PMVictoriaESPPEm Resource

From: Eudy, Michael
Sent: Monday, February 06, 2012 11:55 AM
To: Stieve, Alice
Cc: VictoriaESP Resource
Subject: FW: Exelon Letter to NRC, NP-12-001, Response to NRC RAI Letter No. 14
Attachments: NP-12-0001, Response to Request for Additional Information Letter No. 14.pdf

Importance: High

Courtesy copy

From: david.distel@exeloncorp.com [mailto:david.distel@exeloncorp.com]
Sent: Monday, February 06, 2012 11:49 AM
To: Eudy, Michael
Subject: Exelon Letter to NRC, NP-12-001, Response to NRC RAI Letter No. 14

Mike – Attached is a courtesy copy of Exelon letter to the NRC, NP-12-0001, dated February 6, 2012, providing response to RAI 02.05.01-22. This letter is being submitted via EIE today.

Thanks.

Dave Distel

David J. Distel
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U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
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Subject: Exelon Nuclear Texas Holdings, LLC
Victoria County Station Early Site Permit Application
Response to Request for Additional Information Letter No. 14
NRC Docket No. 52-042

Attached is the response to the NRC staff question included in Request for Additional Information (RAI) Letter No. 14, dated December 13, 2011, related to Early Site Permit Application (ESPA), Part 2, Section 02.05.01. NRC RAI Letter No. 14 contained one (1) Question. This submittal comprises the complete response to RAI Letter No. 14, and includes response to the following Question:

02.05.01-22

No new regulatory commitments are contained in this submittal.

If any additional information is needed, please contact David J. Distel at (610) 765-5517.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 6th day of February, 2012.

Respectfully,

Marilyn C Kray

Marilyn C. Kray
Vice President, Nuclear Project Development

Attachments:
1. Question 02.05.01-22

cc: USNRC, Director, Office of New Reactors/NRLPO (w/Attachments)
USNRC, Project Manager, VCS, Division of New Reactor Licensing (w/Attachments)
USNRC Region IV, Regional Administrator (w/Attachments)

RAI 02.05.01-22:

Question:

The USGS reported the Texas October 20, 2011 earthquake as a shallow (3 km, poorly constrained), Mw 4.8 earthquake with moment tensor solution of normal fault movement oriented northeast. The staff notes that both this earthquake and the November 12, 2011 Mw 3.3 event are located ~65 miles west of VCS, possibly near the surface expression of the Luling and Balcones fault zones. In order for staff to evaluate regional tectonic features within the 200 mile radius of VCS in its review of the VCS application and in support of 10 CFR 100.23, please provide the following:

Provide a discussion that examines the Texas earthquakes (October 20 and November 12, 2011) and implications for a VCS regional tectonic feature that might be considered a capable fault that originates within the Ouachita basement rock, beneath the Gulf Coast Coastal Plain sedimentary section. Include in your discussion the alternative possibilities that the Texas earthquake is induced or that it is a small seismic event on an active growth fault. Additionally, consider and discuss the possibility of an error in the location of the earthquake and the implications that a location error could have on all the above and related event fault and source interpretations.

Response:

The above RAI raises three questions regarding the October 20 Mw 4.8 and November 12 Mw 3.3 events. Each of these questions is addressed in the following response.

Question 1: Provide a discussion that examines the Texas earthquakes (October 20 and November 12, 2011) and implications for a VCS regional tectonic feature that might be considered a capable fault that originates within the Ouachita basement rock, beneath the Gulf Coast Coastal Plain sedimentary section.

The October Mw 4.8 and November Mw 3.3 earthquakes are located near Fashing, Texas, in an area of the Coastal Plain that has experienced several small to moderate earthquakes in the past approximately 40 years (Figure 1). As explained below, researchers studying past earthquakes in this area argue this seismicity is most likely induced by human activities (Davis, et al., 1995; Pennington, et al., 1986), and all information available suggests that the 2011 events are most likely induced by human activity as well.

To address this RAI, Exelon reviewed available published (Davis, et al., 1995; Pennington, et al., 1986) and unpublished literature (Brunt 2011), reviewed maps, and interviewed researchers familiar with Texas earthquakes (e.g., Dr. C. Frohlich, University of Texas, Austin; M. Brunt, Eagle Pass Junior High School). The discussion below summarizes the regional and local geologic setting and describes the information available from the U.S. Geological Survey for the 2011 earthquakes, historical seismicity in the local region, and ongoing research in the area.

Fashing Area: Regional and Local Geologic Setting

The Mw 4.8 and 3.3 events are located along the western margin of the San Marcos arch adjacent to the Charlotte-Jourdanton fault zone (CJFS) and the Karnes fault zone (KFS) (Figures 1 and 2). As discussed in SSAR Subsection 2.5.1.1.4.3.3, the CJFS and KFS (along with the Mexia-Talco, Milano, and Mt. Enterprise-Elkhart Graben fault systems) are a part of the Mesozoic fault systems of the Gulf of Mexico region and are interpreted as being related to bodies of Jurassic salt at depth (SSAR Figures 2.5.1-11 and 2.5.1-12) (Ewing, 1991; Murray, 1961). In general, these fault systems are updip of, and sole into, salt pinchouts or welds, and motion on the faults is related to salt migration that formed the welds and pinchouts (Diegel, et al., 1995; Nelson, 1991).

Together the basin-bounding CJFS, KFS, and the Mexia-Talco fault zone are considered part of the "peripheral graben zone" (Ewing, 1991) and are 30 miles or more southeast of the Luling and the Balcones fault zones (Figure 1). The CJFS and KFS consist of a series of generally northeast-trending, *en echelon*, graben-bordering normal faults (Figures 2 and 3). Stratigraphic relationships suggest that fault movement began in the Jurassic and the youngest rocks displaced by these fault zones are undifferentiated Paleocene-Eocene strata, which is faulted at the ground surface (SSAR Figure 2.5.1-42) (Ewing, 1991). Documented evidence of Quaternary surface faulting is lacking in the Fashing area, but both fault zones are located within a zone of growth faults, defined by the margin of the San Marcos arc, in the USGS Quaternary fault and fold database (SSAR Figure 2.5.1-25) (Wheeler, 1999). Both the CJFS and KFS sole into salt at or just above Paleozoic Ouachita-age basement bedrock (Ewing, 1991; Pennington, et al., 1986). Depth to Ouachita basement in the Fashing region increases dramatically to the southeast because of the plunging San Marcos Arch structure. Depths to basement contours (SSAR Figure 2.5.1-26) suggest that basement is about 4 km below the November 12, 2011, epicenter, and about 5 km below the October 20, 2011, epicenter (Salvador, 1991). Cross sections presented by Pennington et al. (1986) illustrate that basement beneath the Imogene field and Fashing field are between 4.5 and 5 km deep in this area (Figures 3 and 4).

October 20, Mw 4.8, earthquake

The October 20, Mw 4.8, and November, 12 Mw 3.3, Texas earthquakes were located approximately 70 miles west-northwest of the VCS Site near Fashing, Texas (Figure 1). The U.S. Geological Survey National Earthquake Information Center (NEIC) reports that the October 20, 2011, Mw 4.8 event was located at 28.806°N, 98.147°W—approximately one mile north-northwest of the town of Fashing, Texas, with an uncertainty of 12 miles (19.3 km) and an estimated depth of 1.9 miles (3 km) (with ± 1.9 miles [3.1 km] uncertainty; Figure 2) (USGS, 2011b). The double-couple focal mechanism for the Mw 4.8 event includes a generally northeast-oriented (053° and 241°) solution dipping either 72° south-southeast or 18° north-northwest.

November 12, Mw 3.3, Texas earthquake

The November 12, 2011, Mw 3.3 event was located at 28.86°N, 98.21°W approximately 6.4 miles northwest of the town of Fashing, Texas and approximately 5 miles northwest of the Mw 4.8 event (Figures 1 and 2) (USGS, 2011a). Because this event was relatively small, the USGS did not provide a description of the uncertainty associated with the epicenter or the depth of the Mw 3.3 event. In addition, a focal mechanism is

currently not available for this event. It is assumed that the epicentral and hypocentral (depth) uncertainty for the Mw 3.3 event is at least as large as the preceding Mw 4.8 event.

Felt Report for the October 20 Mw 4.8 earthquake

As part of Exelon's interviews with subject matter experts, Mr. Michael Brunt (Eagle Pass Junior High School) and Dr. Cliff Frohlich (University of Texas at Austin) were interviewed to learn about their ongoing research on the October 20 event. Mr. Brunt is assisting Dr. Cliff Frohlich to refine the location of the epicenter of the October 2011 earthquake, using local anecdotes and interviews. Mr. Brunt's efforts included: (1) in-person interviews and phone calls to individuals who experienced effects of the aforementioned earthquake; (2) photographic documentation of selected spots within the epicenter area (conducted on 20 to 22 November 2011); and (3) distribution of a questionnaire via local news and media organizations. The resulting information is summarized in a 3-page report (Brunt, 2011). Accompanying the report are 19 personal accounts of the shaking that accompanied the earthquake, as well as 12 photos taken by Mr. Brunt, photo descriptions, and an index map showing where the photos were taken.

From firsthand accounts, Mr. Brunt concluded that the most intense shaking—a proxy for the epicenter (e.g., the Modified Mercali Intensity Scale)—occurred within an area of approximately 6 miles west-northwest and 5 miles southwest of the reported epicenter of the USGS (Figure 2) (Brunt, 2011; USGS, 2011b). The most intense felt report was on the north side of CR 407 and 1.6 miles northeast of FM 1099, near the town of Peggy (Figure 2). Residents within this general area observed cabinet doors opening, pictures and items falling, items moving, and sheet wall damage. Mr. Brunt noted numerous new oil and gas operations within the vicinity of the most intense shaking. In contrast, closer to the location of the U.S. Geological Survey's reported epicenter, residents experienced only "light to moderate" shaking and an absence of falling objects. The most profound effects felt by residents near the reported epicenter apparently included audible noises, difficulty walking, and trouble standing during the shaking. This research is ongoing, should be considered preliminary and may change after further review by Dr. Frohlich or Mr. Brunt.

Fashing Area: Seismicity

The October and November earthquakes are located along the western margin of the San Marcos arch and the Rio Grande Embayment, historically a seismically quiescent region (see SSAR Figure 2.5.1-22). Davis et al. (1995) summarize that historically this region of the Gulf Coastal Plain of Texas "has been aseismic; prior to 1973, there were no reliable reports of earthquakes within 90 km of the Fashing area" (p. 1888). However, several small to moderate earthquakes have occurred in the area since 1973, including the: 1) m_{bLg} 3.4 Fashing earthquake in July 1983; 2) m_{bLg} 3.9 Pleasanton earthquake in March 1984; 3) m_{bLg} 3.6 Falls City earthquake in July 1991; and 4) m_{bLg} 4.3 Fashing earthquake of April 9, 1993 (Pennington et al., 1986; Davis et al., 1995). Isoseismal maps from Davis et al. (1995) are shown on Figure 5 and illustrate the location of these events in reference to the October and November 2011 earthquakes. The hypocentral depths for these events are poorly constrained, but are estimated to be shallow (~ 3 km) based on isoseismal areas and local recordings at Pleasanton (Davis, et al., 1995; Pennington, et al., 1986).

Based on earthquake epicenter locations, estimated hypocenter depths, and local geology, the November and October earthquakes likely occurred within the Gulf Coast Mesozoic sedimentary rocks and not within the older, deeper Paleozoic Ouachita-age basement (Figure 2). This conclusion is based on the following information. First, the Mw 4.8 earthquake epicenter is near the southern trace of the Karnes fault zone (KFZ) and associated graben (Figures 2 and 3). As discussed previously, the "felt report" developed by Brunt (2011) indicates (qualitatively) a maximum shaking intensity located near the 1993 Fashing, Texas (Mw 4.3) earthquake epicenter, and reduces the radius of uncertainty of the October 20, 2011 earthquake to about a 3 to 6 mile radius (Brunt, 2011; Frohlich, 2011). The Mw 3.3 epicenter is northeast of the Mw 4.8 epicenter, and is spatially associated with *en echelon* step-over half grabens within the Charlotte-Jourdanton fault zone (CJFZ, Figures 2 and 3). Although there is a 12-km-radius of uncertainty in the epicentral location given by the USGS, these two earthquake events are spatially associated with both the CJFZ step over and the KFZ.

The depth of the November 12, 2011, earthquake is likely shallow (about 5 km or less), based on reported depths from the USGS (2011a) and past seismicity in the region. As discussed previously, the hypocentral depths for the 1983, 1984, 1991, and 1993 events are poorly constrained, but also are estimated to be shallow (~ 3 km) based on isoseismal areas and local recordings at Pleasanton (Davis, et al., 1995; Pennington, et al., 1986). The depths of the Mw 4.8 and Mw 3.3 events are likely similar to these past earthquakes, which suggest that the hypocenter is within the Mesozoic Coastal Plain sedimentary rocks, rather than within the deeper, older Paleozoic basement bedrock.

Lastly, the Mw 4.8 and 3.3 earthquakes are spatially associated the CJFS and KFZ, which are interpreted to be associated with bodies of Jurassic salt at depth. These observations suggest that the CJFZ and KFZ do not extend vertically downward into basement rock but instead terminate at relatively shallow depths in the Jurassic-age salt strata (Ewing, 1991; Pennington, et al., 1986). Thus, it is unlikely that these two earthquakes originated along a capable tectonic feature that extends into the Paleozoic Ouachita-age basement bedrock. These earthquakes appear to be shallow events that occurred within the Gulf Coastal plain section and are associated with shallow growth faults that do not extend downward into older bedrock. See the discussion in response to Question #2 for further discussion.

Question 2: Include in your discussion the alternative possibilities that the Texas earthquake is induced or that it is a small seismic event on an active growth fault.

To address the above question, the section below first discusses the possible causes of induced seismicity and then explores the possibility that the October and November earthquakes were induced.

Seismicity can be induced (or caused by human-related activities) through primarily two activities: 1) construction of large reservoirs or 2) fluid extraction or injection. The October and November earthquakes are not located near a large surface-water reservoir. The closest such reservoir is more than 20 miles southwest (Figure 3). Thus, these earthquakes were most likely not related to a surface-water reservoir.

Small earthquakes (magnitude less than about 5) can be induced by fluid (gas, oil, or water) extraction (Frohlich and Davis, 2002; Segall, 1989; Yerkes and Castle, 1976) or

fluid injection (Majer and Peterson, 2007; Seeber, et al., 2004). There are almost no cases of human actions causing large earthquakes (>Mw 5.0) (Frohlich and Davis, 2002; Hanson, et al., 1999). The mechanism for induced seismicity resulting from fluid injection is the reduction in effective stress (from increased pore pressures) and subsequent weakening of faults (Majer and Peterson, 2007). The most notable example of seismicity induced by fluid injection is the seismicity associated with waste fluid injection at the Rocky Mountain Arsenal near Denver, Colorado, in the mid 1960s. About 35 earthquakes greater than mb 3, and 3 earthquakes greater than mb 5, occurred over a 5-year period (Gibbs, 1973). Only one example of injection-induced seismicity in Texas has been identified: the earthquake sequence associated with the Cogdell oil field of west Texas (Davis, et al., 1989). These earthquakes occurred in the Midland basin, in an area of fluid injection associated with secondary oil recovery (waterflooding). From 1974 to 1982, a total of 17 earthquakes greater than mb 2 occurred, including a mb 4.3 earthquake in 1978. This earthquake induced minor damage, and the maximum modified Mercalli intensities (MMI) defined was reported as V (Frohlich and Davis, 2002). It is important to note that the injection rates at Cogdell are an order of magnitude greater than the rates injected at Rocky Mountain Arsenal, yet the induced rate of seismicity and the size of events were considerably smaller.

As mentioned above, there are documented examples of injection-induced seismicity. Davis et al. (1989) find that modeling suggests that reported injection pressures in oil and gas fields under water injection in Texas should cause fault slip. However, only one field (Cogdell) was known to have seismic activity. Davis et al. (1989) interpret this discrepancy by hypothesizing that the stress induced by fluid injections probably is relieved by incremental strain at low rates (i.e., aseismic creep).

The mechanism for induced seismicity due to fluid extraction is not completely known because the removal of fluid decreases pore pressures and increases effective stresses—a change that is generally expected to stabilize faults by restraining slip (Segall, 1989). However, it is expected that poro-elastic changes in the in situ stress state are the causal mechanism for induced seismicity from fluid extraction (Pennington, et al., 1986; Segall, 1989; Van Eijs, et al., 2006). The most notable location of seismicity induced by gas or oil extraction is the Lacq gas field in France, which experienced 44 earthquakes with MMI > III and 4 events with MMI > IV over a 20-year period (Grasso and Wittlinger, 1990; Maury, et al., 1992).

Some earthquakes in south-central Texas have been attributed to local gas and/or oil extraction. Frohlich and Davis (2002) estimate that of the 130 earthquakes felt in Texas over the last 150 years, only 22 were induced by gas or oil production. Additionally, there has been significant gas and oil production, and associated activities within the state of Texas over the past century, yet the seismicity rate remains relatively low (Luminant, 2011).

The largest earthquake possibly induced by fluid extraction in southern Texas was the 1993 m_{bLg} 4.3 event, with isoseismal contours near the Fashing oil and gas field in western Atascosa County (Figures 2, 3 and 5). The 1993 earthquake produced Mercalli intensities (MMI) as high as VI producing significant damage at the Warren Petroleum plant, including cracking of reinforced concrete foundation blocks, failure of a pipe connection, damage to steel bolts, and horizontal movement on the order of an inch (Davis, et al., 1995). The Fashing field is approximately 10 miles long and 2 miles wide and is shown on Figure 2 along with active oil and gas wells. Discovered in 1956, the

structural trap at the Fashing gas field is formed by a simple northeast-trending northwest-side down 40° to 60° northwest-dipping normal fault, which offsets porous limestone in the footwall of the fault at approximately 3 km depth (Figure 5). The Fashing gas field occurs within the Edwards Limestone Formation (Lower Cretaceous), at depths just over 10,500 feet (~3.2 km) (Keahey, 1968; Pennington, et al., 1986).

Davis et al. (1995) investigated the 1993 m_{bLg} 4.3 earthquake with respect to the potential that the earthquake was induced by fluid withdrawal. They observed that no earthquakes were documented in the area prior to establishment of the gas production field; however, earthquakes were documented following the establishment of the gas production field. Earthquake epicenters were located near the production fields or field fault-boundaries, and event hypocenters were located near the production field depths. Further, earthquake occurrence correlates with periods of fluid withdrawal but not with periods of fluid injection. Lastly, Davis et al. (1995) report that initial pressures in the field were close to hydrostatic but have declined significantly (by 80%) since production began in 1956.

Davis et al. (1995) developed nine questions to assess if earthquakes were possibly induced by fluid injection or withdrawal. These questions (and their answers) are listed in Table 1 below. Davis et al. (1995) summarized that "While there is no set number of yes answers that prove conclusively that an earthquake is induced, we suggest that when one can answer yes to seven or more of the nine questions, the evidence is strong that the earthquakes are related to withdrawal" (p. 1891). They found that the 1993 Fashing m_{bLg} 4.3 and 1984 Pleasanton m_{bLg} 3.9 earthquakes satisfied 7 of the 9 criteria listed in Table 1. Using these criteria, they concluded that the available data strongly supported the hypothesis that the 1984 and 1993 earthquakes were induced by fluid withdrawal, but that it is a difficult mechanism to prove directly.

Table 1. Criteria to Determine if Earthquakes Were Induced by Fluid Withdrawal*

Questions	Fashing 1993 m_{bLg} 4.3	Pleasanton 1984 m_{bLg} 3.9	Falls City 1991 m_{bLg} 3.6	Oct. 2011 M_w4.8	Nov. 2011 M_w3.3
1. Timing					
(1a) Are these events the first known earthquakes of this character in the region?	Yes?	Yes?	Yes?	Yes?	Yes?
(1b) Did the events only begin after fluid withdrawal had commenced?	Yes	Yes	Yes	Yes	Yes
(1c) Is there a clear correlation between withdrawal and seismicity?	No	No	No	No	No
2. Location					
(2a) Are epicenters within 5 km of wells?	Yes	Yes	Yes	Yes	Yes
(2b) Do some earthquakes occur at or near production depths?	Yes?	Yes	?	Yes?	?
(2c) Do epicenters appear spatially related to the production region?	?	?	?	Yes?	Yes?
3. Fluid pressures, etc.					
(3a) Did production cause a significant change in fluid pressures?	Yes	Yes	Yes?	Yes?	Yes?
(3b) Did seismicity begin only after the fluid pressures had dropped significantly?	Yes	Yes	Yes?	Yes?	Yes?
(3c) Is the observed seismicity explainable in terms of current models relating withdrawal to fault activity? (Pennington, et al., 1986)	Yes	Yes	Yes?	Yes	Yes
Total Yes answers	7	7	(6)	8	7

*modified from Table 2 of Davis et al. (1995)
**Question marks indicate uncertain answers or conflicting information.
Parentheses for "total yes answers" indicate four or more of the answers are uncertain.

Using the criteria developed by Davis et al. (1995) listed in Table 1, the following discussion reviews the hypothesis that the two 2011 earthquakes may have been induced by human activity. Each question posed in Table 1 is listed below in italics and followed by the answer and discussion.

Question 1(a): Are these events the first known earthquakes of this character in the region?

Tentative "Yes" for both the October and November events. Davis et al. (1995) summarize "that prior to 1973, there were no reliable reports of earthquakes within 90 km of the Fashing area" (p. 1888). The previous 1984, 1991, and 1993 events are thought to be induced events and therefore, do not represent naturally occurring seismicity in the area. Exelon follows Davis et al. (1995) and assigns a tentative yes (?) based on seismicity at greater distances (>20 km; see SSAR Figure 2.5.1-22).

1(b): Did the events only begin after fluid withdrawal had commenced?

"Yes" for both the October and November events. Fluid withdrawal began in the Fashing gas field in 1956 (Keahey, 1968), which significantly predates the post-1973 seismicity.

1 (c): Is there a clear correlation between withdrawal and seismicity?

"No" for both the October and November events. Davis et al., (1995) found no correlation between periods of active fluid withdrawal and past seismicity. Exelon did not compile production values for the Fashing field for this response and therefore, follow Davis et al. (1995).

(2a): Are epicenters within 5 km of wells?

"Yes" for both the October and November events. Figure 2 clearly illustrates that both epicenters are located within 5 km of an active well.

(2b): Do some earthquakes occur at or near production depths?

Tentative "Yes" for the October earthquake and uncertain ("?") for the November event. Production depths at the Fashing gas field occur at approximately 3 km depth (Figure 4), which is similar to the approximately 3 km depth assigned by the USGS (2011a) and for past events based on isoseismals (e.g. 1993 event) (Davis, et al., 1995). In addition, the October 2011 event plots very closely to the KFS (shown in Figure 4) suggesting the earthquake likely occurred on this fault, very near the production area. The uncertainty associated with the depth of the November event make it difficult to provide a definitive answer on this question.

(2c): Do epicenters appear spatially related to the production region?

Tentative "Yes (?)" for both the October and November events. Davis et al. (1995) argue that the location of these events (even using felt reports) are poorly constrained, making it difficult to provide a definitive answer on this question. However, the repeated seismic activity in this area and the coincidence of the 1993 and October 2011 events with the gas fields strongly suggests there is some correlation between production and seismicity in this region.

(3a): Did production cause a significant change in fluid pressures?

Tentative "Yes" for the October and November events. Davis et al. (1995) report that initial pressures in the Fashing gas field were close to hydrostatic but have declined significantly (by 80%) since production began in 1956. Exelon was unable to investigate fluid pressures that have occurred since pressures reported by Davis et al. in the Fashing field and thus, for the responses to Question 3 (a) follow the information in Davis et al. (1995).

(3b): Did seismicity begin only after the fluid pressures had dropped significantly?

Tentative "Yes" for both the October and November events. Again, Davis et al. (1995) summarize that all of the past earthquakes (1984, 1991, and 1993) occurred "only after reservoir pressures had declined by approximately 50% or more" (p. 1893). Exelon was unable to investigate fluid pressures that have occurred in the Fashing field since the pressures reported in Davis et al. (1995) but assumes that fluid pressures have not risen, based on the limited number of injection wells in the Fashing area (Figure 2). Thus, the responses for Question 3 (b) follows Davis et al. (1995).

(3c) Is the observed seismicity explainable in terms of current models relating withdrawal to fault activity?

"Yes" for both the October and November events. Davis et al. (1995) respond "Yes" to question 3(c) for the Fashing and Pleasanton earthquakes. This assignment is based on the results of Pennington et al. (1986), which concluded that the significant fluid pressure changes in these fields were enough to induce seismicity. Exelon follows the assignment of Davis et al. (1995) for Question 3(c).

Based on the above discussion, eight of nine criteria were answered "Yes" for the October 2011 Mw 4.8 event (Table 1). Seven of the nine criteria answered "Yes" for the November 2011 Mw 3.3 earthquake. Following the arguments from Davis et al. (1995), the answers to the Questions listed in Table 1 support the hypothesis that the November and October 2011 events are related to fluid withdrawal.

Summary

The October 20, 2011, Mw 4.8 earthquake is located near the southeastern edge of the Fashing gas field, and the November 11, 2011, Mw 3.3 event is located near the northwest edge of the field (Figure 3). Given the spatial association of the Mw 4.8 October 20, 2011, event with the horizontal and vertical position (3 km depth) of the gas field, coupled with the 1993 m_{bLg} 4.3 Fashing earthquake and subsequent publications suggesting an induced earthquake mechanism (Davis, et al., 1995), it is probable that the October 20, 2011, earthquake was induced by gas field activity and likely reactivated the nearest growth fault (i.e. the KFS; see results summarized in Table 1). At the same time, it cannot be scientifically precluded that the October 20, 2011, event resulted from natural earthquake stress relief along shallow growth faults overlying the Paleozoic basement rocks (i.e., the KFS). However, the spatial coincidence with the Fashing Gas Field and the previous occurrence of withdrawal-induced seismicity in the epicentral area, based on consensus from review of the peer-reviewed literature, suggests that the most likely cause is fluid withdrawal in the subsurface (Table 1).

The November 11, 2011, event is challenging to assess, because the spatial location uncertainty is greater than the October 20, 2011, event because of its smaller magnitude and paucity of seismic network data in south central Texas (Figure 2). The earthquake also may have been induced by fluid withdrawal in the same local area, based on its relatively shallow depth and location with respect to faults bordering the gas-resource field. Although it is plausible that the November 12, 2011, earthquake occurred along a southeast dipping normal fault in the Coastal Plain section, it is probable that the earthquake did not nucleate on a fault originating within the Ouachita basement rock. Because of its spatial association with the CJFS and the KFS *en echelon* step-over

faults (Figures 1 through 3) and the Fashing gas field, this event probably also was induced by hydrocarbon extraction activities (Table 1).

Question 3: Additionally, consider and discuss the possibility of an error in the location of the earthquake and the implications that a location error could have on all the above and related event fault and source interpretations.

As discussed above, the epicenter for the November Mw 4.8 event provided by the USGS is poorly constrained with a 12 mile uncertainty (Figure 2) (USGS, 2011a, b). The Mw 3.3 event is small enough that the USGS does not provide an estimate of epicentral uncertainty. The discussion below focuses on the uncertainty associated with the Mw 4.8 event. An unpublished felt report for the November Mw 4.8 earthquake helps to constrain the location of the event and suggests it may have been located near Peggy, Texas (Brunt, 2011). This location is within the 12-mile uncertainty provided by the USGS and helps to constrain location of the epicenter. Even if the event occurred at the limits of the reported error (12 miles from the USGS epicenter), the October earthquake would not be located on a fault zone other than the CJFZ or the KFZ (Figure 2). Thus, consideration of the epicentral uncertainty for the Mw 4.8 event does not change the response provided above (i.e., addressing Questions #1 and #2).

The depth assignment for the Mw 4.8 and Mw 3.3 events are poorly constrained (Cliff Frohlich, personal communication, 2011). The 3 km depth of the Mw 4.8 earthquake provided by the USGS had a reported uncertainty of 3 km and no depth was provided for the Mw 3.3 event (Figure 2). The depth to Ouachita basement bedrock in the epicentral area is 5 to 6 km and, given the limits of the depth uncertainty, the hypocenter could have been located within basement. However, this appears to be unlikely based on the estimated hypocentral depths for past earthquakes from isoseismals (Davis, et al., 1995). Davis et al. (1995) argue that the intensity and limited extent of the strong ground shaking for the 1993 m_{bLg} 4.3 earthquake suggest the event was likely shallow (i.e., located above basement). Based on this analogy, the Mw 4.8 event likely occurred within the Mesozoic and Tertiary sedimentary section above basement rock. This interpretation is consistent with the hypothesis that the Mw 4.8 event was induced by fluid extraction and/or injection.

Associated ESPA Revisions:

None

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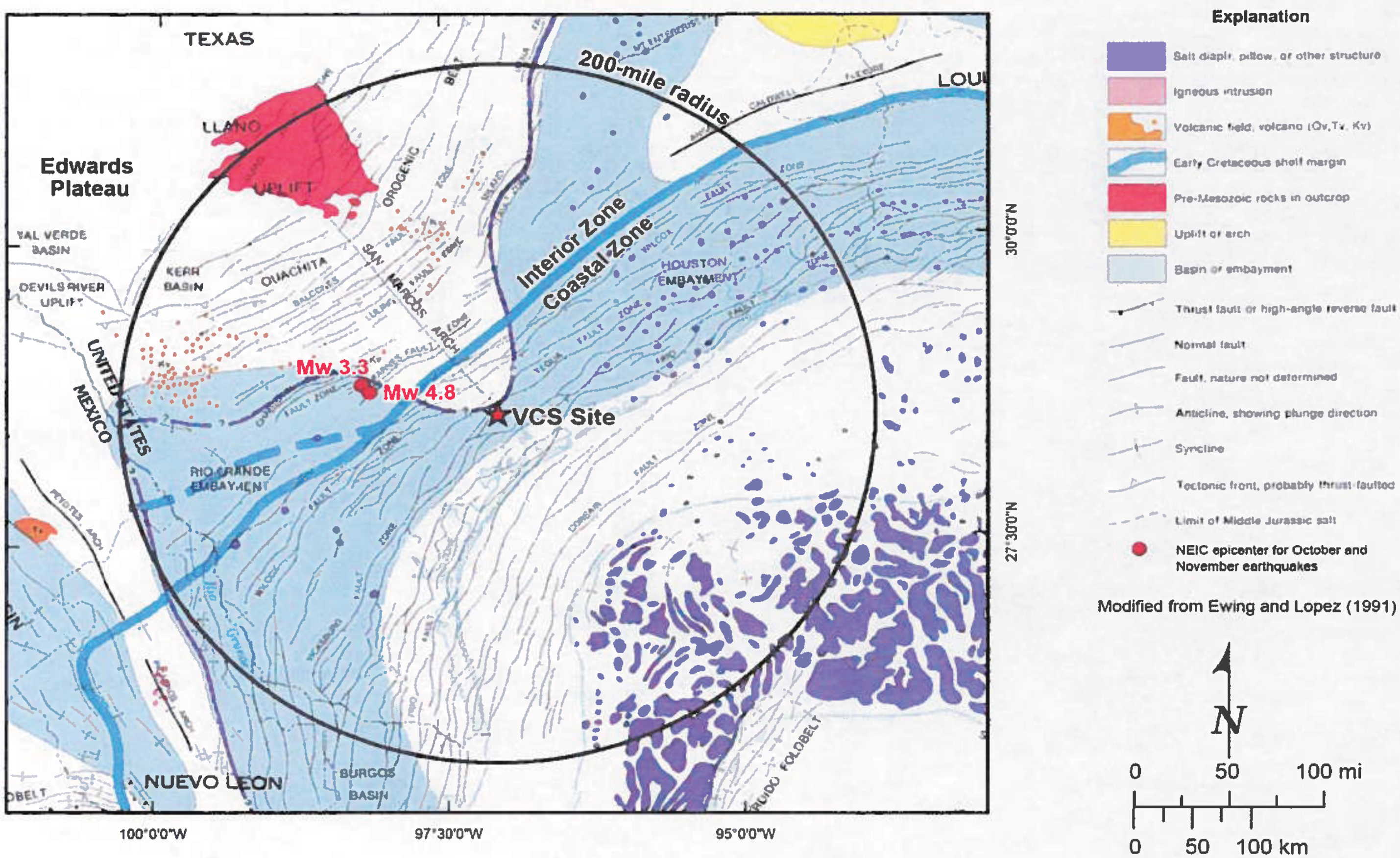


Figure 1. Geologic Features of the Gulf Coast Region with the Locations of the October 20, 2011 M_W 4.8 and November 12, 2011 Mw 3.3 Earthquakes

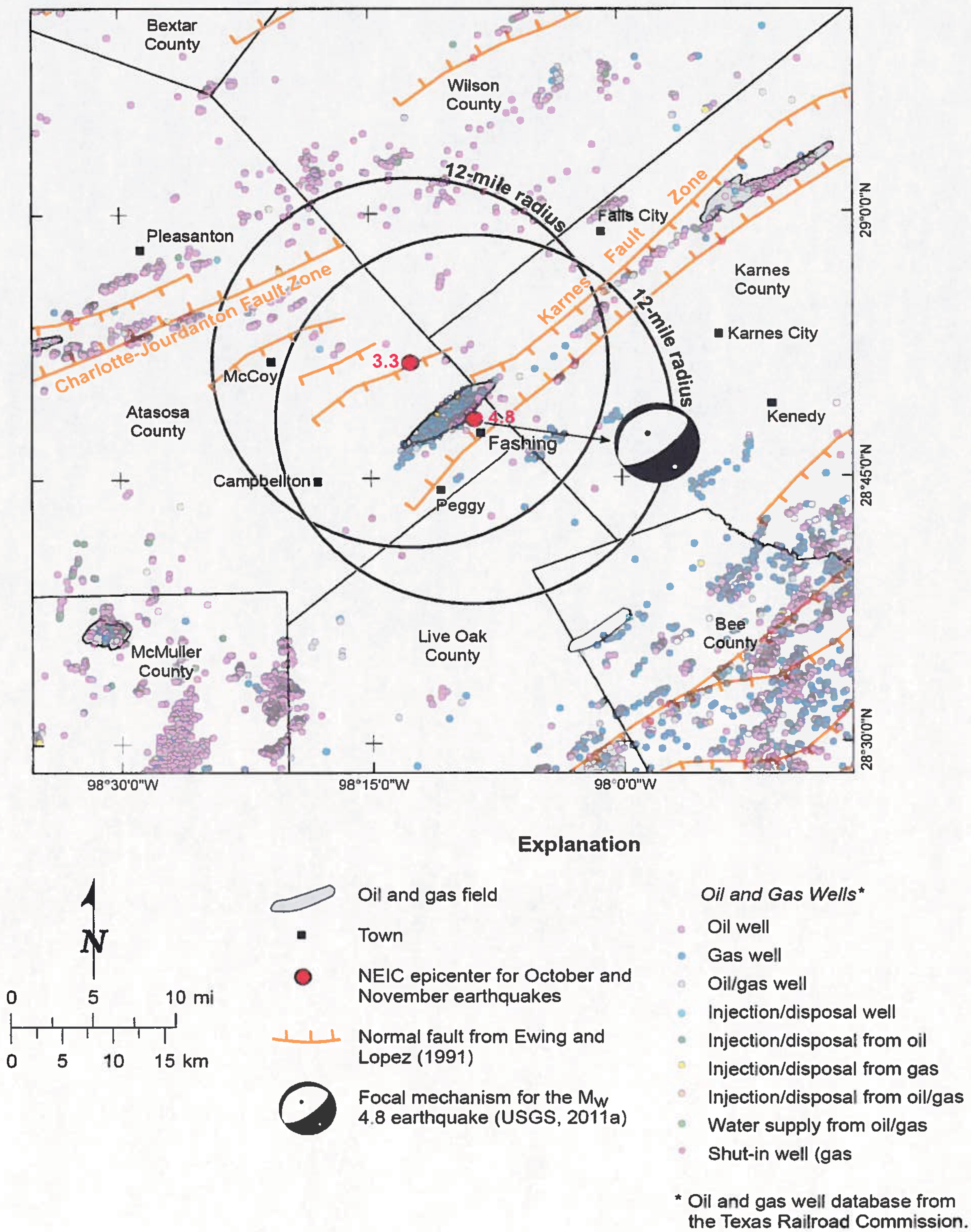
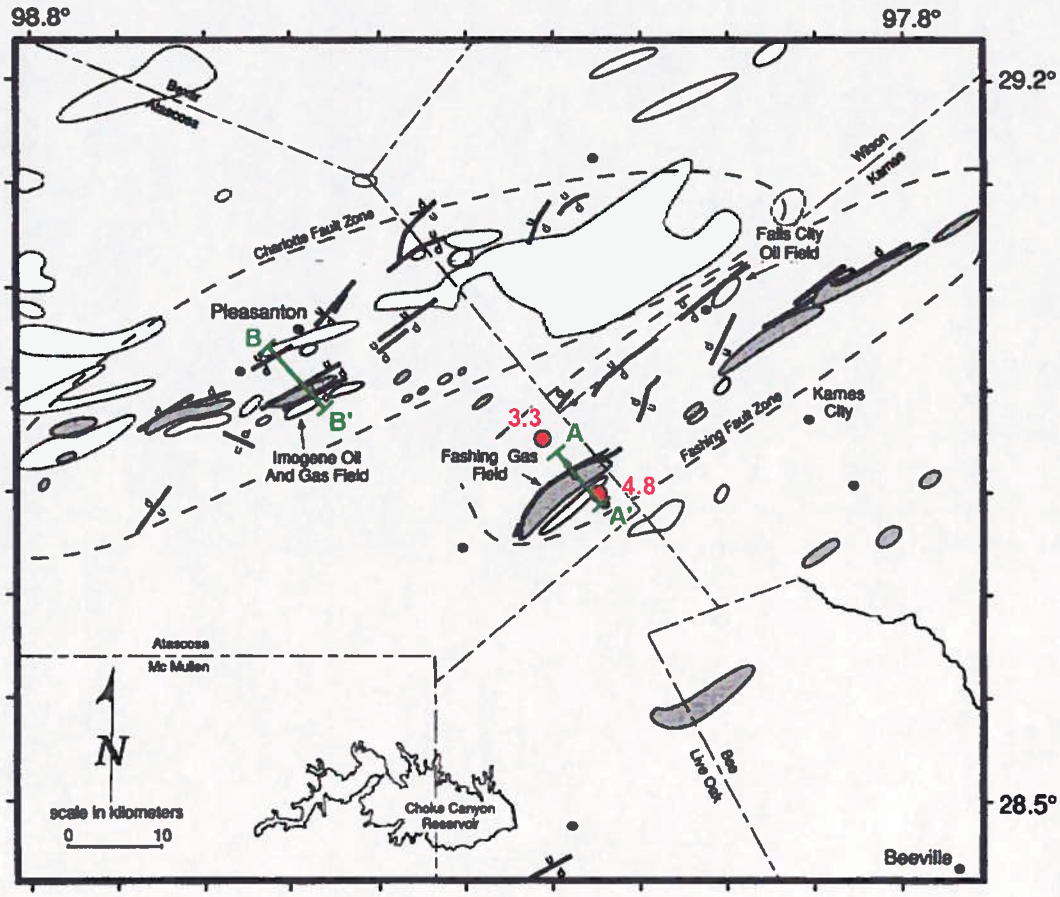


Figure 2. Map of Fashing Area Illustrating October and November Earthquakes, Oil and Gas Wells, and Faults

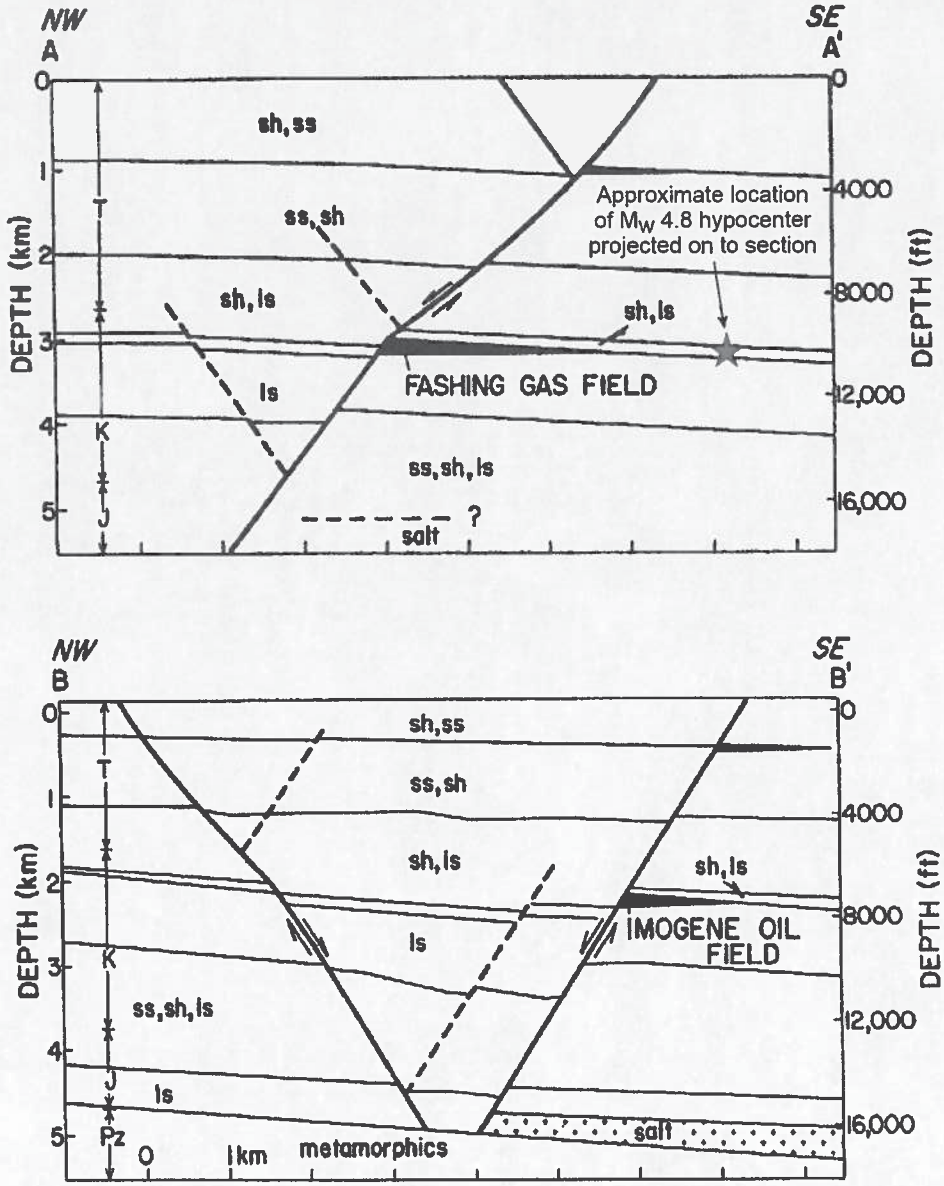


Shaded fileds indicate production from Edwards limestone (2.2 to 3.7 km in depth). Dashed boundaries indicate Upper Cretaceous production (1.0 to 1.7 km in depth); solid unshaded boundaries indicate Tertiary production (0.2 to 1.8 km in depth). Thick solid lines denote mapped surface surface faults. Green lines represent cross sections A-A' and B- B' shown on Figure 4. Modified from Davis et al. (1995)

Explanation

● NEIC epicenter for October and November earthquakes

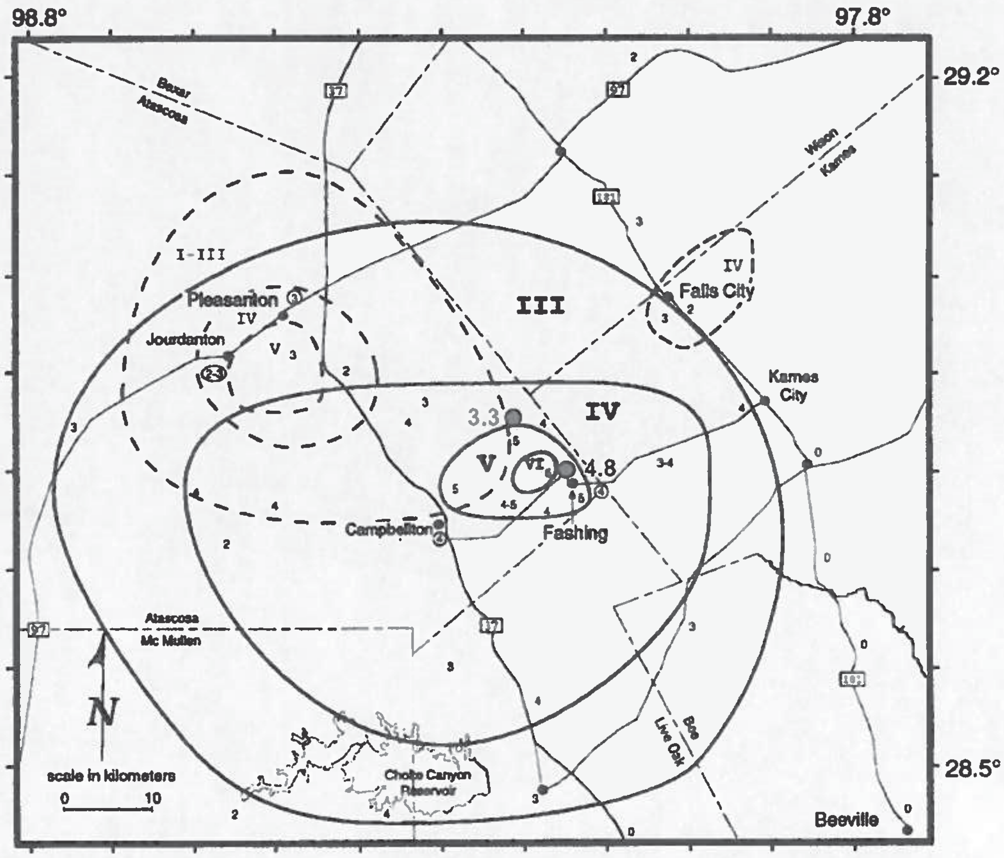
Figure 3. Location of Major Gas Field in the Fashing Area



No vertical exaggeration

Both the Fashing gas field and the Imogene oil field are located in the Edwards Limestone along the upthrown side of a normal fault. T, K, J, and Pz represent Tertiary, Cretaceous, Jurassic, and Paleozoic sections, respectively. Horizons shown as lines are those commonly used as well-log or seismic-reflection "markers." The shaded rock unit at about 5 km depth on section B-B' is a Jurassic salt bed. Generalized lithologies are indicated by the usual abbreviations (ss, sandstone; sh, shale; ls, limestone). Modified from Pennington et al. (1986).

Figure 4. Cross Section across the Fashing Gas Field and Imogene Oil Field.



Isoseismal map for earthquakes in the Atascosa-Karnes-Wilson regions: the m_bL_g = 4.3 Fashing earthquake of 9 April 1993 (bold lines); the m_bL_g = 3.9 Pleasanton earthquake of 3 March 1984 (dashed lines); and the m_bL_g = 3.6 Falls City earthquake of 20 July 1991 (dashed lines). Bold Roman numerals indicate modified Mercalli intensity zones for the 1993 earthquake; lighter Roman numerals indicate modified Mercalli intensity zones for the 1984 and 1991 earthquakes. Small Arabic numerals indicate location of individual felt reports for 1993 event; circled Arabic numerals indicate more than one felt report. Light long- and short-dashed lines designate county boundaries; light lines indicate highways. Modified from Davis et al. (1995)

Explanation

● NEIC epicenter for October and November earthquakes

Figure 5. Isoseismal Map of the 1984, 1991, and 1993 Earthquakes in the Fashing Area of Southern Texas