earthquake ground motions can be reported as peak horizontal ground acceleration (PGA) estimates, as often required for foundation or slope stability analyses, or spectral accelerations (S_a = accelerations at a specified frequency), as commonly used in most modern building codes and structural standards.

The USGS developed national probabilistic seismic hazard models in 1996, 2002 and 2008 (with minor updates in 2010) which all include Wisconsin (e.g., Petersen et al., 2008). Each update of the national probabilistic model and associated hazard maps has incorporated the latest information on fault locations and fault characteristics; historical earthquake locations, magnitudes and effects; and a range of ground motion prediction equations developed from earthquake records from the United States and around the world. The seismic hazard models can be used to estimate probabilistic PGA and S_a for any site in the conterminous United States (USGS, 2012e).

4.1) Seismic Hazard Estimates

We obtained probabilistic PGA estimates for the SHINE site based on the USGS 2008 national hazard model (USGS, 2012a) (Figures 4.1-1 through 4.1-5). For the SHINE site, the USGS 2008 model is limited to the estimation of hazard for outcropping, weak rock and hard rock sites with average shear-wave velocity profiles in the upper 100 feet (30 m) of 760 meters per second (m/s) (soft rock) or 2,000 m/s (hard rock), respectively. We used the 760 m/s value and obtained PGA estimates for five return periods from 475 years to 19,900 years as listed in Table 4.1-1 below.

Table 4.1-1 Probabilistic Estimates of PGA for Selected Return Periods at the SHINE Site for Vs30 (760 m/s) Site Class BC

Return Period (years)	PGA (g)
475	0.017
2,475	0.050
4,975	0.079
9,950	0.124
19,900	0.194

Notes:
1. m/s = meters per second
2. Parameters based on SHINE Janesville project location of 42.624°N, 89.025°W.

The PGA values listed in Table 4.1-1 indicate a low to very low earthquake shaking hazard level at the SHINE site.

4.2) Maximum Earthquake Potential

The review of historical earthquake records indicates that the maximum earthquake that has occurred during the last 200 years within 124 miles (200 km) of the site is an E[**M**] 5.15 event. Well studied historic earthquakes suggest that the strongest shaking experienced at the SHINE site is MMI V, with a maximum in the region of MMI VII. These values are typical for geologically stable, continental interior regions such as the central United States where infrequent, moderate-magnitude earthquakes occur without a clear association with known geologic structures.

A 200-year record is generally considered too short a time period to estimate the longer term earthquake potential, particularly in regions where the larger earthquakes occur infrequently. To estimate the longer term earthquake potential, we reviewed the results of the deaggregation of the 2008 USGS seismic hazard for return periods of 4,975 to 19,900 years. Figures 4.1-3 through 4.1-5 show deaggregation results for 4,975, 9,950, and 19,900 years, respectively. The deaggregation plots for the longer return periods all indicate that the major contributor to seismic hazard are earthquakes with magnitudes between about **M** 5 and 6. The PGA values for the longer return periods increase because the source earthquake has a higher probability of being close to the site.

To assess a reasonable maximum magnitude for the SHINE site and surrounding region, we reviewed the mean earthquake magnitude estimate for return periods of 4,975, 9,950 and 19,900 years. The mean earthquake magnitude for the longer return period deaggregations lies in a narrow range of about **M** 5.7 to 5.8. This magnitude is higher than the E[**M**] 5.15 maximum that is estimated to have occurred in the last 200 years within about 124 miles (200 km) of the SHINE site. We conclude, therefore, that a moment magnitude 5.8 earthquake can reasonably be regarded as the maximum earthquake magnitude to occur within the region. We note, however, that this estimate is largely qualitative because it is based only on deaggregation of the consensus 2008 national earthquake hazard model, and our review of historical earthquake magnitudes and felt intensities.

4.3) 2009 International Building Code Seismic Design Parameters

Interim Staff Guidance Augmenting NUREG 1537 Part 2 Article 6B.3 requires that the criticality accident alarm system (CAAS) be “designed to remain operational during credible events, such as a seismic shock equivalent to the site-specific, design-basis earthquake or the equivalent value specified by the Uniform Building Code.” In Wisconsin, the Uniform Building Code (UBC) has been superseded by the 2009 International Building Code (IBC, 2009). Thus, seismic design parameters for the proposed SHINE project are discussed in terms of the 2009 IBC and associated standards rather than in terms of the UBC.

Seismic provisions within the 2009 IBC Chapter 16 (IBC, 2009) and ASCE 7-05 Chapter 11 (ASCE, 2005) are based on spectral accelerations for a maximum considered earthquake (MConE) with a return period of 2,475 years (2% probability of exceedance in 50 years). Spectral acceleration values for MConE are for soil Site Class B (weak rock) soil conditions (V_s30 = 760 m/sec). For most sites, the short- (S_s) and long- (S_1) period spectral accelerations for weak rock sites (V_s30 = 760 m/sec) can be read from maps included with the code, or they can be calculated from the online USGS Ground Motion Parameter Calculator and U.S. Seismic “Design Maps” web application (USGS, 2012b). These weak rock site values are for 2009 IBC Site Class B sites, and they are modified by the application of site coefficients F_a and F_v for other site classes (Site Class A, C, D, E and F) where $S_{MS} = S_S \times F_a$ and $S_{M1} = S_1 \times F_v$ (IBC, 2009). The USGS Ground Motion Parameter Calculator (USGS, 2012b) indicates S_S and S_1 values of 0.129 g and 0.050 g, respectively (F_a and F_v = 1) for the MConE. These values are slightly different than those obtained from the USGS 2008 national hazard maps because the 2009 IBC-ASCE 7-05 MConE values are based on the earlier 2002 USGS national hazard maps. When modified for a Site Class D site, we obtain S_{MS} and S_{M1} values of 0.206 g and 0.119 g, respectively (F_a = 1.6 and F_v = 2.4). These spectral acceleration values are suitable as a basis for design of site structures to meet the seismic design requirements of the 2009 IBC and ASCE 7-05 standard. Key parameters for the 2009 IBC-ASCE 7-05 procedures are listed in Table 4.3-1 below.

Table 4.3-1 2009 IBC-ASCE 7-05 Seismic Parameters for the SHINE Site

Parameter	**Value**
S_S	0.129 g
S_1	0.050 g
Site Class	D
S_{MS}	0.206 g
S_{M1}	0.119 g
F_a	1.6
F_v	2.4
T_L	12 seconds

Notes:
1. Parameters based on SHINE Janesville project location of 42.624136°N, 89.024875°W.
2. Parameters include: short period spectral response acceleration (S_S), 1-second spectral response acceleration (S_1), maximum considered earthquake spectral response for short period (S_{MS}), maximum considered earthquake spectral response for 1-second period (S_{M1}), site coefficient for short period (F_a), site coefficient for 1-second period (F_v) (IBC, 2009); long-period transition period (T_L) (ASCE, 2005).
3. S_S and S_1 are for Site Class B; S_{MS} and S_{M1} are for Site Class D.

5.0) Summary and Conclusions

Golder's analysis indicates that the SHINE site is located in a region of relative tectonic stability and historic seismic inactivity. This conclusion is based on the long-term geologic history of the emplacement and metamorphism of regional basement rocks; stratigraphy and structure of the local sedimentary bedrock; analysis of the surficial geology and geomorphology; and the historic record of regional earthquake locations, magnitudes and felt intensities. Geologic structures mapped near the site such as the Sandwich and Plum River fault zones, the La Salle anticlinorium, and the Wisconsin and Kankakee Arches appear to have formed under a tectonic regime different from the present day. No "capable" faults are recognized within the SHINE site—the closest known "capable" faults are part of the Wabash Valley liquefaction features located about 170 miles (274 km) south of the site, and the New Madrid seismic zone located about 400 miles (644 km) south of the site. While small to moderate earthquakes up to expected moment magnitude 5.15 have occurred within the region of the SHINE site, they have been infrequent and developed only a moderate level of shaking at the site four times in the last approximately 200 years.

Estimates of seismic hazard for the region by the USGS in 2010 indicate that the site is located within one of the lowest seismic hazard regions in the conterminous United States. The low hazard estimate is illustrated by PGA values of 0.19 g (a strong level of earthquake ground shaking) having a return period of more than 19,900 years. The low hazard is also reflected in the seismic parameters required for application of the 2009 IBC-ASCE 7-05 seismic design procedures as listed in Table 4.3-1 above. Evaluation of 2,475-year to 19,900-year return period deaggregations of the 2008 USGS seismic hazard model indicates that a magnitude 5.8 earthquake is an acceptable estimate of the maximum earthquake magnitude to occur within the region of the SHINE site.

6.0) Closing

We trust that this report meets your requirements. If you have questions or require additional information, please contact one of the undersigned at (714) 508-4400.

GOLDER ASSOCIATES INC.

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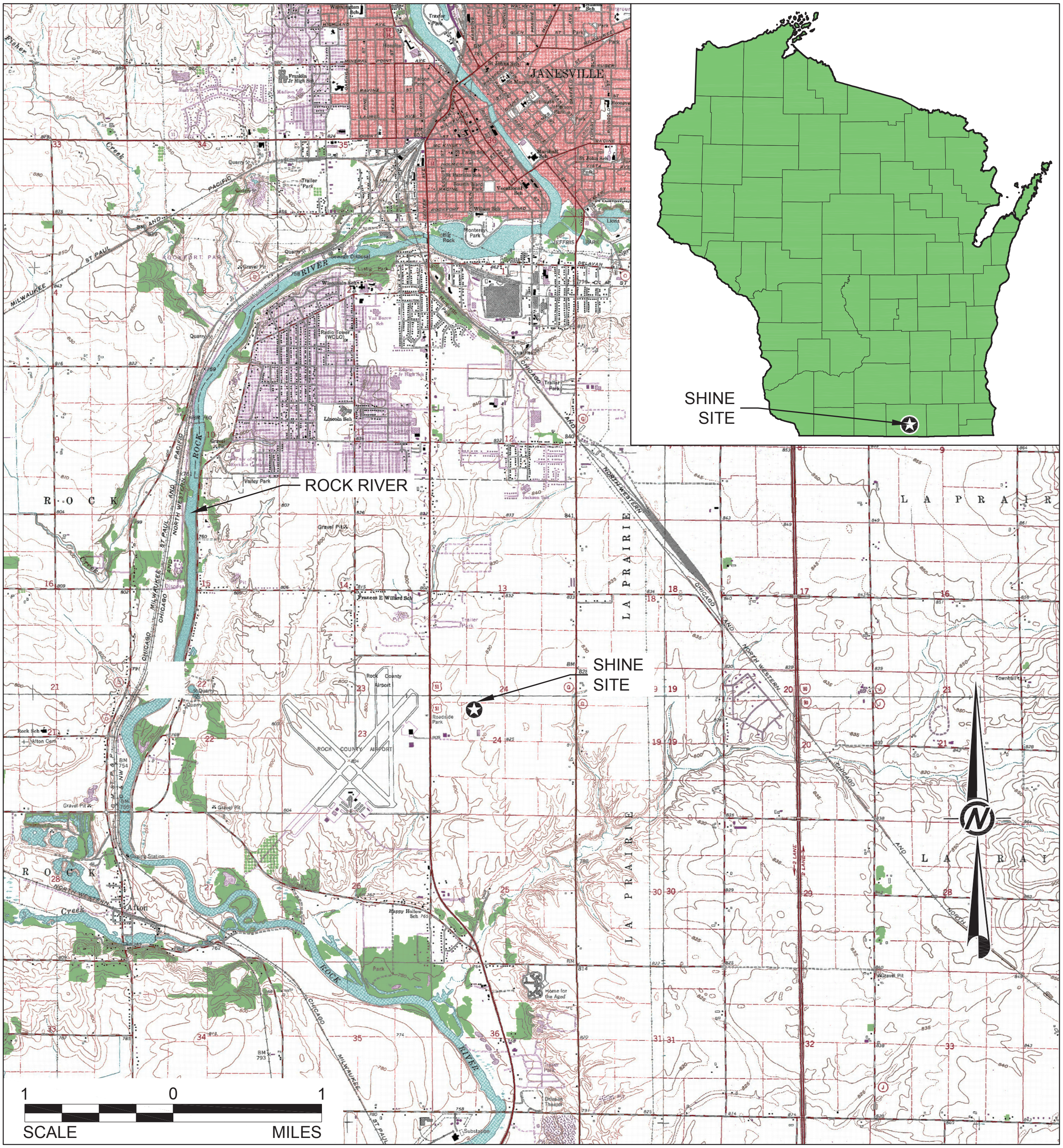
FIGURES

Figure 1.1-1



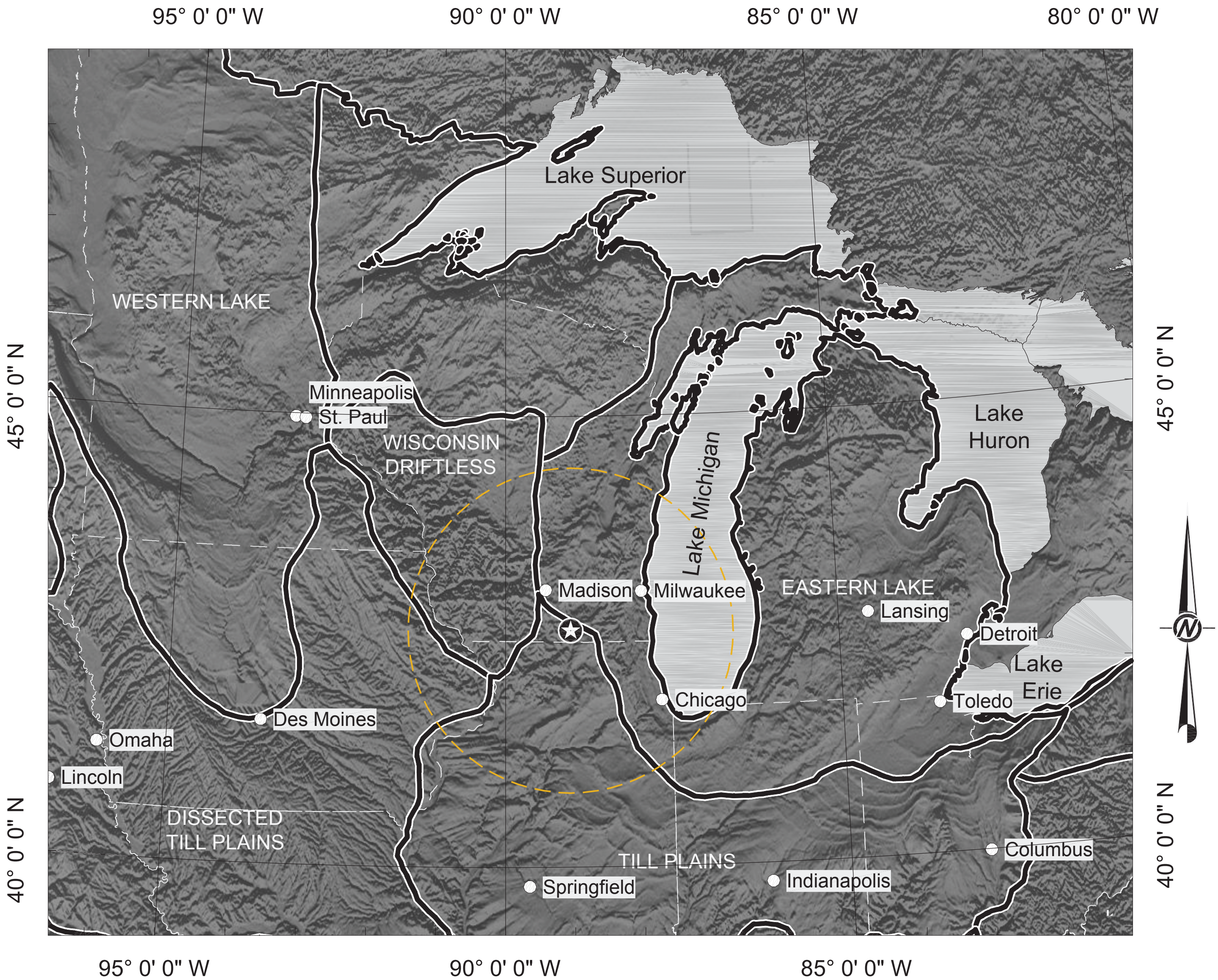
LEGEND

SHINE SITE

REFERENCE

1.) 1:24,000 SCALE TOPOGRAPHIC MAPS PRODUCED BY USGS AND DISTRIBUTED BY WISCONSIN DNR (2012). QUADRANGLES SHOWN INCLUDE JANESVILLE WEST (1997), JANESVILLE EAST (1997), BELOIT (1997), SHOPIERE (1997).

Figure 2.1-1



LEGEND

SHINE SITE

124 MILE (200 KM) RADIUS

BOUNDARY OF PHYSIOGRAPHIC SECTION

STATE BOUNDARY

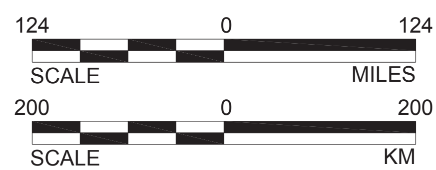


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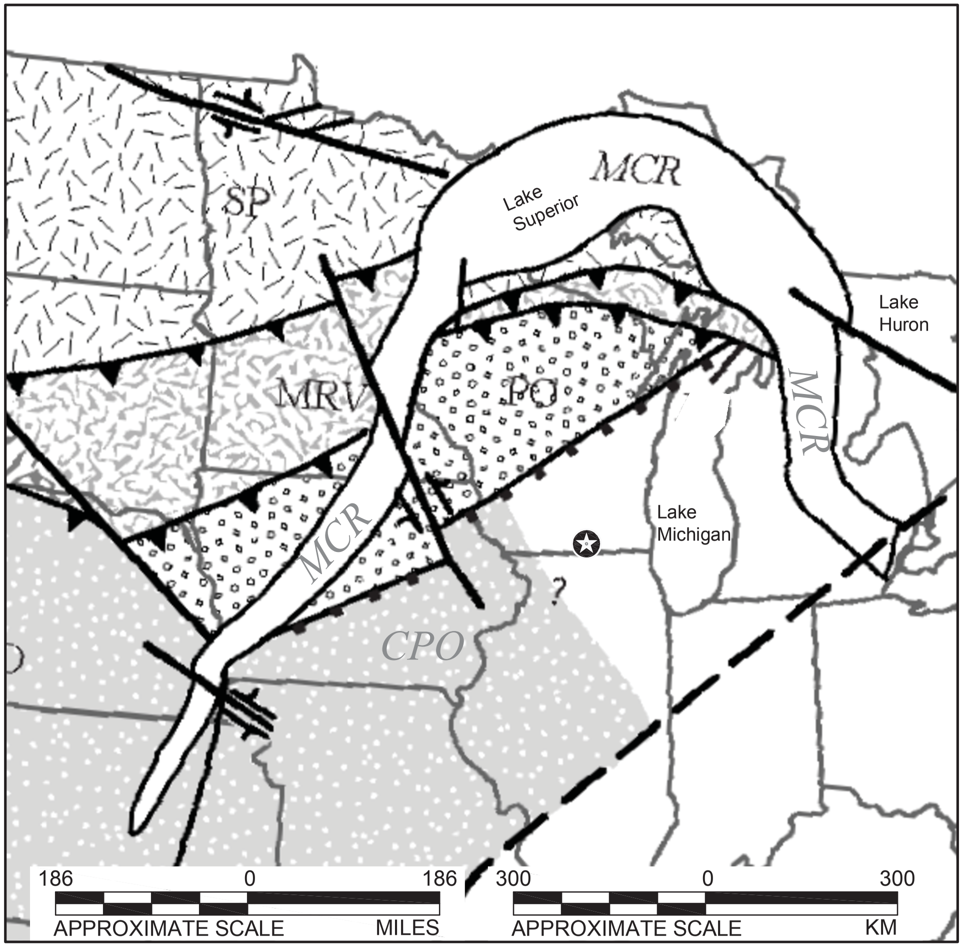
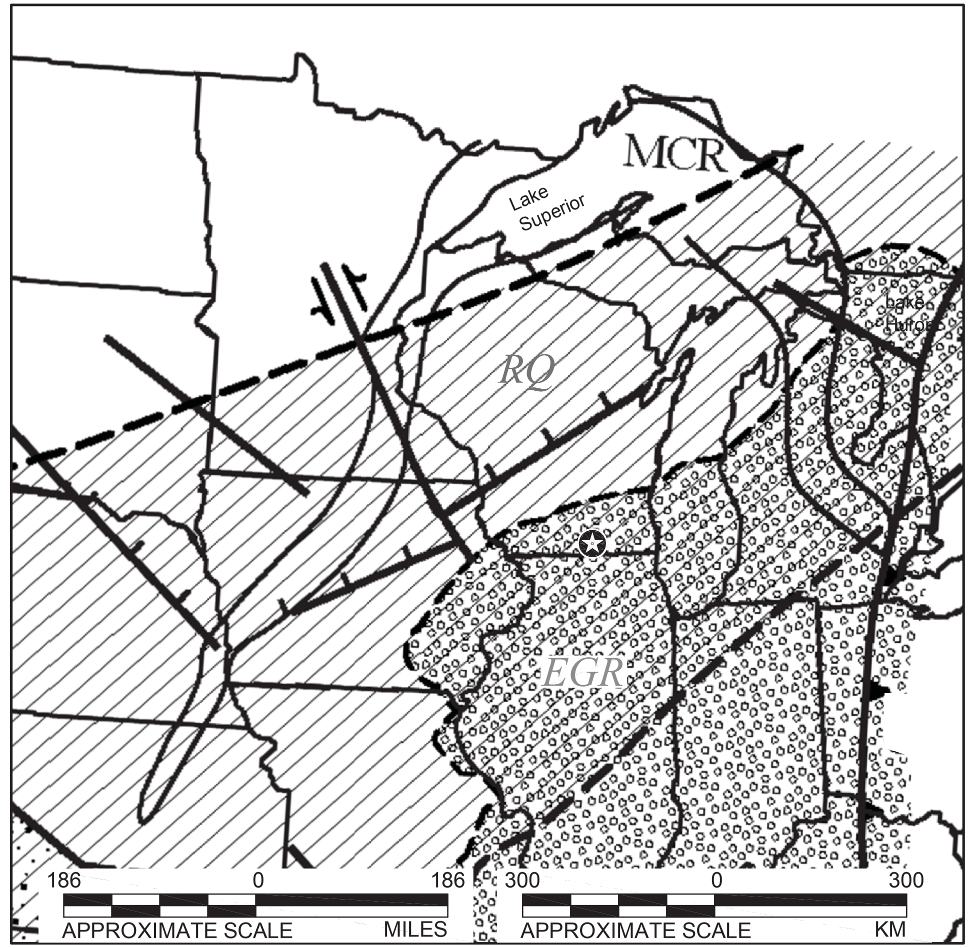
Figure 2.1-2

ARCHEAN AND PALEOPROTEROZOIC GEOLOGIC PROVINCES



LATE PROTEROZOIC AND MESOPROTEROZOIC GEOLOGIC PROVINCES



LEGEND

- CPO — CENTRAL PLAINS OROGEN (INCLUDES YAVAPAI AND MAZATZAL PROVINCES)
- SP — SUPERIOR PROVINCE
- MRV — MINNESOTA RIVER PROVINCE
- PO — PENOKEAN OROGEN (INCLUDES PEMBRINE-WAUSAU AND MARSHFIELD TERRANES)
- MCR — MIDCONTINENT RIFT
- SGR — SOUTHERN GRANITE RHYOLITE PROVINCE
- EGR — EASTERN GRANITE RHYOLITE PROVINCE
- RQ — RHYOLITE-QUARTZ ARENITE BELT

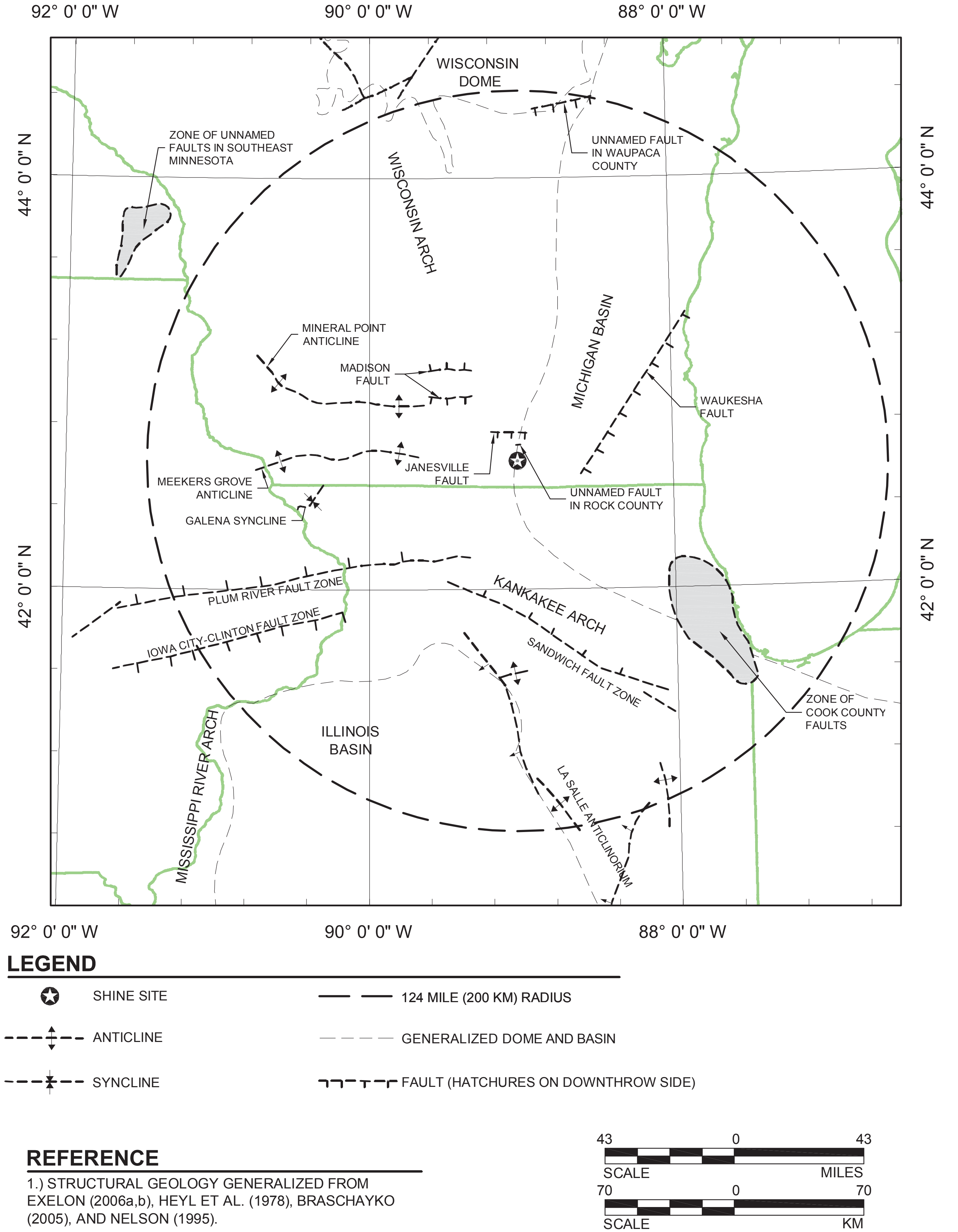
- STRATIGRAPHIC CONTACT (DASHED WHERE APPROXIMATED)
- HIGH-ANGLE FAULT
- STRIKE-SLIP FAULT PREDOMINANT RELATIVE DISPLACEMENT
- THRUST FAULT

- SHINE SITE

REFERENCE

1.) SIMS ET AL. (2005).

Figure 2.1-3



REFERENCE

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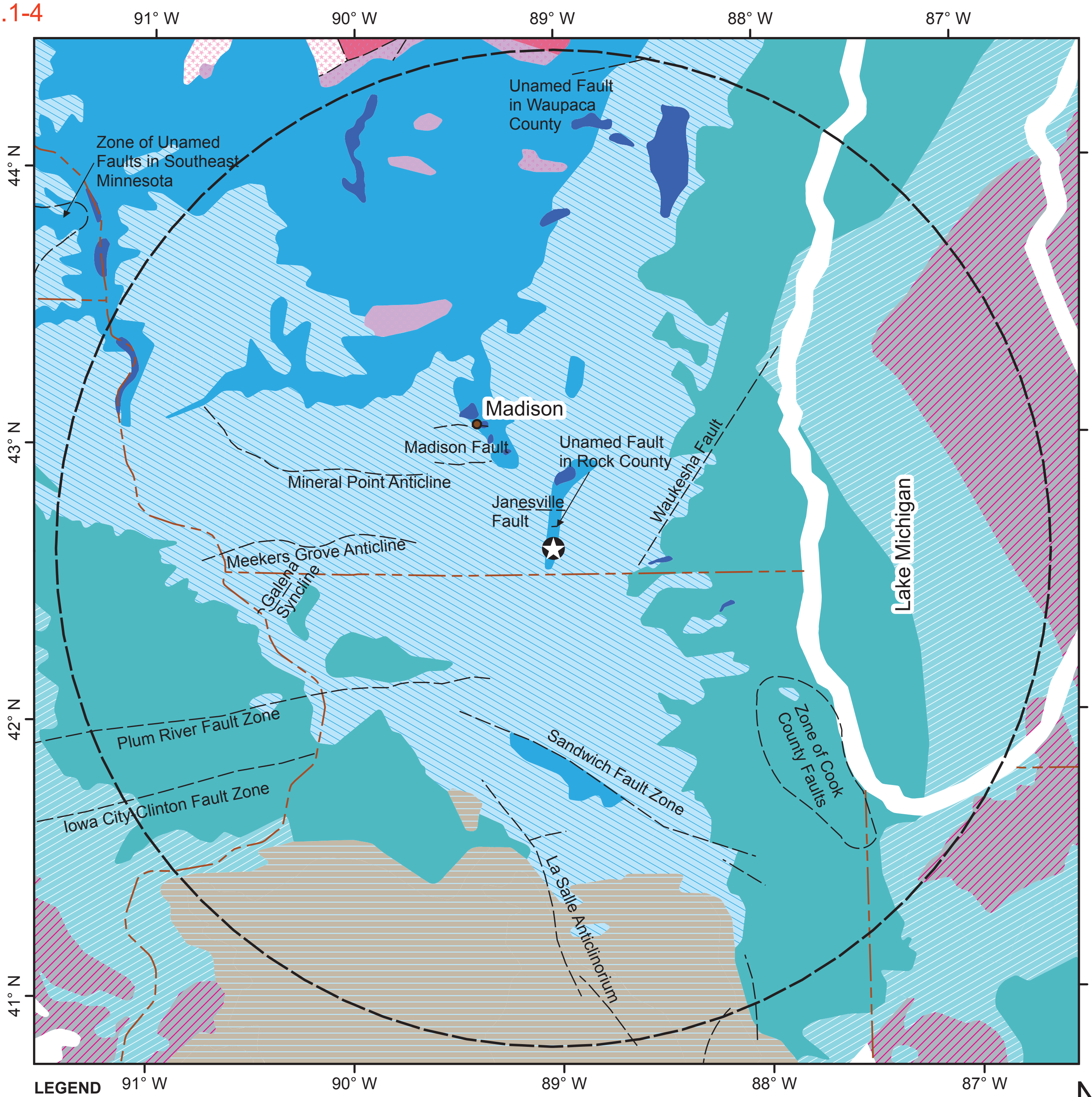
Figure 2.1-4



LEGEND

SHINE SITE

124 Mile (200 KM) Radius

State Boundary

Fault and Fold Trend

Open Water

Geologic Time	Generalized Geologic Units
Pennsylvanian	Coal, limestone, sandstone, shale or clay shale
Mississippian	Limestone, shale or clay shale
Devonian	Carbonate, sandstone
Silurian	Dolomite, silty limestone
Ordovician	Conglomerate, dolomite, limestone, sandstone, shale
Cambrian	Dolomite, sandstone, shale
Early Proterozoic	Quartzite (Wolf River Batholith)
Early Proterozoic	Felsic Rocks (Wolf River Batholith)
Early and Middle Proterozoic	Granitic Rocks (Wolf River Batholith)
Late Archean	Orthogneiss

30 15 0 30 MILES
SCALE

60 30 0 60 KM
SCALE

N

REFERENCE

Bedrock geology map from Garrity and Soller (2009). Geologic units generalized from references cited in report.