2.5.1 BASIC GEOLOGIC AND SEISMIC INFORMATION

The U.S. EPR FSAR includes the following COL Item in Section 2.5.1:

> A COL applicant that references the U.S. EPR design certification will use site-specific information to investigate and provide data concerning geological, seismic, geophysical, and geotechnical information.

This COL Item is addressed as follows:

{Section 2.5.1.1 describes the geologic and tectonic characteristics of the Site Region (200 mile (320 km) radius). Section 2.5.1.2 describes the geologic and tectonic characteristics of the Site Vicinity (25 mile (40 km) radius), Site Area (5 mile (8 km) radius) and Site (0.6 mile (1 km) radius). The geological and seismological information was developed in accordance with the following NRC guidance documents:

- Regulatory Guide 1.206, Section 2.5.1, "Basic Geologic and Seismic Information," (NRC, 2007),
- Regulatory Guide 1.208, "A performance-based approach to define the site-specific earthquake ground motion" (NRC, 2008), and
- Regulatory Guide 1.165, "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion," (NRC, 1997).

As described no geologic or seismic hazards were identified that have the potential to adversely impact the facilities of Callaway Plant Unit 2.

The geological and seismological information presented in this section was developed from previous reports prepared for the Site, published geologic literature, and interpretation of aerial photography. The interpretation of the aerial photography and aerial reconnaissance was reported previously in Callaway Plant Site reports including the AmerenUE, 2004 Final Safety Analysis Report (AmerenUE, 2004) and a report containing the results of detailed excavation mapping for Callaway Plant Unit 1 (Dames & Moore, 1980). A review of more recent published geologic literature was used to supplement and update the existing geological and seismological information. In addition, relevant unpublished geologic literature, studies, and projects were identified by contacting the U.S. Geological Survey (USGS), Missouri Department of Natural Resources and universities. The references used to compile the geological and seismological information is presented in the applicable section and listed in Section 2.5.1.3.

The Callaway Plant Unit 2 siting investigation was accomplished from 2006 through 2008. Components of that investigation included a review of published geological literature, a subsurface investigation during which 71 borings were advanced into the subsurface, and field and aerial reconnaissance program. Field reconnaissance of the Site was conducted by geologists from Paul C. Rizzo Associates, Inc. and John Sims & Associates. The field reconnaissance visits focused on exposed features along rivers, creeks, scarps, and roads within the Site Area, with additional investigations to a 30 mile (48 km) radius to assess certain features related to faults within the Site Vicinity. Key observations and discussion items were documented in field notebooks and photographs. Field locations were logged and hand notations on detailed topographic base maps. The Site Area Paleoliquefaction and Surface Faulting Investigation Program in COLA Part 11G provides additional details on the field reconnaissance investigations performed.

The only feature that relate to a potential hazard at the Site is the New Madrid Seismic Zone located at the boundary of the 200 mile (320 km) Site Region and a postulated small magnitude local earthquake occurring within the Site Region.

2.5.1.1 Regional Geology (200 miles (320 km) radius)

Figure 2.5L-1shows the Site Region. This area includes most of the State of Missouri, southeastern Illinois, small portions of Iowa, Kansas, Arkansas, touches on Oklahoma, Tennessee, and Kentucky. The regional geologic map shown in Figure 2.5L-4 contains information on the geology of the Site Region. Summaries of these aspects of regional geology are presented to provide the framework for evaluation of the geologic and seismologic hazards presented in the succeeding sections.

2.5.1.1.1 Regional Physiography and Geomorphology

The Callaway Plant Unit 2 Site is located 5 miles (8 km) north of the Missouri River at the southern edge of glaciation in North America. The area is characterized by gently rolling upland that has been dissected by downcutting from the Missouri River and its tributary streams. Glacial and postglacial sediments overlie older unconsolidated deposits and lithified formations of Paleozoic age. Regional drainage in Missouri and Arkansas is toward the east and south into the Missouri, Arkansas, and Mississippi Rivers. In Illinois, regional drainage flows west and south into the Illinois and Mississippi Rivers.

The Site Region encompasses six physiographic units which are discussed in the following subsections. Figure 2.5.1-3 shows the location of the Site with respect to the physiographic units (Fenneman, 1931).

The Callaway Plant Unit 2 Site straddles the boundary between the Dissected Till Plains Section of the Central Lowlands Physiographic Province to the north and the Ozark Plateaus Physiographic Province to the south.

Glacial sediments from various ice advances covered Iowa, northern Missouri, and most of Illinois during Pleistocene time (Figure 2.5.1-4). Deposits of glacial till and loess buried a bedrock surface of moderate relief and produced a depositional surface of low relief. The resulting topography is primarily influenced by the glacial sediments, independent of topographic or lithologic variations in the rock surface. The glaciated area which occupies the Central Lowlands Physiographic Province is divided into the Till Plains and the Dissected Till Plains sections primarily on the basis of degree of dissection of the surface by streams.

2.5.1.1.1.1 The Dissected Till Plains Section

The southern boundary of the Dissected Till Plains Section, as defined by the southern limit of glaciation, passes just south of the Site (Figure 2.5.1-3 and Figure 2.5.1-4). As the name implies, this section is well dissected by existing stream drainage. The area is characterized by gently rolling upland that has been dissected by downcutting from the Missouri River and its tributary streams. Glacial and postglacial sediments overlie older unconsolidated deposits and lithified formations of Paleozoic Age. Glacial deposits within the Site Region are Wisconsinan and older in age. Streams on the older glacial tills are better established and, as a result, have more deeply eroded valleys. A notable feature of this physiographic section is the absence of end moraines.

2.5.1.1.1.2 The Till Plains Section

The Till Plains Section lies east of the Mississippi River in Illinois (Figure 2.5.1-3). The topography is characterized by an undulating surface with low relief. Numerous end moraines are present but not strongly developed. They are the result of an oscillating ice front and vary from faint topographic swells to ridges that stand 100 to 150 ft (31 to 46 m) above the surrounding till plain. Drainage is moderately integrated; however, dissection is not well developed except along major streams.

2.5.1.1.1.3 The Ozark Plateaus

The Ozark Plateaus region extends across the State of Missouri from the Missouri and Mississippi Rivers to northern Arkansas and northeastern Oklahoma and includes the Salem and Springfield plateaus and the Boston Mountains. The northern boundary for this section passes just to the south of the Site (Figure 2.5.1-3). Topographic forms are the product of maturely dissected, gently dipping, sedimentary rocks of variable hardness. A series of inward facing escarpments arranged concentrically around the central Ozark Dome has developed on the more resistant formations.

To the south of the Site, the Salem Plateau completely encircles the St. Francois Mountains. This region was once a continuous rolling upland surface with elevations from 1,500 to 1,700 ft (460 to 520 m) msl; however, only remnants remain today. Numerous streams have eroded much of the plateau and cut valleys hundreds of feet deep. Despite extensive dissection, numerous interstream tracts (known locally as “prairies”) justify the section being designated a plateau rather than hills. Local relief on the Salem Plateau uplands is seldom as much as 100 ft (30 m), but relief adjacent to major streams may be as great as 500 ft (150 m). This deep and intricate dissection is one of the features that distinguish the Salem Plateau from the Springfield Plateau (Thornbury, 1965).

The St. Francois Mountains lie at the center of the Ozark Uplift approximately 100 miles (160 km) to the southeast of the Site. Rugged hills of Precambrian igneous rocks rise above the Salem Plateau to a maximum elevation of 1,772 ft (540 m) msl, the highest point in Missouri (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967).

The Springfield Plateau, located to the southwest of the Site, is elevated between 1,000 and 1,500 ft (300 to 460 m) msl, with moderate to low topographic relief. Much of the plateau consists of flat interfluvial “prairies,” separated by stream valleys cut 200 to 300 ft (60 to 90 m) below the upland surface.

Within the Ozark Plateau, outliers of Pennsylvanian rocks locally stand a few hundred feet above the plateau surface and represent persistent remnants of an older, higher land surface that has been interpreted as a peneplain (Thornbury, 1965). The Springfield Plateau is bounded on the south by a prominent escarpment that marks the northern front of the Boston Mountains, located just beyond the 200 mile (320 km) Site Region boundary. The Boston Mountains rise above the Springfield Plateau to form a prominent, northward-facing, irregular escarpment that attains a height of 800 ft (240 m). There are numerous steep cliffs and deep, narrow valleys throughout the province.

2.5.1.1.1.4 Coastal Plain Province

A portion of the Coastal Plain Province lies within the Site Region and consists of the Mississippi Alluvial Plain and East Gulf Coast physiographic sections near the southeast limit of the Site Region (Figure 2.5.1-3). The Mississippi Alluvial Plain, called the Southeast Lowlands in southeastern Missouri, borders the eastern edge of the Ozark Plateaus. This physiographic section lies within the alluvial valley of the Mississippi River and is bounded by prominent valley walls that rise as much as 200 ft (60 m) above the valley floor. The East Gulf Coast Section, in the northwest corner of the Gulf Coastal Plain, displays a series of belted features consisting of several parallel lowlands and cuestas that swing across Alabama and Mississippi (Lobeck, 1950). The lowlands are rich agricultural belts, and the sandy upland cuestas support extensive tracts of pine forests.

2.5.1.1.1.5 The Interior Low Plateaus Province

The Interior Low Plateaus Province occupies a transitional region between the Till Plains and Coastal Plains (Figure 2.5.1-3). Within the Site Region, it consists essentially of low, maturely dissected plateaus with silt-filled valleys located at the northern limit of the Coastal Plain Province at the southeast limit of the Site Region, near the Mississippi River.

2.5.1.1.1.6 The Osage Plains

The Osage Plains lie west of the Ozark Plateaus and extend northward from northern Texas across Oklahoma, and into Kansas and Missouri south of the glaciated areas (Figure 2.5.1-3). Much of the Osage Plains section can best be described as scarped plains. The topography ranges from a nearly featureless plain with low escarpments that are a few hundred feet high to bold escarpments rising as much as 600 ft (180 m) above adjacent plains (Thornbury, 1965). The closest these plains approach the Site is an area approximately 75 miles (121 km) to the west, south of the Missouri River.

2.5.1.1.2 Regional Geologic History

The geologic time scale consists of a number of divisions and subdivisions; specifically, eons are the largest geologic time divisions, containing periods which in turn contain time divisions called series. A geologic time scale is presented in Figure 2.5.1-9 that shows the time frames associated with the various eons, and periods that are discussed below.

The Callaway Plant Unit 2 Site Region is included within the Central Stable Region of North America as shown on Figure 2.5.1-5 and discussed by King (1959). This has had a relatively gentle tectonic history since the beginning of Cambrian time, as contrasted with long records of crustal mobility in other parts of the continent. Ouachita orogenics bordered this area to the south and west, but had a minimal effect on Central Missouri. Clendenin (1989) associates the northwest-trending steep faulting in the Central Stable Region with compressive stresses in the Ouachita belt during the Mississippian and Pennsylvanian Periods. The regional bedrock geologic map is presented on Figure 2.5L-4 and the surficial sediment map for Missouri is presented in Figure 2.5.1-6.

McCracken (1971) defined six major deformational episodes in Missouri (also affecting adjacent states) that occurred during the following geologic time periods:

- Precambrian (Prior to approximately 600 Ma).
- Late Ordovician- causing an unconformity between the Canadian and Champlainian formations (approximately 450 Ma).
- Between Early Devonian and the Mississippian (in places Late to Middle Devonian) (approximately 375 Ma).
- Between the Mississippian and the Middle Pennsylvanian (approximately 324 Ma).
- By the end of the Pennsylvanian (approximately 300 Ma).
- Tertiary (between end of Paleocene and before the Pliocene) (approximately 50 to 55 Ma).

Precambrian rocks are exposed at the surface within the Canadian Shield. The eroded Precambrian surface of crystalline rocks dips beneath the Central Stable Region and is overlain by a southward thickening wedge of Paleozoic and Mesozoic sedimentary rocks. About 75 miles (121 km) south of the Site, the Precambrian basement is exposed in the core of the Ozark Uplift.

The Site lies in a geologic region of broad uplifts and basins within which the continental plate and the overlying sedimentary rocks have interacted throughout geologic time forming arches (domes) and basins, each containing more localized anticlines, synclines, and faults.

The arches, basins, and other structures of the Central Stable Region, with few exceptions, were formed by vertical block tectonics during the Paleozoic Era. Regional faulting, folding, and domes and basins are shown on Figure 2.5L-5, Figure 2.5L-6 and Figure 2.5.1-7 respectively. Many of these structures yield evidence of a prolonged history of development and some of them (located in and around the Mississippi Embayment) completed their formation as recently as the Cretaceous (Eardley, 1962, and Clendenin, 1989).

The following subsections provide a generalized historical framework for more specific considerations of regional structural geology, seismotectonics, and Site geology.

2.5.1.1.2.1 Precambrian

The basement rocks of the Site Region are Precambrian volcanic rocks, intrusive rocks, and metamorphic rocks that are similar to the cratonic assemblage exposed in the Canadian Shield. The oldest rocks are regionally metamorphosed rocks of high metamorphic facies. These rocks are similar to the granulites and schists of the Grenville Province of the Canadian Shield but yield slightly younger radiometric ages (1.46 billion years, Merriam (1963)). Although the precise distribution of basement lithotypes is unknown, the scattered subsurface data available indicate that igneous and metamorphic rock types predominate in the area surrounding the Ozark Region.

Nelson (1995) presents the Precambrian geologic provinces included in the Site Region (Figure 2.5.1-8). All of Illinois, southern Iowa, and part of Missouri in the Site Region belong to the Eastern Granite-Rhyolite Province, where the basement rocks are 1.42 to 1.50 billion years old. The Central Plains Province is present in west-central Missouri, where the basement rocks are 1.63 to 1.80 billion years old.

Two fault-bounded intra-cratonic troughs (aulacogens) extend into the southeastern quadrant of the Site Region: the Rough Creek graben and the Reelfoot rift. These features were superimposed into the craton, and are bounded by large, curved (listric) normal faults that penetrate the crystalline basement. The faults in this area are the source of historical seismic activity in the New Madrid area.

The Site lies on the northern flank of the composite regional structural high known as the Ozark Uplift or the southeast Missouri High (Kisvarsanyi, 1974a). Depth to basement at the Site is approximately 2,000 ft (610 m). The basement surface has a gentle northward regional slope of a few feet per mile. The only surface exposures of Precambrian rocks of any large areal extent in the Mid-continent region are those at the crest of the Ozark Uplift in the St. Francois Mountains, located approximately 100 miles (160 km) to the south-southeast of the Site. These exposures are made up entirely of igneous rocks. They consist of large volumes of acidic extrusive rocks that accumulated on the Precambrian surface around volcanic centers in the St. Francois Mountains. This large mass of extrusive rocks was subsequently intruded by granitic bodies that were perhaps derived from the same magmatic source as the extrusive rocks.

A long period of erosion followed the end of volcanic activity in the Ozark Region. A deeply incised dendritic drainage pattern (local relief of at least 500 ft (152 m)) developed on the flanks of the Precambrian Ozark highland. This topographic surface was exhumed by erosion and generally coincides with the present surface in the most rugged parts of the St. Francois Mountains (Dake and Bridge, 1932). This period of exposure and erosion lasted for several million years until Late Cambrian time, when Paleozoic marine seas at least partly submerged the ancestral Ozark highland. Present day structural relief between the St. Francois Region and the Central Illinois Basin is a minimum of 13,000 ft (4,000 m). Relative uplift and subsidence of these areas subsequent to Cambrian time is undoubtedly responsible for much of this relief. The original relief of the ancestral Ozarks above the surrounding region is impossible to estimate.

Precambrian tectonic activity imprinted the terrain in the area with a strong structural fabric. This fabric is expressed as fracture patterns (Robertson, 1940, and Kisvarsanyi (1974b), Precambrian faults were identified in mine exposures in Iron County, Missouri, and in the geometry of Late Precambrian ultrabasic dikes, which are among the most common structural features in the area (Graves, 1938, and Gibbons, 1972, in AmerenUE, 2004). Most elements of this fabric are vertical and trend northeasterly or northwesterly.

2.5.1.1.2.2 Paleozoic Era

Geologic events that affected the Site Region during the Paleozoic Era are discussed below under the seven subordinate time periods: Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian. The long period of erosion that occurred during the Precambrian as discussed above was followed by slow subsidence and deposition throughout most of the Paleozoic Era, with stability achieved at or near the close of the Pennsylvanian Period. Snyder (1968, in AmerenUE, 2004) and Clendenin (1989) state that the major elements in the time interval that followed the broad uplift and deep erosion during Late Precambrian time included, successively:

- Slow subsidence of the entire Mid-continent, beginning in late Cambrian time;
- Development of major arches and basins with intermittent subsidence and uplift through the Ordovician, Silurian, and Devonian periods;
- Regional fragmentation through subdivision of the basins by minor arches in Early Mississippian time, caused by the Ouachita Orogeny;
- Marine oscillation leading to cyclical deposition through late Pennsylvanian time; and
- Final uplift and stability following the Alleghanian Orogeny in late Pennsylvanian to Early Permian time.

2.5.1.1.2.2.1 Cambrian Period

Due to the absence of Lower and Middle Cambrian rocks throughout most of the Midwest, it is assumed that the long period of erosion that occurred at the close of the Precambrian continued through Early and Middle Cambrian time. At the beginning of Late Cambrian time, the Mid-continent surface consisted of a narrow highland belt of volcanic rock flanked by broad, low, gently undulating plains that sloped toward the Keweenawan and Appalachian basins (Snyder, 1968, in AmerenUE, 2004), neither of which are found in the Site Region. The Precambrian lowlands throughout the Site Region were submerged by shallow seas. Upper Cambrian sandstone was the first Paleozoic sedimentary rock to be deposited over most of the Mid-continent (Snyder, 1968, in AmerenUE, 2004). The Eastern Interior Basin, comprising much of Michigan, Indiana and Illinois, subsided more rapidly than adjacent areas during the Late Cambrian.

The St. Francois Mountains in Missouri remained a topographic high through Cambrian time as indicated by the absence of Upper Cambrian rocks in local areas. The remainder of the Ozark area subsided, however, and sediments transgressively overlapped the higher peaks. The Cherokee and Forest City basins in northwestern Missouri and eastern Kansas began to subside, resulting in tilting movements down to the southeast (Merriam, 1963).

Major ancestral arches and basins of the central United States began to develop in the latter part of Late Cambrian time and continued into Early Ordovician time. The arches were areas that experienced less subsidence than the adjacent basins (Snyder, 1968, in AmerenUE, 2004). Much of Missouri, as well as most of the Midwest, remained submerged under a shallow sea at the end of the Cambrian.

2.5.1.1.2.2.2 Ordovician Period

With the Site Region largely submerged as noted above, sedimentation continued undisturbed with only minor unconformity into Early Ordovician time (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967).

Between the Early and Middle Ordovician, regional uplift occurred throughout a vast region including renewed upward movements of the Ozark Uplift in Missouri. As a result, the seas receded from the Midwest and widespread erosion was initiated. A strong unconformity is recorded within the Site Region at the close of Early Ordovician time.

Following a long period of erosion during which well developed river systems and solution depressions formed in portions of the Midwest, the sea advanced again. Unconsolidated sediments were reworked and sand was deposited unconformably on the erosion surface over a vast area. Renewed Middle and Late Ordovician deposition in Missouri was not as widespread as during the Early Ordovician, being generally restricted to the northern and eastern parts of the state (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967).

The Ordovician Period ended with uplift associated with erosion occurring throughout the Site Region. A major unconformity is present between the Ordovician and Silurian sedimentary rocks.

2.5.1.1.2.2.3 Silurian Period

After an erosional interval of long duration, the Site Region was again inundated by the sea in Silurian time. In Missouri, Silurian and Devonian deposits are relatively thin, restricted in occurrence, and separated below, above, and internally by unconformities (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). In Illinois, data indicate that marine waters advanced from the south during Alexandrian time. Carbonate deposits are predominant throughout the Central U.S., but sandstones and shales are also present. Reef deposits were laid down in shallow seas around the emergent Ozark Uplift.

The Silurian Period ended in Illinois with widespread emergence of the Site Region. It appears that the Site Region remained above sea level throughout Late Silurian time since no marine deposits of this age are known within the area (Willman and Payne, 1942). In Missouri, widespread uplift and erosion accompanied by faulting occurred at the end of Early Devonian time obscuring the record of Silurian sedimentation (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). In Kansas, Silurian rocks are confined primarily to the northeast quarter of the state.

2.5.1.1.2.2.4 Devonian Period

In Missouri, marine deposition continued from Late Silurian time through Early Devonian at which time widespread uplift began with accompanying erosion. In central Missouri, the Middle and Upper Devonian rocks rest unconformably on beds as old as Early Ordovician (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967).

The earliest record of vertical movement of crustal blocks in the Ozark Region is preserved in post-Middle Devonian rocks along the eastern flank of the Ozark Uplift. Relative movements among blocks bounded by the southern and central parts of the Ste. Genevieve Fault Zone resulted in the preservation of abnormally thick sections of Devonian strata on what are now remnants of the downthrown fault blocks. Subsequent changes in the locus of displacement within the fault zone have isolated these fragments and make their stratigraphic relationships with other rocks of similar age in the Site Region unclear. The Ste. Genevieve Fault Zone extends into Missouri from Illinois, and extends to a location 95 miles (150 km) to the southeast of the Site.

In Kansas, Devonian rocks are confined primarily to the northeast quarter of the state.

In northern Illinois, erosion continued from the late Silurian through Early Devonian time. By the Middle Devonian this changed and deposition began with a major transgression of the sea. During this period, the Sangamon and Kankakee arches (Figure 2.5.1-7 and Figure 2.5.1-11 respectively) was formed and acted as a barrier to sediment transport. Sedimentation continued through the late Devonian in Illinois with accumulations of calcareous materials and relatively thick Upper Devonian deposits of silt and mud that extend across the Sangamon Arch. Far to the east of the Site Region, the Eastern Interior Basin was divided into the Michigan and Illinois basins during Devonian time by continued subsidence of areas adjacent to the Kankakee Arch.

The Devonian Period ended with regional uplift, emergence above sea level, and subsequent erosion. This period of erosion appears to have removed many of the Devonian rocks from northern Illinois.

2.5.1.1.2.2.5 Mississippian Period

The Mississippian Period was a time of widespread shallow submergence throughout the Site Region. The deposition of a more or less uniform and thick sequence of marine carbonate rocks with chert and some sandstone and shale is evident. In some adjacent areas, such as northern Illinois, Mississippian seas may never have advanced completely over this region and Mississippian age deposits are rare. The Illinois Basin of southern Illinois contains more than 1,400 ft (427 m) of Late Mississippian strata.

At the close of Mississippian time, the Ozark region rose again in response to the Ouachita Orogeny, and the resultant widespread erosion stripped nearly all the Mississippian rocks from the uplifted area, leveling them over much of the rest of Missouri (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). Pronounced karst topography was developed or exhumed in the Ozarks and stream valleys were eroded into the Mississippian surface. All the borders of the Illinois Basin were uplifted to some extent. The Cincinnati Arch was raised sufficiently to have Chesterian age strata eroded.

2.5.1.1.2.2.6 Pennsylvanian Period

Conditions controlling sedimentation during the Pennsylvanian were considerably different from those during earlier Paleozoic periods. Throughout Pennsylvanian time, highland areas from the Appalachian and Ouachita orogenies existed along the eastern and southern parts of North America. The continental interior was a plain that was repeatedly either submerged by the sea or exposed just a short distance above it (Willman and Payne, 1942). When the plain was submerged, streams from the highland areas carried rock debris into the sea. As the sea receded, deposition continued in a terrestrial environment. The newly emerged plain became covered by swamps that extended unbroken for hundreds of miles. Vegetation flourished and accumulated in thick deposits to form coal layers. Eventually the sea returned to initiate another cycle of sedimentation. Each cycle was therefore partly marine and partly terrestrial. Numerous cycles of deposition, many of which are separated by localized erosional unconformities, are recorded in the Pennsylvanian stratigraphy.

Sometime after the end of the Mississippian Period, but before Middle Pennsylvanian time, the Bourbon Arch divided the North Kansas Basin into the present Forest City and Cherokee basins. The Forest City Basin became separated from the Salina Basin to the west through development of the Nemaha Uplift (Snyder, 1968, in AmerenUE, 2004). Pennsylvanian deposits in Illinois thin over the LaSalle Anticline, indicating some continued tectonic movement of this structural feature. Deepening of the Illinois Basin and accentuation of the smaller structures continued through the Pennsylvanian Period. Differential subsidence within the basin appears to have produced the DuQuoin Monocline which developed gradually throughout Early and Middle Pennsylvanian time.

In central Missouri, Pennsylvanian strata were deposited over the karst topography and in sinkholes that had formed on the Mississippian rock surface. Stream valleys that had eroded into the Mississippian surface were buried by Pennsylvanian deposits.

An erosional unconformity between Pennsylvanian and Permian strata, where observable, suggests that some uplift and erosion of Pennsylvanian rocks occurred prior to Permian deposition.

2.5.1.1.2.2.7 Permian Period

Permian rocks are rare within the Site Region but are present in Nebraska, Kansas, Arkansas, and Oklahoma. The Permian is represented in Missouri by the Indian Cave Sandstone of Early Permian age (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). It is not known if Permian strata ever blanketed much of the Site Region. The existence of marine and non-marine Permian beds in both the eastern and western United States suggests that these strata may have been deposited in the Site Region and subsequently removed by erosion.

The last important structural readjustments of the Illinois Basin occurred at the close of the Paleozoic Era in association with mountain building in the Ouachita Region. These events may have overlapped into the Permian; however, the absence of rocks of this period within the Site Region precludes the possibility of a precise age determination. At this time, the Illinois Basin was separated from its original southward continuation by uplift of the Pascola Arch. Rocks as old as Cambrian were eroded from the crest of the arch, and Pennsylvanian strata were removed as far north as the southern tip of Illinois. Major post-Paleozoic faulting appears to radiate into Illinois and northwestern Kentucky from a focus beneath the Cretaceous deposits of western Kentucky. The Rough Creek Lineament, which trends across the southern margin of the Illinois Basin, has been attributed by Heyl (1965) to horizontal compression. Gibbons (1972) suggests that the Rough Creek Lineament is a zone of upthrust faults similar to the Ste. Genevieve Fault Zone. Pre-existing structures such as the LaSalle Anticline and the Cap au Grès Faulted Flexure were also accentuated at this time.

2.5.1.1.2.3 Mesozoic Era

The Mesozoic Era is subdivided into the Triassic, Jurassic, and Cretaceous periods. Very few deposits of this age are present in the Site Region, indicating an extended period of tectonic stability in the area of study.

Post-Pennsylvanian uplift continued to keep Missouri above sea level, and no marine deposition has taken place since then, except in the area of the Mississippi Embayment (southeast lowlands of Missouri). In the western part of the Mid-continent, the basins and arches that were active during the Paleozoic became dormant. The entire area, as far east as Iowa, Kansas, and Nebraska, subsided slowly and received only a thin blanket of Cretaceous sediment before final uplift.

In the Mississippi Embayment, at the southeast quadrant of the Site Region, rather sharp down warping in Late Cretaceous time permitted the sea to advance from the Gulf of Mexico over a peneplained surface of deeply weathered Paleozoic rocks (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). Cretaceous rocks of reported marine origin have been preserved as far north as west central Illinois. These deposits consist of uncemented sand and gravel unconformably overlying strata of Mississippian and Pennsylvanian age. Their presence suggests that down warping and subsidence of the Mississippi Embayment may have been sufficient to allow Cretaceous seas to advance almost to the Iowa-Illinois boundary.

2.5.1.1.2.4 Cenozoic Era

The Cenozoic Era is subdivided into the Tertiary and Quaternary periods.

2.5.1.1.2.4.1 Tertiary Period

Erosion continued throughout most of the Site Region during Tertiary time, through the Paleocene, Eocene, and Pliocene Epochs. The amount of erosion that occurred after Pennsylvanian time cannot be determined, but it may have removed much of the pre-existing Pennsylvanian strata as well as younger deposits.

In the Mississippi Embayment, beds of the Paleocene Epoch unconformably overlie the Cretaceous formations. Some bentonite beds are present as a result of distant volcanic action. In southeastern Missouri, sediments of the Eocene Claiborne Group were tentatively identified for the first time in a deep test well drilled east of Portageville (Russ and Crone, 1979). The last widespread inundation of the Embayment occurred by the close of the Eocene, and the area has remained above sea level since that time (Cushing et al., 1964).

Brown chert gravels containing minor amounts of sand and red clay either as lenses or as a matrix are widely distributed in southeastern Missouri from the Mississippi Embayment north to St. Louis. These deposits are referred to as the Lafayette gravels and they unconformably overlie all older rocks at elevations generally well above the present streams. They seem to represent remnants of stream deposits formed prior to Pleistocene time, and are tentatively regarded as Pliocene in age (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). Scattered remnants of deposits of possible Tertiary age are present in western Illinois as alluvial gravels now found at high topographic levels.

2.5.1.1.2.4.2 Quaternary Period

Glaciation within the Site Region began in the Pleistocene Epoch about 2 Ma. Glacial deposits of Nebraskan, Kansan, Illinoian, and Wisconsinan stages are present within the Site Region; however, Illinoian and older deposits predominate. The limits of the various glacial advances are shown on Figure 2.5.1-4.

During each advance, the glaciers eroded preexisting deposits. Debris was deposited from the melting ice in the form of till plains, moraines, and outwash during the advance and retreat of the ice sheets. Melt water flowing away from the glacier front was responsible for eroding, reworking, and re-depositing many of these materials. Windblown silt, derived from the outwash, was widely distributed over the land surface well beyond the glacier front. Sand dunes developed locally. Between major glacial advances, the climate returned to more temperate conditions. Streams developed more integrated drainage systems. Initially, stream positions were largely controlled by surface features left by the retreating glaciers. As these materials were exposed, weathering processes began modifying them. The thickness and character of the resulting soils are largely functions of climate and duration of the interglacial age.

Northern Missouri was glaciated during the Nebraskan and Kansan stages. Glacial deposits, including till and outwash sand and gravel, are present throughout northern Missouri with a maximum recorded thickness of nearly 400 ft (120 m). Glacial and post-glacial deposits filled in valleys and the actions of the glaciers planed down the pre-existing prominences, creating a surface with little relief. Topography in this part of Missouri is characterized by gently rolling uplands that are well dissected by downcutting of the Missouri River and its tributary streams. These deposits are associated with and overlie a pre-Pleistocene drainage system that is in part unrelated to the modern topography. Some glacial till of Illinoian age is present in the St. Louis area. The Peoria and other loess (windblown silt) deposits are prominent along the Missouri and Mississippi river bluffs. A regional loess isopach distribution map is presented on Figure 2.5L-7.

The southern part of Missouri was not glaciated and did not receive any of the characteristic glacial deposits, but it was influenced by changes related to glaciation. The alluvial fill in the modern Missouri and Mississippi river valleys is considered to be mostly Wisconsinan in age (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967). Descriptions of the glacial and post-glacial deposits are presented in Section 2.5.1.1.3.4.2, for the region, and Section 2.5.1.2.3.1, for the Site.

2.5.1.1.3 Regional Stratigraphy

Generalized regional stratigraphy are shown on Figure 2.5.1-9. Deposits representing all of the systems in the geologic column, except for those of Jurassic and Triassic age, are found within the Site Region. Surface exposures of igneous and metamorphic Precambrian rocks are largely confined to the St. Francois Mountains area of the Ozark Uplift in Missouri. Paleozoic rocks, with the exception of Permian, form thick deposits of largely carbonate strata (limestones and dolomites) over major portions of the Site Region. Younger deposits, such as Cretaceous and Tertiary, are limited in extent. These are generally clastic deposits whose distribution is confined to the Mississippi River area at the southeastern limit of the Site Region. A major portion of the Site Region is blanketed by Quaternary sediments that were deposited during various Pleistocene glacial advances. These are principally composed of silts and clays deposited on the post-glacial land surface and sands and gravels deposited in pre-glacial valleys. Other Quaternary sediments, consisting primarily of sand and gravel deposits, form flood plain deposits along existing drainages. Figure 2.5L-9 shows the geologic profile in the area of the Site. These profiles are representative of the geology in the Site Region, especially in the regional areas that were subject to glaciation. The discussions of regional sedimentology and stratigraphy in the following paragraphs are confined to major time-stratigraphic units.

2.5.1.1.3.1 Precambrian Rocks

Igneous, metamorphic, and small bodies of clastic sedimentary rock form the Precambrian basement throughout the Site Region (Kisvarsanyi, 1974a). The crystalline rocks are chiefly granitic in composition with some older felsitic lava flows (containing iron ores), metamorphosed volcanic rocks, and younger gabbros are also present. Radioactive dating indicates that much of the metamorphic and intrusive rock in the Ozark region was formed 1.2 to 1.46 billion years ago. A long period of erosion preceded the deposition of Cambrian sediments, and much of the Site Region was reduced to a relatively flat plain. Numerous isolated hills several hundreds of feet high were present in eastern Missouri and in western and southern Illinois. The Ozark region stood as an island, locally as much as 2,000 ft (610 m) above the first Cambrian seas that reached the region.

Although Precambrian rocks underlie the entire Site Region and have been penetrated by deep drilling, outcrops are not widespread except in the area of the St. Francois Mountains, located within the Ozarks Plateau, where more than 5,000 sq. miles (13,000 sq. km) are exposed (Unklesbay, 1992).

2.5.1.1.3.2 Paleozoic Rocks

Paleozoic rocks are subdivided into major rock units called systems beginning with the Cambrian Period and ending with the Permian Period. The thickness, character, and stratigraphic relationships of these various rock systems within the Site Region are discussed in the following sections.

2.5.1.1.3.3 Cambrian System

Cambrian Sedimentology

No rocks of Lower or Middle Cambrian age have been identified in the Site Region. Upper Cambrian strata overlie and were eroded from the Precambrian rocks. The Precambrian-Cambrian contact is a pronounced unconformity. The basal, marine Cambrian unit is an arkosic and conglomeratic quartz sandstone that is widespread throughout the region. The sandstone is more than 1,500 ft (460 m) thick toward the northeast in Illinois. It is only a few feet to a few hundred feet thick in the Site Region, and thin to absent over the isolated hills of the Precambrian surface. The sandstone grades upward to dolomite, indicating continued advance of the shallow seas with subsequent deposition of more offshore sedimentation. A shallow marine shelf was formed that extended from present day Missouri to New York State. Although dolomite predominates in the remaining several hundred feet of Cambrian strata, some fine-grained sandstones, siltstones, and shales also are present, indicating cyclic near-shore sedimentation. Much of the Site Region, including the Ozark area, remained submerged at the end of the Cambrian, and sedimentation continued unbroken or with minor interruption into Early Ordovician time.

Cambrian Stratigraphy

The Cambrian formations beneath the Site Region are composed chiefly of carbonate deposits, with clastic units being in the minority. The basal unit is called the Lamotte Formation a sandstone formation that is 200 to 500 ft (61 to 152 m) thick. This is overlain by the Bonne Terre Formation comprising 400 to 1,500 ft (122 to 457 m) of fossiliferous limestone and dolomite containing lead ore. Above the Bonne Terre is the Davis Formation (approximately 200 ft (61 m) thick) of alternating thin limestones and shales. The Davis is glauconitic and contains flat-pebble limestone conglomerates containing disk-like pebbles. The Davis is overlain by the Derby-Doe Run Formation, consisting of alternating dolomite, siltstone, and shale up to 150 ft (45.7 m) thick. Over the Derby-Doe Run are two thick-bedded carbonate formations, the Potosi (containing barite) and the Eminence (containing caves, springs, and other karst features). The dolomite units and the ore minerals they contain were the result of post-depositional addition by mineralizing solutions, containing solutions of magnesium (transforming dolomite from limestone) and other metals forming ores of zinc, lead, copper, and barium. The regional development of karst features, such as caves and sinkholes, is more fully described in Section

2.5.1.1.5. The Site Area has no karst development, due in part to the thick cover of relatively impermeable surface deposits, as described more full in Section 2.5.1.2.5.

Clastic sedimentary rocks that predate the Upper Cambrian have been identified in Vernon and Bates counties in western Missouri. They have been dated only as pre-Upper Cambrian since the exact age of these sediments is not known and may be as old as Precambrian (Skillman, 1948).

2.5.1.1.3.3.1 Ordovician System

Ordovician Sedimentology

Early Ordovician strata in the Site Region consist chiefly of cherty dolomites with some interbedded quartz sandstones. They are several hundred feet thick in most of the Site Region, but thicken to several thousand feet toward the southeast. These strata are separated from younger sedimentary rocks by a marked unconformity, the result of uplift and erosion throughout the Site Region. Karst features were developed on the uplifted carbonates before Middle Ordovician sandstones and carbonates were deposited. Some abnormal thicknesses of sandstones (up to several hundreds of feet thick) are preserved in sinkholes. The Middle Ordovician carbonates, chiefly limestone, but with some dolomite, are widespread and are evenly bedded. Shale partings and some fine-grained sandstone are present locally, but they generally account for only a small percentage of the section. Uplift and some truncation occurred at the end of Middle Ordovician time. Late Ordovician strata were deposited unconformably on a relatively flat surface. The strata consist chiefly of shale, siltstone, and carbonates that range from a few to about 200 ft (61 m) thick. Although these strata were deposited over large areas in the Site Region, uplift and erosion at the end of Ordovician time subsequently removed portions of Late Ordovician strata from many areas.

Ordovician Stratigraphy

The Ordovician System in Missouri is divided into four stratigraphic series. From lowest to highest stratigraphically, these series are as follows: the Ibexian (formerly or alternately called the Canadian) Series, the Whiterockian (formerly the lower part of the Champlainian) Series, the Mohawkian (formerly the upper part of the Champlainian) Series, and the Cincinnatian Series. The 2003 edition of the Geologic Map of Missouri (MODNR, 2003) has dropped the term Canadian, preferring the Ibexian Series, for the lower Ordovician. Detailed stratigraphy of this System comes from Paleozoic Succession in Missouri, Part 2 Ordovician System (Thompson, 1991).

The dominant rock type of the Ibexian Series is a cherty dolomite, although some sandstone beds are present. Formation names include: the Gasconade Dolomite, the Roubidoux Formation, the Jefferson City Dolomite, the Cotter Dolomite, the Powell Dolomite, and the Smithville Dolomite. Of these formations, the Roubidoux has the most sandstone, but is interbedded with dolomite, as well.

The dominant rock type of the Whiterockian Series is sandstone, specifically rocks of the St. Peter Sandstone. Separated out from, and lying stratigraphically below, the St. Peter at the lower part of the Whiterockian Series is the Everton Formation, comprising mostly limestone with some dolomite and sandstone. In this Site Region, the Whiterockian Series is composed of only these two formations.

The dominant rock types of the Mohawkian Series include limestone and dolomite, with some shale and sandstone. Formation names include the Dutchtown Formation (southeast part of the Site Region only), the Joachim Dolomite, the Plattin and Decorah Groups (treated either as a group or subdivided into formations), and the Kimmswick Limestone.

The dominant rock type of the Cincinnatian Series in the northeast of this Site Region is shale with limestone near the upper part of the Series. Formations include the Maquoketa Shale and the overlying Noix-Cyrene Limestone. In the southeast, shale dominates also, except for limestone in the upper and lower parts of the Series. Formations from lower to upper include the Cape Limestone, the Maquoketa Group (Cape La Croix Shale, Thebes Sandstone, Orchard Creek Shale, and Girardeau Limestone), and the Leemon Formation (mostly calcarenite).

2.5.1.1.3.3.2 Silurian System

Silurian Sedimentology

Silurian strata consist mostly of light gray dolomite and limestone with zones of abundant chert. They disconformably overlie the Ordovician rocks and are restricted in thickness and distribution. They do not exist over the Ozark Uplift, but more than 400 ft (120 m) of Silurian strata are present in the Illinois and Forest City basins, indicating that the Silurian strata may have been deposited and then eroded. Reefs were abundant on the submerged platforms surrounding the Ozark region. The Silurian carbonates are difficult to separate from the overlying Devonian carbonates, and many studies combine them under the general designation of Hunton Group or Supergroup. Uppermost Silurian and Lower Devonian strata are generally absent in the region, indicating a period of non-deposition and/or erosion between the times of deposition of the Silurian and Devonian sediments.

Silurian Stratigraphy

Two stratigraphic series comprise the Silurian System in this region. The Llandoverian and the overlying Wentlockian-Ludlovian Series also called Post-Llandoverian by (Thompson, 1993).

The dominant rock type of the Llandoverian Series is limestone. In the southeast, it comprises the Sexton Creek Limestone. In the northeast, it comprises three formations (from lowest to highest stratigraphically): the Bryant Knob Formation (limestone), the Bowling Green Dolomite, and the Joliet Limestone.

The dominant rock types of the Wentlockian-Ludlovian Series are limestone and shale. Rocks of this series are located only in the southeast part of the Site Region and comprise the Bainbridge Formation.

2.5.1.1.3.3.3 Devonian System

Devonian Sedimentology

A long hiatus occurs in the record following Silurian deposition. The Ozark region, as well as its northern extensions along the Lincoln Fold (Number 42 in Figure 2.5L-6) and the Mississippi River Arch (Figure 2.5.1-7), was uplifted prior to the advance of Late Middle Devonian seas. More than 1,000 ft (300 m) of cherty limestone and dolomite were deposited in the southern part of the Illinois Basin during Early Devonian time, but rocks of this age are generally absent from the remainder of the Site Region.

In Middle Devonian time, calcareous sediments were deposited in the Illinois and Forest City basins. Deposits composed chiefly of limestone, which are locally very fossiliferous, range from a few ft to a few hundred ft in thickness. The Devonian limestone is distinguished from the underlying Silurian carbonates by the presence of thin beds of sandstone or sandy limestone. In southeastern Iowa, anhydrite and gypsum are also present in Middle Devonian strata.

Upper Devonian and lowermost Mississippian sediments unconformably overlie Middle Devonian carbonates. Deposits consist of widespread, dark brown to black, spore-bearing shales with some siltstone and limestone. Their maximum thickness is commonly less than 300 ft (90 m).

Devonian Stratigraphy

The Devonian System of this region can be divided into three Series: Lower, Middle, and Upper. Variations in the lithostratigraphy are recognized in five different regions: southwest, central, northeast, east-central, and southeast (Table 2.5.1-1). Rock types are almost entirely limestone and dolomite.

Devonian strata are absent in much of the southern part of the Site Region because surface rocks are older than Devonian—indicating erosion or non-deposition. Devonian rocks crop out in bluffs on the north side of the Missouri River valley in the vicinity of the Site (in the counties of Boone, Callaway, Montgomery, Warren, and St. Charles) and extend into the subsurface in the northern part of the Site Region beneath younger strata. To the northeast of the Site, in portions of Lincoln, Pike, and Ralls counties, the Devonian strata are absent. The Site Area lies between the Central and East-Central Regions, and contains the Bushberg and Snyder Creek Formations.

2.5.1.1.3.3.4 Mississippian System

Mississippian Sedimentology

Early Mississippian time began with continued submergence of most of the Site Region beneath shallow seas. During the Middle Mississippian, clays and sands (producing shales and thin sandstones) were superseded by widespread deposits of shallow-water carbonates (producing chiefly cherty and fossiliferous limestones). The rocks are several hundred feet thick over much of the Site Region and thicken to more than 1,000 ft (300 m) in the Illinois Basin, where some oolitic limestone and anhydrite are included in the upper part of the section.

Most of the Site Region was uplifted to form a broad, low plateau during the Late Mississippian, and deposition occurred chiefly in the Illinois Basin resulting in more than 1,400 ft (430 m) of strata. The deposits in the basin produced thin, discontinuous, alternating beds of shale, limestone, and sandstone. They consist of about one-half shale and one-fourth each of limestone and sandstone. The units thicken southward to the present southern limits of the Illinois Basin, where they have been truncated by post-Mississippian erosion.

At the close of Mississippian time, widespread uplift occurred and erosion removed the Mississippian deposits in many parts of the Site Region. Sinkholes and erosional stream channels were formed in the carbonates on the flanks of the Ozark Uplift.

Mississippian Stratigraphy

Because of variation of the Mississippian strata over the Site Region, stratigraphic units have been defined in six areas: east-central, southeastern, northeastern, southwestern, northwestern, and central (Unklesbay, 1992 and Thompson, 1986). Throughout the Mid-continent the Mississippian strata are divided into four series: Kinderhookian, Osagean, Meramecian, and Chesterian (Table 2.5.1-2).

The Kinderhookian Series occurs largely in northeast Missouri and adjacent areas of Illinois and Iowa, although this series is present in all of the six areas. The Chouteau Group, a series of limestones and limestones interbedded with sandstones and dolomite, is common to all areas, except for the east central area where the Site is located.

Stratigraphically below the Chouteau are strata of sandstone, shale, and interbedded sandstone and limestone. In the northeast area this sequence is called Hannibal Shale and consists of up to 100 ft (30 m) of gray to bluish-green shale, siltstone, and argillaceous sandstone. In the other areas pre-Chouteau strata are represented mostly by sandstone strata (Bachelor Formation, Bushberg Sandstone) and some limestone.

The Osagean Series is predominantly limestone. The most prominent formations of this series are the Burlington and Keokuk Limestones. They are both crystalline and fossiliferous and contain chert. Other formations of this series, also mostly limestone, lie below the Burlington.

Except for the southeastern and southwestern areas, the Osagean Series is followed conformably by the Meramecian. The lowermost formation in the Meramecian is the Warsaw. The Warsaw varies from crystalline limestone to thin shale. Stratigraphically above the Warsaw is the Salem Formation, which is mostly limestone with some dolomite. The Salem, in turn, is overlain by the St. Louis Limestone. Above is the Ste. Genevieve Limestone (limestone and sandstone). In the southeast, the Ste. Genevieve is overlain by the Aux Vases Sandstone.

The Chesterian Series is characterized by sandstone, shale, and limestone and is represented in the southeastern and southwestern areas.

2.5.1.1.3.3.5 Pennsylvanian System

Pennsylvanian Sedimentology

Deposition during the Pennsylvanian took place in widespread, shallow seas and contiguous swamps and deltas. The deposits are decidedly different from older rocks. They consist of thin units of shale, siltstone, limestone, and coal that can be traced over wide areas. Sandstones are present, commonly as channel fill. Deposition was cyclical, with each cycle composed of both marine and terrestrial sediments. Fossils include both marine invertebrates and land plants. A repetitive sedimentation (called cyclothems), characteristic of coal measures in the eastern United States, occurred during Pennsylvanian time.

Throughout much of the Site Region where cherty carbonate rocks, such as those deposited during Mississippian time, have been exposed to erosion, weathering has formed a deposit consisting of iron-rich insoluble clay containing resistant chert layers and nodules. This chert conglomerate has largely developed by continued weathering of the parent rock. Colluvial and stream action reworked the chert conglomerate during Pennsylvanian and possibly post-Pennsylvanian time. Additional weathering of the reworked deposits may have produced a secondary residuum in some localities, resulting in further alteration of the clay minerals in the units.

Pennsylvanian Stratigraphy

The aggregate thickness of Pennsylvanian strata was more than 3,000 ft (900 m) in the Forest City and Illinois basins. Post-Pennsylvanian erosion has removed these rocks from the Ozark Uplift and the Mississippian Arch, and has caused considerable thinning in many other areas.

2.5.1.1.3.3.6 Permian System

Permian rocks are rare in the Site Region. Some sandstone-filled channels in northwestern Missouri are cut into Upper Pennsylvanian beds and have been identified as being Permian in age. West of the Site Region, Permian rocks conformably overlie Pennsylvanian deposits. They grade upward from an alternating marine and non-marine sequence to dominantly terrestrial red beds, indicating a general emergence during that period. The entire region remained above sea level most of the time until Late Cretaceous seas invaded the Mississippi Embayment.

2.5.1.1.3.4 Mesozoic Rocks

Mesozoic rocks are poorly represented within the Site Region. Of the three rock systems that were formed during Mesozoic time (Triassic, Jurassic, and Cretaceous), only the Cretaceous is present.

2.5.1.1.3.4.1 Triassic System

No rocks of Triassic age are known within the Site Region.

2.5.1.1.3.4.2 Jurassic System

No rocks of Jurassic age are known within the Site Region.

2.5.1.1.3.4.3 Cretaceous System

Downwarping and faulting associated with rifting, sediment load in subsided areas, and deformation under this load along the present course of the Mississippi River permitted Late Cretaceous seas to advance at least as far north as southern and southwestern Illinois and perhaps as far north as the Iowa-Illinois boundary. Cretaceous sediments unconformably overlie rocks ranging from Pennsylvanian age in southern Illinois to those of Cambrian age along the crest of the Pascola Arch in southeastern Missouri and western Tennessee. Cretaceous sediments are several thousand feet thick just south of the Site Region but they thin regularly northward.

Cretaceous rocks in the Site Region are the result of lithification of coastal plain sediments of the Mississippi Embayment. During the Cretaceous, the Site Region was within the upper reaches of the Mississippi Delta. Consequently, one Upper Cretaceous series has been defined (the Gulfian), which consists of three units. The lowermost, consisting of sand, chalk, clay, and limestone, is unnamed in Missouri (but is correlative to the Coffee and Selma Formations of Tennessee). Above it is the McNairy non-marine sand and sandy clay; the upper part of which is a source of sand and forms a regional aquifer. Above the McNairy is the Owl Creek which is a massive sandy and micaceous clay.

Igneous dikes of possible Cretaceous age are discussed in Section 2.5.1.1.4.1.9 (Cryptoexplosive Structural Lineament (38th Parallel)). Some of these structures, located along a line near and extending parallel to the 38th parallel between Kentucky and Kansas, seem to be diatremes (volcanic pipes) caused by gaseous volcanic explosions.

2.5.1.1.3.5 Cenozoic Rocks

The Cenozoic rocks are divided into the Tertiary and Quaternary Systems. As with the Cretaceous rocks and sediments, the Tertiary is also associated with the Mississippi Embayment (including neritic, deltaic, and fluvial sediments). Gravels of possible Pliocene age lie at high levels in the Mississippi Embayment and the Ozark region on a regional erosional surface that truncates strata with ages from Paleozoic to Eocene.

The Quaternary System is represented by glacial tills and associated outwash in the northern and eastern Site Region, loess derived from windblown glacial outwash, terrace deposits along major streams and outwash channels, and recent alluvium and colluvium.

2.5.1.1.3.5.1 Tertiary System

Paleocene strata include sand and clay of the Clayton Formation, and dark gray to almost black clay of the Porters Creek Formation (Unklesbay, 1992). The Porters Creek lies conformably on the Clayton Formation, which in turn, lies unconformably on the Cretaceous rocks. They are found principally in the Mississippi Embayment and are commonly less than 200 ft (61 m) thick in the Site Region.

Eocene strata include sand with some clay and gravel (Holly Springs Formation). The overlying non-marine silty clay is the Ackerman Formation (Unklesbay, 1992). They range up to 450 ft (137 m) thick just south of the Site Region. Sediments of the Eocene Claiborne Group and two formations of the Eocene Wilcox Group have been tentatively identified for the first time in southeastern Missouri in a deep test well (Russ and Crone, 1979).

Strata of possible Pliocene age include high-level, rounded and polished chert gravels in the Mississippi Embayment and the adjacent Ozark region. They have been called the Lafayette Formation due to similarity with gravels near Lafayette, Mississippi. In some localities the gravels are mixed with iron-stained sand.

2.5.1.1.3.5.2 Quaternary System

Pleistocene deposits up to several hundred feet thick unconformably overlie bedrock in the northern and eastern portions of the Site Region. They consist of glacial tills, outwash sands and gravels, and loess. Quaternary alluvial deposits of principally sand and gravel occur along existing drainage courses. Outside the drainage courses, on interfluves, are deposits of colluvium developed from slope-wash and mass movement of debris.

During the last glacial maximum, loess deposition rates were neither spatially nor temporally constant. While all loess deposition took place broadly within the last glacial period, areas close to glaciofluvial source valleys received sediment earlier than those farther away. Within the Site Region, four units have been identified. These units are, from oldest to youngest: Loveland Loess, Roxana Silt, Gilman Canyon Loess, and the Peoria Loess (Busacca et al., 2004).

The Loveland Loess dates from the Illinoian glaciation. It can be distinguished from the other loess deposits due to its reddish color and mainly clay composition (IDNR, 2008). Where unleached it is calcareous and contains gastropods. The maximum thickness is rarely more than 20 ft (6 m) along the Missouri River valley; elsewhere it is generally thin and discontinuous (Bayne, 2008).

The Roxana Silt was deposited during the middle Wisconsinan advance of the Laurentide Ice Sheet. This silt was derived as loess blown from flood plains of proglacial rivers. The texture of the Roxana changes from north to south as does its degree of weathering (Leigh, 1994). It is easily identifiable in the subsurface by the presence of the Robein Silt Member, a dark-brown to black organic-rich silt (Soller, et al., 2008).

The Gilman Canyon Loess was deposited during the early Wisconsinan in local depressions under moist or swampy conditions. Stratigraphic evidence indicates that this loess could include more than one period of deposition (Busacca, 2004). The lower horizon is light-gray to nearly white, and the upper horizon is dark-gray, silty clay. It is approximately 2 to 4 ft (0.6 to 1.2 m) in thickness (Bayne, 2008).

The Peoria Loess was also deposited during the last glacial maximum. It is not uniform throughout, but is separated into three zones. In general, coarse silt is dominant, with zones being distinguished by percent of fine silt present. Quartz/calcite and quartz/dolomite are present in all layers, but with varying abundance. The difference in grain-size properties has been interpreted as having been caused by either a paleoclimatic change or a change in the sediment source (Muhs and Bettis, 2000). This unit is the thickest and most extensive of all of the units described, ranging from 30 to 50 ft (9 to 15 m) in thickness.

The regional distribution of the Quaternary loess deposits is shown in Figure 2.5L-7.

2.5.1.1.4 Regional Tectonic Setting

Tectonic features are formed from the structural deformation of the earth's crust and can be responsible for additional deformations possibly causing seismic events. Regional tectonic structures include structural domes (uplifts) and basins (depressions), folds (anticlines-arches-noses and synclines-troughs-sags), faults, grabens (block faulting), and joints. These types of structures are created by tectonic activities due to plate divergence and convergence, epeiric reaction to stress fields, igneous intrusion, and flexure or warping of the crust from sediment. Cryptoexplosive structures have a more problematic origin involving tectonics, volcanism, and possibly the influence of meteorite impact, as discussed in Section 2.5.1.1.4.1.9.

The Site Region offers an extensive history of tectonic features as discussed in the following sections. However, most of the seismically active features are located at some distance from the Site. Most of the faulting and folding in the Site Region was completed by Late Paleozoic time (approximately 300 Ma), although some structures are postulated to be more recent. The area surrounding the Site is part of a stable region of the continent subject to very limited seismicity and posing extremely low seismic hazard. The structures with more recent seismic activity are located along the Mississippi Embayment 200 miles (320 km) to the southeast of the Site. Exact dating for some structures cannot be determined due to the absence of younger sedimentary sections overlying them. As will be demonstrated in the following discussion, it is apparent that the Site is well removed from the effect of the anomalies and the seismicity of the Site Region.

Tectonic features within the Site Region are illustrated on Figure 2.5L-5, Figure 2.5L-6, and Figure 2.5.1-7. An attempt has been made to show as many structural features within the Site Region as possible; however, some generalization has been necessitated by the small-scale mapping of closely spaced features such as zones of intense faulting in southern Illinois, located some distance from the Site.

Available evidence indicates that the structural style of the entire Ozark Region is block or upthrust faulting. Basement-rooted upthrust faults form the boundaries of crustal blocks sized a few miles to a few tens of miles on a side. Minor faults and folding associated with these basement-rooted faults of all scales are present as subsidiary features within blocks. Block boundaries display a strong preferred orientation, trending northeasterly and northwesterly, and having structural relief from as little as a few tens of feet to more than a thousand feet between blocks. All elements of the structural geometry of the Site Region appear to have been inherited from a Precambrian structural fabric (Gibbons, 1972; Graves, 1938; Robertson, 1940, in AmerenUE, 2004; Tikrity, 1968; Heyl, 1977). Displacements along the individual features represent localized Paleozoic uplift and subsidence.

The tectonic character of the Site Region is the result of a sequence of episodes of relative vertical uplift, subsidence, and tilting of crustal blocks which are bounded by upthrust faults. As previously discussed, the geometry of the blocks appears to be inherited from an older, possibly Grenvillian, structural fabric. Many structural elements reflect a consistent geometry, including the traces of steeply dipping block-bounded faults that are associated with faulted monoclines, the strikes of vertical Precambrian dikes, the fracture patterns in Precambrian rocks, the fracture patterns in the sedimentary rocks, and the traces of minor faults, and the axes of the major folds (Graves, 1938; Robertson, 1940, in AmerenUE, 2004; Gibbons, 1972). The majority of folding in the Site Region is either the result of the passive draping of relatively weak sedimentary rocks over the edges of fault blocks, or of the previously mentioned paleotopographic effects.

In only one area are any features present that represent a tectonic style other than that described above. Several strike slip faults have been noted by mine geologists while working at the St. Joe Minerals Corporation mine site in the Missouri lead belt. These features are restricted to a zone along the strike of the Simms Mountain Fault in the downthrown Farmington block. Only a few such features are known, and they all strike at a high angle to the Simms Mountain Fault; they are all essentially vertical. Horizontal slickensides and mullions are evident in several cases. In the St. Joe Mineral Corporation's Des Lodge Mine, one fault laterally offsets the crest of a reef in the Bonne Terre Formation by 600 ft (180 m). No evidence of strike-slip faulting is present anywhere else in the eastern Ozark Region. The strike-slip faults appear to be the product of local compression of the edge of the Farmington block resulting from the rotation of that edge of the block against the Simms Mountain block when it was tilted during uplift. This tilting is the result of greater uplift along the eastern edge of the block than along the western edge. Westerly primary dips of sedimentary rocks in the Farmington block have been reversed. The oblique nature of the displacement along the Big River Fault substantiates this interpretation (Gibbons, 1972).

The geometry and boundaries of the major blocks represent inherited zones of weakness. Some segmentation of blocks by minor faults has occurred, but blocks several tens of miles on a side have generally acted as cohesive tectonic units. Where major, persistent features have acted as a boundary to several adjacent blocks (for example, the Ste. Genevieve Fault and the Simms Mountain Fault) their role has been passive. These features represent kinematic surfaces which have responded to the episodic uplift of contiguous individual blocks throughout Paleozoic time. The vertical stratigraphic separation and sense of vertical offset along any segment of these features is a reflection of the vertical motions of blocks responding to local uplift, rather than to uniform motion along the entire length of the major faults (Gibbons, 1972).

The response of the sedimentary rocks overlying the faults has been entirely passive. A characteristic assemblage of monoclinal folds, curving reverse fault planes, compensatory normal faults, and minor low angle normal faults illustrate passive response to repeated vertical movements along nearly vertical basement discontinuities (Gibbons, 1972).

The gross regional structural pattern of this portion of the continental interior appears to be the result of local uplift and subsidence of blocks, or groups of blocks, along pre-existing structural discontinuities. The dome and basin character of the Site Region is the direct expression of deep crustal or subcrustal adjustments (McCracken, 1971). These adjustments have produced relief on the basement surface through vertical displacement of basement blocks which inherited their geometry and which appear to have persisted as structural units through the entire history of the Site Region. The tectonics of the region must, therefore, be based upon an understanding of vertical kinematics rather than to lateral or horizontal compressive forces.

The structural features shown on Figure 2.5L-5, Figure 2.5L-6, and Figure 2.5.1-7 probably reflect basement structures, and they must all be considered to be deep-seated. It is possible that some of these features may have been caused or influenced by other mechanisms, such as the differential compaction of sedimentary beds emplaced over a Precambrian surface that has substantial topographic relief. However, it is not possible to definitely delineate such origins for individual structural features with the present level of information available regarding the structural geology of the Site Region.

The structural features in the Site Region were probably formed by differential uplift and settlement of crustal blocks in a manner similar to that which resulted in the formation of the Ozark Uplift. The relationship between these small features and the Ozark Uplift is imperfectly understood due to the poor exposures and lack of subsurface information. It is, nevertheless, clear that the forces that formed the Ozark Uplift were also instrumental in the formation of these minor structures. The tectonic forces were essentially vertical and are considered by some investigators to have resulted from isostatic adjustment. That these forces acted upon blocks of considerable size has been demonstrated by Gibbons (1972).

The work of Dake and Bridge (1932) shows that the Ozark Region has been a topographically positive region since at least early middle Cambrian time. The relief present at that time probably represented the resistance to erosion of the thick, silicic extrusive volcanics that comprise the Precambrian core of the St. Francois Mountains. The Cambrian and Ordovician sedimentary rocks were deposited and subjected to differential compaction over the preexisting topography. Much of the structural geometry of the Site Region is a result of this pronounced paleotopographic effect (Dake and Bridge, 1932; Tikrity, 1968), (Weller and St. Clair, 1928).

Gibbons' discussion of the blocks within the central area of the Ozark Uplift demands comparison to the concept of crustal blocks as proposed by McGinnis (1970). It is conceivable that the uplift and subsidence of crustal blocks is a direct result of vertical forces originating in the mantle. It also might be speculated that the smaller features were formed contemporaneously with the Ozark Uplift and that, consequently, there is a direct relationship. However, this is not necessarily true and it could also be reasonable to speculate that minor faulting and folding near the Site were formed independently by vertical forces working on discrete, independent crustal blocks.

Hayes (1962, in AmerenUE, 2004) proposed major structural lineaments in the Precambrian rocks of Missouri based upon exposed structures, magnetic and gravity features, and sparse information from drill holes penetrating to the Precambrian. These lineaments may be related to structures which are part of the Precambrian structural fabric which has controlled the structural geometry of the Site Region. There are no structures which can be readily related to the lineament nearest the Site, along the Missouri River.

At some of the junctions of Precambrian lineaments cryptoexplosive structures exist. No proven cryptoexplosive structure is present, however, at the lineament junction nearest the Site. This junction is associated with the Wardsville Fault and occurs 30 miles (48 km) west-southwest of the Site. The nearest cryptoexplosive structure is the Crooked Creek structure 60 miles (97 km) to the south-southeast. No recorded seismic activity has been attributed to these two lineament junctions, but two epicenters have been reported near the Palmer Fault System where it joins the Crooked Creek structure.

Recent seismic activity in the Mississippi Embayment area, located 200 miles (320 km) to the southeast of the Site, has resulted from continuing adjustment along zones of weakness in crustal faults that have been active at multiple times in the geologic past. This continued seismic activity along the Mississippi has caused numerous faults to propagate from the Precambrian basement up through the overlying sediments to the surface.

2.5.1.1.4.1 Regional Tectonic Structures

As stated previously, the Site lies in the Central Stable Region of the United States. Tectonic activity largely ceased in the Paleozoic Era approximately 300 Ma.

The major basins and structural features, in general, follow the descriptions in Riggs (1960), and are shown on Figure 2.5.1-7. Local structures are described and referenced in detail in McCracken (1971) for Missouri, Nelson (1995) for Illinois, and Harris and Parker (1964) for Iowa.

The eight main structural elements of interest in the Site Region are:

1. Illinois Basin, including the Wabash Valley Seismic Zone;

2. Mississippi Embayment, including the Reelfoot scarp and New Madrid seismic zone;
3. Ozark Uplift and St. Francois Mountains;
4. Commerce Geophysical Lineament (CGL);
5. Forest City Basin;
6. Lincoln Fold - Mississippi River Arch;
7. North-Central Missouri Region (This is not a recognized tectonic region, but rather an area between basins and arches (uplifts)); and
8. Cryptoexplosive Structural Lineament (38th parallel).

2.5.1.1.4.1.1 The Illinois Basin

The Illinois Basin (Figure 2.5.1-7) is a spoon-shaped intracratonic basin bounded on the northwest by the Mississippi River Arch, on the northeast by the Kankakee Arch, on the southeast by the Cincinnati Arch, and on the south-southwest by the Pascola Arch and the Ozark Uplift (Pitman, 1997). Willman et al. (1975, in Crone, 2000) gives these suggested limits of the basin:

1. Minus 500 ft (150 m) msl contour on top of the Ordovician Galena Group,
2. Minus 1,000 ft (300 m) msl contour on top of the Ordovician Galena Group, or
3. Area underlain by Pennsylvanian strata (Eastern Interior Coal Basin).

The Illinois Basin initially was a broad intracratonic embayment (aulacogen) that formed as a result of rifting in the early Paleozoic (Burke, 1973; Ervin, 1975 in Pitman, 1997), and it accumulated a large volume of sediments. During the remainder of the Paleozoic, the basin experienced multiple periods of tectonic deformation in response to the Taconic, Acadian, and Ouachita orogenies.

Regionally, bedrock consists of Paleozoic strata that dip northeastward from the Ozark Uplift toward the center of the Illinois Basin. Historical earthquakes are scattered throughout the Site Region. The earthquakes are part of the broad, diffuse halo of scattered seismicity that surrounds the New Madrid seismic zone. Numerous large faults, monoclines, and other folds of Paleozoic age are known throughout the Site Region, and are thought to be related to basement structures.

Most of the Paleozoic systems thicken toward the center of the present Illinois Basin. Before they were uplifted and truncated by erosion at the end of the Paleozoic, the systems continued to thicken an unknown distance farther to the south. The southern limits of the Illinois basin formed at about the end of Paleozoic time when the rocks in southeastern Missouri and northwestern Tennessee, between the Ozark Uplift and the Nashville Dome, were uplifted to form the Pascola Arch. The Precambrian basement rocks are 11,000 ft to more than 13,000 ft (3,400 m to more than 4,000 m) lower at the center of the basin than at its edges.

The southern end of the Illinois Basin is one of the most structurally complex regions in the Mid-continental United States, with two major structural elements characterizing this part of the basin (Kolata, 1997): (1) The Wabash Valley Seismic Zone; and (2) The Reelfoot Rift and Rough Creek Graben. Other features in the basin are presented on Table 2.5.1-3. Additional discussions of these significant features are presented in the sections that follow, and details of these fault systems are used in the seismic hazard analysis presented in Section 2.5.2.

2.5.1.1.4.1.2 The Mississippi Embayment

This feature (Figure 2.5.1-11) has been described as a southwest-plunging sedimentary trough, extending north from the Gulf Coast to the southeast region of Missouri, approximately parallel to the Mississippi River. It is characterized, on the surface, by a large alluvial plain interrupted by a line of low hills (MODNR, 2007). During the late Cretaceous and continuing through the Eocene, the embayment was filled with a southward-thickening wedge of predominantly clastic marine and continental sediments. Oligocene sediments are generally absent in the northern Mississippi embayment. The Embayment is underlain by the early Paleozoic Mississippi Valley graben basement fault complex, which was created by the late Precambrian-early Paleozoic rift system (Hildenbrand, 1985). The complex tectonic evolution of the upper Mississippi Embayment started in the late Precambrian or Cambrian with a major rifting event involving the formation of a large graben along a pre-existing shear zone. Reactivation of this graben occurred in Permian and Cretaceous time, which caused the Reelfoot rift area to subside and the Pascola arch to form. The formation of the present Mississippi Embayment and fault zones appears to be driven by these pre-existing rift structures (Hildenbrand, 1985).

Another theory about the development of the Mississippi Embayment is presented by Cox (2002). Previous authors have attributed Embayment subsidence to the opening of the Gulf of Mexico, which created rift structures. However, the Embayment subsided 60 million years after the cessation of the sea-floor spreading in the Gulf. Cox suggests that progressive (northwest-to-southeast) mid-Cretaceous volcanism that crosses the Mississippi Embayment coincides with the predicted Bermuda hotspot path. During the mid-Cretaceous, the weak crust of the Mississippi Valley graben complex moved west of the hotspot and subsided, and the eroded region became a topographic low that filled with fluvio-marine sediments, the Mississippi Embayment.

The Mississippi Embayment, especially the area surrounding the northern end of the Embayment, 200 miles (320 km) to the southeast of the Site, is a site of continued tectonic and seismic activity. The present-day seismicity pattern suggests linear active zones (Stauder, 1982 in Hildenbrand, 1985).

A summary of the structures of this tectonic region is shown in Table 2.5.1-4.

2.5.1.1.4.1.3 Ozark Uplift and St. Francois Mountains

The Ozark Uplift (Figure 2.5.1-7, Figure 2.5.1-12, Figure 2.5.1-13 and Figure 2.5.1-14) is the dominant structural feature in Missouri. The structural center of this uplift is in Iron County, Missouri; however, the topographic axis extends northeast from Barry County to Iron County. The boundaries of the Ozark Uplift are not well defined locally, particularly to the north and northwest; however, they generally correspond to the Ordovician-Mississippian rock contacts to the east and west and to the Mississippi Embayment on the south.

This structural feature was an area of positive topographic relief through most of the Paleozoic, based on the lack of deposition of carbonate rocks on the top of the uplift (Nelson, 1996, and Clendenin, 1989). Since the Ozark uplift does not occur at, or near, a tectonically active plate boundary, Brown, 2004, has suggested that the formation and persistence of the uplift reflects multiple phenomena. Initially, the area of uplift was a felsic intrusive/ extrusive center during the Proterozoic, thickening the crust with relatively low-density rock. Second, regional crustal shortening during the late Paleozoic reactivating faults that outline the block, so it could tilt up like a foreland basement- cored uplift. Such uplift may have been enhanced by thrust-sheet loading in the Ouachitas to the south and stabilized by short-term flow of a mid-crustal weak zone. Explanations for possible post-Paleozoic uplift of the plateau have been harder to formulate. It is not clear whether the present-day elevations are a residual of earlier uplift, or are a consequence of renewed movement on border faults (Brown, 2004).

The tectonic character of the region is the result of a sequence of episodes of relative vertical uplift, subsidence, and tilting of crustal blocks which are bounded by upthrust faults. The geometry of the blocks appears to be inherited from an older possibly Grenvillian, structural fabric. The traces of steeply dipping block-bounding faults, associations with faulted monoclines, the strikes of vertical Precambrian intrusives, fracture patterns in Precambrian rocks, fracture patterns in the sedimentary rocks of the Site Region, and traces of minor faults all reflect a consistent geometry (Graves, 1938; Robertson, 1940, in AmerenUE, 2004; Tikrity, 1968; Gibbons, 1972). Folding in the Site Region is mainly the result of the passive draping of relatively weak sedimentary rocks over the edges of fault blocks or the previously mentioned paleotopographic effects.

A generalized summary of the structures of the Ozark Uplift Region is shown in Table 2.5.1-5.

2.5.1.1.4.1.4 Commerce Geophysical Lineament (CGL) or Commerce Fault

The Commerce Geophysical Lineament (CGL) is a 370 mile (600 km) long, 3 to 6 miles (5 to 10 km) wide, northeast-trending magnetic and gravity anomaly that extends from northeastern Arkansas to central Indiana. The closest distance to the Callaway Plant Unit 2 Site is approximately 170 miles (273 km) as shown in Figure 2.5.1-12, Figure 2.5.1-13 and Figure 2.5.1-14. This feature was originally recognized as a geophysical anomaly, but recent work, (as presented below) has shown this to be a deep-rooted, high-angle fault that is sub-parallel to the New Madrid and Wabash Valley Seismic Zones. Both “Geophysical Lineament” and “Fault” are used in the literature to refer to this feature. The CGL label is more commonly used when describing the geophysical nature of the anomaly, and the term “fault” is used when describing the feature as a capable source.

The CGL was mapped at a scale of 1:24,000 by Harrison (1999). Fault locations in trenches, cut banks, and road cuts are well known; extensions along the strike are poorly constrained because of dense vegetation, extensive colluvial sedimentation, and the blanket-like nature of Quaternary loess that covers the area. Dextral faulting is constrained only to post-date the Pliocene-Miocene Mounds Gravel and pre-date the post-Wisconsinan Peoria Loess (Crone, 2000). Thus, faulting might be of Pliocene age, but no proven Quaternary faulting is reported on this section of the fault complex.

The length of the CGL is difficult to determine because it is poorly exposed, is largely mapped as a concealed structure, and is part of an array of subparallel and interconnected faults that merge and diverge along strike. Because of the poor exposure and these complex relations, it is difficult to clearly identify the termination of a specific fault. Therefore, a fault length has not been computed (Crone, 2000). No slip rate has been reported and the fault length is uncertain.

The seismogenic potential of the CGL is poorly known. However, recent geologic and geophysical studies along faults overlying the CGL support the notion that this prominent geophysical anomaly may be a source of future large-magnitude earthquakes in the central United States (Baldwin, 2006).

The CGL is recognized by Pearce (2005) as one of the three known seismogenic source areas for the St. Louis region along with the New Madrid Seismic Zone and the Wabash Valley Seismic Zone, but do not consider the CGL as one of the main seismic source areas that could produce strong ground motions in the St. Louis region and trigger liquefaction. High resolution seismic reflection data acquired at three sites along the surface projection of the CGL show deformation has occurred during the Quaternary (Stephenson, 1999), with as much of 61 ft (20 m) of apparent vertical displacement occurring in two sites (Vaughn, 1994, and Stephenson, 1999).

Baldwin (2006), in their study at the South Holly Ridge site, near Idalia, Missouri, provide evidence of late Pleistocene to early Holocene deformation on the Idalia Hill fault zone, a 0.5 mile (0.8 km) wide zone of northeast-striking, near-vertical faults that directly overlie the CGL and coincide with the southeastern margin of the Bloomfield Hills.

Tuttle (2005), reports that a possible origin for the liquefaction features along the lower Cache River in Illinois is a very large earthquake originating from a distant source, such as the New Madrid Seismic Zone, or a smaller magnitude earthquake along the CGL. This interpretation is one of the ways to interpret the Middle Holocene liquefaction features until the age estimate is improved.

Dryden (2001), while agreeing on the Commerce Fault as being currently seismically active, reports that inclusion of the Commerce Fault in their modeling, among three other faults, did not significantly impact the large scale displacement fields. These results are based on a 3D modeling that considers the geometry of tectonic deformation in and around the New Madrid Seismic Source and assumes that a deep shear zone from a right lateral strike-slip fault generates slip in upper crustal faults. This model is calibrated based on geomorphic features, river migration, geodetic tilting, and other anomalies produced by tectonic activity during Quaternary time.

The timing of seismic events along the lineament overlaps the late Pleistocene to early Holocene faulting and paleoliquefaction events evaluated elsewhere on northeast-striking fan overlying the CGL in southeastern Missouri. The earthquake timing data from these sites in southeast Missouri indicate that the Commerce section of the CGL acted as a seismogenic source into at least the early Holocene and thus should be considered in future seismic-hazard analysis of the central United States (Baldwin, 2006). They also state that the existing paleoseismic and paleoliquefaction event-timing data for prehistoric large magnitude earthquakes is sparse and poorly constrained, but collectively, indicate that future earthquakes on northeast-striking faults aligned with the CGL should be considered in probabilistic seismic hazard studies of the central United States.

Baldwin (2006), indicates that additional event-timing information is needed along the Commerce section of the CGL to ascertain the possibility of middle to late Holocene earthquakes along structures aligned with the CGL, to assess temporal clustering of large earthquakes in the upper Mississippi embayment between the NMSZ and CGL structures, and to refine the late Pleistocene to early Holocene event chronology for the Commerce section of the CGL.

In conclusion, the Commerce Geophysical Lineament is a known seismogenic source area but the actual knowledge and understating of its seismogenic variables is still not well understood. The epistemic uncertainty associated with this feature is well covered by the maximum magnitude assigned to background seismicity in the Callaway Plant Unit 2 Probabilistic Seismic Hazard Analysis in Section 2.5.2.

2.5.1.1.4.1.5 Forest City Basin

The Forest City Basin (Figure 2.5.1-7) is located in northwest Missouri and adjacent portions of Nebraska, Kansas and Iowa. This structural basin occupies part of a broad depositional region known as the Northern Midcontinent Shelf within the Midcontinent Basin (Heckel, 1999, in Witzke, 2003). It contains beds of Pennsylvanian and Permian age that dip toward a common center located near Forest City, Holt County, Missouri (McCracken, 1971). The structure is bounded to the west by the Nemaha Uplift, to the south by the Bourbon Arch, to the north by the Transcontinental Arch, and to the east by the Ozark Dome (Brown, 2005).

Lee (1943), created a hypothesis of the formation of the Forest City Basin using isopach maps. The Forest City Basin was originally both a structural and topographic basin that did not come into existence until after Mississippian time. The basin was formed by the sharp displacement on the east flank of the Nemaha Anticline prior to Pennsylvanian deposition which was associated with down-warping of a post-Mississippian peneplain that had been formed by long continued erosion. During the early to middle Pennsylvanian the Forest City Basin was influenced by the orogenic activity of the convergent Ouachita system in present-day southeastern Oklahoma such that the Nemaha fault system was actively creating substantial topography on the karsted Mississippian surface (Ham & Wilson, 1967, in Brown, 2005).

A summary of the structures of the Forest City Basin Region is shown in Table 2.5.1-6.

2.5.1.1.4.1.6 Lincoln Fold

The Lincoln Fold and Mississippi River Arch, Figure 2.5.1-7 is a major positive structural feature in Missouri. With the Mississippi River Arch, it forms a discontinuous arcuate succession of highs between the Ozark Uplift to the south and the Wisconsin highlands to the north. This succession of highs separates the Illinois Basin on the east from the Forest City Basin on the west.

The Lincoln Fold, along with the Cap au Grès structure, is a forced fold over a high-angle reverse fault in Precambrian crystalline basement (Nelson, 1996). The axis of the fold follows a general northwesterly trend but turns easterly at its southernmost exposures (ISGS, 2002). It extends more than 93 miles (150 km) across northeastern Missouri and Western Illinois (Collinson et al., 1954, in Nelson, 1996). Structural relief across the fold reaches 984 ft (300 m) in Missouri (McCracken, 1971, in Nelson, 1996) and 1,312 ft (400 m) in Illinois (Rubey, 1952, in Nelson, 1996). The Lincoln anticline portions of the structure have a steeply dipping (45o or steeper) southwest limb and a gently dipping (less than 5o) northeast limb. Near the southeast end where it crosses into Illinois, this fold curves to an easterly trend and becomes the narrow (less than 1.2 miles (less than 2 km) wide) Cap au Grès faulted flexure, a monocline with a vertical to overturned southwest limb that is cut by several parallel high-angle faults (Nelson, 1996).

Geophysical records and a few boreholes that reach Precambrian rocks suggest that a basement ridge existed beneath the present position of the Lincoln Fold before Cambrian sediments were deposited in the region. At the end of Silurian time, the fold appears to have begun to develop as a unique structural feature. Recurrent episodes of folding, erosion and deposition occurred throughout the Devonian and are responsible for much of its configuration. Major uplift along this structure took place during Late Mississippian to Early Pennsylvanian time. This movement involved uplift and regional tilting of the Silurian and older rocks. In sum, the Lincoln Fold- Cap au Grès structure was clearly a positive structure by the late Middle Devonian time, and uplift along the structure persisted into the Mississippian (Nelson, 1996). A long period of erosion followed this major movement, and the fold was tilted to the northwest. Mississippian strata were eroded along the axis of the fold, and in places they were almost completely removed. Pennsylvanian sediments covered the area after the post-Mississippian erosion. They were subsequently gently arched and most of them have been eroded away. No faulting affecting Pennsylvanian beds is known along the Lincoln Fold.

The Mississippi River Arch (Figure 2.5.1-7) is a broad, corrugated fold that extends generally north-south through the bulge of western Illinois. To the north, it blends with the Wisconsin uplands and to the south it intercepts the Lincoln Anticline. The arch separates the Illinois Basin from the Forest City Basin. The present structure of the Mississippi River Arch can be attributed to its predecessor, the Northeast Missouri Arch. The Northeast Missouri Arch is a regional north-northeast-trending uplift that extends north from the Ozark Dome. Along the arch, Middle Ordovician through Middle Silurian strata are tilted, beveled, and unconformably overlain by Middle Devonian strata. The Northeast Missouri Arch was clearly uplifted tectonically at some time between Middle Silurian and early Middle Devonian time. Post-Mississippian uplift in the same general area produced the structure now known as the Mississippi River Arch (Bunker et al., 1985, in Nelson, 1996).

Dating of movements along the arch is difficult because erosion has removed the Pennsylvanian strata. It appears, however, that the Mississippi River Arch existed early in Pennsylvanian time and was probably subjected to additional deformation at the end of Paleozoic time. The arch is cut by numerous cross folds that trend northwest-southeast and, in the case of the features associated with the Lincoln Fold, plunge southeastward into the Illinois Basin.

A summary of the structures of the Lincoln Fold tectonic region is shown in Table 2.5.1-7.

2.5.1.1.4.1.7 North-Central Missouri Region

The North-Central Missouri region (Figure 2.5.1-7) is an area defined for this report as devoid of recognizable regional basins or arches (uplifts). Nevertheless, it contains local structures, which are listed in Table 2.5.1-8. From a geometric viewpoint the contact between a basin and an arch (uplift) should be defined by the inflection points between the basin and each adjacent arch.

2.5.1.1.4.1.8 Cryptoexplosive Structural Lineament (38th Parallel)

Evans (2005), McCracken (1971), Snyder (1965a), Snyder (1965b), and Brown (1954), locate and describe several cryptoexplosive (also called cryptovolcanic or diatreme) features in Missouri extending from Kansas in the west to Illinois and Kentucky in the east (Figure 2.5.1-15). Unklesbay (1992) summarized details of these structures in Missouri.

These features lie along an east-west trending line near the 38th parallel that passes about 50 miles (80 km) south of the Callaway Plant Site. In common, these features are small to medium in size (3.5 to 4.5 miles (5.6 to 7.2 km) in diameter) as compared with the listed features for North America from the Earth Impact Database, University of New Brunswick (UNB, 2008). These are circular or trough-like in shape and exhibit strata that have been disturbed by an explosive process, characteristic of volcanism or meteorite impact. From west to east the features along the lineament are: Rose Dome, Weaubleau-Osceola Structure, Decaturville Dome, Hazelgreen Volcanics, Crooked Creek Structure, Furnace Creek Volcanics, Avon Diatremes and Hicks Dome. This line of structures defines what has been called the “38th parallel lineament” because it closely approximates the 38th parallel line of latitude (Heyl, 1972).

These structures are of various ages, especially Rose Dome (Cretaceous) on the west and Hicks Dome (Permian) on the east. The structures, furthermore, lie near intersections of major regional tectonic features. Several hypotheses have been presented to explain this well-defined, linear set of cryptoexplosive structures. They may be related to the (1) impact of a string of meteorites, or (2) volatile-rich, explosive magmatism. Rampino (1996) was impressed by the analogy in 1994 when fragments of Comet Shoemaker-Levy 9 slammed into the planet Jupiter along a straight line. However, the large time differential (at least 100 million years) argues against a single meteoric event as the cause. Evans (2005) strongly supports the meteorite origin for the Decaturville, Crooked Creek, and Weaubleau-Osceola structures, but considers a meteorite origin for the others in this set to be unsupported. Luczaj (1998) supports the second hypothesis. A unifying hypothesis has not been proposed that describes how some structures were developed from impacts and others from magmatism. Rampino (1999), argues that such magmatism could have been initiated (and later rejuvenated) by meteorite impacts.

Although their origin is still problematic, possible tectonic forces that produced these structures have not been active since the Cretaceous (approximately 70 Ma). There are no known seismogenic sources related to these features, and they are inactive. The potential for present day seicmicity from these features is very low. These features are described in order from west to east as follows:

The Rose Dome Complex (Kansas)

Test drilling at Rose Dome showed that intrusive rock (lamproite) is just beneath the surface (Berendsen, 1991). The intrusive rock comprises granite and various sedimentary rock types. These intrusions at Silver City and Rose Dome took place along deep crust, pre-existing fractures. The intrusions are part of isolated but widespread mid-Cretaceous igneous activity across the central United States and are not believed to be part of the lineament of meteorite impact features along the 38th parallel.

Weaubleau-Osceola Structure

In Missouri (St. Clair County), the Weaubleau-Osceola structure (Evans, 2005) is 12 miles (19 km) in diameter. Mississippian-and Ordovician-age strata are intensely faulted and broken up (brecciated). They are overlain by undisturbed Pennsylvanian-age strata. The Weaubleau breccia contains well-preserved marine fossils (echinoderms, rugose corals, and conodonts) of Mississippian age. Consequently, the authors believe that this structure was formed by a meteorite impact into the sea during Mississippian time.

Decaturville Dome

Continuing to the east along this line is the Decaturville dome in Laclede and Camden counties, Missouri. It comprises a 3.5 mile (5.6 km) diameter ring of low hills. A 1 mile (1.6 km) diameter core comprises intensely broken and crushed rock of granite-like texture. The core is surrounded by broken and down-faulted rocks and Cambro-ordovician age deformed and brecciated blocks, which have been uplifted up to 1,500 ft (457 m) above their normal stratigraphic position (Offield, 1979). These authors believe that the evidence indicates that this dome was formed from the impact of a meteorite or comet younger than the Pennsylvanian and, perhaps, as young as Cretaceous.

Hazelgreen Volcanics

A short distance to the east, also in Laclede County, drilling in the Cambrian Lamotte sandstone revealed a 35 ft (11 m) thick layer of volcanic ash and detritus. The location of the Hazelgreen volcanic source is unknown (Unklesbay, 1992).

Crooked Creek Structure

Additionally, in Crawford County, Missouri there appears another ring-like feature called the Crooked Creek structure. It is the closest one to the Site, located 60 miles (100 km) to the south-southeast. It is a circular complex of Cambro-ordovician rocks, the oldest formation of which is found 1,000 ft (300 m) above its expected stratigraphic position. The Crooked Creek structure is located at the intersection of major faults and is believed to be of volcanic origin.

Furnace Creek Volcanics

To the east in Washington County is a funnel-shaped crater formed in Cambrian sandstone, which extends down to underlying Precambrian granite. Within this crater is Furnace Creek volcanic ash and overlying volcanic-like ejecta. Another feature nearby is the Dent Branch structure.

Avon Diatremes

The structure farthest east in Missouri, located in Ste. Genevieve and St. Francois counties, is the Avon diatremes. They comprise Cambrian-age rocks containing streaks of Precambrian igneous rock, other intensely shattered igneous material, and blocks of sedimentary formations as young as Devonian (Snyder, 1965b).

Hicks Dome (Illinois)

In southern Illinois, near the Kentucky border, and approximately along the extension of the line of these structures to the west, is Hicks Dome. Drilling into the Hicks Dome in 1952 revealed a zone containing diatreme breccias extending from a depth of 1,600 ft (488 m) to the bottom of the hole at 2,944 ft (897 m). The drilling results led to the conclusion that Hicks Dome is a cryptovolcanic structure of possible Permian age (Brown, 1954).

Jeptha Knob and Versailles Structures (Kentucky)

The Jeptha Knob structure is a nearly circular area, approximately 3 miles (4.8 km) in diameter, of uplifted, intensely faulted and folded, Middle to Late Ordovician, shallow marine carbonates. Jeptha Knob is situated about 50 miles (80 km) west of the axis of the Cincinnati Arch and nearly 50 miles (80 km) north of the 38th Parallel Lineament of Heyl (1972).

Seeger (1968) studied Jeptha Knob and performed geophysical work (gravity and magnetic surveys) there. His magnetic survey showed that a basement counterpart to the Jeptha Knob structure is unlikely because deformation essentially disappears 700 ft (210 m) below the present surface, leaving the crystalline basement rocks unaffected 5,500 ft (1,680 m) below. From this and many other findings, Seeger concluded an exogenetic origin for Jeptha Knob, with a hypervelocity impact from a bolide being the most likely mechanism.

2.5.1.1.4.2 Gravity and Magnetic Data and Features of the Site Region and Site Vicinity

Gravity and magnetic anomaly datasets for the Site Region include regional maps of the gravity and magnetic fields in North America. The Bouguer gravity anomaly dataset presented here (Kucks, 1999) is available in digital format via internet from the USGS website. The magnetic anomaly map was published in 2002 with improved reprocessing of existing data and compilation of a new and more complete database (Bankey, 2002 and USGS, 2002). The digital magnetic anomaly database and map for the North American continent is the result of a joint effort by the Geological Survey of Canada, U.S. Geological Survey, and Consejo de Recursos Minerales de Mexico. These two data sets are illustrated on Figure 2.5.1-12 and Figure 2.5.1-13.

Other sources of gravity and magnetic data are available from researchers in the New Madrid Seismic Zone (Mississippi Embayment) and Wabash Valley Seismic Zones (Illinois-Indiana), where the interpretation of existing regional magnetic and gravity data as well as new local high-resolution aeromagnetic data provide insights into the tectonic history and structural development of these, and other local features (Hildenbrand, 1997; Bear, 1997; and Braile, 1997).

Recent publications have advanced the processing of the data and improved the data collection process, making it possible to refine the characteristics and tectonic interpretation of the structural complexities of the New Madrid and Wabash Valley Seismic Zones. However, the gravity and magnetic data published since the field investigation for Callaway Plant Unit 1 FSAR do not reveal any new anomalies related to geologic structures that were not identified previously.

2.5.1.1.4.2.1 Gravity Data and Features

Regional gravity anomaly maps are based on Bouguer anomalies onshore and free air gravity anomalies offshore. The Bouguer gravity anomaly map shows no significant anomalies or gradients in the Site Vicinity or in Central and Northern Missouri. On the other hand, the Bouguer gravity anomaly map does show a wide high gravity anomaly associated with the Reelfoot Rift and enough creek graten. This is called the Paducah Gravity Lineament (PGL). The PGL is shown in Figure 2.5.1-12, Figure 2.5.1-13 and Figure 2.5.1-14).

Figure 2.5.1-14 overlays earthquakes in the Regional Gravity Anomaly map. The New Madrid seismic zone (the cluster of seismic activity along the Reelfoot Rift on Bouguer anomaly map Figure 2.5.1-14) reflects the seismic feature parallel to the Reelfoot Rift and suggests its close relation with it. This figure shows that the gravity anomaly is associated with the earthquake activity in the Reelfoot Rift, Mississippi Embayment, and the Illinois-Indiana border, south of the Illinois Basin.

Magnetic Data and Features

As seen on Figure 2.5.1-13 the Site Vicinity lies in a magnetic low reflecting the thick sedimentary rock cover found in the Site Vicinity, with basement found at depths of approximately 2000 ft (610 m).

As described in Hildenbrand (1997) for the Reelfoot Rift and Illinois Basin region, the major geophysical features include the south-central magnetic lineament (SCML). The Commerce Geophysical Lineament (CGL), a northeast-trending aeromagnetic and gravity anomaly that extends from northeastern Arkansas to central Indiana, is described in Section 2.5.1.1.4.1.4.

Summary Interpretation

The Callaway Plant Unit 2 Site is located approximately 60 miles (96 km) northwest of the closest gravity anomaly high, as shown on Figure 2.5.1-14. It is apparent that the Site is well removed from the effect of the anomalies and their related seismicity.

As discussed in Hildenbrand (1997) for the Reelfoot Rift and Illinois Basin region, the major geophysical features include the south-central magnetic lineament (SCML) and the Paducah gravity lineament (PGL), both shown in Figure 2.5.1-12 and Figure 2.5.1-14. Even though these maps are for two different data types, the relationship between the anomalies shown for each feature in these two maps is evident, with outlines of these features superimposed on similar anomalies on each map. This could indicate a confirmation of the locations of selected blocks in the basement, and a possible focus for the local seismic activity. evident. The overlay of the seismicity on Figure 2.5.1-14 shows a correlation between these tectonic features and the increased number of earthquake occurrences on the Bouguer gravity anomaly map, even if this relationship is not completely understood.

The maps on Figure 2.5.1-12 and Figure 2.5.1-13 show a belt of linear, but discontinuous gravity highs, with several positive aeromagnetic anomalies, in the eastern part of the Site Region, along the Mississippi valley, but well removed from the Site. Positive gravity anomalies in the Mississippi Embayment are interpreted to be caused by blocks of high density rocks that were emplaced beneath the embayment during the late Pre-Cambrian to early Paleozoic rifting event or during the Mesozoic reactivation of that rift. The faults that border these blocks are thought to be the focus of the seismic activity.

2.5.1.1.4.3 Regional Folding, Faulting, and Jointing

2.5.1.1.4.3.1 Regional Folding

Folding features within the Site Region have been identified and are shown in Figure 2.5L-6. Distant or very large features beyond the Site Region, such as the Mississippi Embayment, that have a bearing on the regional and Site geology and seismology are included. These features are presented in the Callaway Plant Unit 1 FSAR (AmerenUE, 2004) and updated with information provided in MODNR (2007c), which is engaged in collecting and cataloguing all structural features in Missouri into a searchable database.

Regional tectonic relationships suggest that most of the folding within the Site Region is Paleozoic in age (Gibbons, 1972). Post-Paleozoic movement on some folds is suggested; however, the age of movement for some folds cannot be defined due to the absence of a younger rock sequence. The only area in the Site Region where post-Paleozoic folding can be demonstrated is in the Mississippi Embayment, where major movements occurred during the Cretaceous and Early Tertiary (see Section 2.5.1.1.4.1.2). This finding of dormant folds of Paleozoic age in the vicinity of the Site, is cause for the local tectonic zone to be classified as stable. The instability in the Site Region lies to the southeast, near the Mississippi Embayment, where recent seismicity is common. No current seismic source is associated with any folded structure besides those described in Section 2.5.1.1.4.2.2, within the Class A features (Crone, 2000). None of these active features is closer that 70 miles (113 km) to the Site.

2.5.1.1.4.3.1.1 Sub-Regional Folds

The larger, more regional folded features (the Illinois Basin, Mississippi Embayment, Ozark Uplift, Commerce Geophysical Lineament, Forest City Basin, and Lincoln Fold) were described in Section 2.5.1.1.4.1. Four other features of regional extent, none of them active since the late Pennsylvanian Period (300 Ma) are described below, in the order of east to west:

Sangamon Arch

The Sangamon Arch (Figure 2.5.1-7) was formed by uplift in central and western Illinois during Devonian and Early Mississippian time. The arch extends from the Mississippi River Arch eastward to Macon and DeWitt counties in central Illinois. Although several hundred feet of Devonian and Silurian strata, normally present in surrounding areas, were either not deposited over or were eroded from the arch, later movements have masked the arch so that it does not show on structure maps of the area. It is a relic structure that is interpreted from stratigraphic evidence in the Site Region.

Bourbon Arch

Merriam (1963) states that this is a low, indistinct, seemingly up-arched feature that trends almost east-west in eastern Kansas through parts of Bourbon, Allen, Anderson, Coffey, Woodson, Lyon, and Chase counties, separating the Forest City Basin on the north from the Cherokee Basin on the south (Figure 2.5.1-7). It is proposed by Merriam (1963) to be pre-Middle Pennsylvanian, post-Mississippian in age. Although its limits are vague, this arch can be construed to cover about 3,000 square miles (7,800 sq km) (Merriam and Goebel, 1956; Baker, 1962, in Merriam, 1963). McMillan (1956 in Merriam, 1963) concluded that the arch exerted some influence on sedimentation as late as Late Pennsylvanian.

MODNR (2007c) describes this structure as a broad low structural divide of Mississippian rocks that separates the Forest City and Cherokee Basins. It trends to the northwest across Bourbon, Allen and Coffey Counties, Kansas and to the east from the Missouri-Kansas border into much of Vernon County, Missouri.

Cherokee Basin

The Cherokee Basin was formed by mild downwarp in Pennsylvania time (Merriam, 1963). It is bounded on the north by the Bourbon Arch and on the west by the Nemaha Uplift (Figure 2.5.1-7). It is the northern extension of the McAlester or Arkoma Basin of Oklahoma that developed in pre-Middle Pennsylvanian, post-Mississippian time (Merriam, 1963). The maximum thickness of the sedimentary sequence in the basin is about 3,500 ft (1100 m) and consists of Permian and older rocks.

Nemaha Anticline

The Nemaha Anticline, or the Nemaha Uplift, is probably the most significant structural feature in Kansas (Figure 2.5.1-7). It is a major pre-Middle Pennsylvanian, post-Mississippian element that extends across Kansas from Nemaha County on the north to Summer County on the south and into Nebraska and Oklahoma (Merriam, 1963). The Nemaha has been subjected to extensive exploration. It is recognizable in surface rocks of Permian and Pennsylvanian age along most of its length but is more pronounced in the subsurface. The structure is faulted along the east side by both high angle reverse and normal faults. Precambrian rocks lie within 600 ft (183 m) of the surface along the crest of the uplift but plunge farther below the surface toward the south.

2.5.1.1.4.3.1.2 Local Folds

The following folded features are of a more local nature (within approximately 50 miles (80 km) of the Site) and are described in order of increasing distance from the Site.

Auxvasse Creek Anticline

The Auxvasse Creek Anticline (No. 2 in Missouri on Figure 2.5L-6) is a structure in Township 8 North, Range 8 West, Callaway County, Missouri, approximately 10 miles (16 km) north of the Site. It trends about North 75° West and is asymmetrical with a relatively steep (average of 6°) southwest limb and a gently dipping (1°) northeast limb. Devonian rocks occur at the surface along the axis of the fold, which has about 175 ft (53 m) of structural relief. Formation of the anticline occurred during Mississippian and possibly as early as Devonian time. Pennsylvanian strata are deformed on the structure, indicating that the folding continued into Pennsylvanian time. No evidence of faulting has been reported (AmerenUE, 2004).

MODNR (2007c) describes this broad asymmetrical structure as striking northwest with a steep southwest limb. The structure trends N. 75o W. Devonian rocks crop out on the crest and beds as young as the Upper Pennsylvanian Myrmidon Group are deformed. Barrett (1940 in MODNR, 2007c) thought this was an extension of the Browns Station anticline and that it was en echelon with the Mineola structure, and notes that the anticline has 175 ft (53 m) of structural relief. The southwest limb has a dip of 6.5o, while the northeast limb has a dip of less than 1o. The entire structure pitches at an angle of 5o, noting evidence for recurrent upward movements that were prior to Burlington deposition and post-Marmaton, and postulating the original structural development as possibly late Devonian.

Mineola Dome

The Mineola Dome (see No. 46 in Missouri on Figure 2.5L-6) is a closed anticline or asymmetrical dome, possibly faulted on its southwestern side, with a short north-south axis. It is located in Township 48 North, Range 6 West, Montgomery County, Missouri, 15 miles (24 km) to the northeast of the Site. It has a steep south-southwest dip and a more gentle north-northeast dip. The Mineola structure brings Cotter (Lower Ordovician) rocks to the surface in Loutre Creek, where they are surrounded by rocks ranging in age from Middle Ordovician to Pennsylvanian (McCracken, 1971).

Big Spring Anticline

The Big Spring Anticline (see No. 4 in Missouri on Figure 2.5L-6) trends North 60° West in Sections 24 and 25, Township 47 North, Range 5 West, Montgomery County, Missouri, approximately 20 miles (32 km) east of the Site. The fold is gentle, but brings a broad area of St. Peter Sandstone to the surface where it is surrounded by younger strata. MODNR (2007c) describes this structure as having an anticlinal axis trending N 60o W in the north-central part of the New Florence Quadrangle.

Kruegers Ford Anticline

The Kruegers Ford Anticline (see No. 36 in Missouri on Figure 2.5L-6) is a fold in Gasconade and Osage counties, Missouri, located 25 miles (40 km) south of the Site. The structure strikes northeast and has a steep southeast flank. There is about 50 ft (15 m) of structural relief that brings the Ordovician Roubidoux Formation to the surface where the crest crosses the Gasconade River. Some movement along the structure occurred in post-Pennsylvanian time.

MODNR (2007c) describes this structure as represented by a window of Roubidoux along the Gasconade River valley in the vicinity of the Town of Bay. It strikes northeast, with the steep flank on the southeast, and is similar to the Mexico anticline. There has been no deep drilling on this structure which occurs in an area of thin Roubidoux. It may lie along a Precambrian ridge or peak.

Davis Creek Anticline

The Davis Creek Anticline (see No. 19 in Missouri on Figure 2.5L-6) is a northwest trending structure in Townships 50 and 51 North, Ranges 9, 10, and 11 West, Audrain County. The anticline is covered by glacial drift and its presence has been established from borehole data. Pennsylvanian strata have been eroded from the crest of the structure, leaving an inlier of Mississippian rocks that is masked by glacial drift. It is located approximately 22 miles (35 km) to the northwest of the Site.

MODNR (2007c) describes the Davis Creek anticline as the structure extending northwest from Sec. 30, T. 50 N., R. 9 W., and is noted as a structure near the Gant settlement. McQueen (1943) states that much of the Mississippian inlier is masked by drift on the surface. Subsurface data were used to map the structure. In addition, the Graydon conglomerate and the Burlington Limestone are exposed in the Valley of Davis Creek.

Mexico Anticline

The Mexico Anticline (see No. 45 in Missouri on Figure 2.5L-6) strikes northeast through the town of Mexico, Audrain County, Missouri, nearly 25 miles (40 km) to the north of the Site. The structure was mapped from subsurface records, and there appears to be more than 200 ft (61 m) of structural relief present on the Mississippian strata. Marked erosion of the Mississippian rocks occurred on top of the structures prior to deposition of the overlying Pennsylvanian strata. However, the latter were also involved in the folding, indicating that movement occurred during or after the close of Pennsylvanian time as well as at the close of Mississippian time.

McQueen (1943) in MODNR (2007c) describes this anticline as striking northeast approximately normal to the general northwest-trending structures of the area. The axis passes through the town of Mexico where it was detected by elevations of formations in well logs. Fire clay deposits mined by the A. P. Green Refractories Company are located along its east flank.

Pershing-Bay-Gerald Anticline

The Pershing-Bay-Gerald Anticline was thought to be a regional structure trending generally northwest from western Franklin County through Gasconade County, Missouri (McQueen, 1943). No more specific location is given in the references, but the border between the two counties lies near the 25-mile (40 km) circle to the southeast of the Site. In an attempt to define the Pershing-Bay-Gerald structure, logs of wells in the area from the Missouri Geological Survey and Water Resources files were examined. Based on these data, a structure contour map was drawn on top of the Roubidoux Formation, a reliable, easily recognizable, and conformable horizon over a large area. The resulting structure map did not show a northwest-southeast trending structure comparable to McQueen's Pershing-Bay-Gerald Anticline. In light of these subsurface data, which were not available to McQueen in 1943, it is concluded that there is not sufficient structural definition in the subsurface to warrant the designation of a northwest-southeast trending Pershing-Bay-Gerald Anticline.

MODNR (2007c) describes this structure as a regional anticline passing through the villages of Pershing, Bay, and near Gerald, to the faulted area near Anaconda. No information as to magnitude or symmetry of the structure is given.

Brown Station Anticline

The Browns Station Anticline (see No. 9 in Missouri on Figure 2.5L-6) trends northwest across northern Boone County, Missouri, approximately 30 miles (48 km) northwest of the Site. It is a faulted asymmetrical anticline with dips up to 35° on the southwest flank. Total structural relief is approximately 400 ft (122 m). Movement occurred recurrently in Mississippian time (Unklesbay, 1952). Maximum movement probably took place at the end of the Mississippian. Significant movements continued at least into Pennsylvanian time, and there may have been some post-Pennsylvanian movement. The structural deformation can be seen in surface outcrops. Based on structure contours drawn on top of the Mississippian age Sedalia Formation from water well data obtained from the Missouri Geological Survey and Water Resources, the Browns Station Anticline terminates in Township 48 North, and Range 11 West, near the boundary between Boone and Callaway counties.

Cuba Anticline

The Cuba Anticline (see No. 68 in Missouri on Figure 2.5L-6) is adjacent and immediately to the west of the Cuba Fault. It extends approximately 25 miles (40 km) from Township 39 North, Range 6 West in Maries County north-northwest to Township 43 North, Range 7 West in Osage County, where it terminates. It is approximately 30 miles (48 km) south-southeast of the Site. It has over 100 ft (30 m) of relief based on contours on top of the Roubidoux Formation. Data for the Roubidoux map were obtained from the well log files at the Missouri Geological Survey and Water Resources and from Donald E. Miller, geologist, Missouri Geological and Water Resources during the field investigations for Callaway Plant Unit 1 FSAR (AmerenUE, 2004).

Regional folding is predominantly Paleozoic and older, and is not a factor in Quaternary seismicity within the region.

Warren County Anticline

The Warren County Anticline (see No. 66 in Missouri on Figure 2.5L-6) trends north-south in Township 4 North, Range 2 West, Warren County, Missouri, at a distance of 35 miles (56 km) to the east of the Site. The Mississippian-age Chouteau Formation is exposed at the crest with younger Burlington Limestone surrounding the inlier. Major movement occurred in post-Mississippian time.

MODNR (2007c) describes this structure 2 miles (3.2 km) west of Warrenton. Chouteau limestone is exposed on the crest of the structure with Burlington limestone surrounding it. Both formations are Mississippian in age, suggesting a post-Mississippian age for the structure.

Cuivre Anticline

The Cuivre Anticline (see No. 18 in Missouri on Figure 2.5L-6) is a small structure located southwest of the Lincoln Fold in Townships 49 and 50 North, Rages 1 West and 1 East, Lincoln County, Missouri, approximately 45 miles (72 km) northeast of the Site. It is separated from the Lincoln Fold by the Troy-Brussels Syncline. The axis of the Cuivre Anticline strikes North 80° West and plunges southeast at about 40 ft per mile (7.5 m per km). The anticline has about 200 ft (61 m) of structural relief and was mapped from borehole data in the area (Gross, 1949, in AmerenUE, 2004).

MODNR (2007c) describes the structure as a small anticline that is adjacent and in strike with the Troy-Brussels syncline. It plunges southeast at about 40 ft per mile (7.5 m per km). The axis strikes N. 80o W. and appears to fade out along the east boundary of the Elsberry quadrangle. The anticline is here named for the Cuivre River, which flows through the area adjacent on the south.

Troy-Brussels Syncline

The Troy-Brussels Syncline (see No. 65 in Missouri on Figure 2.5L-6) separates the Cap au Grès Faulted Flexure from the Ozark Uplift. It lies near the Cuivre Anticline 45 miles (72 km) to the northeast of the Site. The syncline extends westward from just south of Alton, Illinois, to Troy, Lincoln County, Missouri with its deepest part against the eastern flank of the Cap au Grès Structure (see Section 2.5.1.1.4.2.2). The synclinal axis plunges eastward and climbs gradually westward toward the Ozarks. The Troy-Brussels Syncline apparently formed as a result of drag along the downthrown side of the Cap au Grès Flexure (Rubey, 1952) from late Mississippian to post-Pennsylvanian time.

Krey (1924) in MODNR (2007c) described a syncline south of the Cap au Grès fault which plunged gently east with an east-west strike and named it the South Lincoln County syncline. The same structure was studied by Rubey (1952) in MODNR (2007c), who named it the Troy-Brussels syncline. He believed the syncline to be produced by drag along the downthrown side of the Cap au Grès fault. The name South Lincoln County syncline preceded Rubey's name; however, Rubey's term generally has been accepted.

Fish Creek Anticline

The Fish Creek Anticline (see No. 23 on Figure 2.5L-6) trends northwest through northeastern Saline County, Missouri 45 miles (72 km) to the northwest of the Site. It is part of the Saline County Arch. The structure is asymmetrical with a steep southwest flank. Uplift of more than 100 ft (31 m) has brought the Mississippian Chouteau Formation to the surface. The anticline plunges gently to the southeast and terminates in Township 48 North, Range 14 West based on well data available from the Missouri Geological Survey and Water Resources.

Saline County Arch

Although shown as a prominent tectonic feature on the Structural Features Map of Missouri (McCracken, 1971), the Saline County Arch is actually the southwest flank of the Fish Creek Anticline located 45 miles (72 km) to the northwest of the Site, and should not be considered as a separate and distinct structural feature. It is bounded on the southwest by the parallel-trending Saline City Fault.

MODNR (2007c) reports that this rather pronounced structure was described in Middle Ordovician rocks in an outcrop 6 miles (9.7 km) north of Arrow Rock, while to the south and north, Mississippian crops out. The southwest limb is steep with a gentle northeast dip from a northwest axis (N. 55o W.). The crest crosses the Missouri River near Bluffport, NW corner of Sec. 31, T. 51 N., R. 18 W. Steep dips on the southwest limb show up near Buster Branch, Sec. 23, T. 50 N., R. 18 W.

The precise location of the crest of the fold, as described by Dwight (1950), is 0.25 mile (0.4 km) south of the north line of the NE ¼ Sec. 14, T. 50 N., R. 17 W., Howard County. The fold plunges southeast. This is the Howard County expression of the Saline City fault and anticline in Saline County to the northwest.

Eureka-House Springs Anticline

The Eureka-House Springs Anticline is located at 50 miles (80 km) to the east of the Site (see No. 21 in Missouri on Figure 2.5L-6) extends northwestward from House Springs, Missouri, Section 3, Township 42 North, Range 4 East, through Eureka, Missouri, Section 36, Township 44 North, Range 3 East. The structure is best developed between Eureka and House Springs and appears to plunge both to the northwest and southeast. The structure persists in a northwest direction in several outcrops of the Chouteau Group between Wentzville and Wright City, Missouri. Wells drilled in the town of Laddonia encountered Mississippian strata immediately under a thin veneer of drift or alluvium (McCracken, 1971). The age of the anticline is postulated to be Late or post-Paleozoic (~250 Ma).

MODNR (2007c) show this structure consisting of an anticline and a series of closely spaced faults that strike parallel to the axis of the anticline.

Clendenin in MODNR (2007c) separated the two structural features calling the anticline the Eureka-House Springs structure and the parallel faults the Eureka-House Springs fault system. The anticline can be traced from Sulfur Springs northwestward in Glaze Creek through the House Springs-Eureka area to north of St. Albans island where the fold crosses the Missouri River to the Daniel Boone fault zone near Defiance, Missouri. Mapping indicates that this anticline is fairly continuous along strike and that it plunges southeast toward Sulfur Springs and northwest across the Missouri River toward Defiance. Exposures in Glaze Creek and along the Missouri River show that the fold is asymmetric with a steeper northeast flank.

The structure exposed south of Eureka on Route W and northeast of House Springs on Highway 30, which is referred to as the Eureka-House Springs structure, is part of what is here termed the Eureka-House Springs fault system. The Eureka-House Springs fault system strikes northwest and lies to the southwest of the previously described anticline. The two structures are subparallel and are separated by less than 3,300 ft (1,000 m) through the House Springs-Eureka area. The juxtaposition of the two structures and the structural style of the Eureka-House Springs fault system are believed to be reasons for lack of differentiation.

The Eureka-House Springs fault system is a highly complex structure involving uplift and left lateral strike-slip.

Proctor Anticline

The Proctor Anticline (see No. 56 in Missouri on Figure 2.5L-6) is the main structural feature in Morgan County, Missouri, located 75 miles (120 km) to the southwest of the Site. It trends North 25° to 30° West and extends to the southeast into Camden County. The steeper west flank dips about 4°, whereas, the east flank dips about 1°. The Cambrian Eminence Dolomite was brought to the surface in late Paleozoic or early Mesozoic time (Marbut, 1907). From Marbut's structure map, there appears to be about 200 feet (61 m) of structural relief on the anticline.

MODNR (2007c) dates the structure as late Paleozoic or early Mesozoic (~250 Ma). Graves (1938) considered this a part of a Precambrian fault block which had some later rejuvenation. At the southeast end of the Proctor anticline-fault, the fault is downthrown to the northeast forming one side of the Montreal graben.

Dupo-Waterloo Anticline

The Dupo-Waterloo Anticline (No. 3 in Illinois on Figure 2.5L-6) is located 80 miles (130 km) to the east of the Site, and has an axial trend to the north-northwest. It extends from Monroe County, Illinois at its southern end, through St. Louis, Missouri, and terminates before reaching the Cap au Grès Faulted Flexure about 12 miles (19 km) north of St. Louis (AmerenUE, 2004). Outcrops in the Dupo area reveal that the eastern flank of the structure has a dip of 2 to 3° and the western flank has dips of up to 30°. The anticline was probably active intermittently from Silurian time to post-Pennsylvanian time. Major movements appear to have occurred in late Mississippian or in pre-Pennsylvanian and again in pre-Pleistocene time (Bell, 1929). Near Waterloo, total structural relief is at least 500 ft (152 m).

Based upon outcrops and boring data, the southern end of the anticline is terminated in central Monroe County, Illinois about 35 miles (56 km) north of the Ste. Genevieve Fault Zone. Movements of the Ste. Genevieve Fault Zone occurred during the same period as did movements on the Dupo-Waterloo Anticline. Both structures may have resulted from the stresses established during elevation of the Ozark Uplift and downwarp of the Illinois Basin. No structural link, however is known or suspected to exist between the Dupo-Waterloo Anticline and the Ste. Genevieve Fault System.

MODNR (2007c) recognized the same structure crossing the Mississippi River and entering the City of St. Louis and noted its northwest-southeast extension passing the Compton Hill Reservoir and dying out near Grand Avenue. The St. Louis portion of this anticline is named the Workhouse anticline.

The Dupo oil field has been the largest producer of oil on the structure. Also, the Florissant field is located along the northern extension of this structure. It is an anticlinal structure steep to the west and gentler to the east with a series of closed structures lying along the apex.

Florissant Dome

The most productive oil field in Missouri is located on the Florissant Dome (see No. 24 in Missouri on Figure 2.5L-6). It is located 85 miles (137 km) to the east of the Site, inside a wide bend in the Mississippi River. This nearly circular, closed structure lies on a larger northwest-southeast trending structure, the Dupo-Waterloo Anticline, which passes through eastern St. Louis County, Missouri from the Cap au Grès Faulted Flexure, southeast to Dupo and Waterloo, Illinois. The Laclede Gas Company maps of the dome indicate 100 ft (31 m) of closure on the St. Peter Formation. The structure was drilled by Laclede Gas Company of St. Louis as an underground natural gas storage facility. The reservoir rock is the St. Peter Formation Sandstone of Middle Ordovician age.

Pascola Arch

The name Pascola Arch (see No. 52 in Missouri on Figure 2.5L-6) was given by Grohskopf, 1955, to a subsurface structural feature affecting the Paleozoic rocks of southeast Missouri. The Arch crosses the Mississippi Embayment approximately 160 miles (260 km) to the southeast of the Site. The arch appears to have at least 8,000 ft (2,400 m) and possibly as much as 12,000 ft (3,600 m) of sedimentary rock removed by erosion in post-Paleozoic time and later subsided to form part of the upper Mississippi Embayment. Paleozoic rocks in the center of the arch are Cambrian in age with rocks of Ordovician age surrounding the core of the structure. It is possible that the Pascola Arch of Grohskopf is a separate domed area similar to the Farmington or Proctor anticlines in Missouri, but it is, in general, considered to be a part of the overall Ozark Uplift (McCracken, 1971). Buschbach (1978) pointed out that the epicenters of the 1811-1812 New Madrid earthquakes as well as much of the recent seismic activity in the New Madrid region are located in the structurally complex area where the Pascola Arch intersects the Reelfoot Rift and Mississippi Embayment. Stauder et al. (1976) found that northwest trending linear seismically active zones had been detected by a regional micro earthquake network in the New Madrid Seismic Zone. They determined that these trends are parallel to and possibly related to the crest of the Pascola Arch.

Rhea and Wheeler describe in MODNR (2007c) the structure as a wide, gentle uplift that is elongated northwest-southeast. The broad dome of the Pascola arch coincides with the smaller Lake Country arch in Tennessee and the area of intense seismicity between New Madrid, Missouri and Dyersburg, Tennessee.

The arch is about 60 miles (100 km) wide from northeast to southwest. It trends across the Reelfoot rift and forms a divide between the Reelfoot basin located to the northeast and the Mississippi Valley basin located to the southwest.

The name Pascola Arch was given by to a subsurface structural feature affecting the Paleozoic rocks of southeast Missouri. The Arch appears to have been completely beveled in post-Paleozoic (post-Early Devonian) time and later downwarped to form part of the Mississippi embayment. Thus, the structural high is now in reality a topographic low.

2.5.1.1.4.3.2 Regional Faulting

Faults within the Site Region have been identified and are shown in Figure 2.5L-5. Discussions on regional faulting are provided in this section. Distant features beyond the Site Region that have a bearing on the regional and site geology and seismology are also included. Regional faults are updated with the information provided in MODNR (2007), which is engaged in collecting and cataloguing all structural features in Missouri into a searchable database.

Like the folds described in the previous section, the faults in the Site Vicinity have been inactive since the late Paleozoic Era, approximately 300 Ma. And, like the ancient folding described above, this largely aseismic period also speaks to the stability of the Site Vicinity, and to the small hazard presented to the structures. The seismic instability in the Site Region lies to the southeast, near the Mississippi Embayment, where recent seismicity is common. This seismically active zone extends beyond the 200 mile (320 km) Site Region, and represents no hazard to the Site.

Additional discussions of the local faults within the Site Vicinity (25 mile (40 km) radius) are presented in Sections 2.5.1.2 (Site Geology) and 2.5.3 (Surface Faulting). An inspection of the five closes faults was completed in October 2008 to confirm previous information, as part of a three-phase investigation of local paleoseismicity.

The descriptions that follow below fall into three categories: (1) the local faults in the Site Vicinity and beyond to a radius of approximately 50 miles (80 km), (2) The Class “A” features exhibiting Quaternary deformation, described in Crone, 2000, and (3) those faults and fault systems possibly associated with the seismically active area in and around the Mississippi Embayment.

2.5.1.1.4.3.2.1 Local Faults

The descriptions below are for the faults closest to the Site. Generally speaking these are ancient and inactive features that do not pose any threat to the Site. Their last record of movement was in the late Paleozoic, approximately 300 Ma. This set of descriptions generally proceeds from closest to farthest from the Site. Investigation staff have visited the nearest five of these features (the Mineola, Kingdom City, Fox Hollow, Wardsville, and Cuba faults) to confirm their locations and stratigraphic position. The results of the visits to these features are presented in Section 2.5.1.2.4.2.

Mineola Fault

Mineola Fault (No. 52 in Missouri on Figure 2.5L-5) is located in the southwestern portion of Township 48 North, Range 6 West, Montgomery County, Missouri, on the flank of the Mineola Dome. This is the closest reported geologic structure (fault or fold) to the Site, at approximately 12 miles (19 km) to the east-northeast. Interpretation of well log data from the Missouri Geological Survey and Water Resources files (1974) indicates 200 ft (61 m) of downward displacement to the southwest.

MODNR (2007c) describes the fault as the Mineola Structure-Mineola Dome, first mapped as a pronounced anticline in the vicinity of Mineola, with a N. 75o E. trend, and 10o to 20o dips on both flanks; the dips are generally steeper on the south limb. Later work showed the structure to be closed with a short north south axis. It is asymmetrical with a steep south southwest dip and more gentle north northeast dip. An additional closure was mapped and pointed to a number of closed anticlines or domes striking N. 70o W. in an en echelon pattern from the Mineola area to the Browns Station Anticline in Boone County. The Mineola Dome brings Cotter (lower Ordovician) rocks to the surface in Loutre Creek, where they are surrounded by rocks ranging in age from Middle Ordovician (St. Peter Formation) to Pennsylvanian (Cherokee Group).

Kingdom City Fault

Kingdom City Fault (see No. 48 in Missouri on Figure 2.5L-5) is proposed to trend east-northeast in Township 49 North, Range 9 West, Callaway County, Missouri, approximately 14 miles (23 km) to the northwest of the Site. Based on data from well log No. 26595 in the Missouri Geological Survey and Water Resources well log files, it is a reverse fault and cuts the St. Peter Formation twice, displacing it 300 ft (91m). On the basis of surrounding well information, the southeast side was downthrown.

MODNR (2007c) does not describe this fault by this name, rather it uses Fox Hollow Fault – Monocline, to describe a more complex structure revealed by additional mapping. The structure is referred as a monocline because no definite fault plane was discovered and because the stratigraphic displacement can be accounted for by dip alone. However, it is probable that faulting and fracturing accompany the folding. The monocline is uplifted to the east relative to the west. South of Fox Hollow the structure's strike bends to the south and changes from a monocline to a fault.

Fox Hollow Fault

McCracken (1971) and MODNR (2007c) describe the fault as a small, normal fault in Sec. 12, T. 46 N., R. 13 W., approximately 25 miles (40 km) to the west of the Site, with a throw of approximately 120 ft (37 m) (See No. 16 in Missouri on Figure 2.5L-5). Additional mapping revealed a more complex structure. In MODNR (2007c) the structure is identified as a monocline because no definite fault plane was discovered and because the stratigraphic displacement can be accounted for by dip alone. However, it is probable that faulting and fracturing accompany the folding and the description of the monocline was broadened to inlcude the area of the Kingdom City Fault. The monocline is uplifted to the east relative to the west. Areas of Chouteau which have been uplifted relative to the overlying Burlington are exposed in the valleys of Bass Creek in section 28 and in small creek branches in sections 31 and 32.

South of Fox Hollow the structure's strike bends to the south and changes from a monocline to a fault. In Grider Branch (Sec. 24, T. 46 N., R. 13 W.) there is over 80 ft (24 m) of throw on the west side of the fault strike.

A possible extension of this fault into Sec. 36, T. 46 N., R. 13 W. was noted by Gore (1949) in MODNR (2007c). His description notes that the quarry in the SW ¼ of the section has an excellent section of Chouteau limestone with Burlington limestone resting upon it. Approximately one-quarter mile southeast, he notes a cliff at the same elevation as the quarry section that is entirely comprised of Jefferson City Dolomite; additionally, one-eighth mile to the north-northeast of the quarry is another exposure of the Jefferson City at the same elevation. He notes there is no noticeable dip in either section.

Wardsville Fault

McCracken (1971, in AmerenUE, 2004) stated that the Wardsville Fault (see No. 41 in Missouri on Figure 2.5L-5) trends from Section 7, Township 43 North, Range 11 West (west of Wardsville, Missouri) northeast to Section 35, Township 44 North, Range 12 West in Cole County, Missouri. It is located approximately 30 miles (48 km) to the southwest of the Site. The fault is downthrown 100 ft (31 m) to the northeast as substantiated by water well borings at the town of Wardsville.

Ward (1973) in MODNR (2007c) describes the Wardsville Fault as having approximately 50 ft (16 m) of downthrown to the northeast along its northeast extension. In the western half of Sec. 6, T. 43 N., R. 11 W., the fault changes to a more southerly direction. The fault trace at this location is expressed by a linear ridge of recemented Roubidoux sandstone. The fault is interpreted to be downthrown to the west-southwest at this location, although the evidence is not conclusive. The apparent explanation for the recemented sand is that the Roubidoux sandstone was caught in the fault zone, fractured and later recemented with silica. McCracken (1971) and MODNR (2007c) reports that the absence of 100 ft (31 m) of Eminence Dolomite in a well at the St. Martins Church, and surface evidence, indicates the fault to be downthrown to the northeast in the Wardsville area and northward.

Surface work by Martin (Missouri Geological Survey staff member) in the area east of the water well at Wardsville showed a collapse structure with Burlington Limestone preserved. The findings point to an extension of the Wardsville Fault beyond St. Martins, Missouri, and suggest the age of the fault to be post-Early Mississippian in age.

Cuba Fault

The Cuba Fault (see No. 10 in Missouri on Figure 2.5L-5) passes 3 miles (4.8 km) west of Cuba, Missouri, across Crawford and Gasconade counties to Township 43 North, Range 7 East in Osage County, Missouri, approximately 35 miles (56 km) to the south-southeast of the Site (McQueen, 1943). Fox (1954) proposed that the fault extends to the south and possibly joins the Crooked Creek Structure (see No. 9 in Missouri on Figure 2.5L-5). Current work refutes Fox's concept. James A. Martin and James H. Williams of the Missouri Geological Survey and Water Resources accompanied James W. Smith of Dames & Moore in verifying the position of the fault essentially as mapped by McQueen (1943).

The Cuba Fault is downthrown on the east side with a vertical displacement from 125 to 150 ft (38 to 46 m) (McCracken, 1971, in AmerenUE, 2004). As Pennsylvanian strata are reported to be cut by the fault, the age of the last movement is Pennsylvanian or younger.

MODNR (2007c) describes the fault essentially north-south in direction with a slight trend to the northwest. It is downthrown to the northeast with a vertical displacement of from 125 to 150 ft (38 to 46 m). The upthrown side is broadly arched exposing rocks of Ordovician age as old as Gasconade Dolomite in places. The downthrown side is synclinal and probably controls the occurrence of fire clay in the Owensville, Rosebud and Gerald fire clay districts. In places the fault may be replaced by folding. It appears to die out in Osage County, and is expressed by silicified Roubidoux Sandstone in the east bank of the Meramec River, as well as by displacements of the Roubidoux and Gasconade formations.

Cuba Graben

McCracken (1971, in AmerenUE 2004) states that the Cuba Graben (see No. 11 in Missouri on Figure 2.5L-5) is the downthrown area between the Cuba and Leasburg faults which has protected Pennsylvanian beds from erosion, approximately 60 miles (97 km) south-southeast of the Site. The Cuba Graben is probably not due to horizontal tensional forces as with most grabens but is more likely due to vertical movements, since the bounding faults have associated anticlines (Figure 2.5L-6).

Portions of both bounding faults of the Cuba Graben were found by subsurface contours drawn on the top of the Roubidoux Formation. This was substantiated by Donald E. Miller of the Missouri Geological Survey and Water Resources. Because the bounding faults may cut Pennsylvanian strata, the youngest mapped formations in the area, the last movement of the Cuba Graben may be Pennsylvanian or younger.

MODNR (2007c) describes the fault as the downthrown area between the Cuba and Leasburg faults, which contains much of the southern Missouri fire clay district.

Leasburg Fault

The Leasburg Fault (see No. 24 in Missouri on Figure 2.5L-5) generally trends from Section 22, Township 30 North, Range 2 West in Crawford County to Section 20, Township 43 North, Range 2 West, Franklin County, Missouri, approximately 50 miles (80 km) to the southeast of the Site (McCracken, 1971). It appears to change strike several times from northeast to northwest but persists for a distance of some 40 miles (64 km). McQueen (1943) describes the fault as downthrown to the northwest. The preservation of Pennsylvanian age sediments suggests that the faulting is Late or post Pennsylvanian in age (~280 Ma).

Mapped by Dake (1926) in MODNR (2007c) Geologic Map of Missouri, it is described as being in the vicinity of Leasburg and continuing for some distance in a northerly direction.

The fact that the known magnetite-hematite deposits at Bourbon, Kratz Springs, and Pea Ridge all fall within the upthrown block along this fault make it of interest to the structural geologist. Little deep drilling has been done on the downthrown side of the fault to show the configuration or type of rock in the Precambrian. Magnetic data (Figure 2.5.1-13), however, indicate that there may be a different type of basement rock under the Cuba graben west of the Leasburg fault than there is to the east.

Jeffriesburg Fault

The Jeffriesburg Fault is a short, northwest-trending fault that lies 3.5 miles (5.6 km) east of the Leasburg Fault in Township 43 North, Ranges 1 and 2 West, Franklin County, Missouri, approximately 50 miles (80 km) to the southeast of the Site (see No. 22 in Missouri on Figure 2.5L-5). On the surface, Pennsylvanian sandstone is faulted against Jefferson City dolomite (McCracken, 1971, in AmerenUE, 2004). According to subsurface contours on top of the Roubidoux Formation (data collected from the well logs on file at the Missouri Geological Survey and Water Resources), the southwest side of the fault appears to have been upthrown at least 100 ft (31 m). The fault, determined from Roubidoux contours, appears to terminate to the southeast in Section 36, Township 43 North, Range 1 West, and to the northeast in Section 11, Township 43 North, Range 2 West. Displaced Pennsylvanian rocks indicate the age of faulting to be Pennsylvanian or younger.

MODNR (2007c) describes the fault as having a strike of N. 50o W. and is downthrown to the northeast 100 ft (31 m). Along most of the fault the Cotter Formation is downthrown against Jefferson City. The northwest end of the fault encounters the St. Johns fault and the southeast end of the fault merges into the Hellings Lake basin structure. Much of the middle segment of the fault is covered by cherty residuum and loess.

Browns Station Fault

The Browns Station Fault, which is located on the southwestern limb of the Browns Station Anticline (see No. 51 in Missouri on Figure 2.5L-5), Callaway County, Missouri, is interpreted as having 300 ft (91 m) of displacement. It is located approximately 40 miles (64 km) to the northwest of the Site. The southwestern block is downthrown (Laclede Gas Company, 1974, in AmerenUE, 2004).

MODNR (2007c) describes the fault as the southernmost fault in the Valley Mills fault zone. The fault trends almost east-west and is downthrown to the north. Thompson (1986) in MODNR (2007c) states that the north side of the fault is Burlington-Keokuk Formation which forms gently sloping hills. The south side is Pierson and Elsey formations which have rougher topography.

Beveridge (1970) in MODNR (2007c) states that the glauconite found in the beds indicates that they are Keokuk Formation. To the west in Section 4, 1.2 miles (1.9 km) south and 0.22 miles (0.35 km) west of the northeast section corner, in the north draining stream, upthrown brown dolomite from the Middle Pierson Formation dips to the southeast at 4o. Burlington-Keokuk Formation crops out in the stream bed on the north side of the fault showing a minimum throw of 70 ft (21 m). Probably the north side of the fault has been dropped from 100 to 170 ft (31 to 52 m).

Cap au Grès Faulted Flexure

The Cap au Grès Faulted Flexure (see No. 7 in Missouri on Figure 2.5L-5) is a sharp monoclinal fold that extends east-southeast through Lincoln County, Missouri, then generally east through southern Calhoun and Jersey counties in Illinois, approximately 50 miles (40 km) to the east-northeast of the Site. The rocks dip steeply on the southern flank of the structure, and the maximum amount of structural relief is 1,000 to 1,200 ft (305 to 366 m). Faults that occur along the flexure generally are downthrown to the south and have displacements from a few to a few hundred feet. Limited exposures in the area make it difficult to determine the extent and continuity of the faults. Major deformation along the Cap au Grès Faulted Flexure took place in post-Middle Mississippian, pre-Pennsylvanian time. A minor amount of deformation occurred in post-Pennsylvanian, pre-Pleistocene time. Pennsylvanian strata south of the flexure are considerably lower than outliers of similar strata north of the flexure. In addition, the Calhoun peneplain bevels the edges of tilted Pennsylvanian strata in the area, indicating post-Pennsylvanian movement. Displacement probably occurred in Pliocene time and amounts to little more than 100 ft (31 m). No evidence has been found to indicate any deformation of Pleistocene deposits in the area (Buschbach, 1975). A pair of northwest-trending anticlines, the Dupo-Waterloo Anticline to the south and the Lincoln Fold to the north, end abruptly against the flexure. Both anticlines have their steeper flanks to the west, and they appear to have similar geologic histories. The crests of the anticlines are offset about 30 miles (48 km) (Cole, 1961).

Potter (1872) in MODNR (2007c) describes a great fault south of the anticlinal fold crossing Lincoln County in a N. 30o W. direction. He did not name the fault. Ringena (1949b) in MODNR (2007c) suggest the structure to be a "break thrust" fault. The alignment of the Lincoln fold and Waterloo-Dupo anticline (both old features dating from Precambrian time) is parallel to the major northwest-southeast structural grain of Missouri (MODNR, 2007c). Those features are offset at the Cap au Grès fault. In conclusion, Cole states, “It seems possible then from the foregoing evidence to conclude that the Cap au Grès is a left lateral fault that has experienced movement of approximately 30 miles (48 km) , offsetting the Lincoln fold and the Dupo-Waterloo anticline."

Mapping by Harrison (1995) in MODNR (2007c) for the Eolia quadrangle expanded the geological understanding of the fault. The Cap au Grès structure, a major feature of regional extent, changes northward from a faulted asymmetrical, monoclinal fold having relatively high structural relief to a broad anticline having low structural relief. Within 20 miles (32 km) northwest of the quadrangle, the Cap au Grès structure dies out, and structural relief steps over to the en echelon Lincoln fold, another feature of regional extent. Together, these structures constitute a fault-fold system that is consistently down to the southwest and that extends more than 200 miles (320 km). Structural relief across these features increases southeastward to a maximum of 1,000 ft (305 m) on the Cap au Grès structure, approximately 20 miles (32 km) southeast of the Eolia quadrangle.

Harrison (1995) in MODNR (2007c) also noted that The Cap au Grès structure is a faulted monocline, or drape fold, that has a steep southwestern limb. It bends sharply along strike and has a zigzag outcrop pattern. Although it terminates to the southeast in the St. Louis area, he concludes that the Cap au Grès structure and the Waterloo-Dupo faulted asymmetrical anticline in Illinois are probably parts of the same structural system. The Cap au Grès structure and related features in the Eolia quadrangle are thought to be directly controlled by faulting in the Middle Proterozoic basement. Deep drill hole data in the area indicate that basement is approximately 3,000 ft (915 m) below the surface. Multiple episodes of basement faulting are interpreted from the surface geology.

Initially, the monocline formed as a result of compressional faulting in the basement. The time of deformation in the Eolia quadrangle is constrained by the age of the Mississippian (Osagean) Burlington Limestone - the youngest unit affected by faulting and folding - and by deposition of the Pennsylvanian (Morrowan to Desmoinesian) Cherokee Group. The critical area where Pennsylvanian rocks possibly overlie folded and faulted older rocks is covered by Pleistocene glacial deposits, but Pennsylvanian rocks are known to overlie the fault-bounded wedges of St. Peter sandstone. This indicates that they were deposited after deformation and erosion. Elsewhere, deformation on the Cap au Grès structure has been constrained as being post-St. Louis Limestone (Mississippian, Meramecian) and pre-Tradewater Formation (Pennsylvanian, Morrowan to Desmoinesian).

Newburg Fault Zone

The Newburg Fault Zone (see No. 26 in Missouri on Figure 2.5L-5) is a series of faults trending northwest to west for about 4 miles (6.4 km) in Townships 36 and 37, North, Ranges 8 and 9 West, Phelps County, Missouri, approximately 60 miles (97 km) to the south of the Site. This zone consists of three areas of faulting. The southern portion of the fault zone is a graben with the faults striking North 58 West. Maximum displacement is 60 ft (18 m). An intermediate zone occurs north of this feature. A normal fault farther to the northwest strikes almost due east. The downthrown side is to the south. Maximum throw along this segment is 100 ft (31 m). Ordovician age Gasconade and Roubidoux formations are present in fault blocks at the surface. MODNR (2007c) describes the fault as a series of faults beginning in the upper reaches of Treable Creek and extending northwest for nearly 4 miles (6.5 km), the zone is divided into three divisions by Lee. The southern portion, along Treable Creek, is a graben with the faults striking N. 58o E. with a maximum displacement of 60 ft (18 m). An intermediate zone of small faults occurs north of this. The northwest portion, along Hickory Point, is downthrown to the south with a normal fault striking almost east-west.

Catawissa Fault

The Catawissa Fault (see No. 50 in Missouri on Figure 2.5L-5) is based on boring information from the Missouri Geological Survey and Water Resources well log files. It is located in the southwestern portion of Township 43 North, Range 2 East, Franklin County, Missouri, approximately 60 miles (97 km) to the east-southeast of the Site. It has a displacement of 150 ft (46 m) with the northwestern side downthrown (AmerenUE, 2004).

Centralia Fault

The Centralia Fault (see No. 1 in Illinois on Figure 2.5L-5) trends nearly north-south parallel to and 1 mile (1.6 km) east of the DuQuoin Monocline in Marion and Jefferson counties, Illinois, approximately 150 miles (240 km) east of the Site. It is a zone of several parallel faults. Net displacement is downward to the west, with maximum displacement of about 200 ft (61 m). The faults can be seen in several coal mines in the Centralia area, but they are not visible at the land surface. The faults appear to have developed after folding took place on the DuQuoin Monocline. Relief of the stresses was upward on the east side, opposed to the east dip of the monocline. The faulting occurred in post-Pennsylvanian, pre-Pleistocene time (280 Ma to present) (Buschbach, 1973).

2.5.1.1.4.3.2.2 Class A Faults

Crone (2000) compiled published geological information on Quaternary faults, folds, and earthquake-induced liquefaction features in order to develop an internally consistent database on the locations, ages, and activity rates of major earthquake-related features throughout the United States. The Crone publication (Crone, 2000) is the compilation of such features in the Central and Eastern United States (CEUS), which is defined as the region extending from the Rocky Mountain Front eastward to the Atlantic seaboard. A key objective of this compilation is to provide a comprehensive database of Quaternary features having the potential to generate strong ground motion for use in assessing seismic hazards. The definitions of the classifications used in this compilation are listed as follows:

- Class A, Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed for mapping or inferred from liquefaction or other deformational features.
- Class B, Geologic evidence demonstrates the existence of a fault or suggests Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.
- Class C, Geologic evidence is insufficient to demonstrate (1) the existence of tectonic fault, or (2) Quaternary slip or deformation associated with the feature.
- Class D, Geologic evidence demonstrates that the feature is not a tectonic fault or feature; this category includes features such as demonstrated joints or joint zones, landslides, erosional or fluvial scarps, or landforms resembling fault scarps, but of demonstrable non-tectonic origin.

Faults and features assigned to Class C have not demonstrated Quaternary activity and are not considered to be potential earthquake sources (Crone, 2000). Generally, Class C features are not known to have Quaternary deformation. In some cases, detailed studies have revealed evidence showing that specific features actually have a non-tectonic origin. These non-tectonic features are assigned to a separate class, Class D, and include features such as solution collapses, features related to subsidence, landslides, and erosional scarps. Class C and D features are included in this compilation and in the database because their inclusion provides a complete record of all features that have been examined.

The second category in this compilation is Class B, containing features are those where the geologic evidence of Quaternary tectonic activity is far less compelling than for the Class A features (Crone, 2000). In some cases, Class B features may show clear evidence of Quaternary offset or deformation, but it is uncertain if these surface structures extend to sufficient depths to generate strong earthquakes and therefore produce strong ground motion. A feature may also be assigned to Class B if the geologic and/or geomorphic evidence for Quaternary deformation is equivocal. The evidence reported in the geological literature may be incomplete or inconclusive, but is enough that the feature cannot be dismissed as probably non-seismogenic. Quaternary activity on these kinds of features is still a possibility; but considerable uncertainty remains regarding the feature's seismogenic potential.

All tectonic features described for the Site Region in Crone (2000) are listed as Class A features. This classification requires good geological evidence of tectonic origin for features that are potentially seismogenic. The locations of these features with respect to the Site Region are shown on Figure 2.5.1-10. For these features, detailed evidence of Quaternary deformation or strong ground motion has been well documented in the scientific literature. The features within the Callaway Plant Site Region, listed from closest to farthest away, includes the following:

- St. Louis–Cape Girardeau Liquefaction Features,
- Faults of Thebes Gap Area (containing the Albrecht Creek fault, the Commerce fault, the English Hill fault zone, the Happy Hollow fault, the Lambert Trench, and the Sassafras Canyon faults),
- Western Lowlands Liquefaction Features,
- Reelfoot Scarp/ New Madrid Seismic Zone is included in this list, even though it is outside the 200 mile (320 km) Site Region, because of its seismicity and relationship to other features discussed above, and
- Wabash Valley Seismic Zone is also included in this list, even though it is outside the 200 mile (320 km) Site Region because of its important seicmicity.

St. Louis-Cape Girardeau Liquefaction Features

The closest Class A feature to the Site is the St. Louis–Cape Girardeau liquefaction features, located 70 miles (113 km) east of the Site, in a study area that straddled the Mississippi River and extended to the western edge of the Illinois basin more than 200 miles (320 km) to the east of the Site (Crone, 2000 and Tuttle, 2005). Located between the Illinois Basin, the Mississippi Embayment, and the Ozark Uplift, this feature encompasses an area equivalent to the northwestern end of the south-central magnetic lineament (SCML) described in Hildenbrand (1997) (Figure 2.5.1-13). The New Madrid seismic zone is located south-southeast of this area.

Tuttle (1999) examined sand blows, sand dikes, and sand sills that were found during systematic searches of streams in southeastern Missouri and southwestern Illinois. The search extended approximately 31 to 56 miles (50 to 90 km) to the west and east of the Mississippi River, between the St. Louis area on the northwest and the Cape Girardeau area on the southeast. The liquefaction was recognized as the type that is caused by strong ground motion (Obermeier, 1996), and the strong motions are presumed to have been caused by slip on one or more preexisting faults. However, the causative faults have not been identified and the locations and sizes of the liquefaction features studied to date provide poor constraints on the sources of the shaking. Correlation and dating of the liquefaction features remain uncertain as well; however, Tuttle's present interpretation indicates an earthquake of moment magnitude **M** > 6, and perhaps exceeding 7, occurring approximately 6,500 years ago, roughly 37 miles (60 km) east of St. Louis (107 miles (177 km) east of the Site (Crone, 2000). The smaller the postulated earthquake magnitude, the more likely it is that a second earthquake of **M** > 5.2 occurred in or very near St. Louis. A second earthquake caused strong ground shaking in the area during the past 4,000 years. These prehistoric earthquakes have been considered in performance of the Callaway Plant Unit 2 PSHA as a sensitivity study discussed in Section 2.5.2.4.

The Faults of Thebes Gap Area

The Thebes Gap area is located at the head of the Mississippi Embayment, approximately 15 to 20 miles (24 to 32 km) north of the New Madrid seismic zone (Crone, 2000), and 170 miles (274 km) southeast of Callaway Plant Unit 2 (Figure 2.5.1-10). Numerous north-northeast- to northeast-striking strike-slip faults and associated normal faults, high-angle reverse faults, folds, and transtensional pull-apart grabens have been recognized in the area (Harrison, 1999). These structures have had a long-lived and complex Phanerozoic tectonic history, with kinematics indicating an overall right-lateral sense of movement on the north-northeast- to northeast-striking faults (Crone, 2000). However, individual faults typically display complex patterns. Step-overs in displacement between different strands have produced zones of transtension and transpression.

Six individual named faults associated to this area are not sections of a single long fault, but part of a complex network of faults (Harrison, 1999). These faults are: English Hill fault zone, the Happy Hollow fault, the Commerce Fault, the Sassafras Canyon faults, Albrecht Creek fault, and Lambert trench (at the intersection of English Hill and Albrecht Creek faults).

The fault length of these individual faults is uncertain and difficult to determine because they are part of an array of subparallel and interconnected faults that merge and diverge along strike, making it difficult to determine terminations of specific faults (Harrison, 1999). No slip rate has been reported for these faults, and the date for the most recent paleoevent is reported to be between 130,000 years and 6,000 years (Crone, 2000). The Faults of Thebes Gap Area are a known seismogenic source area but the actual knowledge and understating of its seismogenic variables is still not well developed. The epistemic uncertainty associated with this feature is well covered by the maximum magnitude assigned to background seismicity in the Callaway Plant Unit 2 Probabilistic Seismic Hazard Analysis.

The Western Lowlands Liquefaction Features

The Western Lowlands liquefaction features are located approximately 195 miles (314 km) south-southeast of Callaway Plant Unit 2 Site. The evidence for Quaternary faulting in the Western Lowlands of Missouri and Arkansas consists of late Quaternary liquefaction features that are attributed to prehistoric earthquakes, and of seismic-reflection profiles that show offsets of Quaternary reflectors (Stephenson, 1999).

The Western Lowlands Paleoseismological sites studied by Vaughn (1994), Tuttle (1998), and Tuttle (1999), are located several tens of kilometers northwest of the floor of the graben, and also northwest of the wide, step-faulted margin of the graben. No surface ruptures are known from the earthquakes (Crone, 2000).

The liquefaction was recognized as the type that is caused by strong ground motion for example, (Obermeier, 1996), and the strong motions are presumed to have been caused by slip on one or more preexisting faults. However, the causative faults have not been identified and the locations and sizes of the liquefaction features identified to date provide poor constraints on the sources of the shaking. The prehistoric earthquakes are known only from locations and age estimates of liquefaction. A possible source in the Western Lowlands is attributed by Vaughn (1994) to one event dated between 23 and 3.5 ka Tuttle (1999), also attributed a liquefaction event to a Western Lowland source, this one dated at A.D. 1380 plus or minus 70 years. However, the two events were recognized at sites approximately 40 miles (70 km) apart, and are poorly characterized as to the geographic distributions of coeval liquefaction features. Accordingly, neither potential source is known to have had more than one earthquake, so no recurrence interval can be calculated (Crone, 2000).

The Western Lowlands liquefaction features are the expression of a known seismogenic source area, but the actual knowledge and understating of its seismogenic variables is still not well developed. The epistemic uncertainty associated with this feature is well covered by the maximum magnitude assigned to background seismicity in the Callaway Plant Unit 2 Probabilistic Seismic Hazard Analysis.

Reelfoot Scarp and New Madrid Seismic Zone

The New Madrid Seismic Zone and Reelfoot Scarp are located in the central part of the Mississippi River Valley, just beyond the 200 mile (320 km) investigation radius. The New Madrid Seismic Zone (NMSZ) is defined on the basis of abundant and widespread historical and microseismicity that is concentrated in three prominent trends (Figure 2.5.1-11). These concentrations of microseismicity and the major earthquakes that occurred in 1811-1812 indicate that Quaternary faulting is occurring in the seismic zone, but with the exception of the Reelfoot scarp, discrete faults are not expressed at the surface. Therefore, it is difficult to assign a specific length for the entire zone. Overall, the abundant seismicity extends from near Marked Tree, Arkansas, on the southwest to near Charleston, Missouri, on the northeast, which is a distance of about 112 miles (180 km), but diffuse seismicity extends a greater distance.

Because the New Madrid seismic zone is defined by an area of abundant seismicity, and not a fault plane, it is not possible to define an average strike. At present, structural and tectonic information about specific seismogenic faults is limited, in part because the seismogenic faults are not expressed or are poorly expressed at the surface. Most of the seismicity is associated with the Reelfoot rift, which has a northeasterly trend (azimuth of approximately 337°). Based on the historical seismicity, there may be other significant but unexposed faults in the seismic zone.

The Reelfoot scarp is a well-defined feature, but is small in comparison to the general dimensions of the seismic zone. The scarp is a topographic escarpment that extends south-southeastward from near the town of New Madrid, Missouri, along the western margin of Reelfoot Lake, to a point south of the lake. Furthermore, the entire river valley is covered by Quaternary sediments, so only the geologically youngest deformation is expressed at the surface. Recent studies (Crone, 2000) shows that the Reelfoot scarp is approximately 20 miles (32 km) long and the subjacent Reelfoot fault may be as much as 44 miles (70 km) long. This fault is the only feature that has conspicuous surface expression and that can be studied at the surface. Recent studies of the scarp have provided valuable information on the recurrence of deformation on the scarp, calculated uplift rates, and the history of faulting.

In the winter of 1811-1812, major earthquakes occurred in the New Madrid seismic zone, and the area remains the most seismically active area in central and eastern North America. The earthquakes were among the largest historical earthquakes to occur in North America and were perhaps the largest historical intraplate earthquakes in the world. The earthquakes produced widespread liquefaction throughout the seismic zone and prominent to subtle surface deformation in several areas, but they did not produce any known surface faulting

(Crone, 2000). Other than the pervasive sand blows throughout the seismic zone, the Reelfoot scarp is the most prominent geomorphic feature that has been produced by the modern tectonism in the New Madrid Seismic Zone.

Four major earthquakes occurred during the 1811-1812 period. These four earthquakes have been characterized by USGS as three earthquakes. (USGS, 2008a) Two occurred on December 16, 1811, one on January 23, 1812, and one on February 7, 1812 (Street and Nuttli, 1990). The estimated body-wave magnitudes are 7.2, 7.0, 7.1, and 7.3, respectively (Street and Nuttli, 1990). Although the St. Louis area was sparsely populated at the time, there are historical newspaper accounts of the 1811-1812 New Madrid earthquakes. A summary of these accounts is as follows:

> The December 1811 earthquake shocks were preceded by a remarkable calm. The first earthquake was felt around 2:15 A.M. The second shock was felt at 2:47 A.M., the third at 3:34 A.M., the fourth about daylight, the fifth at 8:00 A.M., and the sixth at 11:30 A.M. No lives were lost, and it was reported that many people believed they felt shocks after the sixth earthquake as well (Hough, 2000). Eyewitnesses observed there to be a thick, hazy fog and no wind. The temperature was estimated to be approximately 35 to 40° Fahrenheit. The first four shocks were estimated to be decreasing in violence, but the fifth shock seemed to be as powerful as the first (Louisiana Gazette, 1811).
>
> Newspaper reports noted that the shocks were felt in Cape Girardeau, St. Vincennes, Ohio, Kentucky, Tennessee, New York, Pennsylvania, Virginia, and possibly even further (Louisiana Gazette, 1811). A steam boat, en route from Pittsburgh, felt the shocks while at anchor. After continuing its journey, it came upon the town of New Madrid, where the residents were “considerably alarmed.” The boat next came to Little Prairie, where the residents thought the earth was gradually sinking. Two islands near there had almost disappeared (Louisiana Gazette, 1811).
>
> The February 1812 earthquake appeared to be more powerful than that which occurred a few months previously. It was observed that coal and sand were thrown upwards from fissures in the earth in over 500 places, the largest of which were 8 to 10 ft (2.4 to 3.0 m) in width (Nuttli, 1972; Street and Nuttli, 1990). The waters were severely raised so as to cause drowning. The shocks were felt as far as Richmond, Falenton, Wilmington, Charleston, and Savannah. This second earthquake caused many residents to be displaced from their homes. Some fled the area; others were forced to live in tents. Additionally, it was observed that several islands in the Mississippi River were damaged, rendering the river virtually un-navigable (Nuttli, 1972). These earthquakes caused ground failure over an area of 18,500 sq miles (48,000 sq km), encompassing portions of six states (Street and Nuttli, 1990). It is likely that several individuals may have drowned in the Mississippi River, particularly as a result of the largest shock which occurred on February 7, 1812 (Street and Nuttli, 1990). The towns of Little Prairie and Big Prairie were destroyed by the earthquakes of December 16, 1811. The town of New Madrid was destroyed by the February 7, 1812 earthquake (Street and Nuttli, 1990).

Modern seismicity in the New Madrid Seismic Zone is intimately associated with the Reelfoot rift (Ervin, 1975), a northeasterly-trending, 44 mile (70 km) wide graben that has as much as 1.2 mile (2 km) of structural relief on magnetic basement. The rift is best defined by magnetic data, which also reveal the presence of major positive magnetic anomalies along the flanks and axis of the rift that are inferred to be mafic plutons (Braile, 1997, and Hildenbrand, 1982 in Crone, 2000).

Based on combined information from seismological, seismic-reflection profiling, geomorphic, and geological studies, the Reelfoot Scarp is interpreted as an east-dipping monocline which is the surface expression of a fault-propagation fold associated with the underlying blind Reelfoot thrust fault (Van Arsdale, 1995 and 2000, in Crone, 2000). The following sequence of events summarizes the geologic history of the Reelfoot rift and the current tectonic setting of the New Madrid seismic zone. Crustal extension that resulted in development of the Reelfoot rift began in latest Precambrian or Early Paleozoic time. It is likely that the Reelfoot rift is generally contemporaneous with other large-scale late Precambrian-Early Paleozoic, extensional features along the rifted margin of southeastern North America, including the Southern Oklahoma aulacogen, the Rough Creek-Rome graben system, and the Marathon rift (Thomas, 1991, in Crone, 2000).

In late Quaternary time and probably in earlier episodes, tremendous volumes of glacial melt-water from much of North America flowed down the Mississippi-Ohio Rivers drainage system and through the northern embayment. Braided streams transported the melt-water and deposited outwash sand and gravel into the embayment.These braided stream deposits are typically tens of meters thick in the New Madrid region. In early Holocene time, the Mississippi River changed from a braided stream to a meandering regime and began developing the modern meander belt. As a meandering river, fine-grained overbank sediment that was deposited as annual floods spread across wide expanses of the modern river valley.

The contemporary seismicity and current deformation in the New Madrid region is controlled by a regional stress field in which the maximum compressive stress is oriented approximately east-northeast and west-southwest. Within this stress field, ancient faults, most of which originally formed as extensional features during rifting, have been reactivated mainly as strike-slip faults. The modern seismicity is concentrated into three major trends that form a zigzag pattern that has an overall northeasterly trend. The modern seismicity is largely associated with rift-related features. The southwestern-most trend is a narrow, linear, 75 mile (120 km) long zone of earthquakes in northeastern Arkansas and extreme southeastern Missouri; this zone of earthquakes roughly coincides with the position of an axial fault zone that is commonly present along the center of most rifts.

The sense of movement on active faults is derived from seismological data, which is summarized in the following section. These data indicate that the regional deformation is dominated by dextral slip in the two northeast-trending linear zones of seismicity. The two linear seismicity trends are linked by a zone of northwest-trending seismicity. Accurately located earthquakes in this northwesterly trend suggest the presence of a southwesterly dipping reverse fault (Figure 2.5.1-11).

The geomorphology of the New Madrid seismic zone is dominated by the fluvial features of the Mississippi River and the latest Pleistocene braided stream terraces that are primarily composed of outwash sand and gravel. The most prominent geomorphic expression of contemporary tectonism is the Lake County uplift, a teardrop-shaped uplift in extreme northwestern Tennessee that has a maximum length of about 31 miles (50 km) and a maximum width of about 14 miles (23 km) (Russ, 1982, in Crone, 2000). Geomorphic studies indicate that recent deformation at the uplift has elevated the late Holocene fluvial sediments as much as 30 ft (9 m) (Russ, 1982, in Crone, 2000).

The most widespread expression of recent strong earthquakes in the New Madrid region is the abundant liquefaction features (sand blows and sand-filled fissures), which are concentrated in a 25 to 37 mile (40 to 60 km) wide belt from near Charleston, Missouri on the northeast to south of Marked Tree, Arkansas (Obermeier, 1988, in Crone, 2000). Geologic conditions in the New Madrid region are near optimum for the development of liquefaction features during strong earthquakes: a thin (6 to 26 ft (2 to 8 m) thick), fine-grained “topstratum” deposit overlies water-saturated, unconsolidated “substratum” sand and gravel. Extensive liquefaction occurred during the 1811-1812 earthquakes; locally the ground surface was buried by more than 3.3 ft (1

m) of liquefied sand, and hundreds of square kilometers of the land surface have been mapped as being more than 25 percent covered by liquefied sand (Obermeier, 1988, in Crone, 2000).

Detailed studies of the Reelfoot scarp in northwestern Tennessee have documented evidence of three deformation events within the past 2,400 years and characterized the style of near surface deformation associated with the scarp (Kelson, 1996, in Crone, 2000). Late Holocene fluvial deposits are warped into a 26 ft (8 m) high, east-facing monocline. Borehole data and trenches at three sites characterized the style of near-surface deformation associated with the scarp and constrain the timing of three deformation events on the scarp (Crone, 2000).

Deformation on the scarp associated with the 1811-1812 New Madrid earthquake sequence produced extensive liquefaction, folded the fluvial sediments, and caused minor reactivation of small faults that bound an extensional graben in the uplifted (hanging wall) of the Reelfoot scarp. The penultimate deformation event occurred between A.D. 1260 and 1650 (350-740 yr B.P.), which produced about 4.3 ft (1.3 m) of throw in the graben bounding faults, and caused folding and development of the scarp. The oldest documented event associated with the scarp occurred between A.D. 780 and 1000 (1000-1120 yr B.P.), and initially produced the small graben in the hanging wall of the Reelfoot fault (Crone, 2000).

Despite considerable efforts, reliable geologic data on the recurrence of strong, potentially damaging earthquakes in the New Madrid Seismic Zone (NMSZ) has been elusive, and the currently available data are limited, inconclusive and contradictory. Paleoseismic studies have suggested a recurrence interval of about 500-1100 years for earthquakes that are large enough to produce significant surface deformation or liquefaction in various parts of the seismic zone, with most recent studies suggesting that there were about 900 years between the last two New-Madrid-size events (A.D. 900 to A.D. 1811) and that widespread liquefaction occurs every few hundred years. However, the record studied thus far is too short to be used for a long-term recurrence rate (Crone, 2000). The detailed investigations of the Reelfoot scarp described above provide information that permitted Kelson (1996 in Crone, 2000) to estimate a recurrence interval of 150-900 years, with a more likely range of about 400-500 years. Several articles by Tuttle et al (1998, 2000, and 2005a) provide similar dates for recurrence intervals. It is not clear if these rate estimates reflect the overall behavior of major events for the entire seismic zone or only apply to the Reelfoot scarp.

Despite the lack of well-constrained slip-rate data for specific faults in the New Madrid region, some general inferences can be made about deformation rates using structural and stratigraphic data. A wide range of fault slip rates can be calculated in the New Madrid region depending on time intervals and datums that are being considered. Geodetic studies in the New Madrid seismic zone have yielded results that imply contrasting slip rates. One geodetic study in part of the New Madrid seismic zone yields a contemporary slip rate of 0.2 to 0.28 inches per year (5 to 7 mm per year) (Liu, 1992 in Crone, 2000), but this slip rate is considered to be an anomalously high, very short-term rate, considering the lack of regional topography that would reflect such a deformation rate. Also, if sustained, these rates would have produced much more faulting and deformation in Paleozoic and Cretaceous rocks than actually exists. A more recent geodetic study has questioned whether the Liu, 1992, in Crone, 2000, results are statistically significant (Newman, 1999, in Crone, 2000). Geodetic data analyzed by the latter indicates virtually no significant deformation is currently occurring, that is, their results show that the measured rate does not differ significantly from zero. The significance of the divergent results from these two studies remains unresolved and is the subject of considerable discussion.

The New Madrid events are fully accounted for in the Callaway Plant Unit 2 Probabilistic Seismic Hazard Analysis (PSHA). The New Madrid zone earthquake recurrence is modeled as characteristic earthquakes, and a separate hazard analysis is conducted to account for its contribution. Since 1996, the USGS considered the occurrence of large events in the New Madrid as a characteristic rupture model with a characteristic moment magnitude **M** of 8.0, similar to the estimated magnitudes of the largest events in 1811-1812 (USGS, 1996). USGS included "hypothetical" faults to account for uncertainty in future earthquake ruptures on the New Madrid fault zone. These rupture sources were developed by geological interpretation of the Reelfoot fault, mapped geologic structures, and seismicity characteristics. The geometry of the New Madrid source is modeled as three S-shaped parallel faults encompassing the area of highest historic seismicity. For the Callaway Plan Unit 2 PSHA, the large characteristic earthquakes on the central faults of the NMSZ (**M**>7.0) are characterized with improved logic trees to account for updated assessments of magnitude, location, and return periods. Section 2.5.2.2.2 provides details related to the New Madrid events characterization for seismic hazard.

Wabash Valley Seismic Zone

The Wabash Valley region is located in southeastern Illinois and southwestern Indiana, just beyond the 200 mile (320 km) radius of this investigation. It has been an area of persistent seismicity and the site of several moderate magnitude historical earthquakes (**M**=4.5 to 5.8), but little is known about the causative faults (Crone, 2000). The most prominent network of faults in the region is the Wabash Valley fault system (Bristol, 1979, in Crone, 2000), a series of north-northeast-trending normal faults that are mapped at the surface. Seismic-reflection data show that the faults are rooted in Precambrian basement and define a 25 mile (40 km) long, 13.7 mile (22 km) wide graben named the Grayville graben (Bear, 1997). Dip-slip displacements on some of the faults are as much as 2000 ft (600 m), and laterally offset structural trends suggest horizontal displacement on some faults of up to 2.5 miles (4 km).

There is no known Quaternary surface rupture on faults in the Wabash Valley region. The persistent historical seismicity in the region suggested the possibility of significant seismic source zones in the region. The following discussion focuses on the presence of paleoliquefaction features throughout the study area that includes the southern halves of Indiana and Illinois. Detailed studies (in Crone, 2000) describe the characteristics and distribution of the dikes and offer magnitude estimates of earthquakes that likely caused the liquefaction. A systematic search for paleoliquefaction features was begun in 1990, and more than 1000 paleoliquefaction dikes have been discovered. The dikes are typically filled with sand and gravel, are planar, and have a near-vertical orientation. In the river-bank exposures, many of the dikes extend as much as 13 ft (4 m) above the source beds.

On the basis of the strong evidence that these liquefaction features are late Quaternary in age, they are listed as Class A features (Crone, 2000). Quaternary faults have recently been reported in southernmost Illinois, near Metropolis, but none can be linked with liquefaction features throughout the southern halves of Indiana and Illinois. At least seven and probably eight prehistoric earthquakes have been documented during the Holocene, as well as at least one during the latest Pleistocene. The timing of the most recent paleoevent is the latest Quaternary (<15 ka) (Crone, 2000). At least seven notable paleoevents probably occurred during the Holocene, and one occurred about 12,000 yr B.P.

Prehistoric magnitudes were probably on the order of moment magnitude **M** 7.5, which greatly exceeds the largest historical earthquakes of **M** 5.5 in the region. The strongest prehistoric earthquakes had epicenters in the vicinity of the lower Wabash Valley, where the valley borders both Indiana and Illinois. The precise location of the structures that produced the strong ground motion, which formed the liquefaction features, is unknown. Nearly all of these liquefaction features originated from earthquakes centered in southern Indiana and Illinois, possibly near Vincennes, Indiana, 230 miles (370 km) east of the Callaway Plant Site.

On the basis of gravity and magnetic data, Braile (1982 in Crone, 2000) proposed that the Wabash Valley fault zone is part of the northeastern arm of a late Precambrian-early Phanerozoic rift complex in the central mid-continent. However subsequent studies indicate that the Wabash Valley faults are the expression of relatively minor tectonic structures and are probably not part of a failed rift arm (Hildenbrand, 1997). At present, the seismicity in the region cannot be directly associated with any bedrock structures at shallow depth, although a geophysical magnetic and gravity lineament (the Commerce Geophysical Lineament, CGL) seems to be a good candidate (Hildenbrand, 1997), and a possible fault zone has been located at depth. The lineament, some 373 miles (600 km) in length, extends from Arkansas into the Wabash Valley, and terminates in the epicentral region of the strongest paleoearthquakes (**M**~7.5 and 7.1) (Figure 2.5.1-14).

Some historical seismicity also persists throughout southern Indiana-Illinois, but the strongest events are concentrated in the vicinity of the Wabash Valley. Earthquake focal mechanisms for events in the Wabash Valley region indicate dominantly strike-slip and reverse-slip motion (Herrmann, 1979; Taylor, 1989; Langer, 1991, in Crone, 2000). Without knowledge of the structural features that are present at hypocentral depths, it is impossible to determine the preferred nodal planes for the focal mechanisms (Crone, 2000). No historical earthquakes in the Wabash Valley region have been strong enough to cause liquefaction.

Recurrence intervals on individual faults have not been definitively determined, however a regional recurrence interval for **M** >6 earthquakes of at least every 500 to 1,000 years is reasonable in the southern half of Indiana and Illinois (Crone, 2000). Causative faults have not been identified in the Wabash Valley area. In the absence of well-determined data on the timing of paleoevents and the amount of tectonic slip associated with those events, it is impossible to estimate reliable or even meaningful Holocene or late Quaternary slip rates.

The Wabash Valley Seismic Zone is fully accounted for in the Callaway Plant Unit 2 PSHA. Paleoliquefaction evidence is incorporated for by an updated maximum magnitude distribution that is higher to that estimated by the postulated Springfield earthquake (i.e., **M** 6.2 to 6.8). The Callaway Plant Unit 2 PSHA centers the maximum magnitude at **M** 7.4. Section 2.5.2.2.3 provides details related to the maximum magnitude update for the Wabash Valley Zone.

Slinkard Quarry Graben

Wheeler (2005) references the Slinkard quarry graben as a Class "A" feature within the city limits of Cape Girardeau, Missouri, approximately 160 miles (260 km) to the southeast of the Site. A Quaternary graben is partly exposed in the quarry, and strikes northeast, is approximately 500 ft (152 m) wide, and is filled with syntectonic gravel. Faults that bound the graben or are near it have undergone multiple periods of movement including pre-Cenozoic, Paleocene, and at least two periods in the Quaternary, with the youngest being post-Sangamon Geosol and pre-Wisconsinan loess. The northwest margin of the graben juxtaposes Quaternary gravel against late Tertiary Mounds Gravel. The fault on the northwest margin strikes N. 35°-40° E. and dips approximately 74° SE. Mounds Gravel in the footwall has been rotated to dip 54°-85° SE., with strike parallel to the fault.

2.5.1.1.4.3.2.3 Other Faults Related to the Mississippi Embayment

The following descriptions are for faults near the Mississippi that have insufficient information or insufficient activity to be named Class "A" features.

Mississippi Valley Faults

A series of faults located in the Mississippi Valley (see No. 42 in Missouri on Figure 2.5L-5) in the Upper Mississippi Embayment, more than 200 miles (320 km) to the southeast of the Site, has been described by the American Association of Petroleum Geologists (AAPG) (1971). According to the interpretation and description by Schwalb (1978): "Many faults are exposed in the Paleozoic rocks around the northeastern edge of the embayment; some of these faults probably extend into the Reelfoot basin beneath the Mesozoic and Cenozoic strata. Because of the sparse subsurface control, only the major displacements can be plotted in the embayment area. A fault that trends northeast is downthrown on the west, has 700 to 800 ft (210 to 240 m) of displacement, and follows the course of the Mississippi River. A very large fault trending slightly south of east crosses the Mississippi River fault near the junction of the Missouri-Arkansas-Tennessee boundaries. Displacement exceeds 4,000 ft (1,220 m) at the Mississippi River and decreases eastward; the downthrown side is on the south, but the fault may scissor to the east, reversing the displacement. A third fault is mapped in Missouri almost parallel with the Mississippi River fault. The downthrown side is on the east, producing a graben within the Mississippi River flood plain. South of the major east-west fault, another displacement follows the trend of the Mississippi River, but downthrow is on the east."

MODNR (2007c) describes the fault as the Mississippi Valley Graben, a 135 km long structure first identified from satellite imagery (Marple (1989) in MODNR (2007c) as a southwest - northeast - trending lineament.

The graben structure and shape were defined by geophysical, aeromagnetic, and gravity data (Figure 2.5.1-12 and Figure 2.5.1-13) with the edges of the graben are formed by Precambrian basement strata.

Ste. Genevieve Fault System

The Ste. Genevieve Fault System is a complex fault zone of variable character, located approximately 95 miles (153 km) to the southeast of the Site (see No. 38 in Missouri on Figure 2.5L-5). At various points along its trace, from two to four steeply dipping reverse faults and a faulted monocline account for most of the structural relief across the feature. Compensatory normal faults are generally present in the edge of the upthrown block. The character of the monocline changes from a small flexure whose steep limb dips approximately 40° northeast to a large feature with the steep limb overturned at least 50° southwest. The dips of the reverse faults in the fault zone vary from vertical to 50°. The fault zone is uniformly upthrown on the west although evidence for minor reversals in the sense of movement along the fault does exist.

Stratigraphic displacement varies from approximately 450 ft (140 m) along the edge of the Potosi block, 900 ft (275 m) along the edge of the Farmington block, to a possible maximum of 2,000 ft (610 m) along the edge of the Perryville block. The Ste. Genevieve Fault Zone is interpreted as a boundary for several of the crustal blocks in the eastern Ozarks. It trends straight along the edges of the blocks, but may bend sharply where it intersects another block boundary, as at its intersection with the Big River and Saint Mary's Fault Systems.

The Ste. Genevieve Fault System is likely an inherited feature, the strike of whose segments represent a Precambrian structural grain and its position controlled by the dynamics of subcrustal block uplift. It has probably existed as an inter-related series of faults that comprise a major structural discontinuity in the region since at least late Precambrian time. It represents a major element in the limb between the Ozark Uplift and the Illinois Basin. Structural and magnetic lineaments of the 38th Parallel lineament discussed by Lidiak and Zietz (1977 in AmerenUE, 2004) were found to be interrupted by the prominent northwest trending magnetic anomalies associated with the Ste. Genevieve Fault.

Northwest trending gravity anomalies also associated with the Ste. Genevieve Fault zone were recognized by Keller and Austin (1977, in AmerenUE, 2004). The extension of the Ste. Genevieve

Fault System into Illinois has also been called the Rattlesnake Ferry Fault (see No. 4 in Illinois on Figure 2.5L-5). For the purpose of this study, the name Ste. Genevieve will be used for all branches of the fault system.

Weller and St. Clair (1928 in MODNR (2007c) described this fault as a faulted zone which crosses Ste. Genevieve County in an east-west direction. It is oriented northwest-southeast, entering Ste. Genevieve County from Perry County in a land grant located in the southwest part of T. 37 N., R. 10 E., about 3 miles (5 km) south of St. Mary. This fault zone strikes essentially east-west across Ste. Genevieve County from the Perry County line to near Auxvasse River in the N 1/2 Sec. 7, T. 36 N., R. 8 E., where it bends northwest, passing west of Weingarten. It crosses the St. Francois-Ste. Genevieve County line in Sec. 26, T. 36 N., R. 6 E. It continues across northern St. Francois County where it branches into two faults; one continues northwest (see Valles Mines-Vineland fault zone), while the other strikes southwest through St. Francois County (see Big River fault zone). East of Ste. Genevieve County, this zone extends east through Perry County through Lithium, and then southeast along the Mississippi River to south of Wittenberg where it crosses the Mississippi River into Illinois at Grand Tower (see Wittenberg fault zone, Red Rock thrust, Red Rock-Union School fault zone).

Maximum displacement is about 550 ft (170 m) for the northwest part of the fault and over 1,000 ft (305m) in the east-west section. Faulting is so intense within these blocks it would appear that they are caused by tectonic rather than sedimentary processes. It is a long, narrow block of Jefferson City Formation surrounded by older rocks. The entire system may be tensional, developed by the rising Ozark mass against the sinking Illinois basin.

Ste. Mary's Fault

Mateker (1956) recognized a strong gravity gradient that trended northeasterly and crossed the Mississippi River at Ste. Mary's, Missouri; approximately 120 miles (193 km) to the southeast of the Site (see No. 53 in Missouri on Figure 2.5L-5). No faulting was recognized at the surface until road cuts for Interstate Route 50 were completed. Tikrity (1968) described 200 to 400 ft (61 to 122 m) of downward displacement to the southeast, toward the Illinois Basin, and considered it to be a northeast extension of the Ste. Genevieve Fault System. A wide fault zone that includes steeply dipping fault zones and monoclines was noted during reconnaissance for this study. This fault zone coincides with the gravity gradient noted by Mateker (1956) and with the southern boundary of the Farmington block.

MODNR (2007c) describes the fault as thought to be a northeast extension of the Ste. Genevieve fault system with structural mapping indicating the throw to be from 200 to 400 ft (61 to122 m) down to the southeast toward the Illinois basin.

Simms Mountain Fault

The Simms Mountain Fault separates the Precambrian terrain of the St. Francois Mountains from the Cambrian sedimentary rocks of the Missouri lead belt (see No. 37 in Missouri on Figure 2.5L-5), approximately 120 miles (193 km) to the southeast of the Site. The brittle basement rocks and dolomites along the fault trace have been severely shattered and a broad, gentle valley has been eroded along the fault trace along most of its length. The sedimentary rocks immediately adjacent to the fault trace dip approximately 45o to the east, probably representing the remnant of a faulted monocline. The fault is uniformly upthrown to the west and dips steeply, since its trace crosses topographic features of considerable relief without deflection. Total vertical stratigraphic separation is probably less than 200 ft (61 m).

MODNR (2007c) describes the fault as one of the major fault systems in the St. Francois Mountain area with the fault had been mapped by Buckley, (1908 in MODNR, 2007c) as the Irondale fault.

Mapping by Amos (1984, 1985) and Satterfield (1973) in MODNR (2007c) extended the fault system further to the southeast. It stretches from the Big River fault near Irondale to the Mississippi River floodplain at Cape Girardeau, a distance of almost 75 miles (121 km), and it ranges from 8 to 12 miles (13 to 21 km) in width.

Within the fault system are various shaped horsts (Cape Girardeau quadrangle), up to 5 miles (8 km) in length, dipping blocks, and wedges. The geometric patterns of the faults are indicative of strike-slip movement.

Previously mapped structures such as the Radio Tower structure, Jackson fault, and Cape Girardeau fault are a part of the Simms Mountain fault system.

Big River Fault

The Big River Fault is a steeply dipping reverse fault. Its trace defines the boundary between the Farmington and Potosi blocks; approximately 130 miles (210 km) to the southeast of the Site (see No. 3 in Missouri on Figure 2.5L-5). Total structural relief across the feature is 280 ft (85 m) at Bonne Terre, Missouri. Structural relief decreases along strike to the southwest, reflecting the tilting of the Farmington block. The Big River Fault terminates against the Ste. Genevieve Fault on the northeast and the Simms Mountain Fault on the southwest.

MODNR (2007c) describes the fault as displaced a maximum of 120 ft (37 m), down to the northwest. The fault system is zigzag in strike having two distinct lines of displacement. It is high-angle, normal with a total length of about 17 miles (27 km), and is post-Roubidoux in age. It is complex in some places, consisting of several en echelon faults.

Black Fault

The Black Fault is a steeply dipping fault whose trace trends northwesterly; approximately 100 miles (160 km) to the south-southeast of the Site (see No. 4 in Missouri on Figure 2.5L-5). Poor exposure makes precise definition of fault geometry impossible. The fault is downthrown to the west, and near the town of Black, Missouri, the entire vertical stratigraphic separation is within the thickness of the Bonneterre Formation (approximately 100 ft (31 m)). The Black Fault defines the western boundary of the St. Francois block and represents the easternmost structure on the western limb of the Ozark Uplift.

MODNR (2007c) describes the fault as having a displacement of 300 ft (91 m) involving beds of Cambrian age, bringing Potosi against Bonneterre beds, and may extend northwestward to connect with (or be cut off by) the Palmer fault system. The structure is down to the southwest, with an average strike of N. 35o W. The structure intersects the Sabula basin. Dipping beds near Goodwater (Sec. 28, T. 35 N., R. 1 W.) point to a northwest extension.

A small fault branches off at the NW ¼ NW ¼ Sec. 16, T. 33 N., R. 1 W., and extends in a generally westerly direction for approximately 1 mile (1.6 km), then N. 10-15o W. for approximately 2 miles (3 km). The westerly portion is down to the north; the northerly portion is down to the east.

Anthonies Mill Fault

The Anthonies Mill Fault is described by McCracken (1971, in AmerenUE, 2004) as being observed at the surface, approximately 60 miles (97 km) to the southeast of the Site. Its existence was substantiated by drilling near the Pea Ridge iron deposit. The fault extends from Section 19, Township 39 North, Range 1 West, Washington County, Missouri, to Section 11, Township 39 North, Range 2 West, Crawford County, Missouri. The displacement on the fault is 150 to 200 ft (45 to 60 m) with the downthrown side on the southwest (see No. 49 in Missouri on Figure 2.5L-5).

MODNR (2007c) describes the fault as near Anthonies Mill, discovered at the surface and substantiated by drilling in the vicinity of the Pea Ridge iron deposit. Displacement is 150 to 200 ft (45 to 61 m) with the southwest side downthrown. The fault may extend northwest and southeast of the mapped structure.

Fluorspar Area Fault Complex

The Fluorspar Area Fault Complex (see No. 2 in Illinois on Figure 2.5L-5) is an area of numerous northeast to nearly east trending faults centered in Hardin and Pope counties, Illinois, and in Crittenden and Livingston counties in Kentucky, approximately 200 miles (320 km) southeast of the Site. It has been active in Quaternary time. The complex extends southward from the Rough Creek Lineament to some focal point beneath the Cretaceous deposits of the Mississippi Embayment in western Kentucky. Maximum displacements of about 2,000 ft (610 m) are present on the northeast trending faults. Numerous cross faults with lesser displacements form a complex mosaic pattern (Baxter, 1963, 1965, 1967). Although the faulting is reported to be dominantly normal, some faults have been formed by thrust (compression) faulting. Slickensides along the fault planes suggest that there have been important horizontal components in the movements. Displacements along some faults appear to have taken place at different angles at different times.

Crone (2000) reports that the Fluorspar Area fault complex refers to the multitude of fractures in the fluorspar-mining district of southern Illinois and western Kentucky. Fault orientations vary, but most trend NE-SW in Illinois, curving to ENE-WSW eastward into Kentucky. Most faults dip 65° or steeper and they comprise normal, reverse, strike-slip, and oblique slip faults, many showing evidence of two or more episodes of movement. Associated with faulting are Permian ultramafic dikes, sills, diatremes, and a large intrusive breccia structure known as Hicks Dome. This was historically the richest fluorite-mining district in the United States. Sizeable quantities of lead, zinc, silver, barite, and other minerals also were mined from vein and bedded-replacement deposits. The Fluorspar Area Fault Complex overlies the junction area of a Proterozoic-Cambrian failed rift complex that consists of the northeast trending Reelfoot rift and the east-trending Rough Creek graben. Of more than passing significance, the New Madrid seismic zone also lies within the Reelfoot Rift and is directly in line with the Fluorspar Area fault complex. The Fluorspar Complex consists of six main subdivisions of faults. They are the Rock Creek Graben, Barnes Creek Fault, Hobbs Creek Fault, Raum Fault Zone, Lusk Creek Fault, and the Kelley Structure. Each subdivision is discussed below:

Rock Creek Graben (inside the Fluorspar Area Fault Complex)

The Rock Creek graben is a large, complex graben of the Fluorspar Area Fault Complex. The Rock Creek follows a curving path southwestward from Union County, Kentucky into Hardin County, Illinois, back into Kentucky, finally returning to Pope and Massac Counties, Illinois where Quaternary activity is in evidence. Overall, the Rock Creek graben is composed dominantly of high-angle normal faults that trend northeast.

Barnes Creek Fault Zone (inside the Fluorspar Area Fault Complex)

This fault zone has been mapped about 25 miles (40 km) across Illinois. It strikes NE-SW, and along most of its length consists of either a single fault or a pair of faults that outline a graben less than 984 ft (300 m) wide. Where it enters the Mississippi Embayment, the Barnes Creek widens to nearly 1.24 miles (2 km) and becomes much more complex. It is here that Quaternary deformation has been demonstrated. Strike-slip component is strongly suspected. A seismic profile shows positive and negative flower structures. Deep, narrow pull-apart grabens are common. Most faults dip 65° or steeper.

Hobbs Creek Fault Zone (inside the Fluorspar Area Fault Complex)

Seismic profiles show that most faults are high-angle normal, but a few reverse faults are present. As with other faults listed here, strike-slip appears likely, but no information on the magnitude or direction of strike-slip is available. Most faults dip to the southeast or northwest 70 to 90°. Pairs of faults commonly outline grabens and horsts.

Raum Fault Zone (inside the Fluorspar Area Fault Complex)

The Raum fault zone outlines the southeast side of the Dixon Springs graben, one of several large, complex grabens within the Fluorspar Area Fault Complex. Most faults are high-angle normal, but high-angle reverse faults are present. Most faults dip to the southeast and northwest 70 to 90°.

Lusk Creek Fault Zone (inside the Fluorspar Area Fault Complex)

The Lusk Creek fault zone delimits the northwest margin of the Fluorspar Area Fault Complex and also was a northwest boundary fault of the Proterozoic-Cambrian Reelfoot Rift. The net displacement is down to the southeast and increases toward the northeast, where the Lusk Creek merges with the western end of the Rough Creek Fault System. Principally high-angle normal faults are present, in association with high-angle reverse faults.

The Lusk Creek Fault Zone trends North 35° East from the northeastern corner of Massac County, Illinois and extends into Hardin County, Illinois where it terminates against the Herod Fault and the Shawneetown Fault Zone (Stonehouse and Wilson, 1955). According to Weller et al. (1952) and Lusk Creek Fault Zone is a complex structure consisting of normal and reverse faults. Closely spaced drilling has shown that faulting is more abundant and more complex than surface features indicate. The faulting cuts Pennsylvanian strata and the southern end of the Lusk Creek Fault Zone is overlain by unfaulted Cretaceous deposits (Willman et al., 1967). The faults are considered to be younger than igneous dikes which have intruded the sedimentary strata (Grogan and Bradbury, 1968). The igneous intrusions have been dated from stratigraphic relationships as later than Middle Pennsylvanian (Cleg and Bradbury, 1956) and from K-Ar methods as Permian or older (Zartman et al, 1967, in AmerenUE, 2004). From the history of crustal movements in the Illinois basin, faulting is post-Pennsylvanian, pre-Late Cretaceous, or possibly Paleocene (Atherton, 1971). There are a few faults in Kentucky near the Lusk Creek Fault Zone that displace Cretaceous deposits and possibly some Paleocene deposits (Olive, 1972). Olive shows no faults displacing the Claiborne Formation of Eocene age.

The southwestern part of the complex is in a seismically active area. The intensity of these earthquakes, however, is lower than in the New Madrid Seismic Zone to the south.

Field work has been performed by the Illinois State Geological Survey in an effort to provide evidence which might support or negate the existence of structural continuity between the New Madrid Seismic Zone and the faulting in the Fluorspar Area Fault Complex. Faulting of the Paleozoic rocks on the northeast where they are exposed at the surface was confirmed as being post-Paleozoic and pre-Late Cretaceous in age.

Examination of apparent faulting in unconsolidated Tertiary and Quaternary deposits that overlie the Paleozoic rocks to the southwest beneath the Mississippi Embayment has been examined. However, it has yielded no unequivocal evidence of tectonic faulting in the Illinois part of the Mississippi Embayment during or after Late Cretaceous time. Faulting found in the overlying unconsolidated deposits was attributed to landslides and solution collapse (Kolata, 1978; Kolata et al., 1979).

Kelley Structure (inside the Fluorspar Area Fault Complex)

The Kelley structure, which trends N-S to NNW-SSE, lies along what may be a cross-fault connecting the Lusk Creek and Raum fault zones. Most faults are normal and reverse faults.

Rough Creek Lineament

The Rough Creek Lineament (see No. 3 in Illinois on Figure 2.5L-5) is a series of faults and fault zones extending generally east-west through western Kentucky and southern Illinois, approximately 150 to 200 miles (240 to 320 km) to the east of the Site. In Kentucky, it includes the Rough Creek Fault Zone (Sutton, 1953; Stonehouse and Wilson, 1955). In Illinois, it includes the east-west portion of the Shawneetown Fault Zone to the east and the Cottage Grove Fault System to the west.

Heyl (1972, 1977) suggests that strike-slip faulting or wrench faulting is a major component in the Rough Creek Lineament. He tentatively includes the lineament in a line or zone of faults, monoclines, and igneous intrusions. The line extends east-west for 800 miles (1300 km) along the 38th parallel from West Virginia to at least as far west as the Ozark Uplift in south-central Missouri. In the Illinois-Missouri-Kentucky region the lineament appears as a complex of faults, associated magnetic and gravity anomalies, and breaks in magnetic anomaly patterns (Lidiak and Zietz, 1976, in AmerenUE, 2004; Hinze et al., 1977; Braile et al., 1978; Heyl, 1977).

The Rough Creek Lineament appears to form the northern boundary of the Rough Creek Graben that developed in Precambrian rocks before late Cambrian time. The zone of weakness was reactivated near the close of the Paleozoic Era (Buschbach, 1978). North of this lineament in southeastern Illinois is the Fairfield Basin, the deepest part of the Illinois Basin. The Rough Creek Graben is now considered to be relatively inactive, being seismically indistinguishable from the craton (Wheeler, 1997).

In Illinois, the lineament is dominated by numerous high angle reverse faults with the south side upthrown, and there are a number of normal faults (Weller et al., 1952). The faults display evidence of some horizontal movement. The eastern part of the lineament, the Shawneetown Fault Zone, is dominated by thrust faulting. Displacement is locally as great as 3,400 ft (1,040 m) and may be considerably more. The Shawneetown Fault Zone extends westward along the prominent hills in southern Gallatin County, curves southward from Cave Hill in Saline County, leaves the Rough Creek Lineament and joins the southwest-trending Herod Fault to the Lusk Creek Fault Zone.

The Shawneetown Fault Zone cuts Pennsylvanian strata and is presumed to be post-Pennsylvanian in age (Willman et al., 1967). The southern end of the Lusk Creek Fault is overlain by unfaulted deposits of Cretaceous age and therefore, it is inferred that the most recent faulting within the Shawneetown Fault Zone is post-Pennsylvanian, pre-Late Cretaceous (Buschbach, 1973). The western portion of the lineament, the Cottage Grove Fault System, extends from Saline County westward to Jackson County, Illinois and appears to have formed at roughly the same time as the Shawneetown. Displacements are diminished, with maximum displacements of about 250 ft (76 m). Pennsylvanian strata are cut by the faulting and therefore the age of faulting along the Cottage Grove Fault Zone is presumed to be post-Pennsylvanian, pre-Late Cretaceous (Willman et al., 1967; Buschbach, 1973).

The geometry described by Heyl (1972, 1977) does not coincide with the geometries of buried strike slip faults in analogous situations in other localities (Ottawa-Bonechere structure, Oklahoma en echelon fault zone, Montana Lineaments). These features display lineaments composed of en echelon normal faults, giving rise to an elongated belt of horst and graben terrain. No reverse faulting is predicted by dynamic models of such structures (Friedman, 1967, in AmerenUE, 2004; Billings, 1972). Limited reconnaissance by Gibbons (1972) during his study of the eastern Ozarks suggested strong similarities with the structural style of the Ste. Genevieve Fault System. Upthrust faulting and minor features observed by Heyl (1972, 1977). Large vertical displacements associated with reverse faulting, compensatory normal faults, monoclines and horizontal movements along minor faults are all common features in upthrust terrains (Prucha, et al., 1965). This feature lies within a structural province with demonstrated upthrusting associations. It is, therefore, likely that the Rough Creek-Cottage Grove-Shawneetown System may represent a series of upthrust faults along block boundaries similar to those in the eastern Ozarks.

The Chesapeake and Bolivar-Mansfield Fault Systems are inactive features that lie on the Border between Kansas and Missouri.

Chesapeake Fault Zone

The Chesapeake Fault (see No. 1 in Kansas and No. 8 in Missouri on Figure 2.5L-5) is a major structure that is best developed in eastern Lawrence County, Missouri (McCracken, 1971). It is located approximately 150 miles (240 km) to the west-southwest of the Site. MODNR (2007c) describes the fault as highly visible in quarries and road cuts. It was first described by Newton, 1894, in MODNR, 2007c) who gave it the name Chesapeake-Kirbyville anticline. Rutledge (1921a in MODNR, 2007c) was the first to describe the structure as a fault extending from the center of the east line of Sec. 12, T. 27 N., R. 25 W., to some 25 miles (40 km) northwest across Lawrence County into Dade County. He states that while brecciation along the fault plane is not conspicuous, some is present (SW ¼ NE ¼ Sec. 22, T. 28 N., R. 25 W., south side of road). Local dolomitization of the upper Burlington-Keokuk and Reeds Spring formations is found in the vicinity of the fault. He also noted that formations near the fault assume a steep dip in the direction of the down thrown side and are near-vertical near the fault plane. Rutledge named the fault and dated it as late Mississippian, since a Pennsylvanian channel sandstone that crosses the structure (Sec. 1, T. 27 N., R. 25 W.) is not displaced.

The fault was extended to the Kansas line by structure contouring of widely scattered drill hole data on the base of the Roubidoux Formation. Cole (1962, 1976) extended the fault into Bourbon County, Kansas and shows approximately 100 ft (31 m) of downward displacement to the northeast. The control for extending this structure into eastern Kansas is extremely sparse and therefore, the extension of this fault into Kansas is inferred.

Thompson (1995 in MODNR, 2007c) shows the fault crossing Interstate Highway 44 in Lawrence County. The fault extends into western Christian County and further south, in Stone and Taney Counties, is aligned with the Ponce de Leon graben and Ten O'clock fault and monocline.

For most of its course, the structure offsets Ordovician and Mississippian formations. Portions of the upthrown side form topographic highs. The throw of the structure is variable, but is as high as 175 ft (60 m). High angle dips are common along the structure.

A small fault, also trending northwest from the Kansas/Missouri border located north of the Chesapeake Fault, has been inferred from sparse control (Cole, 1976). It had been previously interpreted as a bedrock valley. An extension of this fault is not mapped to the southeast in Missouri (Missouri Geological Survey, 1979 in AmerenUE, 2004; McCracken, 1971 in AmerenUE, 2004).

Bolivar-Mansfield Fault System

The Bolivar-Mansfield Fault System (see No. 5 in Missouri on Figure 2.5L-5) is a broad zone of discontinuous; generally parallel faulting that extends northwest from Douglas through St. Clair and Bates counties, Missouri into Kansas, approximately 150 miles (240 km) west-southwest of the Site. Many of the individual faults in this system have been named separately. This zone may extend southeastward into Arkansas (McCracken, 1971, in AmerenUE, 2004) and has been extended northwestward through Bates County by Gentile (1965, 1976). The Eldorado Springs North fault has been extended from Bates County into Kansas (McCracken, 1971, in AmerenUE, 2004) and is shown as an unnamed fault on the top of the Precambrian in Linn County, Kansas by Cole (1976). It had previously been interpreted as a valley on the basement surface (Cole, 1962). The system appears to border the southwest flank of the Ozark Uplift. Faulting is mostly high angle normal, with throws of up to 300 ft (91m) (McCracken, 1971, in AmerenUE, 2004). The faulting involves beds ranging in age from early Pennsylvanian (Cherokee Group) to early Ordovician (Roubidoux Formation).

2.5.1.1.4.3.3 Regional Jointing

Regional joint or fracture patterns are consistent and well developed throughout the Site Region. Two systems of fractures are prevalent. The most common and the most widely distributed fracture system is made up of two sets that parallel the general regional structural trends (northwest and northeast). This system is present in the basement rocks and is represented there by fractures intruded by ultrabasic rocks of known Precambrian age. The second system is subordinate and has two joint sets that strike north-northwest and east-northeast. The two systems are statistically difficult to distinguish in large samples and may represent local variants of the same system. The near right angle of intersection and vertical attitude of both systems suggest that these are regional orthogonal fracture systems common to areas that have been uplifted by upthrust tectonics (Gibbons, 1972).

2.5.1.1.4.4 Seismic Sources Defined by Regional Seismicity

In 1986, the Electric Power Research Institute (EPRI) developed a seismic source model for the Central and Eastern United States (CEUS), which includes the Callaway Plant Site Region (EPRI, 1986). The CEUS is a stable continental region (SCR) characterized by low rates of crustal deformation and no active plate boundary conditions. The EPRI source model included the independent interpretations of six Earth Science Teams (ESTs) and reflected the general state of knowledge of the geoscience community as of 1986. Each of these teams developed a tectonic framework, defined as the collection of tectonic features thought to have a non-negligible probability of generating magnitude 5 (m_b) or greater earthquakes in the present stress regime due to tectonic processes, using comprehensive geophysical and seismological databases compiled in initial stages of the project. In order to develop their individual framework each of the six groups: (1) interpreted the crustal stress regime, (2) identified the tectonic features that might produce moderate to large earthquakes, (3) listed and evaluated criteria for assessing the likelihood of activity of those features, and (4) quantified the probability of activity of each feature. Using this tectonic framework they later extended the tectonic evaluations and seismic source zones assessment to the entire Central and Eastern United States, for which they estimated seismicity parameters based on advanced and traditional analyses of the historical earthquake data set by means of a consistent, systematic format with full documentation (EPRI, 1986).

Seismic source zones have been configured either to coincide with tectonic features, or to envelope tectonic features and adjacent patterns of observed seismicity. The original seismic sources identified by EPRI are thoroughly described in the EPRI study reports (EPRI, 1986) and details for each are summarized in Sections 2.5.1.1.4.3.1 through 2.5.1.1.4.3.6. These sections present particulars of the interpretations from each of the six ESTs: Weston Geophysical Corporation, Dames & Moore, Law Engineering Testing Company, Woodward-Clyde Consultants, Bechtel Group, Inc., and Rondout Associates Incorporated. Each EST was initially responsible for a particular region of the Central and Eastern United States. After these regional tectonics evaluations were made, each of the ESTs extended the tectonic evaluations and source zone assessments to the entire Central and Eastern United States (EPRI, 1986).

Each of the models prepared by the six ESTs varies from the other five, based on differing interpretations of the data presented to them. Within those variations, however, there are consistencies among the models that reflect on the projected seismicity of the Site. Each of the models places the Callaway Plant Site in a stable area of the mid-continent, and each one locates the seismically active source areas inside the southeast quadrant of the 200 mile (320 km) radius circle about the Site. The distance from the Site to the nearest boundary of an active seismic zone varies from approximately 30 to 50 miles (50 to 80 km), depending on the interpretation. Therefore, all six models agree that the Site Area is in an area that is stable and located at least 30 miles (50 km) from the nearest edge of a seismic source area.

Section 2.5.1.1.4 summarizes specific tectonic features and characteristics within these evaluations, their evolution in time and the current state of knowledge on the tectonic setting and tectonic structures in the Site Region. Section 2.5.2 gives details of the assigned frequency and magnitude of earthquake activity in these seismic sources. Based on interpretations of the size of the prehistoric earthquakes, and the uncertainty in the magnitude of the largest prehistoric earthquakes in the EPRI zones that are within lower Wabash Valley region, the maximum magnitude of these zones was increased (EGC, 2006). Examples of these zones are the Souther Illinois Area and the St. Louis Arm. Details of this update are provided in Section 2.5.2.2.1. The large earthquakes in New Madrid Zone were removed from the EPRI source models and treated within the New Madrid characteristic earthquake model. Finally, the background seismicity, which encompasses earthquakes that are not included within any of the specified EPRI zones, was reinterpreted with new distributions of maximum magnitude, as described in Section 2.5.2.2.4.

2.5.1.1.4.4.1 Tectonic Interpretations by Weston Geophysical Corporation

Weston Geophysical Corporation's tectonic interpretation and proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-16 and Figure 2.5.1-17. Their interpretation for tectonic features affecting the Site Region includes: New Madrid Graben and Reelfoot Rift, Mississippi Embayment, Wabash River Zone, Ste. Genevieve Complex, Fairfield Basin (inner central deep basin in the Illinois Basin), and the Ozark Uplift.

Seismic sources are defined by three source zones and two background zones. The three seismic source zones are: (31 & 32) New Madrid Fault Zone and Reelfoot Rift, (33) Indiana Arm of the New Madrid Rift Complex (NMRC) Seismic Source, and (34) St. Louis Arm of the NMRC Source Region. The two Background Region Seismic Sources are: (105) North-Central Background including Zone (030), and (108) Great Plains Background, including Zone (035) (Nemeha Uplift, outside the Site Region (EPRI, 1986).

2.5.1.1.4.4.2 Tectonic Interpretations by Dames & Moore

Dames & Moore's tectonic interpretation and proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-18 and Figure 2.5.1-19. Their tectonic feature assessment for the Site Region includes: Central Reelfoot Rift/New Madrid Seismic Zone (33) as part of the Mesozoic/ Cenozoic Rifts; Eocambrian Rifts, including St. Louis Arm (34) and Southern Indiana Arm (35), both interpreted as failed arms of the New Madrid Seismic Complex; Ozark Uplift (48), within the set of structures identified as domes and uplifts; and the Illinois/ Fairfield Basin (60), within the set of basin structures.

Seismic sources are defined by nine source zones on Figure 2.5.1-19: (18) Southern Illinois/ Southern Indiana/ Fairfield Basins; (18a) Illinois Basin; (19) St. Louis Arm; (21 & 21b) New Madrid Compression Zone; (22) Reelfoot Rift; and (23) Eastern Ozark. Zones (B36) Mid Continent Province, and (B70) Wisconsin-Michigan Block are considered background zones (EPRI, 1986).

2.5.1.1.4.4.3 Tectonic Interpretations by Law Engineering Testing Company

Law Engineering Testing Company's tectonic interpretation and proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-20 and Figure 2.5.1-21. Their interpretation for tectonic features affecting the Site Region comprises: New Madrid Rift Complex, including the Reelfoot Rift, Wabash Valley Arm, and the St. Louis Arm that includes the St. Genevieve Fault Zone; Wabash Valley Fault Zone, and Cottage Grove Fault; and the Ozark Uplift.

Seismic source zones, also illustrated in the figures, are defined by five source zones and four background zones. The five seismic source zones on Figure 2.5.1-21 are: Reelfoot Rift (4a & 4b), two alternative configurations; St. Louis Arm of the New Madrid Rift Complex (6); Wabash Valley Arm (7); Ozark Uplift (15); and postulated faults in Reelfoot Rift (18). The four Background Seismic Source Zones are based on seismotectonic regions, and include: Illinois Block (116), Mississippi Embayment (117), Missouri Block (118), and Eastern Mid-Continent (119) (EPRI, 1986).

2.5.1.1.4.4.4 Tectonic Interpretations by Woodward-Clyde Consultants

Woodward-Clyde Consultants tectonic interpretation and proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-22. Their interpretation for tectonic features affecting the Site Region includes: Central Disturbed Zone of Reelfoot Rift (40), Reelfoot Rift/New Madrid Rift Complex (41), St. Louis Arm of the New Madrid Rift Complex (42), Southern Indiana Arm of the New Madrid Rift Complex (43), Kansas/Nebraska Offset of the Mid-Continent Geophysical Anomaly (47), and the Great Plains Crustal Block (54).

Seismic source zones, as Illustrated in Figure 2.5.1-22, are defined by seven source zones, all part of two defined regions: the New Madrid Region and the Western Nebraska/Western Kansas region. The New Madrid Region comprises the Disturbed Zone of Reelfoot Rift (40), the Reelfoot Rift Source Zone (41), the St. Louis Arm Source Zone (42), the Southern Indiana Arm Source Zone (43), and the New Madrid Loading Volume (44). The western Nebraska/Western Kansas region includes the Kansas – Nebraska Offset of the Mid-Continent Geophysical Anomaly (47), and the Great Plains Crustal Block (54). There is no defined background zoning within the Woodward-Clyde interpretation (EPRI, 1986).

2.5.1.1.4.4.5 Tectonic Interpretations by Bechtel Group, Inc.

The Bechtel Group's. tectonic interpretation and proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-23 and Figure 2.5.1-24. Their interpretation for tectonic features affecting the Site Region includes: New Madrid Fault Zone (30), Reelfoot Rift (31), Wabash Valley Fault Zone (34), Cottage Grove Fault Zone (35), St. Genevieve Fault Zone (36), and Tennessee – Montana Geopotential Trend (42).

The Bechtel group identified eight source zones and two background zones. These seismic source zones are first, and primarily, identified for each tectonic feature with an assessed activity of 0.05 or greater. Six of the eight sources zones were defined in this manner and were given a number designator; they include: New Madrid (30), Reelfoot Rift (31), Wabash Valley (34), Cottage Grove (35), and St. Genevieve (36). A second type of seismic source was defined for areas where either no adequate tectonic feature could be identified, or where the identified features were not able to adequately explain the local seismicity. The remaining two seismic sources were defined in this manner and were given a letter designator: the Ozark Area (J) and the Southern Illinois Area (K). Two background zones are left after all seismic sources have been considered: the New Madrid Region (BZ0) and the Northern Great Plains Region (BZ3) (EPRI, 1986).

2.5.1.1.4.4.6 Tectonic Interpretations by Rondout Associates, Inc.

The tectonic interpretation by Rondout Associates, Incorporated and their proposed seismic source zone configuration and dependencies are presented in Figure 2.5.1-25 and Figure 2.5.1-26. Their interpretation for tectonic features affecting the Site Region includes: New Madrid Rift Complex Reelfoot Wrench/Paleorift Structure (NMRC-A), New Madrid Rift Complex Southern Indiana Arm (NMRC-B), and New Madrid Rift Complex St. Louis Arm (NMRC-D).

Seismic source zones, illustrated in the same figures, are defined by six source zones, and one background zone. The six seismic source zones are: New Madrid (1), New Madrid Rift Complex (2), Ozark Uplift (3), Southern Illinois/Indiana (4), Northern Illinois (15), and Great Plains (21). The one Background Region Seismic Sources considered is the Pre-Greenville Precambrian Craton (52) (EPRI, 1986).

2.5.1.1.4.5 Regional Stability

The Site Region is tectonically and seismically stable (King, 1959). The closest epicenter mapped by the USGS is 38 miles (62 km) from the Callaway Plant Site. No potential zones of instability, either natural or caused by man's activities, have been found that would adversely affect construction and operation of the plant at the Site.

2.5.1.1.4.5.1 Natural Features

Regional solution activity by ground water is discussed in Section 2.5.1.1.5.1. Solution and weathering features at the Site are discussed in Section 2.5.1.2.6.2. There are no natural geologic features at or near the Site that adversely affect construction and operation of the plant at the Site.

2.5.1.1.4.5.2 Man's Activities

Man's activities in the Site Region include surface and subsurface mining of both metallic and nonmetallic minerals, production of fuels such as coal, oil, and gas, and withdrawal of water from subsurface aquifers. None of these activities has taken place near the Site Area with the exception of minor quarrying of limestone and clay, and small-scale groundwater withdrawals. Each of these activities is located a sufficient distance from the Site or operated on such a small scale as to cause no concern with regard to regional stability. The effects of man’s activities at the Site are discussed in Section 2.5.1.2.6.5.

Regional Mineral Production

In 2005, the latest year for which the U.S. Geological Survey (USGS) has published data for the state (USGS, 2008), Missouri's nonfuel raw mineral production was valued at $1.94 billion. The State rose to 8th from 10th in rank among the 50 States in total nonfuel mineral production value, of which Missouri accounted for 3.5% of the U.S. total.

A map of the Mineral Resources in Missouri is shown on Figure 2.5.1-42.

A map of the Mineral Industries in Missouri is shown on Figure 2.5.1-43.

Crushed stone, cement (Portland and masonry), lead, and lime in descending order of value, accounted for nearly 90% of Missouri's total nonfuel mineral production value in 2005.

The Industrial Minerals and Metals Produced in Missouri Include:

- Cement- In Missouri, cement was produced at five separate cement plants in 2005. From north to south along the Mississippi River; Continental Cement Co. LLC operated the Hannibal plant in Ralls County; Holcim (US) Inc. operated the Clarksville plant in

Pike County; and Buzzi Unicem USA operated a plant in Selma in Jefferson County and a plant at Cape Girardeau in Cape Girardeau County. In western Missouri, Lafarge North America operated the Sugar Creek plant in Jackson County.

- Clays- The three types of clay produced were common clay, fire clay, and fuller's earth. The majority of the common clay mined was used in the production of Portland cement.
- Construction Sand and Gravel- The Land Reclamation Program permitted 390 sand and gravel operations in 61 Missouri counties during 2005.
- Crushed Stone- The Land Reclamation Program in 379 crushed limestone or dolomite quarries in 96 Missouri counties under permit during 2005. Four granite or traprock quarries were permitted in Iron and Wayne Counties.
- Dimension Stone- Missouri Red Quarries, Inc. produced dimension granite from the Graniteville Quarry in Iron County.
- Gemstones- Quartz geodes from the Mississippian-age Warsaw Formation in extreme northeastern Missouri constituted the only substantial gemstone production in Missouri during 2005.
- Lime- Quicklime and hydrated lime were manufactured in Greene and Ste. Genevieve Counties by Mississippi Lime Co., and quicklime was produced by Chemical Lime Co., in St. Francois County, produced dolomitic lime for the steel industry.
- Copper, Lead, Silver, and Zinc.- All production of metals in Missouri came from Doe Run Co.'s underground mines in the Viburnum Trend on the west side of the St. Francois Mountains in the southeastern portion of the State. Ore minerals were galena, sphalerite, chalcopyrite, and bornite, in order of decreasing abundance, with small amounts of silver associated with the galena. The company's Viburnum, Buick, Bushy Creek, Fletcher, and Sweetwater Mines were operating in 2005.

Mineral and metal production in the Site Region poses no hazard to the construction and operation of Callaway Plant Unit 2.

2.5.1.1.4.5.3 Regional Warping

As discussed in regional geologic history (Section 2.5.1.1.2), and reflected by unconformities in the geologic column of Missouri, as well as folds, arches, domes and troughs, the Site Region has experienced uplift and warping several times during the Paleozoic Era. The effects on the Site Area are reflected by erosional unconformities and gentle folding and tilting of the rock strata with a reported regional dip of 5 to 10 ft per mile (1 to 2 m per km) to the northwest, away from the Ozark Uplift (Unklesbay, 1955).

Regional warping or rebound due to unloading of glacial ice may be occurring in northern portions of the Site Region where glacial deposits are extensive and still display evidence of over-consolidation. At the Site, however, rebound is not considered significant because the presence of thin glacial deposits in the Site Area suggests that the advancing ice sheet was relatively thin and/or of short duration. The glacial till is believed to have been deposited during Kansan time, approximately 0.7 Ma (see Section 2.5.1.2.2.8).

2.5.1.1.5 Regional Ground Water

Abundant ground water is contained in the alluvial deposits within the Missouri and Mississippi River valleys and in the Mississippi Alluvial Plain Physiographic Section. An extensive area occupied by the Ozark Plateaus Section is underlain by more than 2,000 ft (610 m) of Paleozoic carbonates and sandstones that dip away from the Precambrian core of the Ozark Uplift. In this area, recharge to aquifers is by infiltration of precipitation. Natural discharge is commonly by springs that are abundant throughout the Ozarks. The Osage Plains Section generally contains relatively small quantities of highly mineralized ground water. Within the Till Plains and Dissected Till Plains sections, limited ground water is locally available from sand and gravel outwash deposits associated with Pleistocene glaciation. The most important water-bearing areas, however, occupy buried valleys that are filled with clean granular outwash deposits.

Regionally, water quality becomes poorer in areas away from the Ozark Plateaus Section due to an increase in total dissolved solids from less than 200 parts per million to over 40,000 parts per million in some areas of the Site Region (U.S. Geological Survey and Missouri Division of Geological Service and Water Resources, 1967).

A detailed treatment of ground water and surface water hydrology is presented in Section 2.4.

2.5.1.1.5.1 Regional Solution Activity by Ground Water

Large scale solution activity has taken place in the thick carbonate sequence south of the Missouri River as evidenced by the numerous large springs and caves found in that region (see Figure 2.5.1-27 and Figure 2.5.1-28). There is, however, a notable decrease in the number of caves and the size of springs in areas north of the Missouri River and in a large area of west central Missouri. There have been no caves or springs noted in the Site Area. This marked reduction in the number of caves and large springs reflects a regional change in solution activity which can be directly correlated with changes in both surface and subsurface soil and rock stratigraphy.

Where springs are large and numerous, (see Figure 2.5.1-27) the underlying rock units consist primarily of cherty limestone and dolomite which range from Mississippian to Cambrian in age. Some sandstone units are present but shale rarely occurs. The surficial soil deposits contain characteristically high percentages of residual chert. Precipitation is readily channeled through the permeable, cherty soils and into the underlying thick carbonate rock sequence in which karst features, springs, and caves are developed by solution activity.

In those areas shown on Figure 2.5.1-27 and Figure 2.5.1-28 where springs are small or absent and caves are few, the underlying stratigraphic section contains formations that consist largely or entirely of shale. These shale units retard or block the vertical movement of groundwater and effectively reduce solution activity. Pennsylvanian-age deposits in Missouri are largely composed of these materials that inhibit ground water flow. The areas in northern and western Missouri in which Pennsylvanian rocks occur are illustrated on Figure 2.5L-4. In these areas, springs are small and many are highly mineralized (U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967).

The Mississippian-age rocks of northeastern Missouri also contain shaly units such as the Hannibal and Warsaw formations which retard groundwater movement. By contrast, the Mississippian-age rocks of southwestern Missouri contain relatively little shale (Missouri Geological Survey and Water Resources, 1961) and a corresponding increase is noted in the number of springs and caves (Figure 2.5.1-27 and Figure 2.5.1-28). The middle Devonian Snyder Creek Shale which occurs in the Site Area retards the downward percolation of ground water as discussed in Section 2.4.12.1.2.1.

Soil type and thickness are significant factors which contribute to reduced solution activity in northern Missouri. The occurrence of relatively impermeable glacial and lacustrine soils which were deposited during Pleistocene time beginning approximately 1 million years ago, generally thicken northward from the southern limit of glaciation (Figure 2.5L-7). These clayey soil deposits blanket vast areas and severely retard the downward movement of precipitation into the underlying rock units, thereby significantly reducing solution activity.

2.5.1.1.5.1.1 Springs

More than 1,100 springs have been recorded in Missouri (Figure 2.5.1-27) among these are some of the largest in the United States. Eleven of the largest have an average daily discharge of more than 50 million gallons, and are located on the Salem and Springfield Plateaus of the Ozark Region (Unklesbay, 1992). Springs are also present in the Pennsylvanian rocks of the Osage Plateau. The closest springs to the Callaway Plant Unit 2 Site are 4.5 to 4.7 miles (7.2 to 7.6 km) towards the southeast (MODNR, 2007a), close to Logan Creek (Figure 2.5.1-27. These springs remain unnamed and no flow data are available.

Surface and subsurface conditions are favorable to the development of the large Ozark spring system. The surface conditions include the Cambrian and Ordovician limestones and dolomites of this region that are readily soluble and extensively fractured, expediting the subsurface movement of water, and the formation of closed depressed areas (sinks) that are conducive to collecting and channeling precipitation into the subsurface. Geologic structures have a strong influence on the locations of springs. Many springs can be found where significant fractures intercept the ground surface, as in a hillside. Most of the Ozark area springs are outlets of subterranean streams that have been intersected by erosional valleys. As a result, most of the large springs are found at or near the local valley floor level of the principal streams.

Although caves and springs are discussed separately, in many locations a cave and a spring are different terms for the same feature (Unklesbay, 1992). In some cases, the spring is the surface exposure of an underground stream; in others, it is the site where the spring becomes the "head" of the surface stream.

2.5.1.1.5.1.2 Caves

Bretz (1956, in Unklesbay, 1992) defines a cave as "a natural roofed cavity in a rock which may be penetrated for an appreciable distance by a human." Caves are found in many regions of the state, with the exception of the areas north of the Missouri River where Pennsylvanian rocks are covered by glacial drift. As of 1991, 5,100 caves were on record at the Division of Geology and Land Survey; by 2005 there were 6,037 caves recorded (MSS, 2005b). Over 2,900 cave maps are currently on file with the MODNR, Geologic Survey/Resource Assessment Division. Figure 2.5.1-28 shows relative density of these caves for the entire state of Missouri with an enlarged area for the Site Vicinity.

Caves occur in a wide variety of patterns, and these are largely controlled by the rock structure (Unklesbay, 1992). Jointing in many rock formations creates intersecting passageways that develop into mazelike arrangements of corridors and cross channels. In less jointed beds, the patterns may resemble meandering streams with branching tributaries. Many caves are deep below the general land surface, some as far as 200 to 300 ft (61 to 91 m). In fact, the deepest known cave in Missouri is 383 ft (117 m) deep. Others are at shallower depths. Shallower caves have thinner "roofs" and are more susceptible to collapse at the surface.

Thirteen caves have been discovered in Callaway County and six have been mapped; all of them located in the southern and western side of the county. These caves were measured using available maps (MSS, 2005a) and maximum potential affected areas are no larger than 500 ft x 300 ft (152 m x 91 m), with the minimum mapped cave being only 20 ft x 20 ft (6.1 m x 6.1 m).

The small size of the areas affected by cave development; their locations that are removed from the Callaway Plant Unit 2 Site; and the lack of any cavernous findings during the subsurface investigation indicate that no cave development is present at the Callaway Plant Unit 2 Site.

2.5.1.1.5.1.3 Sink Holes

Although caves and springs in karst areas may form scenic and otherwise desirable features, the sinkholes that sometimes accompany them are often troublesome and may cause serious problems (Unklesbay, 1992). A sinkhole forms when the roof of an underground cavity becomes too thin and weak to support the overlying material and collapses. Frequently this happens without warning, and there may be costly damage to overlying buildings or other structures. Sometimes utility pipelines or cables may be exposed or broken. Sink holes for the entire State of Missouri, as well as springs, are shown in Figure 2.5.1-27. The closest recorded sink hole is located 15.5 miles (24.9 km) NE of the Site, 3 miles (5 km) SSW of New Florence in Montgomery County; the closest, within Callaway County is located 20 miles (32 km) to the WSW, just south of Holts Summit (MODNR, 2007a). There are no references to sink holes in the Callaway Plant Unit 1 FSAR, and the current field reconnaissance for the Site Area did not find any visible depression that might precede or be indicative of an incipient sink hole.

2.5.1.2 Site Geology

Significant surface and subsurface investigations were conducted for the Callaway Plant Unit 2 geologic investigation. Those investigations included: detailed field surveys of local streams, and geologic outcrops; drilling for subsurface and geothechnical characterizations; surface and borehole geophysics; trenching to undersand the local persistence of geologic units; and an extensive search of the literature to ascertain the state of understanding of the local geology. The investigations comply with the Regulatory Guide 1.208 and provide a detailed understanding of the subsurface conditions within the Site, the Site Area and the Site Vicinity. Additional information was obtained from the Callaway Plant Unit 1 FSAR (AmerenUE, 2004), and from the results of the deeper borings advanced during the Missouri Department of Natural Resources Cambrian correlation effort to describe the Cambrian sequence that lies beneath the Ordovician layers near the Site (MODNR, 2007a).

The requirements of Regulatory Guide 1.132, Site Investigations for Foundations of Nuclear Power Plants, Regulatory Guide 1.138, Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants, and Regulatory Guide 1.198, Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites, have been specifically addressed in Section 2.5.4, Stability of Subsurface Materials and Foundations.

Figure 2.5L-8 (Site Vicinity Geologic Map) and Figure 2.5.1-29 (Site Area Geologic Map) show details of the bedrock geology surrounding Callaway Plant Unit 2 Site. Figure 2.5L-9 demonstrates the subsurface relationships across the Site Area. A Site Geologic map is unnecessary because, as can be observed in Figure 2.5.1-29, the top of the bedrock at the Site is composed entirely of Pennsylvanian-aged Graydon Chert Conglomerate within the Cabaniss Subgroup.

Sections 2.5.1.2.1 through 2.5.1.2.6 are added as a supplement to the U.S. EPR FSAR.

2.5.1.2.1 Site Vicinity and Site Area Physiography and Geomorphology

The Callaway Plant Unit 2 Site lies immediately north of the southern boundary of the Dissected Till Plains Physiographic Section. The Ozark Plateaus Physiographic Province begins approximately 2 miles (3.2 km) to the south of the Site, where the glacial deposits have been eroded (Figure 2.5.1-3 and Figure 2.5.1-4).

During Early Pleistocene time, the Site Area was largely a glacial till plain. Subsequent erosion and downcutting by the Missouri River and its tributary streams has dissected the plain, leaving a nearly isolated plateau with an area of between 6 and 8 square miles (15 and 20 square km). Topographic relief on the plateau is nearly 60 ft (18 m), and the elevation varies from 800 ft (244 m) msl near the perimeter to a maximum of 858 ft (262 m) msl. Ground surface elevations range from 858 ft (262 m) at the crest of the plateau to approximately 508 ft (155 m) at the Missouri River, with an average elevation of approximately 846 ft (258 m) for the Callaway Plant Unit 2 Site. The highest elevations are found along a very broad, low ridge in the southern and western portions of the area, where the terrain is generally higher than elevation 840 ft (256 m) msl. The plateau is higher than any surrounding land feature within a radius of 6 miles (10 km). The Missouri River is about 5 miles (8 km) south of the plant. Its floodplain is about 2.5 miles (4 km) wide and has an average surface elevation of about 525 ft (160 m) msl. The normal flow level of the Missouri River is about 509 ft (155 m) above mean sea level (AmerenUE, 2004).

The area between the plateau and the Missouri River flood plain is highly dissected. Mud Creek and its intermittent stream branches have incised deeply into the southern flank of the plateau with stream gradients that drop more than 200 ft (61 m) within a distance of less than 0.5 mile (0.8 km). Topographic relief is more than 150 to 200 ft (46 to 61 m) between valleys and ridges, and the overall drop in elevation between the crest of the plateau and the river is about 350 ft (107 m). Surface drainage to the east and northeast of the Site Area is intercepted by intermittent tributaries to Logan Creek. Those intermittent streams have cut deeply into the eastern flank of the plateau, resulting in more than 200 ft (61 m) of rugged local relief. Logan Creek is deeply incised, and has developed a 1,000 ft (300 m) wide floodplain prior to its draining into the Missouri River.

Auxvasse Creek, a major tributary of the Missouri River, is located about 2 miles (3.2 km) west of the Site and intercepts all the surface drainage from the western and northern flanks of the plateau. The creek is more than 30 miles (48 km) long and has developed a number of fairly large tributary branches. Adjacent to the Site, the stream flows within entrenched meanders on a 0.25 to 0.5 mile (0.40 to 0.80 km) wide floodplain at an approximate elevation of 530 ft (162 m) msl. Numerous intermittent streams about 1.5 miles (2.4 km) long have cut deeply into the western and northwestern flanks of the plateau, resulting in more than 250 ft (76 m) of rugged local relief.

2.5.1.2.2 Site Vicinity and Site Area Geologic History

The geologic history of the Site is interpreted through study of the stratigraphy and structure of the subsurface units exposed during the Site investigation. In addition to the exposed subsurface units, regional geologic events, such as periods of uplift and erosion, are important in the interpretation of the Site history. A regional history of geologic events and the geologic time scale has been discussed previously in Section 2.5.1.1.2.

The Site geologic history has been quiet since the end of the Pennsylvanian Period. At that time the central portion of North America became more stable and tectonic movements became rare. The only disturbance of this quiet state was the advance of several ice sheets in the Pleistocene. Since the Site is located at the extreme southern limit of the glaciated area, the ice sheets were at their thinnest and any crustal depression or subsequent rebound from the ice load has been minimal. A brief synopsis of the geologic history for precambrian to present day is provided in the following sections.

Table 2.5.1-9 shows resulting formations thickness calculations for the Site Vicinity.

2.5.1.2.2.1 Precambrian

Precambrian rocks have not been drilled in Callaway County but they have been encountered in borings in several surrounding counties: Boone (boring 18139), Gasconade (boring 26254) and Audrain (boring 25355) (MODNR, 2007a). The nearest boring that reached Precambrian rocks (Robertson, 1974) is the Continental Ozark No. CO-10 located in the NE quarter of the NE quarter of Section 3, Township 44 North, Range 8 West, approximately 10 miles (16 km) south of the Site. This boring was drilled in 1969 to a total depth of 1,955 ft (596 m). Precambrian basement was reached at a depth of 1,844 ft (562 m) (1,214 ft (370 m) below msl). At that location the Precambrian rocks consist of slightly to highly altered serpentine, which becomes porphyritic with depth and is underlain by rhyolite porphyry and tuff. Table 2.5.1-9 shows resulting formation thickness calculations for the Site Vicinity.

Data are insufficient to determine precisely what occurred within the Site Vicinity during Precambrian time; however, it is assumed that many of the same geologic events revealed by Precambrian exposures in central and northern Wisconsin also took place here. Historical events in the Precambrian at the Site probably included volcanism and periods of granitic intrusions (rhyolite porphyry and tuff). At some point metamorphic processes transformed some of the rocks to their current high grade state (serpentine). A long period of erosion followed the end of volcanic activity allowing a deeply incised dendritic drainage pattern to form.

2.5.1.2.2.2 Cambrian period

Site borings have penetrated rocks of Cambrian age only in the case of MODNR drilling to complete their Cambrian correlation effort. Descriptions of drill cutting allowed MODNR to determine formation tops for the various formations units encountered; these interpretations, available in MODNR, 2007a, provided the needed information to complete their investigation.

In addition to the data developed from these borings, the sequence of geologic events during Cambrian time at the Site must be inferred from observations in adjacent areas. It is likely that the period of erosion that closed the Precambrian time continued through Early and Middle Cambrian times. Late Cambrian sedimentation in transgressing seas began with the deposition of the Lamotte Sandstone on the eroded Precambrian basement surface. This appears to have been followed by the deposition of a thick carbonate sequence that began with the Bonneterre Formation, followed by the Davis, Derby-Doe Run, Potosi, and Eminence formations. These units consist principally of cherty dolomite, indicative of a long continued marine environment. The Site Area probably remained submerged at the end of Cambrian time.

2.5.1.2.2.3 Ordovician Period

The carbonate deposition that characterized Cambrian time was interrupted briefly during the initial Ordovician deposition, as indicated by the Gunter Sandstone Member. Deposition of a thick carbonate sequence continued during Early Ordovician time. The Gasconade and Cotter-Jefferson City formations were deposited in a marine environment, which was temporarily altered during Roubidoux time as near-shore sands were deposited.

Between Early and Middle Ordovician time, regional uplift at the Site initiated erosion and solution activity that removed all post-Cotter-Jefferson City deposits and produced an irregular karst topography having scattered, rubble-lined sinkholes. During Middle Ordovician time, the sea advanced over the erosional topography of the Site Area. Deposition of the St. Peter Sandstone in sinkholes was followed by deposition of the dolomite of the Joachim Formation over wider areas. Significant quantities of carbonates were probably deposited in post-Joachim time, but uplift and erosion at the end of the Ordovician period removed unknown quantities of Upper or Middle Ordovician sediments from the Site Area.

2.5.1.2.2.4 Silurian Period

Rocks of Silurian age are not present at the Callaway Plant Site. They are present in other areas of Missouri, as shown on the Regional Geologic Map (Figure 2.5L-4). It is possible that Silurian deposits occupied the Callaway Plant Site Area at one time, but were removed by a subsequent period of erosion.

2.5.1.2.2.5 Devonian Period

The regional geologic events discussed in Section 2.5.1.1.2.2.4 indicate that the Site Area was subjected to uplift and erosion at the end of Early Devonian time. At the Site, Middle Devonian rocks rest unconformably on beds of Middle to Lower Ordovician age. It appears likely that the periods of erosion, which occurred at the close of Ordovician time and again at the end of Early Devonian time, removed all of the Silurian and Lower Devonian rocks as well as significant quantities of Ordovician rocks.

Middle Devonian seas advanced over an erosional surface. The Callaway Limestone was deposited over the Cotter-Jefferson City Formation and the patchy deposits of Joachim and St. Peter formations. After a brief period of erosion that ended Callaway deposition, marine conditions changed and silty sediments were laid down to form the calcareous shale, siltstone, and impure limestone of the Upper Devonian Snyder Creek Formation. The Devonian Period at the Site ended with uplift and emergence.

2.5.1.2.2.6 Mississippian Period

Initial sedimentation during Mississippian time consisted of the deposition of thin Bushberg sands as the sea transgressed over the Site Area. The sand deposition was followed by deposition of a thick sequence of cherty Burlington Limestone.

Uplift at the close of Mississippian time resulted in widespread stream erosion and possible development of karst topography in some areas. Significant quantities of post-Burlington and Burlington rocks were probably removed from the Site Area. Extensive deposits of cherty clay residuum may have formed at this time.

2.5.1.2.2.7 Pennsylvanian through Tertiary Periods

Sedimentary processes initiated during Pennsylvanian time probably resulted in reworking of most or all of the chert and clay residuum that accumulated earlier during a period of uplift at the end of Mississippian time. Sandstone and sandy chert conglomerate appear to have been deposited locally in buried valleys which were cut into the Mississippian rock surface. The chert and clay deposits, along with the local sandstone and sandy chert conglomerate, collectively form the Graydon Chert Conglomerate, which is tentatively assigned the age of Early Pennsylvanian on the basis of similarity with deposits that are overlain by Cheltenham Clay. The Graydon is underlain by the Burlington Limestone in the northern portion of the area. In some areas this unit is as young as Desmoinesian where it is directly overlain by, and in some cases interfingering with, sandstone of the Cherokee Group (Gentile, 2004).

Pennsylvanian deposits are thin in the Site Area. Little is known of the geologic events that occurred at the Site during the approximately 300 million years which separate the Lower Pennsylvanian from the overlying Pleistocene deposits at the Site. Regional events during this period are discussed in Sections 2.5.1.1.2.2.6, 2.5.1.1.3.2.6, as well as in Section 2.5.1.1.4. From these regional descriptions, it can be inferred that the Site Area was inundated multiple times by a shallow sea having contiguous swamps and deltas that produced widespread, thin, repeating beds of coal, shale, siltstone and limestone. Uplift and erosion at the end of the Pennsylvanian Period removed all but the Graydon Chert Conglomerate. This uplift persisted through the Permian, Triassic, Jurassic, Cretaceous and Tertiary Periods, when no deposition occurred at the Site.

2.5.1.2.2.8 Quaternary Period

Glaciation occurred at the Site during the Kansan stage of Pleistocene time, some 700,000 years ago, as discussed in Section 2.5.1.1.2.4.2. The deposits are thin at the Site and absent to the south.

Surficial deposits of post-Kansan Accretion-gley, also of Pleistocene age, indicate that lacustrine, poorly drained, or undrained environments existed at the Site for a considerable time following deposition of the glacial till, perhaps in response to damming of glacial melt water as the Kansan ice sheet retreated northward.

Windblown soil (loess) of Illinoian and/or Wisconsinan age occupies the topographically high portions of the Site Area. These soils were transported from major drainages, such as the Missouri River, following the retreat of the last of the Pleistocene ice sheets.

These glacial deposits were laid down in a manner that left an undulating surface with little relief. Since that time, the erosional effects of local surface water runoff have cut deeply into the sides of the plateau surrounding the Site, and has created a deeply incised drainage pattern with radiating steep-sided valleys.

2.5.1.2.3 Site Vicinity and Site Area Stratigraphy

The sequence and character of the soil, older sediments, and lithified formations underlying the Site Area and Vicinity are shown on the composite stratigraphic column (Figure 2.5L-13). This column is based on data obtained results of the subsurface investigation for Callaway Plant Unit 2, from the FSAR for Callaway Plant Unit 1 (AmerenUE, 2004), and on published literature. Site Area geologic cross section are shown on Figure 2.5L-9.Subsurface geologic cross sections that show relationships among the various stratigraphic units underlying the Site are illustrated on Figure 2.5L-10 (5 sheets). Logs of 71 borings drilled at the Site during the recent geologic investigations for Callaway Plant Unit 2 are discussed in Section 2.5.4. Borings were drilled during the Site investigation between December 2006 and April of 2007. The Callaway Plant Unit 2 boring layout is also shown in Figure 2.5L-10.

2.5.1.2.3.1 Glacial and Postglacial Soil Deposits

Deposits of Quaternary age within the Site Area consist of soils that are associated either directly or indirectly with Pleistocene glaciation. Locally, these deposits are the loess, accretion gley, and till. Geologic discussions of glacial and postglacial soil deposits are presented below. Callaway Site Area Soils Map is shown in Figure 2.5.1-30, the legend is shown in Figure 2.5.1-31, the Site Soils Map is shown in Figure 2.5.1-32. Engineering properties of these soils are discussed in Section 2.5.4.2.

2.5.1.2.3.1.1 Modified Loess

Most of the plateau area is blanketed by a fairly continuous layer of mottled reddish brown and gray silty clay that varies in thickness from 3 to 15.5 ft (0.9 to 4.7 m) (AmerenUE, 2004), and from 4.5 to 22 ft (1.4 to 6.7 m) at the Callaway Plant Unit 2 Site. This soil was deposited over the Site during the Wisconsinan and/or Illinoian glacial stages as windblown silt, known as loess. The loess was deposited on an irregular topographic surface. Subsequent erosion, resulting in the present surface features, has stripped the loess from some areas. Weathering has altered the original physical properties of the loess at most locations to form silty clay. Engineering properties of the loess are presented in Section 2.5.4.2.

2.5.1.2.3.1.2 Accretion-gley

The modified loess is underlain by a deposit of moderately plastic, gray, silty clay. The concept of accretion-gley is discussed by different authors including Piskin (1975) and Kay (2002). There is an agreement in what appears to be the most reasonable theory for the origin of the clay, on the basis of Site observations. The accretion-gley is postulated to be the product of slow accumulation of predominantly fine-textured material in poorly drained or undrained areas on the surface of the till plain left after retreat of the glacier. In the Site Area, glacial till deposited during the Kansan stage of glaciation formed the surface on which the accretion-gley rests. Furthermore, the accretion-gley at the Site is fine textured, massively bedded, and is not a product of intense in-situ weathering. The upper and lower boundaries of the accretion-gley are former erosional surfaces on which some topographic relief was developed; consequently, the thickness of the deposit, as determined by the Site borings, ranges from 0 to about 25 ft (0 to 8 m). Lens-shaped deposits of silt and sand encountered in test borings were locally observed and mapped at the top of the accretion-gley during geologic mapping of excavations for Callaway Plant Unit 1. These lenses are approximately 3 ft to 5 ft (0.9 m to 1.5 m) in thickness with apparent widths of 38 ft to 120 ft (12 to 37 m) in the reactor excavations (Dames and Moore, 1980).

These deposits were probably formed by streams prior to deposition of the overlying loess. The accretion-gley is slightly pre-consolidated by desiccation. Engineering properties of the accretion-gley are presented in Section 2.5.4.2.

2.5.1.2.3.1.3 Glacial Till

The Glacial Till layer consists of over-consolidated brown or mottled brown and gray silty clay containing some mixed sand and gravel with occasional lenses of silty or clayey sand. It underlies the accretion-gley deposit in topographically high portions of the Site Area. The till has been identified as Kansan in age on the basis of paleomagnetic investigations (Kukla, 1973, in AmerenUE, 2004). The till was observed to vary in thickness from 2.5 to 21 ft (0.8 to 6.4 m) in the test borings for Callaway Plant Unit 2 Site. Sand lenses in the basal portion of the till were observed and mapped during geologic mapping of the reactor excavation for Callaway Plant Unit 1 (Dames and Moore, 1980). These lenses vary in apparent width from 5 ft to 35 ft (1.5 to 10.7 m) and have a maximum thickness of 6 ft (1.8 m). The deposits are stratified and are probably outwash stream deposits that formed in advance of Kansan glaciation of the Site. It is slightly pre-consolidated and hard. Engineering properties of the glacial till are presented in Section 2.5.4.2.

2.5.1.2.3.2 Older Sediments (Pennsylvanian)

For this report, the name Graydon Chert Conglomerate, as well as Graydon Conglomerate (Gentile, 2004), applies to deposits of cherty clay, sandstone, and sandy chert conglomerate that occur in the Site Area between the underlying Burlington Limestone and the overlying glacial deposits. Based on current experience at Unit 1, the Unit 2 structures will be founded on this material. The geotechnical properties of the Graydon Chert are discussed in Section 2.5.4.

Review of the literature indicates there has been considerable lack of agreement on the lithology of the Graydon Chert Conglomerate. Some identify the basal Pennsylvanian shales as Graydon, while others regard only the basal sandstones, or only the basal chert conglomerate (composed of Mississippian chert cemented within a sandstone matrix) as the Graydon Chert Conglomerate. The sandstone associated with conglomerate, once called “Graydon”, may in most areas be regarded as the Warner Sandstone. Similarly, the shales associated with this conglomerate may in some regions be regarded as the Riverton shale, but in others maybe the Rowe or Drywood formations. Therefore, Graydon Conglomerate is a conglomeratic unit that is not everywhere representative of the same age or the same depositional environment. Its one prominent characteristic is that it is the basal unit of the Pennsylvanian Subsystem, wherever found. It may be associated with a sandstone, a shale, both, or neither, but remains a distinctive unit that retains the name “Graydon.”

Stratigraphically, the Graydon Conglomerate may not be the oldest Pennsylvanian unit in Missouri. It may not even be Atokan in age in some areas, and probably is as young as Desmoinesian where directly overlain by, and some cases interfingering with, sandstone of the Cherokee Group. However, where present, it usually rests on the eroded upper surface of older strata, Mississippian and/or Ordovician, and constitutes the “basal Pennsylvanian conglomerate” of early reports.

The Graydon Conglomerate, found at the Callaway Plant Unit 2 Site, consists of hard clay containing irregular, angular chert fragments, sandy chert conglomerate, and local deposits of indurated, iron-stained quartz sandstone. The chert fragments vary from pebble-size to boulders nearly 2 ft (0.6 m) in diameter. Locally, coarse chert conglomerate is interbedded within thin beds of ferruginous sandstone. At other exposures the deposit is composed mostly of sand and small chert fragments. No open spaces or voids are expected between fragments in this conglomerate. The Graydon Chert Conglomerate, with the exception of local deposits of indurated sandstone and sandy chert conglomerate, is not indurated as are the underlying rock strata belonging to the Burlington and older formations; however, the cherty clay deposits that largely form the Graydon Conglomerate in the Site Area are at least 300 Ma. They are hard and competent. It is present in the topographically high areas surrounding the Site and was encountered in all plant Site borings.

Data obtained during the Callaway Plant Unit 1 Site investigation suggest that the Graydon Conglomerate is composed of material that has in part been transported before deposition, while other portions reveal a residual (weathered-in-place) nature (AmerenUE, 2004). Bedding can be observed only in the localized, well-indurated sandstone and sandy chert conglomerate portions of the Graydon Conglomerate. No joints or bedding planes have been observed in the non-indurated clayey and cherty Graydon Conglomerate that underlies the Site. At the Site, it is extremely difficult to visually distinguish chert and clay of residual origin from transported chert and clay. A distinction can be made on the basis of clay mineralogy. A high percentage of kaolinite is characteristic of residuum produced by weathering, while high percentages of elite suggest transportation and deposition. Test results from the investigation at Callaway Plant Unit 1 revealed that some samples contain a high percentage of elite, and others are high in kaolinite. This indicates that both residual and transported clays are present in the Graydon Conglomerate in the Site Area (AmerenUE, 2004).

It appears likely that during the period of uplift, which occurred at the close of Mississippian time, significant quantities of chert and residual clays were produced by weathering of the exposed Mississippian rock surface in the Site Area (AmerenUE, 2004). Depositional processes initiated in Pennsylvanian time probably reworked most or all of the Mississippian chert and residual soil. It is possible that some portions of extensive residual deposits remained undisturbed and were subsequently buried by Pennsylvanian and younger deposits. Basal Pennsylvanian strata consist primarily of rounded chert gravels, cobbles, and boulders within a matrix of multi-colored clay, which is high in elite content. Locally, streams deposited sand and chert that are now well indurated sandy chert conglomerates. It is also possible that some residual soils have been produced by reworking and weathering of the Pennsylvanian cherty clays during Cretaceous or even Tertiary time. The Graydon Chert Conglomerate at the Plant Site is probably Pennsylvanian in age; however, this cannot be stated with certainty due to the absence of overlying Pennsylvanian strata. The Graydon Chert Conglomerate was observed to vary in thickness from 11.5 to 54.8 ft (3.5 to 16.7 m) and was generally first encountered between elevations of 812.4 and 802.5 ft (247.6 and 244.6 m) msl throughout the Site Area. Maps documenting the distribution of the Graydon Chert Conglomerate are shown in Figure 2.5.1-33, Figure 2.5.1-34, Figure 2.5.1-35 and Figure 2.5.1-36.

Core recovery in the Graydon Chert Conglomerate experienced during the Callaway Plant Unit 2 Site investigation varied between 0 and 100 percent in individual borings. An overall average core recovery from a total of 71 borings was 80 percent. These values are relatively low in comparison with those of the underlying rock units. Poor core recovery in the Graydon Conglomerate is due to the nature of the material. For the most part, it is a cherty to sandy hard clay containing cobble to boulder size chert fragments. It is extremely difficult to maintain good core recovery. As chert fragments are encountered, the driller must increase bit and water pressure in order to core through them. Once the chert is penetrated, the increased water pressure and rotary action of the drill bit blasts away the clay matrix until pressure adjustments can be made by the driller. In addition, the chert fragments often loosen from the clay matrix and turn under the bit during coring. This action grinds away the clay and reduces core recovery. No significant drilling fluid losses were experienced in the Graydon Chert Conglomerate.

Engineering properties of the Graydon Chert Conglomerate are discussed in Section 2.5.4.2.

Well-indurated sandstone and sandy chert conglomerate were described in Callaway Plant Unit 1 FSAR (AmerenUE, 2004) tentatively identified as Pennsylvanian in age. Well-indurated chert conglomerates have been observed above the Burlington Limestone in widely scattered exposures during reconnaissance geologic mapping of the Site Area. Field evidence suggests that they represent Early Pennsylvanian stream deposits that formed in valleys carved on the Mississippian rock surface. The sandy chert conglomerates appear to be alluvial in origin. Marine fossils preserved in the reworked chert fragments indicate the chert source to be primarily Mississippian-age carbonate rocks. A buried channel deposit containing chert conglomerate and sandstone may occur in the northern portion of the Site Area as its dimensions and course are poorly defined; however, no evidence of similar channel deposits was encountered in other Site borings and no buried alluvial channels are present in the immediate plant Site Area.

2.5.1.2.3.3 Lithified Formations

An average 2,140 ft (652 m) of Paleozoic rock strata underlie the Site Area between the ground surface and the Precambrian basement. The formations range in age from Mississippian to Cambrian. The units penetrated by test borings at the Site are illustrated on the Site Stratigraphic Column, Figure 2.5L-13. The top of bedrock surface for the Site (the base of the Graydon Chert Conglomerate) is shown on Figure 2.5.1-36.

2.5.1.2.3.3.1 Mississippian System

The sedimentary rock strata that occur immediately below the Graydon Chert Conglomerate form the uppermost lithified formations throughout almost all of the Site Area are Mississippian in age, with two formations present on Site: the Burlington and Bushberg formations.

The Burlington Formation of Middle Mississippian age is a medium-to thick-bedded or massive, coarse-grained, cherty, fossiliferous limestone, composed almost entirely of crinoid columnals and plates cemented by calcium carbonate. A few clay layers, less than 1 inch (2.5 cm) thick, which appear to be insoluble material left after solution of parts of the limestone, occur locally. This formation has an upper and lower portion. The upper is white to light gray or tan, and the lower is characteristically light tan to reddish brown. The Burlington is expected to be discontinuous across the Site allowing the very thin Bushberg Formation or thicker Snyder Creek Formation to contact the overlying Graydon Chert Conglomerate.

The Burlington Formation generally forms the top of hard rock in the Site. Based on data from the recent 71 Site borings that were drilled through the horizon of the Burlington Formation, the unit varies in thickness from 0 to 19.7 ft (0 to 6.0 m). It was entirely absent in about 23 percent of the borings as a result of pre-Pennsylvanian weathering and erosion over 300 million years ago. The average thickness of the Burlington in the 71 borings in which it was encountered is 6.5 ft (2 m); an isopach map for the Burlington Formation is shown in Figure 2.5.1-37. Contours on top of rock (Figure 2.5.1-36) reveal a somewhat irregular surface in which there is a NE trending ridge with depocenters to NNW and SSE; this resembles an earlier antiform that governed the depositional space availability, based on the fact that the isopach map for the same formation follows this same pattern. The Burlington Limestone, together with the overlying Graydon Chert Conglomerate, forms a resistant layer that caps and sustains the topographically high portions of the Site Area.

The Burlington Limestone typically is weathered and contains solution features formed by a period of weathering and erosion that occurred prior to deposition of the overlying Graydon Chert Conglomerate, over 300 Ma. The solution features are now filled with hard green to brown, silty to sandy clay with some limestone and chert fragments. Weathered zones were observed to vary in thickness from 0 ft to 27.2 ft (0 to 8.3 m), generally averaging about 7.5 ft (2.3 m) in thickness (AmerenUE, 2004).

Core recovery in the Burlington Formation ranged from 0 percent to 100 percent. The average recovery for all borings in the Burlington Formation was greater than 92 percent. Loss of drilling fluid while coring in the Burlington Formation was rare, and in every case, it was temporary.

The Bushberg Formation is thin persistent basal Mississippian sandstone, which occurs throughout the Site Area. Field data suggest that it is conformable with the overlying Burlington Limestone, and it rests unconformably on beds of Devonian age. The Bushberg varies in thickness from 0 ft to 7 ft (0 to 2.1 m). Average thickness throughout the Site is 2.2 ft (0.7 m). The formation consists typically of a medium-to fine-grained poorly sorted sandstone, most commonly pale green, but in some locations it is white or grades from white to yellowish brown. Weathered exposures are commonly dark brown to dark gray. Most of the sand is stained with ferruginous material apparently derived from weathering of included pyrite. The sandstone is composed mostly of well-rounded quartz grains. Locally the grains have been secondarily enlarged and exhibit well developed crystal faces. Core recovery in the Bushberg Formation ranged from 0 percent to 100 percent. The average recovery for all borings in the Bushberg Formation was greater than 95 percent. Loss of drilling fluid while coring in the Bushberg Formation was rare, and in every case, it was temporary.

The isopach map for the Bushberg Formation (Figure 2.5.1-38) reveals that it is thin throughout the Site, except in the N-NNE quadrant where thicker sections are described. Contours on top of this unit are shown in Figure 2.5.1-39.

2.5.1.2.3.3.2 Devonian System

The Snyder Creek Formation underlies the Bushberg Sandstone throughout the Site Area. The upper part is characteristically a light gray to light cream highly calcareous block shale. The uppermost part of the formation in some exposures is a dense dark reddish limestone resembling the lower part of the Burlington Formation. It is generally silty and locally contains numerous brachiopod fossils in thin nodular beds of light gray limestone which vary from fossiliferous to barren. The basal Snyder Creek becomes shaley and typically contains some zones that have weathered to clay; it is a yellowish brown calcareous shale with poorly defined bedding which locally contains thin lenses of light gray argillaceous limestone. A few thin sandstone beds occur throughout the shale. Pyrite is scattered sporadically throughout the Snyder Creek but is largely altered to limonite. The formation thickness varies from 22.4 to 32.2 ft (6.8 to 9.8 m), averaging 29.3 ft (8.9 m), as observed in 71 test borings at the Site. Contours on top of the Snyder Creek are shown on Figure 2.5.1-40.

Core recovery in the Snyder Creek Formation ranged from 10 percent to 100 percent. The average recovery for all borings in the Snyder Creek Formation was greater than 97 percent. Loss of drilling fluid while coring in the Snyder Creek Formation was rare, and in every case, it was temporary.

The Callaway Formation of Middle Devonian age unconformably underlies the Snyder Creek and rests with pronounced unconformity on the Ordovician Cotter-Jefferson City formations in the Site Area. It is noted in Callaway Plant Unit 1 FSAR (AmerenUE, 2004) that deposits of Ordovician-age Joachim and St. Peter formations, were found below the Snyder Creek Formation; this was not the case for Callaway Plant Unit 2, where these two formations were not encountered. The absence of these two formations beneath the Unit 2 location indicates that paleokarst features are not present on the top of the Ordovician age Cotter-Jefferson City Formation there.

Limestone is the dominant lithology; sandstone or sandy limestone is not uncommon in the lower beds. The limestone is commonly densely to finely crystalline, light to medium brownish gray, and weathers to light bluish gray. In many areas these beds are very fossiliferous, but in some areas they are barren. Another common lithology is a medium to finely granular (sugary) light yellowish brown limestone which forms well-defined beds and generally contains many corals and stromatoporoids. Chert is not common but is abundant in a few exposures as dark chert nodules or chalcedonic chert as large as 5 to 6 inches (12.7 to 15.2 cm) in length, 10 ft (3 m) below the top of the formation. Pyrite is common and is found disseminated throughout the non fossiliferous portion of the formation. Shaly material is not common; where present it forms lenticular separations along bedding planes. In many places the basal part of the Callaway Formation is a white to light brown friable calcareous sandstone from a few inches thick to as much as 5 ft (1.5 m) thick. Where the sandstone is absent the basal limestone is sandy.

The Callaway Formation thickness observed in test borings ranged from 31.3 to 41.2 ft (9.5 to 12.6 m). Average thickness is about 37.7 ft (11.5 m). Detailed data indicate that a brief period of erosion occurred in the Site Area before Snyder Creek deposition, producing a minor unconformity. This conclusion is based on observations of the structural cross sections and a sedimentary breccia, in the basal Snyder Creek, found at some localities. The contact between the Callaway and Snyder Creek is extremely abrupt and generally angular instead of gradational and horizontal, as would be expected if deposition had been continuous.

Core recovery in the Callaway Formation ranged from 85 percent to 100 percent. The average recovery for all borings in the Callaway Formation was greater than 99 percent; loss of drilling fluid while coring in the Callaway Formation was not significant, and in every case, temporary.

Lower Devonian rocks are not present in the Site Area. It appears likely they were deposited and subsequently removed by a period of erosion that was initiated by regional uplift at the close of Early Devonian time.

2.5.1.2.3.3.3 Silurian System

Silurian rocks are not present at the Site. Since they are present in adjacent regions (Figure 2.5L-4) it is possible that they occurred within the Site Area at one time. The period of erosion that accompanied uplift throughout central Missouri at the close of Early Devonian time may have removed all of the Silurian rocks, as well as Lower Devonian rocks.

2.5.1.2.3.3.4 Ordovician System

The oldest rocks penetrated by on-site borings are of Ordovician age. The only formation of this age that was observed in borings during the Callaway Plant Unit 2 investigation was the

Cotter-Jefferson City Formation. Current subsurface investigation for Callaway Plant Unit 2 did not encountered the Joachim and St. Peter formations as well as the paleokarst rubble that separates the St. Peter Sandstone from the underlying Cotter-Jefferson City Dolomite as found in the investigation for Callaway Plant Unit 1. The investigation for Callaway Plant Unit 1 encountered the Joachim and St. Peter formations, as well as a zone of pre-St. Peter/post-Cotter-Jefferson City paleokarst rubble that separates the St. Peter Sandstone from the underlying Cotter-Jefferson City Dolomite, and those descriptions are used in this report. The underlying Roubidoux and Gasconade formations are also of Ordovician age but were not penetrated by borings at the Site. Description for these two formations, as well as the paleokarst rubble, comes from Thompson (1991) and Unklesbay (1992).

The Joachim Formation

The Joachim Formation is present at the Site in thin, scattered, and isolated patches (AmerenUE, 2004). This unit was encountered in 9 borings and ranges in thickness from 3.0 to 10.2 ft (0.9 to 3.1 m). It occurs as a dolomite that unconformably underlies the Callaway Plant Site and rests with apparent conformity on the St. Peter Formation, if present, or unconformably on the Cotter-Jefferson City Formation. The Joachim Dolomite is brown to gray, fine grained, silty, and fossiliferous. Small vugs are common.

The St. Peter Formation

The St. Peter Formation is a white, fine grained, sugary sandstone, generally cross-bedded and friable (AmerenUE, 2004). The St. Peter Formation is present in the Site Area in the form of isolated depression fillings on the eroded Cotter-Jefferson City surface. The depressions reflect ancient buried karst (paleokarst) features that developed during a period of uplift and erosion that occurred in Ordovician time, approximately 425 million years ago. On exposed surfaces, it weathers yellowish brown and becomes resistant to erosion as a result of secondary cementation. The St. Peter Formation was observed in numerous locations throughout the Site Area with patchy distribution. Surface exposures are typically rounded in form and in all cases appear to be isolated depression fillings.

A zone of pre-St. Peter/post-Cotter-Jefferson City paleokarst rubble separates the St. Peter Sandstone from the underlying Cotter-Jefferson City Dolomite, as observed in the paleokarst features that underlie the plant Site. The rubble consists of interbedded layers, lenses, slump blocks, and recemented disoriented debris consisting of dolomite, sandstone, siltstone, and shale. Bedding angles vary from horizontal to vertical. No voids have been observed in the rubble and no losses of drilling mud were experienced while drilling through it.

The Cotter-Jefferson City Formations

The Cotter-Jefferson City Formations underlie the entire Site Area and crop out in the rugged terrain surrounding the Site. These formations form prominent bluffs along the sides of the Missouri River. The Cotter Formation lies conformably on the underlying Jefferson City Formation. Because it is difficult to differentiate between the two formations, they are often designated as a combined unit. Site test borings have penetrated only 143.6 ft (43.8 m) of the Cotter-Jefferson City formations; however, their combined average throughout Missouri is reported to be about 400 ft (122 m). The Cotter-Jefferson City is typically a light gray dolomite, fine grained, thinly bedded, with beds becoming numerous and closely spaced in some zones. Dark gray and white banded chert is present in thin layers. Siltstone and sandstone beds are present at some locations.

These rock units are illustrated on the Site Stratigraphic Column (Figure 2.5L-13). Descriptions and thicknesses are based on data published in AmerenUE Callaway Plant Unit 1 FSAR and Callaway Plant Unit 2 subsurface investigation.

Core recovery in the Cotter-Jefferson Formation ranged from 84 percent to 100 percent. The average recovery for all borings in the Formation was greater than 99 percent. Loss of drilling fluid while coring in it was rare, and in every case, it was temporary.

The Roubidoux Formation

The Roubidoux Formation underlies the Cotter-Jefferson City formations. It consists of sandstone, dolomitic sandstone, and cherty dolomite. In central Missouri, it is predominantly quartzose sandstone. The sandstone is composed of fine to medium grained quartz sand that characteristically is subrounded and frosted. Gray and brown colors are predominant on weathered surfaces, but the color of the fresh sandstone is commonly light yellow, tan, or red at the surface and white in the subsurface. The dolomite in the Roubidoux is finely crystalline, light gray to brown in color, and thinly to thickly bedded. Individual beds contain brown to gray, banded, oolitic sandy chert. The thickness of the Roubidoux ranges from 95 ft to 170 ft (29 to 52 m), with average thickness of 118 ft (36 m).

The Gasconade Formation

The Gasconade Formation underlies the Roubidoux and is the basal formation of Ordovician age. It is predominantly a light brownish gray, cherty dolomite. The formation contains a persistent sandstone unit in its lowermost part that is designated the Gunter Member. The lower part of the dolomite that overlies the Gunter Member is coarsely crystalline and characterized by large amounts of chert that often exceed 50 percent of the total volume of the rock. In contrast, the upper part of the dolomite is dominantly, finely crystalline and contains smaller amounts of chert. In the central Ozark Region, the average thickness of the Gasconade ranges from 240 ft to 340 ft (73 to 104 m), with average thickness of 296 ft (90 m).

2.5.1.2.3.3.5 Cambrian System

All of the Cambrian strata in Missouri are regarded as being Late Cambrian in age. The combined thickness of the Upper Cambrian Series totals approximately 1,200 ft (366 m). Six formations are present at the Callaway Site Vicinity. Description for these formations comes from AmerenUE (2004) and Unklesbay (1992), and thicknesses are calculated from 9 borings from Callaway (6), Boone, Gasconade and Audrain counties. These results are shown in Table 2.5.1-9.

The Eminence Formation

The Eminence Formation is the youngest Cambrian formation, and it unconformably underlies the Gunter Member of the Gasconade Formation. It is composed primarily of sandy dolomite abundantly supplied with chert, which may suggest a clearing and warming of the sea. The existence of sand suggests the possible uprising of an area to the west or north, which exposed to erosion older, clean sandstones. The Formation contains a small amount of chert in the form of small nodules and angular fragments are present mostly in the upper half of the formation. In some areas, the Eminence Formation contains large massive chert boulders and blocks as much as 6 ft (1.8 m) in diameter. Many of these boulder-like masses of chert seem to have been formed as algal masses. White oolitic chert is locally present in the upper part of the formation. Molds and casts of gastropods are commonly found in the Eminence chert, and in places masses of Crypotozoan occur near the top of the formation. The Eminence Formation throughout the Site Vicinity has an approximate thickness of 90 ft to 235 ft (27.4 to 71.6 m), with an average thickness of 177 ft (54 m).

The Potosi Formation

The Potosi Formation conformably underlies the Eminence. The similarity of their lithologies and other characteristics tends to obscure their actual contact. The Potosi is thick bedded, fine grained dolomite and it contains an abundance of small quartz crystals among red clay beds. In several localities, this formation has been the source of Missouri's barite. The rock is typically brownish gray in color and weathers to a light gray. A notable characteristic of the Potosi, as well as of a few other Lower Paleozoic formations, is that the freshly broken rock gives off a pronounced bituminous odor. The Potosi is present in the subsurface throughout most of the state, but at widely scattered localities, it is thin or absent. The Potosi Formation conformably overlies the Derby-Doe Run formations. The Potosi Formation has an approximate thickness throughout the Site Vicinity of 45 ft to 175 ft (14 to 53 m), with an average thickness of 110 ft (34 m).

The Derby and the overlying Doe Run Formations

The Derby and Doe Run Formations were originally defined in 1908 from exposures in the vicinity of mines operated by the Derby Lead Company and the Doe Run Lead Company in the Lead Belt area at that time. However, the conformable relationship and similar lithology of the two units has since led most stratigraphers to consider them as a single unit, and the combination of the two names, Derby and Doe Run, is now accepted as the formation name: Derby-Doe Run. In its outcrop area in southeast Missouri, the Derby-Doe Run consists of thin- to medium-bedded dolomite that alternates with thin-bedded siltstone and shale. The dolomite beds are medium to fine grained, buff to brown, argillaceous, and silty. Chert content of the formation is very low, accounting for less than 10 percent of the rock by volume. Glauconite is present in the lower 40 ft to 50 ft (12.2 to 15.2 m) of the formation. The thickness of the Derby-Doe Run Formation is 202 ft (62 m) in average; however, it ranges in thickness from 135 to 325 ft (41 to 99 m).

The Davis Formation

The Davis Formation is conformable with both the overlying Derby-Doe Run and the underlying Bonneterre formations. The Davis contains shale, siltstone, fine-grained sandstone, dolomite, and limestone conglomerate. Much of the siltstone and fine-grained sandstone is glauconitic and has a “salt and pepper” appearance. “Flat-pebble” and edgewise conglomerates are characteristic of the Davis. The “flat-pebble” conglomerates consist of rounded disc-like pebbles of fine-grained limestone that are embedded in a medium-grained limestone matrix. The thickness of the Davis formation is 163 ft (50 m) in average; however, it ranges in thickness from 155 ft to 170 ft (47 to 52 m).

The Bonneterre Formation

The Bonneterre Formation is typically a light gray, medium- to fine-grained, medium-bedded dolomite which locally can consist of relatively pure limestone. In places, it is very coarse grained and contains small cavities lined with dolomite rhombs. Locally, parts of the Bonneterre are glauconitic and shaly with the shale occurring in beds less than 2 inches (5 cm) thick. The lower part of the Bonneterre consists of alternating beds of dolomite and arenaceous dolomite with the amount of sand increasing toward the base. The Bonneterre occurs in the subsurface throughout most of the state of Missouri and rests conformably on the Lamotte Formation. This formation has been penetrated in 3 off-Site borings, located to the north of the Missouri River and within the Site Vicinity, in Boone, Gasconade and Audrain counties. The Bonneterre Formation has an approximate thickness throughout the Site Vicinity of 295 ft to 330 ft (90 to 101 m), with an average thickness of 307 ft (94 m).

The Lamotte Formation

The Lamotte Formation rests unconformably on Precambrian basement rocks. It is persistent in the subsurface throughout much of Missouri, but regional variations in thickness have been recognized. It is predominantly a quartzose sandstone that in many places grades laterally into arkose and conglomerate. Pebbles and boulders of felsite are the chief constituents of the conglomerates that immediately overlie Precambrian rocks in many places. The color of the sandstone ranges from light gray or white to yellow, brown or red. Red to purple silty shale is locally present, and lenses of arenaceous dolomite are scattered through the upper part of the formation. The Lamotte Formation has been penetrated in 3 off-site borings, located to the north of the Missouri River and in the Site Vicinity, in Boone, Gasconade and Audrain counties. The Lamotte Formation has an approximate thickness throughout the Site Vicinity of 130 ft to 385 ft (40 to 117 m), with an average thickness of 253 ft (77 m).

The nearest exposures of Precambrian age rocks are located in the St. Francois Mountains, about 75 miles (121 km) southeast of the Site. The nearest boring that reached Precambrian rocks (Robertson, 1974) is the Continental Ozark No. CO-10 located in the NE quarter of the NE quarter of Section 3, Township 44 North, Range 8 West, approximately 10 miles (16 km) south of the Site. This boring was drilled in 1969 to a total depth of 1,955 ft (596 m). Precambrian basement was reached at a depth of 1,844 ft (562 m) (1,214 ft (370 m) below msl). At this location the Precambrian rocks consist of slightly to highly altered serpentine, which becomes porphyritic with depth and is underlain by rhyolite porphyry and tuff. Information from this well was not used to complete Table 2.5.1-9 because it is located south of the Missouri River, missing the upper deposits of Mississippian and Pennsylvanian age, as well as the Quaternary glacial and post-glacial derived deposits.

2.5.1.2.4 Site Area Structural Geology

Geologic studies to determine the Site structural characteristics have been performed utilizing data obtained from Site borings, excavation mapping for the Callaway Plant Unit 1 foundations, and geophysical surveys. In addition, bedrock exposures were mapped throughout the Site Area. Dip and strike measurements were taken on bedding planes and joints where possible. A thorough search for faulting was made throughout the Site Area as described in Section 2.5.3. Subsurface sections (Figure 2.5L-10) were prepared correlating boring data. Detailed mapping of all Category I excavations was performed for Callaway Plant Unit 1 (Dames and Moore, 1980), and results from the current subsurface investigation for Callaway Plant Unit 2 encountered no major structures that would adversely affect construction and operation of the plant.

2.5.1.2.4.1 Site Folding

The effect of regional warping on the Site Area has been discussed in Section 2.5.1.1.4.1. Gentle warping of Pennsylvanian and older strata appears to have occurred in the Site Vicinity; it is evident also from the geologic cross sections in Figure 2.5L-10. At the Site, the age of the broad flexures cannot be determined precisely. Devonian and Mississippian age rocks appear to be involved. Reconnaissance geologic field data suggests that the Graydon Chert Conglomerate also reflects the gentle flexures. If the tentative age of Early Pennsylvanian is correct for the Graydon Conglomerate Formation, the age of the last warping must be Late or post-Pennsylvanian. There is no evidence to support any of these gentle movements during Pleistocene time.

The rocks at the Site generally dip gently toward the north and northwest. Detailed examinations of changes in attitude were conducted in field reconnaissance for the Site Area. Dip and strike data were recorded. Photographs were taken where possible. Rock exposures were traced horizontally and vertically as far as possible in order to determine the magnitude and possible origin of any fold structures.

There are four named folds within a 25-mile (40- km) radius of the Site. In order of increasing distance from the Site they are: the Auxvasse Creek Anticline, the Mineola Dome, Big Spring Anticline, and Kruegers Ford Anticline. The youngest of these was active in the Pennsylvanian Period (300 Ma), and none of them presents a risk to the Site.

2.5.1.2.4.2 Site Faulting

No faulting, except for slumping into ancient karst features, has been revealed within 25 miles (40 km) of the Site either by drilling, by field mapping, by detailed geologic mapping of excavations, or by the study of aerial photographs and ERTS imagery during either the Callaway Plant Unit 1 investigation or the current study for Callaway Plant Unit 2. The slump faults are downthrown toward the solution feature in all cases and display vertical displacements of 1 to 3 ft (0.3 to 0.9 m), which diminishes vertically. The slumps are contained within the Ordovician rocks and as such are pre-Middle Devonian in age (over 350 Ma). Section 2.5.3 describes the results of a field reconnaissance that included visits to the 5 faults located within the Site Vicinity: the Mineola, Kingdom City, Cuba, Fox Hollow and Wardsville faults. The results of the field efforts in the Site Area and Vicinity refined the understanding of local geological relationships, and were consistant with the published literature reviewed for this investigation. No conclusive paleoliquefaction evidence for strong ground motion was found in the sediments along the rivers and creeks within the Site Area or Site Vicinity.

Interpreted seismic sections (Bay Geophysical, 2008) interpretation of southeast wave reflection surveys are displayed in Figure 2.5L-12. In this figure interpreted seismic sections are identified by the correlation of the Graydon Chert Conglomerate and the Snyder Creek events traced across each seismic profile. The Graydon Chert Conglomerate and the Snyder Creek event are highlighted on each of the seismic figures.

The minimal vertical time shifts noted in Figure 2.5L-12 have not been interpreted as significant offsets within the Snyder Creek event that could be attributed to faulting. These offsets do not appear above or below the Snyder Creek event. This observation, when considered along with Site Area geology, eliminates post-depositional movements as their cause. It is probable that apparent offsets could be a result of lenticular facies, erosion remnants, or a depositional feature within the Snyder Creek Formation (noted in Figure 2.5L-12). Other apparent offsets may be the result of low fold (low statistical redundancy) that occurs at the line ends of seismic reflection data and thus reducing the confidence of the interpreted apparent offsets. The slump features noted on the seismic sections are not related to tectonic activity, and there is no likelihood of recurrence since the ancient solution features in the Site Area appear to be completely filled, lithified, and inactive.

2.5.1.2.4.3 Site Jointing

The joint pattern of the Site location is representative of the regional jointing pattern as discussed in Section 2.5.1.1.4.2. Regional joint or fracture patterns are consistent and well developed throughout the Site Region with two systems of fractures that are prevalent: two sets, northwest and northeast, parallel to the general regional structural trends; the second system is subordinate and has two joint sets that strike north-northwest and east-northeast.

2.5.1.2.5 Site Area Geologic Hazard Evaluation

No geologic hazards have been identified within the Callaway Plant Unit 2 Site Area. Significant conclusions are listed below:

- Results from the drilling, geophysical investigation, field reconnaissance, and literature searches show no indication of capable faults (as discussed in Sections 2.5.1.2 and 2.5.3) at Callaway Plant Unit 2 Site, eliminating the possibility for a surface fault rupture.

- No deformation zones were encountered in the exploration or excavation for Callaway Plant Unit 1 and none have been encountered in the Site investigation for Callaway Plant Unit 2.

- Since no faults, folds or shear zones of any significance were encountered in the Site Area, and since the Site is located on a nearly isolated plateau with deeply incised drainages on all sides, no unrelieved residual stresses in the rock strata are present.

- Since the Site Area is within the Central Stable Region of the US, it is not anticipated that any significant regional warping or differential uplift would occur during the design life of the project.

- Because of the complete coverage of the Site with the glacial and post glacial deposits (a fairly continuous layer of silty clay and clay, 5.5 to 62 ft (2 to 19 m) thick, water percolation is strongly minimized and the geologic units underneath are subjected to very limited dissolution.

- No voids or active solution channels occur within the filled paleokarst features or in the carbonate rocks below or adjacent to them as a result of either incompletely filled ancient channels or regenerated secondary solution activity in post-Ordovician time.

- Field exploration programs show no evidence of any actual or potential surface or subsurface subsidence, uplift, or collapse resulting from tectonic depressions or cavernous terrain at the Site.

- As discussed in Section 2.5.4 the Site soils and rocks found in the subsurface are sufficiently strong and stable to support the intended structures for Callaway Plant Unit 2.

2.5.1.2.6 Site Engineering Geology Evaluation

2.5.1.2.6.1 Engineering Soil Properties and Behavior of Foundation Materials

Engineering soil properties, including index properties, static and dynamic strength, and compressibility are discussed in Section 2.5.4. Variability and distribution of properties for the foundation bearing soils will be evaluated and mapped as the excavations for the Callaway Plant Unit 2 structures are completed.

2.5.1.2.6.2 Zones of Alteration, Weathering, and Structural Weakness

Examination of bedrock exposures in areas adjacent to the plant Site for Callaway Plant Unit 1 FSAR (AmerenUE, 2004) revealed several geologic features related to solution activity in the Cotter-Jefferson City Formations of Early Ordovician age. It appears likely that these features formed during a period of erosion that was initiated by regional uplift prior to Middle Ordovician time, over 400 ma. The sinkholes or karst topography, which were then developed on the Ordovician bedrock surface, are now filled with rock consisting of angular, disoriented blocks of dolomite, sandstone, and conglomerate that are tightly and completely cemented within a calcareous matrix. Small-scale slump faulting was also observed. These minor faults, which have displacements of 1 to 3 ft (0.3 to 0.9 m), are demonstrated to be at least pre-Middle Devonian in age. They are not related to tectonic activity and there is no likelihood of recurrence since the ancient solution feature is completely filled, lithified, and inactive. Sandstone of the St. Peter Formation was deposited in many of these ancient solution features during Middle Ordovician time, over 425 Ma as discussed in Section 2.5.1.2.3.3.4. The locations of these isolated, oval-shaped patches of St. Peter Sandstone are shown on the Site Vicinity and Site Area geologic maps, Figure 2.5L-8 and Figure 2.5.1-29.

Extensive research was performed in Callaway Plant Unit 1 FSAR to characterize the paleokarst rubble that was found between St. Peter and Cotter-Jefferson formations (AmerenUE, 2004). It consists of interbedded layers, lenses, slump blocks and recemented, disoriented debris consisting of dolomite, sandstone, siltstone, and shale. Bedding angles vary from horizontal to vertical. No voids were encountered in the rubble zone and no fluid losses were experienced while drilling through it. Core recovery in the rubble zone ranged between 36 and 100 percent and averaged approximately 90 percent. Pressure testing in the rubble indicated low permeabilities. These results are discussed in detail in the hydrology section of this report. As shown on Figure 2.5L-13, the St. Peter Formation, and its related formations (the Joachim and Paleokarst Rubble) were absent in the borings drilled for the Callaway Plant Unit 2 investigation. Apparently, the paleokarst on the Cotter-Jefferson City Formation was not developed beneath the Callaway Plant Unit 2 Site, and provided no opportunity for the deposition of the St. Peter and related units.

Considerable research was performed in the Callaway Plant Unit 1 FSAR (AmerenUE, 2004) in order to investigate paleokarst features below foundations for Callaway Plant Unit 1 where sixteen deep borings were drilled. Because these paleokarst features were not found during the subsurface investigation for Callaway Plant Unit 2, the Callaway Plant Unit 1 test results were used for this assessment. More than 3,500 ft (1,067 m) of rock core were analyzed and described in detail, subsurface maps and cross sections were prepared by correlating between borings, water pressure tests were performed, and permeability values were calculated. Important geologic and hydrologic data were obtained; and conclusions regarding solution activity and weathering, subsurface stability, and movements of ground water remain unchanged. The conclusions resulting from this detailed investigation of paleokarst features have, however, added greatly to the scientific evidence in support of the following conclusions that apply to the Site Area:

- The drilling data indicate that no voids or active solution channels occur within the filled paleokarst features and that no voids or solution channels occur in the carbonate rocks below or adjacent to the paleokarst features as a result of either incompletely filled ancient channels or regenerated secondary solution activity in post-Ordovician time.

- The results of pressure tests in and adjacent to the Ordovician paleokarst features indicate that there are no regenerated secondary solution activities present and that they cannot occur under the present geologic and hydrologic Site conditions.

- Site borings and reconnaissance field investigations have not revealed any caves or significant open cavities in the younger carbonate rocks of the Site Area. No voids larger than 2 inches (5 cm) in diameter were encountered during the test drilling, confirming the results from Callaway Plant Unit 1 FSAR.

- The Snyder Creek and Callaway formations have very low permeabilities and essentially act as aquitards restricting the vertical movement of ground water (see Section 2.4.12.1.2).

- No significant hydraulic connection exists between the sandstone-filled paleokarst features and deeper aquifers beneath the Site. The paleokarst features and the adjacent and immediately underlying Cotter-Jefferson City Formation have similar low permeabilities.

- Based on detailed rock core examinations and laboratory testing, there are no zones of weathering in the lithified formations that could adversely affect construction and operation of a nuclear power plant.

- Because of the low permeabilites of the rocks and of the overlying glacial soils along with the lack of voids in the rocks, there is no possibility for the formation of subsurface cavities, or eventual sinkholes by the collapse of overlying soil and rock in the Site Area.

2.5.1.2.6.3 Deformational Zones

Geologic studies related to Site structure are discussed in Section 2.5.1.2.4. Minor flexing of the lithified formations appears to have occurred in the late Paleozoic, nearly 300 Ma (Section 2.5.1.2.4.1). Faulting in the Site Area is confined to minor displacements related to ancient solution features (Section 2.5.1.2.4.2). No major structures or zones of deformation have been encountered that would adversely affect construction and operation of the Callaway Plant Unit 2. Based on detailed analysis of borings, there are no geologic features that could adversely affect construction and operation of a nuclear power plant.

2.5.1.2.6.4 Prior Earthquake Effects

The Site is located in a region that has experienced only infrequent minor earthquake activity, with the closest epicentral location (a 3.0 to 3.9 m_b event) situated approximately 38 miles (61 km) southwest of the Callaway Plant Site, west of Cole County. There has been only one other cataloged earthquake (also a 3.0 to 3.9 m_b event) within 50 miles (80 km) of the Callaway Plant Site. The epicenter was approximately 45 miles (72 km) south-southeast of the Site, to the south of Gasconade County (Figure 2.5L-5). Section 2.5.2 provides a full discussion on the seismicity analysis for the Callaway Plant Site.

2.5.1.2.6.5 Effects of Human Activities

Investigations at the Site have not revealed any adverse geologic conditions that can be attributed to man's activity (AmerenUE, 2004). The addition or withdrawal of subsurface fluids, including ground water, at the Site has not been significant. Mineral extraction in the Site Vicinity has consisted of minor amounts of surface quarrying of limestone and fire clay. At present, there are no active mining operations within 4.5 miles (7.2 km) of the Site. There has been no mining or petroleum production in the Site Area that would cause any surface or subsurface subsidence. Based on current knowledge of the Site Vicinity, no mining or petroleum activity is anticipated. Central Missouri is not a promising area for oil or gas production (AAPG, 1971). Petroleum and gas associated drilling in Missouri (MODNR, 2007a) are shown on Figure 2.5.1-41, with the nearest producing oil or gas well located in the Florissant Field in St. Louis County, 70 miles (113 km) from the Site. This oil field is associated with the Lincoln Fold Structure, an anticline that extends from northern St. Louis northwest to Knox County (MODNR, 2007b), and is part of the only three areas with potential for conventional oil and gas production in Missouri: Forest City Basin, Lincoln Fold, and the Mississippi Embayment. There is no potential for gas storage in structures around the Site due to the absence of suitable reservoir and cap rock units.

A map showing the Mineral Resources in Missouri is shown on Figure 2.5.1-42. A map showing the Mineral Industries in Missouri is shown on Figure 2.5.1-43.

2.5.1.2.6.6 Site Groundwater Conditions

A detailed discussion of the regional and local groundwater environment is given in Sections 2.4.13, and 2.5.1.1.5.1. The latter provides detailed descriptions of the processes governing the formation of springs, caves and sink holes as well as the relation between their locations and the pertinent conditions of Callaway Plant Unit 2 Site.

2.5.1.3 References

This section is added as a supplement to the U.S. EPR FSAR.

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Table 2.5.1-1—{Devonian Formations in Missouri Regions}

	SW	Central	NE	E-Central	SE
Upper	Chattanooga Sh Sylamore Ss	Holts Summit Ss Snyder Creek Sh	Louisiana Ls Saverton Sh Grassy Creek Sh Turpin Ss	Bushberg Ss Glen Park Ls	Peridotite diatremes
Middle	Fortune Fm	Cedar Valley Ls	Cedar Valley Ls		St. Laurent Ls Beauvais Ss Grand Tower Ls
Lower					Clear Creek Chert Little Saline Ls Grassy Knob Chert Bailey Fm

Table 2.5.1-2—{Mississippian Formations in Missouri Regions}

	E-Central	SE	NE	SW	N	Central
Chesterian		Vienna Ls Tar Springs Ss Glen Dean Fm Hardinsburg Fm Golconda Fm Cypress Fm Paint Creek Fm Yankeetown Ss Renault Fm		Fayetteville Fm Batesville Fm Hindsville Ls (Carterville Fm)		
Meramecian	Ste Genevieve Ls St Louis Ls Salem Fm Warsaw Fm	Aux Vases Ss Ste Genevieve Ls St Louis Ls Salem Fm Warsaw Fm	Ste Genevieve Ls St Louis Ls Salem Fm Warsaw Fm	Warsaw Fm	St Louis Ls Salem Fm Warsaw Fm	Salem Fm Warsaw Fm
Osagean	Keokuk Ls Burlington Ls Fern Glen Fm	Keokuk Ls Burlington Ls Fern Glen Fm	Keokuk Ls Burlington Ls	Keokuk Ls Burlington Ls Elsey Fm Reeds Spring Fm Pierson Ls	Keokuk Ls Burlington Ls Elsey Fm Pierson Ls	Keokuk Ls Burlington Ls "Pierson Ls"
Kinderhookian	Bachelor Fm Bushberg Ss	Chouteau Gr. Bachelor Fm Bushberg Ss	Chouteau Gr. Hannibal Sh Horton Cr Ls.	Chouteau Gr. Bachelor Fm Bushberg Ss	Chouteau Gr. Bachelor Fm	Chouteau Gr. Bachelor Fm

Table 2.5.1-3—{Structures within the Illinois Basin and within a 200 mile (320 km) radius of Callaway Plant Unit 2}

Structure	County/State
Clay City anticline	Jasper/Ill. Richland/Ill. Wayne/Ill.
Cottage Grove fault system	Saline/Ill. Williamson/Ill. Jackson/Ill.
Downs anticline	DeWitt/Ill. McLean/Ill.
Du Quoin monocline	Perry/Ill. Washington/Ill. Clinton/Ill. Marion/Ill.
Fairfield basin	Marion/Ill. Clay/Ill. Wayne/Ill. Jefferson/Ill.
Fishhook anticline	Pike/Ill. Adams/Ill.
Glasford disturbance	Peoria/Ill.
Louden anticline	Fayette/Ill.
Mattoon anticline	Coles/Ill. Cumberland/Ill.
Pittsfield anticline	Pike/Ill.
Salem anticline	Marion/Ill.
Valmeyer anticline	Monroe/Ill.
Wabash Valley fault system	Edwards/Ill. Gallatin/Ill. Wabash/Ill. White/Ill. Gibson/Ind. Knox/Ind. Posey/Ind.
Waterloo-Dupo Anticline	Monroe/Ill. City of St. Louis/Mo.

Table 2.5.1-4—{A Summary of the Structures of the Mississippi Embayment Tectonic Region}

Structure	County/State
Albright Creek fault	Scott/Mo.
Aquilla fault	Stoddard/Mo.
Beech Grove faulting and folding	Stoddard/Mo.
Bell City faults	Stoddard/Mo.
Chalk Bluff fault	Scott/Mo.
Commerce anticlinorium or Commerce folded area	Scott/Mo.
Counterfeit Rock fault	Scott/Mo.
English Hill fault	Scott/Mo.
Holden Creek fault	Scott/Mo.
Idalia fault (Idalia Hill fault)	Stoddard/Mo.
Jenkins basin fault	Stoddard/Mo.
Mississippi embayment (Mississippi structural trough)	Butler/Mo. Dunklin/Mo. Mississippi/Mo. New Madrid/Mo. Pemiscot/Mo. Ripley/Mo. Scott/Mo. Stoddard/Mo.
Pascola arch	Dunklin/Mo. Pemiscot/Mo.
Poplar Branch faulting and folding	Stoddard/Mo.
Tiptonville dome	New Madrid/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 1 of 6)

Structure	County/State
Alba-Neck City structures	Jasper/Mo.
Alice Mine structure	Ozark/Mo.
Anthonies Mill fault	Crawford/Mo. Washington/Mo.
Aptus fault	Washington/Mo.
Ashbank fault	St. Francois/Mo.
Avon block	St. Francois/Mo. Ste. Genevieve/Mo.
Avon diatremes (dikes)	Ste. Genevieve/Mo.
Bannister fault *(see Mitchell fault)*	St. Francois/Mo.
Belleview Valley block *(see Munger fault)*	Reynolds/Mo.
Benton County anticline	Benton/Mo.
Berryman fault	Crawford/Mo. Washington/Mo.
Big River fault system	St. Francois/Mo. Washington/Mo.
Black fault	Iron/Mo. Reynolds/Mo.
Blue Ridge School anticline	Cedar/Mo.
Bodenschatz-Lick fault	Perry/Mo.
Bolivar fault	Polk/Mo.
Bolivar-Mansfield fault system	Douglas/Mo. Polk/Mo.
Bolivar-Marshfield anticline	Dallas/Mo. Polk/Mo. Webster/Mo.
Bourbon uplift	Crawford/Mo.
Brooks dome	Cape Girardeau/Mo.
Brush Creek fault	McDonald/Mo.
Bryant Creek fault	Douglas/Mo.
Bucksnort Hollow faults and folds	Webster/Mo.
Cabanne fault	St. Francois/Mo. Washington/Mo.
Cape Girardeau fault	Cape Girardeau/Mo.
Caplinger Mills fault	Cedar/Mo.
Carterville-Oronogo complex	Jasper/Mo.
Cassville anticline	Barry/Mo.
Cedar Creek fault	St. Francois/Mo. Washington/Mo.
Cedar Point anticline	Hickory/Mo.
Chesapeake fault	Christian/Mo. Dade/Mo. Lawrence/Mo.
Coal Mine fault	Bollinger/Mo.
Crooked Creek structure	Crawford/Mo.
Cruise Mill-Fertile fault zone	Washington/Mo.
Crystal City anticline	Jefferson/Mo.
Cuba fault	Crawford/Mo. Gasconade/Mo. Osage/Mo.
Cuba graben	Crawford/Mo. Franklin/Mo. Gasconade/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 2 of 6)

Structure	County/State
Dade County faults	Dade/Mo.
Danforth graben	Greene/Mo.
Decaturville structure (dome or uplift)	Camden/Mo.
Decaturville-Crooked Creek axis	Perry/Mo.
Dent Branch structure	Washington/Mo.
Diggins fault	Webster/Mo.
Ditch Creek fault system	Washington/Mo.
Doe Run-Higdon fault zone	St. Francois/Mo. Madison/Mo.
Dogwood fault	Douglas/Mo. Webster/Mo.
Doniphan fault	Ripley/Mo.
Dry Creek anticline-Dry Creek fault complex	Webster/Mo.
Duenweg-Webb City-Carl Junction minor flexures	Jasper/Mo.
Eldorado Springs fault (Eldorado Springs North fault)	Cedar/Mo.
Ellington fault	Reynolds/Mo.
Enon faults	Moniteau/Mo.
Esther fault	St. Francois/Mo.
Eureka-House Springs anticline	Jefferson/Mo.
Fair Grove fault	Greene/Mo. Polk/Mo.
Fair Grove fault	Polk/Mo.
Fair Play fault	Polk/Mo.
Farmington anticline	St. Francois/Mo. Ste. Genevieve/Mo.
Federal fault	St. Francois/Mo.
Flat River structural block	St. Francois/Mo.
Fordland anticline	Webster/Mo.
Fordland fault	Webster/Mo.
Fruitland faults	Cape Girardeau/Mo.
Furnace Creek structure	Washington/Mo.
Galena anticline	Jasper/Mo.
Galena graben	Stone/Mo.
Galesburg-Pittsburg anticline	Jasper/Mo.
Galmey Church anticline	Hickory/Mo.
Glenallen faults	Bollinger/Mo.
Glover faults	Iron/Mo.
Golden City-Miller anticline	Dade/Mo. Lawrence/Mo.
Granby fault	Newton/Mo.
Grand Gulf fault	Oregon/Mo.
Graydon Springs fault zone	Greene/Mo. Polk/Mo.
Graydon-Northview Anticline	Polk/Mo. Webster/Mo.
Greasy Creek fault	Barry/Mo.
Greenville fault	Wayne/Mo.
Hazelgreen diatreme *(see Dent Branch structure)*	Laclede/Mo.
Highlandville fault	Christian/Mo. Stone/Mo.
Hogan fault	Iron/Mo.
Hogan Mountain faults	Iron/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 3 of 6)

Structure	County/State
Honey Creek anticline	Lawrence/Mo.
Horse Creek anticline	McDonald/Mo.
Humansville anticline	Polk/Mo.
Huron fault	Polk/Mo.
Irondale fault	St. Francois/Mo. Washington/Mo.
Ironton fault	Iron/Mo.
Jackson fault	Cape Girardeau/Mo.
Jasper anticline	Jasper/Mo. Newton/Mo.
Jeffries Mine fault	Franklin/Mo.
Jeffriesburg fault	Franklin/Mo.
Johnson Mill fault	Lawrence/Mo.
Joplin anticline	Jasper/Mo.
Jordan Creek anticline	Hickory/Mo.
Ketcherside Gap fault	Iron/Mo.
King fault	Madison/Mo.
King-Ritter fault	Greene/Mo.
Kinser Bridge fault	Greene/Mo.
Kruegers Ford anticline	Gasconade/Mo. Osage/Mo.
Lamar syncline	Jasper/Mo. Lawrence/Mo.
Lampe fault	Stone/Mo.
Lawton trough	Jasper/Mo.
Leasburg fault	Crawford/Mo. Franklin/Mo.
Libertyville graben	Madison/Mo. St. Francois/Mo. Ste. Genevieve/Mo.
Little Weaubleau anticline	Hickory/Mo.
Lutesville fault	Bollinger/Mo.
Mahken Branch fold	Perry/Mo.
Manger fault	Iron/Mo.
Mansfield faults	Douglas/Mo. Webster/Mo. Wright/Mo.
Marble Hill fault	Bollinger/Mo.
Marble Hill structure *(see Marble Hill fault)*	Bollinger/Mo.
Menfro faults	Perry/Mo.
Mine LaMotte faults	Madison/Mo. St. Francois/Mo.
Mitchell fault	St. Francois/Mo.
Moccasin Springs anticline	Cape Girardeau/Mo.
Morrisville-Brighton fold	Greene/Mo. Polk/Mo.
Moselle fault	Franklin/Mo.
Mt. Shira uplift	McDonald/Mo.
Munger fault	Reynolds/Mo.
Murphy Hill fault	St. Francois/Mo. Madison/Mo.
Nashville-Carthage sag	Jasper/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 4 of 6)

Structure	County/State
New Wells faults	Cape Girardeau/Mo.
Newburg fault zone	Phelps/Mo.
Newport basin	Dade/Mo.
North Dry Sac syncline	Greene/Mo. Polk/Mo.
Omete Creek fault	Perry/Mo.
Osage anticline	Barry/Mo. Lawrence/Mo.
Palmer fault system	Crawford/Mo. Washington/Mo.
Pearson Creek fault system	Greene/Mo.
Pence de Leon fault	Stone/Mo.
Pershing-Bay-Gerald anticline	Franklin/Mo. Gasconade/Mo.
Pim fault	St. Francois/Mo.
Pineville fault	McDonald/Mo.
Plattin Creek anticline	Jefferson/Mo.
Pleasant Creek monocline	Perry/Mo.
Pleasant Hope anticline	Greene/Mo. Polk/Mo.
Ponce de Leon fault	Christian/Mo.
Portland fault	Jasper/Mo.
Proctor anticline	Camden/Mo. Morgan/Mo.
Radio Tower structure	Cape Girardeau/Mo.
Red Arrow fault	Camden/Mo.
Red Rock thrust (Red Rock-Union School fault zone)	Perry/Mo.
Richwoods fault zone	Washington/Mo.
Ritchey fault	Lawrence/Mo. Newton/Mo.
Roaring River syncline	Barry/Mo.
Rock Burst fault	Washington/Mo.
Roselle lineament	Jefferson/Mo. Madison/Mo.
Rugley School fault block or fault	Jefferson/Mo. St. Francois/Mo.
Sac River anticline	Greene/Mo. Lawrence/Mo.
Sac River fault	Christian/Mo. Greene/Mo. Lawrence/Mo.
Sarvis Point fault	Webster/Mo.
Schofield fault	Reynolds/Mo.
Schultz fault (Schultz-Federal fault system)	St. Francois/Mo.
Scopus structure *(see Coal Mine fault)*	Bollinger/Mo.
Seneca fault	Newton/Mo.
Shannon County block	Shannon/Mo.
Shell Knob-Eagle Rock structure	Barry/Mo.
Shirley fault zone	Washington/Mo.
Shirley syncline	Washington/Mo.
Silver Creek fault	Newton/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 5 of 6)

Structure	County/State
Simms Mountain fault system	Bollinger/Mo. Washington/Mo.
South Sac-Ash Grove syncline	Dade/Mo. Greene/Mo.
South West City fault	McDonald/Mo.
Spavinaw arch	McDonald/Mo.
Springfield anticline	Greene/Mo. Laclede/Mo. Webster/Mo.
St. Clair fault	Franklin/Mo.
St. Francois Mountain block	Iron/Mo. Madison/Mo. St. Francois/Mo.
St. Francois thrust	Iron/Mo. Madison/Mo. St. Francois/Mo. Washington/Mo.
St. Marys fault	Ste. Genevieve/Mo.
Ste. Genevieve fault system	Franklin/Mo. Jefferson/Mo. Perry/Mo. St. Francois/Mo. Ste. Genevieve/Mo. Jackson/Ill. Union/Ill.
Stinton anticline	Lawrence/Mo.
Stockton faulting	Cedar/Mo.
Stono Mountain faults	St. Francois/Mo.
Strafford fault	Greene/Mo. Webster/Mo.
Strafford graben	Greene/Mo. Webster/Mo.
Sulfur Springs anticline	McDonald/Mo.
Summit Park structure	Jefferson/Mo.
Sutton Creek fault zone	Shannon/Mo.
Sycamore Creek fault	Greene/Mo.
Ten O'Clock Run fault	Stone/Mo. Taney/Mo.
Thayer faults	Oregon/Mo.
Tiff fault zone	Washington/Mo.
Vales Mines-Vineland fault zone	Jefferson/Mo.
Valles Mines-Vineland fault zone	Franklin/Mo.
Valley Mills fault zone	Greene/Mo.
Vanderman Branch syncline	Hickory/Mo.
Verona anticline	Barry/Mo. Lawrence/Mo.
Virginia Mines fault	Franklin/Mo.
Waco minor structures	Jasper/Mo.
Wardsville fault	Cole/Mo.
Washburn syncline	Barry/Mo.
Weaubleau Creek structural complex	Hickory/Mo.
Weingarten graben (see Ste. Genevieve)	Ste. Genevieve/Mo.

Table 2.5.1-5—{A Summary of the Structures of the Ozark Uplift Region}

(Page 6 of 6)

Structure	County/State
Wheatland faults	Hickory/Mo.
Wittenberg fault zone	Perry/Mo.
Wolf Creek-Greasy Creek fault zone	Perry/Mo. St. Francois/Mo.

Table 2.5.1-6—{A Summary of the Structures of the Forest City Basin Tectonic Region}

(Page 1 of 3)

Structure	County/State
Adams Cemetery anticline	Jackson/Mo.
Allendale structure	Worth/Mo.
Anderson and Walkerhorst dome	Jackson/Mo.
Anderson dome	Jackson/Mo.
Archie-Lone Tree-Peculiar syncline	Cass/Mo.
Archie-Pleasant Hill-Strasburg structural area	Cass/Mo.
Atchison county	Andrew/Mo.
Avondale structure	Clay/Mo.
Bannister Ridge anticline	Jackson/Mo.
Belgium Bottoms (Lakeside) structure	Platte/Mo.
Belton fault complex	Cass/Mo.
Bethany structure	Harrison/Mo.
Blackburn School anticline	Grundy/Mo. Livingston/Mo.
Blackwell anticline	Jackson/Mo.
Blue Mound structure	Livingston/Mo.
Blue Ridge anticline	Jackson/Mo.
Blue Springs anticline	Jackson/Mo.
Bosworth structure	Carroll/Mo.
Breckenridge anticline	Caldwell/Co.
Brown dome	Cass/Mo.
Burns syncline	Jackson/Mo.
Cameron structure	Caldwell/Co. Clinton/Mo. DeKalb/Mo.
Cameron-Union Star syncline	DeKalb/Mo.
Carlson dome	Jackson/Mo.
Centerview-Kansas City anticline	Jackson/Mo.
Central anticline	Cass/Mo.
Centropolis dome	Jackson/Mo.
Chillicothe (Medicine Creek) structure	Livingston/Mo.
Cockrell sink	Jackson/Mo.
Coleman anticline	Cass/Mo.
Coloma anticline	Carroll/Mo.
Corning structure	Holt/Mo.
Cox dome	Jackson/Mo.
Dehoney dome	Jackson/Mo.
Denver structure	Worth/Mo.
Duck dome	Jackson/Mo.
East Cleveland anticline	Cass/Mo.
East Grandview anticline	Jackson/Mo.
Eastern anticline	Cass/Mo.
Ellington structure	Clay/Mo.
Everett fault complex	Cass/Mo.
Farley structure	Platte/Mo.
Fillmore structure	Andrew/Mo.
Freeman-West Line anticline	Cass/Mo.
Gallatin fault	Daviess/Mo.
Gower anticline	Clinton/Mo.

Table 2.5.1-6—{A Summary of the Structures of the Forest City Basin Tectonic Region}

(Page 2 of 3)

Structure	County/State
Hamilton-King City-Quitman axis (anticline)	Caldwell/Co. Gentry/Mo. Nodaway/Mo.
Hammond (North Plattsburg) structure	Clinton/Mo.
Harless Creek-South Creek anticline	Cass/Mo.
Harrisonville anticline	Cass/Mo.
Herr syncline	Cass/Mo.
Iatan structure	Platte/Mo.
Independence nose	Jackson/Mo.
Indian Creek dome	Jackson/Mo.
Jamesport structure	Grundy/Mo.
Jaudon anticline	Cass/Mo.
Jerrard dome	Jackson/Mo.
Johnson terrace	Cass/Mo.
Kansas City-Blue Springs-Lone Jack syncline	Jackson/Mo.
King anticline	Cass/Mo.
Klapmeyer dome	Jackson/Mo.
Knoche anticline	Cass/Mo.
Knorpp dome	Jackson/Mo.
Lathrop dome	Clinton/Mo.
Lees Summit nose	Jackson/Mo.
Lester dome	Jackson/Mo.
Liberty structure	Clay/Mo.
Lone Jack dome	Jackson/Mo.
Macon-Sullivan trough	Mercer/Mo.
Martin City anticline	Jackson/Mo.
Mohr-Oakcrest anticline	Cass/Mo.
Mullen depression	Cass/Mo.
Nashua structure	Clay/Mo.
New Santa Fe dome	Jackson/Mo.
Nodaway structure	Andrew/Mo.
North Coleman anticline	Cass/Mo.
North Freeman anticline	Cass/Mo.
North West Line syncline	Cass/Mo.
Paradise (Smithville) anticline	Clay/Mo.
Parkville structure	Platte/Mo.
Pattonsburg structure	Daviess/Mo. Gentry/Mo.
Pearson anticline	Cass/Mo.
Penn Valley syncline	Jackson/Mo.
Pleasant Hill-Garden City-Dayton syncline	Cass/Mo.
Polo structure	Caldwell/Co.
Powell School fault	Jackson/Mo.
Prairie Point structure	Platte/Mo.
Prettyman anticline	Cass/Mo.
Raymore nose	Cass/Mo.
Raytown anticline	Jackson/Mo.
Red Bridge dome	Jackson/Mo.
Richmond-St. Joseph anticline	Buchanan/Mo. Ray/Mo.
Riner dome	Cass/Mo.

Table 2.5.1-6—{A Summary of the Structures of the Forest City Basin Tectonic Region}

(Page 3 of 3)

Structure	County/State
Robinson dome	Jackson/Mo.
Rock Creek nose	Jackson/Mo.
Rock Crusher dome	Cass/Mo.
Salisbury-Quitman anticline	Nodaway/Mo.
Savannah structure	Andrew/Mo.
Schwartz dome	Jackson/Mo.
Seba anticline	Cass/Mo.
Shawhan dome	Jackson/Mo.
Shoal Creek structure	Clay/Mo.
Sour dome	Cass/Mo.
South Plattsburg structure	Clinton/Mo.
Spring Hill syncline	Livingston/Mo.
Stark dome	Cass/Mo.
Tarkio structure	Andrew/Mo.
Trenton anticline	Grundy/Mo.
Underbrink dome	Cass/Mo.
Wallace State Park structure	Clinton/Mo.
Wells dome	Jackson/Mo.
West Dolan syncline	Cass/Mo.
West Grandview structure-West Grand view terrace	Jackson/Mo.
Western anticline	Cass/Mo.
Wiser dome	Jackson/Mo.

Table 2.5.1-7— {A Summary of the Structures of the Lincoln Fold Tectonic Region}

Structure	County/State
Adams County terrace	Clark/Mo.
Adams County terrace	Lewis/Mo.
Bowling Green syncline	Pike/Mo.
Cap au Gres fault	Lincoln/Mo.
Cuivre anticline	Lincoln/Mo.
Lincoln fold	Knox/Mo. Lincoln/Mo. Marion/Mo. Pike/Mo. Ralls/Mo. Shelby/Mo. Calhoun/Ill. Jersey/Ill.
Pittsfield-Hadley anticline	Lewis/Mo.
Troy-Brussels syncline (South Lincoln County syncline)	Lincoln/Mo.

Table 2.5.1-8—{A Summary of the Structures of The North-Central Missouri Tectonic Region}

(Page 1 of 2)

Structure	County/State
Ackerman structure	Bates/Mo.
Auxvasse Creek anticline	Callaway/Mo.
Big Spring anticline	Montgomery/Mo.
Blue Lick anticline	Saline/Mo.
Blue Ridge School anticline	St. Clair/Mo.
Bolivar-Mansfield fault system	St. Clair/Mo.
Browning and Purdin structure	Linn/Mo.
Browns Station anticline	Boone/Mo.
Brunswick structure	Chariton/Mo.
Centerview-Kansas City anticline	Johnson/Mo.
Cheltenham syncline	St. Louis/Mo.
College Mound-Bucklin anticline	Macon/Mo.
Cow Creek anticline	Saline/Mo.
Davis Creek anticline	Audrain/Mo.
Decaturville-Crooked Creek axis	Vernon/Mo.
Dupo anticline	St. Louis/Mo.
Eldorado Springs fault (Eldorado Springs North fault)	Bates/Mo. St. Clair/Mo.
Eureka-House Springs anticline	St. Louis/Mo.
Fish Creek anticline	Saline/Mo.
Florissant dome	St. Louis/Mo.
Fox Hollow fault	Boone/Mo.
Golden City-Miller anticline	Barton/Mo.
Howard County syncline	Howard/Mo.
Humansville anticline	St. Clair/Mo.
Jasper anticline	Barton/Mo.
Kirksville-Mendota anticline	Adair/Mo. Putnam/Mo.
Knobnoster anticline	Johnson/Mo.
La Due-Freeman anticline	Henry/Mo.
Lamar syncline	Barton/Mo.
Leon-Powersville anticline	Putnam/Mo.
Lewis trough	Henry/Mo.
Long dome	Bates/Mo.
Macon-Sullivan trough	Sullivan/Mo.
Mexico anticline	Audrain/Mo.
Milan structure	Sullivan/Mo.
Mineola structure (Mineola dome)	Montgomery/Mo.
Nashville-Carthage sag	Barton/Mo.
Newport basin	Barton/Mo.
North St. Louis syncline	St. Louis/Mo.
Pape graben	St. Clair/Mo.
Saline City fault-Saline City anticline-Saline County arch-Fish Creek anticline	Saline/Mo.
Salisbury-Quitman anticline	Chariton/Mo.
Salt Fork fault	Saline/Mo.
Schell City-Rich Hill anticline	Bates/Mo. Vernon/Mo.
Springs North fault)	St. Clair/Mo.

Table 2.5.1-8—{A Summary of the Structures of The North-Central Missouri Tectonic Region}

(Page 2 of 2)

Structure	County/State
St. Louis depression	St. Charles/Mo. St. Louis/Mo.
St. Louis fault	St. Louis/Mo.
Swarts-Garland dome	Vernon/Mo.
Trenton anticline	Linn/Mo.
Vernon syncline	Vernon/Mo.
Warren County anticline	Warren/Mo.
Weaubleau Creek structural complex	St. Clair/Mo.
Woodland Mills structure	Linn/Mo.
Workhouse anticline *(see Dupo anticline)*	St. Louis/Mo.

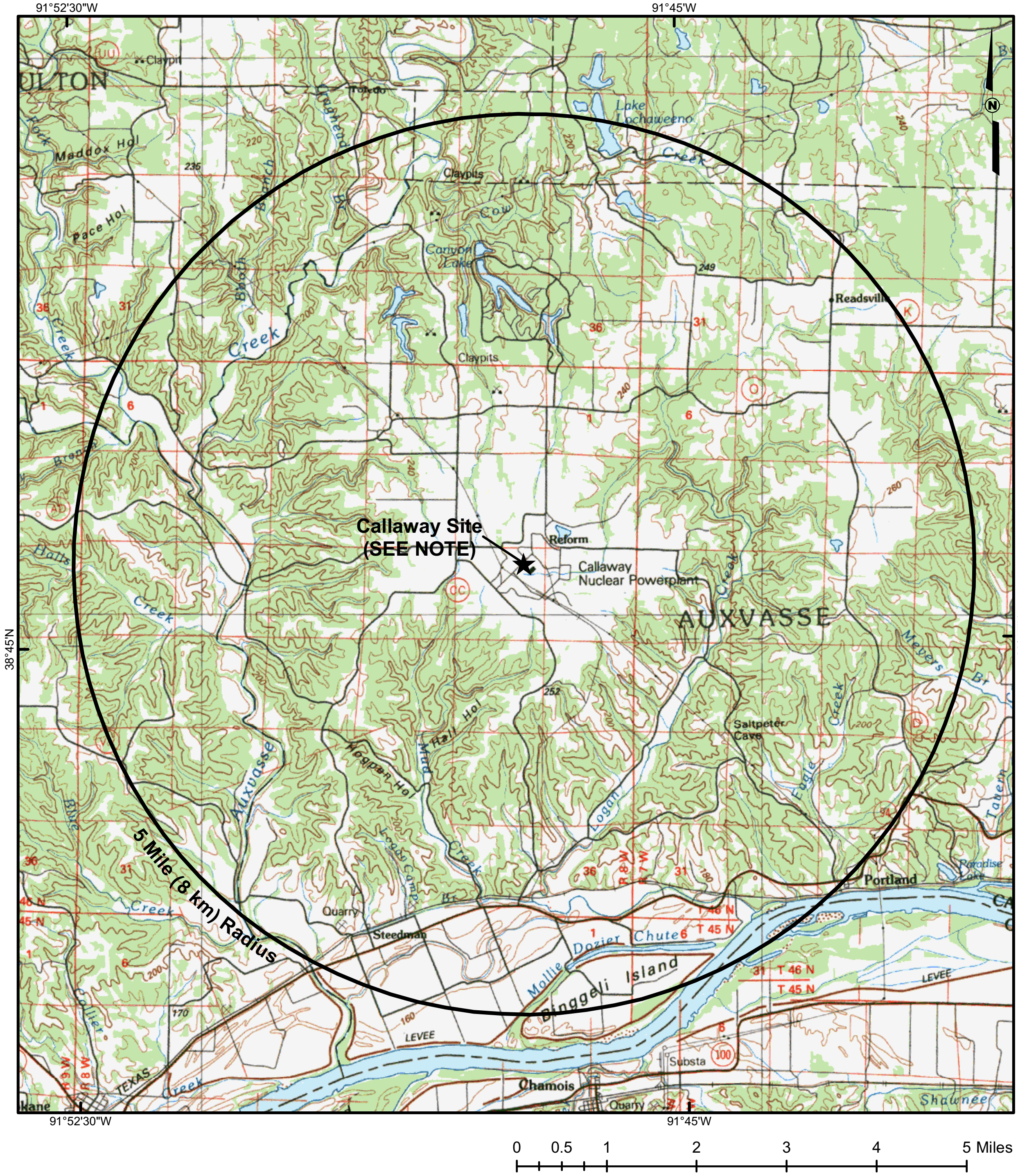
Table 2.5.1-9—{Callaway Plant Unit 2, Site Vicinity Formation Thicknesses (ft)}

						DNR MEGA 2007 Well Logs														
						WELL INFORMATION BY COUNTY														
		Unit 1 FSAR		DNR Reports		Callaway						Boone	Gasconade	Audrain	RESULTS			Unit 2 FSAR (PCRA Drilling)		
System	Formation or Unit	min.	max	min.	max	27975	28076	28347	28466	28833	27708	18139	26254	25355	Min	Max	Avg	Min	Max	Avg
Q (Palest)	Loess	3	15															4.5	22.0	9.4
	Accretion-Gley	4	28															0.0	25.5	15.8
	Glacial Till	3	27															2.5	21.0	10.9
Penn	Graydon Conglomerate	4	50															11.5	54.8	32.2
Miss	Burlington	0	42	10	42													0.0	19.7	6.5
	Bushberg	0	8	0	12													0.0	7.0	2.2
Def	Snyder Creek	10	47	8	40													22.4	32.2	29.3
	Callaway	11	47	18	65													31.3	41.2	37.7
Or	Joachim	0	10	0	10													0.0	0.0	0.0
	St. Peter	0	100	25	75													0.0	0.0	0.0
	Paleokarst-rubble	0	36															0.0	0.0	0.0
	Coffer			175	200		235		270	210	230	295			210	295	248			
	Jefferson City			150	180	165	170	150	170	155	170	160			150	170	163			
	Roubidoux	830	900	125	200	105	95	125	100	170	115	115			95	170	118			
	Gasconade			250	300	305	310	285	260	290	230	225			225	310	272			
	Gunter Member			20	40	30	20	30	25	30	25	20		15	15	30	24			
Came	Eminence						155		225	180	235	175		90	90	235	177			
	Potosi						145		130		175	55		45	45	175	110			
	Derby-Doe Run	700	860						145			135		325	135	325	202			
	Davis											170		155	155	170	163			
	Bonneterre											295	295	330	295	330	307			
	Lamotte	160	300									130	385	245	130	385	253			
Pre-Came	Pre-Cambrian																			

	MIN	MAX	AVG
Depth to top of Pre-Cambrian rocks (ft)	1617.2	2818.4	2180.1

FSAR: Tables 2.5.1

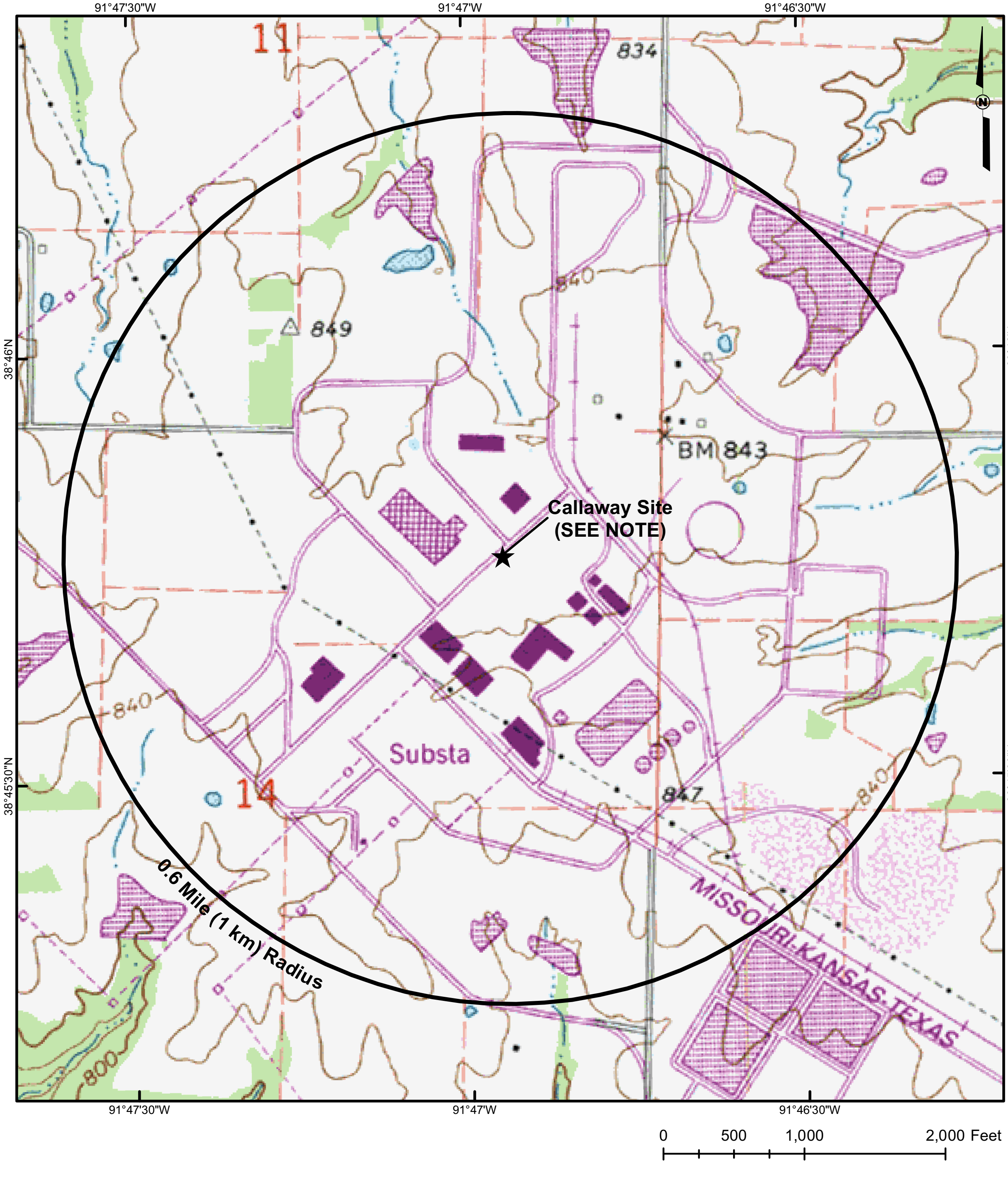
Figure 2.5.1-1—{Site Area Topographic Map} 5 Mile (8 km) Radius



NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AS THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY PLANT UNIT 1 AND REACTOR FOR CALLAWAY PLANT UNIT 2.

REFERENCE:
USGS,1985a.

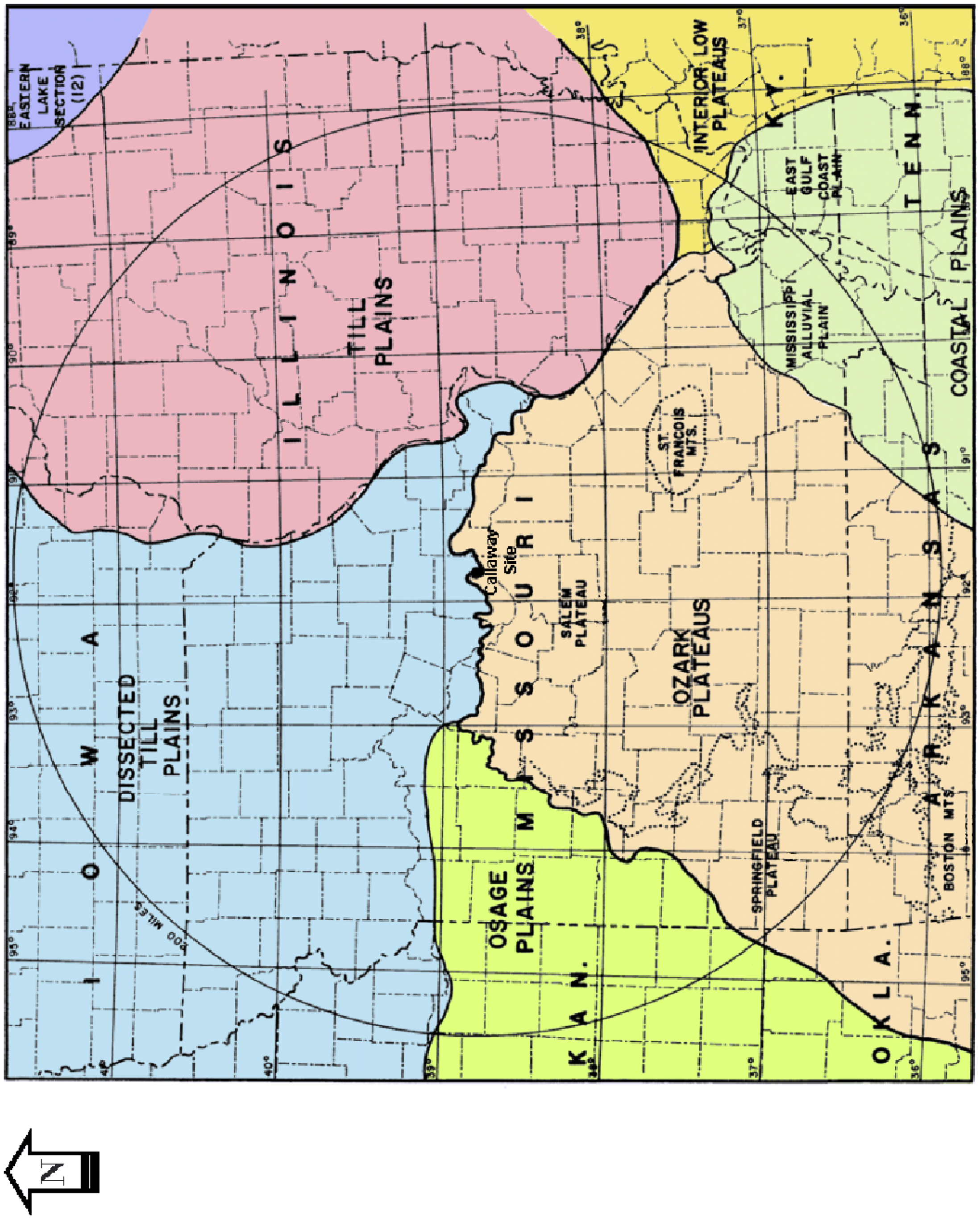
Figure 2.5.1-2—{Site Topographic Map}
0.6 Mile (1 km) Radius



NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AS THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY PLANT UNIT 1 AND REACTOR FOR CALLAWAY PLANT UNIT 2.

REFERENCE:
USGS,1985b.

Figure 2.5.1-3—{Map of Physiographic Provinces}



Modified from Figure 2.5-2 Regional Physiography) in Callaway Unit 1 FSAR (AmerenUE, 2004).

FSAR: Figures 2.5.1

Figure 2.5.1-4—{Limits of Glaciation}

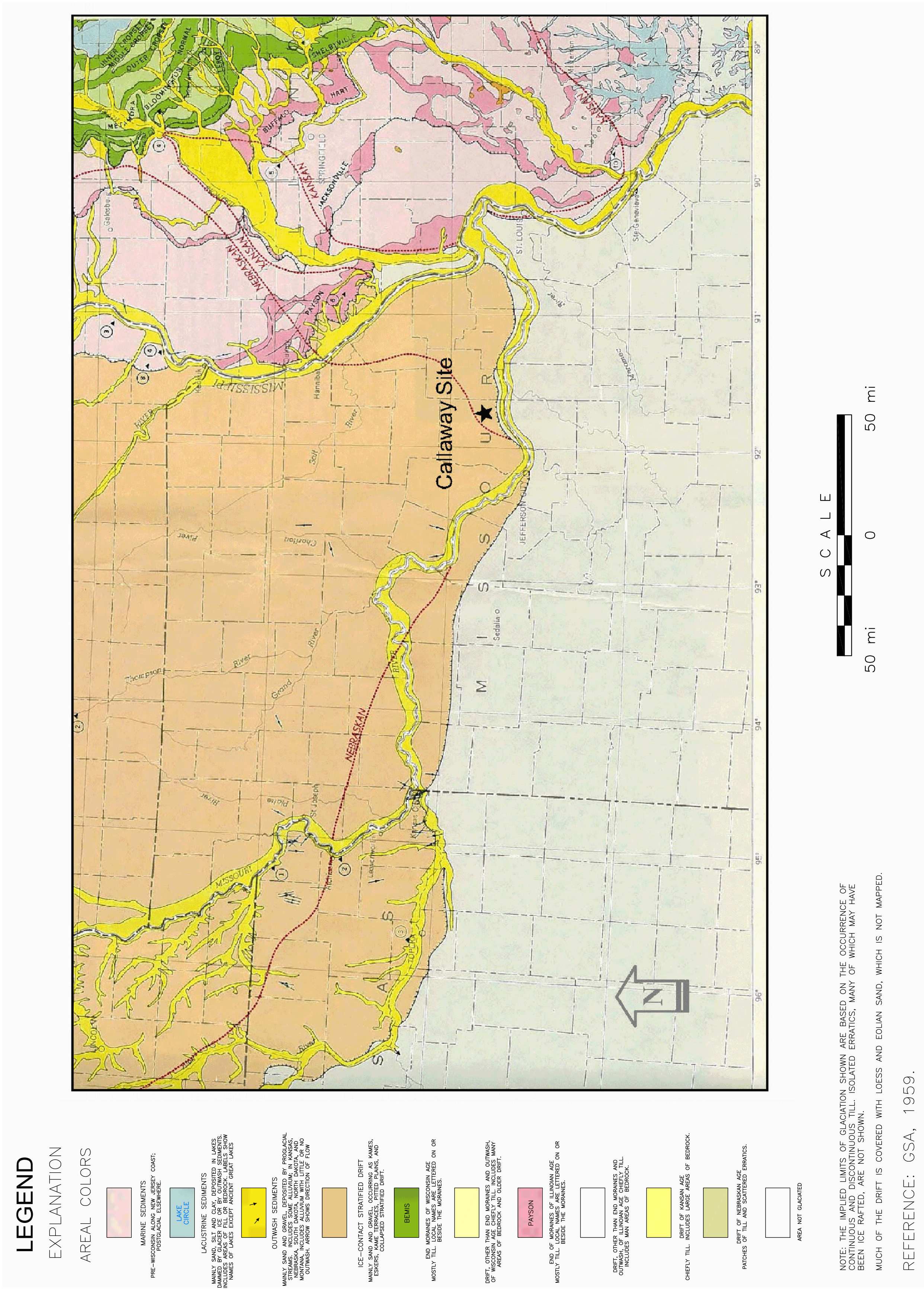
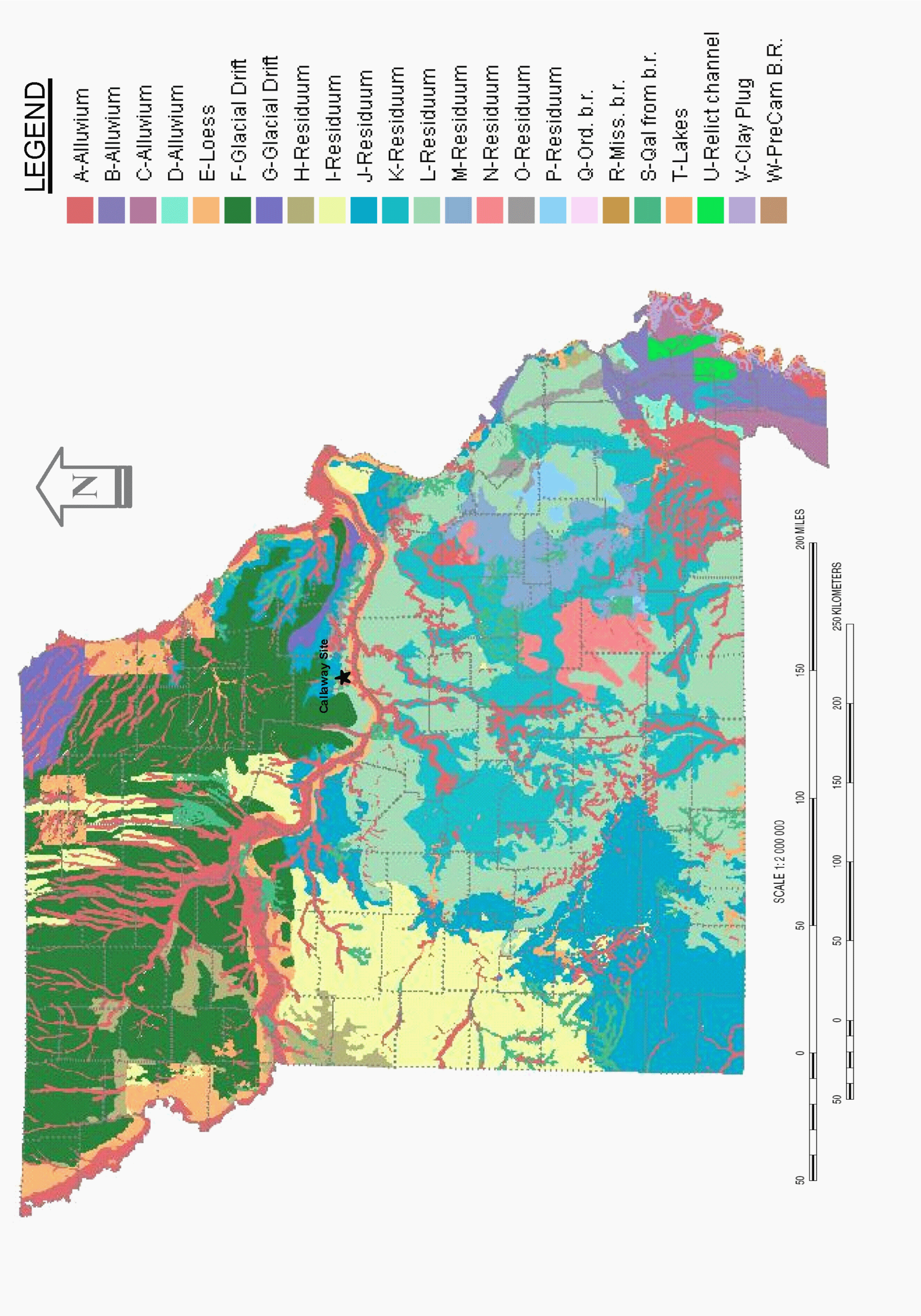


Figure 2.5.1-5—{Central Stable Region}

Reference: Modified from Figure 2.5-4 in Callaway Plant Unit 1
FSAR (AmerenUE 2004)

Figure 2.5.1-6—{Missouri Surficial Deposits}



Modified from MODNR, 2007.

Figure 2.5.1-7—{Regional Domes and Basins}

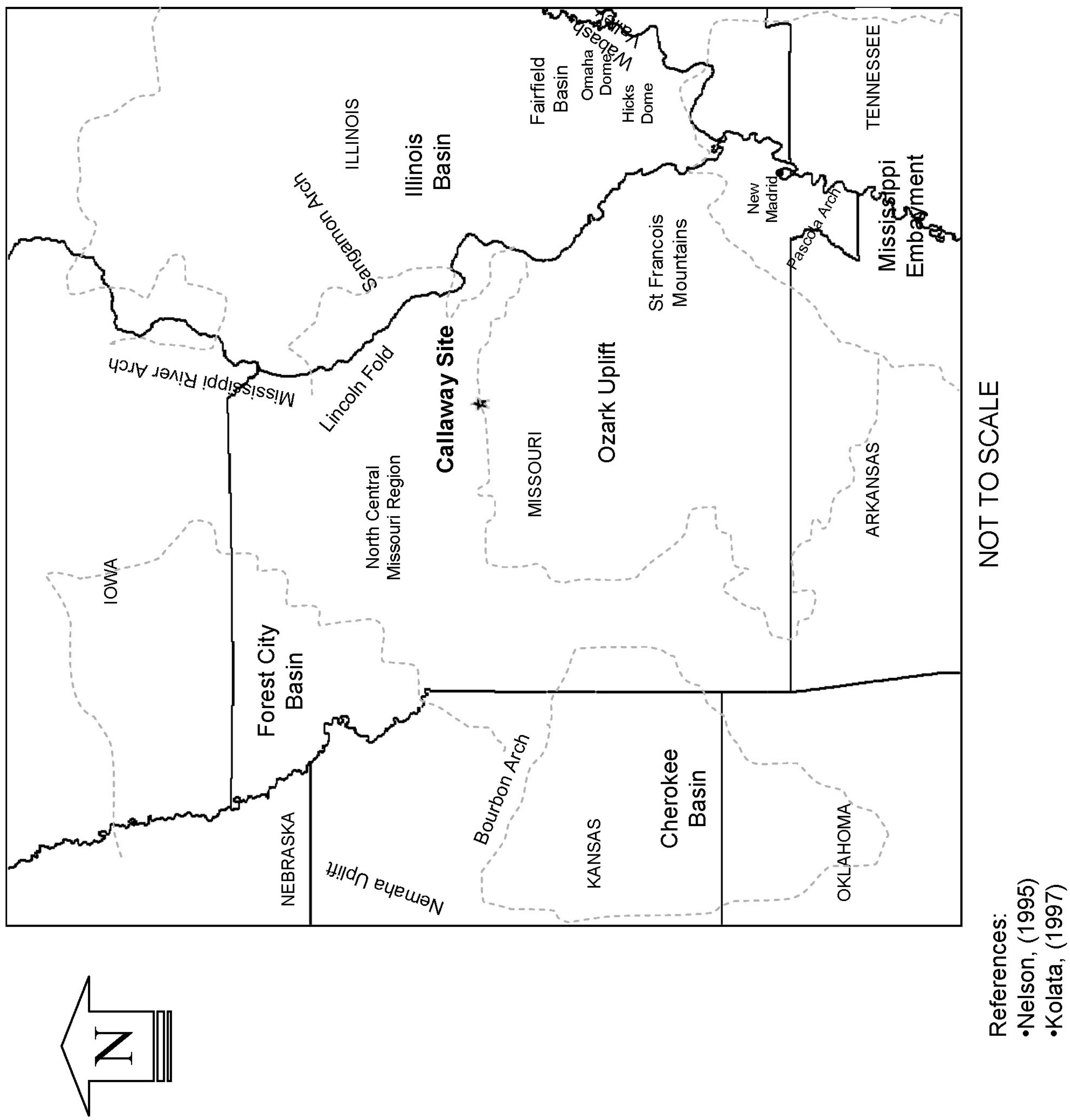
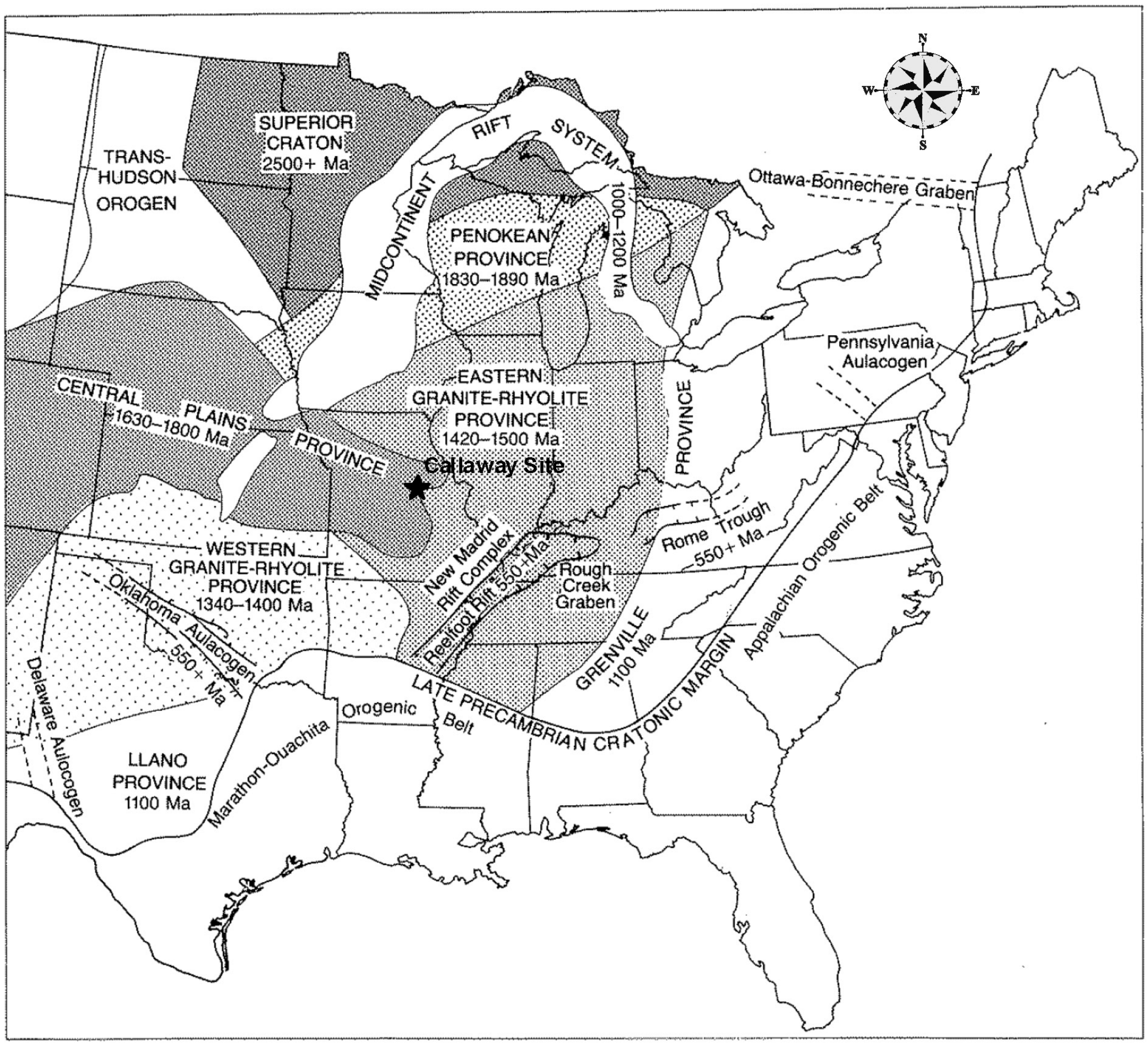


Figure 2.5.1-8—{Precambrian Geologic Provinces}



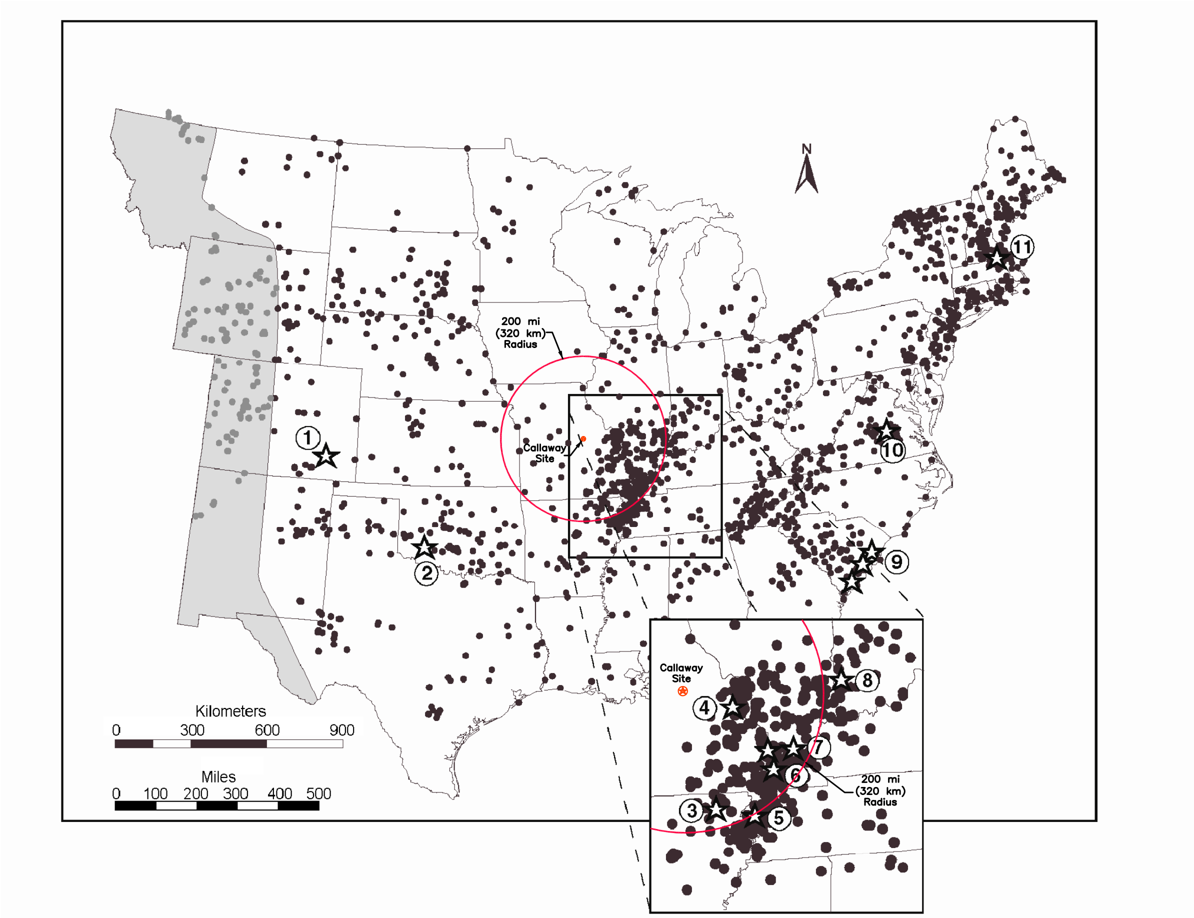
NOT TO SCALE

REFERENCE: Nelson, 1995.

Figure 2.5.1-9—{General Stratographic Column of the Region}

MAJOR DIVISIONS OF GEOLOGIC TIME		ROCK and SOIL TYPES AND DISTRIBUTION	REPRESENTATIVE FORMATIONS - REGIONAL GEOLOGY
ERAS	**PERIODS**		
CENOZOIC	**QUATERNARY** 0-2 million years ago	Sand, gravel, clay and shale; largely restricted to Southeastern Lowlands.	Loveland Loess, Roxana Silt, Gilman Canyon Loess, Peoria Loess
	TERTIARY 2-64 million years ago	Sand, gravel, clay and shale; largely restricted to Southeastern Lowlands.	Clayton, Porters Creek, Ackerman, Lafayette
MESOZOIC	**CRETACEOUS** 64-136 million years ago	Clay and sand; restricted to Southeastern Lowlands.	McNairy, Owl Creek
	JURASSIC 136-180 million years ago	No rocks in Missouri of Jurassic age.	None
	TRIASSIC 180-230 million years ago	No rocks in Missouri of Triassic age.	None
PALEOZOIC	**PERMIAN** 230-280 million years ago	Sandstone; known from single locality in Atchison County.	None
	PENNSYLVANIAN 280-310 million years ago	Shale, limestone, sandstone, clay and coal; present in more than two-thirds of the state's counties; extensive in western and northern Missouri.	Graydon Chert Conglomerate, Numerous formations in Atokan, Desmoinesian, Missourian, and Virgilian Series
	MISSISSIPPIAN 310-345 million years ago	Predominantly limestone, some shales; principal areas of outcrop are southwestern, central, east-central, and northeastern parts of the state.	Chouteau Group, Hannibal, Bachelor, Bushberg Sandstone, Burlington, Keokuk, Warsaw, Salem, St. Louis, Ste. Genevieve, Auxvasse
	DEVONIAN 345-400 million years ago	Predominantly limestone; exposed in central, eastern and southeastern Missouri.	Bushberg, Snyder Creek
	SILURIAN 400-425 million years ago	Predominantly limestone; exposed in northeastern and southeastern Missouri.	Sexton Creek, Bryant Knob, Bowling Green, Joliet, Bainbridge
	ORDOVICIAN 425-500 million years ago	Dolomite (magnesian limestone), limestone, sandstone, and shale; extensively exposed in Ozark area as far north as Montgomery County and west to McDonald and St. Clair counties; also exposed in parts of Ralls, Pike, and Lincoln counties.	Gasconade, Roubidoux, Jefferson City, Cotter Powell, Smithville, St. Peter, Everton, Dutchtown, Joachim, Plattin, Decorah, Kimmswick, Maquoketa, Noix-Cyrene, Cape, Maquoketa Group, Leemon
	CAMBRIAN 500-600 million years ago	Dolomite, sandstone and shale; major outcrops restricted to St. Francois Mountians area.	Lamotte, Bonneterre, Davis, Derby-Doe Run, Potosi, Eminence
PRECAMBRIAN 600 million - 4 billion years ago		Igneous and metamorphic rocks; igneous exposed in St. Francois Mountains area.	Basement Rocks

Figure 2.5.1-10—{Quaternary Class "A" features in the CEUS}

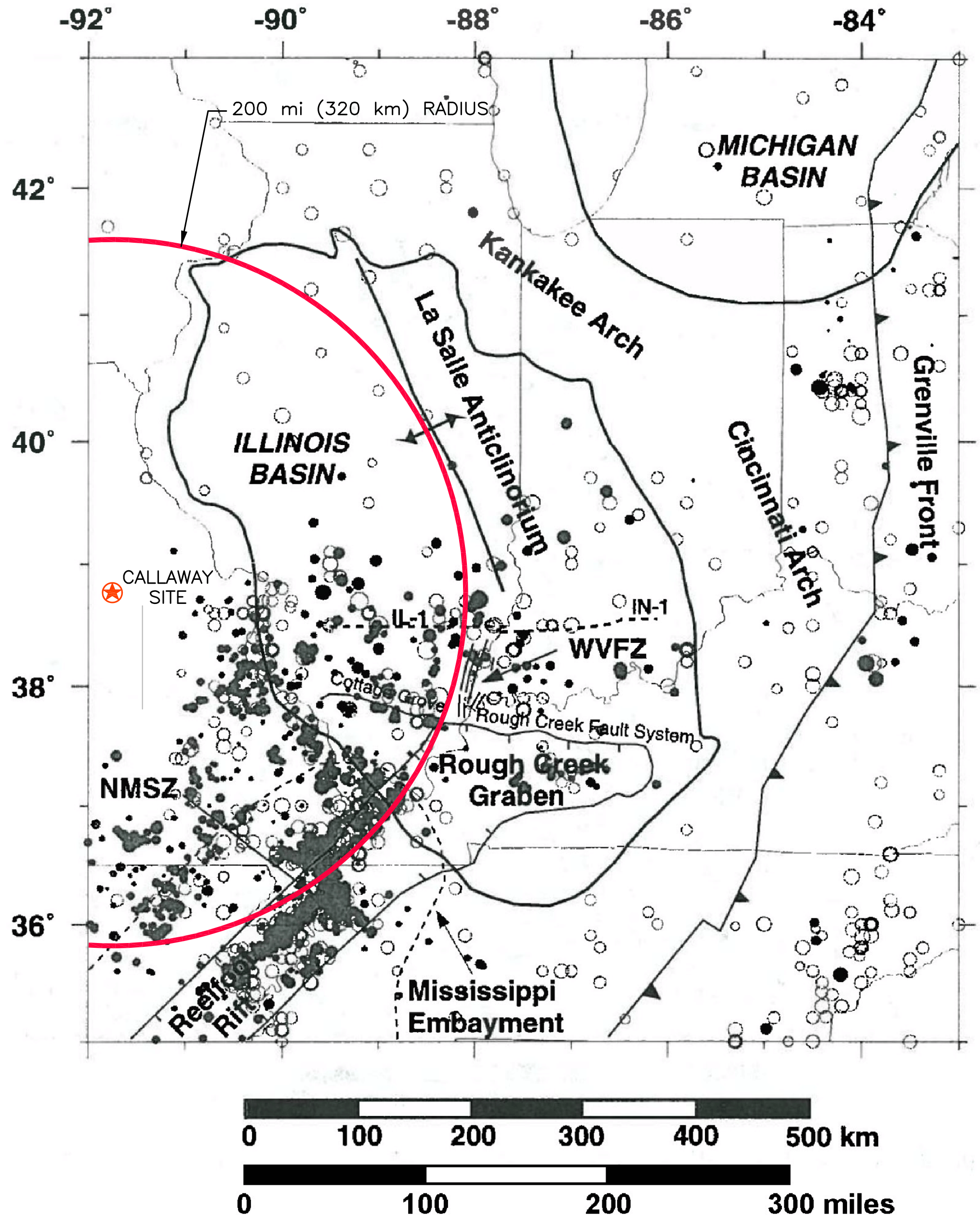


LEGEND.

1. - Cheraw fault, Colorado
2. - Meers fault, Oklahoma
3. - Western Lowlands liquefaction features, Missouri- Arkansas
4. - St. Louis-Cape Girardeau liquefaction features, Missouri-Illinois
5. - Reelfoot scarp and New Madrid seismic zone, Missouri-Arkansas-Tennessee
6. - Thebes Gap area, Missouri
7. - Fluorspar Area fault complex, Illinois-Kentucky
8. - Wabash Valley liquefaction features, Indiana-Illinois
9. - Charleston-Bluffton-Georgetown liquefaction features, South Carolina-North Carolina
10. - Central Virginia seismic zone
11. - Newbury liquefaction features, Massachusetts.

NOTE: Solid dots are historical earthquakes of mb 3.0 or greater; seismicity catalog provided by C. Mueller, USGS 2008.

Figure 2.5.1-11—{Structural Features and Seismicity of the Central US}



LEGEND

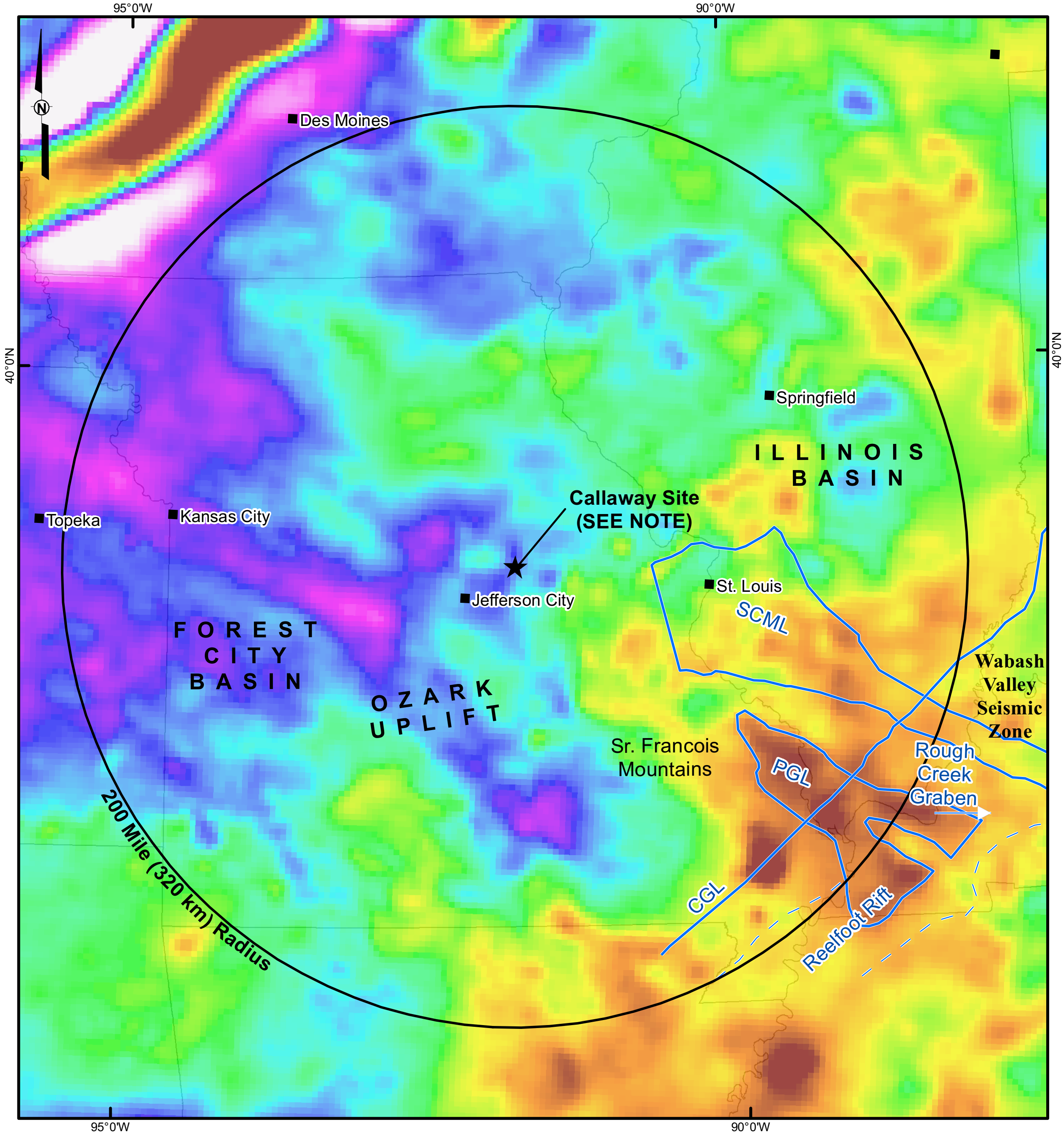
- Filled Circles, earthquake epicenters located by the Memphis State University and St. Louis University networks.
- Open Circles, epicenters of historic earthquakes

NMSZ New Madrid Seismic Zone

WVFZ Wabash Valley Fault Zone

REFERENCE: Modified from Bear, 1997

Figure 2.5.1-12—{Regional Gravity Anomaly Map}



LEGEND

0 50 100 Miles

Gravity Anomaly

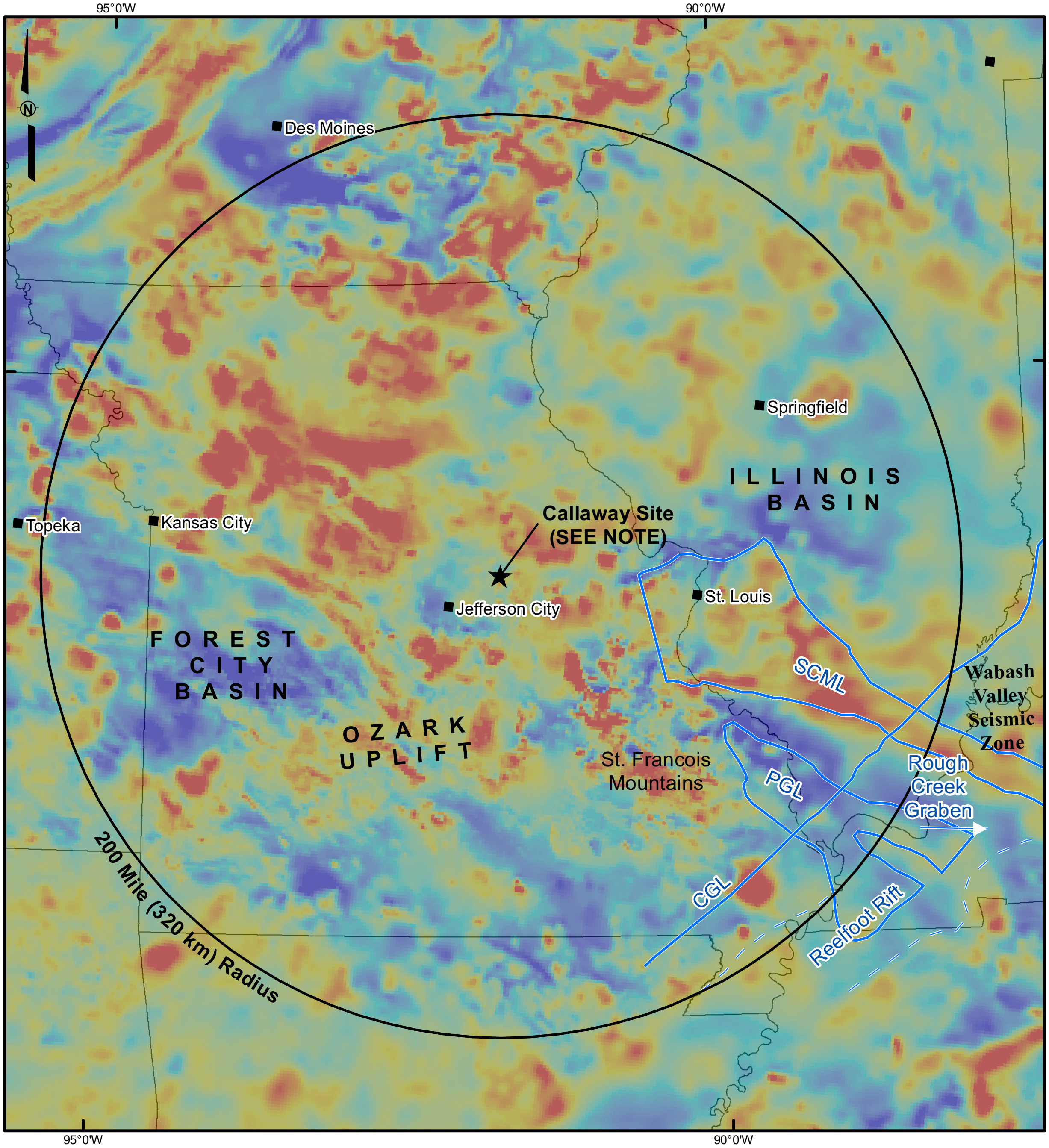
0 High : 65.6537

Low : -112.67

CGL - Commerce Geophysical Lineament
PGL - Paducah Gravity Lineament
SCML - South-Central Magnetic Lineament

NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED REACTOR FOR CALLAWAY UNIT 2.
REFERENCE:
- Kucks, 1999.

Figure 2.5.1-13—{Regional Magnetic Anomaly Map}



LEGEND

Aeromagnetics

High : 6012.16

0 -

Low : -3086.11

CGL - Commerce Geophysical Lineament
PGL - Paducah Gravity Lineament
SCML - South-Central Magnetic Lineament

NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCE:
• USGS, 2002.
• Kolata, 1997.

Figure 2.5.1-14—{Regional Gravity Anomaly Map with Earthquake Overlays}

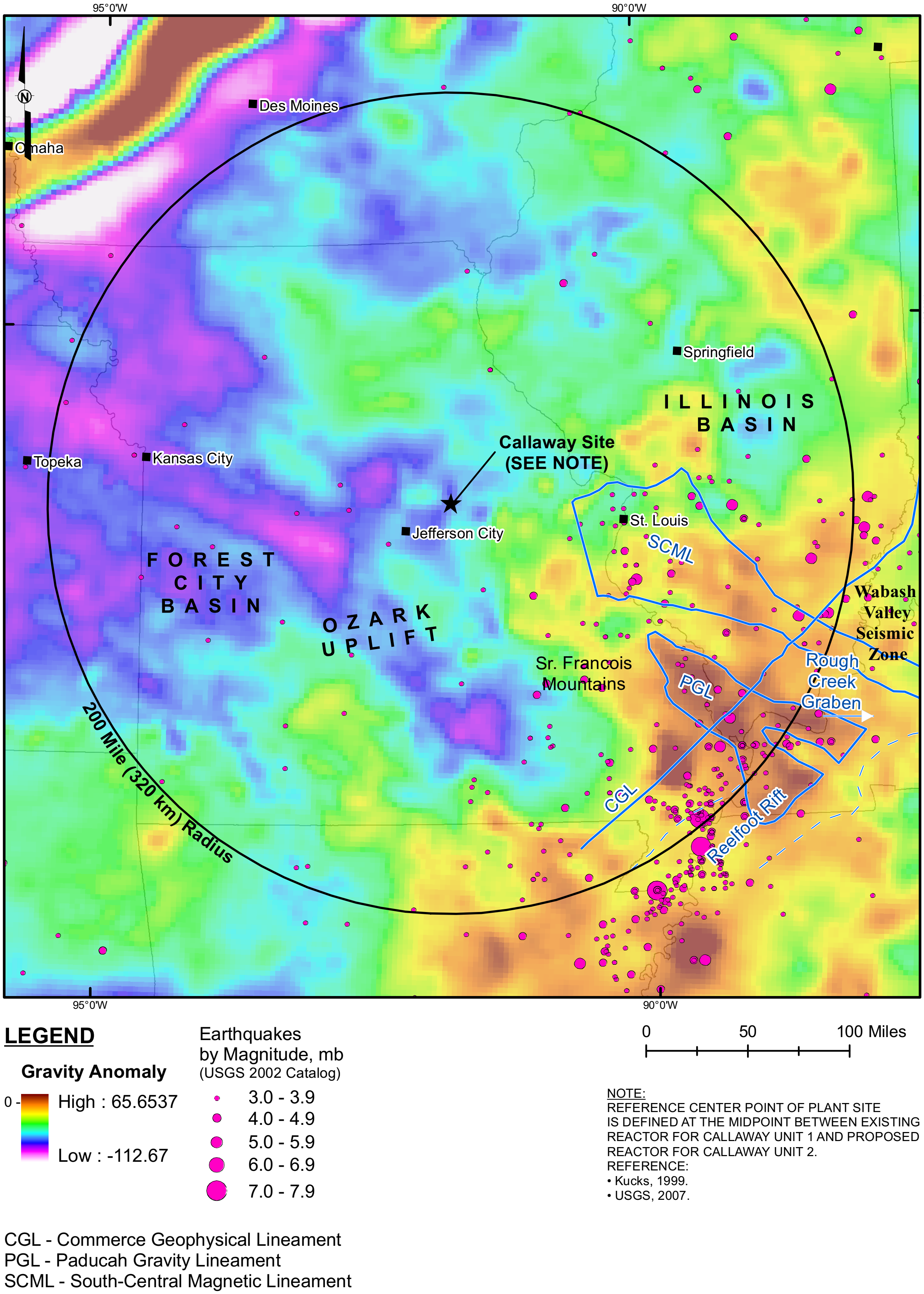
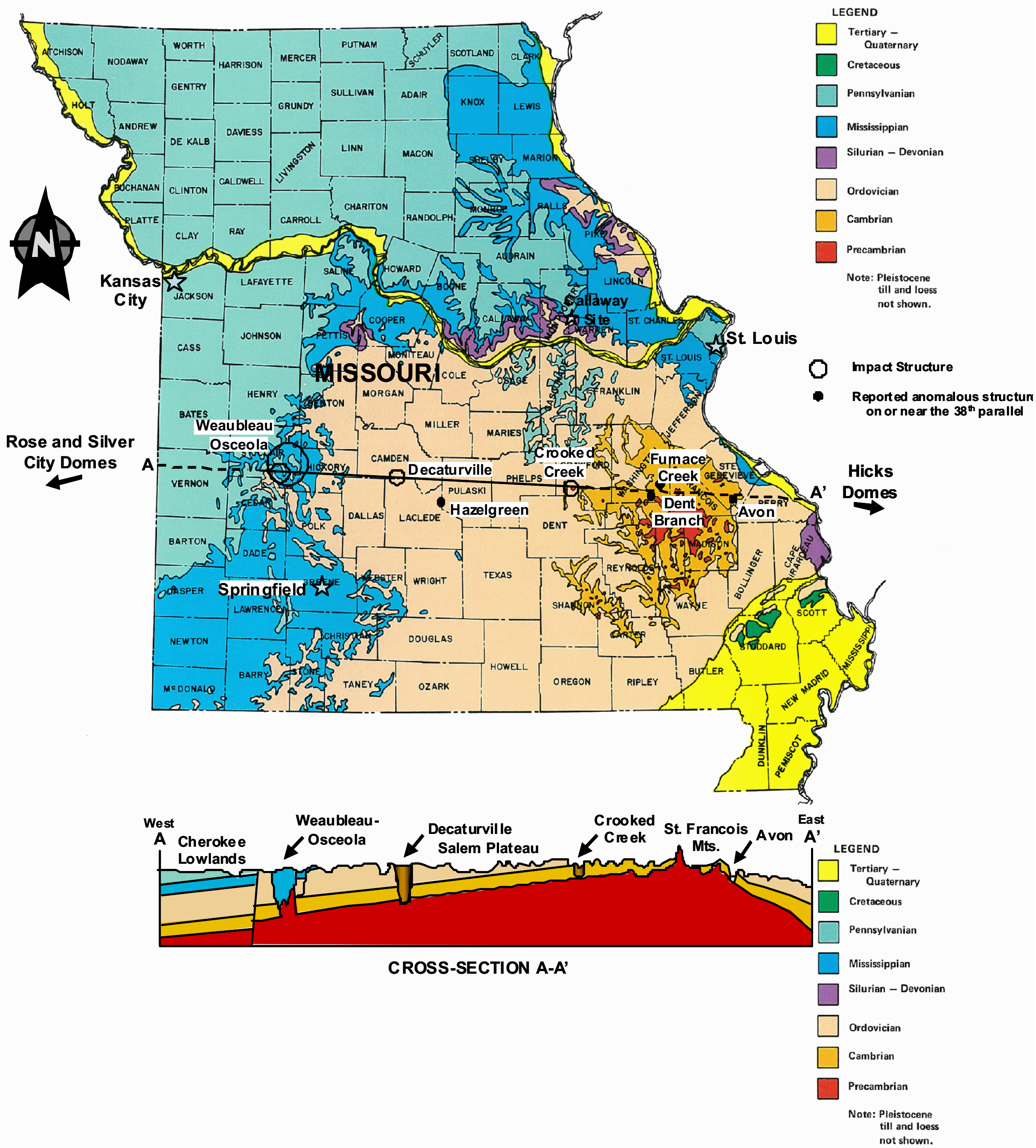
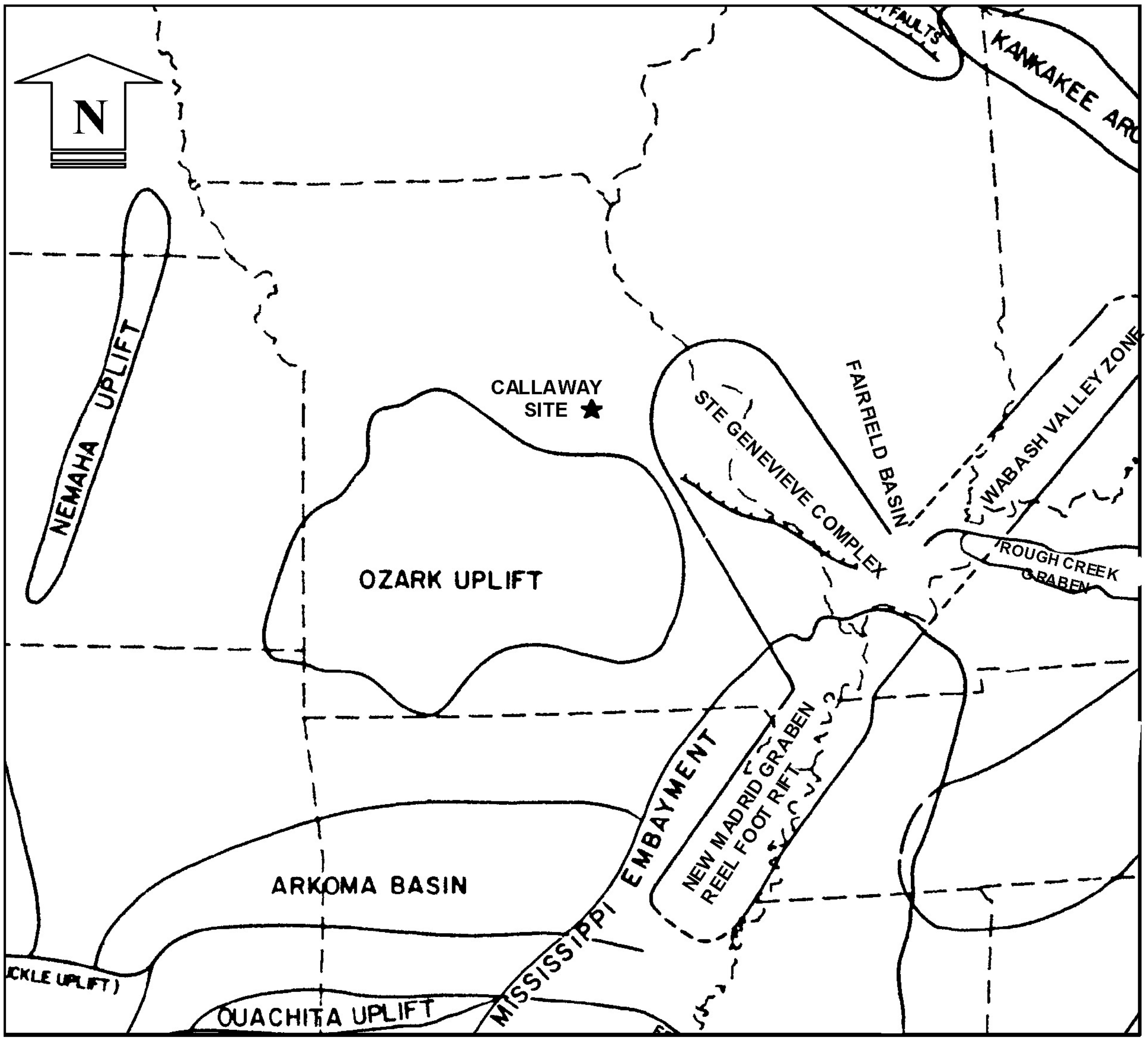


Figure 2.5.1-15—{Cryptoexplosive Structures}



REFERENCE:
Modified from Evans, 2005, and MODNR 1990

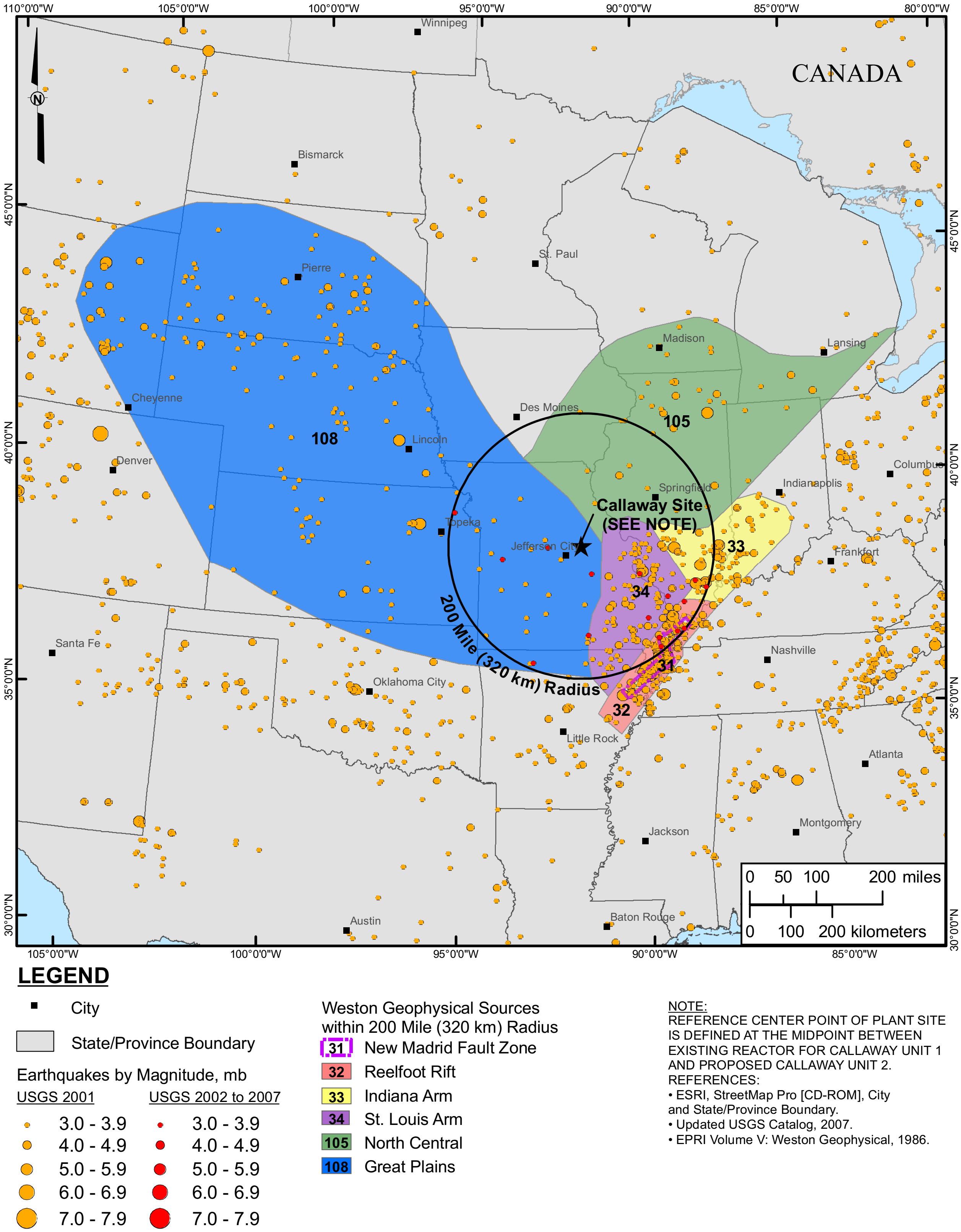
Figure 2.5.1-16—{Tectonic Interpretation by Weston Geophysical Corporation}



NOT TO SCALE

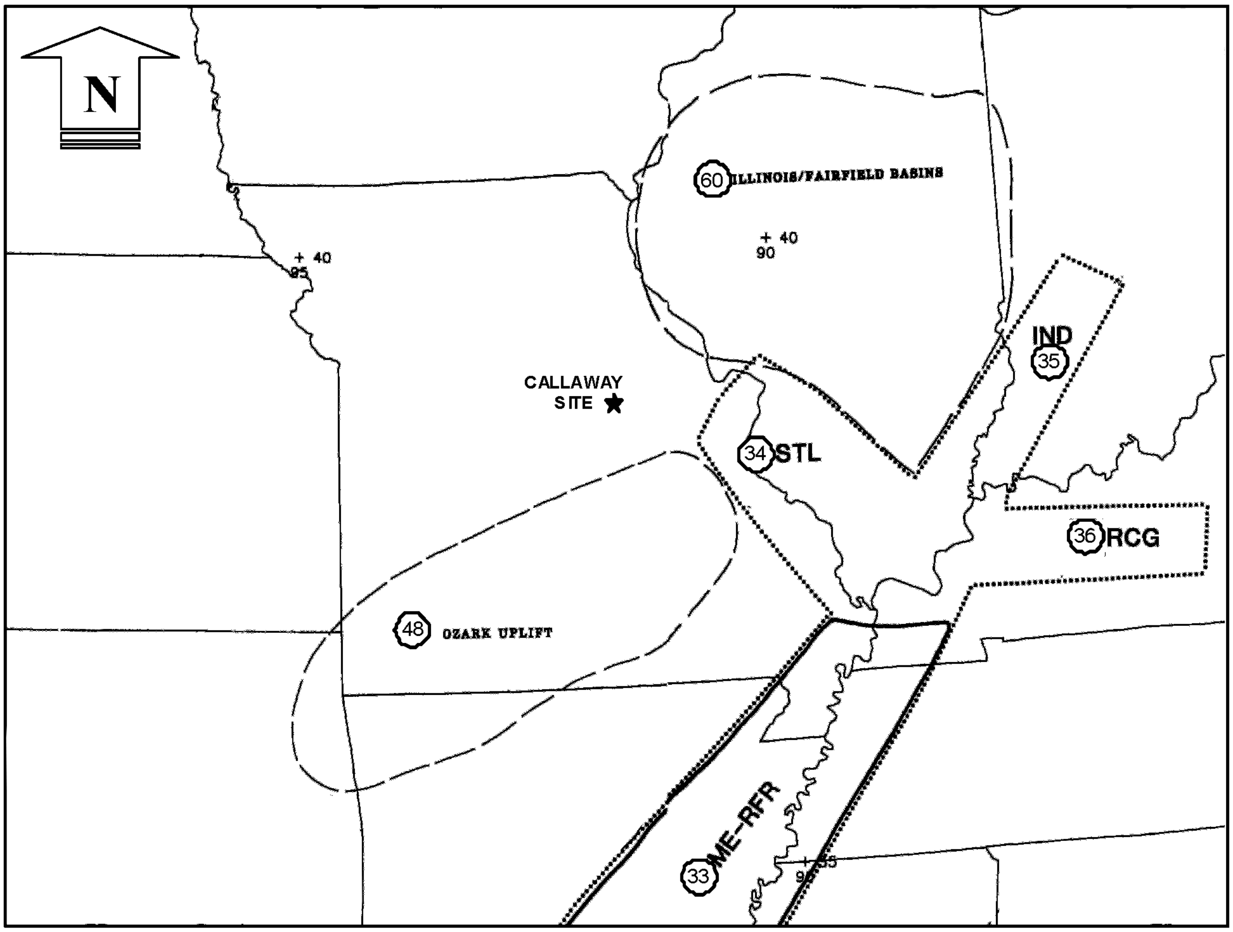
Reference: Modified from EPRI (1986), Volume 5

Figure 2.5.1-17—{Seismic Source Zones Interpretation by Weston Geophysical Corporation}



NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCES:
• ESRI, StreetMap Pro [CD-ROM], City and State/Province Boundary.
• Updated USGS Catalog, 2007.
• EPRI Volume V: Weston Geophysical, 1986.

Figure 2.5.1-18—{Tectonic Interpretation by Dames & Moore}



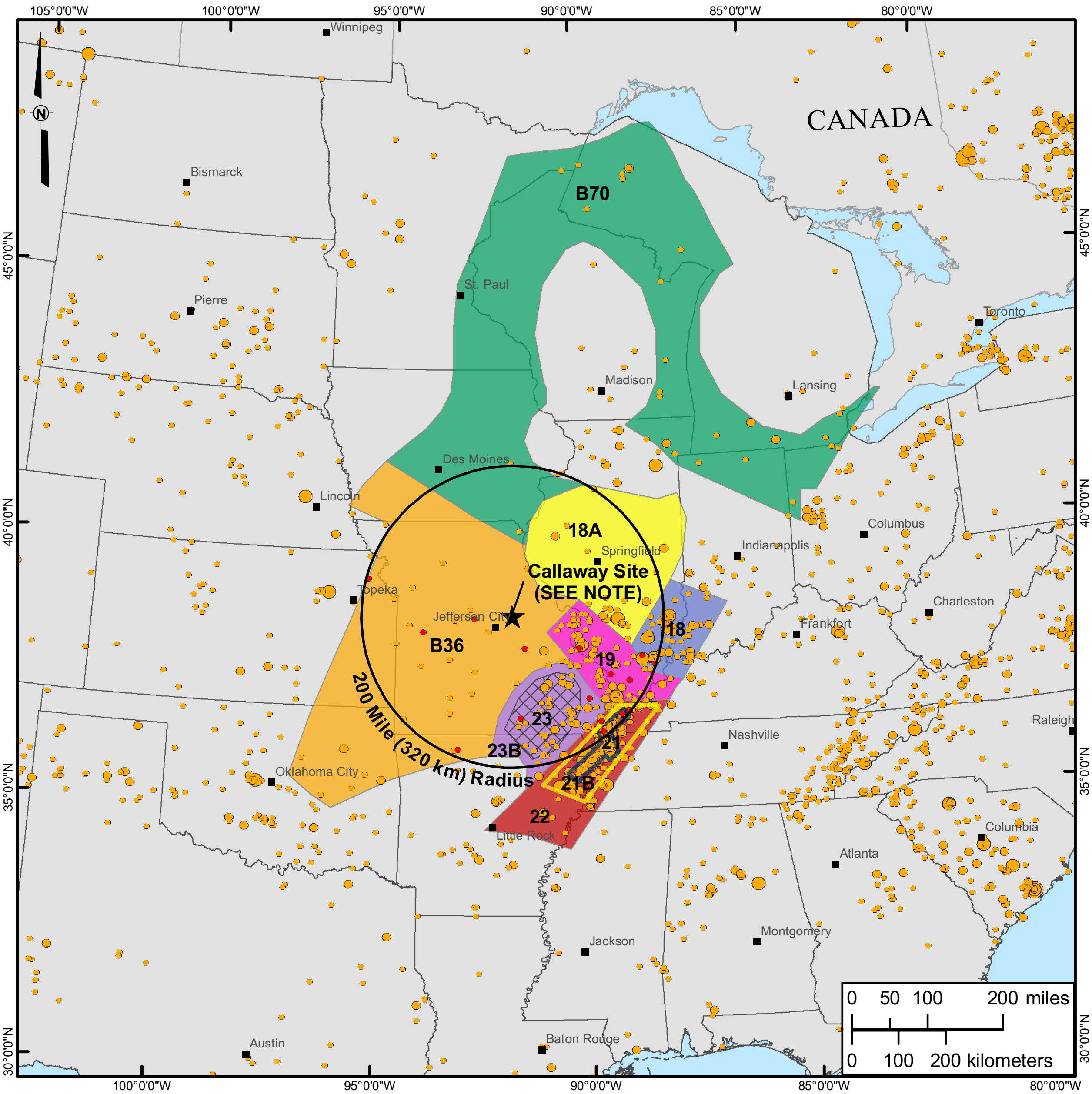
NOT TO SCALE

Legend for Tectonic Features:

33 Central Reelfoot Rift / New Madrid Seismic Zone
34 St Louis Arm (Eocambrian Rifts)
35 Southern Indiana Arm (Eocambrian Rifts)
36 Rough Creek Graben (Eocambrian Rifts)
48 Ozark Uplift
60 Illinois / Fairfield Basin

Reference: Modified from EPRI (1986), Volume 6

Figure 2.5.1-19—{Seismic Source Zones Interpretation by Dames & Moore}



LEGEND

■ City

State/Province Boundary

Earthquakes by Magnitude, mb

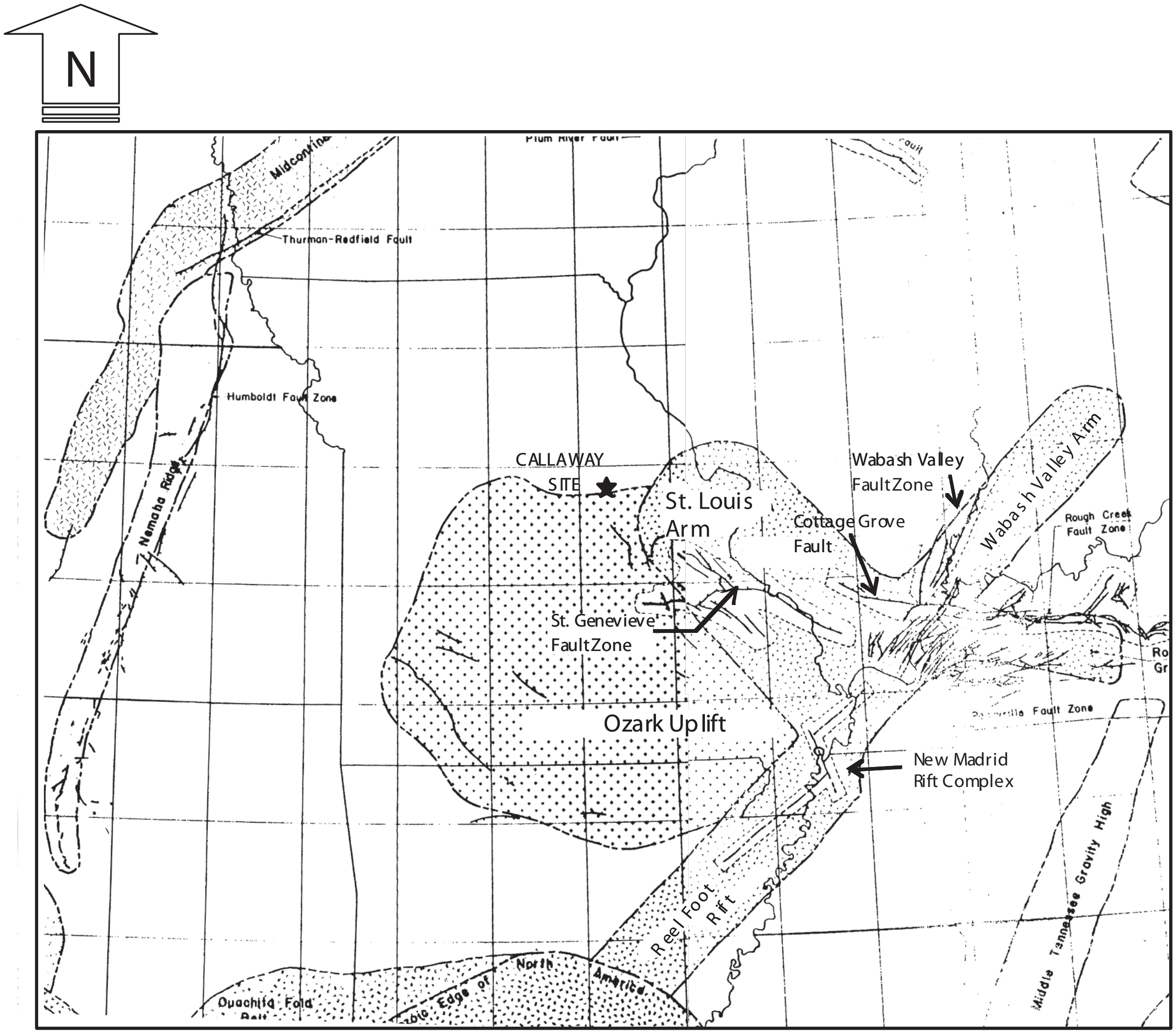
USGS 2001	USGS 2002 to 2007
3.0 - 3.9	3.0 - 3.9
4.0 - 4.9	4.0 - 4.9
5.0 - 5.9	5.0 - 5.9
6.0 - 6.9	6.0 - 6.9
7.0 - 7.9	7.0 - 7.9

Dames and Moore Sources within 200 Mile (320 km) Radius

- 18 Southern Illinois/ Southern Indiana/ Fairfield Basin
- 18A Illinois Basin
- 19 St. Louis Arm
- 21 New Madrid Compression Zone
- 21B New Madrid Count Zone
- 22 Reelfoot Rift
- 23 Eastern Ozarks
- 23B Default (Regional Source)
- B36 Midcontinent Province
- B70 Wisconsin-Michigan Block

NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCES:
- ESRI, StreetMap Pro [CD-ROM], City and State/Province Boundary.
- Updated USGS Catalog, 2007.
- EPRI Volume VI: Dames and Moore, 1986

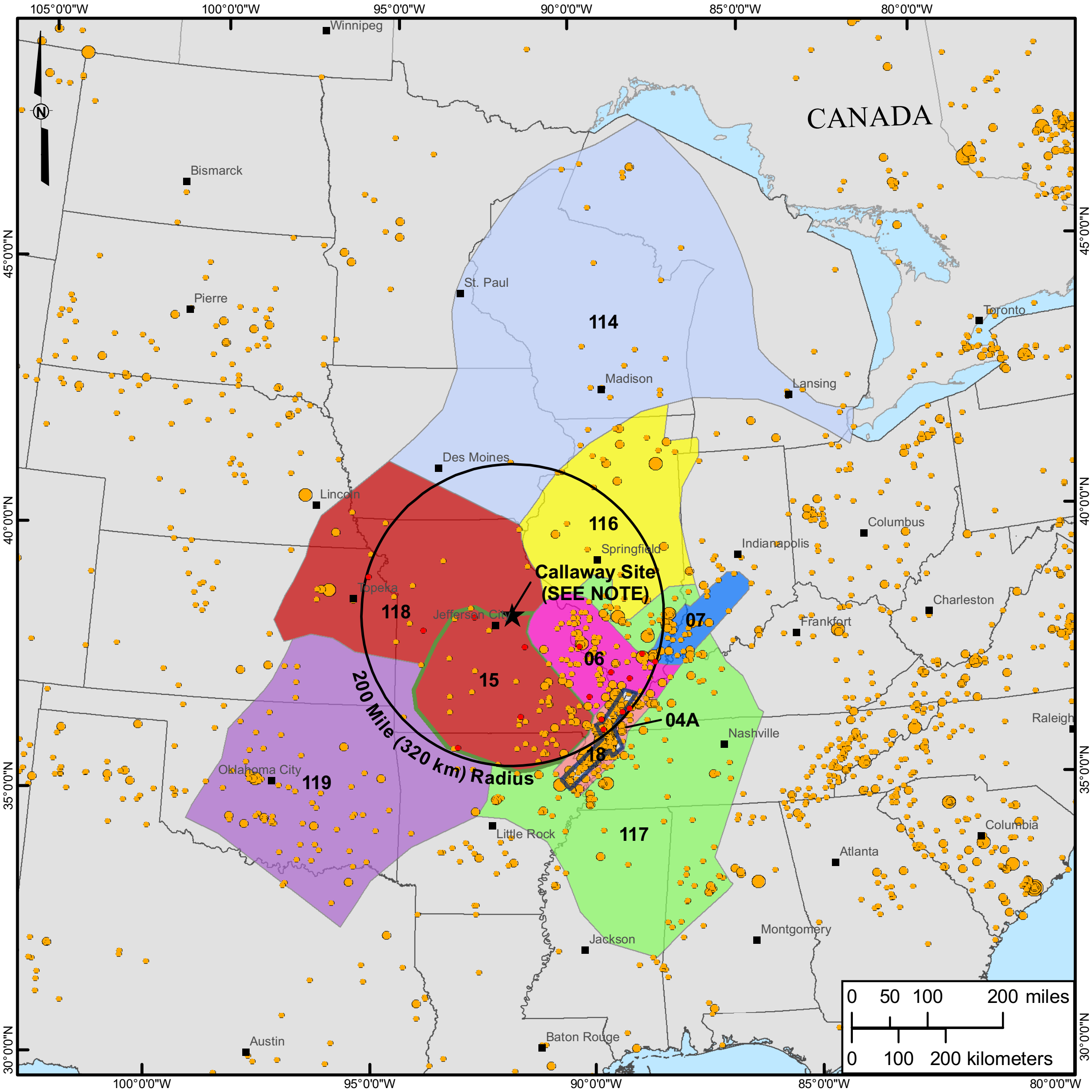
Figure 2.5.1-20—{Tectonic Interpretation by Law Engineering Testing Company}



NOT TO SCALE

Reference: Modified from EPRI (1986), Volume 6

Figure 2.5.1-21—{Seismic Source Zones Interpretation by Law Engineering Testing Company}



LEGEND

■ City

State/Province Boundary

Earthquakes by Magnitude, mb

USGS 2001	USGS 2002 to 2007
3.0 - 3.9	3.0 - 3.9
4.0 - 4.9	4.0 - 4.9
5.0 - 5.9	5.0 - 5.9
6.0 - 6.9	6.0 - 6.9
7.0 - 7.9	7.0 - 7.9

Law Engineering Sources within 200 Mile (320 km) Radius

- 04A Reelfoot Rift
- 06 St Louis Arm of the New Madrid Rift Complex
- 07 Wabash Valley Arm
- 15 Ozark Uplift
- 18 Postulated Faults in Reelfoot Rift
- 114 Wisconsin Block
- 116 Illinois Block
- 117 Mississippi Embayment
- 118 Missouri Block
- 119 Eastern Mid-Continent

NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCES:
- ESRI, StreetMap Pro [CD-ROM], City and State/Province Boundary.
- Updated USGS Catalog, 2007.
- EPRI Volume VII: Law Engineering, 1986.

Figure 2.5.1-22—{Tectonic and Seismic Source Zones Interpretation by Woodward-Clyde Consultants}

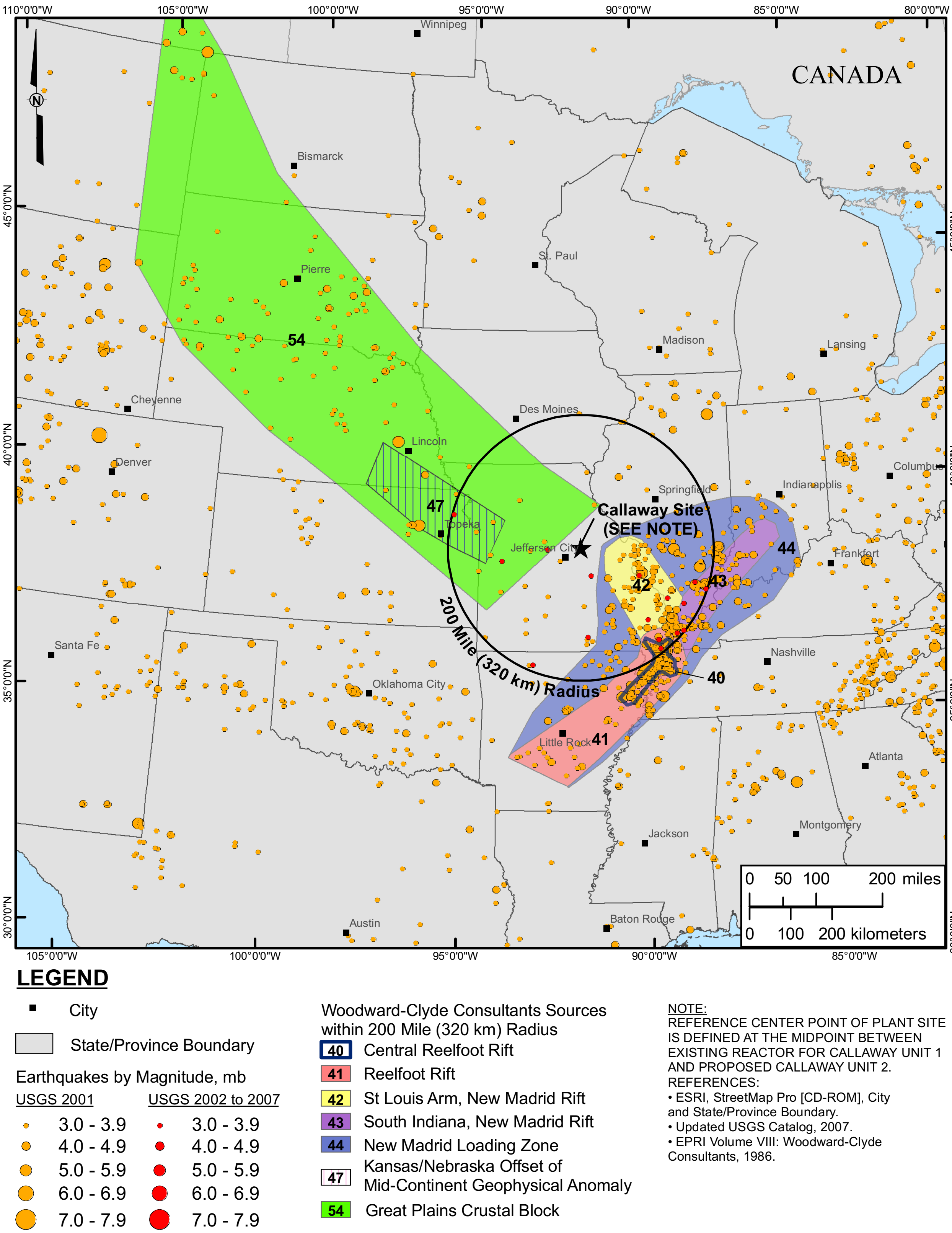
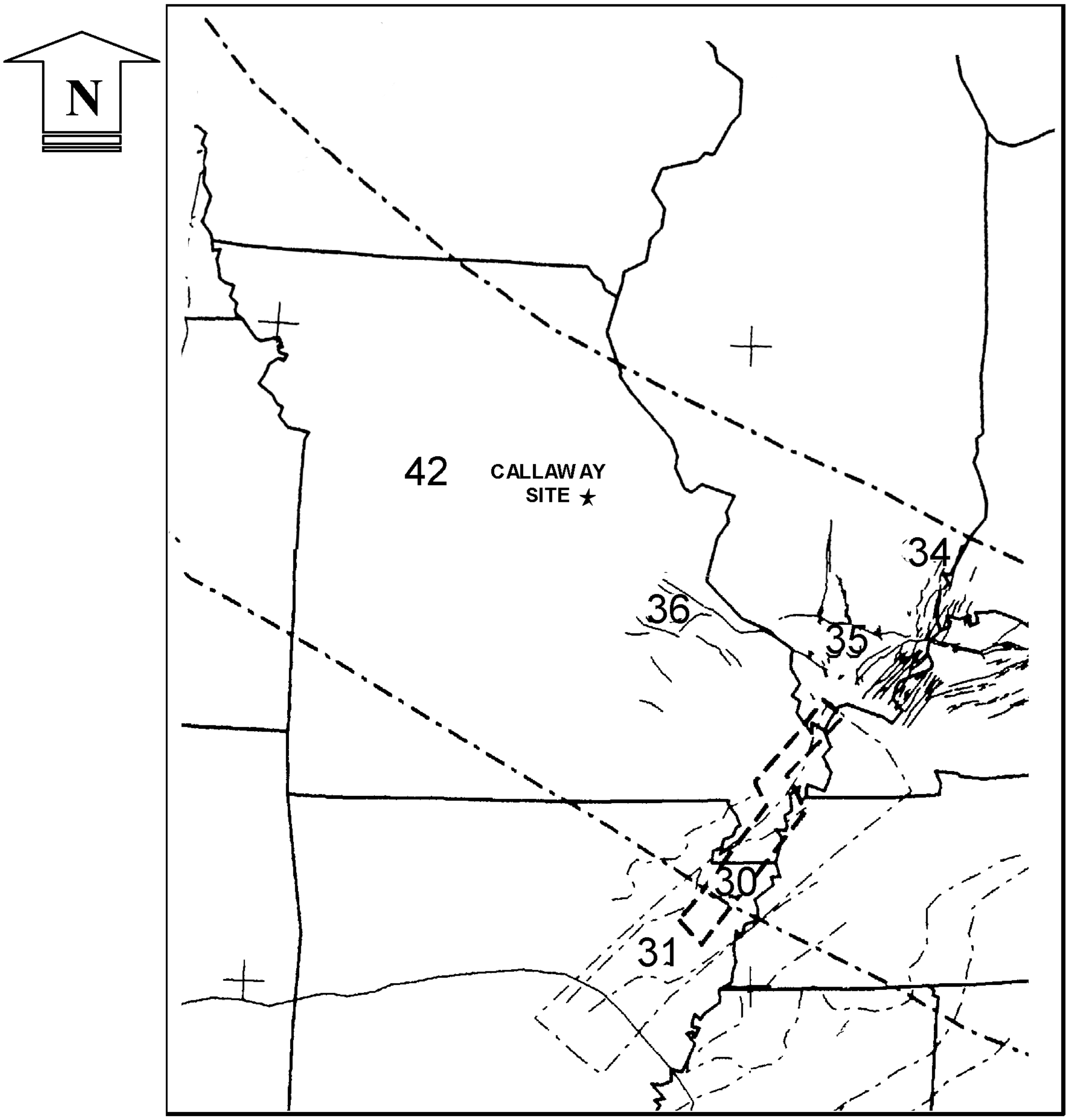


Figure 2.5.1-23—{Tectonic Interpretation by Bechtel Group, Inc.}



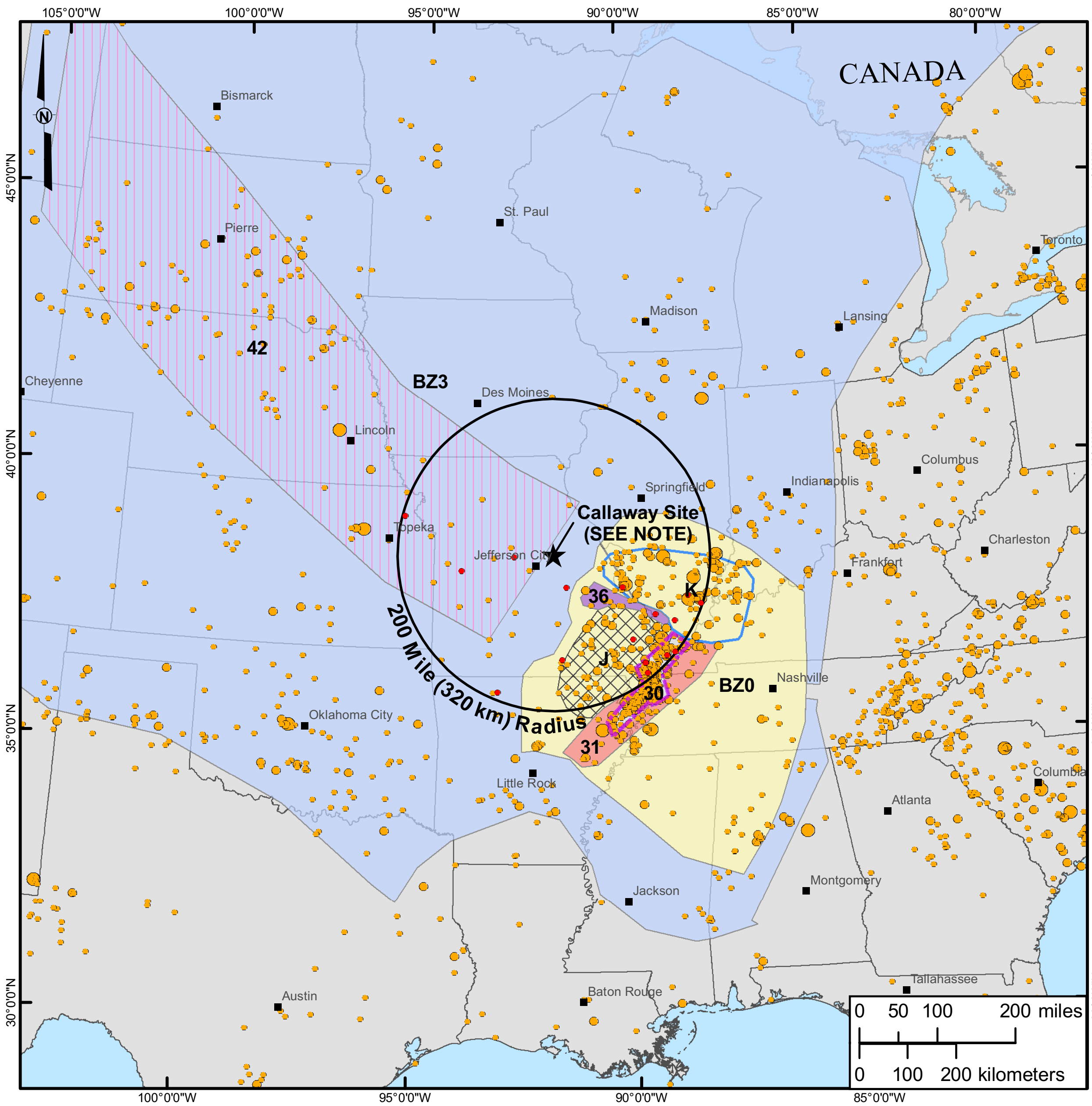
NOT TO SCALE

Legend for Tectonic Features:

30 New Madrid Fault Zone
31 Reelfoot Rifts
34 Wabash Valley Fault Zone
35 Cottage Grove Fault Zone
36 Ste. Genevieve Fault Zone
42 Tennessee – Montana Geopotential Trend

Reference: Modified from EPRI (1986) Volume 9

Figure 2.5.1-24—{Seismic Source Zones Interpretation by Bechtel Group, Inc.}



LEGEND

- City
- State/Province Boundary

Earthquakes by Magnitude, mb

USGS 2001	USGS 2002 to 2007
3.0 - 3.9	3.0 - 3.9
4.0 - 4.9	4.0 - 4.9
5.0 - 5.9	5.0 - 5.9
6.0 - 6.9	6.0 - 6.9
7.0 - 7.9	7.0 - 7.9

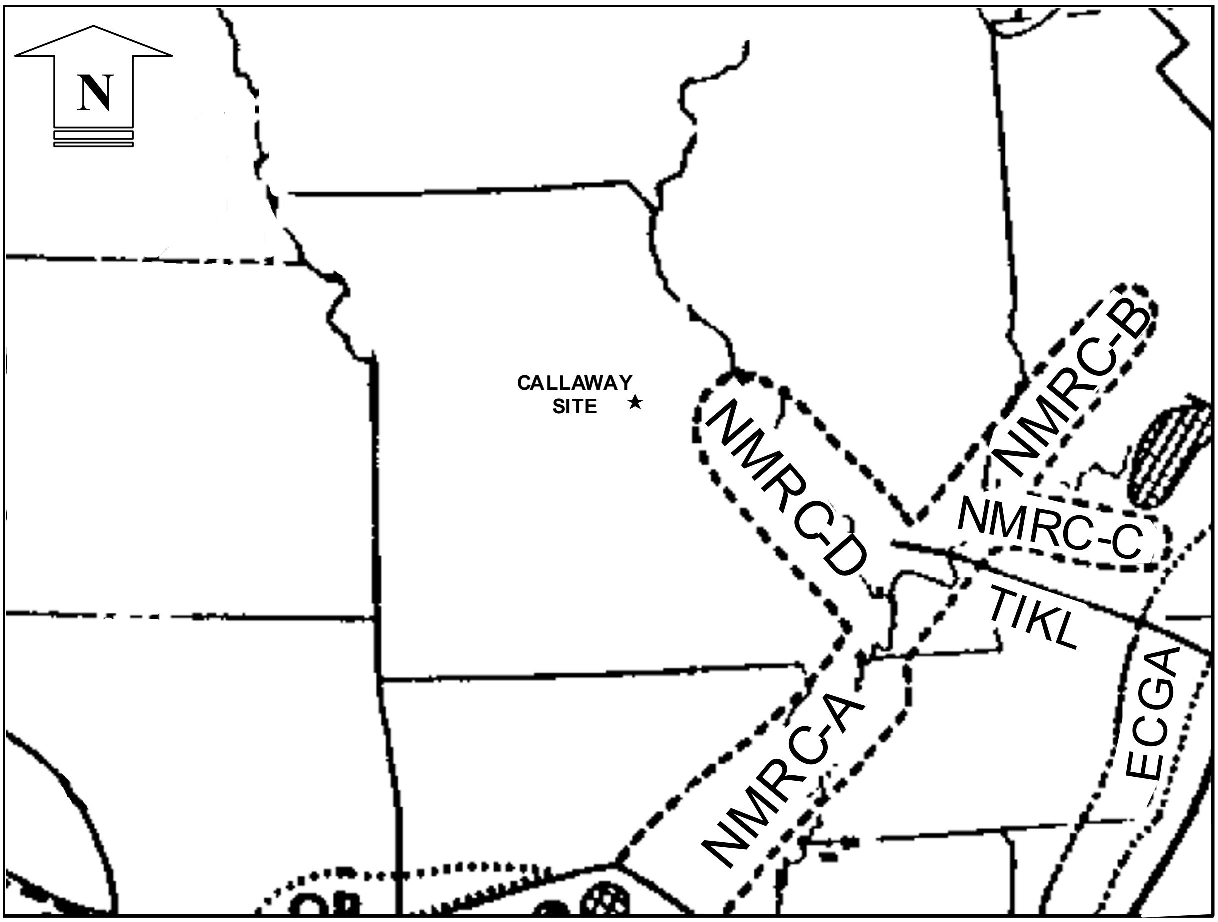
Bechtel Group Sources within 200 Mile (320 km) Radius

- 30 New Madrid
- 31 Reelfoot Rift
- 36 St. Genevieve
- 42 TN-MT Trend
- J Ozark Area
- K Southern Illinois Area
- BZ0 Background Zone 0
- BZ3 Background Zone 3

NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCES:
• ESRI, StreetMap Pro [CD-ROM], City and State/Province Boundary.
• Updated USGS Catalog, 2007.
• EPRI Volume IX: Bechtel Group, 1986.

FSAR: Figures 2.5.1

Figure 2.5.1-25—{Tectonic Interpretation by Rondout Associates, Inc.}



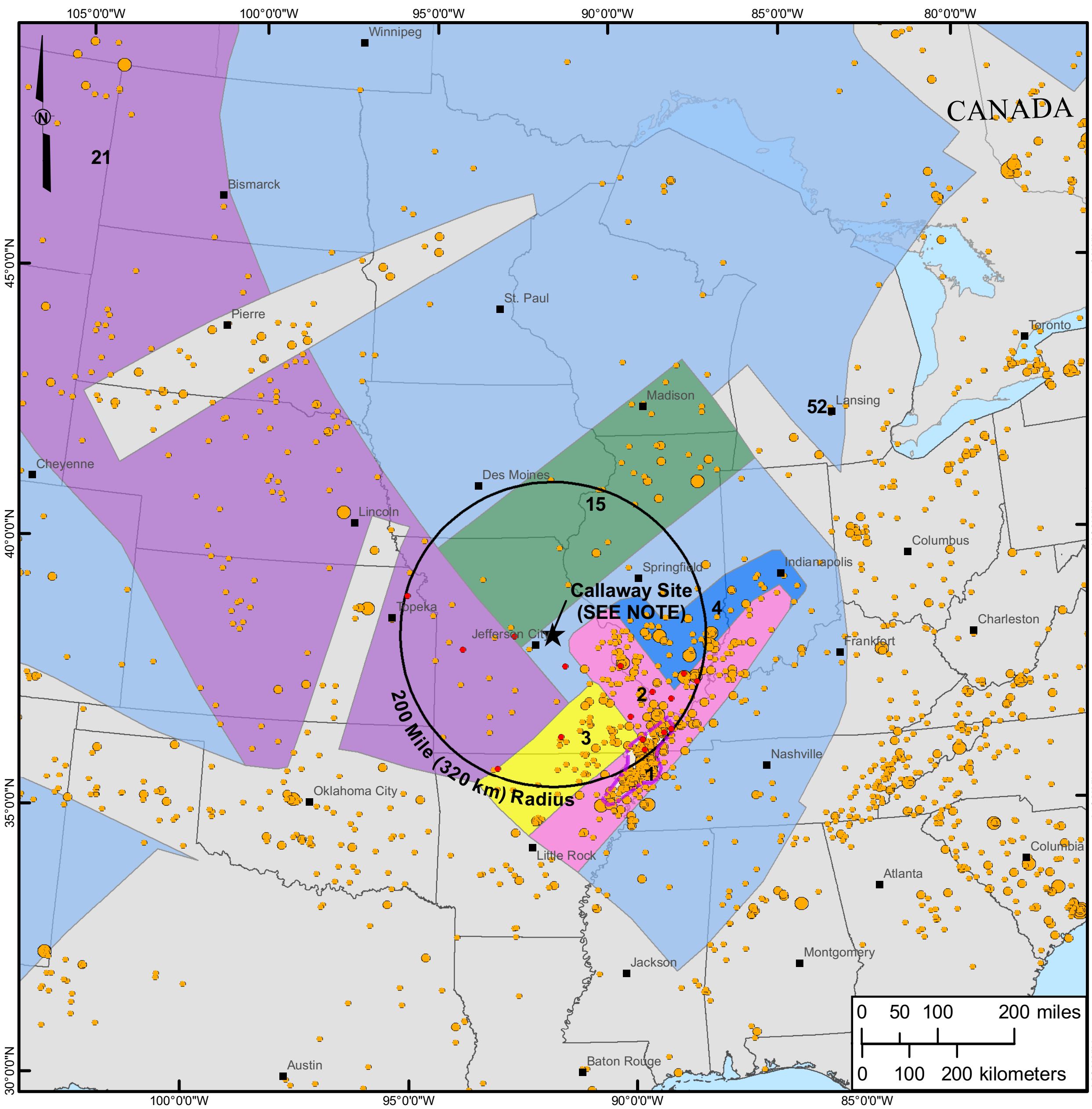
NOT TO SCALE

Legend for Tectonic Features:

NMRC - A Reelfoot Rift
NMRC - B Southern Indiana Arm)
NMRC - C Rough Creek Graben
NMRC - D St Louis Arm
TIKL Tennessee-Illinois-Kentucky Lineament
ECGA East Continent Geophysical Anomaly

Reference: Modified from EPRI (1986), Volume 10

Figure 2.5.1-26—{Seismic Source Zones Interpretation by Rondout Associates, Inc.}



LEGEND

- City
- State/Province Boundary

Earthquakes by Magnitude, mb

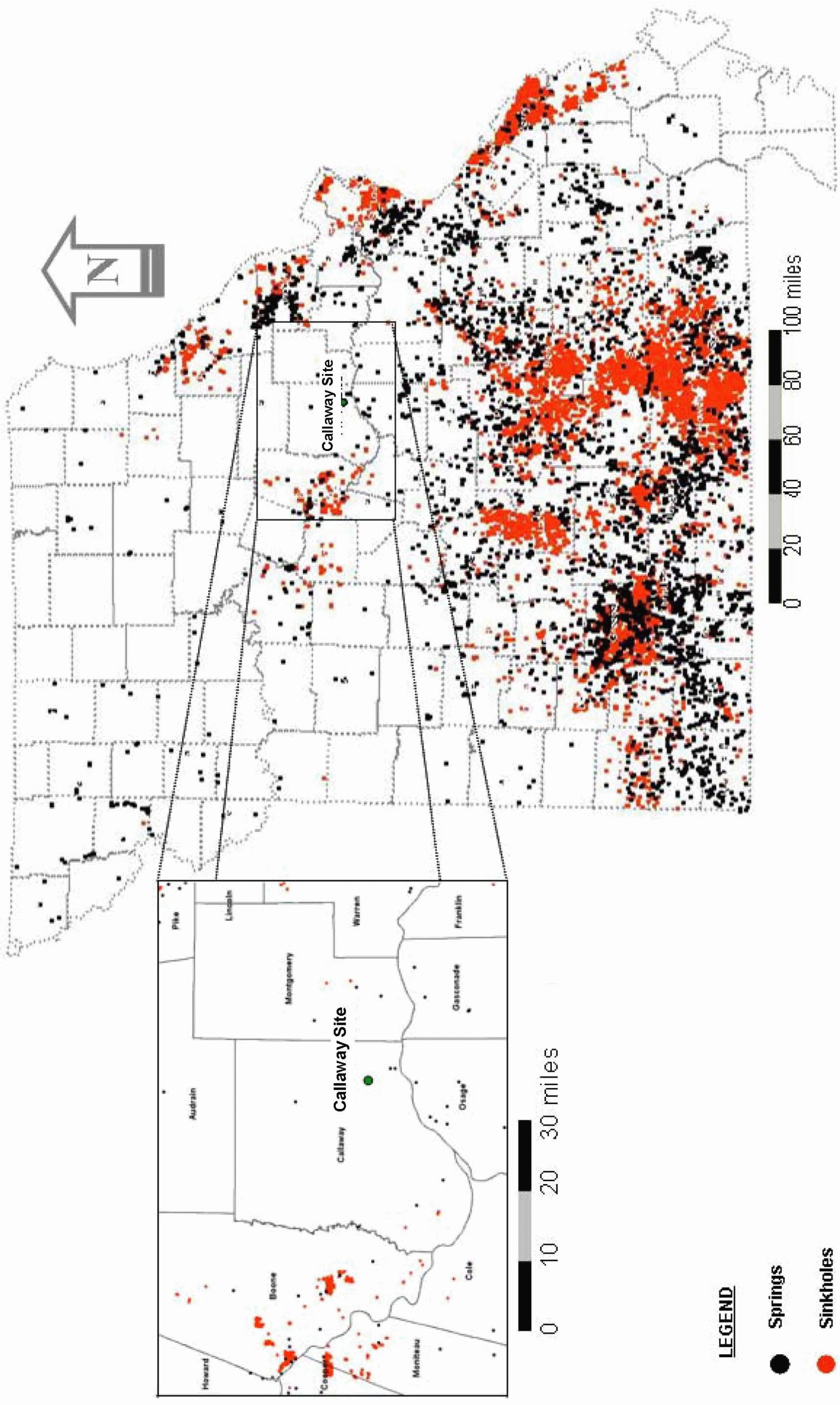
USGS 2001	USGS 2002 to 2007
3.0 - 3.9	3.0 - 3.9
4.0 - 4.9	4.0 - 4.9
5.0 - 5.9	5.0 - 5.9
6.0 - 6.9	6.0 - 6.9
7.0 - 7.9	7.0 - 7.9

Rondout Associates Sources within 200 Mile (320 km) Radius

- 1 New Madrid
- 2 New Madrid Rift Complex
- 3 Ozark Uplift
- 4 Southern Illinois
- 15 Northern Illinois
- 21 Great Plains
- 52 Pre-Grenville Precambiran Craton (Background Zone)

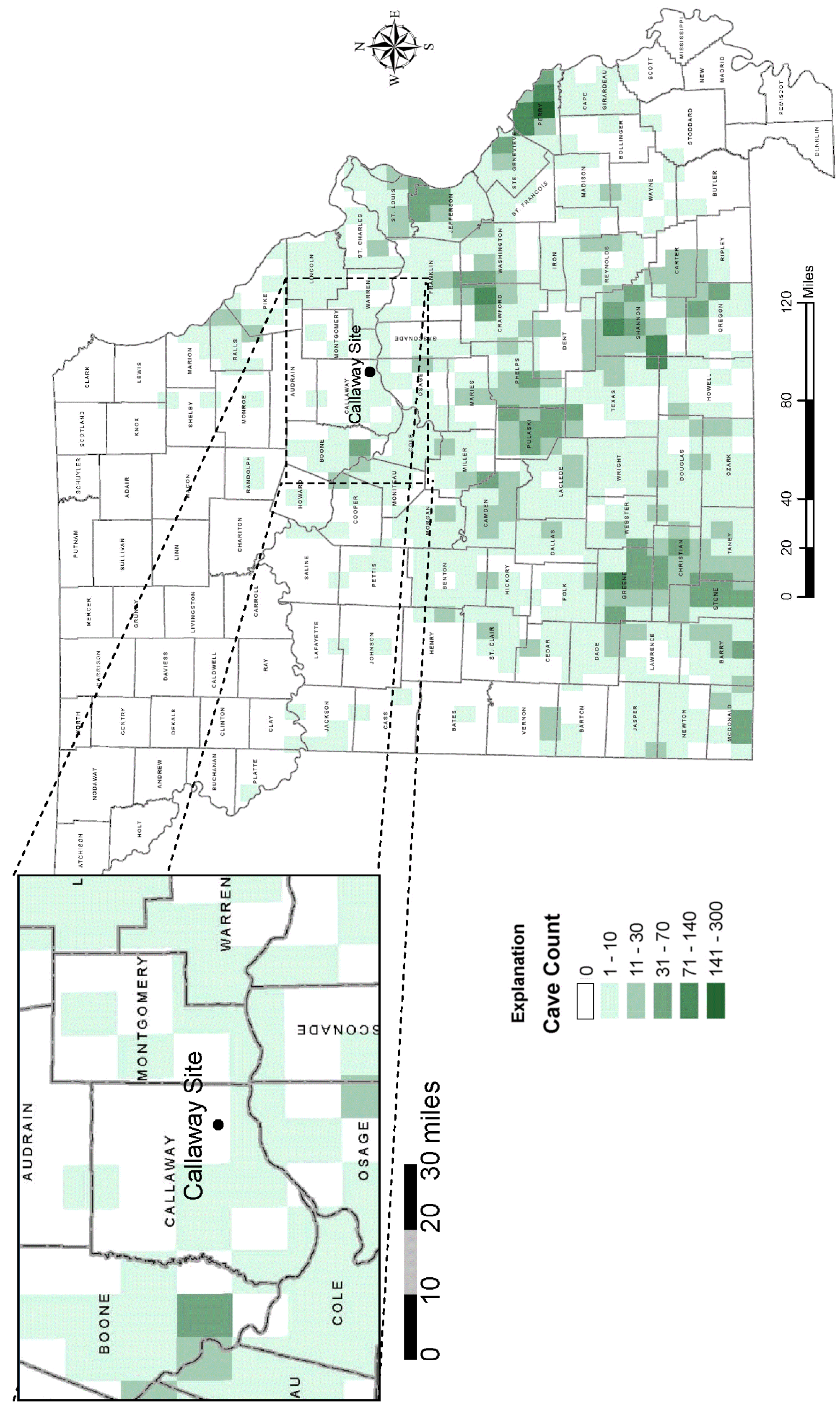
NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND PROPOSED CALLAWAY UNIT 2.
REFERENCES:
• ESRI, StreetMap Pro [CD-ROM], City and State/Province Boundary.
• Updated USGS Catalog, 2007.
• EPRI Volume X: Rondout Associates, 1986.

Figure 2.5.1-27—{Springs and Sinkholes of Missouri}



REFERENCE:
Modified from Missouri Department of Natural Resources (MODNR, 2007).

Figure 2.5.1-28—{Cave Density of Missouri}



REFERENCE:

Modified from Missouri Department of Natural Resources (MODNR, 2007).

Figure 2.5.1-29—{Site Area Geologic Map}
5 Mile (8 km) Radius

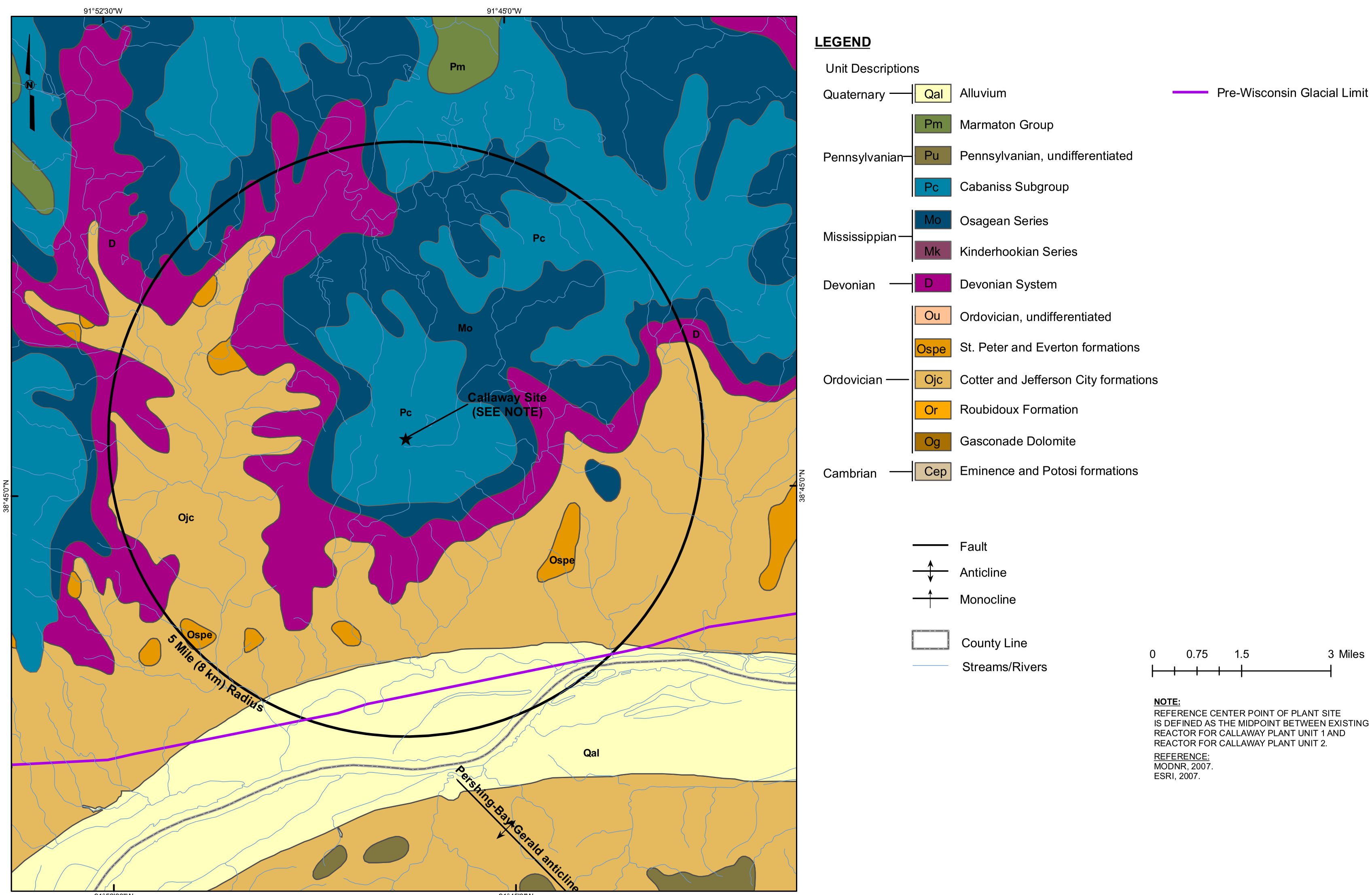
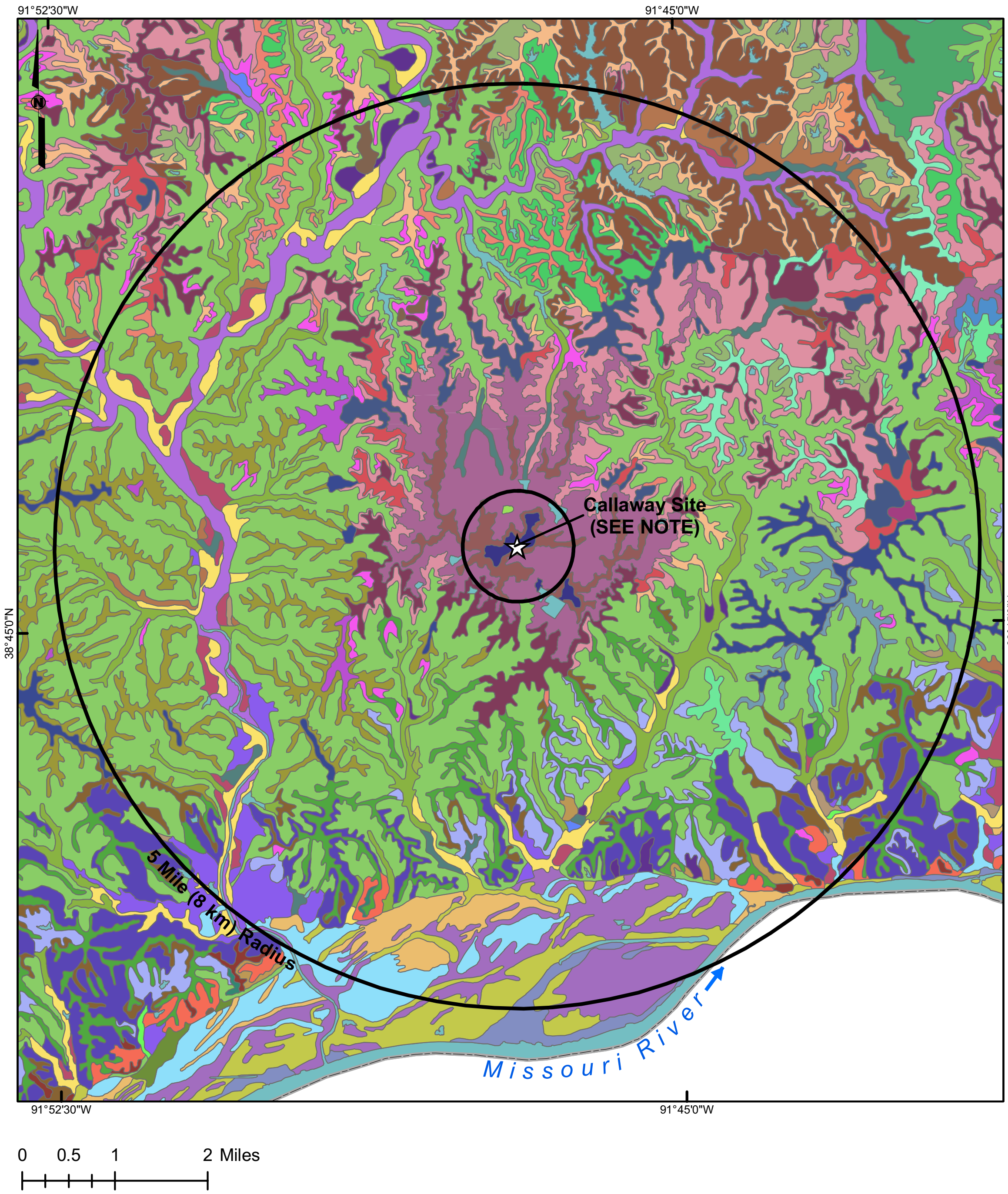


Figure 2.5.1-30—{Site Area Soils Map}



NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND REACTOR FOR CALLAWAY UNIT 2.
LEGEND FOR THIS FIGURE IS LOCATED ON NEXT PAGE.

REFERENCE:
ESRI, 2007.
USDA, NRCS, 2007.

Figure 2.5.1-31—{Site Area Soils Map Legend}

LEGEND

County Line

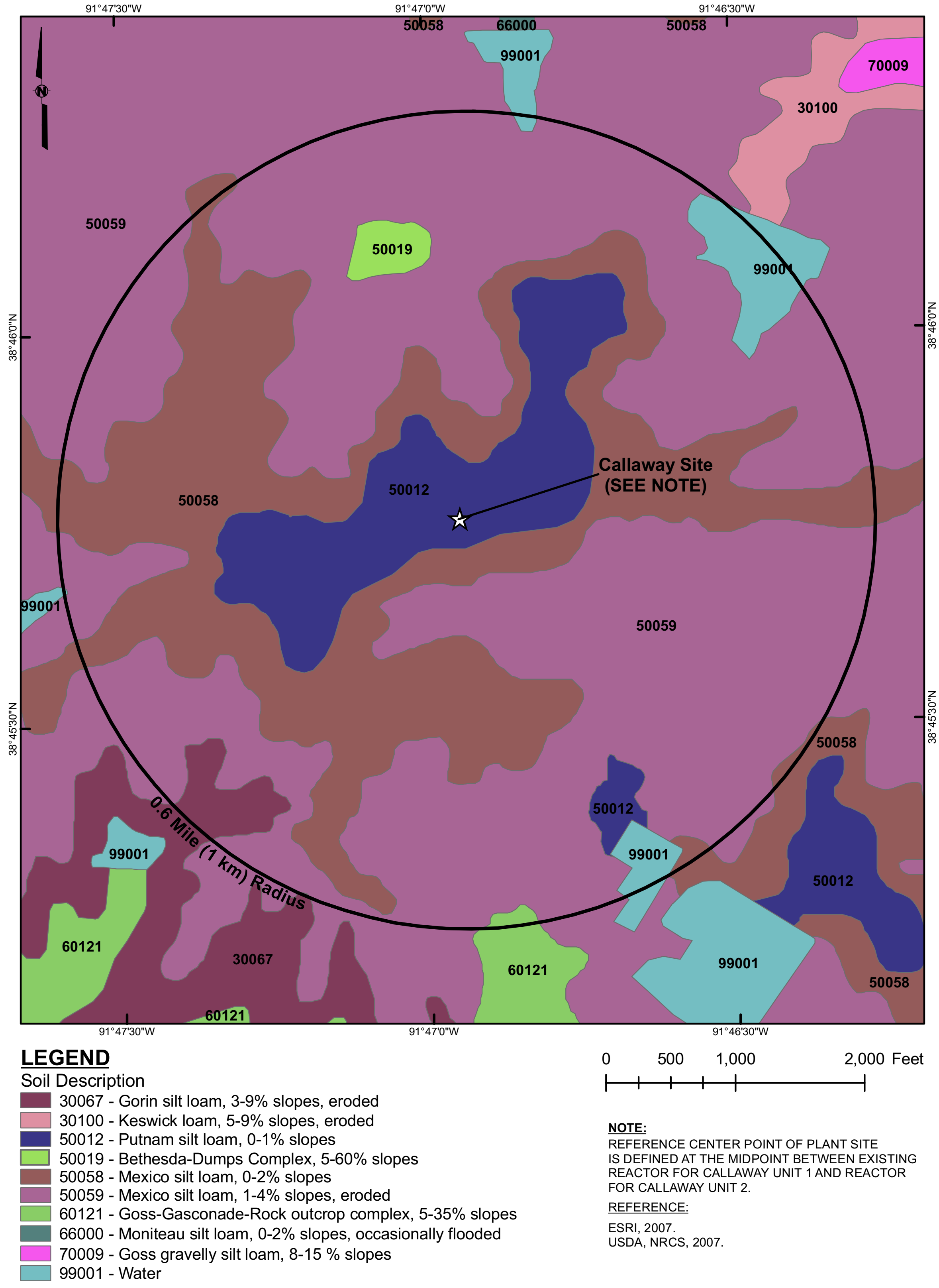
Soil Descriptions

- 13598 - Booker silty clay , 0-2% slopes, occasionally flooded, frequently ponded
- 30067 - Gorin silt loam, 3-9% slopes, eroded
- 30100 - Keswick loam, 5-9% slopes, eroded
- 36025 - Landes loam, 0-2% slopes, frequently flooded
- 50012 - Putnam silt loam, 0-1% slopes
- 50020 - Calwoods silt loam, 2-5% slopes
- 50021 - Calwoods silt loam, 2-5% slopes, eroded
- 50041 - Lindley loam, 14-35% slopes
- 50058 - Mexico silt loam, 0-2% slopes
- 50059 - Mexico silt loam, 1-4% slopes, eroded
- 60003 - Menfro silt loam, 9-14% slopes, eroded
- 60004 - Menfro silt loam, 14-20% slopes, eroded
- 60005 - Menfro silt loam, 20-35 % slopes, eroded
- 60024 - Menfro silt loam, 3-9% slopes, eroded
- 60028 - Weller silt loam, 5-9% slopes, eroded
- 60031 - Winfield silt loam, 9-14 % slopes, eroded
- 60084 - Crider silt loam, 5-9% slopes, eroded
- 60086 - Crider silt loam, 9-14% slopes, eroded
- 60108 - Gorin silt loam, 3-9% slopes
- 60121 - Goss-Gasconade-Rock coutcrop complex, 5-35% slopes
- 60127 - Hatton silt loam, 3-9% slopes
- 60128 - Hatton silt loam, 3-9% slopes, eroded
- 60152 - Lily-Winfield-Rock outcrop complex, 5-35% slopes
- 60157 - Lindley clay loam, 9-14% slopes, eroded
- 60158 - Lindley loam, 9-14% slopes
- 60231 - Weingarten silt loam, 5-14% slopes, eroded
- 60234 - Weller silt loam, 2-5% slopes
- 60237 - Weller silt loam, 9-14% slopes, eroded
- 60238 - Weller silt loam, bench, 3-9% slopes
- 60240 - Winfield silt loam, 14-20% slopes, eroded
- 60244 - Winfield silt loam, 5-9% slopes, eroded
- 60247 - Winfield silt loam, 20-30% slopes, eroded
- 60253 - Winfield silt loam, 3-9% slopes
- 60267 - Marion silt loam, 0-2% slopes
- 64004 - Auxvasse silt loam, 0-2% slopes, rarely flooded
- 64019 - Freeburg silt loam - 3-9% slopes, rarely flooded
- 64039 - Wiota silt loam, 2-5% slopes, rarely flooded
- 66000 - Moniteau silt loam, 0-2% slopes, occasionally flooded
- 66034 - Hodge fine sand, loamy substratum, 0-2% slopes, frequently flooded
- 66043 - Leta silty clay loam, sandy substratum, 0-2% slopes, occasionally flooded
- 66071 - Cedargap loam, 0-2% slopes, frequently flooded
- 66095 - Grable very fine sand loam, loamy substratum, 0-2% slopes, occasionally flooded
- 66111 - Waldron silty clay, loamy substratum, 0-2% slopes, occasionally flooded
- 66116 - Haymond silt loam, 0-2% slopes, occasionally flooded
- 70009 - Goss gravelly silt loam, 8-15 % slopes
- 99000 - Pits, Quarry
- 99001 - Water

NOTE: This legend is for the Site Area Soils Map figure located on previous page.

REFERENCE:
USDA, 2007.

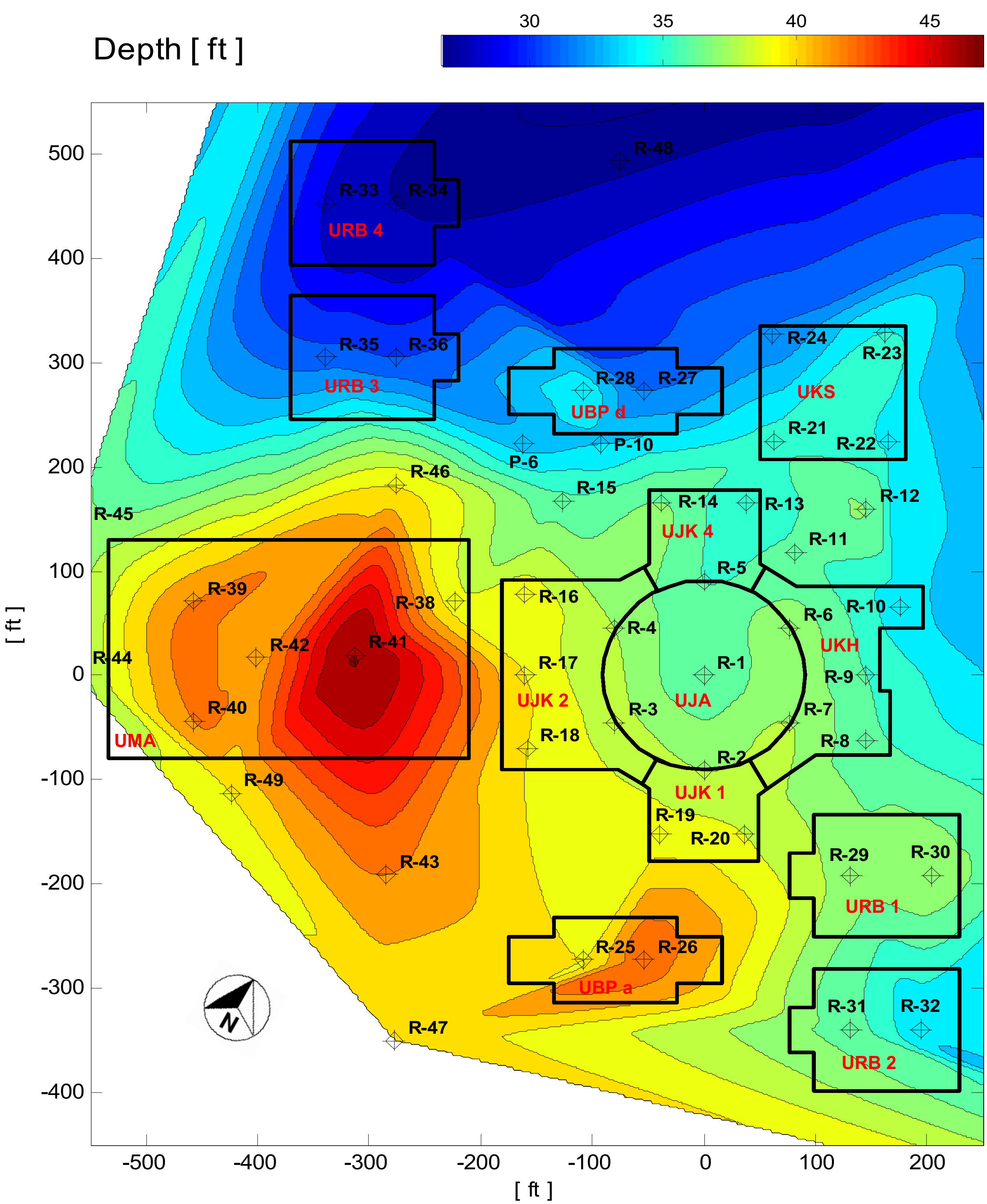
Figure 2.5.1-32—{Site Soils Map}



NOTE:
REFERENCE CENTER POINT OF PLANT SITE IS DEFINED AT THE MIDPOINT BETWEEN EXISTING REACTOR FOR CALLAWAY UNIT 1 AND REACTOR FOR CALLAWAY UNIT 2.

REFERENCE:
ESRI, 2007.
USDA, NRCS, 2007.

Figure 2.5.1-33—{Depth to Graydon Chert Conglomerate}

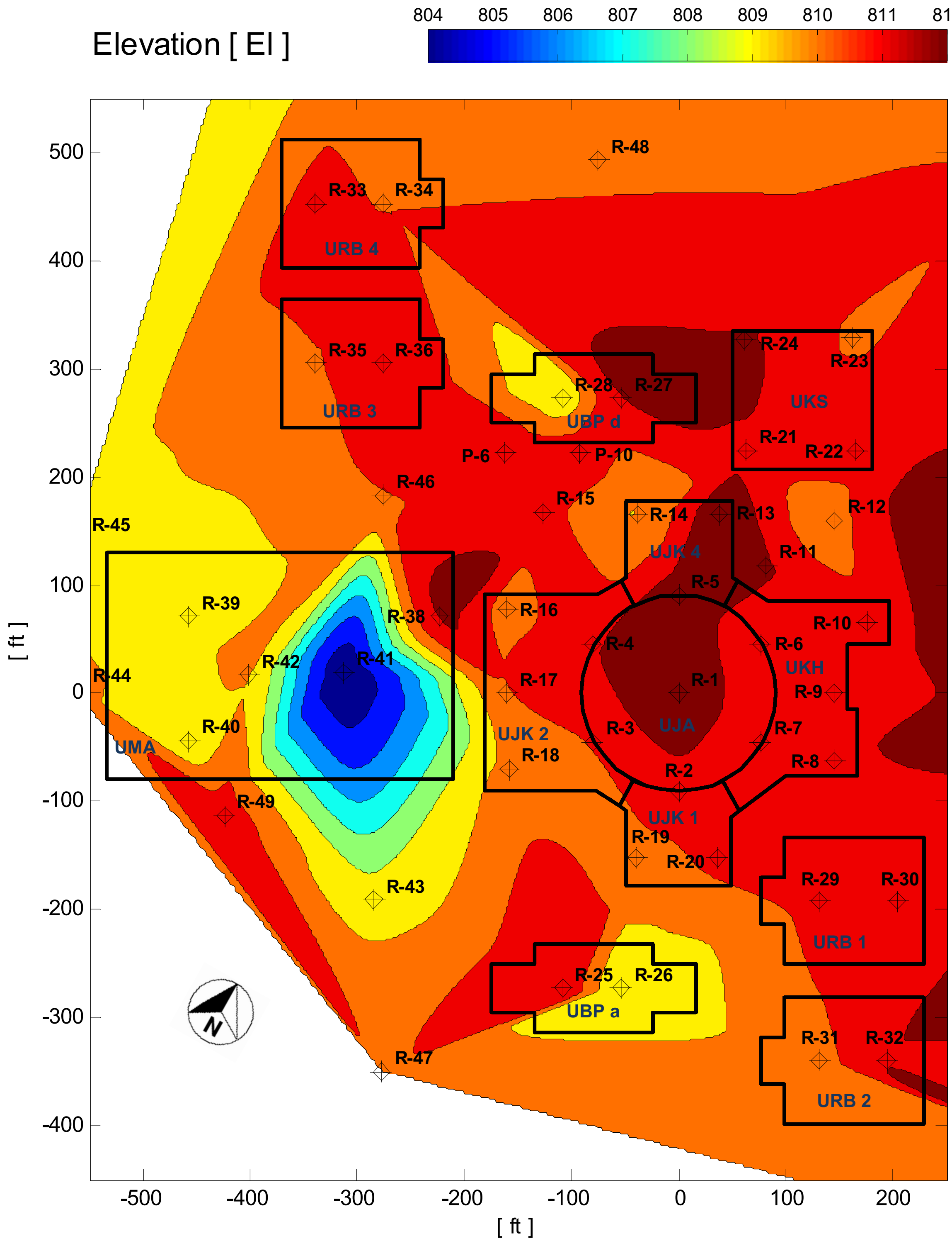


Callaway Plant Unit 2 Facilities:

UBP Emegency Diesel Generator Building
URB Essential Service Water Cooling Tower Structure
UJA Reactor Building
UJK Safeguard Buildings Electrical
UKH Vent Stack
UKS Radioactive Waste Processing Building
UMA Turbine Building

Note: Contours have a 1-ft resolution. Values between borings are obtained by linear interpolation

Figure 2.5.1-34—{Graydon Chert Conglomerate (Elevation of Top Surface)}

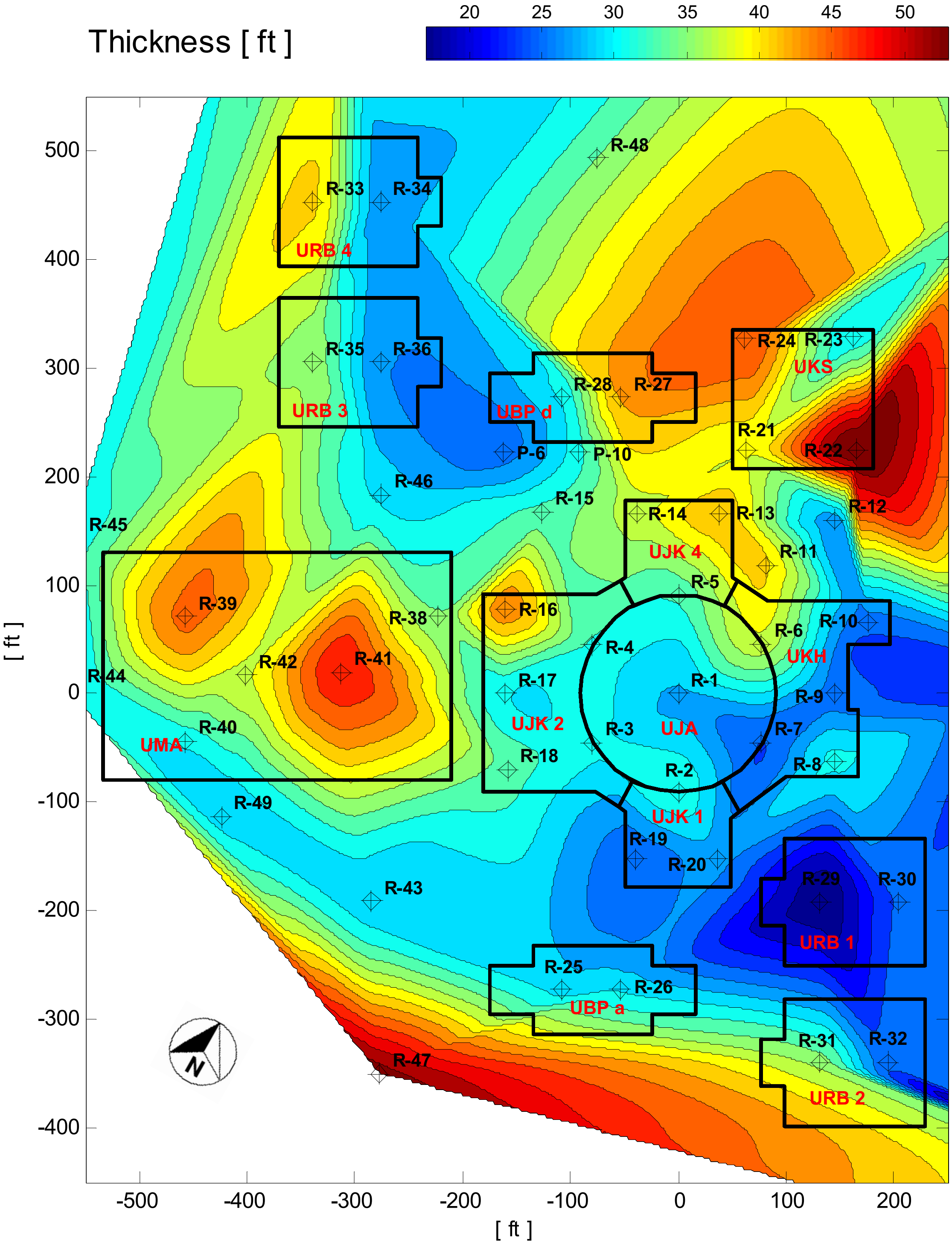


Callaway Plant Unit 2 Facilities:

UBP Emegency Diesel Generator Building
URB Essential Service Water Cooling Tower Structure
UJA Reactor Building
UJK Safeguard Buildings Electrical
UKH Vent Stack
UKS Radioactive Waste Processing Building
UMA Turbine Building

Note: Contours have a 1-ft resolution. Values between borings are obtained by linear interpolation

Figure 2.5.1-35—{Graydon Chert Conglomerate (Thickness) }

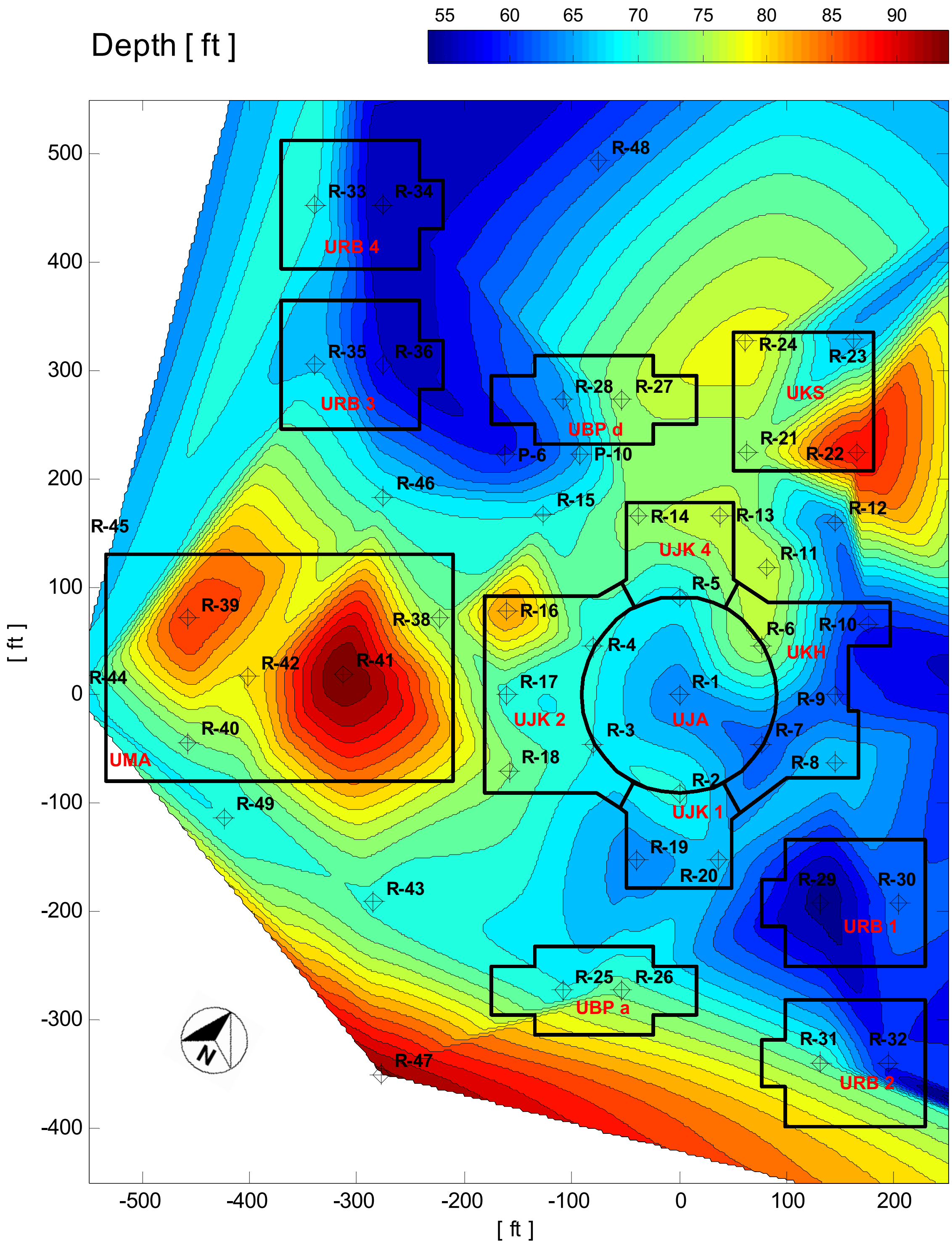


Callaway Plant Unit 2 Facilities:

UBP	*Emegency Diesel Generator Building*
URB	*Essential Service Water Cooling Tower Structure*
UJA	*Reactor Building*
UJK	*Safeguard Buildings Electrical*
UKH	*Vent Stack*
UKS	*Radioactive Waste Processing Building*
UMA	*Turbine Building*

Note: Contours have a 2-ft resolution. Values between borings are obtained by linear interpolation

Figure 2.5.1-36—{Depth to Bottom of Graydon Chert}

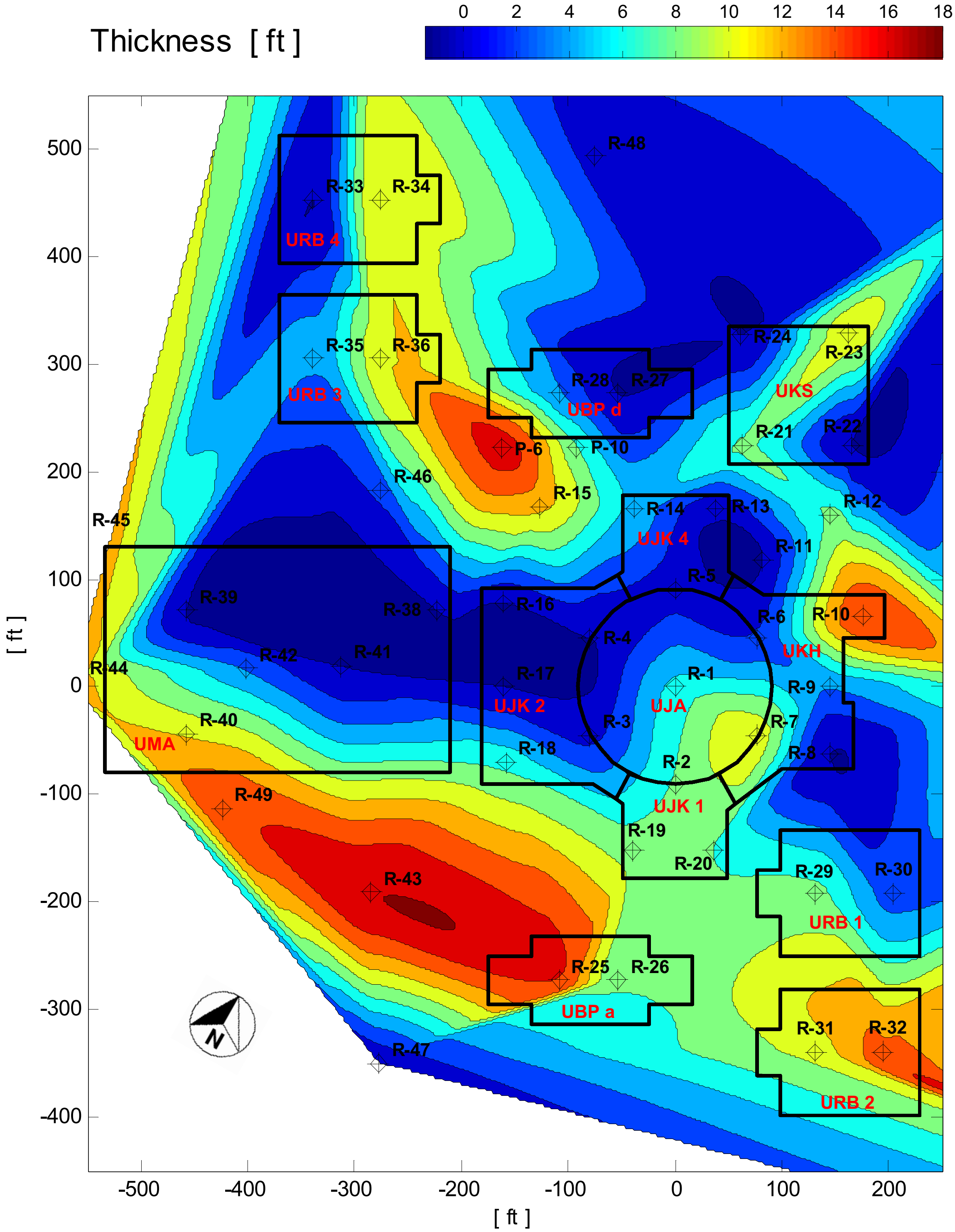


Callaway Plant Unit 2 Facilities:

UBP	*Emegency Diesel Generator Building*
URB	*Essential Service Water Cooling Tower Structure*
UJA	*Reactor Building*
UJK	*Safeguard Buildings Electrical*
UKH	*Vent Stack*
UKS	*Radioactive Waste Processing Building*
UMA	*Turbine Building*

Note: Contours have a 2-ft resolution. Values between borings are obtained by interpolation

Figure 2.5.1-37—{Burlington Formation (Thickness)}

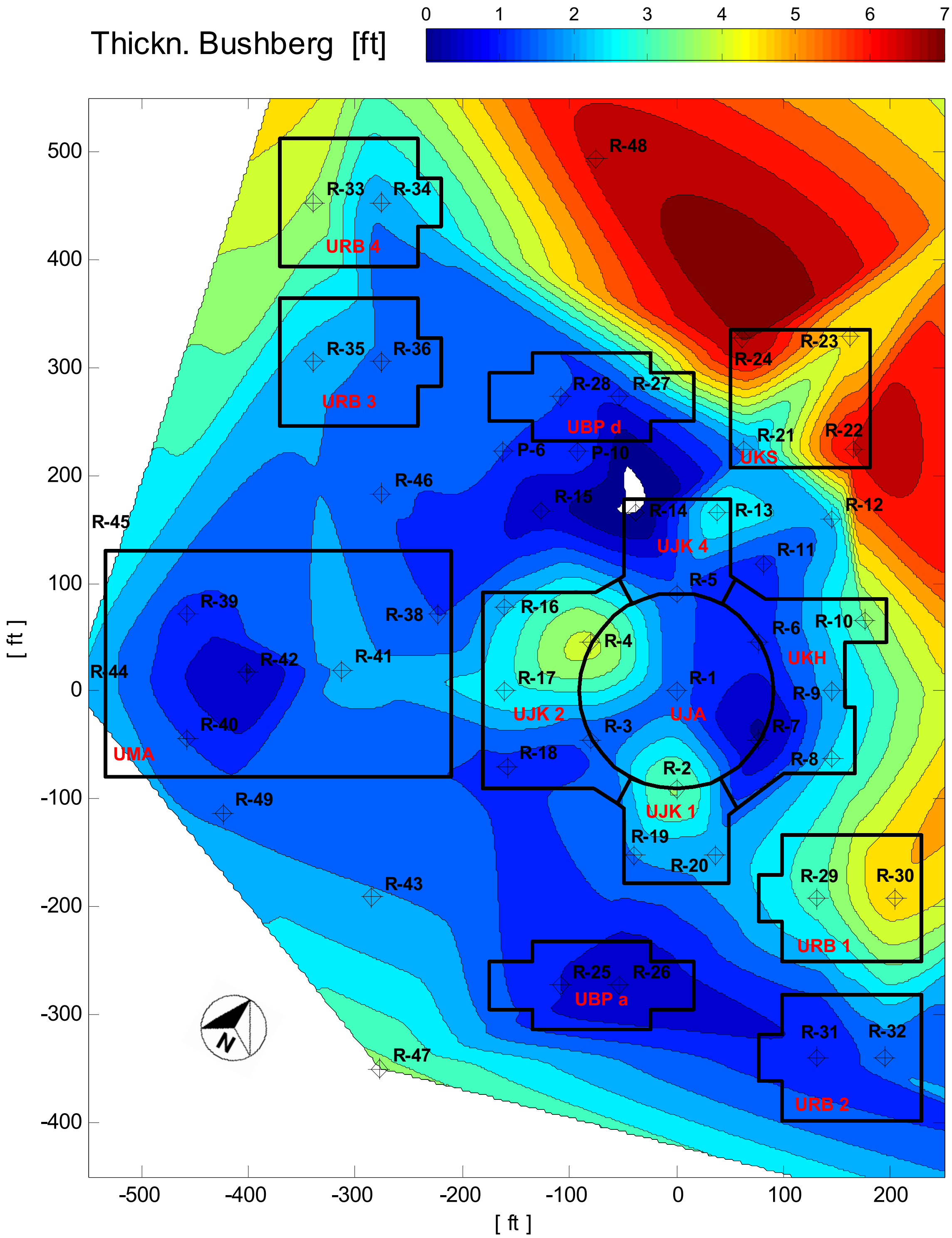


Callaway Plant Unit 2 Facilities:

UBP	*Emegency Diesel Generator Building*
URB	*Essential Service Water Cooling Tower Structure*
UJA	*Reactor Building*
UJK	*Safeguard Buildings Electrical*
UKH	*Vent Stack*
UKS	*Radioactive Waste Processing Building*
UMA	*Turbine Building*

Note: Contours have a 0.5 ft resolution. Values between borings are obtained by interpolation

Figure 2.5.1-38—{Bushberg Formation (Thickness)}

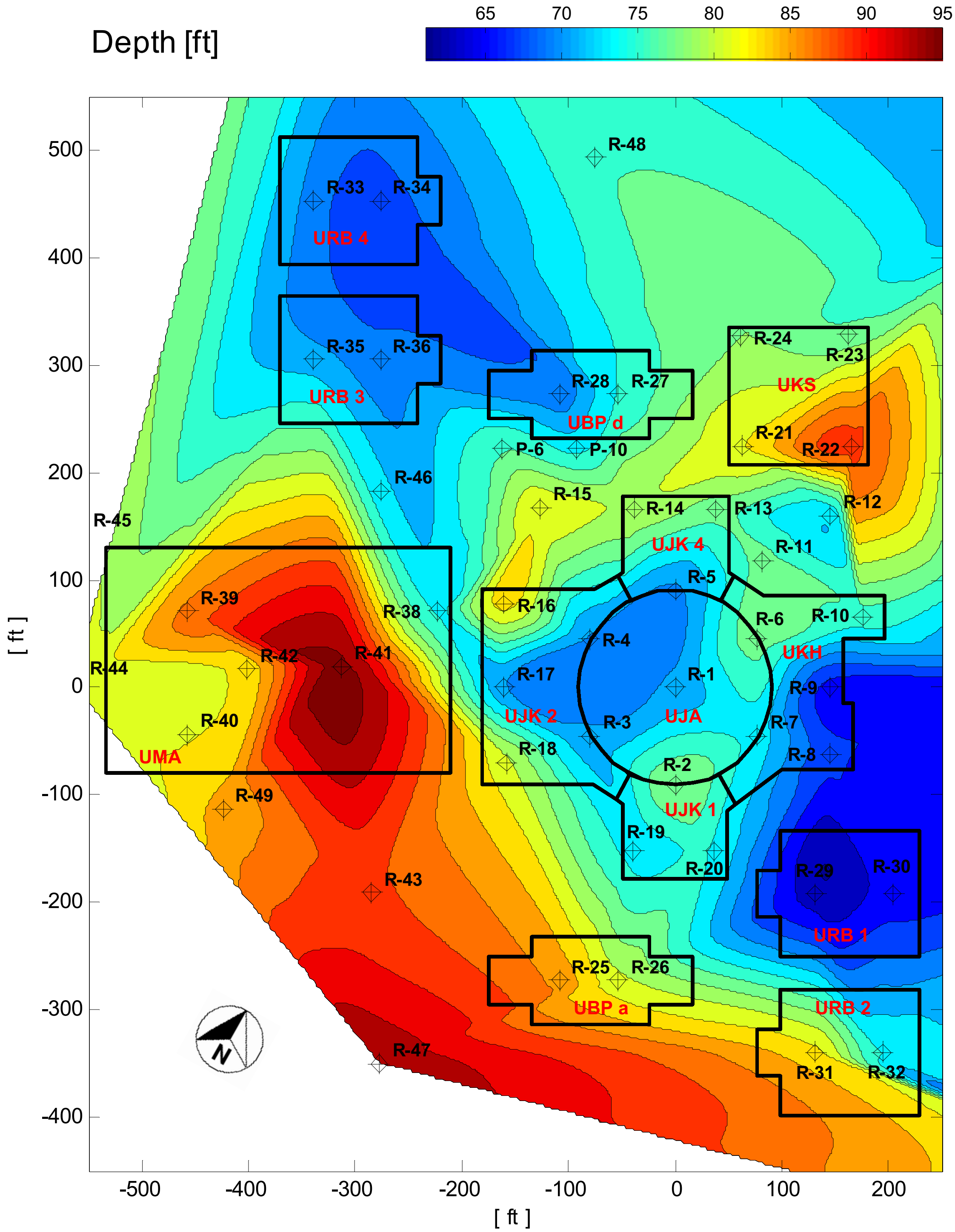


Callaway Plant Unit 2 Facilities:

UBP	*Emegency Diesel Generator Building*
URB	*Essential Service Water Cooling Tower Structure*
UJA	*Reactor Building*
UJK	*Safeguard Buildings Electrical*
UKH	*Vent Stack*
UKS	*Radioactive Waste Processing Building*
UMA	*Turbine Building*

Note: Contours have a 0.5 ft resolution.
Values between borings are obtained by interpolation

Figure 2.5.1-39—{Bushberg Formation (Depth to Top Surface)}

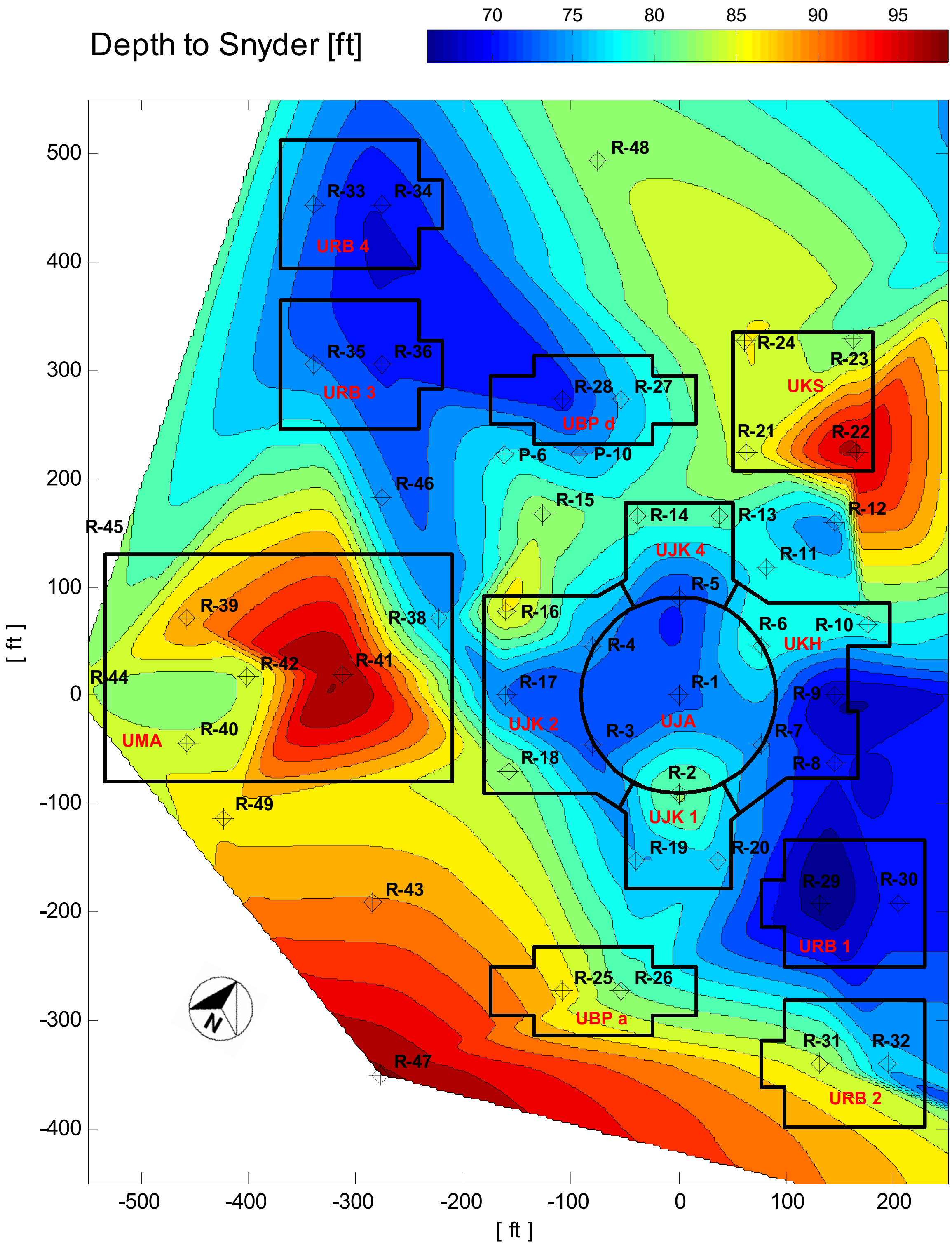


Callaway Plant Unit 2 Facilities:

UBP	*Emegency Diesel Generator Building*
URB	*Essential Service Water Cooling Tower Structure*
UJA	*Reactor Building*
UJK	*Safeguard Buildings Electrical*
UKH	*Vent Stack*
UKS	*Radioactive Waste Processing Building*
UMA	*Turbine Building*

Note: Contours have a 2 ft resolution. Values between borings are obtained by interpolation

Figure 2.5.1-40—{Snyder Creek Formation (Depth to Top Surface)}



Callaway Plant Unit 2 Facilities:

UBP Emegency Diesel Generator Building
URB Essential Service Water Cooling Tower Structure
UJA Reactor Building
UJK Safeguard Buildings Electrical
UKH Vent Stack
UKS Radioactive Waste Processing Building
UMA Turbine Building

Note: Contours have a 2 ft resolution. Values between borings are obtained by interpolation

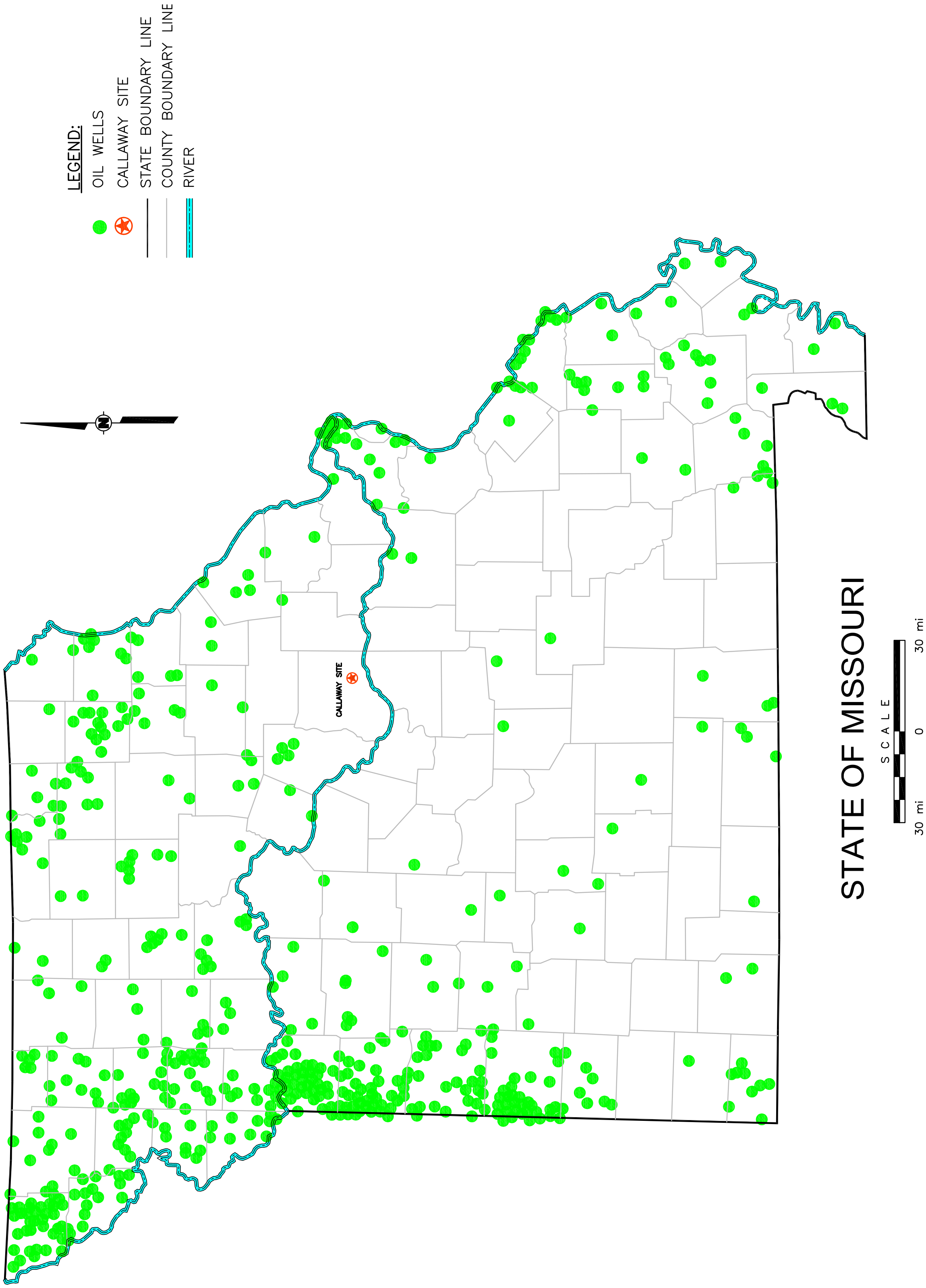


Figure 2.5.1-41—{Oil and Gas Related Well locations (Oil Wells)}
Sheet 1 of 5

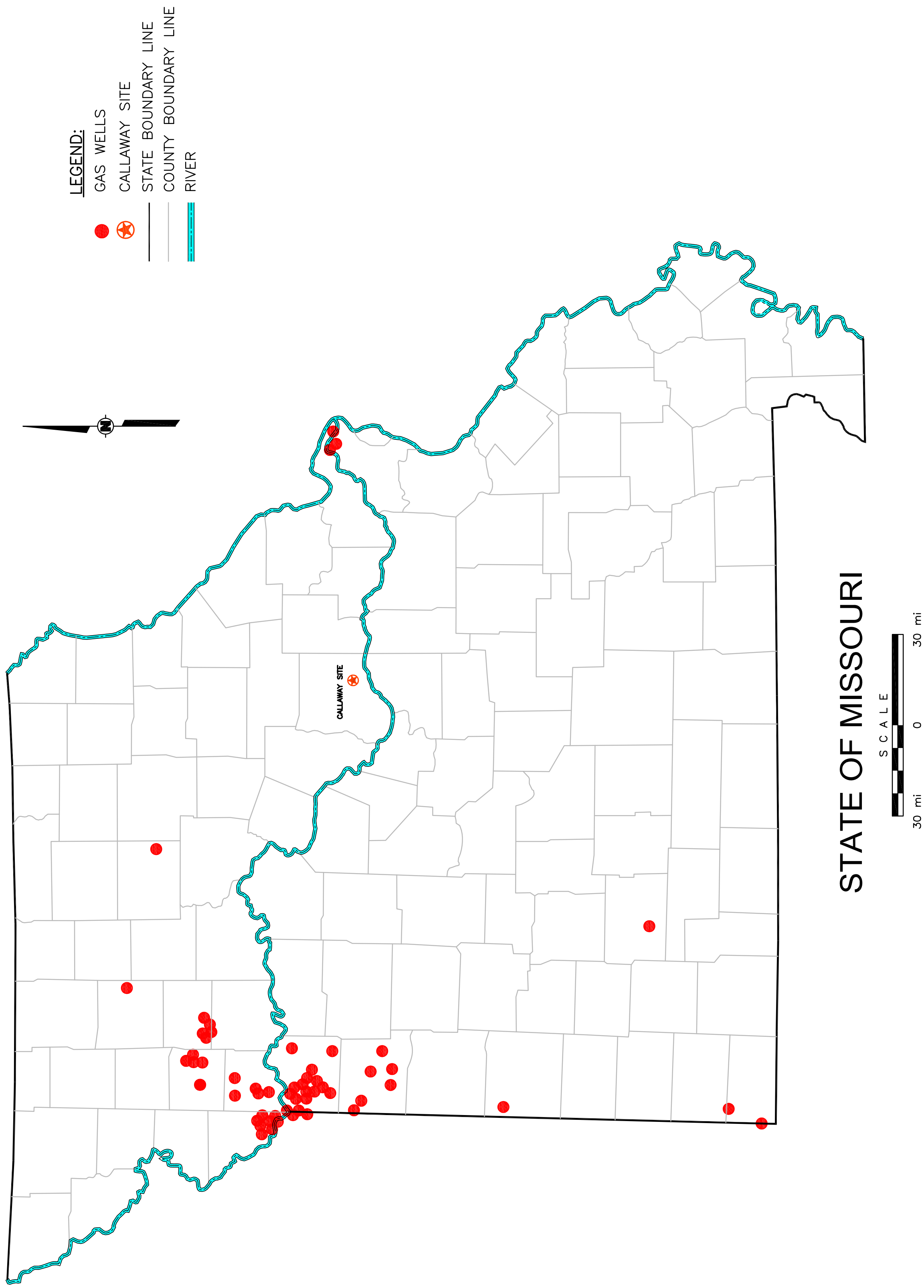


Figure 2.5.1-41—{Oil and Gas Related Well locations (Gas Wells)}

Sheet 2 of 5

Figure 2.5.1-41—{Oil and Gas Related Well locations (Dry Oil or Gas Wells}

Sheet 3 of 5

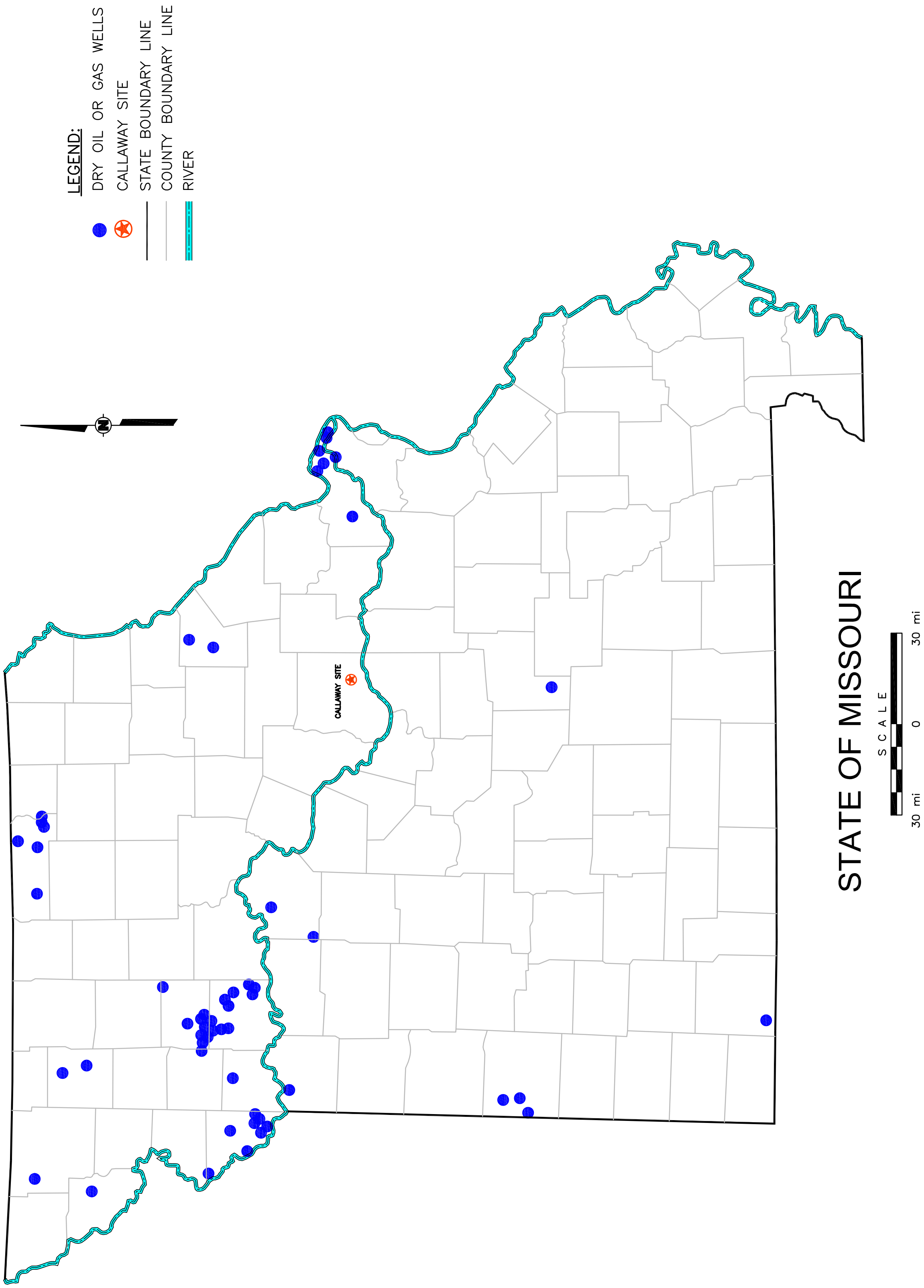
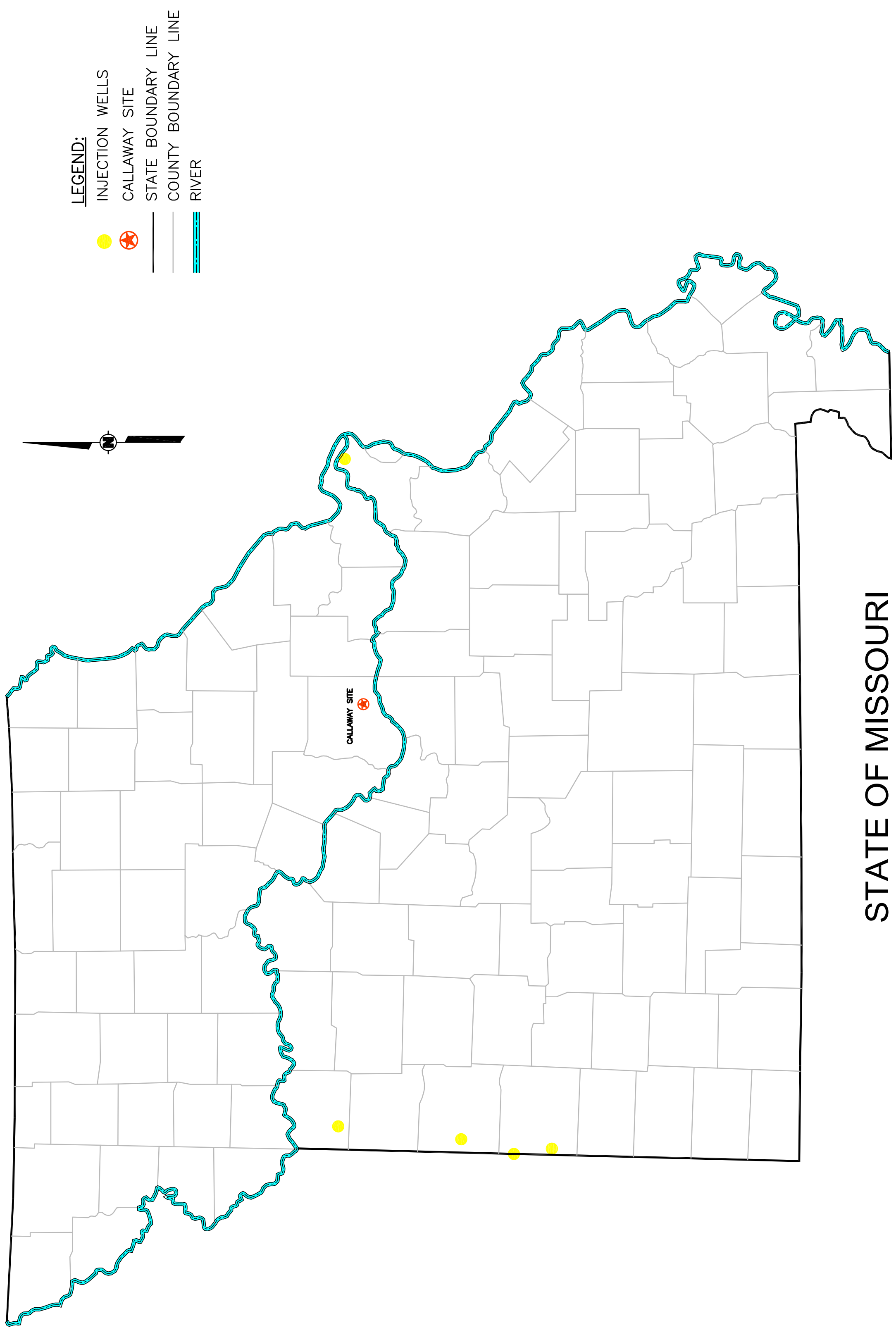


Figure 2.5.1-41—{Oil and Gas Related Well locations (Injection Wells)}
Sheet 4 of 5



FSAR: Figures 2.5.1

Figure 2.5.1-41—{Oil and Gas Related Well locations(Exploratory Wells)}

Sheet 5 of 5

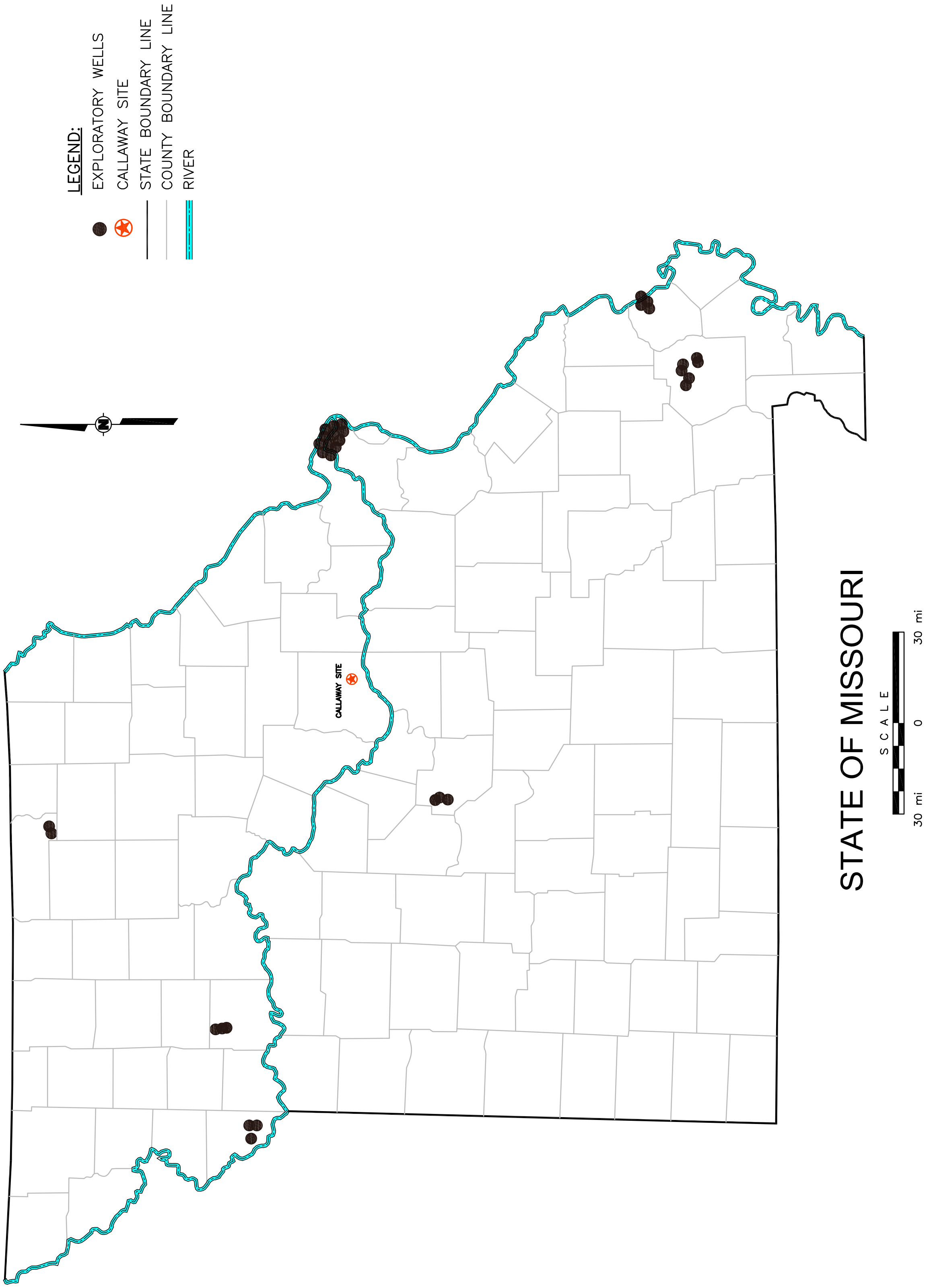


Figure 2.5.1-42—{Mineral Resources in Missouri}

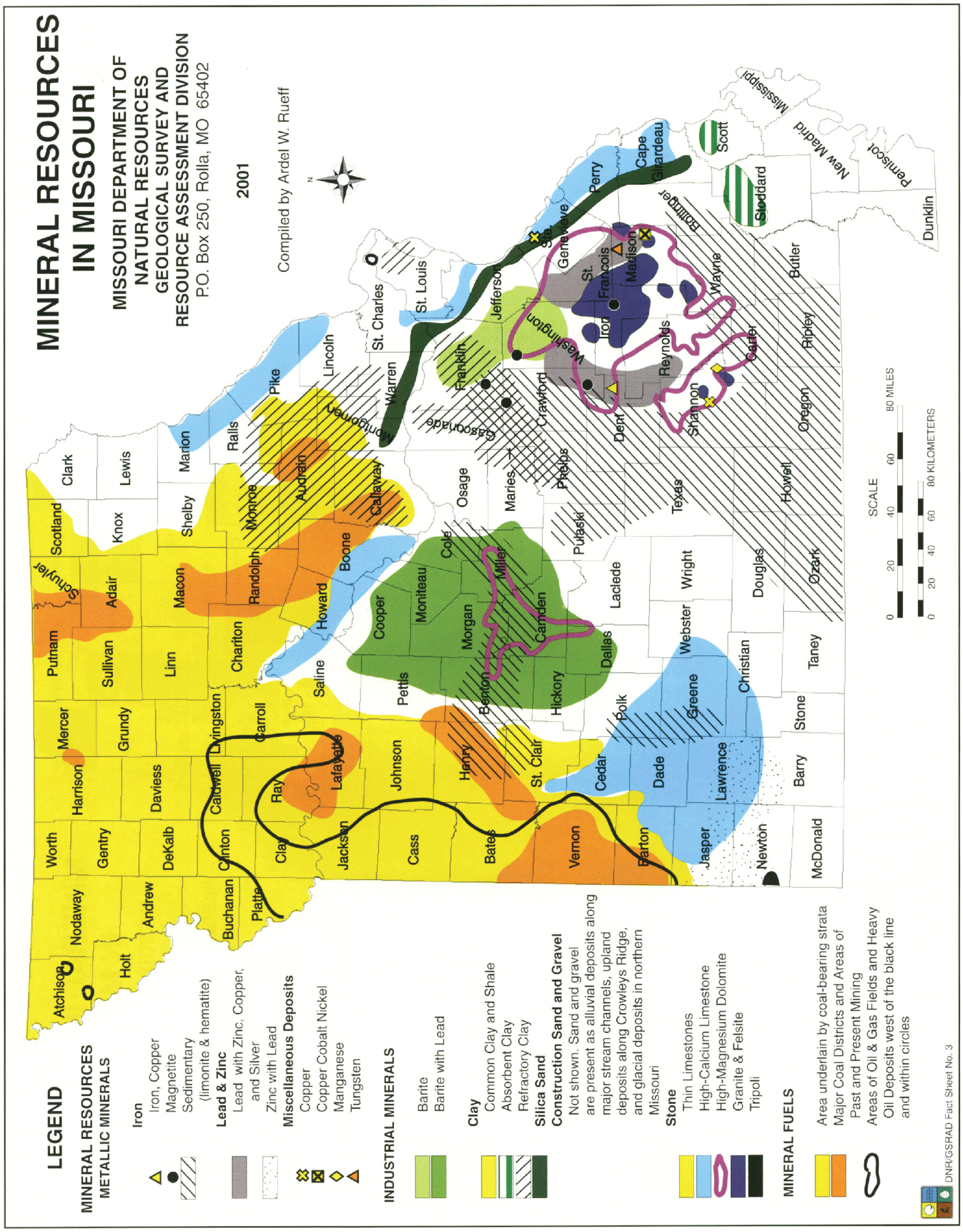


Figure 2.5.1-43—{Mineral Industries in Missouri}