J. A. "Buzz" Miller
Senior Vice President
Nuclear Development

Southern Nuclear Operating Company, Inc.
40 Inverness Center Parkway
Post Office Box 1295
Birmingham, Alabama 35201

Tel 205.992.5754
Fax 205.992.6165

SOUTHERN COMPANY
Energy to Serve Your World℠

JAN 19 2007

Docket No.: 52-011

AR-07-0004

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Southern Nuclear Operating Company
Vogtle Early Site Permit Application
Response to Requests for Additional Information on Vibratory Ground Motion

Ladies and Gentlemen:

By letter dated December 14, 2006, the U.S. Nuclear Regulatory Commission (NRC) provided Southern Nuclear Operating Company (SNC) with requests for additional information (RAIs) following their review of the Site Safety Analysis Report (SSAR) portion of the Vogtle Early Site Permit (ESP) application. Specifically, the RAIs involve SSAR Section 2.5.2, *Vibratory Ground Motion*. A summary of SNC's proposed response to the RAIs was discussed with the NRC at the Vogtle site during the Site Geology Audit on January 10-11, 2007. SNC's formal response to the Vibratory Ground Motion RAIs is provided in the three enclosures to this letter. As discussed with the NRC Vogtle ESP Project Manager, the electronic data files contained on the compact disc (CD) in Enclosure 3 are not intended to meet NRC electronic submittal criteria.

The SNC contact for this RAI response letter is J. T. Davis at (205) 992-7692.

D078
CD available
at NRC File Center
T5F27

Mr. J. A. (Buzz) Miller states he is a Vice President of Southern Nuclear Operating Company, is authorized to execute this oath on behalf of Southern Nuclear Operating Company and to the best of his knowledge and belief, the facts set forth in this letter are true.

Respectfully submitted,

SOUTHERN NUCLEAR OPERATING COMPANY

JA Miller

Joseph A. (Buzz) Miller

Sworn to and subscripted before me this 19th *day of* January, *2007*

Dana M. Williams
Notary Public

My commission expires: 12/29/2010

JAM/BJS/dmw

Enclosures:
1. Response to December 14, 2006 RAIs # 2.5.2-1 and #2.5.2-3
2. Response to December 14, 2006 RAI # 2.5.2-2
3. Electronic Files (CD) For RAIs # 2.5.2-1 and # 2.5.2-3

cc: Southern Nuclear Operating Company
Mr. J. B. Beasley, Jr., President and CEO (w/o enclosures)
Mr. J. T. Gasser, Executive Vice President, Nuclear Operations (w/o enclosures)
Mr. T. E. Tynan, Vice President - Vogtle (w/o enclosures)
Mr. D. M. Lloyd, Vogtle Deployment Director (w/o enclosures)
Mr. C. R. Pierce, Vogtle Development Licensing Manager (w/o enclosures)
Mr. D. P. Moore, Engineering Programs Consulting Engineer (w/o enclosures)
Document Services RTYPE: AR01
File AR.01.01.06

Nuclear Regulatory Commission
Mr. J. E. Dyer, Director of Office of Nuclear Regulation (w/o enclosures)
Mr. W. D. Travers, Region II Administrator (w/o enclosures)
Mr. D. B. Matthews, Director of New Reactors (w/o enclosures)
Ms. S. M. Coffin, AP1000 Manager of New Reactors (w/o enclosures)
Mr. C. J. Araguas, Project Manager of New Reactors (with enclosures, including 3 CDs)
Mr. M. D. Notich, Environmental Project Manager (w/o enclosures)
Mr. G. J. McCoy, Senior Resident Inspector of VEGP (w/o enclosures)

Georgia Power Company
Mr. O. C. Harper, Vice President, Resource Planning and Nuclear Development (w/o enclosure)

Oglethorpe Power Corporation
Mr. M. W. Price, Chief Operating Officer

Municipal Electric Authority of Georgia
Mr. C. B. Manning, Senior Vice President and Chief Operating Officer (w/o enclosure)

Dalton Utilities
Mr. D. Cope, President and Chief Executive Officer (w/o enclosure)

Bechtel Power Corporation
Mr. J. S. Prebula, Project Engineer (w/o enclosures)
Mr. R. W. Prunty, Licensing Engineer (w/o enclosures)

Southern Nuclear Operating Company

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Enclosure 1

Response to December 14, 2006

RAIs # 2.5.2-1 and # 2.5.2-3

Section 2.5.2 - Vibratory Ground Motion

RAI 2.5.2-1 In order for the staff to determine the adequacy of the Probabilistic Seismic Hazard analysis (PSHA) for the Vogtle ESP site, please provide the following data electronically:

1. **Electric Power Research Institute (EPRI) seismicity catalog (EPRI NP-4726-A 1988) for the region of interest (30° to 37° N, 78° to 86° W).**
2. **Updated EPRI seismicity catalog as shown in Standard Safety Analysis Report Table 2.5.2-1.**
3. **Geographic coordinates of the corner points for the primary (99% of total hazard) source zones for each of the 6 EPRI-SOG Earth Science Teams (ESTs).**
4. **1- and 10-Hz mean hazard curves for each of the 6 EPRI-SOG ESTs for each of their source zones.**
5. **1- and 10-Hz mean hazard curves for the updated Charleston seismic source.**

Response:

Electronic ASCII data files are provided (on the compact disc in Enclosure 3) as specified below:

1. ***EPRI_CAT_VOGTLE.DAT*** is the EPRI catalog, filtered to include MAIN events between 30-37 N and 78-86 W. The columns EMB, SMB, and RMB correspond to the following:

   EMB is expected magnitude (mb) per Eqn 4-1 of EPRI (1988)

   SMB is the standard deviation of the magnitude estimate

   RMB is mb* per Eqn 4-2 of EPRI (1988)

2. ***UPDATE_CAT_VOGTLE.DAT*** is the updated catalog, 1985-2004, for the same geographical region, with the same columns.

3. ***BEC_geom.dat, DAM_geom.dat, LAW_geom.dat, RND_geom.dat, WCC_geom.dat*** and ***WGC_geom.dat*** are coordinates for the six EPRI-SOG teams of source zones that contribute to the 99% hazard for the EPRI-SOG study. These source zones are listed in Tables 2.5.2-2 through 2.5.2-7 of SNC (2006).

4. & 5. Response to Items 4 and 5 is in accordance with the agreement reached at the Site Geology Audit (January 10-11, 2007) on the type of data needed to satisfy this NRC request. ***Vogtle_rock_hazard.txt*** contains mean rock hazard curves for 10 Hz and 1 Hz, for each EPRI-SOG team (the total mean hazard for that team's sources with the updated Charleston sources removed), for the updated Charleston characteristic source, for the updated Charleston exponential source, and for the final total mean hazard that includes the updated Charleston sources in the teams' sources (weighting each EPRI-SOG team equally). These curves were calculated using the ground motion equations of EPRI (2004).

References

EPRI (1988) Seismic hazard methodology for the central and eastern United States, Volume 1, Part 2: Methodology (Revision 1). EPRI NP-4726-A Rev. 1 dated November 1988.

EPRI (2004) CEUS ground motion project final report. Elec. Power Res. Inst. Rept. 1009684, Dec.

SNC (2006) Vogtle early site permit application. Southern Nuclear Operating Co, August.

RAI 2.5.2-3 In order for the staff to verify the adequacy of the SSE, please provide electronically 1, 2.5, 5, 10, 25, and 100 Hz mean hazard curves at the prescribed elevation, which take into account the effect of rock and soil above the hard rock horizon.

Response

The electronic ASCII file ***Vogtle_soil_hazard.txt*** contains mean soil hazard values for 0.5, 1, 2.5, 5, 10, 25, and 100 Hz, for the control point elevation (86' depth, top of Blue Bluff Marl). These values have been calculated only for 1E-4, 1E-5, and 1E-6 annual exceedance frequencies. (Refer to the compact disc in Enclosure 3 for the electronic files.)

Southern Nuclear Operating Company

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Enclosure 2

Response to December 14, 2006

RAI # 2.5.2-2

Section 2.5.2 Vibratory Ground Motion

RAI 2.5.2-2 **In order for the staff to fully evaluate the update for the Charleston seismic source, provide a copy of Bechtel engineering study report 25144-006-V14-CY06-00006 entitled "Update of Charleston Seismic Source and Integration with EPRI Source Models."**

Response:

A copy of Bechtel engineering study report 25144-006-V14-CY06-00006 (76 pages in length) directly follows this page.

BECHTEL CORPORATION
Southern Nuclear Company ALWR ESP Application – 25144-002

UPDATE OF CHARLESTON SEISMIC SOURCE AND INTEGRATION WITH EPRI SOURCE MODELS

25144-006-V14-CY06-0006 - Revision 002 - 20060908
September 8, 2006

Prepared by: Scott Lindvall and Ross Hartleb
William Lettis & Associates, Inc.

Checked by: Stephen Thompson
William Lettis & Associates, Inc.

Approved by: William Lettis
William Lettis & Associates, Inc.

UPDATE OF CHARLESTON SEISMIC SOURCE AND INTEGRATION WITH EPRI SOURCE MODELS

25144-006-V14-CY06-0006 - Revision 002
September 8, 2006

Prepared by: Scott Lindvall and Ross Hartleb
William Lettis & Associates, Inc.

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A. PURPOSE

This report updates the 1986 EPRI-SOG seismic source model to reflect new information regarding the geometry, maximum magnitude (Mmax), and recurrence of the Charleston seismic source. The 1986 EPRI-SOG seismic source model (or EPRI model, as used in this report) includes independent assessments of the Charleston seismic source by six Earth Science Teams (ESTs; EPRI, 1986). These six independent assessments represented the range of current understanding at that time of the Charleston source parameters by the informed technical community and were given equal weight in the EPRI model. Since publication of the 1986 EPRI seismic source model, significant new information has been developed for assessing the earthquake source that produced the 1886 Charleston earthquake. This new information shows that the Charleston seismic source should be updated according to Regulatory Guide 1.165 (Nuclear Regulatory Commission, 1997). This report provides: (1) the basis for updating the Charleston source model, (2) a summary of the new data, (3) the methodology used to update the Charleston seismic source model, and (4) documentation of the Updated Charleston Seismic Source (UCSS) model. Appendix A provides the approach for integrating the UCSS model into the 1986 EPRI source model.

B. BASIS FOR UPDATING THE CHARLESTON SEISMIC SOURCE

New information available since the EPRI EST assessments provides the basis for updating the Charleston source model, as described in Regulatory Guide 1.165 (Nuclear Regulatory Commission, 1997). Appendix E of Regulatory Guide 1.165 states:

> *"If new information identified by the site-specific investigations would result in a significant increase in the hazard estimate for a site, and this new information is validated by a strong technical basis, the new PSHA may have to be modified to incorporate the new technical information."*

Appendix E also states that one of the most important types of new information is the discovery of paleoliquefaction features that can be used to estimate both magnitude and recurrence intervals:

> *"Among the new site-specific information that is most likely to have a significant impact on the hazard is the discovery of paleoseismic evidence such as extensive soil liquefaction features, which would indicate with reasonable confidence that much larger estimates of the maximum earthquake than those predicted by the previous studies would ensue. The paleoseismic data could also be significant even if the maximum magnitudes of previous studies are consistent with the paleo-earthquakes if there are sufficient data to develop return period estimates significantly shorter than those previously used in the probabilistic analysis."*

Paleoliquefaction features and other new information published since the 1986 EPRI study have significant implications regarding the geometry, Mmax, and recurrence of Mmax in the Charleston seismic source. Results from the 1989 EPRI Probabilistic Seismic Hazard Analysis (PSHA) study also show that the Charleston seismic source is the most significant contributor to seismic hazard at the Vogtle site (EPRI, 1989). These factors show that an update of the Charleston seismic source is needed for the Vogtle site PSHA currently being developed as part of the Vogtle Early Site Permit (ESP) application.

C. NEW INFORMATION

It has been nearly 20 years since the six EPRI Earth Science Teams (ESTs) evaluated hypotheses for earthquake causes and tectonic features and assessed seismic sources in the central and eastern United States (EPRI, 1986). The seismic source models of the Bechtel, Dames & Moore, Law, Rondout, Weston, and Woodward-Clyde teams were equally weighted in the EPRI PSHA study summarized in the EQ Primer report (EPRI, 1989). Several studies that post-date the 1986 EPRI EST's assessments have demonstrated that the source parameters for geometry, Mmax, and recurrence of Mmax in the Charleston seismic source need to be updated to capture a more current understanding for both the 1886 Charleston earthquake and the seismic source that produced this earthquake. In addition, recent PSHA studies of the South Carolina region (Savy *et al.*, 2002; Chapman and Talwani, 2002) and the southeastern United States (Frankel *et al.*, 2002) have developed models of the Charleston seismic source that differ significantly from the earlier EPRI characterizations.

New data that post-date the 1986 EPRI EST evaluations provide significant information regarding characterization of the geometry, Mmax, and recurrence of Mmax in the Charleston seismic source. These new data are summarized below:

Geometry

Several recent studies provide direct or indirect evidence regarding the geometry of the Charleston seismic source. Studies that provide direct evidence are those that identify or hypothesize specific tectonic features that may have produced the 1886 Charleston earthquake. The geometries of these tectonic features, therefore, directly reflect the possible geometry of the Charleston seismic source. These tectonic features are summarized in Table 1 and shown in Figures 1 and 2. Uncertainty in the location and existence of these tectonic features and their hypothesized relationship to the 1886 Charleston earthquake is described below.

Studies that provide indirect evidence are those that present information on the geographic distribution of phenomena that may be related to the Charleston seismic source. These phenomena include liquefaction features and strong motion data from the 1886 Charleston earthquake, paleoliquefaction features from prehistoric earthquakes in the region, historical and instrumental seismicity data, and use of global intraplate seismicity to associate large magnitude intraplate earthquakes within specific tectonic environments.

Direct Evidence
A compilation of local and regional tectonic features is shown in Figures 1 and 2. These features are differentiated to show both pre- and post-1986 EPRI information. Recent post-EPRI studies that have identified tectonic features in the 1886 Charleston meizoseismal area include those by Marple and Talwani (1993, 2000, 2004), Weems *et al.* (1997), Weems and Lewis (2002), and Talwani and Katuna (2004). In particular, five postulated faults have been identified in the Charleston area since 1986 (Table 1 and Figure 1) and additional information has been developed on the offshore Helena Banks fault zone. These are described below:

> **East Coast fault system.** The East Coast fault system (ECFS, the southern section of which is also known as the 'zone of river anomalies' or ZRA), is a northeast-trending, ~600-km-long fault system extending from west of Charleston, South Carolina to

southeastern Virginia (Marple and Talwani, 2000). The ECFS consists of three, ~200-km-long, right-stepping sections (southern, central, and northern; Figures 2 and 3). Evidence for the southern section is strongest, with evidence becoming successively weaker northward (Wheeler, 2005). Marple and Talwani (1993) identified a series of geomorphic anomalies (*i.e.*, ZRA) located along and northeast of the Woodstock fault, and attributed these to a buried fault much longer than the Woodstock fault. Marple and Talwani (1993, 2000, 2004) suggested that this structure, the southern section of the ECFS, may have been the source of the 1886 Charleston earthquake.

Marple and Talwani (2000) provided additional evidence for the existence of the southern section of the ECFS, including seismic reflection data, linear aeromagnetic anomalies, exposed Plio-Pleistocene faults, local breccias, and upwarped strata. Since most of the geomorphic anomalies associated with the southern section of the ECFS are in late Pleistocene sediments, Marple and Talwani (2000) speculated that the fault was active 130-10 ka, and perhaps remains active. Wildermuth and Talwani (2002) subsequently used gravity and topographic data to postulate the existence of a right-stepping pull-apart basin between the southern and central sections of the ECFS. Existence of the pull-apart basin suggests a component of right-lateral slip on the northeast-trending ECFS, which is consistent with the inferred sense of slip based on the orientation of the fault in the regional stress field.

Wheeler (2005) classified the ECFS as a class C feature; that is, one for which "geologic evidence is insufficient to demonstrate (1) the existence of tectonic faulting, or (2) Quaternary slip or deformation associated with the feature."

Based on our independent evaluation of the geomorphic, seismic reflection, and seismicity data, our confidence in the existence and activity of the ECFS is low to moderate. In our judgment, all of the geomorphic "anomalies" have credible non-tectonic (*i.e.*, fluvial geomorphic) explanations. Our 3-D analysis of microseismicity in the vicinity of the ECFS does not clearly define a discrete structure (Figure 5). Available seismic reflection data do not unambiguously delineate a through-going structure in the vicinity of the ECFS.

Adams Run fault. Weems and Lewis (2002) postulated the existence of the Adams Run fault on the basis of microseismicity and borehole data (Figures 1 and 4). Their interpretation of borehole data suggests the presence of areas of Cenozoic uplift and subsidence separated by the inferred fault (Figure 4). However, our review of these data show that the pattern of uplift and subsidence (1) do not appear to persist through time (*i.e.*, successive stratigraphic layers) in the same locations and (2) that the intervening structural lows between the proposed uplifts are highly suggestive of erosion along ancient river channels. In addition, there is no geomorphic evidence for the existence of the Adams Run fault, and our 3-D analysis of microseismicity in the vicinity of the proposed Adams Run fault does not clearly define a discrete structure (Figure 5). Thus, our confidence in the existence and activity of this fault is low.

Sawmill Branch fault. Talwani and Katuna (2004) postulated the existence of the Sawmill Branch fault on the basis of microseismicity and further speculated that this feature experienced surface rupture in the 1886 earthquake. According to Talwani and Katuna (2004), this ~5-km-long, northwest-trending fault, which is a segment of the larger Ashley River fault, offsets the Woodstock fault in a left-lateral sense (Figure 1). Earthquake damage at three localities was used to infer that surface rupture occurred in

1886. However, our field review of these features along the banks of the Ashley River (small, discontinuous cracks in a tomb that dates to 1671 A.D. and displacements (<10 cm) in the walls of colonial Fort Dorchester) are almost certainly the product of shaking effects as opposed to fault rupture. Moreover, our 3-D assessment of microseismicity in the vicinity of the proposed Sawmill Branch fault does not clearly define a discrete structure distinct or separate from the larger Ashley River fault, which was defined based on seismicity (Figure 5). Thus, our confidence in the existence and activity of this fault is low.

Summerville fault. Weems *et al.* (1997) postulated the existence of the Summerville fault on the basis of microseismicity (Figure 1). However, there is no geomorphic or borehole evidence for the existence of the Summerville fault, and our 3-D analysis of microseismicity in the vicinity of the proposed Summerville fault does not clearly define a discrete structure (Figure 5). Thus, our confidence in the existence and activity of this fault is low.

Helena Banks fault zone. The Helena Banks fault zone is clearly imaged on seismic reflection lines offshore of South Carolina (Behrendt *et al.* 1983; Behrendt and Yuan, 1987) and was known to the six EPRI ESTs at the time of the 1986 EPRI study as a possible Cenozoic-active fault zone. Some ESTs recognized the offshore fault zone as a candidate tectonic feature for producing the 1886 event and included it in their Charleston seismic source zones. However, since 1986 three additional sources of information have become available:

- In 2002, two magnitude $m_b \geq 3.5$ earthquakes (m_b 3.5 and 4.4) occurred offshore of South Carolina in the vicinity of the Helena Banks fault zone in an area previously devoid of seismicity (Figures 1 and 2).

- Bakun and Hopper (2004) reinterpreted intensity data from the 1886 Charleston earthquake and show that the calculated intensity center is located over 150 km offshore from Charleston, suggesting that the source of the 1886 earthquake may lie offshore of South Carolina. Bakun and Hopper (2004) ultimately conclude, however, that the epicentral location most likely lies onshore in the Middleton Place-Summerville area; Figures 2 and 6) based on the concentrated seismicity in this area.

- Crone and Wheeler (2000) described the Helena Banks fault zone as a potential Quaternary tectonic feature, but classified the fault zone as a Class C feature that lacks sufficient evidence to demonstrate Quaternary activity).

  In our review of available information, we assign a high confidence to the existence of this fault zone and a low to moderate confidence that the fault may be active and the source of the 1886 earthquake. Seismic reflection data clearly show the existence of the Helena Banks fault zone (as opposed to a deep-seated landslide) extending to a depth of >1 km. Furthermore, the occurrence of 2002 earthquakes and location of the Bakun and Hopper (2004) intensity center offshore suggest, at a low probability, that the fault zone could be considered a potentially active fault. If the Helena Banks fault zone is an active source, its length and orientation could possibly explain the distribution of paleoliquefaction features along the South Carolina coast. Therefore, we include the Helena Banks fault zone as a possible source for the 1886 Charleston earthquake in our update of the Charleston seismic source geometry in order to capture the uncertainty associated with this fault.

Indirect Evidence

Indirect evidence relating to the geometry of the Charleston seismic source includes:

(1) The relationship of large intraplate earthquakes worldwide to specific tectonic environments,

(2) The geographic distribution, density, and size of liquefaction features produced by the 1886 and prehistoric earthquakes in the Charleston region,

(3) Earthquake intensity data from the 1886 Charleston earthquake, and

(4) Instrumental seismicity.

Johnston *et al.* (1994) evaluated the correlation of large magnitude intraplate earthquakes to specific tectonic environments throughout the world. They concluded that large magnitude earthquakes generally occur in tectonic environments characterized by Mesozoic and younger rifted crust. The Charleston meizoseismal region occurs in a region of Mesozoic extended crust along the southeastern margin of the North American craton (Johnston *et al.*, 1994). Several Mesozoic basins are defined in the region. In our assessment of Charleston geometry, we considered the location, structural orientation (*i.e.*, NE-SW), and spatial correlation of possible Mesozoic basins and structures to characterize alternative models of the source zone geometry.

The 1886 Charleston earthquake produced widespread significant liquefaction. The distribution and density of this liquefaction was documented by Dutton (1989) and provides useful information on the epicentral location of the earthquake. Additional studies by Obermeier *et al.* (1989, 1990), Amick (1990), Amick *et al.* (1990a, 1990b), Talwani and Schaeffer (2001), and others evaluated the distribution of 1886 liquefaction and earlier paleoliquefaction features to assess the geometry as well as the stationarity or non-stationarity of the Charleston seismic source.

Several researchers have performed searches for paleoliquefaction features both in the 1886 Charleston epicentral area and in the southeastern U. S. coastal region to better define the location and geometry of the Charleston seismic source. Obermeier *et al.* (1989, 1990, 2001) investigated the spatial distribution, size, and abundance of paleoliquefaction features in the Charleston region and beyond. Obermeier *et al.* (1989, 1990) observed that both the abundance and diameters of pre-1886 Holocene sandblow craters are greatest within the meizoseismal zone of the 1886 Charleston earthquake. No features were found beyond 100 km from Charleston (Obermeier *et al.*, 2001).

Amick *et al.* (1990) searched for paleoliquefaction features in late Quaternary beach and near-shore deposits (*i.e.*, deposits susceptible to liquefaction) in Virginia, North Carolina, South Carolina, Georgia, and in the Wilmington, Delaware area. Their search identified liquefaction features almost exclusively in South Carolina. Liquefaction features were not found in susceptible deposits outside of South Carolina (the lone exception being a liquefaction feature discovered directly north of the South Carolina-North Carolina state line). The negative evidence provided by Obermeier *et al.* (2001) and Amick *et al.* (1990) (*i.e.*, the dearth of features outside of the Charleston area) strongly suggest that the seismic source that produced the 1886 Charleston earthquake and earlier large magnitude earthquakes is localized in the Charleston meizoseismal area.

Based on the geographic and temporal distribution of paleoliquefaction features in coastal South Carolina, Talwani and Schaeffer (2001) proposed two scenarios for the occurrence in time and space of Charleston-area earthquakes. In their first scenario, three seismic sources are inferred to occur within the coastal plain of South Carolina: a Charleston source that has produced earthquakes with magnitudes $\geq$ ~7, and a source in each of the Georgetown and Bluffton areas that have produced more moderate earthquakes with magnitudes ~6. In Talwani and Schaeffer's (2001) second scenario, all events recorded in the paleoliquefaction record were centered at Charleston with magnitudes $\geq$ ~7.

Intensity data for the 1886 Charleston earthquake reported by Dutton (1899) and reinterpreted by Bollinger (1977) indicate a meizoseismal area centered on Charleston (Figures 1 and 2). Bakun and Hopper (2004) calculated an intensity center for the 1886 Charleston earthquake that is located offshore about 200 km east of Charleston (Figure 6). The offshore location for the intensity center may be a function of the spatial distribution of the input data, all of which lie onshore (Bakun and Hopper, 2004). Bakun and Hopper's (2004) preferred intensity center for the 1886 Charleston earthquake is onshore within the Middleton Place-Summerville seismic zone.

The Middleton Place-Summerville seismic zone (MPSSZ) is an area of elevated microseismic activity located ~20 km northwest of Charleston (Tarr and Rhea, 1983; Bollinger *et al.*, 1991; Madabhushi and Talwani, 1993; Talwani and Katuna, 2004). Between 1980 and 1991, 58 events with Md 0.8 – 3.3 were recorded in an 11 x 14 km^2 area, with hypocentral depths ranging from 2 to 11 km (Madabhushi and Talwani, 1993). The elevated seismic activity of the MPSSZ has been attributed to stress concentrations associated with the intersection of the Ashley River and Woodstock faults (Talwani, 1982; Madabhushi and Talwani, 1993; Talwani and Katuna, 2004; Gangopadhyay and Talwani, 2005). Persistent foreshock activity was reported in the MPSSZ area (Dutton, 1889), and it has been speculated that the 1886 Charleston earthquake occurred within the MPSSZ (*e.g.*, Talwani, 1982; Tarr and Rhea, 1983; Bakun and Hopper, 2004).

Given the direct and indirect data described above, significant revision to the Charleston geometry provided in the EPRI seismic source model is warranted. New information published since 1986 strongly indicate that the Charleston earthquake is localized in the 1886 Charleston meizoseismal area or in the region of coastal South Carolina constrained by the paleoliquefaction data.

Maximum Magnitude (Mmax)

Multiple methods and types of data have been used to characterize the maximum magnitude (Mmax) of the Charleston seismic source. These approaches include using the worldwide data set to constrain the minimum and maximum range of Mmax for regions of Mesozoic and younger extensional crust (Johnston *et al.*, 1994) and evaluating the size of the 1886 Charleston earthquake as a proxy for the maximum earthquake that may be produced by the Charleston seismic source (Table 2). The latter approach has used both intensity data (Johnston, 1996; Bakun and Hopper, 2004) and the size and geographic distribution of the liquefaction fields (Obermeier, *et al.*, 1989, 1990, 2001; Johnston, 1996) to estimate the magnitude of the 1886 event. Because the causative fault for the 1886 event is unknown, we consider estimates of

Mmax based on the 1886 earthquake magnitude and world-wide data base more reliable than using postulated fault dimensions to estimate Mmax for the Charleston seismic source.

Johnston *et al.* (1994) compiled a world-wide database of earthquakes in stable continental regions (SCRs) to evaluate the correlation of large magnitude SCR earthquakes to specific tectonic environments, if any. The database showed that the largest SCR earthquakes (>**M**7) are confined to regions of Mesozoic and younger extended crust. The maximum observed magnitude for Mesozoic extended crust along passive cratonic margins similar to the southeastern U. S. is **M**7.7 ± 0.2 (Johnston *et al.*, 1994, Chapter 4). Based on an analysis of intensity data, Johnston *et al.* (1994, Chapter 3) estimated the 1886 Charleston earthquake to be **M**7.56 ± 0.35. Using Bayesian statistics, Johnston *et al.* (1994, Chapter 6) indicated that the Mmax for the Charleston seismic source should not be much larger than the 1886 event. This conclusion supports the idea that an Mmax developed for the Charleston seismic source should be primarily based on the estimate of the size of the 1886 Charleston event.

Martin and Clough (1994) used a geotechnical approach to back-calculate ground motions for the 1886 Charleston earthquake based on soil properties of 1886 paleoliquefaction features. The threshold peak ground acceleration required to cause ground deformation was estimated based on the intersection of the layer curve effect of Ishihara (1985) and the cyclic stress method (*e.g.*, Seed *et al.*, 1985). Martin and Clough (1994) concluded that the liquefaction evidence was consistent with an earthquake no larger than **M**7.5, and possibly as small as **M**7.0 (Table 2).

Johnston (1996) developed specific eastern North America regressions of seismic moment based on isoseismal area and averaged these with global stable continental regions relations to estimate the magnitude of the 1886 Charleston earthquake. After considering multiple regressions, options for best-weighted values, and a correction for wedge effects of Coastal Plain sediments on isoseismals, a preferred best estimate of **M**7.3 ± 0.26 (**M**7.04-7.56) was obtained (Table 2). The Johnston (1996) study also estimated a magnitude of **M**7.4 ± 0.35 (**M**7.05-7.77) using the extent and severity of liquefaction and the Liquefaction Severity Index (LSI). These estimates of Mmax reflect a slight downward revision from the estimate from the estimate of Mmax provided in Johnston *et al.* (1994) of **M**7.56 ± 0.35. Johnston (1996) concluded that while uncertainties in magnitude are reported, "the final results of this study are best stated in general terms." For the 1886 Charleston earthquake, Johnston (1996) concluded that the best estimate of magnitude is "in the low- to mid-**M**7 range." We consider this estimate as a credible magnitude and it is incorporated into our assessment of Mmax for the UCSS.

In comparing intensity attenuation with epicentral distance for different stable continental regions, Bakun and McGarr (2002) showed that eastern North America exhibits lower attenuation of seismic energy than other worldwide stable continental regions. Johnston (1996) also recognized this difference and developed eastern North America relations, which were averaged with global stable continental regions relations, to arrive at a best estimate of **M**7.3 for the 1886 Charleston earthquake. Based on this observation, Bakun and McGarr (2002) concluded that the Johnston (1996) magnitude estimates for 1811-1812 New Madrid earthquakes, derived solely on a global stable continental regions attenuation model, are overestimated. Bakun and McGarr (2002) also state that magnitude estimates based on averaging intensity attenuation relations from eastern North America and other stable continental regions may be overestimated. This suggests that Johnston (1996) may have overestimated the magnitude of the 1886 Charleston earthquake.

Bakun and Hopper (2004) estimated the magnitude and location of the 1886 Charleston earthquake using eastern North America intensity models that relate intensity and epicentral distance (Bakun *et al.,* 2003). Assuming that the 1886 event was centered in the Middleton Place-Summerville cluster of seismicity (and not offshore at their estimated intensity center), Bakun and Hopper (2004) estimated a magnitude range of **M**6.4-7.2 at the 95% confidence interval. Bakun and McGarr's (2004) preferred magnitude estimate for the Charleston earthquake is M_I6.9 (M_I is considered equivalent to **M**). The Bakun and Hopper (2004) magnitude estimate suggests that the 1886 event may have been smaller than the Johnston (1996) estimate. We consider that both of these studies represent the most credible estimates of the 1886 Charleston earthquake.

Obermeier *et al.* (1989, 1990, 2001) investigated the spatial distribution, size, and abundance of paleoliquefaction features in the Charleston coastal region and beyond. Based on the widespread distribution of sand blow craters in coastal South Carolina, Obermeier *et al.* (1990) stated that these features were likely the result of earthquakes with magnitudes of at least m_b 5.5, and probably much stronger. Based on the observation that the limits of prehistoric liquefaction extend at least as far from Charleston as those formed during the 1886 earthquake (and the liquefaction susceptibility of deposits subjected to prehistoric earthquakes was likely as high as the liquefaction susceptibility of those subjected to the 1886 earthquake), Obermeier *et al.* (2000) suggested that prehistoric Charleston area earthquakes were probably at least as strong as the 1886 Charleston earthquake.

For paleo-earthquakes, Talwani and Schaeffer (2001) estimated the magnitudes of past Charleston area events based on the spatial distribution and areal extent of paleoliquefaction sites (Figure 7). Talwani and Schaeffer (2001) did not use a rigorous empirical method in their estimation of the magnitudes of past events, but instead they used a simple approach by which all past liquefaction episodes interpreted as having spanned a region comparable in size to the 1886 liquefaction field were assigned **M**7+, and all past liquefaction episodes interpreted as having spanned a smaller areal extent were assigned **M**6+.

Hu *et al.* (2000a, 2002b) used the event chronology as interpreted by Talwani and Schaeffer (2001) and the energy-stress method to estimate magnitudes of past Charleston area earthquakes. For earthquakes that produced liquefaction features over extended areas centered near Charleston, Hu *et al.* (2002b) estimated magnitudes of **M**6.8-7.8, and they estimated magnitudes of **M**5.5-7.0 for earthquakes that produced liquefaction over more limited areas.

Leon (2003) and Leon *et al.* (2005) also estimated the magnitudes of past Charleston area earthquakes using the event chronology as interpreted by Talwani and Schaeffer (2001), but the Leon (2003) and Leon *et al.* (2005) method takes into account the effects of sediment age on the liquefaction potential of those sediments. Using the magnitude-bound method, Leon *et al.* (2005) estimated magnitudes of **M**6.9-7.1 for earthquakes that produced liquefaction features over extended areas, and **M**5.7-6.3 for earthquakes that produced liquefaction over more limited areas. Using the energy-stress method, Leon *et al.* (2005) estimated magnitudes of **M**5.6-7.2 for earthquakes that produced liquefaction features over extended areas, and **M**4.3-6.4 for earthquakes that produced liquefaction over more limited areas.

The magnitude ranges estimated for earthquakes that produced liquefaction over extended areas (Hu *et al.*, 2002a; 2002b; Leon *et al.,* 2005) have significant overlap with magnitude estimates of the 1886 earthquake by Johnston (1996) and Bakun and Hopper (2004). However, given the large uncertainties in working with the paleoliquefaction record and methods for estimating magnitudes from these data, we consider that the best representation of the Mmax for the Charleston seismic source should be based on estimates of the size of the 1886 earthquake (Table 2).

It is important to note that the magnitudes estimated from the paleoliquefaction record for earthquakes that produced liquefaction over limited areas may have been less than **M**6.3 (Leon *et al.*, 2005). This implies that some events in the paleoliquefaction record may not represent large, 1886-type characteristic earthquakes. Therefore, the inclusion of any smaller paleo-earthquakes in the recurrence model described below may bias the recurrence toward moderate-sized earthquakes and may overestimate the frequency of large events.

Taken together, these new data suggest that Mmax for the 1886 Charleston earthquake is on the order of **M** 6 ¾ to 7 ½ (Martin and Clough, 1994; Johnston, 1996; Bakun and Hopper, 2004; Table 2). The 95% confidence interval of Bakun and Hopper (2004) implies the magnitude could have been as low as **M**6.4; however, the preponderance of the data and evaluations indicate that the low end of this estimate likely underestimates the size of the 1886 earthquake.

<u>Recurrence</u>

Recent studies of paleoliquefaction features in the southeast United States provide new insight into the recurrence interval for Charleston area earthquakes (*e.g.,* Amick, 1990; Amick *et al.*, 1990a, 1990b; Talwani and Schaeffer, 2001). The post-EPRI studies of paleoliquefaction features suggest that recurrence of large earthquakes on the Charleston seismic source is on the order of hundreds of years. This is significantly less than the EPRI model recurrence of several thousand years predicted by historical seismicity.

Earthquakes recorded in the paleoliquefaction record may include events significantly less than Mmax because the minimum threshold magnitude for earthquakes to cause liquefaction is estimated as m_b>5.5 (Obermeier *et al.*, 1990) or **M**4.3 – 6.4 (Leon *et al.*, 2005). Therefore, estimates of Mmax recurrence intervals based upon the paleoliquefaction record may include events smaller than Mmax and overestimate the frequency of Mmax recurrence. Simply because the age determinations for paleoliquefaction features at widely distributed sites overlap, does not necessitate that the features were the result of a single, large earthquake. The possibility that paleoliquefaction features of similar age (*i.e.,* within the uncertainty in age determination) resulted from smaller earthquakes that occurred over a wide area, closely-spaced in time is an inherent uncertainty in the paleoliquefaction record.

Recent post-EPRI (1986) studies that characterized the recurrence of prehistoric earthquakes from the paleoseismic record are described below:

> Amick (1990) and Amick *et al.* (1990a, 1990b) described the spatial distribution and dating of paleoliquefaction features on the Atlantic Seaboard, including the coastal regions of the Carolinas and Georgia, as well central Virginia, and Willmington, Delaware. Amick (1990) and Amick *et al.* (1990a, 1990b) used the liquefaction data to suggest that large earthquakes occur every 500 to 600 years in Coastal South Carolina, and that paleoliquefaction evidence for earthquakes located outside of South Carolina is lacking.
>
> Talwani and Schaeffer (2001) combined previously published data with their own studies of liquefaction features in the South Carolina coastal region (Figure 7). Talwani and Schaeffer (2001) used the spatial distribution of paleoliquefaction features in

combination with estimates on the timing of the formation of the liquefaction features in order to derive possible earthquake recurrence histories for the region. Talwani and Schaeffer's (2001) scenario 1 allows for the possibility that *some* events in the paleoliquefaction record are smaller in magnitude (~**M**6+), and these more moderate events occurred to the northeast (Georgetown) and southwest (Bluffton) of Charleston. In scenario 2 (Talwani and Schaeffer, 2001), all earthquakes in the record are large shocks (~**M**7+) located near Charleston. Talwani and Schaeffer's (2001) preferred estimate for the recurrence of large earthquakes in coastal South Carolina is 500 to 600 years.

In summary, post-EPRI (1986) studies suggest that Charleston Mmax recurrence is on the order of hundreds of years, significantly less than the EPRI model recurrence of several thousand years predicted by historical seismicity. For this reason, a detailed evaluation of paleoliquefaction-based recurrence is warranted.

Recent Seismic Source Models (post 1986 EPRI study)

In addition to the new data described above, three recent seismic source models have been developed that include post-EPRI information to define the Charleston seismic source. These source models include geometries, Mmax, and recurrence parameters that differ significantly from the EPRI characterization and are summarized below:

2002 USGS Model (Frankel *et al.*, 2002) - As part of the 2002 update of the National Seismic Hazard Maps, the USGS developed a model of the Charleston source that incorporates recent available data regarding recurrence, Mmax, and geometry of the source zone. The USGS model uses two equally weighted source geometries, one geometry represented by an areal source enveloping most of the tectonic features and liquefaction data in the greater Charleston area, and a second north-northeast-trending elongated areal source enveloping the southern half of the southern segment of the East Coast fault system (ECFS) (Table 3 and Figure 8). The Frankel *et al.* (2002) report does not specify why the entire southern segment of the ECFS is not contained in their source geometry. For Mmax, the study defines a distribution of magnitudes and weights of **M**6.8 [.20], 7.1 [.20], 7.3 [.45], 7.5 [.15]. For recurrence, Frankel *et al.* (2002) adopted a mean paleoliquefaction-based recurrence interval of 550 years and represent the uncertainty with a continuous lognormal distribution.

2002 SCDOT Model (Chapman and Talwani, 2002) - The South Carolina Department of Transportation (SCDOT) model employs a combination of line and area sources in order to characterize Charleston-type earthquakes in three separate geometries, and uses a slightly different Mmax range (**M**7.1-7.5) than the USGS 2002 model (Table 3 and Figure 9). Three equally-weighted source zones defined for this study include (1) a source capturing the intersection of the Woodstock and Ashley River faults, (2) a larger Coastal South Carolina zone that includes most of the paleoliquefaction sites, and (3) a southern ECFS source zone. The magnitude distribution and weights used for Mmax are M7.1 [.20], 7.3 [.60], 7.5 [.20]. The paleoliquefaction-based recurrence interval used in the SCDOT study is a mean recurrence interval of 550 years.

The Trial Implementation Project (TIP) Study (Savy *et al.*, 2002) - The Lawrence Livermore National Laboratory TIP study focused on seismic zonation and earthquake recurrence models for two sites in the southeastern U.S., including the Vogtle site and the Watts Bar site in Tennessee. The TIP study used an expert elicitation process to characterize the Charleston seismic source considering published data through 1996. The TIP study identified multiple, alternative zones for the Charleston source and for the South Carolina-Georgia seismic zone, as well as alternative background seismicity zones for the Charleston region. However, the TIP study focused primarily on implementing the SSHAC (1997) PSHA methodology and was designed to be as much of a test of the methodology as a real estimate of seismic hazard. As a result, its findings are not included explicitly in this report.

D. METHOD USED TO UPDATE THE CHARLESTON SEISMIC SOURCE

Methods used to update the Charleston seismic source follow guidelines provided in Regulatory Guide 1.165 (Nuclear Regulatory Commission, 1997). A Senior Seismic Hazard Advisory Committee (SSHAC) Level 2 study was performed to incorporate current literature and data, and the understanding of experts into an update of the Charleston seismic source model. This effort is outlined in the SSHAC (1997) report, which provides guidance on incorporating uncertainty and the use of experts in PSHA studies.

The intent of the SSHAC process is to represent the range of current understanding of seismic source parameters by the informed technical community. A SSHAC Level 2 process utilizes an individual, team, or company to act as the Technical Integrator (TI), who is responsible for reviewing data and literature and contacting experts who have developed interpretations or who have specific knowledge of the seismic source. For this effort, the TI was a team of six WLA personnel (Scott Lindvall, Ross Hartleb, William Lettis, Jeff Unruh, Keith Kelson, and Steve Thompson). This team (1) compiled and reviewed all new information developed since 1986 regarding the Charleston 1886 earthquake and the seismic source that may have produced this earthquake; (2) compared this new information with information available prior to 1986 and the EPRI EST assessments of the Charleston seismic source; (3) contacted researchers familiar with recent and ongoing studies of the Charleston seismic source; and (4) integrated this information to develop an updated characterization of the Charleston seismic source that captures the composite representation of the informed technical community. Mr. Lindvall directed efforts of the TI team. Dr. Hartleb compiled available literature and data and facilitated data review by the team members through overseeing the development of a GIS data base. Dr. Lettis, Dr. Unruh, Mr. Kelson, and Dr. Thompson worked with Mr. Lindvall and Dr. Hartleb to critically review and evaluate the available data and to develop the updated Charleston source model.

Specific activities performed during the SSHAC Level 2 study included:

- Review published literature, data and maps, with a focus on post-EPRI data (c. 1986)

- Review the EPRI source model to understand the intent of each EST's modeling of the Charleston source.

- Interview local experts and researchers familiar with geologic/seismologic data and recent characterizations of the Charleston seismic source. The following experts were consulted:

  Dr. David Amick, SAIC
  Dr. Martin Chapman, Virginia Polytechnic Institute
  Dr. Chris Cramer, US Geological Survey

Dr. Art Frankel, US Geological Survey
Dr. Arch Johnston, Center for Earthquake Research and Information, University of Memphis
Dr. Richard Lee, Los Alamos National Laboratory
Dr. Joe Litehiser, Bechtel Corp (original team leader of the 1986 Bechtel EST)
Dr. Steve Obermeier, US Geological Survey (retired)
Dr. Pradeep Talwani, University of South Carolina
Dr. Robert Weems, US Geological Survey

- Update the Charleston seismic source based on published information and data (*e.g.*, seismicity) and knowledge of current researchers. This activity included a two-day workshop held on September 13-14, 2005 to develop the UCSS at the WLA Valencia office after several weeks of literature and data review. The workshop included the TI team, who integrated Charleston area data and expert interpretations, discussed uncertainties, and developed UCSS geometries (Figure 10) and the logic tree (Figure 11).

- Update the 1986 EPRI ESTs' seismic source models with the updated assessment of the Charleston seismic source (Tables A-1a through A-1f). A meeting was held at Bechtel's San Francisco office on September 15, 2005, with Joe Litehiser and Robin McGuire (PSHA analyst) and two members of the TI team (Lindvall and Lettis) to determine how the UCSS would be integrated into the EPRI source models for each EST (Appendix A).

- Recalibration and reanalysis of radiocarbon ages and timing of Charleston area paleoliquefaction episodes to develop a quantitative estimate of recurrence. Results of these analyses are presented in two separate calculation sheets (Bechtel 2006a, 2006b).

E. UPDATED CHARLESTON SEISMIC SOURCE MODEL (UCSS)

Geometry

The Updated Charleston Seismic Source (UCSS) model includes four, mutually exclusive source zone geometries (A, B, B', and C; Figure 10). The four geometries of the UCSS are defined based upon current understanding of geologic and tectonic features in the 1886 Charleston earthquake epicentral region, the 1886 Charleston earthquake shaking intensity, distribution of seismicity, and the geographic distribution, age and density of liquefaction features associated with both the 1886 and pre-historic earthquakes. These features are shown in Figures 1 and 10, and strongly suggest that the majority of evidence for the Charleston source is concentrated in the Charleston area and is not widely distributed throughout South Carolina. Table 1 provides a subset of the Charleston tectonic features differentiated by pre- and post-EPRI (1986) information. In addition, pre- and post-1986 instrumental seismicity (m_b>3) is shown on Figure 1. Seismicity continues to be concentrated in the Charleston region in the Middleton Place-Summerville Seismic Zone (MPSSZ), which has been used to define the intersection of the Woodstock and Ashley River faults (Tarr *et al.*, 1981; Madabhushi and Talwani, 1990; Figure 5). Notably, two earthquakes in 2002 (m_b 3.5 and 4.4) are located offshore of South Carolina along the Helena Banks fault zone in an area previously devoid of seismicity greater than m_b3. A compilation of the EST Charleston source zones are provided in Figure 12 as a comparison to the UCSS geometries shown in Figure 10.

The dominant structural grain in the eastern United States is oriented northeast-southwest and has been shaped through a long history of both extensional and compressional large-scale tectonic deformation. Seismicity in the Eastern Tennessee and Giles County seismic zones appears to be occurring on reactivated, steeply-dipping, northeast-striking Iapetan normal faults beneath the Appalachian crust. The overlying Appalachian crust contains a lower detachment and multiple overlying tectonic terrain boundaries and thrust faults that strike northeasterly. Subsequent extensional Mesozoic basins and bounding faults also have similar northeasterly orientations and may have, in part, reactivated pre-existing Paleozoic basement structures in the Appalachian crust (*e.g.,* Wentworth and Mergner-Keefer, 1983). Mesozoic extensional faults offshore, such as the Helena Banks fault zone, also exhibit a northeasterly strike. This northeasterly trend of tectonic structure near the Atlantic Seaboard suggests that whatever tectonic source produced the 1886 Charleston earthquake, the most likely trend for this structure would also be northeasterly. We incorporate this trend, therefore, in our evaluation of the Charleston source geometry described below.

Four mutually exclusive source zone geometries are defined for the UCSS. The latitude and longitude coordinates that define the 4 source zones (A, B, B', and C) are presented in Table 4, and details regarding each source geometry are given below:

Geometry A- Charleston. Geometry A is a ~100 x 50-km, northeast-oriented area centered on the 1886 meizoseismal area (Figure 10). Geometry A is intended to represent a localized source area that generally confines the Charleston source to the 1886 Charleston meizoseismal area (*i.e.*, a stationary source in time and space). Geometry A completely incorporates the 1886 earthquake Modified Mercalli Intensity (MMI) X isoseismal (Bollinger, 1977), the majority of identified Charleston-area tectonic features and inferred fault intersections (Table 1), and the majority of reported 1886 liquefaction features. We exclude the northern extension of the southern segment of the East Coast fault system because it extends well north of the meizoseismal zone and include this segment in its own source geometry (Geometry C below). We also exclude outlying liquefaction features, because liquefaction occurs as a result of strong ground shaking that may extend well beyond the areal extend of the tectonic source. Geometry A also envelopes instrumentally located earthquakes spatially associated with the MPSSZ (Tarr *et al.*, 1981; Tarr and Rhea, 1983; Madabhushi and Talwani, 1990; Figure 1).

The preponderance of evidence strongly supports the conclusion that the seismic source for the 1886 Charleston earthquake is located in a relatively restricted area defined by geometry A. Geometry A envelopes (1) the meizoseismal area of the 1886 earthquake, (2) the area containing the majority of local tectonic features (although many have large uncertainties associated with their existence and activity, as described earlier), (3) the area of ongoing concentrated seismicity, and (4) the area of greatest density of 1886 liquefaction and pre-historic liquefaction. These observations show that future earthquakes having magnitudes comparable to the Charleston earthquake of 1886 most likely will occur within the area defined by geometry A. We assign a weight of 0.70 to geometry A (Figure 11). In order to confine the rupture dimension to within the source area and to maintain a preferred northeast fault orientation, we represent Geometry A in the model by a series of closely spaced, northeast-trending faults parallel to the long axis of the zone.

Geometries B, B', and C. While the preponderance of evidence supports the assessment that the 1886 Charleston meizoseismal area and geometry A as the area where future events will most likely be centered, there is uncertainty that the tectonic feature responsible for the 1886 earthquake either extends beyond or lies outside geometry A. Therefore, the remaining three geometries (B, B' and C) are assessed to capture the uncertainty that future events may not be restricted to geometry A. The distribution of liquefaction features along the entire coast of South Carolina and observations from the paleoliquefaction record that a few events were localized, moderate earthquakes to the northeast and southwest of Charleston, suggests that the Charleston source could extend well beyond Charleston proper. Geometries B and B' are assessed to represent a larger source zone, while geometry C represents the southern segment of the East Coast fault system as a possible source zone. The combined geometries of B and B' are assigned a weight of 0.20 and geometry C is assigned a weight of 0.10. The purpose for defining geometry B', a subset of B, was to formally define the onshore coastal area as a source (similar to the SCDOT coastal source zone) that would restrict earthquakes to the onshore region. Both geometry B, which includes the onshore and offshore regions, and geometry B', are mutually exclusive and given equal weight in the UCSS model. Therefore, the resulting weights are 0.10 for geometries B and B'.

Geometry B- Coastal and Offshore Zone. Geometry B is a coast-parallel, ~260 x 80-km source area that: (1) incorporates all of geometry A, (2) is elongated to the northeast and southwest in order to capture other, more distant liquefaction features in coastal South Carolina (Amick, 1990; Amick *et al.*, 1990a, 1990b; Talwani and Schaeffer, 2001), and (3) extends to the southeast to include the offshore Helena Banks fault zone (Behrendt and Yuan, 1987; Figure 1). The elongation and orientation of geometry B is roughly parallel to the regional structural grain, as well as roughly parallel to the elongation of 1886 isoseismals (Figure 10). The northeastern and southwestern extents of geometry B are controlled by the mapped extent of paleoliquefaction features (*e.g.,* Amick 1990; Amick *et al.*, 1990a, 1990b; Talwani and Schaeffer, 2001).

The location and timing of paleoliquefaction features in the Georgetown and Bluffton areas to the northeast and southwest of Charleston have suggested to some researchers that the earthquake source may not be restricted to the Charleston area (Obermeier *et al.*, 1989; Amick *et al.*, 1990a; Talwani and Schaeffer, 2001). A primary reason for defining geometry B is to account for the possibility that there may be an elongated source or multiple sources along the South Carolina coast. Paleoliquefaction features in Georgetown and Bluffton areas may be explained by an earthquake source both northeast and southwest of Charleston, as well as possibly offshore.

Geometry B extends southeast to include an offshore area and the Helena Banks fault zone. The Helena Banks fault zone is clearly shown by multiple seismic reflection profiles, and has demonstrable late Miocene activity (Behrendt and Yuan, 1987). Recent offshore earthquakes in 2002 (m_b 3.5 and 4.4) suggest a possible spatial association of seismicity with the mapped trace of the Helena Banks fault system (Figures 1 and 10). Whereas these two events in the vicinity of the Helena Banks fault system do not provide a positive correlation with seismicity or demonstrate recent fault activity, these small earthquakes are considered new data since the EPRI studies. The pre-1986 EPRI earthquake catalog was devoid of any events ($m_b \geq 3.0$) offshore from Charleston. The recent offshore seismicity also post-dates the development of the USGS and SCDOT source models that excluded any offshore Charleston source geometries.

A low weight of 0.10 is assigned to geometry B (Figure 11), because the preponderance of evidence indicates that the seismic source that produced the 1886 earthquake lies onshore in the Charleston meizoseismal area, and not in the offshore region. In order to confine the rupture dimension to within the source area and to maintain a preferred northeast fault orientation, we represent Geometry B in the model by a series of closely spaced, northeast-trending faults parallel to the long axis of the zone.

Geometry B'- Coastal Zone. Geometry B' is a coast-parallel ~260 x 50–km source area that incorporates all of geometry A, as well as the majority of reported paleoliquefaction features (Amick, 1990; Amick *et al.*, 1990a, 1990b; Talwani and Schaeffer, 2001). Unlike geometry B, however, geometry B' does not include the offshore Helena Banks fault zone (Figure 10).

The Helena Banks fault system is excluded from zone B' to reflect that the preponderance of the data and evaluations support the assessment that the fault is not active, and because the weight of evidence strongly suggests that the 1886 Charleston earthquake occurred onshore, in the 1886 meizoseismal area and not on an offshore fault. Whereas there is little uncertainty regarding the existence of the Helena Banks fault, there is a lack of evidence that this feature is still active. Isoseismal maps documenting shaking intensity in 1886 indicate an onshore meizoseismal area (the closed bull's eye centered onshore north of downtown Charleston, Figure 1). An onshore source for the 1886 earthquake as well as the prehistoric events is supported by the instrumentally recorded seismicity in the MPSSZ and the corresponding high density cluster of 1886 and prehistoric liquefaction features.

Similar to geometry B above, a weight of 0.10 is assigned to geometry B' and reflects the assessment that source zone B' has a much lower probability of being the source geometry for Charleston-type earthquakes than geometry A (Figure 11). In order to confine the rupture dimension to within the source area and to maintain a preferred northeast fault orientation, we represent Geometry B' in the model by a series of closely spaced, northeast-trending faults parallel to the long axis of the zone.

Geometry C- East Coast Fault System- south (ECFS-s). Geometry C is a ~200 x 30–km, north-northeast-oriented source area enveloping the southern segment of the proposed East Coast fault system (ECFS-s) shown in Figure 3 of Marple and Talwani (2000) (Figure 3). The USGS hazard model (2002; Figure 8) incorporated the ECFS-s as a distinct source geometry (also known as the zone of river anomalies (ZRA)); however, as described earlier, this model truncates the northeastern extent of the proposed fault segment (Figure 8). The South Carolina Department of Transportation hazard model (Chapman and Talwani, 2002) also incorporates the ECFS-s as a distinct source geometry; however, this model extends the southern segment of the proposed East Coast fault system farther to the south than originally postulated by Marple and Talwani (2000) to include, in part, the distribution of liquefaction in southeastern South Carolina (M. Chapman, personal communication, 2005) (Figure 9). We restrict the area of geometry C to envelope the original depiction of the ECFS-s by Marple and Talwani (2000). Truncation of the zone to the northeast as shown by the 2002 USGS model is not supported by available data, and the presence of liquefaction in southeastern South Carolina is best captured in our source geometries B and B' rather than extending the ECFS-s farther to the south than defined by the data of Marple and Talwani (2000).

A low weight of 0.10 is assigned to geometry C to reflect our assessment that Geometries B, B', and C all have equal, but relatively low, likelihood of producing Charleston-type earthquakes (Figure 11). As with the other UCSS geometries, geometry C is represented as a series of parallel, vertical faults oriented northeast-southwest and parallel to the long axis of the narrow rectangular zone. The faults and extent of earthquake ruptures are confined within the rectangle depicting geometry C.

Model Parameters. Based upon studies by Bollinger *et al.* (1985, 1991) and Bollinger (1992), we assume a 20-km-thick seismogenic crust for the UCSS. To model the occurrence of earthquakes in the characteristic part of the Charleston distribution (**M**>6.7), the model uses a series of closely-spaced, vertical faults that are parallel to the long axis of each of the 4 source zones (A, B, B', and C). Faults and earthquake ruptures are limited to within each respective source zone and are not allowed to extend beyond the zone boundaries, and ruptures are constrained to occur within the depth range of 0 to 20 km. Modeled fault rupture areas are assumed to have a length-to-width aspect ratio of 2:1, conditional on the assumed maximum fault width of 20 km. To obtain Mmax earthquake rupture lengths from magnitude, Wells and Coppersmith's (1994) empirical relationship between surface rupture length and **M** for earthquakes of all slip types is used.

In order to maintain as much similarity with the original EPRI model, the UCSS model treats earthquakes in the exponential part of the distribution (**M** <6.7) as point sources uniformly distributed within the source area (full smoothing), with a constant depth fixed at 10 km.

Maximum Magnitude (Mmax)

The six EPRI ESTs developed a distribution of weighted Mmax values and weights to characterize the largest earthquakes that could occur on Charleston seismic sources. On the low end, the Law team assessed a single Mmax of m_b 6.8 to seismic sources they considered capable of producing earthquakes comparable in magnitude to the 1886 Charleston earthquake. On the high end, four teams defined Mmax upper bounds ranging between m_b 7.2-7.5. For this study, the m_b magnitude values were converted to moment magnitude as described by Bechtel (2005). The m_b value and converted moment magnitude (**M**) value for each team is shown below. The range in **M** by the six ESTs is 6.5 to 8.0.

Team	Charleston Mmax range
Bechtel	m_b 6.8 to 7.4 (**M**6.8 to 7.9)
Dames & Moore	m_b 6.6 to 7.2 (**M**6.5 to 7.5)
Law Engineering	m_b 6.8 (**M**6.8)
Rondout	m_b 6.6 to 7.0 (**M**6.5 to 7.2)
Weston Geophysical	m_b 6.6 to 7.2 (**M**6.5 to 7.5)
Woodward-Clyde Consultants	m_b 6.7 to 7.5 (**M**6.7 to 8.0)

The **M** equivalents of EPRI m_b estimates for Charleston Mmax earthquakes show that the upper bound values are similar to, and in two cases exceed, the largest modern estimate of **M**7.3 ± 0.26 (Johnston, 1996) for the 1886 earthquake. The upper bound values for 5 of the 6 ESTs also exceed the preferred estimate of M_I 6.9 by Bakun and Hopper (2004) for the Charleston event. The EPRI Mmax estimates are more heavily weighted toward the lower magnitudes, with the upper bound magnitudes given relatively low weights by several ESTs (Tables A-1a through A-1f). Therefore, updating the Mmax range and weights to reflect the current range of technical interpretations is warranted for the UCSS.

A graphical comparison of Charleston seismic source Mmax distributions is provided in Figure 13. This figure shows a composite magnitude distribution for the EPRI ESTs, along, with distributions for the USGS (Frankel *et al.*, 2002), SCDOT (Chapman and Talwani, 2002), and UCSS (this study) models.

Based on assessment of the currently available data and interpretations regarding the range of modern Mmax estimates (Table 2), we have modified the USGS magnitude distribution (Frankel *et al.*, 2002), to include a total of five discrete magnitude values, each separated by 0.2**M** units (Figure 13). The UCSS Mmax distribution includes a discrete value of **M**6.9 to represent Bakun and Hopper's (2004) best estimate of the 1886 Charleston earthquake magnitude, as well as a lower value of **M**6.7 to capture a low probability that the 1886 earthquake was smaller than Bakun and Hopper's (2004) mean estimate of **M**6.9. Bakun and Hopper (2004) do not explicitly report a 1-sigma range in magnitude estimate of the 1886 earthquake, but do provide a 2-sigma range of **M**6.4-**M**7.2.

The UCSS magnitudes and weights are as follows:

M	weight	
6.7	0.10	
6.9	0.25	Bakun and Hopper (2004) mean
7.1	0.30	
7.3	0.25	Johnston (1996) mean
7.5	0.10	

This results in a weighted Mmax mean magnitude **M**7.1 for the UCSS, which is slightly lower than the mean magnitude of **M**7.2 in the USGS model (Frankel *et al.*, 2002).

Recurrence Model

In the 1989 EPRI study, the six EPRI ESTs used an exponential magnitude distribution to represent earthquake sizes for their Charleston sources. Parameters of the exponential magnitude distribution were estimated from historical seismicity in the respective source areas. This resulted in recurrence intervals for Mmax earthquakes (at the upper end of the exponential distribution) of several thousand years.

Our current model for earthquake recurrence is a composite model consisting of two distributions. The first is an exponential magnitude distribution used to estimate recurrence between the lower-bound magnitude used for hazard calculations and **M**6.7. The parameters of this distribution are estimated from the earthquake catalog, as they were for the 1989 EPRI study. This is the standard procedure for smaller magnitudes, and is the model used, for example, by the USGS 2002 national hazard maps (Frankel *et al.*, 2002). In the second distribution, Mmax earthquakes (**M**≥6.7) are treated according to a characteristic model, with discrete magnitudes and mean recurrence intervals estimated through analysis of geologic data, including paleoliquefaction studies. In this document, the term Mmax (maximum magnitude) is used to describe the range of largest earthquakes in both the characteristic portion of the UCSS recurrence model and the EPRI exponential recurrence model.

This composite model achieves consistency between the occurrence of earthquakes with **M**<6.7 and the earthquake catalog, and achieves consistency between the occurrence of large earthquakes (**M**≥6.7) with paleoliquefaction evidence. It is a type of "characteristic earthquake" model, in which the recurrence rate of large events is higher than what would be estimated from an exponential distribution inferred from the historical seismic record.

Mmax Recurrence. This section of the report describes how the UCSS model determines mean recurrence intervals for Mmax earthquakes. Additional detail is provided in two separate Bechtel calculation sheets (Bechtel 2006a, 2006b). The UCSS model incorporates geologic data in order to characterize the recurrence intervals for Mmax earthquakes. As described earlier, the identification of paleoliquefaction features and the dating of these features provide a basis for estimating the recurrence of large Charleston area earthquakes. Most of the available geologic data pertaining to the recurrence of large earthquakes in the Charleston area were published after 1990, and therefore were not available to the six EPRI teams. In the absence of geologic data, the six EPRI ESTs estimates of recurrence for large, Charleston-type earthquakes were based on a truncated exponential model using historical seismicity (EPRI, 1986; 1989). The truncated exponential model also provided the relative frequency of all earthquakes greater than m_b 5.0 up to Mmax in the EPRI PSHA. The recurrence of Mmax earthquakes in the EPRI models were on the order of several thousand years, which is significantly greater than more recently published estimates of ~500 - 600 years based on paleoliquefaction data (Talwani and Schaeffer, 2001).

Paleoliquefaction Data. Strong ground shaking during the 1886 Charleston earthquake produced extensive liquefaction, and liquefaction features from the 1886 event are preserved in geologic deposits at numerous locations in the region. Documentation of older liquefaction-related features in geologic deposits provides evidence for prior strong ground motions during prehistoric large earthquakes. Estimates of the recurrence of large earthquakes in the UCSS are based on dating paleoliquefaction features. Many potential sources of ambiguity and/or error are associated with the dating and interpretation of paleoliquefaction features. This assessment does not reevaluate field interpretations and data; rather, it reevaluates criteria used to define individual paleoearthquakes in the published literature. In particular, we reevaluate the paleoearthquake record interpreted by Talwani and Schaeffer (2001) based on that study's compilation of sites with paleoliquefaction features.

Talwani and Schaeffer (2001) compiled radiocarbon ages from paleoliquefaction features along the coast of South Carolina. These data include ages that provide contemporary, minimum, and maximum limiting ages for liquefaction events. Radiocarbon ages were corrected for past variability in atmospheric ^{14}C using well established calibration curves and converted to "calibrated" (approximately calendric) ages. From their compilation of calibrated radiocarbon ages from various geographic locations, Talwani and Schaeffer (2001) correlated individual earthquake episodes. They identified an individual earthquake episode based on samples with a "contemporary" age constraint that had overlapping calibrated radiocarbon ages at the 68% (~1-sigma) confidence interval. The estimated age of each earthquake was, "calculated from the weighted averages of overlapping contemporary ages." (Talwani and Schaeffer, 2001, p. 6632). They defined as many as eight events from the paleoliquefaction record (named 1886, A, B, C, D, E, F, and G in order of increasing age), and offered two scenarios to explain the distribution and timing of paleoliquefaction features (Table 5).

The two scenario paleoearthquake records proposed by Talwani and Schaeffer (2001) have different interpretations for the size and location of prehistoric events (Table 5). In their scenario 1, the four prehistoric events that produced widespread liquefaction features similar to the large 1886 Charleston earthquake (A, B, E, and G) are interpreted to be large, Charleston-type events. Three events, C, D, and F, are defined by paleoliquefaction features that are more limited in geographic extent than other events, and are interpreted to be smaller, moderate-magnitude events (~M6). Events C and F are defined by features found north of Charleston in the Georgetown region and event D is defined by sites south of Charleston in the Bluffton area. In their scenario 2, all events are interpreted as large, Charleston-type events. Furthermore, events C and D are combined into a large event C'. Talwani and Schaeffer (2001) justify the grouping of the two events based on the observation that the calibrated radiocarbon ages that constrain the timing of events C and D are indistinguishable at the 95% (2-sigma) confidence interval.

The length and completeness of the paleoearthquake record based on paleoliquefaction features is a source of epistemic uncertainty in the UCSS. The paleoliquefaction record along the South Carolina coast extends from 1886 to the mid-Holocene (Talwani and Schaeffer, 2001). The consensus of the scientists who have evaluated these data (Talwani and Schaeffer, 2001; Talwani, pers. comm. 9/8/05; S. Obermeier, pers. comm. 9/2/05) is that the paleoliquefaction record of earthquakes is complete only for the most recent ~2,000 years, and that it is possible that liquefaction events are missing from the older portions of the record. The suggested incompleteness of the paleoseismic record is based on the argument that past fluctuations in sea level have produced time intervals of low water table conditions (and thus low liquefaction susceptibility), during which large earthquake events may not have been recorded in the paleoliquefaction record (Talwani and Schaeffer, 2001). While this assertion may be true, it cannot be ruled out that the paleoliquefaction record is complete back to the mid-Holocene.

2-Sigma Analysis of Event Ages. Our analysis of the coastal South Carolina paleoliquefaction record is based on Talwani and Schaeffer's (2001) data compilation. As described above, Talwani and Schaeffer (2001) use calibrated radiocarbon ages with 1-sigma error bands in order to define the timing of past liquefaction episodes in coastal South Carolina. The standard in paleoseimology, however, is to use calibrated ages with 2-sigma (95.4% confidence interval) error bands (*e.g.*, Sieh *et al.*, 1989, Grant and Sieh, 1994). Likewise, in paleoliquefaction studies, in order to more accurately reflect the uncertainties in radiocarbon dating, the use of calibrated radiocarbon dates with 2-sigma error bands (as opposed to narrower 1-sigma error bands) is advisable (Tuttle, 2001). Talwani and Scheaffer's (2001) use of 1-sigma error bands may lead to over-interpretation of the paleoliquefaction record such that more episodes are interpreted than actually occurred. In recognition of this possibility, the conventional radiocarbon ages presented in Talwani and Schaeffer (2001) were recalibrated and reported with 2-sigma error bands. The recalibration of individual radiocarbon samples and estimation of age ranges for paleoliquefaction events are presented in a separate calculation sheet (Bechtel, 2006a). The broader age ranges with 2-sigma error bands are then used to obtain broader age ranges for paleoliquefaction events in the Charleston area.

Event ages based on overlapping 2-sigma ages of paleoliquefaction features are presented in Table 5 and in Bechtel (2006a). Paleoearthquakes were distinguished based on grouping paleoliquefaction features that have contemporary radiocarbon samples with overlapping calibrated ages. The event ages were then defined by selecting the age range common to each of the samples. For example, an event defined by overlapping 2-sigma sample ages of 100-200 cal yr BP and 50-150 cal yr BP would have an event age of 50-150 cal yr BP (Table B-2). We consider the "trimmed" ages to represent the ~95% confidence interval, with a "best estimate" event age as the midpoint between the ~95% age range.

The 2-sigma analysis identified six distinct paleoearthquakes in the data presented by Talwani and Schaeffer (2001). As noted by that study, events C and D are indistinguishable at the 95% confidence interval, and in the UCSS those samples define our event C' (Table 5). Additionally, our 2-sigma analysis suggests that Talwani and Schaeffer's (2001) events F and G may have been a single, large event, which we define as F'. One important difference between our result and that of Talwani and Schaeffer's (2001) is that the three events C, D, and F in their scenario 1, which are inferred to be smaller, moderate-magnitude events, are grouped into more regionally extensive events C' and F' (Table 5). Therefore, we interpret all earthquakes in the 2-sigma analysis to represent large, Charleston-type events. Our analysis suggests that there have been four large earthquakes in the most-recent, ~2,000-year portion of the record (1886, and events A, B, and C'). In the entire ~5,000-year paleoliquefaction record there is evidence for six large, Charleston-type earthquakes (1886, A, B, C', E, F'; Table 5).

Recurrence intervals developed from the earthquakes recorded by paleoliquefaction features assume that these features were produced by large, Mmax-type events, and that both the ~2,000-year and ~5,000-year records are complete. However, we mention at least two concerns regarding the use of the paleoliquefaction record to characterize the recurrence of past Mmax events. First, it is possible that the paleoliquefaction features associated with one or more of these pre-1886 events were produced by multiple, moderate-sized events closely spaced in time. If this were the case, then the calculated recurrence interval would yield artificially short recurrence for Mmax, since it was calculated using repeat times of both large (Mmax) events, as well as smaller earthquakes. Limitations of radiocarbon dating and limitations in the stratigraphic record often preclude the identification of individual events in the paleoseismologic record that are closely spaced in time (*i.e.*, separated by only a few years to a few decades). Several seismic sources have demonstrated tightly clustered earthquake activity in space and time that are indistinguishable in the radiocarbon and paleoseismic record:

- New Madrid (1811, 1811, 1812)
- North Anatolian Fault (1999 and 1999)
- San Andreas Fault (1812 and 1857)

Therefore, we acknowledge the distinct possibility that Mmax occurs less frequently than what we calculate from the paleoliquefaction record.

A second concern is that the recurrence behavior of the Mmax event may be highly variable through time. For example, we consider it unlikely that **M**6.7 to **M**7.5 events have occurred on a Charleston source at an average repeat time of about 500 to 600 years (Talwani and Schaeffer, 2001) throughout the Holocene Epoch. Such a moment release rate would likely produce tectonic landforms with clear geomorphic expression, such as are present in regions of the world with comparably high rates of moderate to large earthquakes (for example, faults in the Eastern California shear zone with sub-millimeter per year slip rates and recurrence intervals on the order of about 5,000 years have clear geomorphic expression [Rockwell et al., 2000]). Perhaps it is more likely that the Charleston source has a recurrence behavior that is highly variable through time, such that a sequence of events spaced about 500 years apart is followed by quiescent intervals of thousands of years or longer. This sort of variability in inter-event time may be represented by the entire mid-Holocene record, in which both short inter-event times (*e.g.*, about 400 years between events A and B) are included in a record with long inter-event times (*e.g.*, about 1900 years between events C' and E).

Calculation of Recurrence. For the UCSS model, we calculate two average recurrence intervals covering two different time intervals, which will be used as two recurrence branches on the logic tree (Figure 11). The first average recurrence interval is based on the four events that occurred within the past ~2,000 years. This time period is considered to represent a complete portion of the paleoseismic record based on published literature (*e.g.*, Talwani and Schaeffer, 2001) and feedback from those researchers questioned (Talwani, pers. comm. 9/8/05; S. Obermeier, pers. comm. 9/2/05). These events include 1886, A, B, and C' (Bechtel, 2006a) (Table 5). The average recurrence interval calculated for the most-recent portion of the paleoliquefaction record (four events over the past ~2,000 years) is given 0.80 weight on the logic tree (Figure 11).

The second average recurrence interval is based on events that occurred within the past ~5,000 years. This time period represents the entire paleoseismic record based on paleoliquefaction data (Talwani and Schaeffer, 2001). These events include 1886, A, B, C', E, and F' (Bechtel, 2006a) (Table 5). As mentioned previously, published papers and researchers questioned suggest that the older part of the record (older than about 2,000 years ago) may be incomplete. Whereas this assertion may be true, it is also possible that the older record, which exhibits longer inter-event times, is complete. The average recurrence interval calculated for the ~5,000-year record (six events) is given 0.20 weight on the logic tree (Figure 11). The 0.80 and 0.20 weighting of the 2,000-year and ~5,000-year paleoliquefaction records, respectively, reflects our incomplete knowledge of both the current short-term recurrence behavior and the long-term recurrence behavior of the Charleston source.

The mean recurrence intervals for the most-recent ~2,000-year and past ~5,000-year records represent the average time interval between earthquakes attributed to the Charleston seismic source. The mean recurrence intervals and their parametric uncertainties were calculated according to the methods outlined by Savage (1991) and Cramer (2001). The method provides a description of mean recurrence interval with a best estimate mean T_{ave} and an uncertainty described as a lognormal distribution with median $T_{0.5}$ and parametric lognormal shape factor $\sigma_{0.5}$. Full details of these calculations are provided in a separate calculation sheet (Bechtel, 2006b).

The lognormal distribution is one of several distributions, including the Weibull, Double Exponential, and Gaussian distributions, among others, used to characterize earthquake recurrence (Ellsworth *et al.*, 1999). Ellsworth *et al.* (1999) and Mathews *et al.* (2002) propose a Brownian-passage time model to represent earthquake recurrence, arguing that it more closely simulates the physical process of strain build-up and release. This Brownian-passage time model is currently used to calculate earthquake probabilities in the greater San Francisco Bay region (WGCEP, 2003). Analyses show that the lognormal distribution is very similar to the Brownian-passage time model of earthquake recurrence for cases where the time elapsed since the most recent earthquake is less than the mean recurrence interval (Cornell and Winterstein, 1988; Ellsworth *et al.*, 1999). This is the case for Charleston, where 120 years have elapsed since the 1886 earthquake, and the mean recurrence interval determined over the past ~2,000 years is about 548 years. We choose to calculate average recurrence interval using a lognormal distribution because its statistics are well known (NIST/SEMATECH, 2006) and it has been used in numerous studies (*e.g.*, Savage, 1991; WGCEP, 1995; Cramer, 2001).

The average interval between earthquakes is expressed as two continuous lognormal distributions. The average recurrence interval for the ~2,000-year record, based on the three most recent inter-event times (1886-A, A-B, B-C'), has a best estimate mean value of 548 years, and an uncertainty distribution described by a median value of 531 years and a lognormal shape factor of 0.25. The average recurrence interval for the ~5,000-year record, based on five inter-event times (1886-A, A-B, B-C', C'-E, E-F'), has a best estimate mean value of 958 years, and an uncertainty distribution described by a median value of 841 years and a lognormal shape factor of 0.51. At one standard deviation, the average recurrence interval for the ~2,000-yr record is between 409 and 690 years; for the ~5,000-yr record, it is between 452 and 1564 years. Combination of these mean values of 548 and 958 years with their respective logic tree weights of 0.8 and 0.2 results in a weighted mean of 630 years for Charleston Mmax recurrence.

The mean recurrence interval values used in the UCSS model are similar to those determined by earlier studies. Talwani and Schaeffer (2001) consider two possible scenarios to explain the distribution in time and space of paleoliquefaction features. In their scenario 1, large earthquakes have occurred with an average recurrence of 454 ± 21 years over the past ~2,000 years; in their scenario 2, large earthquakes have occurred with an average recurrence of 523 ±

100 years over the past ~2,000 years. Talwani and Schaeffer (2001) state that, "In anticipation of additional data we suggest a recurrence rate [*sic*] between 500 and 600 years for **M**7+ earthquakes at Charleston" (p. 6641). For the ~2,000-year record, our 1-standard deviation range of 409 to 690 years completely encompasses the range of average recurrence interval reported by Talwani and Schaeffer (2001). Our best-estimate mean recurrence interval value of 548 years is indistinguishable from the midpoint of Talwani and Schaeffer's (2001) best-estimate range of 500 to 600 years. Our best estimate mean recurrence interval value from the ~5,000-yr paleoseismic record of 958 years is outside the age ranges reported by Talwani and Schaeffer (2001), although they did not determine an average recurrence interval based on the longer record.

In the updated seismic hazard maps for the coterminous United States, Frankel *et al.* (2002) use a mean recurrence value of 550 years for characteristic earthquakes in the Charleston region. This value is based upon the above-quoted 500 - 600 year estimate from Talwani and Schaeffer (2001). Frankel *et al.* (2002) do not incorporate uncertainty in mean recurrence interval in their calculations.

For computation of seismic hazard, discrete values of activity rate (inverse of recurrence interval) are required as input to the PSHA code (Cornell, 1968). To evaluate PSHA based on mean hazard, the mean recurrence interval and its uncertainty distribution (Table 2 of Bechtel, 2006b) should be converted to mean activity rate with associated uncertainty. The final discretized activity rates used to model the UCSS in the PSHA should reflect a mean recurrence of 548 years and 958 years for the ~2,000-year and ~5,000-year branches of the logic tree, respectively. Lognormal uncertainty distributions in activity rate may be obtained by the following steps: (1) invert the mean recurrence intervals to get mean activity rates; (2) calculate median activity rates using the mean rates and lognormal shape factors ($\sigma_{0.5}$) of 0.25 and 0.51 prior, for the ~2,000-year and ~5,000-year records, respectively (Table 2 and Equation 2 of Bechtel, 2006b); and (3) determine the lognormal distributions based on the calculated median rate and shape factors. The lognormal distributions of activity rate can then be discretized to obtain individual activity rates with corresponding weights.

F. CONCLUSIONS AND RECOMMENDATIONS

The incorporation of the UCSS described here will accurately reflect how new information on the Charleston earthquake should affect the EPRI ESTs interpretations. Use of these revisions in the seismic hazard calculations will respond to the requirements of Regulatory Guide 1.165 (Nuclear Regulatory Commission, 1997).

G. REFERENCES

Amick, D., Paleoliquefaction investigations along the Atlantic seaboard with emphasis on the prehistoric earthquake chronology of coastal South Carolina, unpub. Ph.D. dissertation, University of South Carolina, selected pages, 1990.

Amick, D., Gelinas, R., Maurath, G., Cannon, R., Moore, D., Billington, E., and Kemppinen, H., Paleoliquefaction features along the Atlantic seaboard, U.S. Nuclear Regulatory Commission Report, NUREG/CR-5613, 147p., 1990a.

Amick, D., Maurath, G., and Gelinas, R., Characteristics of seismically induced liquefaction sites and features located in the vicinity of the 1886 Charleston, South Carolina earthquake, Seismological Research Letters, v. 61, no. 2, p. 117-130, 1990b.

Bakun, W. H. and McGarr, A., Differences in attenuation among the stable continental regions, Geophysical Research Letters, v. 29, no. 23, p. 2121-2124, 2002.

Bakun, W. H., Johnston, A. C., and Hopper, M. G., Estimating locations and magnitudes of earthquakes in eastern North America from modified Mercalli intensities, Bulletin of the Seismological Society of America, v. 93, n. 1, p. 190-202, 2003.

Bakun, W. H. and Hopper, M. G., Magnitudes and locations of the 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes, Bulletin of the Seismological Society of America, v. 94, no. 1, p. 64-75, 2004.

(Bechtel, 2005) Marrone, J., Procedure for conversion between moment magnitude and body wave magnitude, Southern Nuclear Company ALWR ESP, Bechtel calculation sheet, 25144-K-002, SNC calculation number AR01-SSAR-XSC-2002, 2005.

(Bechtel, 2006a) Hartleb, R. D., Calculation of recalibrated radiocarbon (14C) ages for Charleston, South Carolina area paleoliquefaction analysis, Bechtel calculation sheet number 25144-K-004, SNC calculation number A01-S SAR-XSC-2003, 2006.

(Bechtel, 2006b) Thompson, S., Mean recurrence interval for maximum magnitude earthquakes UCSS, Bechtel calculation number 25144-K-004, SNC calculation number AR01-SSAR-XSC-2004, 2006.

Behrendt, J. C. and Hamilton, R. M., Could a Charleston-type earthquake occur elsewhere along the east coast of North America?, Abstracts with Programs- Geological Society of America, v. 13, no. 7, p. 406, 1981.

Behrendt, J. C., Hamilton, R. M., Ackermann, H. D., Henry, V. H., and Bayer, K. C., Marine multichannel seismic-reflection evidence for Cenozoic faulting and deep crustal structure near Charleston, South Carolina in Studies Related to the Charleston, South Carolina, Earthquake of 1886- Tectonics and Seismicity, U. S. Geological Survey Professional Paper 1313-J, p. J1-J29, 1983.

Behrendt, J. C. and Yuan, A., The Helena Banks strike-slip (?) fault zone in the Charleston, South Carolina, earthquake area: results from a marine, high-resolution, multichannel, seismic-reflection survey, Geological Society of America Bulletin, v. 98, p. 591-601, 1987.

Bollinger, G. A., Reinterpretatin of the intensity data for the 1886 Charleston, South Carolina, earthquake in Studies Related to the Charleston, South Carolina, Earthquake of 1886- A Preliminary Report (D. W. Rankin, ed.), U. S. Geological Survey Professional Paper 1028, p. 17-32, 1977.

Bollinger, G. A., Chapman, M. C., Sibol, M. S., and Costain, J. K., An analysis of earthquake focal depths in the southeastern U. S., Geophysical Research Letters, v. 12, no. 11, p. 785-788, 1985.

Bollinger, G. A., Johnston, A. C., Talwani, P., Long, L. T., Shedlock, K. M., Sibol, M. S., and Chapman, M. C., Seismicity of the southeastern United States; 1698-1986 in Neotectonics of North America, Decade map volume to accompany the neotectonic maps (D. B. Slemmons, E. R. Engdahl, M. D. Zoback, D. B. Blackwell, eds.), p. 291-308, 1991.

Bollinger, G. A., Specification of Source Zones, Recurrence Rates, Focal Depths, and Maximum Magnitudes for Earthquakes Affecting the Savannah River Site in South Carolina, U.S. Geological Survey Bulletin 2017, 1992.

Bronk Ramsey, C., Radiocarbon calibration and analysis of stratigraphy: the OxCal program, Radiocarbon, v. 37, no. 2, p. 425-430, 1995.

Bronk Ramsey, C., Development of the radiocarbon program OxCal, Radiocarbon, v. 43, no. 2A, p. 355-363, 2001.

Chapman, M. C. and Talwani. P., Seismic hazard mapping for bridge and highway design in South Carolina, South Carolina Department of Transportation Report, 2002.

Colquhoun, D. J., Woollen, L. D., Van Nienwenhuise, D. S., Padgett, G. G., Oldham, R. W., Boylan, D. C., Bishop, J. W., and Howell, P. D., Surface and subsurface stratigraphy, structure and aquifers of the South Carolina Coastal Plain, State of South Carolina, Office of the Governor, Columbia, South Carolina, 78 p., 1983.

Cook, F. A., Albaugh, D. S., Brown, L. D., Kaufman, S., Oliver, J. A., and Hatcher, R. D., Thin-skinned tectonics in the crystalline southern Appalachians, COCORP seismic-reflection profiling of the Blue Ridge and Piedmont, Geology, v. 7, p. 563-567, 1979.

Cook, F. A., Brown, L. D., Kaufman, S., Oliver, J. A., and Petersen, T. A., COCORP seismic profiling of the Appalachian orogen beneath the coastal plain of Georgia, Geological Society of America Bulletin, v. 92, p. 738-748, 1981.

Cornell, C. A., Engineering seismic risk analysis, Bulletin of the Seismological Society of America, v. 58, no. 5, p. 1583-1606, 1968.

Cornell, C. A. and Winterstein, S. R., Temporal and magnitude dependence in earthquake recurrence models, Bulletin of the Seismological Society of America, v. 79, p. 1522-1537, 1988.

Cramer, C. H., A seismic hazard uncertainty analysis for the New Madrid seismic zone, Engineering Geology, v. 62, p. 251-266, 2001.

Crone, A. J. and Wheeler, R. L., Data for Quaternary Faults, Liquefaction Features, and Possible Tectonic Features in the Central and Eastern United States, east of the Rocky Mountain front, U.S. Geological Survey Open-File Report 00-260, 2000.

Dutton, C. E., The Charleston earthquake of August 31, 1886, U. S. Geological Survey Ninth Annual Report 1887-88, p. 203-528, 1889.

Electric Power Research Institute (EPRI), Volumes 5–10, Seismic Hazard Methodology for the Central and Eastern United States, Tectonic Interpretations, July 1986.

Electric Power Research Institute (EPRI), EQHAZARD Primer, Prepared by Risk Engineering for Seismicity Owners Group and EPRI, June 1989.

Ellsworth, W. L., Matthews, M. V., Nadeau, R. M., Nishenko, S. P., Reasenberg, P. A., and Simpson, R. W., A Physically-Based Earthquake Recurrence Model for Estimation of Long-Term Earthquake Probabilities, U.S. Geological Survey Open-File Report 99-522, 22p., 1999.

Fletcher, J. B., Sbar, M. L., and Sykes, L. R., Seismic trends and travel time residuals in eastern North America and their tectonic implications, Geological Society of America Bulletin, v. 89, p. 1656-1676, 1978.

Frankel, A. D., Petersen, M. D., Mueller, C. S., Haller, K. M., Wheeler, R. L., Leyendecker, E. V., Wesson, R. L., Harmsen, S. C., Cramer, C. H., Perkins, D. M., and Rukstales, K. S., Documentation for the 2002 update of the national seismic hazard maps, U.S Geological Survey Open-File Report 02-420, 2002.

Gangopadhyay, A. and Talwani, P., Fault intersections and intraplate seismicity in Charleston, South Carolina: insights from a 2-D numerical model, Current Science, v. 88, no. 10, 2005.

Grant, L. B. and Sieh, K., Paleoseismic evidence of clustered earthquakes on the San Andreas fault in the Carrizo Plain, California, Journal of Geophysical Research, v. 99, n. B4, p. 6819-6841, 1994.

Hamilton, R. H., Behrendt, J. C., and Ackermann, H. D., Land multichannel seismic-reflection evidence for tectonic features near Charleston, South Carolina in Studies Related to the Charleston, South Carolina, Earthquake of 1886- Tectonics and Seismicity, U. S. Geological Survey Professional Paper 1313-I, p. I1-I18, 1983.

Hu, K., Gassman, S. L., and Talwani, P., In-situ properties of soils at paleoliquefaction sites in the South Carolina coastal plain, Seismological Research Letters, v. 73, no. 6, p. 964-978, 2002a.

Hu, K., Gassman, S. L., and Talwani, P., Magnitudes of prehistoric earthquakes in the South Carolina coastal plain from geotechnical data, Seismological Research Letters, v., 73, no. 6, p. 979-991, 2002b.

Ishihara, K., Stability of natural soils during earthquakes in Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, A. A. Balkema, Rotterdam/Boston, v. 1, p. 321-376, 1985.

Johnston, A. C., Coppersmith, K. J., Kanter, L. R., and Cornell, C. A., The earthquakes of stable continental regions, volume I: assessment of large earthquake potential, Final Report TR-102261-V1, prepared for Electric Power Research Institute, 105p., 1994.

Johnston, A. C., Seismic moment assessment of earthquake in stable continental regions – III. New Madrid 1811-1812, Charleston 1886 and Lisbon 1755, Geophysical Journal International, v. 126, p.314-344, 1996.

Lennon, G., Identification of a northwest trending seismogenic graben near Charleston, South Carolina, U. S. Nuclear Regulatory Commission Report, NUREG/CR-4075, 43p., 1986.

Leon, E., Effect of aging of sediments on paleoliquefaction evaluation in the South Carolina coastal plain, unpub. Ph.D. dissertation, University of South Carolina, 181p., 2003.

Leon, E., Gassman, S. L., and Talwani, P., Effect of soil aging on assessing magnitudes and accelerations of prehistoric earthquakes, Earthquake Spectra, v. 21, no. 3, p. 737-759, 2005.

Madabhushi, S. and Talwani, P., Composite fault plane solutions of recent Charleston, South Carolina, earthquakes, Seismological Research Letters, v. 61, no. 3-4, p. 156, 1990.

Madabhushi, S. and Talwani, P., Fault plane solutions and relocations of recent earthquakes in Middleton Place-Summerville Seismic Zone near Charleston, South Carolina, Bulletin of the Seismological Society of America, v. 83, no. 5, p. 1442-1466, 1993.

Marple, R. T. and Talwani, P., Field investigations of the Woodstock lineament, Seismological Research Letters, v. 61, no. 3-4, p. 156, 1990.

Marple, R. T. and Talwani, P., Evidence for possible tectonic upwarping along the South Carolina coastal plain from an examination of river morphology and elevation data, Geology, v. 21, p. 651-654, 1993.

Marple, R. T. and Talwani, P., Evidence for a buried fault system in the Coastal Plain of the Carolinas and Virginia - Implications for neotectonics in the southeastern United Sates, Geological Society of America Bulletin, v. 112, no. 2., p. 200-220, 2000.

Marple, R. T. and Talwani, P., Proposed Shenandoah fault and East Coast-Stafford fault system and their implications for eastern U. S. tectonics, Southeastern Geology, v. 43, no. 2., p. 57-80, 2004.

Martin, J. R. and Clough, G. W., Seismic parameters from liquefaction evidence, Journal of Geotechnical Engineering, v. 120, no. 8, p. 1345-1361, 1994.

Matthews, M. V., Ellsworth, W. L., and Reasenberg, P. A., A Brownian model for recurrent earthquakes, Bulletin of the Seismological Society of America, v. 92, p. 2233-2250, 2002.

Nishenko, S. P. and Sykes, L. R., Fracture zones, Mesozoic rifts and the tectonic setting of the Charleston, South Carolina earthquake of 1886, Eos- Transactions of the American Geophysical Union, v. 60, p. 360, 1979.

NIST/SEMATECH, e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, accessed 11 January 2006.

Nuclear Regulatory Commission, Regulatory Guide 1.165, Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion, U.S. Nuclear Regulatory Commission, March 1997.

Obermeier, S. F., Weems, R. E., Jacobson, R. B., and Gohn, G. S., Liquefaction evidence for repeated Holocene earthquakes in the coastal region of South Carolina, Annals of the New York Academy of Sciences, v. 558, p. 183-195, 1989.

Obermeier, S. F., Jacobson, R. B., Smoot, J. P., Weems, R. E., Gohn, G. S., Monroe, J. E., and Powars, D. S., Earthquake-induced liquefaction features in the coastal setting of South Carolina and in the fluvial setting of the New Madrid seismic zone, U. S. Geological Survey professional paper 1504, 44p., 1990.

Obermeier, S. F., Pond, E. C., and Olson, S. M., Paleoliquefaction studies in continental settings: geologic and geotechnical factors in interpretations and back-analysis, U. S. Geological Survey Open-File Report 01-29, 53p., 2001.

Reimer, P. J, Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C., Blackwell, P. G., Buck, C. E., Burr, G., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hughen, K. A., Kromer, B., McCormac, F. G., Manning, S., Bronk Ramsey, C., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J., and Weyhenmeyer, C. E., IntCal04 Terrestrial Radiocarbon Age Calibration, 0–26 Cal Kyr BP, Radiocarbon, v. 46, no. 3, p. 1029-1058, 2004.

Rockwell, T. K., Lindvall, S., Herzberg, M., Murbach, D., Dawson, T., and Berger, G., Paleoseismology of the Johnson Valley, Kickapoo, and Homestead Valley faults: clustering of earthquakes in the Eastern California shear zone, Bulletin of the Seismological Society of America, v. 90, no. 5, p. 1200-1236, 2000.

Savage, J. C., Criticism of some forecasts of the National Earthquake Evaluation Council, Bulletin of the Seismological Society of America, v. 81, no. 3, p. 862-881, 1991.

Savy, J. B., Foxall, W., Abrahamson, N., and Bernreuter, D., Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site: Example Application to the Southeastern United States, U.S. Nuclear Regulatory Commission, NUREG-CR/6607, 2002.

Seeber, L. and Armbruster, J. G., The 1886 Charleston, South Carolina earthquake and the Appalachian detachment, Journal of Geophysical Research, v. 86, no. B9, p. 7874-7894, 1981.

Seed, H. B., Tokimatsu, K., Harder, L. F., and Chung, R. M., Influence of SPT procedures in soil liquefaction resistance evaluations, Journal of Geotechnical Engineering, v. 111, p. 1425-1445, 1985.

Sieh, K., Stuiver, M., and Brillinger, D., A more precise chronology of earthquakes produced by the San Andreas fault in southern California, Journal of Geophysical Research, v. 94, n. B1, p. 603-623, 1989.

Smith, W. A. and Talwani, P., Preliminary interpretation of a detailed gravity survey in the Bowman and Charleston, S. C. seismogenic zones, Abstracts with Programs- Geological Society of America southeastern section, v. 17, no. 2, p. 137, 1985.

SSHAC, Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, Prepared by Senior Seismic Hazard Analysis Committee (SSHAC), NUREG/CR-6372, 1997.

Sykes, L. R., Intraplate seismicity, reactivation of preexisting zones of weakness, alkaline magmatism, and other tectonism post-dating continental fragmentation, Review of Geophysics and Space Physics, v. 16, p. 621-688, 1978.

Talwani, P., An internally consistent pattern of seismicity near Charleston, South Carolina, Geology, v. 10, p. 655-658, 1982.

Talwani, P., Fault geometry and earthquakes in continental interiors, Tectonophysics, v. 305, p. 371-379, 1999.

Talwani, P., Macroscopic effects of the 1886 Charleston earthquake, A Compendium of Field Trips of South Carolina Geology, South Carolina Geological Survey, p. 1-6, 2000.

Talwani, P. and Schaeffer, W. T., Recurrence rates of large earthquakes in the South Carolina Coastal Plain based on paleoliquefaction data, Journal of Geophysical Research, v. 106, no. B4, p. 6621-6642, 2001.

Talwani, P. and Katuna, M., Macroseismic effects of the 1886 Charleston earthquake, Carolina Geological Society Field Trip Guidebook, 18p., 2004.

Tarr, A. C., Talwani, P., Rhea, S., Carver, D., and Amick, D., Results of recent South Carolina seismological studies, Bulletin of the Seismological Society of America, p. 71,1883-1902, 1981.

Tarr, A. C. and Rhea, S., Seismicity near Charleston, South Carolina, March 1973 to December 1979 in Studies Related to the Charleston, South Carolina Earthquake of 1886: Tectonics and Seismicity, G. S. Gohn (ed.), U. S. Geological Survey Professional Paper 1313, R1-R17, 1983.

Tuttle, M. P., The use of liquefaction features in paleoseismology: lessons learned in the New Madrid seismic zone, central United States, Journal of Seismology, v. 5, p. 361-380, 2001.

Weems, R. E., Lemon Jr., E. M., Gohn, G. S., and Houser, B. B., Geology of the Pringletown, Ridgeville, Summerville, and Summerville Northwest 7.5-minute quadrangles, Berkeley, Charleston, and Dorchester Counties South Carolina, U.S. Geological Survey Open-File Report 87-661, 159p., 1997.

Weems, R. E. and Lewis, W. C., Structural and tectonic setting of the Charleston, South Carolina, region: evidence from the Tertiary stratigraphic record, Geological Society of America Bulletin, v. 114, no. 1, p. 24-42, 2002.

Wells, D. L. and Coppersmith, K. J., New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bulletin of the Seismological Society of America, v. 84, no. 4, p. 974-1002, 1994.

Wentworth, C. M. and Mergner-Keefer, M., Regenerate faults of small Cenozoic offset- probable earthquake sources in the southeastern United States in Studies Related to the Charleston, South Carolina, Earthquake of 1886- Tectonics and Seismicity, U.S. Geological Survey Professional Paper 1313-S, p. S1-S20, 1983.

Wheeler, R. L., Known or suggested Quaternary tectonic faulting, central and eastern United States- new and updated assessments for 2005, U.S. Geological Survey Open-File Report 2005-1336, 37p., 2005.

Wildermuth, E. and Talwani, P., Tectonic observations of a pull-apart basin in the South Carolina coastal plain, Seismological Research Letters, v. 73, no. 3, p. 420, 2002.

Working Group on California Earthquake Probabilities, Seismic hazards in southern California: Probable earthquakes, 1994 to 2024, Bulletin of the Seismological Society of America, v. 85, p. 379-439, 1995.

Working Group on California Earthquake Probabilities, Earthquake probabilities in the San Francisco Bay region: 2002-2031, U. S. Geological Survey Open-File Report 03-2134, 2003.

Table 1. Local Charleston area tectonic features

Name of Feature	Evidence	Key References
Adams Run fault	**subsurface stratigraphy**	**Weems and Lewis (2002)**
Ashley River fault	microseismicity	Talwani (1982, 2000) Weems and Lewis (2002)
Appalachian detachment (decollement)	gravity & magnetic data seismic reflection & refraction	Cook *et al.* (1979, 1981) Behrendt *et al.* (1981, 1983) Seeber and Armbruster (1981)
Blake Spur fracture zone	oceanic transform postulated to extend westward to Charleston area	Fletcher *et al.* (1978) Sykes (1978) Nishenko and Sykes (1979) Seeber and Armbruster (1981)
Bowman seismic zone	microseismicity	Smith and Talwani (1985)
Charleston fault	subsurface stratigraphy	Colquhoun *et al.* (1983) Lennon (1986) Talwani (2000) Weems and Lewis (2002)
Cooke fault	seismic reflection	Behrendt *et al.* (1981, 1983) Hamilton *et al.* (1983) Wentworth and Mergner-Keefer (1983) Behrendt and Yuan (1987)
Drayton fault	seismic reflection	Hamilton *et al.* (1983) Behrendt *et al.* (1983) Behrendt and Yuan (1987)
East Coast fault system/ Zone of river anomalies (ZRA)	**geomorphology seismic reflection microseismicity**	**Marple and Talwani (1993) Marple and Talwani (2000, 2004) Wildermuth and Talwani (2004)**
Gants fault	seismic reflection	Hamilton *et al.* (1983) Behrendt and Yuan (1987)
Garner-Edisto fault	subsurface stratigraphy	Colquhoun *et al.* (1983)
Helena Banks fault zone	seismic reflection	Behrendt *et al.* (1981, 1983) Behrendt and Yuan (1987)
Middleton Place-Summerville seismic zone	microseismicity	Tarr and Rhea (1981) Madabhushi and Talwani (1990)
Sawmill Branch fault	**microseimicity**	**Talwani and Katuna (2004)**
Summerville fault	**microseimicity**	**Weems *et al.* (1997)**
Woodstock fault	geomorphology microseismicity	Talwani (1982, 1999, 2000) Marple and Talwani (1990, 2000)

Notes:
Those tectonic features identified following publication of the EPRI teams' reports (post-1986) are highlighted by **bold-face** type.

Table 2. Comparison of post-EPRI magnitude estimates for the 1886 Charleston earthquake

Source Reference	**Magnitude Estimation Method**	**Reported Magnitude Estimate**	**Assigned Weights**	**Mean Magnitude (M)**
Johnston *et al.* (1994)	worldwide survey of passive-margin, extended-crust earthquakes	**M**7.56 ± 0.35 [a]	--	7.56
Martin and Clough (1994)	geotechnical assessment of 1886 liquefaction data	**M**7 - 7.5	--	7.25
Johnston (1996)	isoseismal area regression, accounting for eastern North America anelastic attenuation	**M**7.3 ± 0.26	--	7.3
Chapman and Talwani (2002) (South Carolina Department of Transportation)	consideration of available magnitude estimates	**M**7.1 **M**7.3 **M**7.5	0.2 0.6 0.2	7.3
Frankel *et al.* (2002) (USGS National seismic hazard mapping project)	consideration of available magnitude estimates	**M**6.8 **M**7.1 **M**7.3 **M**7.5	0.20 0.20 0.45 0.15	7.2
Bakun and Hopper (2004)	isoseismal area regression, including empirical site corrections	M_I 6.4 - 7.2 [b]	--	6.9 [c]

Notes:
[a] Estimate from Johnston *et al.* (1994) Chapter 3.
[b] 95% confidence interval estimate; M_I (intensity magnitude) is considered equivalent to M (Bakun and Hopper, 2004).
[c] Bakun and Hopper's (2004) *preferred* estimate.

Table 3. USGS and SC DOT source models

Team	Source [weight]	Mmax[a] [probability]	Recurrence Model (years)
USGS (Frankel *et al.*, 2002)	Charleston Area **[0.5]**	6.8 [0.20] 7.1 [0.20] 7.3 [0.45] 7.5 [0.15]	mean recurrence of 550 years
	East Coast fault system (south). Zone of river Anomalies (ZRA) **[0.5]**	6.8 [0.20] 7.1 [0.20] 7.3 [0.45] 7.5 [0.15]	
SC DOT (Chapman and Talwani, 2002)	Charleston Area Source **[0.33]**	7.1 [0.20] 7.3 [0.60] 7.5 [0.20]	mean recurrence of 550 years
	Characteristic Line Source (ZRA) **[0.33]**	7.1 [0.20] 7.3 [0.60] 7.5 [0.20]	
	Characteristic Line Source (3 parallel faults) **[0.33]**	7.1 [0.20] 7.3 [0.60] 7.5 [0.20]	

Notes:
[a] Mmax in m_b (body wave magnitude) units

Table 4. Geographic coordinates (latitude and longitude) of corner points of Updated Charleston Seismic Source (UCSS) geometries

Source Geometry	**Longitude** (decimal degrees)	**Latitude** (decimal degrees)
A	-80.70749522	32.81112535
A	-79.84088532	33.35496229
A	-79.52731238	32.99701771
A	-80.39226348	32.45530134
B	-81.21675102	32.48553747
B	-78.96501990	33.89152189
B	-78.34361482	33.16845483
B	-80.58719764	31.77585917
B'	-78.96501990	33.89152189
B'	-78.65410603	33.53156662
B'	-80.90097367	32.13134181
B'	-81.21675102	32.48553747
C	-80.39799172	32.68720677
C	-79.77673867	34.42525215
C	-79.48305080	34.35114826
C	-80.10951638	32.61465207

Table 5. Comparison of Talwani and Schaeffer (2001) and UCSS age constraints on Charleston area paleoliquefaction events

	Talwani and Schaeffer (2001)[a]					UCSS (this study)
		scenario 1		*scenario 2*		
Liquefaction Event	**Event Age** (YBP)[b]	**Source**	**M**	**Source**	**M**	**Event Age** (YBP)[b, c, d]
1886 A.D.	64	Charleston	7.3	Charleston	7.3	64
A	546 ± 17	Charleston	7+	Charleston	7+	600 ± 70
B	1,021 ± 30	Charleston	7+	Charleston	7+	1,025 ± 25
C	1,648 ± 74	*Northern*	6+	--	--	--
C'	1,683 ± 70	--		Charleston	7+	1,695 ± 175
D	1,966 ± 212	*Southern*	6+	--	--	--
E	3,548 ± 66	Charleston	7+	Charleston	7+	3,585 ± 115
F	5,038 ± 166	*Northern*	6+	Charleston	7+	--
F'	--	--	--	--	--	5,075 ± 215
G	5,800 ± 500	Charleston	7+	Charleston	7+	--

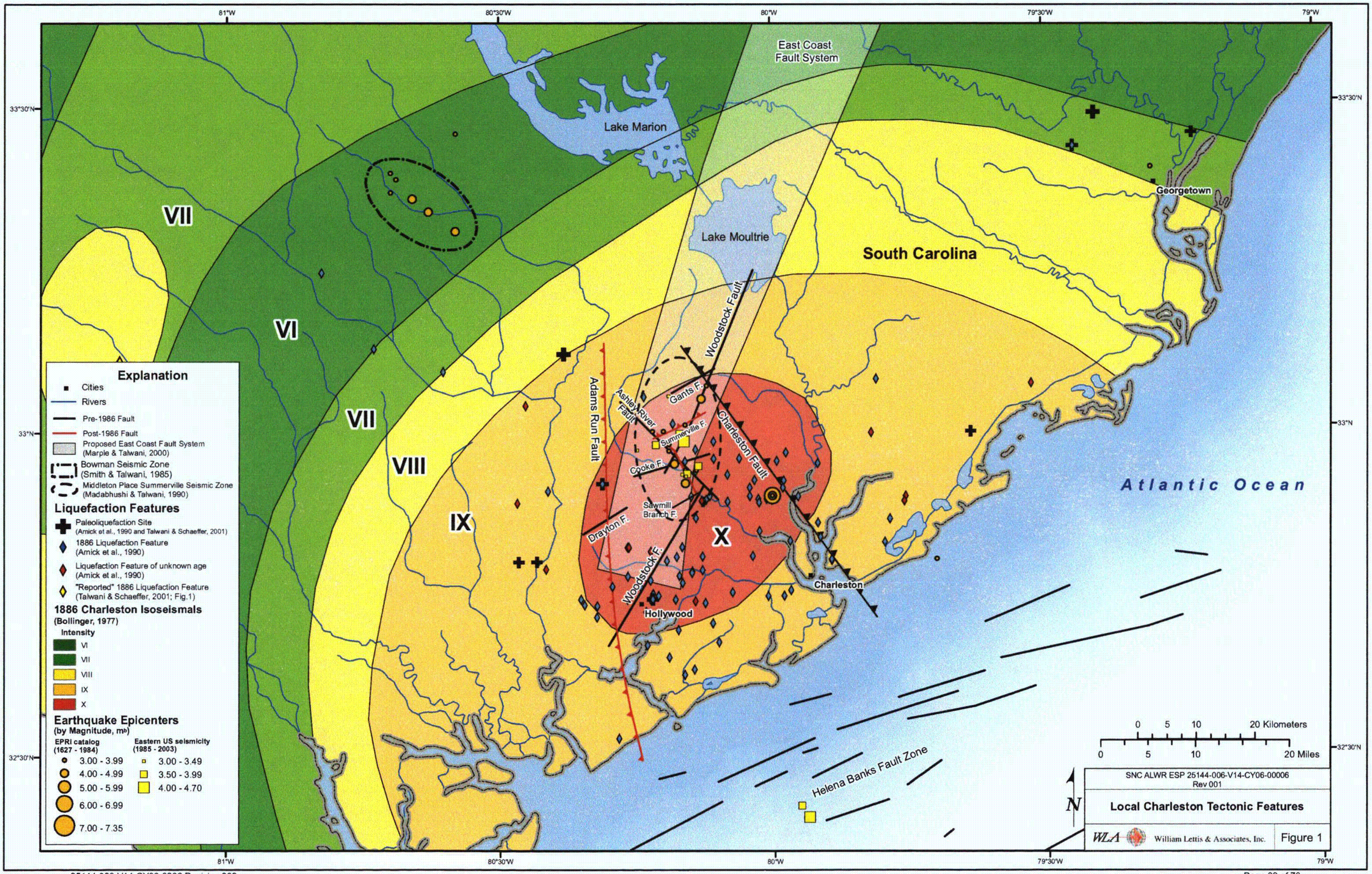
Notes:

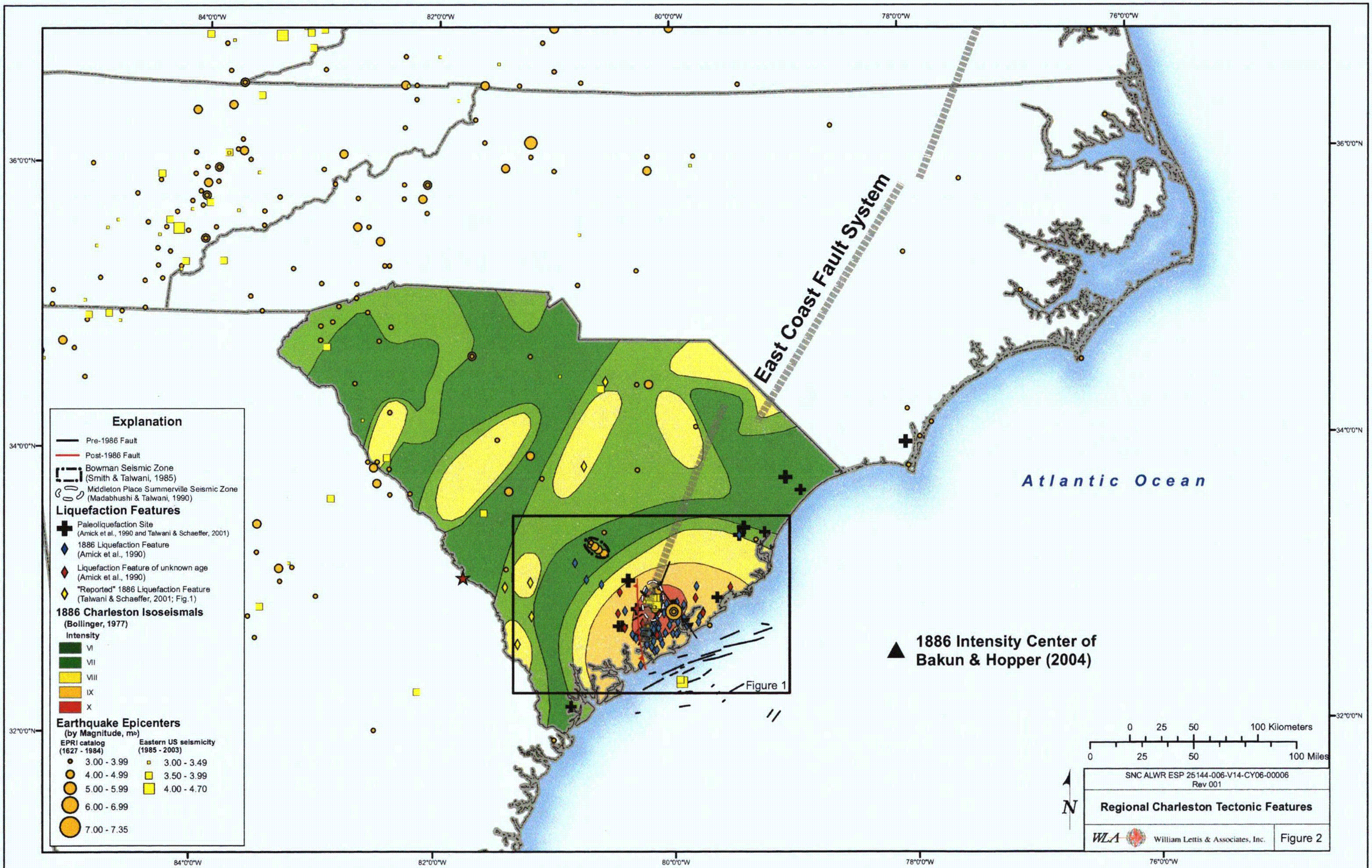
[a] Modified after Talwani and Schaeffer's (2001) Table 2.

[b] Years before present, relative to 1950 A.D.

[c] Event ages based upon our recalibration of radiocarbon (to 2-sigma using OxCal 3.8 (Bronk Ramsey, 1995; 2001) data presented in Talwani and Schaeffer's (2001) Table 2.

[d] See Table B-1 for recalibrated 2-sigma sample ages and Table B-2 for 2-sigma age constraints on paleoliquefaction events.


East Coast Fault System
Lake Marion
Lake Moultrie
South Carolina
Georgetown
Atlantic Ocean
Charleston
Hollywood
Woodstock Fault
Charleston Fault
Adams Run Fault
Ashley River Fault
Gants F.
Summerville F.
Cooke F.
Sawmill Branch F.
Drayton F.
Woodstock F.
Helena Banks Fault Zone
VII
VI
VII
VIII
IX
X
81°W
80°30'W
80°W
79°30'W
79°W
33°30'N
33°N
32°30'N
Explanation
Cities
Rivers
Pre-1986 Fault
Post-1986 Fault
Proposed East Coast Fault System (Marple & Talwani, 2000)
Bowman Seismic Zone (Smith & Talwani, 1985)
Middleton Place Summerville Seismic Zone (Madabhushi & Talwani, 1990)
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 5 10 20 Kilometers
0 5 10 20 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006 Rev 001
Local Charleston Tectonic Features
William Lettis & Associates, Inc.
Figure 1



East Coast Fault System
Atlantic Ocean
1886 Intensity Center of Bakun & Hopper (2004)
Figure 1
Explanation
Pre-1986 Fault
Post-1986 Fault
Bowman Seismic Zone (Smith & Talwani, 1985)
Middleton Place Summerville Seismic Zone (Madabhushi & Talwani, 1990)
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
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X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
Eastern US seismicity (1985 - 2003)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Regional Charleston Tectonic Features
WLA William Lettis & Associates, Inc.
Figure 2
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N

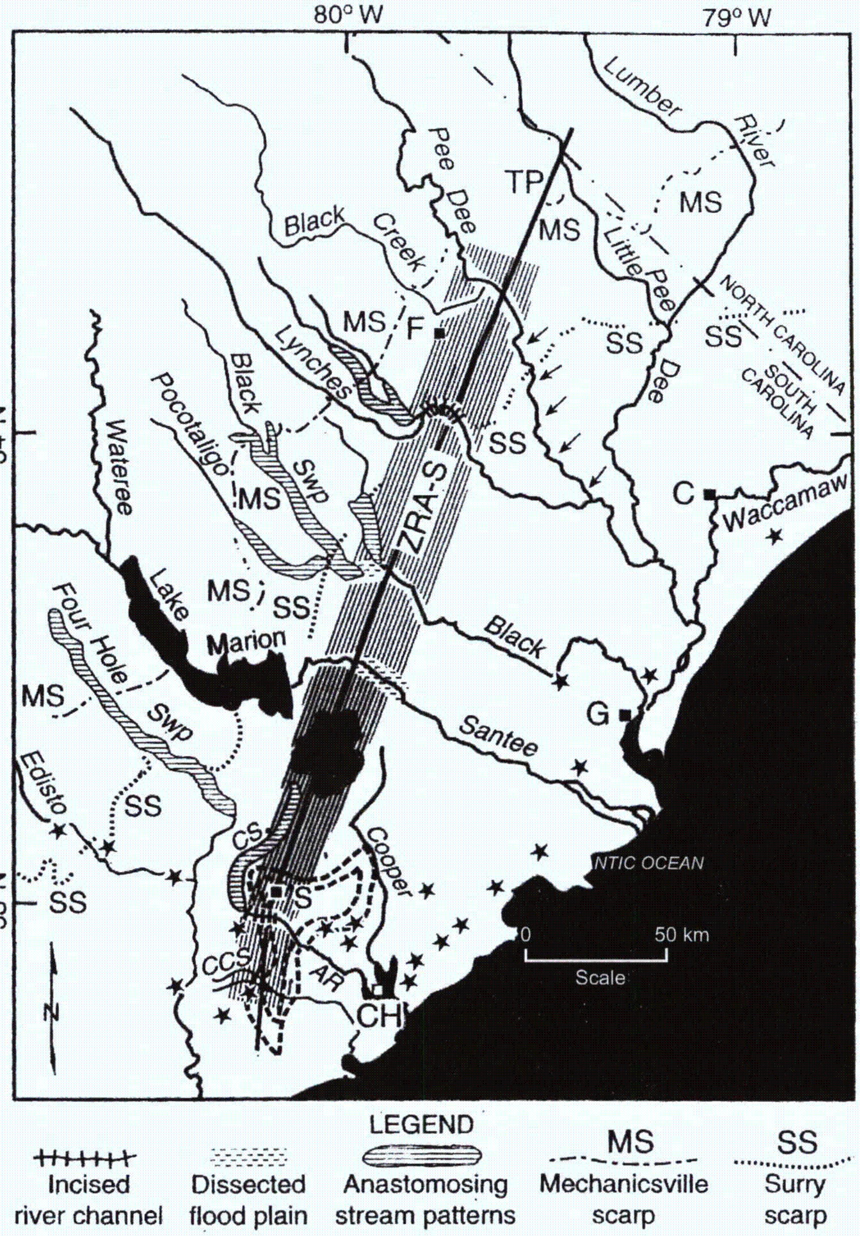


Figure 3. Map of ZRA-S from Marple and Talwani (2000). Figure shows southern zone of river anomalies (ZRA-S; striped area), anastomosing stream patterns, pre 1886 sandblow sites (stars), and topographic profile (TP, bold line) approximately along the ZRA-S axis. Arrows along Pee Dee River denote reach flowing against southwest valley wall. Closed dashed contours near Summerville are highest-intensity isoseismals of the 1886 Charleston, South Carolina, earthquake (from Dutton, 1889). Abbreviations are as follows: AR - Ashley River; C - Conway; CCS - Caw Caw Swamp; CH - Charleston; CS - Cypress Swamp; F - Florence; G - Georgetown; LM - Lake Moultrie; MS - Mechanicsville littoral scarp; S - Summerville; SS - Surry littoral scarp.

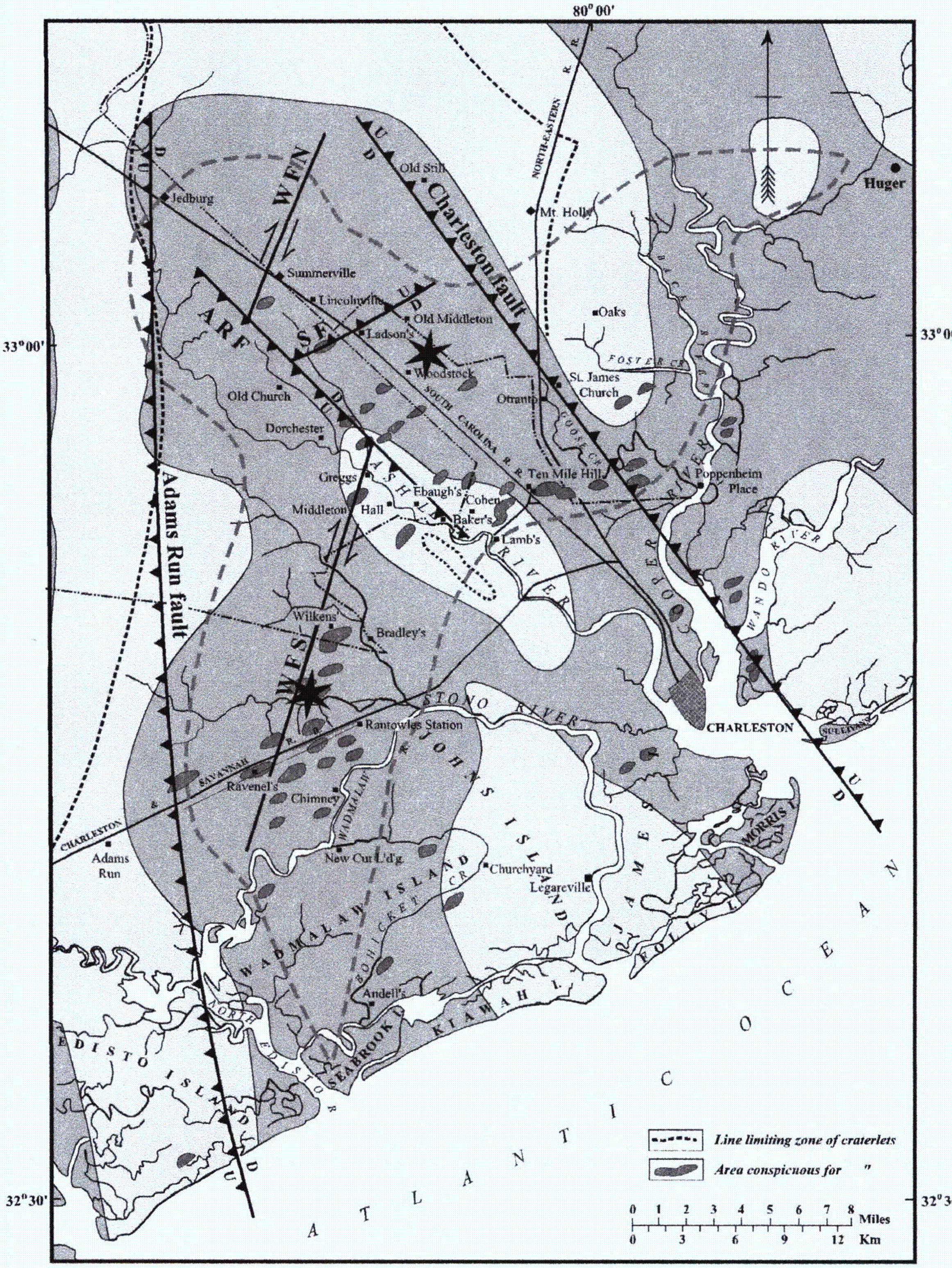
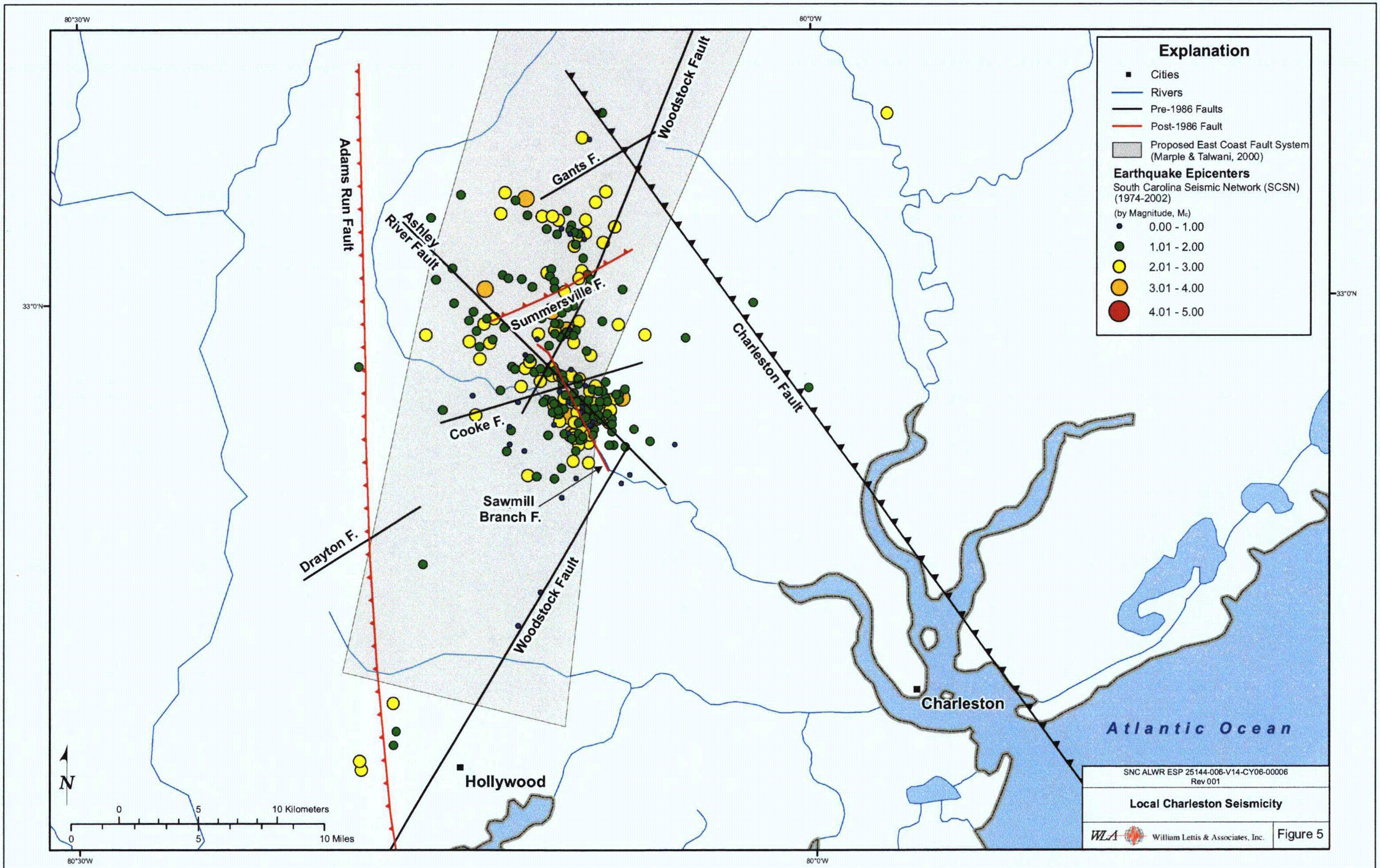


Figure 4. Map of local tectonic features from Weems and Lewis (2002). Figure shows the distribution of 1886 liquefaction features ("craterlets"), isoseismal boundaries (irregular gray dashed line), and two epicenters (starburst symbols) located by Dutton and Sloan (in Dutton, 1889). The positions of the Charleston fault, Adams Run fault, Woodstock fault northern segment (WFN), Woodstock fault southern segment (WFS), Ashley River fault (ARF), and the Summerville fault (SF) are indicated as black lines. Lighter gray areas are regions that have shown persistently upward relative movement over the past 34 m.y. (Weems and Lewis, 2004).



80°30'W
80°0'W
33°0'N
Explanation
Cities
Rivers
Pre-1986 Faults
Post-1986 Fault
Proposed East Coast Fault System (Marple & Talwani, 2000)
Earthquake Epicenters
South Carolina Seismic Network (SCSN) (1974-2002)
(by Magnitude, Mc)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
Adams Run Fault
Woodstock Fault
Gants F.
Ashley River Fault
Summersville F.
Cooke F.
Sawmill Branch F.
Drayton F.
Charleston Fault
Charleston
Hollywood
Atlantic Ocean
N
0 5 10 Kilometers
0 5 10 Miles
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Local Charleston Seismicity
WLA William Lettis & Associates, Inc.
Figure 5

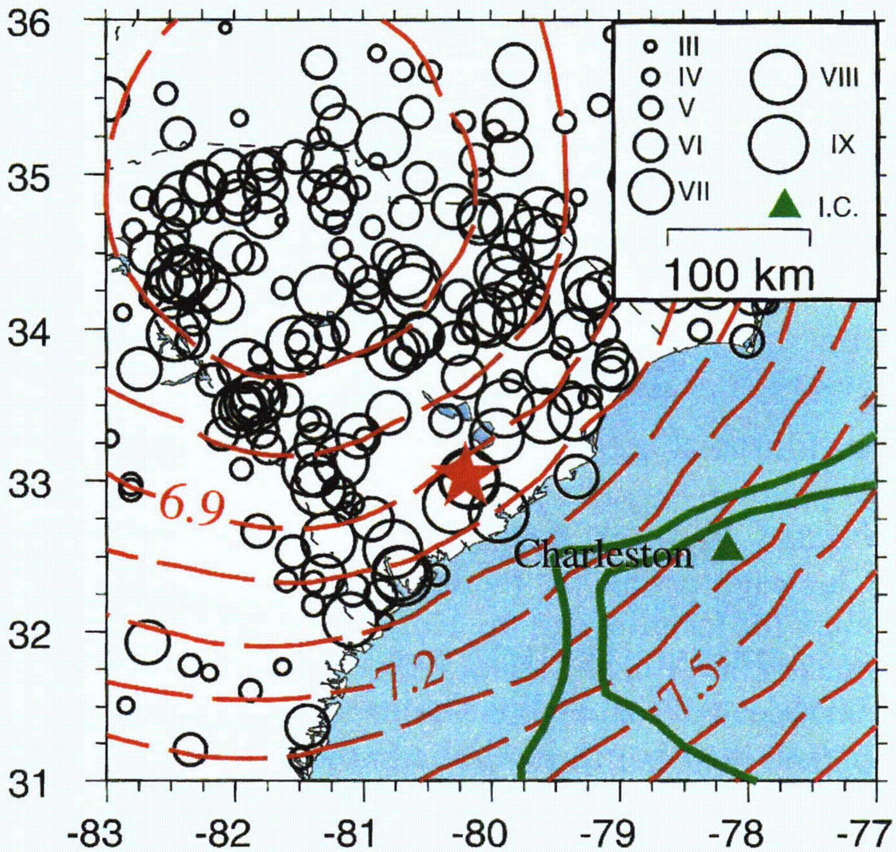


Figure 6. Map of 1886 offshore intensity center from Bakun and Hopper (2004). Figure shows the offshore location of estimated intensity center (green triangle) for the September 1, 1886 Charleston, South Carolina, earthquake . Red star is the location of a cluster of epicenters of recent small earthquakes near Summerville-Middleton Place and the preferred epicenter. Black circles are sites with MMI assignments. The contours of intensity magnitude (dashed red lines) are the best esimates of **M** from the MMI assignments for assumed epicenters on that contour.

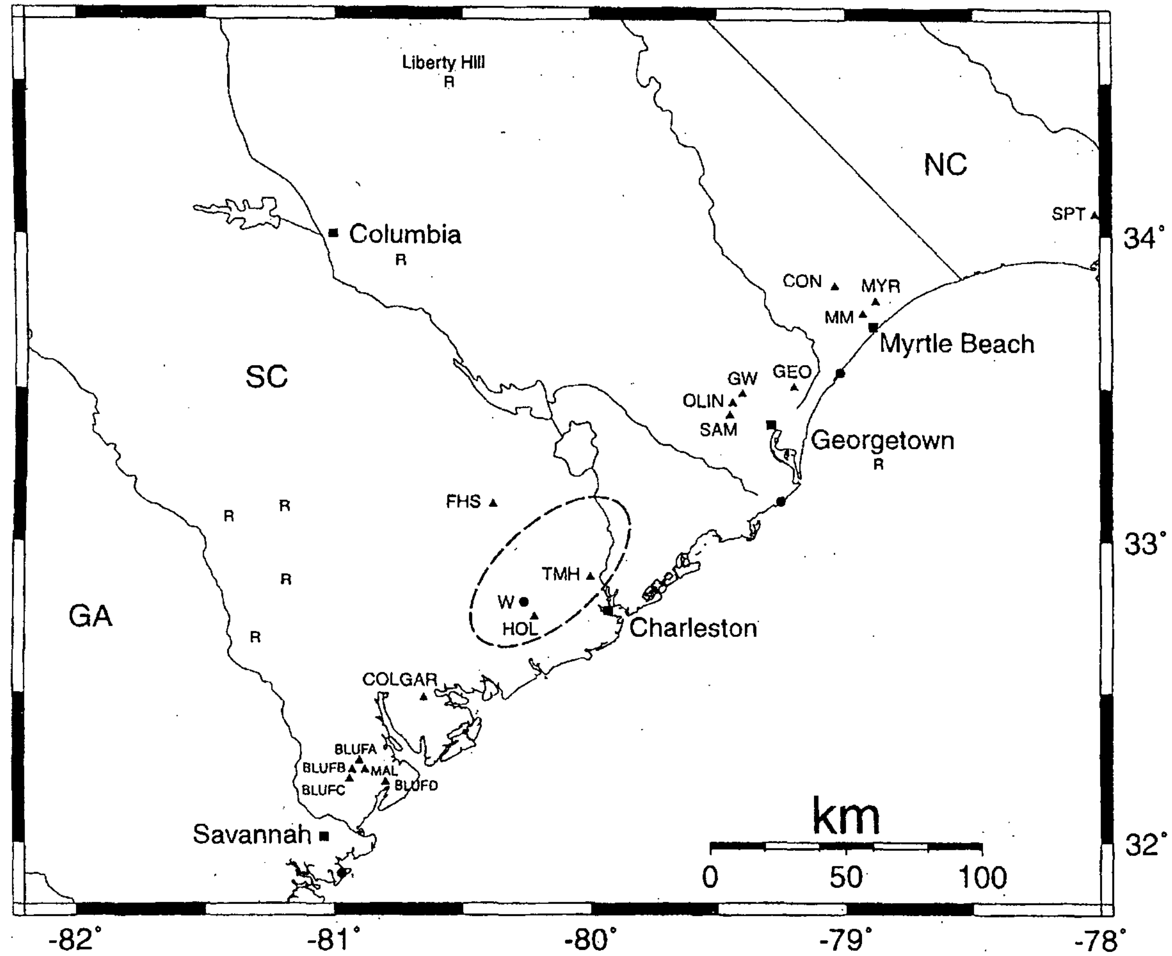
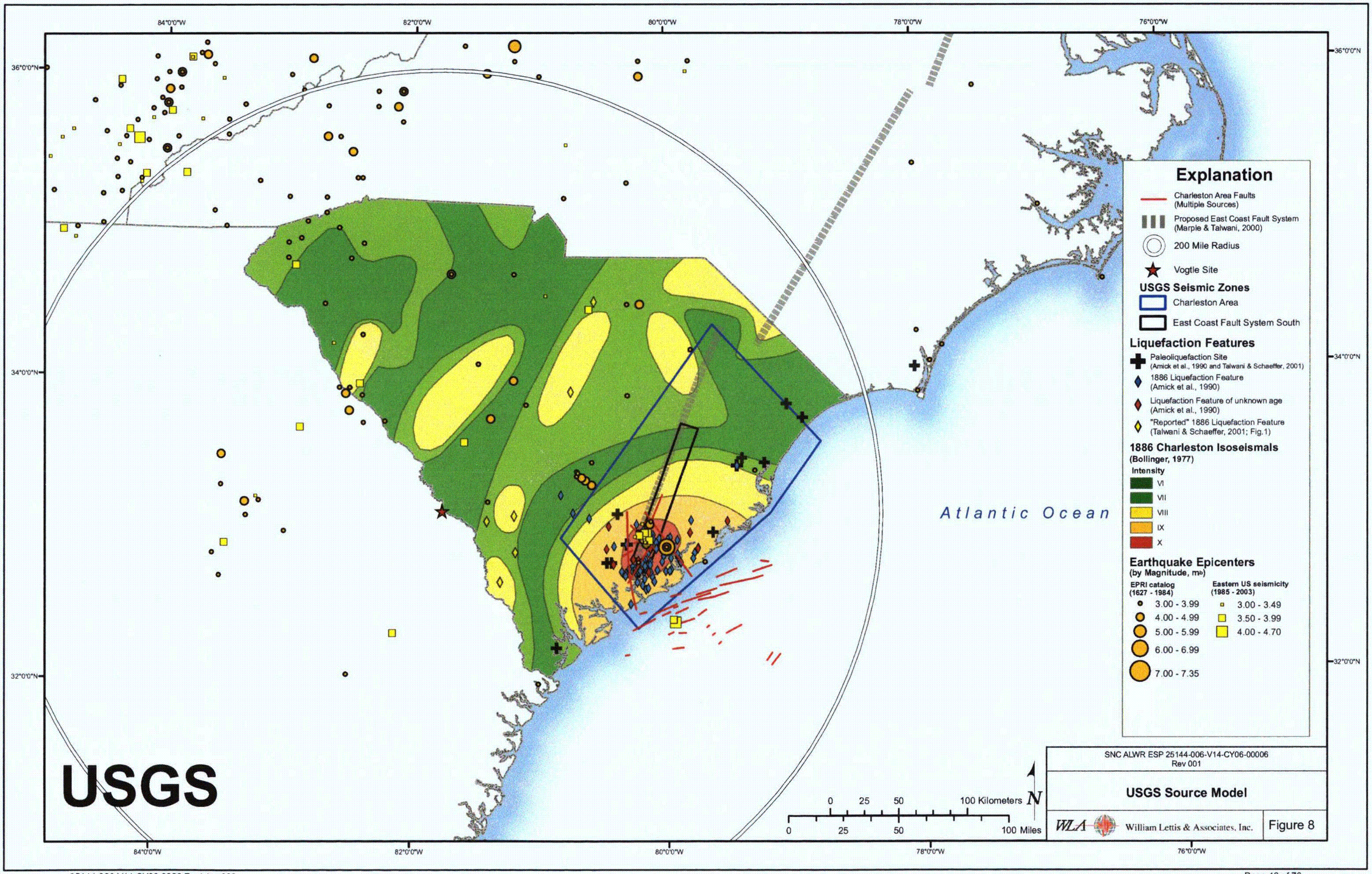
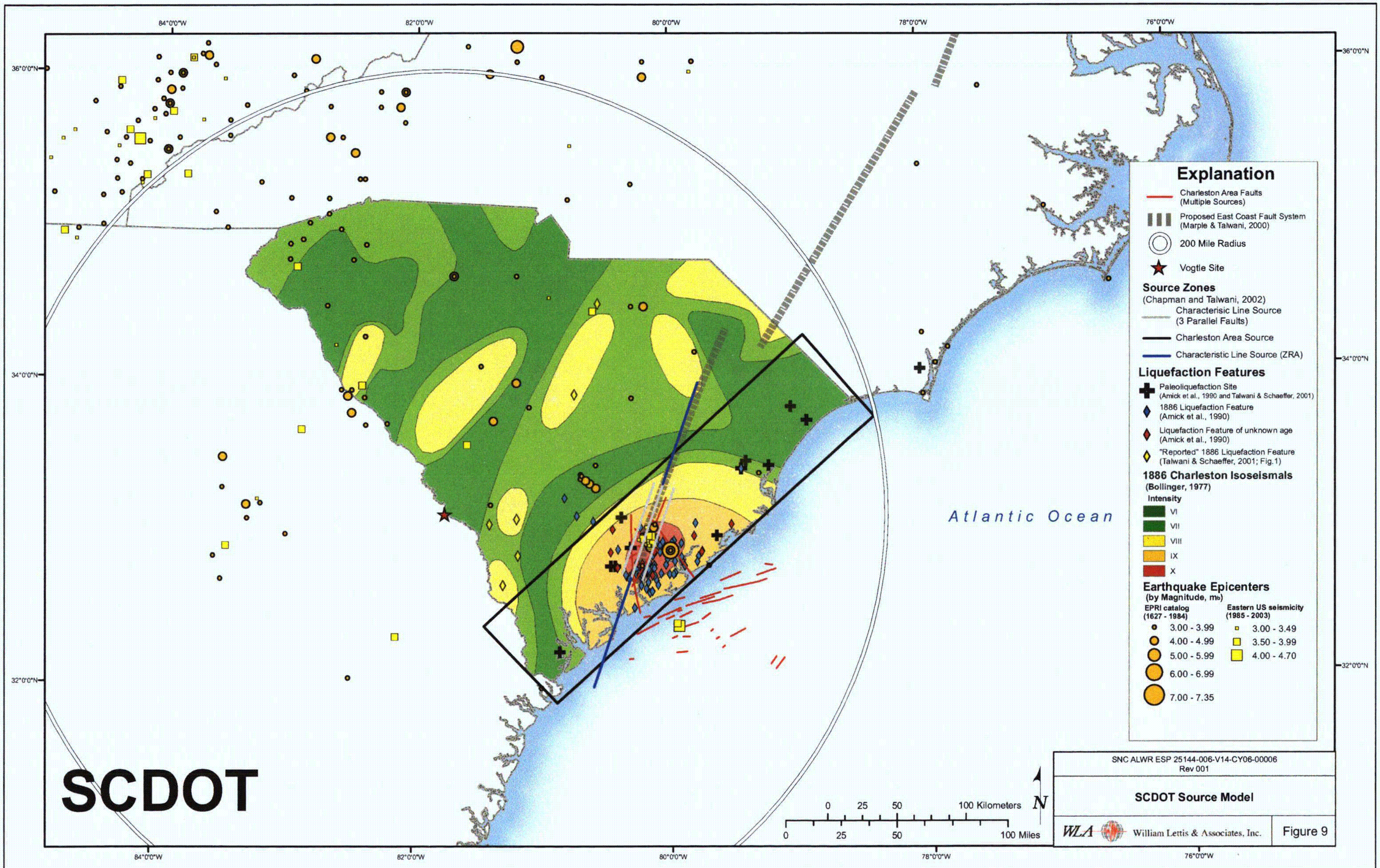


Figure 7. Map of paleoliquefaction sites from Talwani and Schaeffer (2001). Figure shows the location of paleoliquefaction sites in the North Carolina and South Carolina Coastal Plain from which datable material associated with prehistoric earthquakes was obtained (triangles). Dashed lines encloses area of pronounced craterlet activity associated with the 1886 earthquake (from Dutton, 1889). Reports (R) of liquefaction features extend to Columbia and Georgetown (Seeber and Armbruster, 1981) and to Sand Hills near Liberty Hill (Floyed, 1969). Abbreviations are as follows: Bluffton, BLUF; Colony Gardens, COLGAR; Conway, CON; Four Hole Swamp, FHS; Gapway, GW; Georgetown, GEO; Hollywood, HOL; Malpherous, MAL; Martin Marietta, MM; Myrtle Beach, MYR; Sampit, SAM; South Port, North Carolina, SPT; and Ten Mile Hill, TMH.



84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
USGS
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
USGS Seismic Zones
Charleston Area
East Coast Fault System South
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
USGS Source Model
WLA William Lettis & Associates, Inc.
Figure 8


SCDOT
Atlantic Ocean
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
(Chapman and Talwani, 2002)
Characterisic Line Source (3 Parallel Faults)
Charleston Area Source
Characteristic Line Source (ZRA)
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
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"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals
(Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters
(by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
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Eastern US seismicity (1985 - 2003)
3.00 - 3.49
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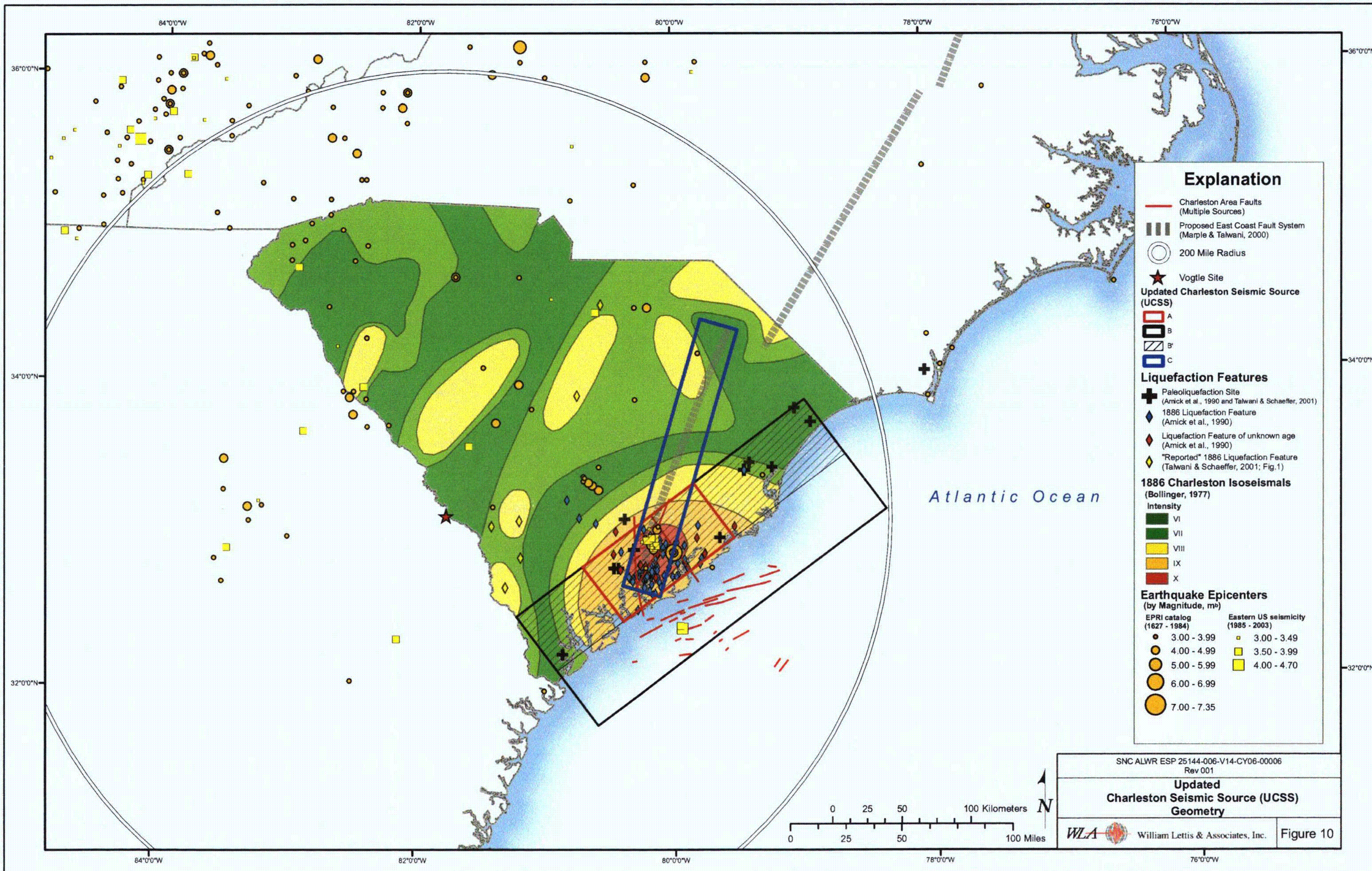
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
SCDOT Source Model
WLA William Lettis & Associates, Inc.
Figure 9
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N



84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Updated Charleston Seismic Source (UCSS)
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals
(Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters
(by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Updated
Charleston Seismic Source (UCSS)
Geometry
WLA William Lettis & Associates, Inc.
Figure 10

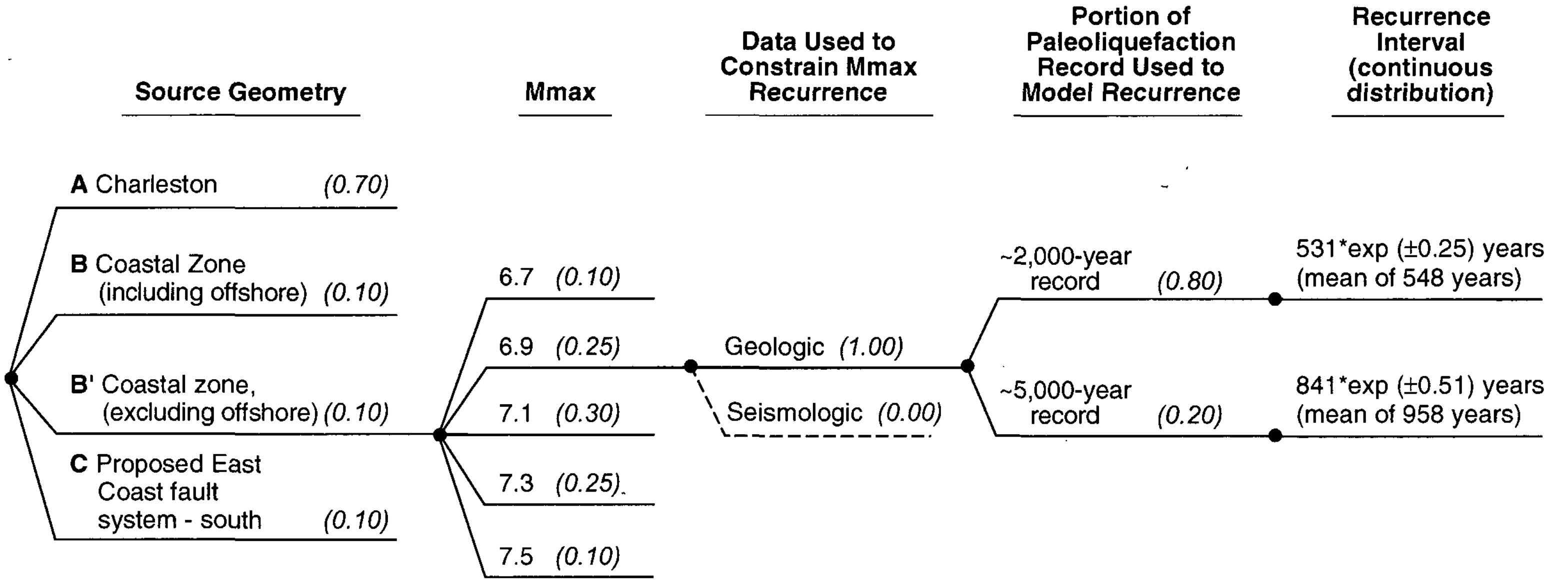
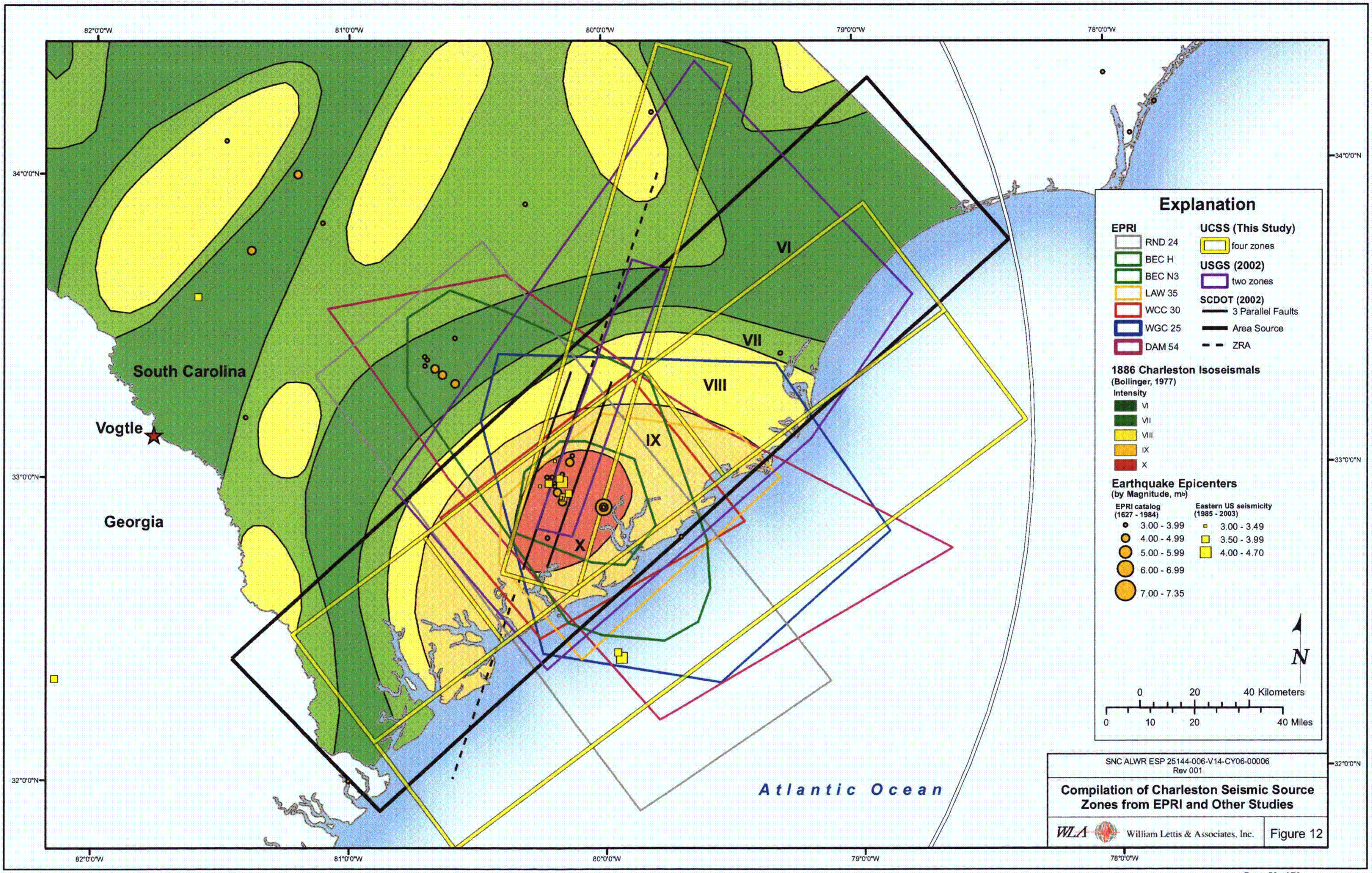


Figure 11. Updated Charleston seismic source (USGS) logic tree with weights for each branch shown in italics.



82°0'0"W
81°0'0"W
80°0'0"W
79°0'0"W
78°0'0"W
34°0'0"N
33°0'0"N
32°0'0"N
South Carolina
Vogtle
Georgia
VI
VII
VIII
IX
X
Atlantic Ocean
Explanation
EPRI
RND 24
BEC H
BEC N3
LAW 35
WCC 30
WGC 25
DAM 54
UCSS (This Study)
four zones
USGS (2002)
two zones
SCDOT (2002)
3 Parallel Faults
Area Source
ZRA
1886 Charleston Isoseismals
(Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters
(by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
N
0 20 40 Kilometers
0 10 20 40 Miles
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Compilation of Charleston Seismic Source Zones from EPRI and Other Studies
WLA William Lettis & Associates, Inc.
Figure 12

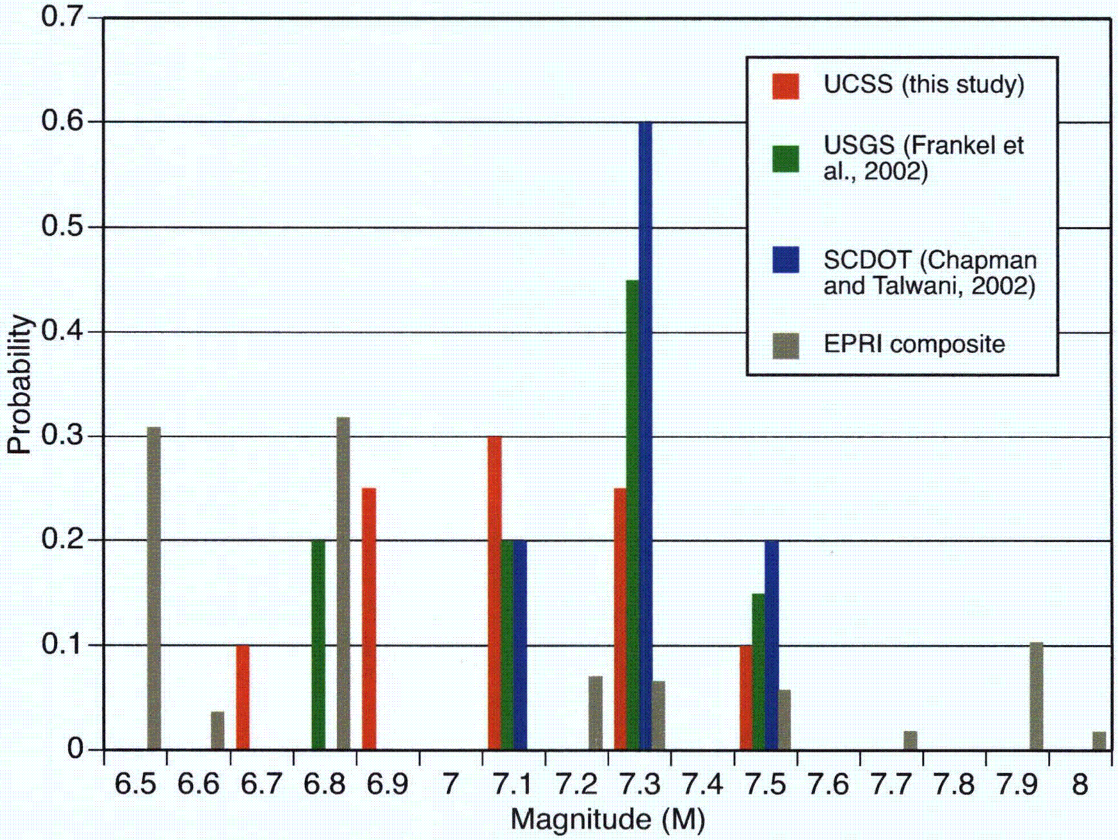


Figure 13. Maximum magnitude distributions for different models of the Charleston seismic source

APPENDIX A

Integration of the UCSS with the EST Seismic Source Models

APPENDIX A

Integration of the UCSS with the EST Seismic Source Models

We have developed an Updated Charleston Seismic Source (UCSS) model, which incorporates new information and interpretations from the technical community regarding the source geometry, Mmax, and recurrence that have been developed since the 1986 EPRI-SOG EST assessments. This appendix describes the approach used to integrate the UCSS with each of the EST seismic source models. The intent is to provide an identical representation of the Charleston seismic source (*i.e.* the UCSS) in each of the six EPRI ESTs while limiting any revision to non-Charleston sources in each model. To incorporate the UCSS into the EPRI source model, we used the following steps:

(1) ***Remove*** **EST Charleston sources**. The overall strategy is to remove Charleston-type earthquakes from the EPRI team models so that when the UCSS is added to the model, we avoid double-counting the hazard from Charleston-type earthquakes. To achieve this, we removed any source identified as a Charleston source from the EPRI EST interpretations. Most ESTs specifically described which sources represented Charleston sources (*e.g.*, Bechtel, Dames & Moore, and Rondout). Other teams were less explicit and we had to deduce whether they intended Charleston-type earthquakes to occur in certain zones based mainly on Mmax values and weights.

(2) ***Input*** **the Updated Charleston Seismic Source (UCSS) model**. The UCSS alternative source geometries, Mmax and recurrence distributions were incorporated into each of the six EST models.

(3) ***Calculate seismicity*** **parameters of UCSS**. The new geometries of the UCSS will be used to calculate seismicity parameters for smaller earthquakes (**M**<6.7). An up-to-date earthquake catalog and the EPRI seismicity software EQPARAM will be used for this purpose. The underlying assumption of each source geometry is that future earthquakes are spatially homogeneous, so full smoothing of seismicity parameters will be used in these calculations.

(4) **Reconcile differences in geometries of new and old sources by allowing portions of "old" EPRI source zones that lie outside the new replacement source geometries to *default* to the existing EPRI background zones.** Because old and new source geometries are not coincident, we cannot simply swap new sources for old sources without impacting how gridded seismicity is counted in the hazard. This avoids having any areas in the seismic hazard model that are aseismic, which would not be defensible.

(5) ***Recalculate seismicity*** **parameters of revised "old" EPRI sources.** The seismicity parameters of the revised EPRI sources from step (2) are recalculated, using an up-to-date earthquake catalog and using the smoothing assumptions on parameters selected by the EPRI ESTs. This provides the parameters for seismic hazard calculations for these modified sources.

In application of the new UCSS, earthquake ruptures will be modeled with a set of parallel faults trending NE-SW, since this is structural trend in the coastal plain and is the likely trend of faulting associated with future earthquakes. This will apply to all earthquakes. The spacing of faults will be sufficiently close such that the exact spacing has no mathematical impact on hazard. Seismicity will be distributed among the multiple faults, and will be assumed to occur anywhere along a fault, in a spatially homogeneous fashion.

A specific example of how sources from one EST model were removed, defaulted, or modified is described below to illustrate how we updated the EPRI source models. The example discussed is the Woodward-Clyde Consultants (WCC) team, which identified sources 30, 29, and 29A (which are all mutually exclusive with one another) as sources capable of producing Charleston-type events (Table 2f). The magnitudes assigned to these sources also reflect this intent. In implementing the revision, we removed sources 30, 29, and 29A from the WCC EST source model and replaced them with the UCSS (geometries A, B, B', and C). Any portion of WCC sources 30, 29, and 29A that fall outside of the new source geometries are defaulted to the "Vogtle background zone". This avoids having any portions of the region becoming aseismic. WCC source 29B was retained in our revised model since this source (1) does not cover the 1886 Charleston epicentral area, (2) encompasses the elevated seismicity in South Carolina and Georgia, and (3) was assigned significantly lower Mmax values than sources 30, 29, and 29A. This source was not intended to represent a Charleston-type event by WCC, and therefore was retained in our revision as unmodified. In the WCC model, no regional or background sources were modified, because they were not intended by WCC to model Charleston-type earthquakes.

For the Law team, the consistent upper-bound Mmax values of 6.8 that were assigned to all sources presented a unique challenge in integrating the UCSS with their model. Even though the Law report states that they consider 5 sources capable of producing Charleston-type events (35, C09, 22, 108, and mafic plutons) (Table 2c), we felt that most of these sources should remain in the final model and were not removed (Table 2C)s. If each of these sources were removed, there would remain only two combination zones to account for seismicity for the Vogtle analysis. In addition, the Law Mmax value of m_b 6.8 is lower than the UCSS weighted mean Mmax of **M**7.2, and therefore, there should be very little effect of "double-counting" Charleston-type events by retaining these sources to model background and moderate seismicity. The only source we recommend removing from the Law model is source 35, the local Charleston source.

Below, we describe the modifications to each EST team.

EST Model Modifications

Bechtel Team. The Bechtel team identified three sources that were judged to be capable of producing Charleston-type earthquakes. These sources, which are listed in Table 2a with their parameters, are N3 (Charleston faults), H (Charleston), and BZ4 (background). To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Bechtel source model in Figure A-1. The revised model, where the UCSS has been added and the old Charleston sources removed, is shown in Figure A-2.

The following modifications to the Bechtel source model are proposed:

- Add new UCSS with four mutually exclusive geometries.
- Remove sources N3 (Charleston faults) and H (Charleston).
- For locations formerly in sources N3 and H that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to BZ4.

- No other sources are modified. While BZ4 was considered to have a 5% likelihood of producing a Charleston event by the Bechtel team, we chose not to reduce the large Mmax values [and weights] of BZ4 (6.6 [.1], 6.8 [.4], 7.1 [.4], and 7.4 [.1] to 5.7 [.1]) to maintain the possibility of large, infrequent events occurring in BZ4.

Dames & Moore Team. The Dames & Moore team defined a simple model in which source 54 (Charleston) was thought to be capable of producing Charleston-type earthquakes. Parameters for this source are listed in Table 2b. To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Dames & Moore source model in Figure A-3. The revised model, where the UCSS has been added and the old Charleston source removed, is shown in Figure A-4.

The following modifications to the Dames & Moore source model are proposed:
- Add new UCSS with four mutually exclusive geometries.
- Remove source 54 (Charleston).
- For locations formerly in source 54 that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to sources 52 (Charleston Mesozoic rifts) and 53 (Southern Appalachian Mobile belt).
- No other sources are modified.

Law Team. The Law team identified five sources that were judged to be capable of producing Charleston-type earthquakes. These sources, which are listed in Table 2c with their parameters, are 35 (Charleston), C09 (bridged Mesozoic basins), 22 (Reactivated Eastern Seaboard Normal), 108 (Brunswick background), and M (mafic plutons). To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Law source model in Figure A-5. The revised model, where the UCSS has been added and the old Charleston sources removed, is shown in Figure A-6.

The following modifications to the Law source model are proposed:
- Add new UCSS with four mutually exclusive geometries.
- Remove source 35 (Charleston).
- Retain sources C09, 108, 22, and M (mafic plutons) because these sources appear to represent an earthquake process that extends beyond the Charleston area.
- For locations formerly in source 35 that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to sources 8 and 108.
- No other sources are modified.

Rondout Team. The Rondout team defined a simple model in which source 24 (Charleston, South Carolina) represented the Charleston earthquake source. Parameters for this source are listed in Table 2d. To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Rondout source model in Figure A-7. The revised model, where the UCSS has been added and the old Charleston source removed, is shown in Figure A-8.

The following modifications to the Rondout source model are proposed:
- Add new UCSS with 4 mutually exclusive geometries.
- Remove source 24 (Charleston).
- For locations formerly in source 24 that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to source 26.
- No other source zones are modified.

Weston Team. The Weston team defined a simple model in which one source (25) represented the Charleston earthquake source. Parameters for this source are listed in Table 2e. To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Weston source model in Figure A-9. The revised model, where the UCSS has been added and the old Charleston source removed, is shown in Figure A-10.

The following modifications to the Weston source model are proposed:

- Add new UCSS with four mutually exclusive geometries.
- Remove source 25 (Charleston Seismic Zone).
- For locations formerly in source 25 that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to combination sources involving sources 26 and 104.
- No other source zones are modified.

Woodward Clyde Team. The Woodward Clyde team defined a complex model in which three sources were judged to be capable of producing Charleston-type earthquakes. These sources, which are listed in Table 2f with their parameters, are 30 (Charleston), 29 (SC Gravity Saddle - extended), and 29A (SC Gravity Saddle No. 2). To illustrate the differences in source geometry and dimensions, the UCSS is overlaid on the Woodward Clyde source model in Figure A-11. The revised model, where the UCSS has been added and the old Charleston sources removed, is shown in Figure A-12.

The following modifications to the Woodward Clyde source model are proposed:

- Add new UCSS with four mutually exclusive geometries.
- Remove source 30, 29, and 29A.
- Retain source 29B (South Carolina gravity saddle #3), since it appears to be enveloping the elevated seismicity of South Carolina and Georgia and that its lower Mmax values imply that it is not a "Charleston" source.
- For locations formerly in sources 30, 29, and 29A that fall outside (are not covered by) the UCSS geometries, allow seismicity to default to the Vogtle background zone.
- No other sources are modified.

Table A-1a. Summary of Bechtel seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
H	**Charleston Area**	0.50	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]	1 [0.33] 2 [0.34] 4 [0.33]	P(H|N3)=0.15
N3	**Charleston Faults**	0.53	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]	1 [0.33] 2 [0.34] 4 [0.33]	P(N3|H)=0.16
BZ4	**Atlantic Coastal Region**	1.00	6.6 [0.10] 6.8 [0.10] 7.1 [0.40] 7.4 [0.40]	1 [0.33] 2 [0.34] 3 [0.33]	Background; PB=1.00
BZ5	S. Appalachians	1.00	5.7 [0.10] 6.0 [0.40] 6.3 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 3 [0.33]	Background; PB=1.00
F	S.E. Appalachians	0.35	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	ME with G; ME with 13, 15, 16, 17
G	NW South Carolina	0.35	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	ME with F; ME with 13, 15, 16, 17
Other Sources within 200 mi (320 km)					
13	Eastern Mesozoic Basins	0.10	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	no overlap with H or N3; ME with all sources in BZ5
24	Bristol Trends	0.25	5.7 [0.10] 6.0 [0.40] 6.3 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	ME with 19, 25, 25A
15	Rosman Fault	0.05	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	ME with all other sources
16	Belair Fault	0.05	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	ME with all other sources

Notes: Charleston sources shown in **bold**

Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)

Table A-1b. Summary of Dames & Moore seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
54	**Charleston Seismic Zone**	1.00	6.6 [0.75] 7.2 [0.25]	1 [0.22] 2 [0.08] 3 [0.52] 4 [0.18]	none
52	Charleston Mesozoic Rift	0.46	4.7 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	ME with 47 thru 50, 65; ME with 52
53	S. Appalachian Mobile Belt	0.26	5.6 [0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Default for 47 thru 52, 65
41	S. Cratonic Margin (Default	0.12	6.1 [0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Default for 42, 43, and 46
20	S. Coastal Margin	1.00	5.3 [0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	none
Other Sources within 200 mi (320 km)					
4	Appalachian Fold Belts	0.35	6.0 [0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	ME with 4A, 4B, 4C, 4D
4A	Kink in Fold Belt	0.65	5.0 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	ME with 4
49	Jonesboro Basin	0.28	6.0 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	PD with 47, 48, 50, 51, 65; ME with 52
50	Buried Triassic Basins	0.28	6.0 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	PD with 47, 48, 49, 51, 65; ME with 52
51	Florence Basin	0.28	6.0 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	PD with 47 thru 50, 65; ME with 52
65	Dunbarton Triassic Basin	0.28	5.9 [0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	PD with 47 thru 51; ME with 52
C01	Combination zone 4-4A-4B-4C-	NA	6.0 [0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	NA

Notes: Charleston sources shown in **bold**

Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)

Table A-1c. Summary of Law Engineering seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
35	**Charleston Seismic Zone**	0.45	6.8 [1.00]	2a [1.00]	Overlaps 8 and 22
17	Eastern Basement	0.62	5.7 [0.20] 6.8 [0.80]	1b [1.00]	none
22	**Reactivated E. Seaboard Normal**	0.27	6.8 [1.00]	2a [1.00]	ME with 8 and 21; overlaps 24, 35, and 39
108	**Brunswick, NC Background**	1.00	4.9 [0.50] 5.5 [0.30] 6.8 [0.20]	2a [1.00]	Background; PB=0.42
C09	**Mesozoic Basins (8 - Bridged)**	NA	6.8 [1.00]	2a [1.00]	NA
C10	8-35	NA	6.8 [1.00]	2a [1.00]	NA
C11	22 - 35	NA	6.8 [1.00]	2a [1.00]	NA
M33	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M36	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M37	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M38	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M39	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M40	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M41	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
M42	**Mafic Pluton**	0.43	6.8 [1.00]	5 [1.00]	none
Other Sources within 200 mi (320 km)					
217	Eastern Basement Background	1.00	4.9 [0.50] 5.7 [0.50]	1b [1.00]	Background; PB=0.29; same geometry as 17

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
107	Eastern Piedmont	1.00	4.9 [0.30] 5.5 [0.40] 5.7 [0.30]	1a [1.00]	Background; PB=0.42
GC13	22 - 24 - 35	NA	6.8 [1.00]	2a [1.00]	NA
GC12	22 - 24	NA	6.8 [1.00]	2a [1.00]	NA
8	Mesozoic Basins	0.27	6.8 [1.00]	a and b values calculated for C09	ME with 22; overlaps with 35

Notes: Charleston sources shown in **bold**

Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)

Table A-1d. Summary of Rondout seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
24	**Charleston**	1.00	6.6 [0.20] 6.8 [0.60] 7.0 [0.20]	1 [1.00] (a=-0.710, b=1.020)	none
26	South Carolina	1.00	5.8 [0.15] 6.5 [0.60] 6.8 [0.25]	1 [1.00] (a=-1.390, b=0.970)	none
Other Sources within 200 mi (320 km)					
49	Appalachian	1.00	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	2 [1.00]	Background; PB=1.00
C01	Background 49	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	none
C09	49+32	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	none
50	Grenville	1.00	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	2 [1.00]	Background; PB=1.00
C02	Background 50	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	does not contain 12 or 13
C07	50 (02) + 12	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	none
25	Southern Appalachians	0.99	6.6 [0.30] 6.8 [0.60] 7.0 [0.10]	1 [1.00] (a=-0.630, b=1.150)	none
27	Tennessee-VA Border Zone	0.99	5.2 [0.30] 6.3 [0.55] 6.5 [0.15]	1 [1.00] (a=-1.120, b=0.930)	none

Notes: Charleston sources shown in **bold**
Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)

Table A-1e. Summary of Weston seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
25	**Charleston Seismic Zone**	0.99	6.6 [0.90] 7.2 [0.10]	1b [1.00]	none
26	South Carolina	0.86	6.0 [0.67] 6.6 [0.27] 7.2 [0.06]	1b [1.00]	none
104	Southern Coastal Plain	1.00	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 2a [0.80]	Background; PB=1.00
C19	103-23-24	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [1.00]	NA
C20	104-22	NA	6.0 [0.85] 6.6 [0.15]	1a [0.30] 2a [0.70]	NA
C21	104-25	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	NA
C23	104-22-26	NA	5.4 [0.80] 6.0 [0.14] 6.6 [0.06]	1a [0.50] 2a [0.50]	NA
C24	104-22-25	NA	5.4 [0.80] 6.0 [0.14] 6.6 [0.06]	1a [0.50] 2a [0.50]	NA
C26	104-28BCDE-22	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	NA
C27	104-28BCDE-22-25	NA	5.4 [0.30] 6.0 [0.70]	1a [0.70] 2a [0.30]	NA
C33	26-25		6.6 [0.90] 7.2 [0.10]	1b [1.00]	NA
C35	104-28BE-25	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 1b [0.80]	NA
Other Sources within 200 mi (320 km)					
C22	104-26	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 1b [0.70]	NA

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interde-pendencies
C34	104-28BE-26	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 1b [0.80]	NA
C25	104-28BCDE	NA	5.4 [0.24] 6.6 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	NA
C28	104-28BCDE-22-26	NA	5.4 [0.30] 6.0 [0.70]	1a [0.70] 2a [0.30]	NA
28B	Zone of Mesozoic Basin	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	PD with 28C, 28D, and 28E
C01	28A thru E	NA	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	NA
103	Southern Appalachians	1.00	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.20] 2a [0.80]	Background; PB=1.00
C17	103-23	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.70] 2a [0.30]	NA
C18	103-24	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.70] 1b [0.30]	NA
28D	Zone of Mesozoic Basin	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	PD with 28B, 28C, and 28E
28E	Zone of Mesozoic Basin	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	PD with 28B, 28C, and 28D
102	Appalachian Plateau	1.00	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1a [0.20] 2a [0.80]	Background; PB=1.00
24	New York-Alabama-Clingman	0.90	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1b [1.00]	Contained in 103

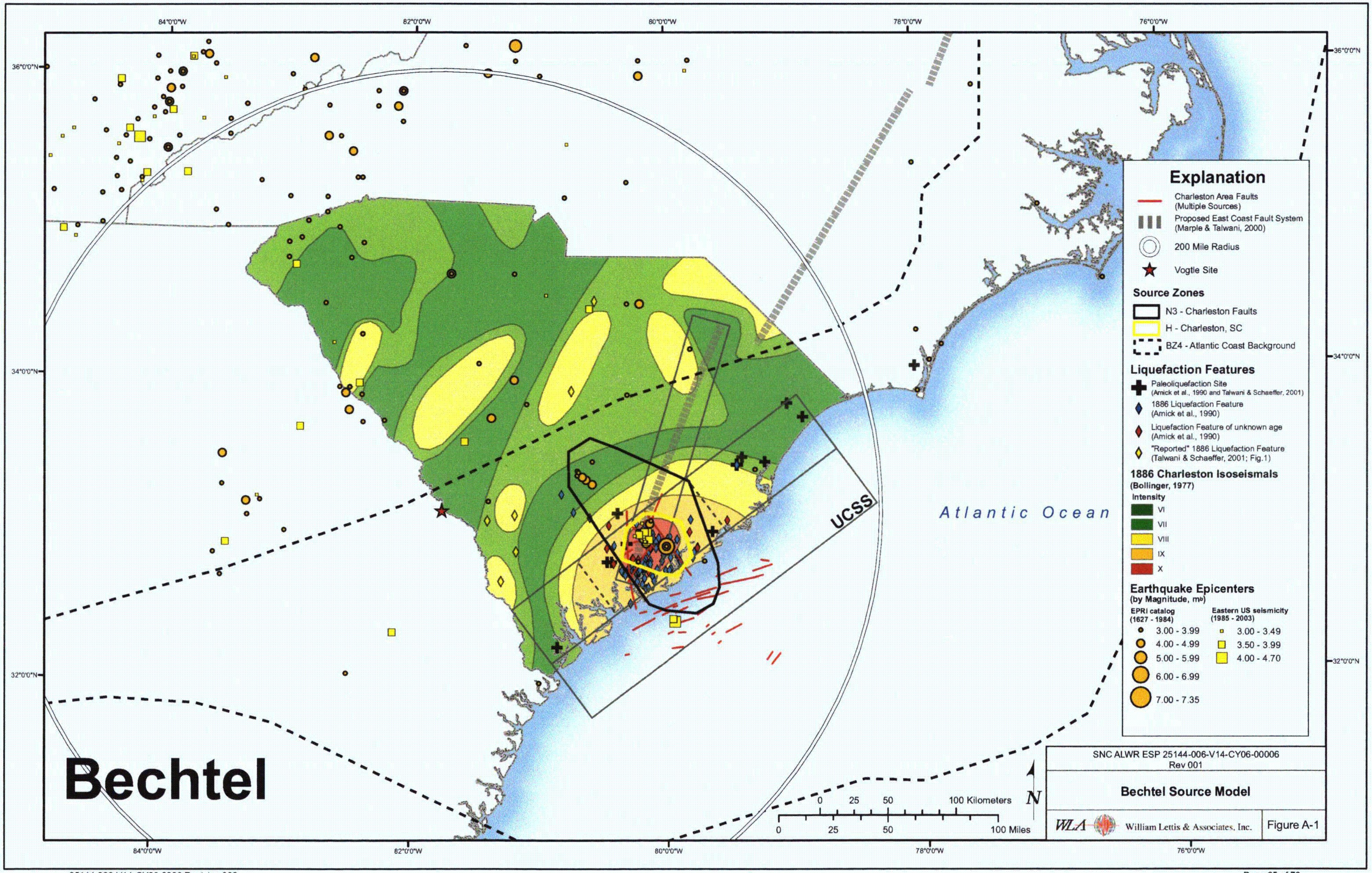
Notes: Charleston sources shown in **bold**

Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)

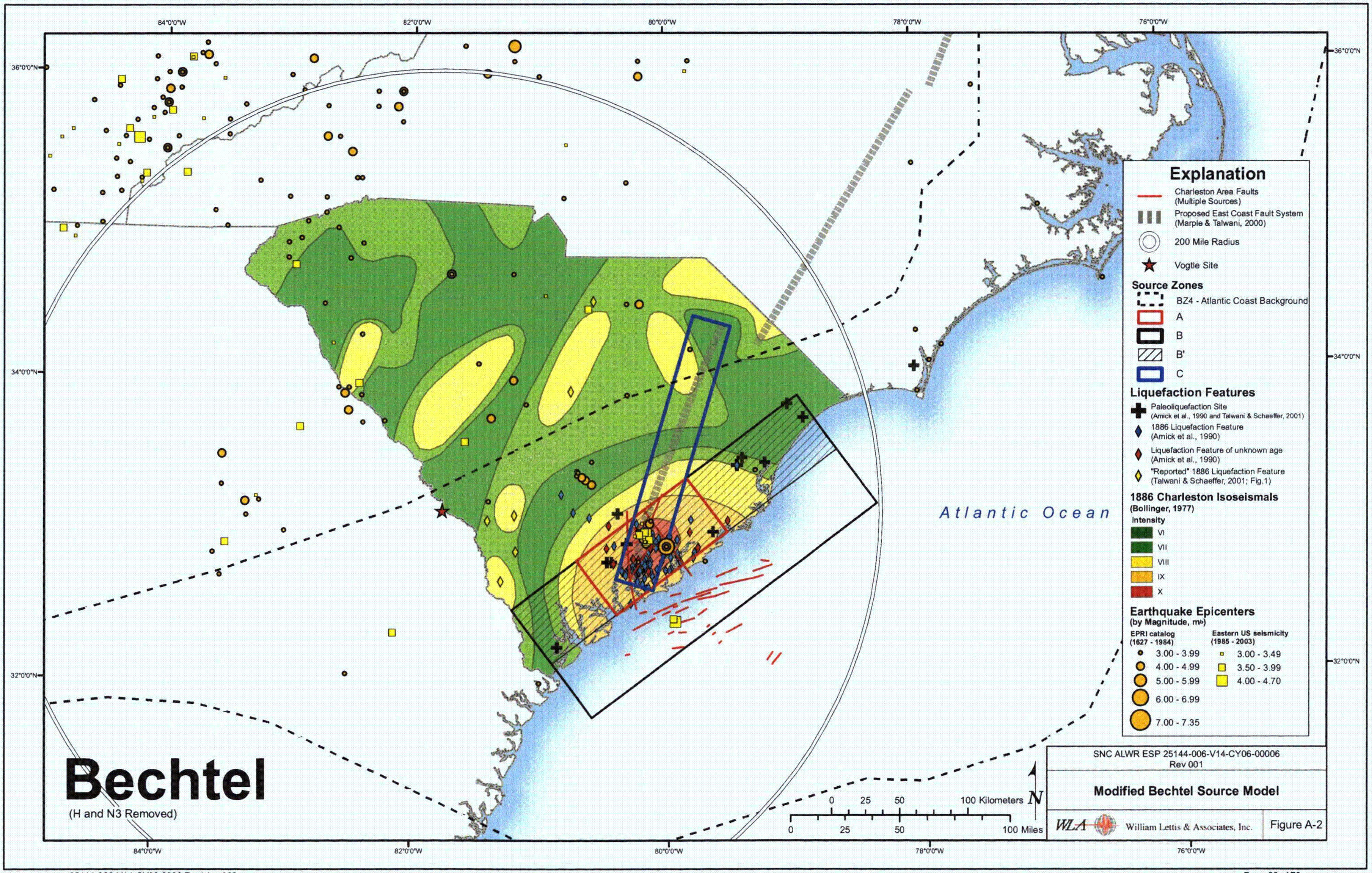
Table A-1f. Summary of Woodward-Clyde seismic sources

Source	Description	Pa	Mmax (mb) and Wts.	Smoothing Options and Wts.	Interdependencies
Sources within 200 mi (320 km) that contributed to 99% of EPRI Hazard					
30	**Charleston (includes NOTA)**	0.573	6.8 [0.33] 7.3 [0.34] 7.5 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a = -1.005, b = 0.852)	ME with 29, 29A
29	**S. Carolina Gravity Saddle (Extended)**	0.122	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	ME with 29A, 29B, and 30
29A	**SC Gravity Saddle No. 2 (Combo C3)**	0.305	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	ME with 29, 29B, and 30
29B	SC Gravity Saddle No. 3 (NW Portion)	0.183	5.4 [0.33] 6.0 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	ME with 29, 29A
B32	Vogtle Background		5.8 [0.33] 6.2 [0.34] 6.6 [0.33]		
Other Sources within 200 mi (320 km)					
31	Blue Ridge Combo	0.024	5.9 [0.33] 6.3 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	ME with 31A
31A	Blue Ridge Combination - Alternate Configuration	0.211	5.9 [0.33] 6.3 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	ME with 31

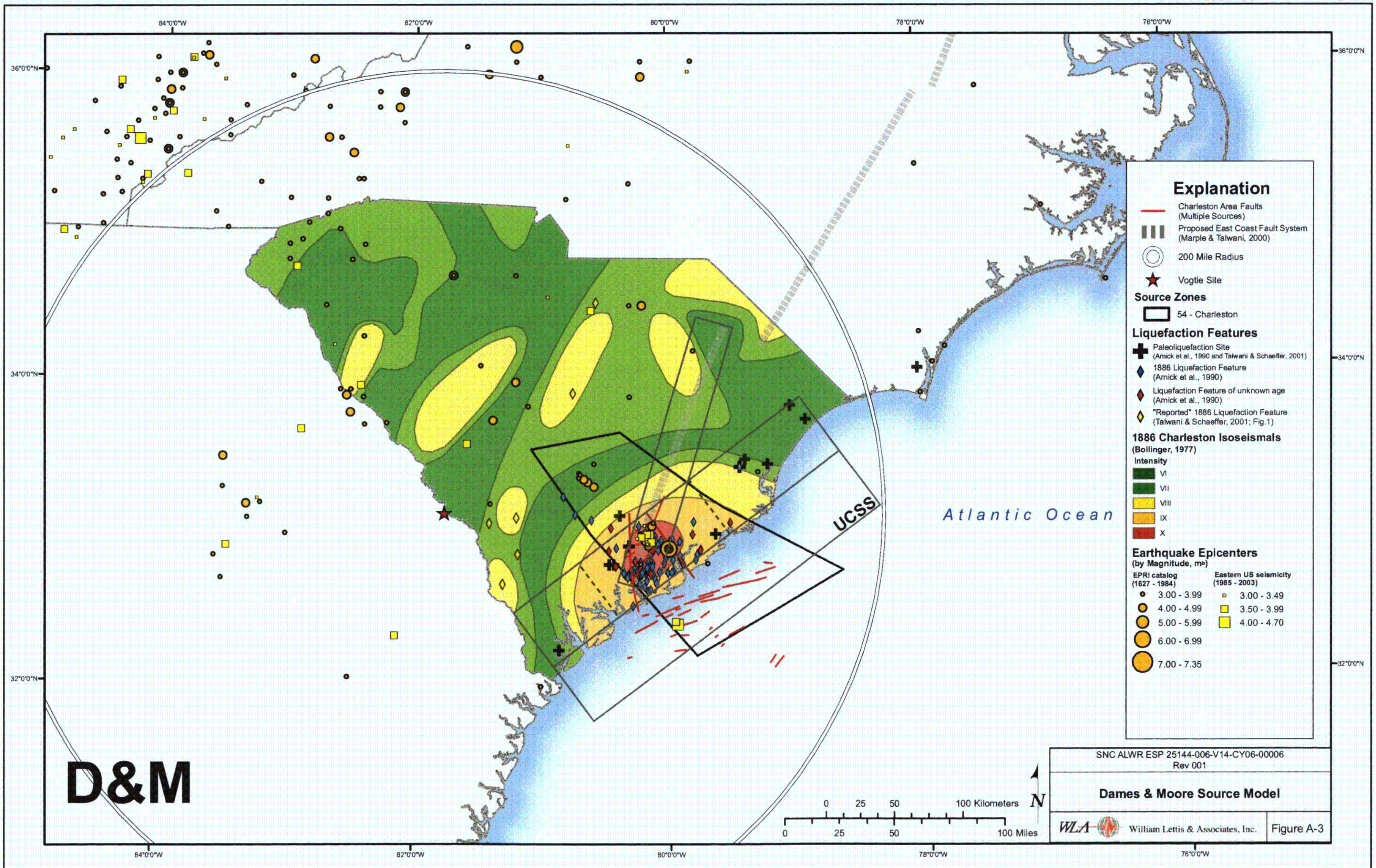
Notes: Charleston sources shown in **bold**
Probability of activity (Pa), Mmax, smoothing options, and interdependecies from EQHAZARD Primer (EPRI, 1989)



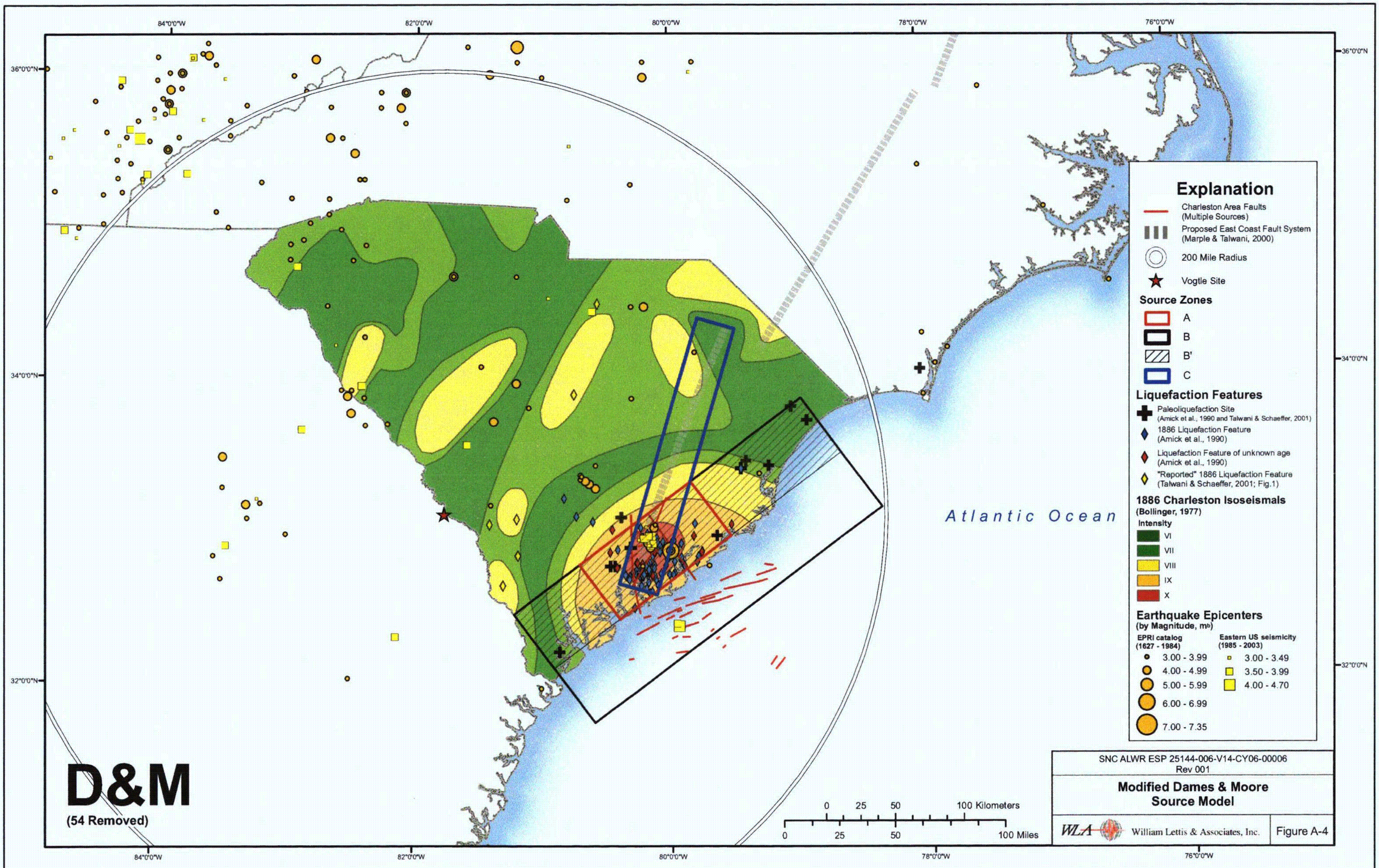
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
N3 - Charleston Faults
H - Charleston, SC
BZ4 - Atlantic Coast Background
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Atlantic Ocean
UCSS
Bechtel
0 25 50 100 Kilometers
0 25 50 100 Miles
N
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Bechtel Source Model
William Lettis & Associates, Inc.
Figure A-1

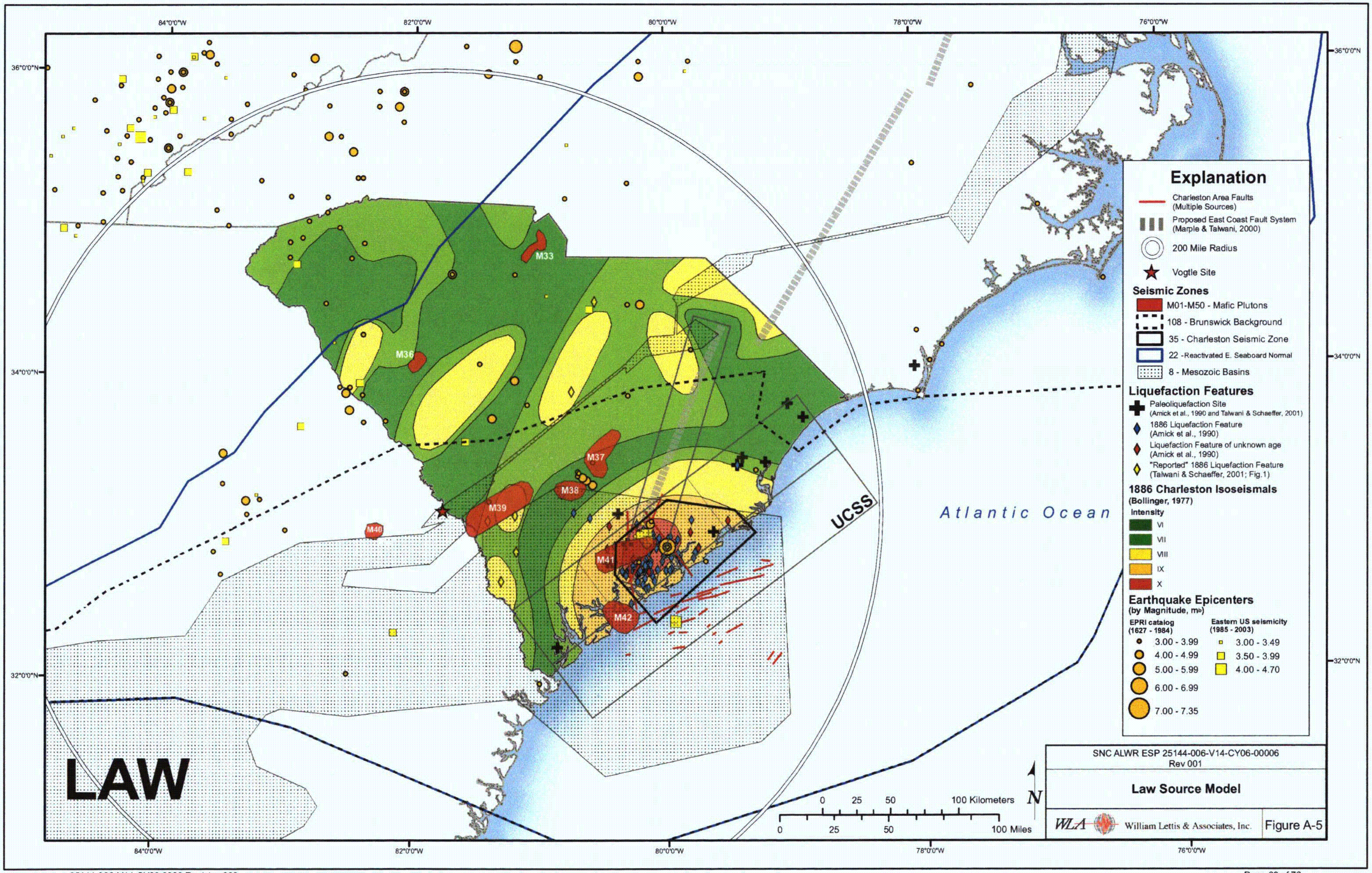


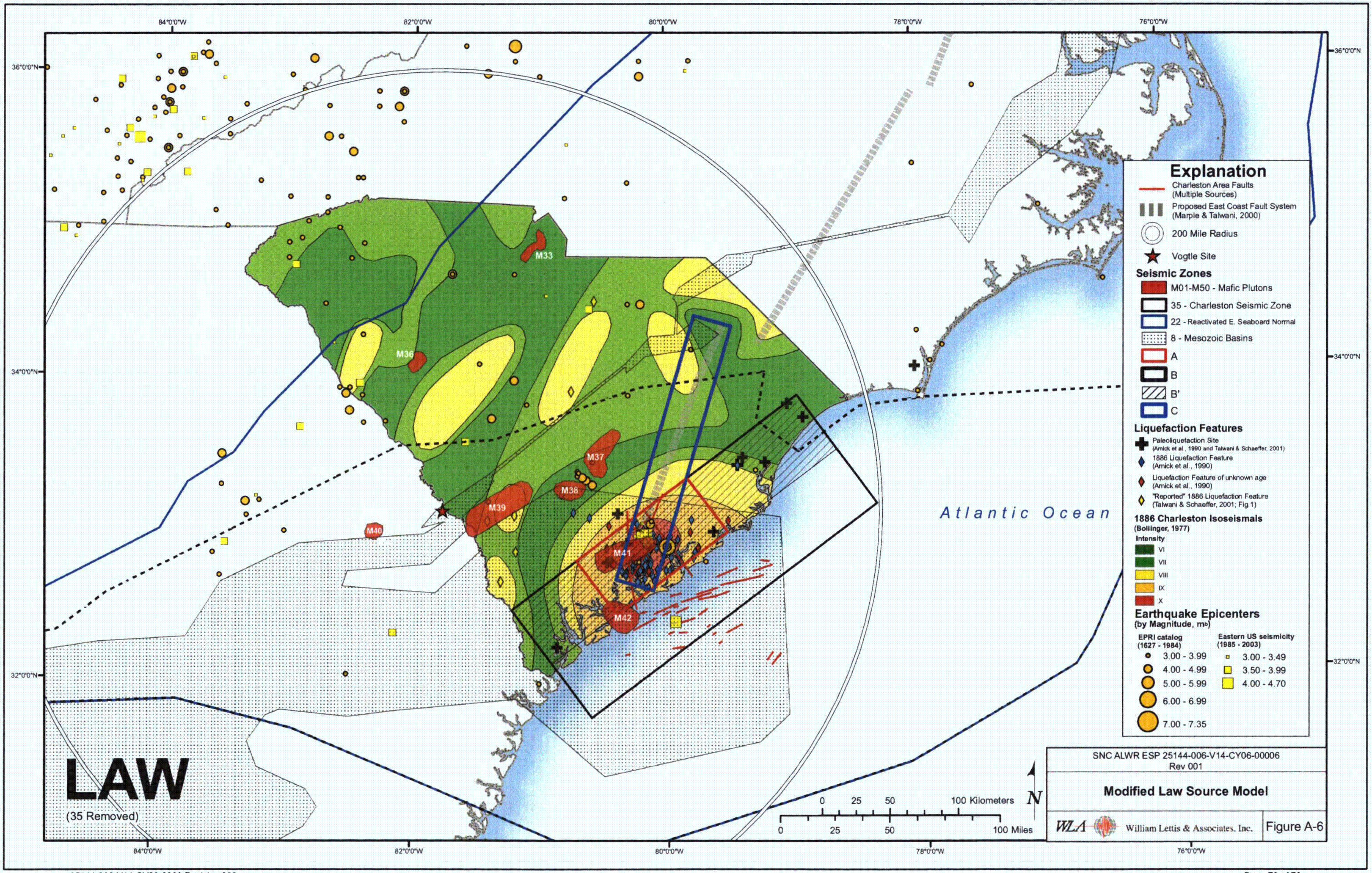
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
BZ4 - Atlantic Coast Background
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
Bechtel
(H and N3 Removed)
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Bechtel Source Model
WLA William Lettis & Associates, Inc.
Figure A-2



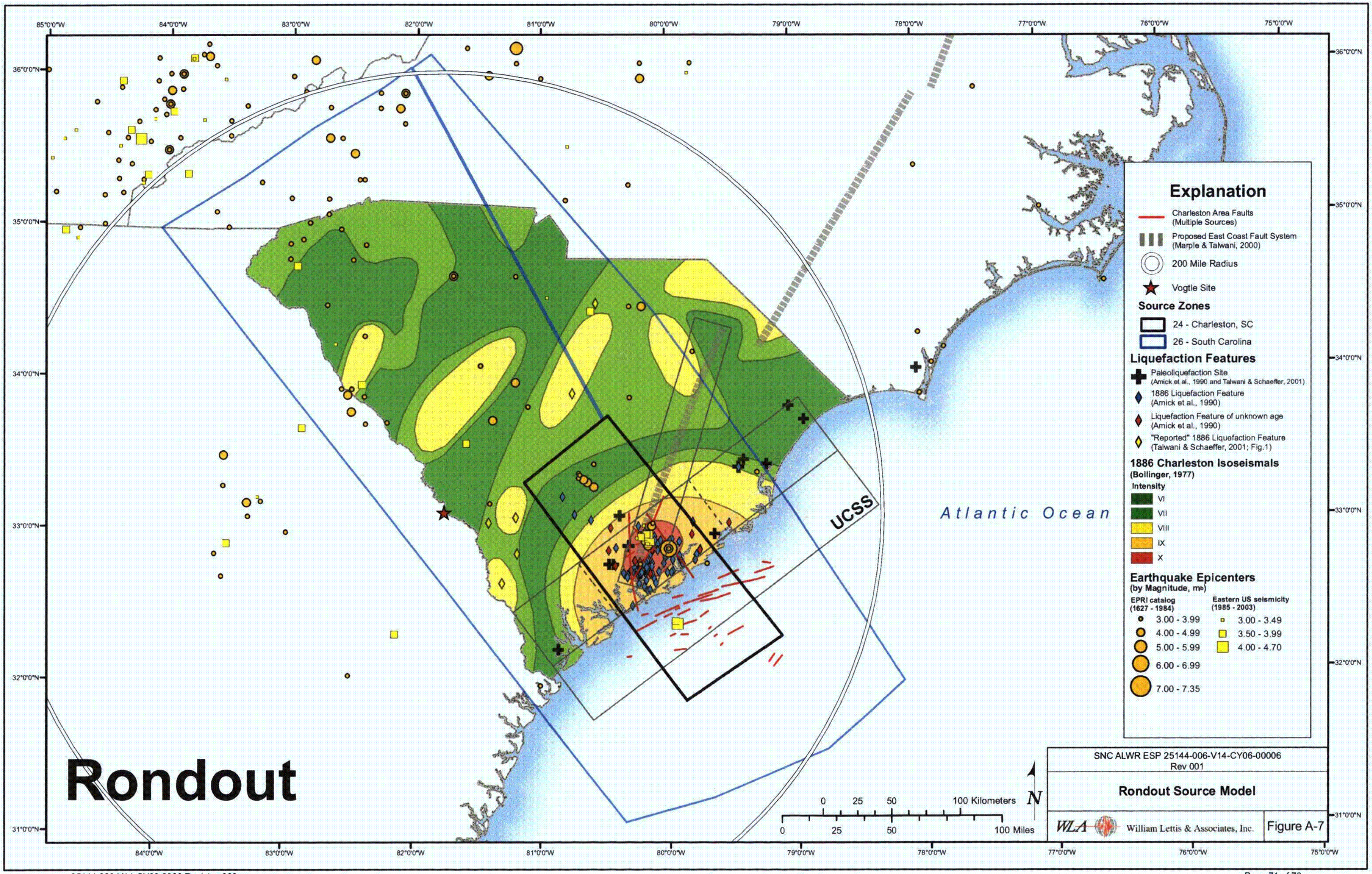
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
54 - Charleston
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Atlantic Ocean
UCSS
D&M
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Dames & Moore Source Model
William Lettis & Associates, Inc.
Figure A-3


84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
D&M
(54 Removed)
0 25 50 100 Kilometers
0 25 50 100 Miles
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Dames & Moore Source Model
WLA William Lettis & Associates, Inc.
Figure A-4

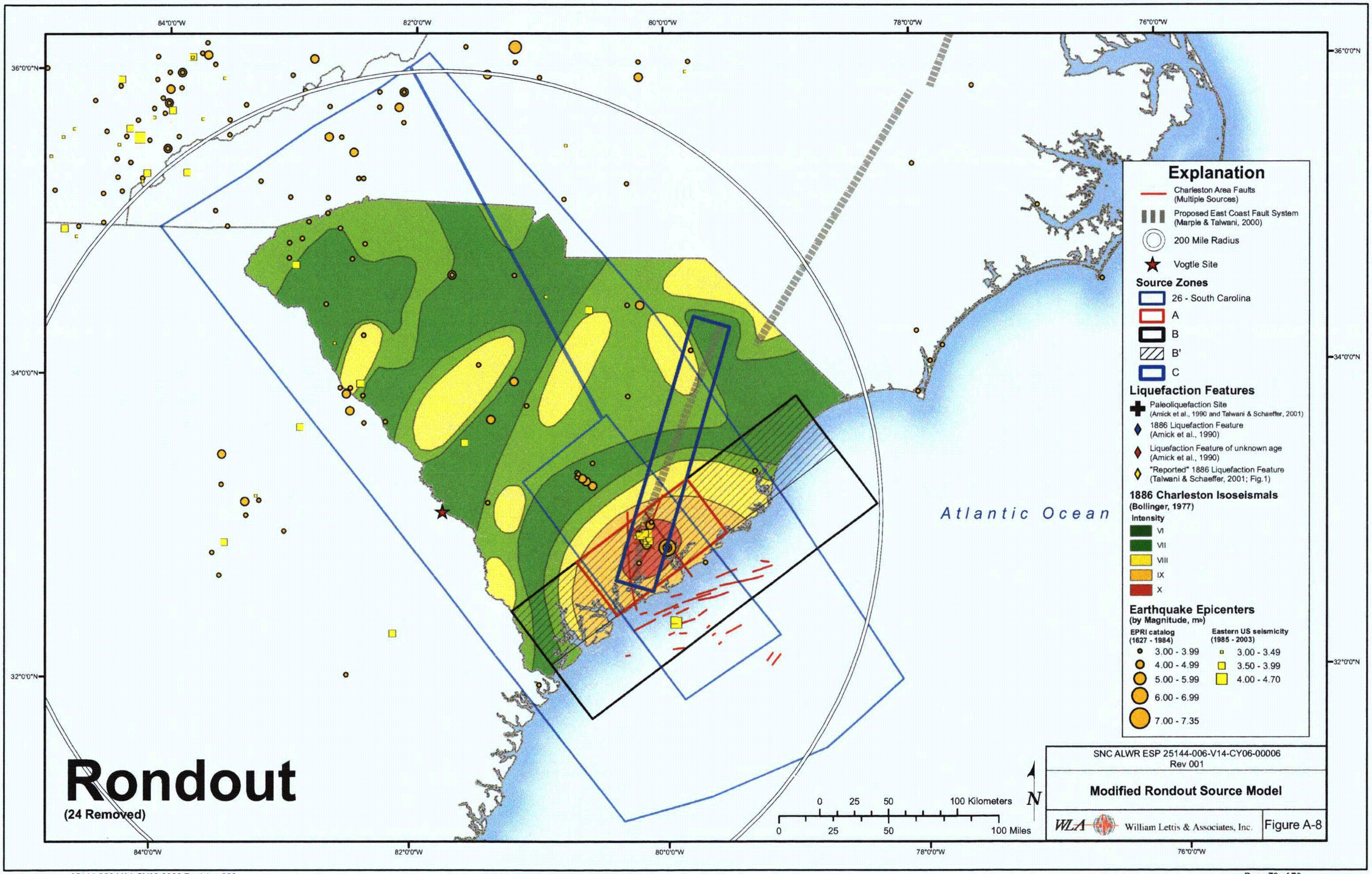

84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
M33
M36
M37
M38
M39
M40
M41
M42
UCSS
Atlantic Ocean
LAW
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Seismic Zones
M01-M50 - Mafic Plutons
108 - Brunswick Background
35 - Charleston Seismic Zone
22 - Reactivated E. Seaboard Normal
8 - Mesozoic Basins
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Law Source Model
WLA William Lettis & Associates, Inc.
Figure A-5

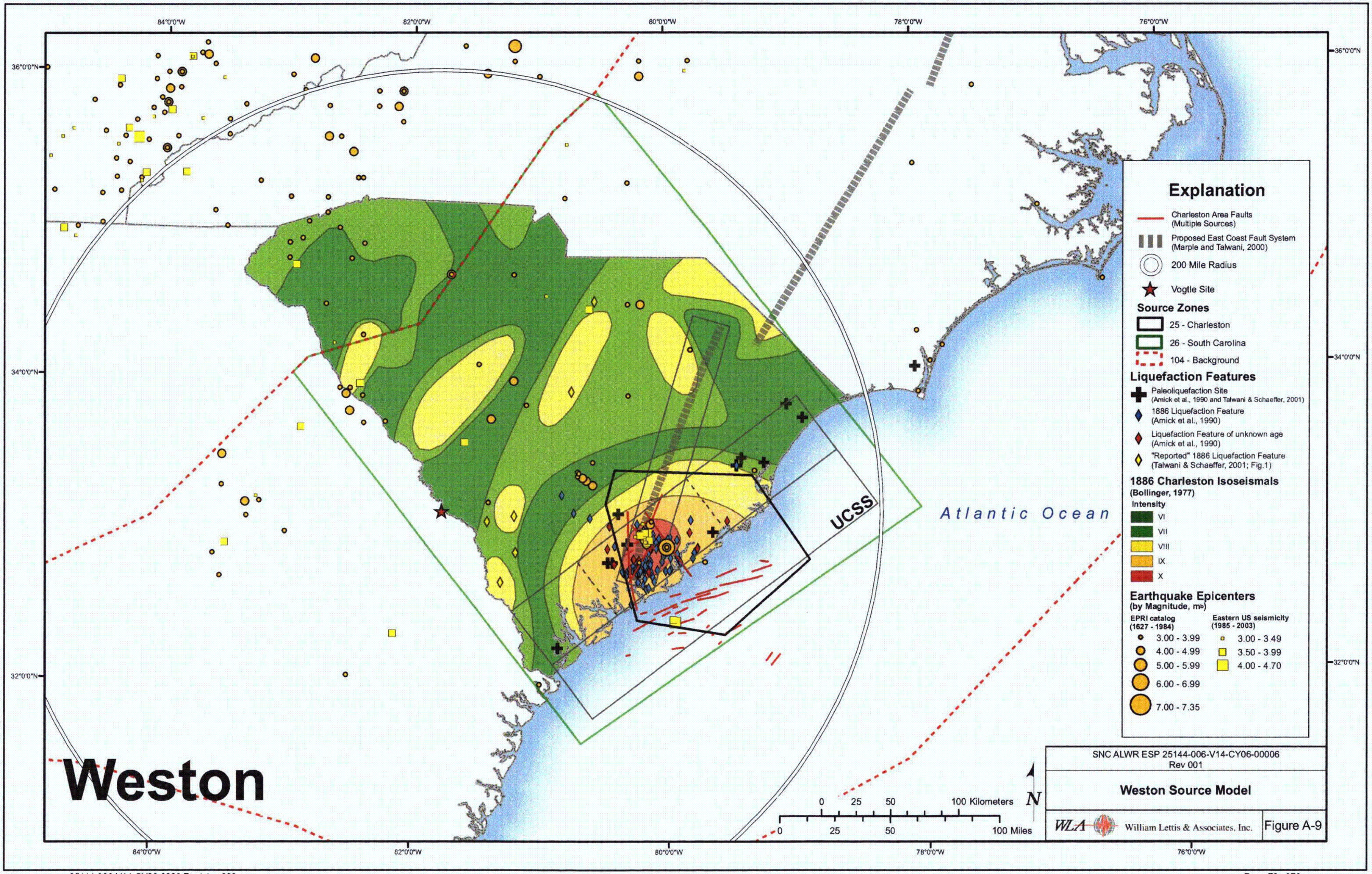


Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Seismic Zones
M01-M50 - Mafic Plutons
35 - Charleston Seismic Zone
22 - Reactivated E. Seaboard Normal
8 - Mesozoic Basins
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Atlantic Ocean
M33
M36
M37
M38
M39
M40
M41
M42
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
LAW
(35 Removed)
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Law Source Model
WLA William Lettis & Associates, Inc.
Figure A-6

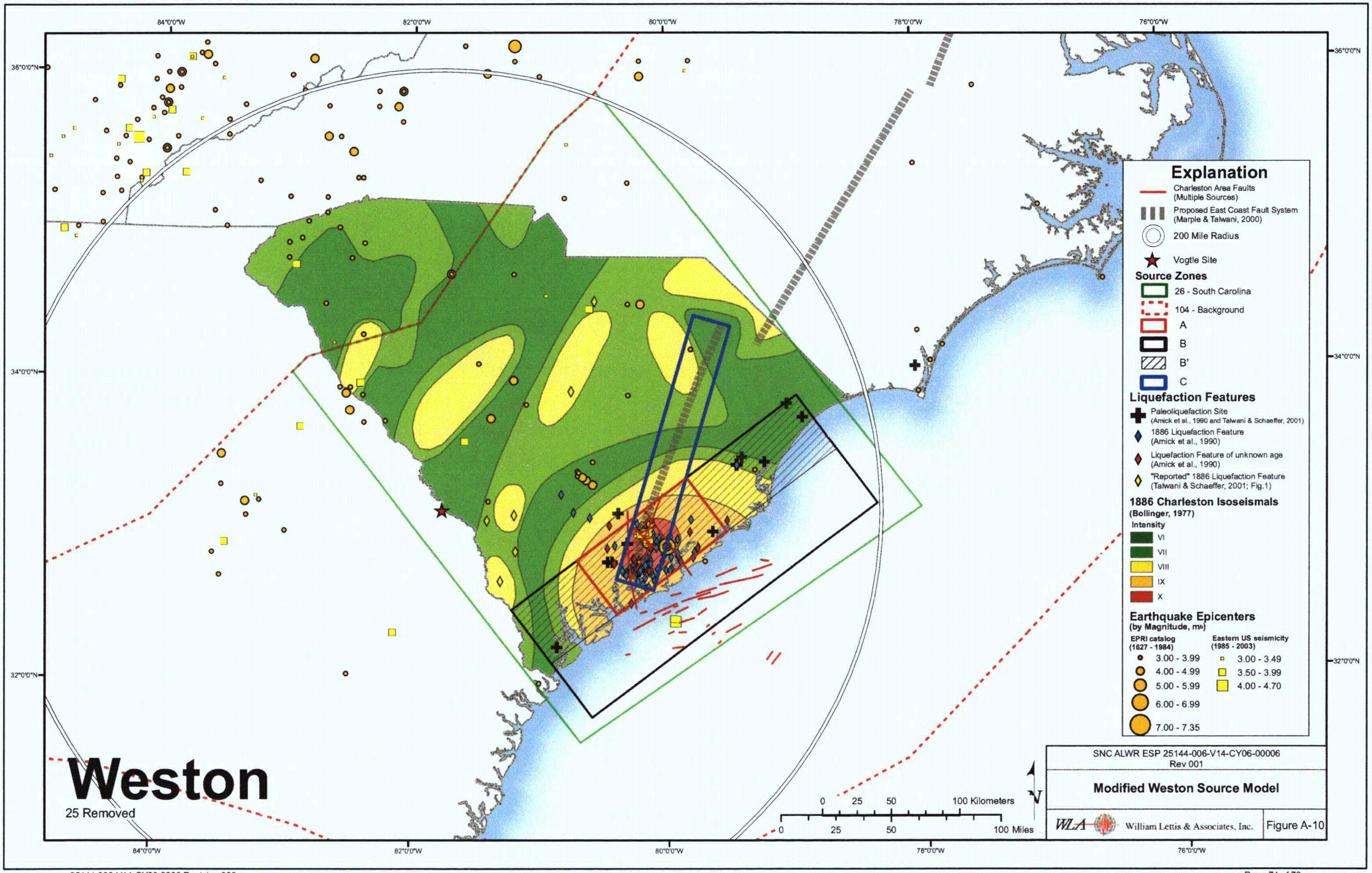


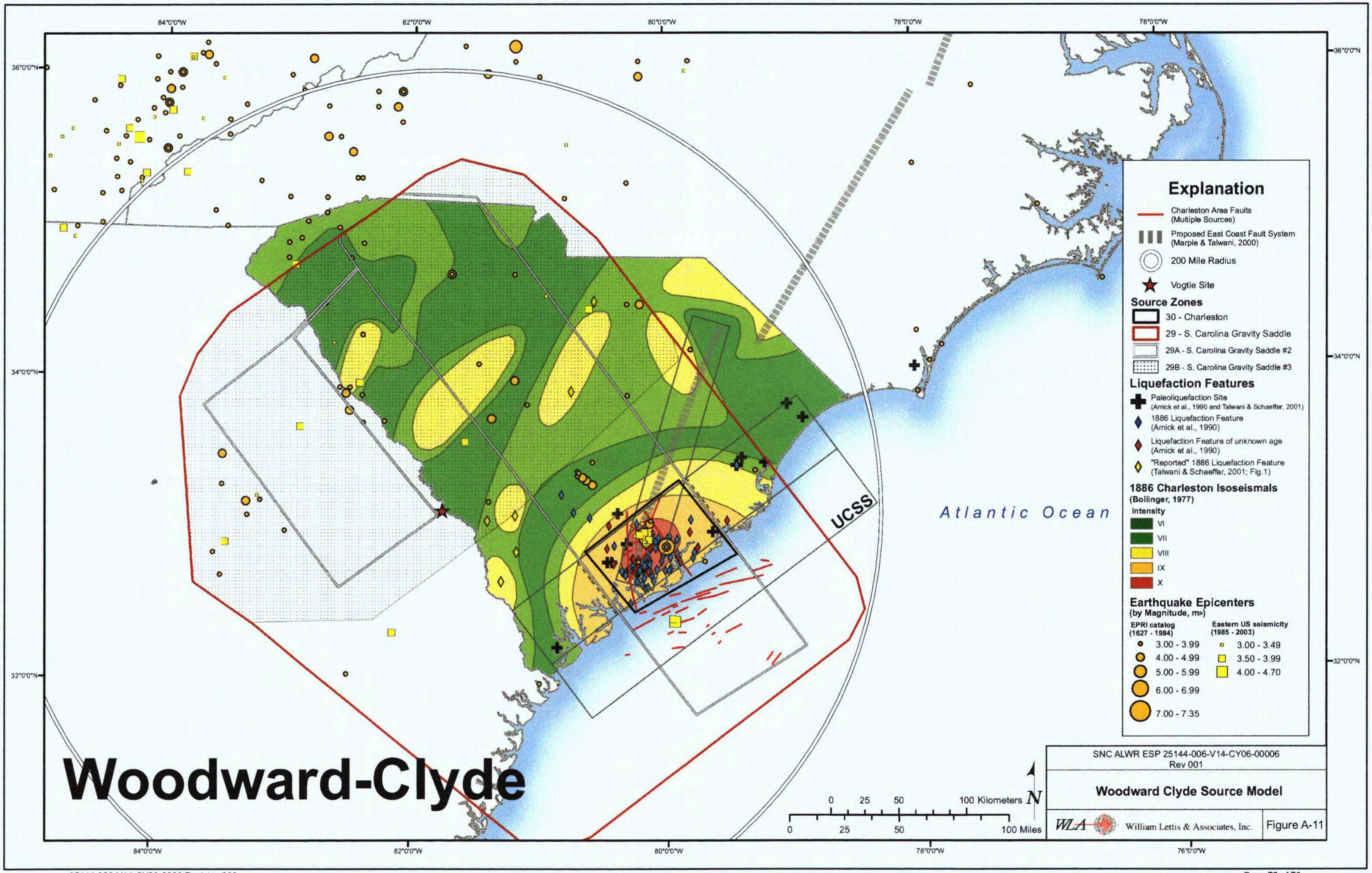
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
24 - Charleston, SC
26 - South Carolina
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Atlantic Ocean
UCSS
Rondout
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Rondout Source Model
WLA William Lettis & Associates, Inc.
Figure A-7

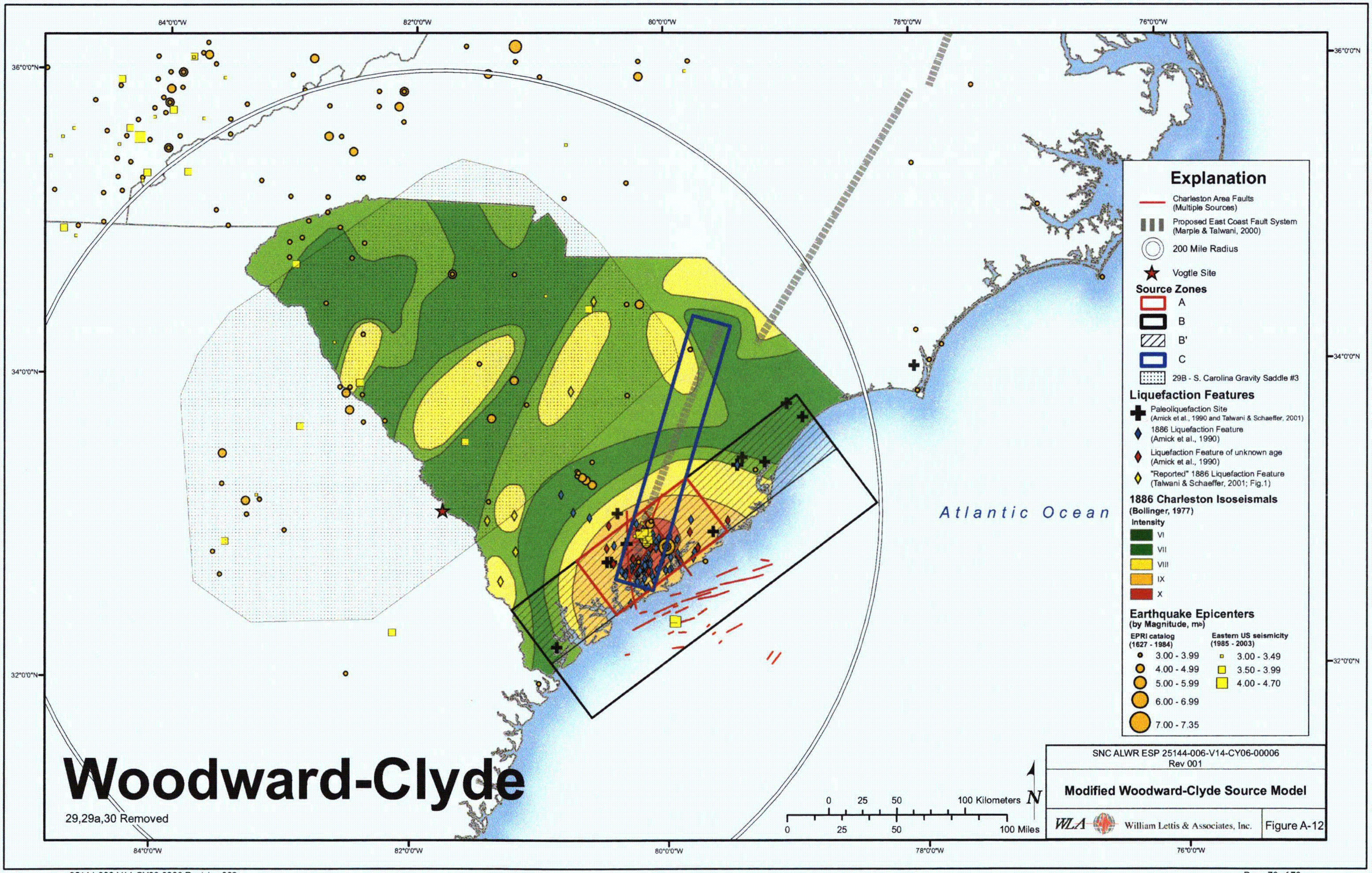

Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
26 - South Carolina
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Atlantic Ocean
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Rondout
(24 Removed)
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Rondout Source Model
WLA William Lettis & Associates, Inc.
Figure A-8



84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
UCSS
Atlantic Ocean
Weston
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple and Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
25 - Charleston
26 - South Carolina
104 - Background
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Weston Source Model
WLA William Lettis & Associates, Inc.
Figure A-9


Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
26 - South Carolina
104 - Background
A
B
B'
C
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Weston
25 Removed
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Weston Source Model
WLA William Lettis & Associates, Inc.
Figure A-10


84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
UCSS
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
30 - Charleston
29 - S. Carolina Gravity Saddle
29A - S. Carolina Gravity Saddle #2
29B - S. Carolina Gravity Saddle #3
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
0 25 50 100 Kilometers
0 25 50 100 Miles
N
Woodward-Clyde
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Woodward Clyde Source Model
WLA William Lettis & Associates, Inc.
Figure A-11



84°0'0"W
82°0'0"W
80°0'0"W
78°0'0"W
76°0'0"W
36°0'0"N
34°0'0"N
32°0'0"N
Atlantic Ocean
Explanation
Charleston Area Faults (Multiple Sources)
Proposed East Coast Fault System (Marple & Talwani, 2000)
200 Mile Radius
Vogtle Site
Source Zones
A
B
B'
C
29B - S. Carolina Gravity Saddle #3
Liquefaction Features
Paleoliquefaction Site (Amick et al., 1990 and Talwani & Schaeffer, 2001)
1886 Liquefaction Feature (Amick et al., 1990)
Liquefaction Feature of unknown age (Amick et al., 1990)
"Reported" 1886 Liquefaction Feature (Talwani & Schaeffer, 2001; Fig.1)
1886 Charleston Isoseismals (Bollinger, 1977)
Intensity
VI
VII
VIII
IX
X
Earthquake Epicenters (by Magnitude, mb)
EPRI catalog (1627 - 1984)
3.00 - 3.99
4.00 - 4.99
5.00 - 5.99
6.00 - 6.99
7.00 - 7.35
Eastern US seismicity (1985 - 2003)
3.00 - 3.49
3.50 - 3.99
4.00 - 4.70
Woodward-Clyde
29,29a,30 Removed
0 25 50 100 Kilometers
0 25 50 100 Miles
N
SNC ALWR ESP 25144-006-V14-CY06-00006
Rev 001
Modified Woodward-Clyde Source Model
WLA William Lettis & Associates, Inc.
Figure A-12

Southern Nuclear Operating Company

AR-07-0004

Enclosure 3

Electronic Files (CD)

For

RAIs # 2.5.2-1 and # 2.5.2-3

NOTE: Enclosed CD contains the following files:

For RAI # 2.5.2-1:	(1)	EPRI_CAT_VOGTLE.DAT
	(2)	UPDATE_CAT_VOGTLE.DAT
	(3)	BEC_geom.dat
		DAM_geom.dat
		LAW_geom.dat
		RND_geom.dat
		WCC_geom.dat
		WGC_geom.dat
	(4&5)	Vogtle_rock_hazard.txt
For RAI # 2.5.2-3:		Vogtle_soil_hazard.txt