RAILROAD COMMISSION OF TEXAS

HEARINGS DIVISION

PROPOSAL FOR DECISION

OIL AND GAS DOCKET NO. 09-0296410

COMMISSION CALLED HEARING TO CONSIDER WHETHER OPERATION OF THE ENERVEST OPERATING LLC, BRIAR LEASE, WELL NO. 1 (API NO. 42-497-36875, UIC PERMIT NO. 12112), IN THE COUGHLIN (STRAWN) FIELD, IS CAUSING OR CONTRIBUTING TO SEISMIC ACTIVITY IN THE VICINITY OF RENO, PARKER COUNTY, TEXAS.

HEARD BY: Paul Dubois – Technical Examiner
Marshall Enquist – Administrative Law Judge

APPEARANCES:	**REPRESENTING:**
RESPONDENT:	
Brian Sullivan	EnerVest Operating LLC
Paul Tough	
Alex Zazzo	
Jud Walker	
William Keller, PhD	
Stephen McDaniel	
Ron Whitmore	
Lindsey Threlkeld	
INTERVENOR:	
David Cooney	Oil & Gas Division

PROCEDURAL HISTORY

Notice of Hearing:	April 24, 2015
Date of Hearing:	June 15, 2015
Transcript Received:	June 22, 2015
Proposal For Decision Issued:	September 10, 2015

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STATEMENT OF THE CASE

From November 11, 2013, through April 12, 2014, a series of earthquakes were felt by persons in and around the communities of Azle and Reno, in Tarrant and Parker Counties, respectively. Two deep underground injection wells that dispose of water produced from oil & gas production activities are located in the vicinity of the reported earthquakes. One of those wells is the Briar Lease Well No. 1 (API No. 42-497-36875) operated by EnerVest Operating LLC (EnerVest).[1] The Briar Well No. 1 injects produced salt water into the Ellenburger Formation in the depth interval from 7,430 feet to 9,250 feet.

On April 21, 2015, the results of a study entitled "Causal Factors for Seismicity Near Azle, Texas" (hereinafter, the "Causal Factors" study) were published in the journal *Nature Communications*.[2] The authors of the article include scientists from the Huffington Department of Earth Sciences at Southern Methodist University (SMU), the United States Geological Survey (USGS), the Institute for Geophysics at the University of Texas at Austin, and the Department of Petroleum and Geosystems Engineering at the University of Texas at Austin. The Causal Factors Study (elements of which will be discussed later) concluded:

> "*On the basis of modeling results and the absence of historical earthquakes near Azle, brine production combined with wastewater disposal represented the most likely cause of recent seismicity near Azle.*"

On April 24, 2015, the Executive Director of the Railroad Commission of Texas directed the Hearings Division to call a hearing to consider whether the operation of EnerVest's Briar Lease Well No. 1 is causing or contributing to seismic activity near Azle and Reno, Texas. The Hearings Division was directed to call the hearing to "*fully consider the (Causal Factors) Report, any controverting evidence from the operator of the wells at issue, and any other admissible, relevant evidence offered by any party with standing to participate...*"[3]

Regulatory Authority

Pursuant to the Commission's Statewide Rule 9 (16 Tex. Admin. Code §3.9, hereinafter "Rule 9"), any person who disposes of salt water or other oil and gas waste by injection into a porous formation not productive of oil, gas, or geothermal resources shall

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1 The second well is the West Lake Salt Water Disposal (SWD) Well No. 1 (API No. 42-367-34693) operated by XTO Energy, Inc. (XTO), for which a similar hearing was held on June 10, 2015, and a Proposal for Decision was issued on August 31, 2015 (Oil & Gas Docket No. 09-0296411).

2 "Causal Factors for Seismicity near Azle, Texas." Hornback, Matthew J., *et al.* Nature Communications. Nature Publishing Group. April 21, 2015.

3 Memorandum from Milton A. Rister, Executive Director, to Ryan Larson, Director, Hearings Division, dated April 24, 2015.

be responsible for complying with this section, Texas Water Code, Chapter 27, and Title 3 of the Natural Resources Code. After a permit has been issued under Rule 9, the Commission may take subsequent action as follows:

> *"A permit for salt water or other oil and gas waste disposal may be modified, suspended, or terminated by the commission for just cause after notice and opportunity for hearing, if:*
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> *(i) a material change of conditions occurs in the operation or completion of the disposal well, or there are material changes in the information originally furnished;*
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> *(ii) freshwater is likely to be polluted as a result of continued operation of the well;*
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> *(iii) there are substantial violations of the terms and provisions of the permit or of commission rules;*
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> *(iv) the applicant has misrepresented any material facts during the permit issuance process;*
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> *(v) injected fluids are escaping from the permitted disposal zone;*
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> *(vi) injection is likely to be or determined to be contributing to seismic activity; or*
>
> *(vii) waste of oil, gas, or geothermal resources is occurring or is likely to occur as a result of the permitted operations."*
> (16 Tex. Admin. Code §3.9(6)(A)(i - vii))

Notice

On April 24, 2015, the Commission issued notice of the hearing by first class mail, e-mail, and facsimile to EnerVest, the individual authors of the Causal Factors Study, the mayors of Azle and Reno, Texas, and to the Commission's Oil & Gas Division. The notice made specific reference to Rule 9(6)(A)(i, v, and vi), as provided above, and stated the recipients may seek party status at the hearing in order to present evidence and arguments.

Parties

The hearing was called to order on June 15, 2015. At the call of the hearing, two entities requested party status in the proceeding: EnerVest and the Railroad Commission's Oil & Gas Division. The authors of the Causal Factors Study and mayors of Azle and Reno, Texas were given notice, but did not appear at the hearing to participate in the proceedings. Several other persons were present to observe the hearing but did not request party status. The Examiners granted EnerVest's request to set the parties as EnerVest and the Commission's Oil & Gas Division.

Burden of Proof

The Respondent, EnerVest, has the burden of proof to show that the injected fluids from its Briar Lease Well No. 1 are not likely to be or determined to be contributing to seismic activity.

Standard of Review

The standard of review in this case is a preponderance of evidence. This, and a previously issued companion case, are matters of first impression before the Commission.[4] The question before the Examiners in this matter is expressed in Rule 9(6)(A)(vi):

> *Is injection likely to be or determined to be contributing to seismic activity?* (16 Tex. Admin. Code §3.9(6)(A)(vi))

The minimum finding necessary for an affirmative answer to this question can be reduced to:

> *Injection is <u>likely</u> <u>contributing</u> to seismic activity.*

Rule 9 does not further define or provide direction for interpreting the phrase "likely contributing." The Examiners conclude the term "likely" represents a preponderance of the evidence standard.[5] That is, simply, it is more likely than not that injection is causing seismic activity.

The Examiners understand the term "contributing" to indicate that the subject action (injection) provides at least a part of the force necessary to cause or achieve an outcome (seismic activity). A rudimentary overview of the mechanics of induced seismicity is presented in the Appendix. Thus, the injection stimulus and the consequent seismic activity must occur in a mechanically connected system, and the actual operational parameters of the mechanical system must be such to allow for stress to be transferred to the location of rupture, and thus "contribute" to an event.

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4 Oil & Gas Docket No. 09-0296411.

5 See *Ellis County State Bank v. Keever*, 888 S.W.2d 790, 792 (Tex. 1994) ("[n]o doctrine is more firmly established than that issues of fact are resolved from a preponderance of the evidence") (quoting *Sanders v. Harder*, 227 S.W.2d 206, 209 (1950))

Matters Officially Noticed

EnerVest did not offer the Causal Factors Study into evidence. At the hearing the Examiners did, however, take official notice of the study, to which EnerVest objected. The Examiners believe the claims made in the Causal Factors Study to be essential to establishing the context of EnerVest's evidence in response to the study. EnerVest objected as the Causal Factors Study was not sponsored by a party or witness who could defend it and be subject to cross-examination. Therefore, EnerVest argues that the study should be regarded as hearsay and not admissible. The Examiners overruled EnerVest's objection.[6]

By letter dated July 31, 2015, the Examiners notified the parties of their intention to take official notice of the following documents, incorporate them into the record, and afford the parties an opportunity to contest the materials:[7]

1. Commission posting of initial seismic rule proposal 39 Texas Register, pages 6775 to 6779 (August 29, 2014).

2. Comments regarding Commission posting. 39 Texas Register, pages 8988 to 9005 (November 14, 2014).

3. Commission records for API No. 42-439-32673, Chesapeake Operating, Inc., DFW Lease, Well No. C1DE, including injection well permitting records, well completion and plugging records, and Form H-10 injection volume summary.

4. Murphy, L. M. & Ulrich, F. P. United States Earthquakes, 1950. U.S. Coast and Geodetic Survey, Serial No. 755, pp. 1-9. Washington, D. C., 1952, pages 1 through 9 only; full document available at http://digital.library.unt.edu/ark:/67531/metadc40343/m1/1/).

5. Pacific Gas and Electric Company. Desabla-Centerville Hydroelectric Project, FERC Project No. 803. Draft Historic Properties Management Plan. Vol I. Pages 1-12. February, 2008 (pages 1 through 12 only; full document available at http://www.buttecreek.org/documents/HistoricProperties_DC_Project.pdf).

6. EnerVest's Exhibit No. 46 contained two figures from "Schweig, E. S., III, et al, 1991. Subsurface Structure in the Vicinity of an Intraplate Earthquake

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6 See Tex. R. Evid. 106 (Remainder of or Related Writings or Record Statements), 402 (Test for Relevant Evidence), 803 (Exceptions to Rule Against Hearsay).

7 An examiner on his or her own motion may propose to take official notice of facts, materials, records, or documents. See 16 Tex. Admin. Code 1.102 (Official Notice); Tex. Gov't Code 2001.090 (Official Notice; State Agency Evaluation of Evidence).

Swarm, Central Arkansas. Tectonophysics, 186: 107-114." The Examiners will take official notice of the full document.

By letter dated August 20, 2015, EnerVest reserved the right to object to official notice of these documents because the Examiners did not indicate the grounds for taking official notice. Staff did not respond to the letter.

By letter dated August 31, 2015, the Examiners notified the parties of their intention to take official notice of the following documents, incorporate them into the record, and afford the parties an opportunity to contest the materials:

1. Arkansas Oil and Gas Commission Order No. 602A-2010-12, Class II Commercial Disposal Well or Class II Disposal Well Moratorium. Cleburne, Conway, Faulkner, and Van Buren Counties. February 8, 2011;

2. Arkansas Oil and Gas Commission Order No. 180A-2-2011-074, Class II Commercial Disposal Well or Class II Disposal Well Moratorium. Cleburne, Conway, Faulkner, and Van Buren Counties. August 2, 2011; and

3. A map of the Permanent Disposal Well Moratorium Area obtained from the Arkansas Oil and Gas Commission website on August 26, 2015 (http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf).

By letter dated September 4, 2015, EnerVest reserved the right to object to official notice of these documents because the Examiners did not indicate the grounds for taking official notice. Staff did not respond to the Examiners' letter. In its September 4, 2015, letter EnerVest did request that the Examiners take official notice of the Proposal for Decision (PFD) issued on August 31, 2015, in the XTO case (Oil & Gas Docket No. 09-0296411). The Examiners agree to take official notice of th PFD in Oil & Gas Docket No. 09-0296411 issued on August 31, 2015.

Limitations

The purpose of the present matter is to evaluate the evidence in the record to determine whether EnerVest's Briar Well No. 1 is likely contributing to the specific earthquakes detected in and near Azle and Reno, Texas, which were first observed on November 11, 2013. The purpose of this matter was not to conduct an independent investigation of these events. The term "likely contributing" given the preponderance of the *evidence in the record* forms the standard by which the Examiners have formed a recommendation for Commission consideration.

EnerVest was the only party offering direct evidence into the record in this case–several hours of expert witness testimony and 58 exhibits, including late-filed supplements. EnerVest's evidence challenged the findings of the Causal Factors Study. The Commission's Oil & Gas Division cross-examined EnerVest's witnesses but did not otherwise offer a direct case or take a position on the matter. The Oil & Gas Division offered one exhibit into the record–a report from the USGS on the national seismic hazard model–to which EnerVest objected. Because the Oil & Gas Division did not provide a witness to sponsor the exhibit, the Examiners rule the exhibit to be inadmissible. The Commission's seismologist did not participate in the hearing. No evidence was offered in support of the Causal Factors Study.[8]

THE CAUSAL FACTORS STUDY

This hearing was called in response to the publication of the article "Causal Factors for Seismicity Near Azle, Texas" in the journal *Nature Communications* on April 21, 2015. The Causal Factors Study implicated the EnerVest Briar Well No. 1 as a cause of the recent earthquakes in the Azle-Reno area. What follows is a brief summary of salient aspects and findings of the Causal Factors Study.

The Causal Factors Study was undertaken to consider several regional factors that might have caused the recent seismic activity in the Azle-Reno area. The study's seismic analysis of the observed earthquake activity is consistent with two steeply dipping conjugate normal faults–a primary fault and an antithetic fault–an interpretation that is in agreement with industry interpretations based on 3-dimensional seismic data.[9] The faults follow the southwest to northeast strike of the Newark East fault zone. The parent normal fault dips about 60° to 70° to the northwest, and the antithetic normal fault dips about 70° to 80° to the southeast. Both faults are about 2 miles south of the injection well. The parent (Azle) fault is about 2 to 3 miles long and extends into the crystalline basement rock that underlies the sedimentary Ellenburger Formation. The antithetic fault is less than a mile long. The antithetic fault cuts across the Ellenburger Formation and penetrates into the crystalline basement rock (see Attachment 1).[10]

The study identifies several natural and anthropogenic (originating in human activity) factors that may reactivate faults and cause earthquakes. These factors alter the stress

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8 Additionally, on June 5, 2015, the Commission held a public meeting to discuss the Causal Factors Study. The meeting was attended by Commissioner Sitton and representatives from EnerVest, XTO, the Causal Factors Study team, and others. The Examiners were not present at this meeting, have not watched the online webcast, and have not read the transcript of the meeting.

9 A fault is a planar fracture in brittle rock across which there is observable displacement. A normal fault is a fault in which the hanging wall (the block of rock above the fault) has moved downward relative to the footwall (the block of rock below the fault). An antithetic normal fault is a minor fault associated with a primary or parent fault that dips in the opposite direction.

10 Causal Factors Study, Figures 2a and 2b.

regime of the subsurface and may include: (1) natural tectonic processes;[11] (2) water table fluctuations; and (3) the removal and injection of fluids in the deep subsurface.

Causal Factors Study – Natural Tectonic Processes

Most naturally-occurring seismic activity occurs along inter-plate boundaries, often on continental margins. Although uncommon, earthquakes may occur in intra-plate regions in stable continental interior areas far from known seismic zones. The Causal Factors Study notes the following:

- The Fort Worth Basin has been permanently settled for about 150 years.
- Before 2008, only one report of a felt earthquake was documented in the Fort Worth Basin, an area of about 140,000 square kilometers (54,000 square miles).[12]
- In 2008, a sequence of earthquakes occurred in the Dallas-Fort Worth area.
- On July 11, 2010, while the Earthscope Transportable Array was deployed in the region, one small unfelt (magnitude [M] less than 2.5) earthquake was detected in the Azle area.[13]
- The increase in seismic activity in North Texas since 2008 is unusual.

The Causal Factors Study attributes most of the faulting in the area to karst-collapse features in the Ellenburger Formation that date to about 300 million years ago. The faults in the area do not present surface expressions as evidence of recent significant movement. The Causal Factors Study concludes that naturally-occurring intra-plate tectonic stress changes are an unlikely cause of seismicity in the region.

Causal Factors Study – Water Table Fluctuations

Eagle Mountain Lake is a large reservoir located about 5 kilometers (3.1 miles) east of the subject area. Drought conditions have lowered the lake level about 2.1 meters (m) (6.9 feet) from April 2012 to November 2013. This reduction of mass would reduce the

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11 The term "tectonic" relates to the structure of the earth's crust and the large-scale processes that take place within it.

12 This appears to be the 1950 earthquake reported to be near Chico, Texas, about 25 miles north-northwest of Reno-Azle. This event will be discussed later.

13 The 'Moment Magnitude Scale', or simply 'Magnitude' (M) is a measure of earthquake size in terms of the energy released. Typically, the threshold for humans to sense a seismic event is about M2.5 and greater. Events of less than M2.5 usually pass unnoticed, although individual sensitivity varies.

stress on the Ellenburger Formation (the injection zone) by about 0.0006 mega Pascals (mPa), or about 0.09 pounds per square inch (psi). The Causal Factors Study does not attribute the seismic activity to changes in the lake level.

Similarly, the Causal Factors Study evaluated the potential for water levels in the shallow Trinity Aquifer (at a depth of about 100 meters, or 328 feet). The study identified no significant changes in aquifer water levels in the last six to eight years, and therefore concluded the aquifer water level has not affected seismicity in the area.

Causal Factors Study – Oil and Gas Activity

A significant portion of the Causal Factors Study attended to modeling changes in fluid pressure in the Ellenburger Formation (the disposal zone) as a result of oil and gas activities–in particular, the injection of waste fluids and the withdrawal of salt water that is produced concurrently with oil and gas.[14] Much of this salt water is flowback from the fracture treatment process. The model calculated variations in subsurface pressure on the nearby antithetic fault caused by two waste disposal injection wells and 70 gas wells that also produce salt water. A very brief summary of the model construction is as follows:

- Single-phase liquid flow was modeled through the nearly flat-lying Ellenburger Formation. The model domain was limited to the Ellenburger Formation only, not adjacent strata.

- Modeled Ellenburger Formation permeability values ranged from $3x10^{-14}$ m^2 to $10x10^{-14}$ m^2 (about 30 millidarcies [md] to 100 md). The mean formation permeability was used; the formation was modeled with homogenous isotropic properties without spatial variation due to karst structures or other factors.

- The faults in the Ellenburger Formation were modeled with permeability values that were reduced by 50 percent ($1.5x10^{-14}$ m^2 to $5x10^{-14}$ m^2). That is, the faults were modeled as less permeable than the formation itself.

- Vertical flow constraints were provided by significantly lower permeability values of $1x10^{-18}$ m^2 (about 0.001 md) above and below the Ellenburger Formation.

- Injection volumes and injection pressures for both EnerVest's Briar Well No. 1 and XTO's West Lake SWD Well No. 1 and were obtained from Commission records and based on monthly averages.

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14 The Causal Factors Study refers to this salt water as "brine."

- Salt water production volumes from 70 nearby gas wells were obtained from Commission records.

- The modeled period was 10 years. Salt water production began in 2004, and the injection began in 2009.

A series of model runs were performed varying certain parameters: bottom hole pressure; permeability; thickness of the permeable interval; specific storage; with and without salt water production; and open and closed boundary conditions. The modeling analysis indicated subsurface pressure increases along the antithetic fault ranging from 0.01 mPa to 0.14 mPa (1.45 psi to 20.3 psi).[15] The study states, "*Although uncertainty exists, model-predicted pressure changes are consistent with values that are known to trigger earthquakes on critically stressed faults.*"[16] The study further provides references for this assertion.

The Causal Factors Study identified some temporal correlation between: (1) a period of increased injection volume and pressure; and (2) modeled pressure increases on the antithetic fault and subsequent felt earthquake activity (Attachment 2).[17] An increase in injection activity in the Summer and Fall of 2013 resulted in a modeled pressure increase on the antithetic fault from 1 to 3 months later. The felt seismic activity began in November of 2013.[18] These pressure changes were modeled within the Ellenburger Formation, not the underlying Precambrian crystalline basement rock. Acknowledging that many of the earthquakes (larger magnitude events, especially) occurred in the basement rock along the primary fault, the Causal Factors Study "*hypothesize(s) that the deeper earthquakes are due to downward pressure transfer within the fault system.*"[19] This hypothesis was not explored.

The Causal Factors Study concludes: "*On the basis of modeling results and the absence of historical earthquakes near Azle, brine production combined with wastewater disposal represented the most likely cause of recent seismicity near Azle.*"[20] The Causal Factors Study acknowledges that certain aspects of this work represent "first-order estimates." The study describes a number of areas in which further study is needed.

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15 Causal Factors Study, Table 1.

16 Causal Factors Study, p. 6 (emphasis added).

17 The Causal Factors Study notes that higher injection pressure and volumes were reported prior to this localized increase.

18 Causal Factors Study, Figure 4.

19 Causal Factors Study, p. 7 (emphasis added).

20 Causal Factors Study, p. 1 (emphasis added).

ENERVEST'S EVIDENCE

Four witnesses testified for EnerVest. Alexander Zazzi is a petroleum engineer who currently serves as EnerVest's Vice President and General Manager of the Barnett Shale area. Mr. Zazzi testified to matters pertaining directly to the Briar Well No. 1. Judson Bryan Walker is a geologist who currently serves as Executive Vice President and Chief Operating Officer of EnerVest. Mr. Walker's testimony focused on the geology of the Fort Worth Basin in which the Briar well is located. William Keller, PhD, is EnerVest's Chief Geophysicist and Director of Geoscience Technology. Dr. Keller's testimony focused on analysis of the seismic data and events in the Azle-Reno area. Finally, Stephen McDaniel, a petroleum engineer currently serving as EnerVest's President and Chief Executive Officer testified on several issues, including a critique of the Causal Factor's Study.

In addition, EnerVest offered into evidence all of the evidence offered in the XTO hearing held on June 10, 2015 (Docket No. 09-0296411), including the hearing transcript.[21]

EnerVest's Evidence – Briar Lease Well No. 1

The Briar Lease Well No. 1 was originally permitted for injection into the Strawn Formation, a porous formation not productive of oil or gas, in the depth interval from 1,300 to 1,900 feet. Permit No. 12112 was issued to Denbury Onshore, LLC on July 25, 2005. The permit was amended on April 11, 2006, changing the injection interval and injection parameters. As amended, the permit authorized disposal into the Ellenburger Formation in the depth interval from 7,340 feet to 10,900 feet. The maximum injection volume was set at 10,000 barrels per day (bpd) and the maximum operating surface injection pressure was set at 3,670 pounds per square inch (psi). Disposal authority was limited to salt water, and the well was assigned to the Coughlin (Strawn) Field for administrative purposes.

Denbury Resources drilled the Briar Lease Well No. 1 to a total depth of 9,250 feet in September 2009. The well was completed on January 9, 2010. The base of usable quality water (BUQW) requiring protection was estimated to be at a depth of 670 feet. Surface casing was set at 1,275 feet, and cement was circulated to the surface. Production casing was set to 7,430 feet, and cement was circulated up to a depth of 4,270 feet as confirmed by a cement bond log. Injection tubing (3 ½ inch) was set with a packer at a depth of 7,343 feet. The open hole injection interval is from 7,430 feet to 9,250 feet, a 1,820-foot interval.

The well passed mechanical integrity tests (Form H-5) on January 13, 2010, and on December 4, 2014. Both tests were witnessed by Commission staff.

Talon Oil & Gas LLC became the operator of the well on April 11, 2010. EnerVest became the operator of the well on January 1, 2011.

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21 EnerVest Exh. No. 24.

Injection activity began in May 2010.[22] Since April 2013 the average daily injection volume has been fairly stable at about 2,800 bpd and the average daily surface injection pressure has been about 400 psi. From May 2012 through March 2013, the average daily injection volume was somewhat higher, between about 4,000 bpd and 5,000 bpd. A total of 5.9 million barrels of salt water have been injected into the well.

EnerVest estimates the initial formation pressure in the Ellenburger Formation at the mid-point of the injection interval (8,340 feet) to be between 4,120 psi to 4,163 psi, based on mud weights of 9.5 pounds per gallon and 9.6 pounds per gallon, respectively. The formation flowed when the mud weight was 9.4 pounds per gallon, and 9.6 pounds per gallon was the mud weight used to stabilize the well. In May 2015, EnerVest hired Fesco Petroleum Engineers to perform pressure transient and gradient survey tests on the well. Fesco determined that no apparent reservoir boundaries were encountered during the 25-hour injection test, and system radial flow occurred after 4 hours.

Using downhole direct pressure measurement gauges, Fesco concluded the formation pressure to be 4,172 psi. Based on the subjectivity of the graphical data interpretation, EnerVest represents any value between 4,160 and 4,172 to be an acceptable interpretation of the test results. Therefore, EnerVest concludes, there has been no significant formation pressure change during the life of the well. Further, EnerVest stated that with a 400 psi surface injection pressure, the friction loss to the injection tubing was about 310 psi, resulting in only a 90 psi increase at the mid-point of the injection interval.

The Briar Well No. 1 shares a well pad with two horizontal wells operated by EnerVest that produce from the Newark, East (Barnett Shale) Field. The Engler 1H well (API No. 42-497-35559) was completed in 2004. 65,620 barrels of water were pumped into the well for hydraulic fracture stimulation. Since completion the well has produced 25,254 barrels (38 percent of the stimulation volume). The Stancil Roberts 2H well (API No. 42-497-35756) was completed in 2005. Fracture stimulation required 104,058 barrels of water be pumped into the well. Since completion the well has produced 32,912 barrels of water (32 percent of the stimulation volume).

EnerVest's Evidence – Geologic Characterization of the Fort Worth Basin

Geologically, the Azle-Reno area is located within the Fort Worth Basin. The Fort Worth Basin is bounded to the east by the Ouachita Thrust Fault, to the north by the Muenster and Red River Arches, to the west by the Bend Arch, and to the south by the Llano Uplift. A map illustrating the boundary and major structural features of the basin is included on Attachment 3.[23] A locator map of the Briar Lease Well No. 1 area is included

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22 Exh. No. 18.

23 Exh. No. 26.

on Attachment 4.[24] Mr. Walker affirmed the accurate and comprehensive nature of the testimony about the Fort Worth Basin offered by XTO at its hearing in Docket No. 09-0296411.[25]

1. *Tectonics and Structure*

Tectonic forces have been at work in the basin throughout geologic time. Two orogenic events, in particular, have shaped and continue to influence basin structure.[26] As mentioned, the Fort Worth Basin is bounded on the east by the Ouachita Thrust Fault. The Ouachita orogeny and associated structures date to the Pennsylvanian time (~270-300 million years ago), when a continental collision occurred between the ancestral North and South American plates as the supercontinent of Pangea was forming. This compressional tectonic event thrust strata from southeast of the Ouachita Front over and on top of existing strata to the northwest. The thrusting top-loaded the existing strata, causing or reactivating movement along normal faults in the basement rock. One result of this activity is a series of *en echelon* normal faults down-thrown to the east-southeast that are generally northwest of and parallel to the thrust front, as strata closer to the thrust fault system were pushed deeper into the crust from increasing overburden (Attachment 5; the *en echelon* faults are prominent near the City of Irving).[27] The Ouachita uplifting also stimulated the erosion of source rock ultimately deposited in the basin as the extensive sequence of Pennsylvanian-age formations. Structural features related to the Ouachita Orogeny are evident on Bouger gravity anomaly maps.[28]

The second orogeny occurred during Triassic time (~200-225 million years ago) as the ancestral North and South American continental masses began to pull apart, which resulted in rifting–an extensional process in which the dominant crustal stress is tension. The deep East Texas Basin began to form during this time as a result of the extensional processes. Additionally, the normal faults in the Fort Worth Basin showed continued movement during this time as indicated by fault traces extending through the Pennsylvanian-age strata.

Other events–such as faulting, arching, uplift and down-warping–have also occurred and are represented in the current basin structure. Particularly, the Mineral Wells-Newark East fault systems (Attachments 4 and 5) strike southwest to northeast across the northern

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24 Exh. No. 2.

25 Tr. pg. 73, ln. 23, to pg. 74, ln. 11. All of the evidence, including transcript, from the XTO matter was admitted by EnerVest into the record in the present matter as Exhibit No. 24.

26 An "orogeny" refers to large-scale geologic forces and events leading to a large structural deformation of the Earth's crust due to the interaction between tectonic plates.

27 Exh. No. 24 (Exhibit No. 16 in Docket No. 09-0296411).

28 Exh. Nos. 36 and 44.

half of the basin.[29] The Newark East fault system and associated structures were formed during the development of the Llano Uplift and Fort Worth basin, with faulting ending by early Missourian time (middle Pennsylvanian).[30] The Newark East fault system has a normal disposition that is down-thrown on the northwest side. Notably, as shown on Attachment 5, the subsurface trace of the Newark East fault through the Newark, East (Barnett Shale) gas field is marked by a narrow zone with limited gas well development. In the Azle-Reno area, the Newark East fault system splays into a system of smaller normal faults. These ancient fault systems are rooted in Precambrian crystalline basement rocks.

Today, the ancient deep-seated fault systems continue to represent the zones of weakness in the crust.

2. *Stratigraphy*

The basin is underlain by Precambrian-age crystalline basement rocks of the North American Craton–or continental core–consisting of granite, diorite and metamorphosed sedimentary rock. The top of the crystalline basement is at a depth of about 10,000 feet in the Azle-Reno area and deepens to about 15,000 feet in the east, adjacent to the Ouachita Thrust Fault and Muenster Arch. Earthquake hypocenter depths are evidence of faults extending into the crystalline basement rocks to depths of up to 28,000 feet.

The Ordovician-age Ellenburger Formation is about 2,800 to 3,000 feet thick in this area and extends across the entire basin. In the Briar Well No. 1 the top of the Ellenburger Formation was encountered at a depth of 7,180 feet, at the Ordovician unconformity. The base of the Ellenburger Formation/top of the Precambrian crystalline basement rock is estimated to be at a depth of about 10,000 feet, or about 750 feet below the base of the open-hole injection interval. The carbonate Ellenburger Formation was deposited as a limestone in an open-shelf environment. The formation now exhibits diagenetic porosity from dolomitization. Sub-aerial exposure of the formation during late Ordovician time resulted in dissolution of the carbonate matrix and the formation (and collapse) of karst features. The Ellenburger Formation is not indicated to be a hydrocarbon source rock in the Fort Worth Basin.[31]

The Mississippian-age Barnett Shale Formation overlies the Ellenburger Formation and extends across the entire basin. The Barnett Shale is considered to be the source rock for nearly all of the hydrocarbons in the Basin. The Barnett Shale was deposited in a low-energy environment with high organic carbon content, and the formation increases in thickness from about 50 feet to 1,000 feet as one travels from west to east across the

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29 Exh. Nos. 2 and 24 (Exhibit No. 16 in Docket No. 09-0296411).

30 Exh. No. 24 (Exhibit No. 24A in Docket No. 09-0296411).

31 Exh. No. 24 (Exhibit Nos. 24 & 24A in Docket No. 09-0296411).

basin. The formation has an average porosity of 5 to 6 percent. EnerVest estimates the permeability to range from 100 to 1,000 nanodarcies. In the Briar Well No. 1 the top of the Barnett Shale was encountered at a depth of 6,819 feet and is 361 feet thick, extending down to the top of the Ellenburger Formation.

Pennsylvanian-age formations (Marble Falls, Bend, Strawn, Canyon and Cisco) overlie the Barnett Shale, forming a thick sequence of mostly carbonate formations that have trapped hydrocarbons migrating from the Barnett Shale source rock. Some Pennsylvanian strata are hydrocarbon source rocks of secondary importance. The historic Boonsville (Bend Conglomerate, Gas) Field is located in and north of the Azle-Reno area.

Finally, Cretaceous-age formations (Trinity, Fredericksburg and Washita) cap the Basin by directly overlaying an erosional unconformity on top of the Pennsylvanian strata.

The basin as a whole and individual formations generally thicken and deepen to the east. The stratigraphic column contains two large gaps. There are no rocks from the Silurian to Devonian periods, corresponding to the time when the Ellenburger Formation was near surface and subject to dissolution and karsting. There are no preserved Triassic or Jurassic-aged strata, although some Permian-aged rocks are present west of the Bend Arch.

3. The Barnett-Paleozoic Total Petroleum System

The Barnett Shale is considered to be the primary source rock for producible hydrocarbons throughout the Fort Worth Basin.[32] Geologic process acting upon the highly organic Barnett Shale provided the necessary and optimal conditions for hydrocarbon formation, including burial at depth, time, and temperature. The ongoing tectonic and structural processes in the basin also provided a mechanism for the hydrocarbons to migrate from the source rock into trapped reservoir rocks over time. Movement along the Newark East Fault allowed the migration of gas from the Barnett Shale into the overlying Bend Conglomerate Formation, which has long been developed through the large Boonsville (Bend Conglomerate, Gas) Field. Hydrocarbon generation, migration and accumulation are thus the result of the geologic processes–including seismic activity–that continue to this day.[33] These processes are rooted in the deep-seated structural stress dynamics in the crystalline basement rocks, and the seismic stress relief originates in the crystalline basement. The individual fault movements during these events are on the scale of millimeters, which are sufficient, over time, to enable hydrocarbon migration into reservoir rock, but are not expressed as features on the current ground surface.

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32 Exh. No. 24 (Exhibit No. 24 in Docket No. 09-0296411).

33 Exh. No. 24 (Exh. No. 24., Tr. pg. 124, lns. 1-8 in Docket No. 09-0296411).

EnerVest's Evidence – Geology of the Azle-Reno Area

The geologic structure of the Azle-Reno area is dominated by the Mineral Wells-Newark East normal fault system. The Newark East fault zone impacts hydrocarbon production in the area. As shown on Attachment 5, the fault zone has resulted in a halo-zone devoid of wells.[34]

The Ellenburger Formation porosity averages 2 to 5 percent, and the average permeability is 2 md to 9 md. However, these values understate the porosity and permeability that result from the interconnectedness of the dual-porosity system associated with dolomitization, karsting, and faulting. In such cases, porosity could be in the darcy range. According to Mr. Walker, "*it is a very complex, very permeable zone.*"[35] The Ellenburger Formation in the Azle-Reno area is marked by many karst features. These structures developed in the late Ordovician time–or perhaps Silurian or Devonian, for which there is no stratigraphic record–when the Ellenburger Formation was at or near the ground surface and could be exposed to dissolution mechanisms. Dissolution processes and karsting result in the formation of subsurface channels, caves, and sinkholes that may significantly increase the permeability of a formation. Attachment 6 illustrates the development of karst features and subsequent collapse and filling, which may affect permeability.[36] EnerVest provided evidence demonstrating that these processes have, in fact, created karst structures in the subsurface at the location of the Briar Well No. 1 (Attachment 5, note the fine, irregular red lines.) The open hole well log of the Briar Well No. 1 in the Ellenburger Formation indicates multiple zones with high porosity and low (salt water) resistivity.[37] A seismic coherence attribute cross section indicates correlation between the high porosity/low resistivity zones and coherence attribute data. High porosity zones extend through the whole Ellenburger Formation.[38]

Mr. Walker testified that faults within the Ellenburger Formation indicate a throw (displacement) of about 150 feet and would not create effective permeability barriers to horizontal flow because very porous and permeable rock would still be placed against very porous and permeable rock. Thus, fluids would dissipate rapidly around the wellbore and into the formation, and pressure would not increase along a fault plane.[39]

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34 Exh. No. 24 (Exh. No. 16 in Docket No. 09-0296411).

35 Tr. pg. 82, lns. 2-3.

36 Exh. No. 29.

37 Exh. No. 31.

38 Exh. No. 32.

39 Tr. pg. 85, ln. 1, to pg. 86, ln. 3. The Examiners note 150 feet of throw may create permeability barriers to horizontal flow at the top and bottom of the Ellenburger Formation, where the displacement causes the Ellenburger Formation to abut the Barnett Shale Formation and the Precambrian crystalline basement granite, respectively.

There is some production of natural gas from the Ellenburger Formation in the area. The Barnett Shale is considered to be the source rock for Ellenburger Formation hydrocarbons.[40] In the surrounding four county (Tarrant, Wise, Parker and Denton) area there are 23 historic Ellenburger Formation producing wells, the nearest of which is about 7 miles to the northwest. These 23 wells produced a combined 6 billion cubic feet (BCF) gas from the Ellenburger Formation.[41] In addition, a gas show was encountered in the Ellenburger Formation while drilling the nearby XTO West Lake SWD Well No. 1.

EnerVest asserts the Ellenburger Formation is capable of accepting significant quantities of injected fluid without a corresponding increase in reservoir pressure because the formation is an expansive and thick porous unit, and because the compressibility of gas that is present in the formation would increase the available fluid storage capacity.

EnerVest's Evidence – Incompleteness of the Historic Earthquake Record

The Causal Factors Study based its findings, in part, on the absence of historical earthquakes in the Azle-Reno area. In response, EnerVest contends that seismic events likely have occurred through history, but they have not been recorded either by persons experiencing ground motion or by seismographs.

There are two ways in which earthquakes are recorded. First, an earthquake may be detected by a seismograph network of at least three independent stations. The quality of the information depends on several factors, including the distance from the event to the detecting stations. Generally, the closer the better. Permanent seismograph data has only been available for North Texas since about 1960, and reliable seismograph data in catalogue form since 1974. From 1960 to 1974, there were six seismograph stations in all of Texas (one in the Fort Worth Basin), and four more in Oklahoma. Between 2005 to 2015, the number of Texas stations had increased to 12 (two in the Fort Worth Basin), and the Oklahoma stations to about 16. Very generally speaking, the existing network has detected events in the Azle-Reno area with minimum magnitudes of M2.1 to M2.5, which is at or slightly below the sensation threshold. Smaller events are not detectable with this network. Also, the existing network is not capable of accurately locating the earthquake epicenter to an accuracy of better than 5 to 10 kilometers (about 3 to 6 miles). Depth location is also uncertain (the temporary network installed by SMU and USGS in December 2013, is capable of better resolution).

The second means of recording earthquakes is by reporting felt experiences of ground motion. For this to happen, a sequence of events must occur as follows:

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40 Exh. No. 24 (Exhibit Nos. 24 & 24A in Docket No. 09-0296411).

41 Tr. pg. 96, lns 14-20. The Examiners note the 23 wells are in a four-county (Denton, Parker, Tarrant and Wise) area covering about 3,600 square miles.

- Local residents feel ground movement and recognize it as an earthquake;
- The experience must be reported to a newspaper, letter to a friend, or other written evidence; and
- The written evidence is identified by a researcher and recorded in scientific literature.[42]

Permanent settlements of the Fort Worth Basin began about 150 years ago. In 1880, the population of the City of Fort Worth was 6,663; by 2000 it had increased to more than 534,000. Generally, the smaller the population the more likely an earthquake event will pass without being felt. Further, cultural development brings multi-story structures in which ground motions can be more easily sensed. Cultural development also brings more media repositories for reporting felt events. Again, the smaller the population and the lower the degree of cultural development, the more likely earthquakes–especially small ones–will go unnoticed. Therefore, EnerVest asserts the possibility that the Fort Worth Basin through history has experienced low levels of seismic activity that, until recently, have not been detected and reported.

EnerVest acknowledged one historic earthquake in the Fort Worth Basin. On March 20, 1950, an earthquake was reported near Chico, Texas, which is about 25 miles north-northwest of the Briar Lease Well No. 1. This event was based on one felt report stating "*One abrupt shock felt at the Centerville Powerhouse Camp. Flower pot moved and windows rattled.*"[43] The magnitude was later estimated to be M3.3 to M3.8. According to EnerVest Exhibit No. 24, the location of the Centerville Powerhouse Camp is unknown.

EnerVest's Evidence – Analysis of Azle-Reno area Earthquake Activity

The USGS NEIC seismograph network detected five events in the Azle-Reno area before the local network was operational. However, the ability of the USGS NEIC network to spatially locate these events was not sufficient to accurately determine the depth at which the ruptures occurred. To address this question, EnerVest matched the early USGS NEIC data (which had poor depth control) to known waveforms from subsequent, known deep events. The waveform signatures of the five earliest events closely match the waveform signatures of known deep events; the five earliest events correlate poorly with known shallow events. EnerVest argues its analysis demonstrates that the five earliest recorded events were, in fact, deep events originating in the crystalline basement. Thus, the earliest felt events originated in the crystalline basement rocks underlying the Ellenburger Formation disposal zone.

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42 Tr. pg. 113, lns. 4-12.

43 Exh. No. 24 (Exhibit No. 26 in Docket No. 09-0296411).

EnerVest also used event waveforms with a high signal-to-noise ratio as a tool to query the data catalogue of a USGS NEIC seismograph station located 175 miles to the northwest (station WMOK in southwestern Oklahoma). EnerVest worked backwards through the WMOK data to identify events that matched the waveform signature of the Azle-Reno area deep events. In the six weeks prior to the onset of felt seismicity on November 11, 2013, about 11 events were identified. These events range from about M0.5 to M1.7, too small to be felt, but suggest a level of seismicity preceding the onset of the felt events. Dr. Keller stated that EnerVest is continuing to work backwards in time through WMOK recorded events.

EnerVest analyzed the seismic moment of (that is, energy released by) the Azle-Reno area earthquakes, and concluded that most of the energy, by far, was released in 4^{th} quarter of 2013 in the depth interval from 20,000 to 22,500 feet. The number of events per day in the Azle-Reno area displays an exponential decline curve.

EnerVest's Evidence – Earthquake Activity in Irving, Texas, and Enola, Arkansas

The Irving, Texas, area is directly west of the Ouachita Thrust Front in western Dallas County. As described in the XTO matter, the Irving area has experienced recent seismic activity that appears to be unrelated to oil and gas production and waste disposal activities.[44] Therefore, EnerVest concurs with XTO's position and evidence that the recent Irving activity is indicative of the natural seismic processes at play in the Fort Worth Basin. To support this position, EnerVest also presented evidence on historical seismic activity in Enola, Arkansas, which overlies a structural environment similar to that of Irving, Texas.

In 1982 a series of earthquakes occurred in Enola, Arkansas. Several of the earthquakes were larger than M4.0. The earthquake sequence was similar to that in Azle-Reno, in some ways. The early events were larger in magnitude and more frequent in number than later events. Up to 900 events were recorded per day. The events demonstrated an exponential decline in energy released. In 2001, a similar sequence occurred. Dr. Keller affirmed the Enola sequences have been well studied and the consensus is that they are resultant from natural causes.

Geologically, the Enola area is located in a similar structural setting to Irving, Texas. The Ouachita Thrust Front (locally named the Ross Creek Thrust), is south of Enola. A series of *en echelon* normal faults are present north of the Ouachita Front, a result of over-loading during the Ouachita Orogeny. These faults extend into the crystalline basement rock. The crystalline basement rock is overlain by a carbonate rock that is age-equivalent to the Ellenburger Formation, which is in turn overlain by Pennsylvanian-age strata. The earthquake events indicate normal basement fault movement at depths of 10,000 to 20,000 feet, similar to Irving and Azle. No fault offset is interpreted across shallower (Pennsylvanian) strata. Attachment 7 illustrates a comparison to the geology in Enola,

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[44] Exh. No. 24.

Arkansas, and Irving, Texas.[45] EnerVest contends this information indicates a similar structural regime and naturally occurring earthquake activity in Enola and Irving. Dr. Keller stated, "*There's no oil and gas activity near this area at the time. And so I think it provides a good comparison to what we're seeing here in Irving and in the Fort Worth Basin.*"[46]

EnerVest's Evidence – Critique of the Causal Factors Study

EnerVest's witnesses testified to a number of shortcomings with the Causal Factors Study. These shortcomings, in the witnesses' opinions, undermined the study's conclusion of a likely causal relationship between EnerVest's injection and seismicity in the Azle-Reno area. EnerVest was critical of the following aspects of the Causal Factors Study:

- The model employed was not capable of handling the highly anisotropic geological and hydrological system which includes the Ellenburger Formation (with its dolomite porosity and extensive karst features), the Newark East fault system, and the Precambrian crystalline basement rock.

- The model did not consider the regional fracture pattern orientation of northeast to southwest, or the associated preferential groundwater flow direction.

- The model domain did not include the Precambrian crystalline basement rock in which the initial earthquakes originated. Pressure was not modeled to the depth of the initial events.

- The modeling did not consider multi-phase flow. There is evidence of gas in the Ellenburger Formation, the compressibility of which would affect the formation's ability to accept fluid without a corresponding increase in fluid pressure.

- The model assumed the faults were less permeable than the Ellenburger Formation, but there is no evidence that this is the case. The modeling of faults with lower permeability values resulted in an increase in the modeled pore pressure along the fault.

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45 Exh. Nos. 24 (Exhibit No. 26 in Docket No. 09-0296411) and 46.

46 Tr. pg. 123, lns. 17-21 (emphasis added). The Examiners note that since the 2001 sequence areas of north-central Arkansas, including Enola, have experienced oil & gas development of the Fayetteville Shale Formation, which is the Arkoma Basin geologic equivalent to the Barnett Shale Formation in the Fort Worth Basin. As will be discussed later, underground injection associated with the oil & gas development has since been implicated in recent seismic activity in the area.

- The model considered salt water production from the Ellenburger Formation, when, in fact, the salt water is produced from the overlying Barnett Shale and mostly includes stimulation flow-back, not connate water production.

- The model and modeling results were not calibrated to known conditions, such as measured shut-in bottom-hole pressure.

Citing the Causal Factors Study's modeling results, Mr. McDaniel stated that only one out of the 15 modeling runs were based on bottom-hole pressure and open boundary conditions comparable to those found at the location of the Briar Well No. 1. This one model run estimated a pressure difference at the antithetical fault of only 0.02 mPa (2.9 psi).

EXAMINERS' ANALYSIS OF THE EVIDENCE

The Causal Factors Study is a commendable first-order investigation that posits the plausibility of injection-induced seismicity in this case. The Causal Factors Study presents data indicating a weak temporal correlation between injection and seismic activities–too small, however, to imply a causal relationship without further corroborating evidence. The Causal Factors Study also reports a single-phase modeling effort that demonstrates a pressure increase on the nearby antithetic fault within the Ellenburger Formation. Several flaws identified with the model, however, limit its use. Specifically, the pressure modeling effort was not sufficient to establish a mechanical (hydraulic) linkage between the site of injection and the locus of initial rupture on the Azle Fault at a depth of 20,000 feet. Thus, evidence demonstrating a "likely contribution" from the site of injection is lacking.[47]

Therefore, the Examiners conclude that the evidence in the record does not support a finding of fact that EnerVest's Briar Lease Well No. 1 is likely contributing to seismic activity. The Examiners recommend entry of an order maintaining EnerVest's current disposal permit for its Briar Lease Well No. 1.

Examiners' Analysis – Plausibility of a Mechanical System

The evidence in the record contains sufficient information to plausibly construct a mechanical system by which injection activities may contribute to seismic activity. The key

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47 The record, however, does not support a finding that injection activity is definitively unrelated to EnerVest's injection activities. EnerVest, for its part, was successful in identifying several significant deficiencies in the Causal Factors Study's modeling methodology and results. EnerVest presented an encompassing portrait of the geology, tectonic processes and history of the Fort Worth Basin demonstrating the area has, indeed, been subject to faulting and deformative stress throughout geologic time. This historical activity, in and of itself, does not prove that the injection of oil and gas waste liquids are likely not contributing to the seismic activity. Moreover, the tectonic history does not demonstrate that the recent seismic activity is solely the result of natural processes.

elements of this system are the Ellenburger Formation and the existing fault structures (Attachment 8).[48]

As a geologic unit the Ellenburger Formation exhibits characteristics that enable it to be an exceptional disposal zone. The formation is porous and permeable. In five years it has accepted more than 5.9 million barrels of water from EnerVest's Briar Well No. 1. Pressure transient testing indicates residual formation pressure returns to virgin pressure at the wellbore. The formation exhibits two, and perhaps three, forms of porosity and permeability:

- Diagenetic matrix porosity enhancement by dolomitization;
- Development of karst structures during a period of sub-areal exposure; and
- The potential for porosity and permeability development along the faults and fault zones which transect the formation.

EnerVest estimates the average porosity of the formation rock to be about 5.5 percent and the average permeability ranges from 2 md to 9 md based on the well testing. This is likely a gross, or bulk, estimate. The permeability in karst (and perhaps fault) structures could possibly be much, much greater than the properties of the rock matrix. Also, a 150-foot throw on the permeable Azle Fault, would result in the bottom 150 feet of the permeable Ellenburger Formation abutting the impermeable Precambrian granite, which is on the up-thrown footwall side of the fault. This change in permeability could affect the local pore pressure regime.

The fault structures that transect most of the regional section–from the crystalline basement rock up through the Pennsylvanian-age strata–have demonstrated the creation of permeable pathways enabling the migration of hydrocarbons from the Barnett Shale source rock up into the Pennsylvanian reservoirs. Some gas has migrated down into the Ellenburger Formation as well, presumably along these same pathways. The permeability of the fault zones into the crystalline basement rock has not been established. However, the faults are demonstrated to be permeable through the sedimentary section (so much so that operators drilling wells near the Newark East Fault appear to intentionally avoid it), so it is not unreasonable to posit continued permeability along the faults into the basement rock.

Examiners' Analysis – Historic Earthquake Activity

There is no credible evidence in the record of felt seismic events originating in the Fort Worth Basin prior to 2008. The Examiners conclude the reported 1950 event near Chico, Texas (25 miles north-northwest of Azle-Reno), most likely occurred near Chico,

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48 Modified from Exh. No. 24 (Exhibit No. 21 in Docket No. 09-0296411).

California, and was mis-reported in the records of the US Coastal and Geodetic Survey (precursor agency to the USGS). The basis for this conclusion is as follows:

- Exhibit No. 26, an excerpt from a 2002 book entitled Texas Earthquakes, indicates this event was based on one felt report stating "*One abrupt shock felt at the Centerville Powerhouse Camp. Flower pot moved and windows rattled.*" This one felt report was obtained from a publication by "Murphy and Ulrich, 1952." Exhibit No. 26 also states that the location of the Centerville Powerhouse Camp is unknown.

- The Examiners identified a document authored by Murphy and Ulrich, dated 1952, and entitled "United States Earthquakes 1950, Serial No. 755, U.S. Department of Commerce, U.S. Coast and Geodetic Survey." On page 6, under a list of earthquakes in the Central Region, the Chico, Texas, event was documented at 7:23 am on March 20, 1950, with the description *"One abrupt shock felt at the Centerville Powerhouse Camp. Flower pot moved and windows rattled."*

- On page 9 of the Murphy and Ulrich document, under a list of earthquakes in California and Western Nevada, at 7:22:19 am on March 20, 1950, an earthquake was reported across a 4,000 square mile area. A report from the city of Chico, California, indicated a felt intensity of V on the Mercalli scale.[49]

- A "Centerville Powerhouse" is located about 25 miles east of Chico, California, and was identified in a "Draft Historic Properties Management Plan" prepared by Pacific Gas and Electric Company in February 2008.

Therefore, the Examiners conclude the reported 1950 event near Chico, Texas (25 miles north-northwest of Azle-Reno), most likely occurred near Chico, California. The Examiners conclude the record contains no credible evidence of felt seismic events originating in the Fort Worth Basin prior to 2008.

Examiners' Analysis – Recent Earthquake Activity

The evidence of record, including the Causal Factors Study, contains several references to other earthquake sequences that have occurred in North Texas since 2008, apart from those described in the Azle-Reno and Irving sequences. Two of these sequences occurred near DFW Airport in 2008-2009, and near Cleburne, Texas in 2009-2010. These sequences and other earthquake events are a matter of public record

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49 The Modified Mercalli Intensity Scale is a measure of earthquake intensity and is a measure of observed effects of an earthquake. A Mercalli intensity of V is associated with being felt by nearly everyone; many awakened; some dishes, windows broken; unstable objects overturned.

and have been studied by researchers with their results published in peer reviewed journals, both of which were referenced by the Causal Factors Study, as follows:

- Frohlich, C., et al. The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009. Bulletin of the Seismological Society of America, Vol. 101, No. 1, pp. 327-340. February, 2011.
- Justinic, A. H., et al. Analysis of the Cleburne, Texas, Earthquake Sequence from June 2009 to June 2010. Bulletin of the Seismological Society of America, Vol. 103, No.6, pp. 3083-3093. December 2013.

The Examiners make no findings in the present matter based on these documents, other than to acknowledge the occurrence of the events in the DFW Airport and Cleburne areas. These articles contain publicly available information on earthquake sequences that have occurred in the Fort Worth Basin since 2008–information which was not offered into evidence at the hearing. Second, with regard to the 2008-2009 DFW Airport sequence, an oil and gas injection well was permitted and in operation during the time of the earthquake sequence. The Examiners have taken official notice of Commission records for this injection well, API No. 42-439-32673, Chesapeake Operating, Inc., DFW Lease, Well No. C1DE, including injection well permitting records, well completion and plugging records, and Form H-10 injection volume summary.

Injection activities at the Chesapeake well began in September 2008, and the first felt earthquake occurred on October 30, 2008. Injection ceased in August 2009. The well injected oil and gas waste into the Ellenburger Formation in an open-hole depth interval from 10,252 feet to 13,729 feet. The well was plugged in 2014. This oil and gas well location was faintly indicated on EnerVest's maps of the Irving area, but it was not clearly identified as a disposal well. The Examiners have highlighted this well location on Attachment 9; it is close to the Airport Fault.[50] The Airport Fault is one of the several *en echelon* normal faults in eastern Tarrant and western Dallas County that parallel the Ouachita Front–as illustrated, the Airport Fault appears to be within the same fault system that has recently been active in the Irving area. The stress relationships between the various faults and fault blocks (i.e., the effect that stress, strain and movement along one fault in the system may have on adjacent blocks and faults) in this system are unknown.

Examiners' Analysis – Initial Event Sequence in the Azle-Reno Area

Both EnerVest and the Causal Factors Study demonstrated that the initial earthquake events in the Azle-Reno area in November and December 2013 occurred along the Azle Fault within the crystalline basement rock, below the Ellenburger Formation injection zone. EnerVest has demonstrated that the first five events, before the local monitoring network was in place, occurred in the deeper basement rock. Shallow events

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50 Exh. No. 24 (Exhibit No. 18 in Docket No. 09-0296411).

on the antithetic fault within the Ellenburger Formation occurred later, notably on January 28, 2014, after the deeper initial events. Although a time-sequence analysis of the Irving earthquakes is not in evidence, researchers from SMU and USGS have reached a preliminary conclusion that most of the earthquakes in the Irving area are located in the shallow crystalline basement rocks.[51]

The location at depth of the initial rupture of a particular earthquake event is referred to as its hypocenter. The hypocenter is the location at which the shear stress exceeds the shear strength and causes the rock (or fault) to rupture, releasing energy which may be felt or recorded as a seismic event. The occurrence of an earthquake along a fault within the Precambrian crystalline basement rock does not necessarily mean that the contributing causes of the earthquake are solely attributable to naturally-occurring tectonic processes. It does mean that the Coulomb failure criterion (shear stress exceeds the shear strength) was met at that location.

Examiners' Analysis – Modeling in the Causal Factors Study

To assess the possibility that injection activities contributed to a seismic event, a mechanical connection between the injection stimulus and the location of the seismic response must be identified. In the Causal Factors Study, the researchers employed a groundwater model to estimate pore pressure changes at a depth of about 10,000 feet along the antithetic fault two kilometers southeast of the injection well. This modeling predicted a pressure change of 1 to 20 psi along the antithetic fault, which is within a range of values documented in scientific literature that may induce earthquakes on critically-stressed faults. This position is consistent with the Commission's understanding of the phenomena during the rule-making process for Rule 9. During rule-making, the Commission responded to comments from stakeholders regarding certain technical aspects of the proposed rules. Based on these comments, the Commission altered its initial proposed approach to screening injection wells for potential seismic concerns. A number of these comments and responses pertained to pore pressure in an injection zone, including the following:

- Responding to a comment about calculating a 5 psi pressure-front over 10 years, the Commission stated it originally proposed 5 psi as a pressure-front differential on the lower side of the 1.4 to 14 psi range mentioned by the commenting party as a conservative number.[52]

- The Commission disagreed with a comment that the 10-year 5 psi pressure-front boundary is arbitrary and not founded in sound science and engineering practice. The Commission went on to respond that "*Published research*

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[51] Exh. No. 24 (Exhibit No. 29 in Docket No. 09-0296411).

[52] 39 Tex. Reg. 8990 (2014).

indicates that inducing earthquakes on preferentially oriented faults requires positive pressure differentials of as little as one pound per square inch to as much as 75 pounds per square inch. The Commission proposed five pounds per square inch as a conservative number."[53] Also, while understanding the wide range of possible values for real reservoir characteristics, the Commission expected operators would enter realistic values in the calculation to yield a first-order scientific and engineering calculation.[54]

- One comment stated *"Injected fluids may well stay confined in the injection interval but the pressure perturbation induced by the injections (sic) fluids can have farther reaching effects."*[55] This comment further stated that the perturbation may be more important in locally changing stress in a manner sufficient to allow earthquakes along pre-existing fault structures, and noted that there are a number of other critical data sets related to the fluids and the rock properties that control fluid migration, including, but not limited to downhole pressures in the injector, static pressures at injection depth, permeability and fault locations including their connection to layers above and below the injection interval. The Commission agreed with the comment.[56]

However, the initial earthquake events occurred within the crystalline basement rock at depths of about 20,000 feet, which is about 10,000 feet deeper than the zone modeled in the Causal Factors Study. The Causal Factors Study "*...hypothesize(s) that the deeper earthquakes are due to downward pressure transfer within the fault system,*"[57] but this hypothesis was not explored. Therefore, there is no evidence in the record establishing the operation of a mechanical system capable of transferring energy from the injection well (or at least from the deepest modeled location along the antithetic fault) to the location of initial rupture.

In addition, the evidence in the record demonstrates the deficiencies identified by EnerVest in the Causal Factors Study's modeling are generally legitimate. Future modeling efforts should address the potential for significant heterogeneity and isotropy in the Ellenburger Formation and the fault system, and the impact of gas in the formation (if, from a modeling perspective, gas is present in significant quantities.) The Causal Factors Study acknowledged the need for additional and refined reservoir modeling.

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53 39 Tex. Reg. 8995-8996 (2014).

54 *Id.*

55 39 Tex. Reg. 8990 (2014).

56 *Id.*

57 Causal Factors Study, p. 7 (emphasis added).

EnerVest also stated the model and modeling results were not calibrated to known conditions, such as measured shut-in bottom-hole pressure. The Examiners, however, find there to be some, albeit thin, evidence of a temporal correlation between injection activity and observed events. First, as shown on Attachment 2, the Causal Factors Study's modeling results indicate an increase in pressure along the antithetic fault just prior to the initial earthquakes in November 2013. True, the modeled location on the antithetic fault was 10,000 feet above the location of initial rupture, but the modeled pressure increase also preceded the initial activity by one to three months, which may allow time for a pressure disturbance to move down the Azle Fault to the point of rupture.

Second, the record in the earlier XTO case contains seismic event data from November 11, 2013, through January 12, 2015.[58] However, EnerVest's exhibits indicate the last seismic event in evidence occurred on or about March 22, 2015 (Attachment 10).[59] The Examiners requested EnerVest provide available Azle-Reno area seismic data from January 12, 2015, through May 31, 2015. EnerVest responded that it had no additional data in the format requested–although it did, apparently, acknowledge having some other data). As highlighted on Attachment 10, the Examiners note that the gap in seismic activity between January 12, 2015, and March 22, 2015, correlates to the 53 days in which XTO's West Lake SWD Well No. 1 was shut in for tubing replacement.[60] This time gap in earthquake events is consistent with the time delay indicated in the Causal Factors Study (See Attachment 2). This data is very limited, but may suggest the potential for a temporal correlation and should be explored further.

The Examiners recognize the EnerVest well has injected about 5.9 million barrels of water into the Ellenburger Formation, and the XTO well has injected more than 22 million barrels. Further, the XTO well is closer to the central location of earthquake activity. All else being equal, the XTO well might be more strongly suspected to have a causal relationship to the recent earthquake activity. However, in the rule making process, the Commission also recognized that multiple wells, some with smaller permitted injection volumes, should not be given special consideration in the permitting process with regard to screening for historical seismic events in the area:

- In response to a recommendation that the Commission relax the seismic area of review requirements for low capacity injection wells, the Commission declined, acknowledging that the potential for increased impact of several "small volume" disposal wells in one area could have the same impact as one "large volume" disposal well.[61]

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[58] Exh. No. 24 (Exhibit No. 36 in Docket No. 09-0296411).

[59] Exh. Nos. 48 and 52.

[60] Exh. No. 24.

[61] 39 Tex. Reg. 8991 (2014).

The Causal Factors Study appropriately included both wells in its analysis.

Examiners' Analysis – Formation Pressure in the Ellenburger Formation

EnerVest asserts the formation pressure within the Ellenburger Formation has not changed since the well was completed. EnerVest estimates the initial formation pressure based on drilling mud weight to be 4,163 psi. In May 2015, pressure transient testing indicated the formation pressure to be about 4,160 psi to 4,172 psi. The difference in these two does not appear to be significant given the margins of error for the measurement methodologies.

While this information is useful, it is not necessarily conclusive. What is not assessed is the pressure response of the formation to sustained injection conditions, to the cessation of sustained injection conditions, or, for that matter, how pressure is transmitted through the formation when injection conditions change in any way. This question is key: how are fluid pressures, both sustained and transient changes, transmitted through and diffused by the reservoir in all of its complexity?

EnerVest asserts that natural gas within the Ellenburger Formation should also be considered in the reservoir's pressure response. If the natural gas in the Ellenburger Formation exists in a gas phase in the formation, then gas compression may provide additional volume for water storage. But if the gas exists in an aqueous solution, then it is doubtful that much compression would occur as liquids are not significantly compressible. Regardless, the question to be addressed should be how the formation responds temporally and spatially to pressure changes due to injection, and whether this response is sufficient to transmit force to the point of rupture in the crystalline basement rock.

Monthly average data of injection rates and pressures may not be discrete enough to model formation pressure responses in time and space. Modeling daily injection rate and pressure data, if available, will likely yield more accurate results.

Examiners' Analysis – Naturally-Occurring Seismic Activity

EnerVest presented a detailed characterization of the historical processes and current structure of the Fort Worth Basin in the Azle-Reno and Irving areas. The Examiners note the Newark East Fault and the normal faults in the Irving area appear to have arisen from different source events.[62] In addition, the Newark East Fault dips to the northwest, while the Irving area normal faults dip to the east-southeast. The area between

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[62] Exh. No. 24. (Tr. pg. 87, lns. 14-22; Tr. pgs. 95-96; Exh. No. 24A in Docket No. 09-0296411).

the two zones did not have sufficient data to map.[63] EnerVest argues that the historical record of earthquakes in the Fort Worth Basin is incomplete. This is undoubtedly true. However, EnerVest also failed to openly disclose other significant earthquake swarms that have occurred in the area recently (i.e., DFW Airport, Cleburne). The Examiners conclude there is insufficient evidence in the record to demonstrate the seismic activity in the Azle-Reno area is caused solely by natural tectonic processes.

The geologic record on the Fort Worth Basin indicates a long history of faulting and deformation over millions of years. In terms of geologic time, the 150 years of human settlement in the Fort Worth Basin is insignificant. Nonetheless, the unusual activity in Azle, Irving, DFW Airport, Cleburne, and elsewhere in the basin since 2008, including sustained swarms of felt events, does not automatically implicate a naturally occurring tectonic origin.

EnerVest also presented the Enola, Arkansas, area as a geologic and seismologic analog to the Irving, Texas, area. Both areas overlie the margins of the Ouachita Front and associated normal faulting. In 1982 and 2001, Enola, Arkansas experienced large earthquake swarms that appeared to be unrelated to oil and gas activity. If the Enola and Irving seismic events are unrelated to oil and gas activities, then EnerVest contends those in Azle-Reno might also be unrelated. The Enola, Arkansas, events of 1982 are also associated with localized uplift in the earthquake swarm area. Two leveling surveys indicated a vertical uplift in the swarm area of 14.3 to 20 centimeters (5.6 to 7.9 inches) since benchmarks were set in 1961.[64] The record contains no evidence of similar leveling surveys having been conducted in the Azle-Reno or Irving areas.

Since the 1982 and 2001 Enola sequences, the north-central Arkansas area, including Enola, has experienced oil and gas activity related to development of the Fayetteville Shale Formation, which is geologically equivalent to the Barnett Shale. The record demonstrates an earthquake swarm that occurred in 2010 about 8 miles northwest of Enola, near the cities of Guy and Greenbriar. These earthquakes also occurred in an area of *en echelon* normal faults adjacent to the Ouachita Front. In Order No. 602A-2010-12, dated February 8, 2011, the Arkansas Oil & Gas Commission (AOGC) found circumstantial evidence that recent earthquakes in the area may be either enhanced or potentially induced by the operation of Class II disposal wells. In Order No. 180A-2011-074, dated August 2, 2011, the AOGC established a permanent moratorium on new injection wells in an area that includes Guy, Greenbriar, and Enola, Arkansas (Attachment 11). This evidence tends to cut against EnerVest's contention that seismic activity associated with normal faulting along the Ouachita Front, and unrelated to oil and gas activity, is occurring in the Fort Worth Basin as it is in Enola. However, the Examiners do

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63 Exh. No. 24. (Tr. pgs. 163-164 Docket No. 09-0296411).

64 "Schweig, E. S., III, et al, 1991. Subsurface Structure in the Vicinity of an Intraplate Earthquake Swarm, Central Arkansas. Tectonophysics, 186: 112."

not take a position as to whether or not the Enola earthquake swarms were induced by oil and gas activity or seismic activity.

Indeed, the either-or dichotomy–either the earthquakes are caused by natural forces or by injection–is a misleading one. The natural occurrence of stress in the subsurface is a fact, as is the occurrence of stress at critical levels in some places. The problem is, however, that we typically do not know enough about the stress regime to anticipate which areas are near failure... until after failure has occurred. Injection-induced seismic events are generally recognized to result when a pressure disturbance caused by injected fluid is the stimulus that brings to failure a fault that was already critically-stressed by natural processes. Dr. Keller stated, "*Seems unlikely to me that you would have numerous regional faults critically stressed waiting to go and never create an earthquake in the last 300 million years. That seems implausible to me.*"[65] That seems implausible to the Examiners, too. But, if there are "...*numerous regional faults critically stressed waiting to go...*", then injection could provide a pressure disturbance that initiates–or contributes to–a rupture. Again, we generally have no way of knowing whether or not a particular fault rupture may occur given injection pressure disturbances, nor is it currently reasonably possible to know whether an event would have occurred in the absence of an induced pressure disturbance. Developing such understandings take significant amounts of time and study. The Causal Factors Study is a useful initial study regarding possible induced seismicity in the Fort Worth Basin, but the findings to date are not sufficient to reach a conclusion.

Examiners' Analysis – Recommendation

The Examiners conclude that the preponderance of the evidence supports a finding that the EnerVest Briar Lease Well No. 1 was constructed and operated in accordance with its permit. Further, the Examiners conclude that the preponderance of the evidence does not support a finding that fluids injected into the Ellenburger Formation through the Briar Lease Well No. 1 are "...*escaping from the permitted disposal zone*" or are "...*likely to be or determined to be contributing to seismic activity*" [16 Tex. Admin. Code §3.9(6)(A)(i)(v) and (vi)]. Therefore, on this basis the Examiners recommend that EnerVest's disposal permit for its Briar Lease Well No. 1 remain active and unchanged.

The Examiners also conclude that the evidence in the record does not support a finding of fact that EnerVest's Briar Lease Well No. 1 is not contributing to seismic activity in the Azle-Reno area, or that the seismic activity is solely the result of natural tectonic processes.

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65 Tr. pg. 139, lns. 14-17.

FINDINGS OF FACT

1. Notice of this hearing was given to all parties entitled to notice at least ten days prior to the date of hearing.

2. The Briar Lease Well No. 1 was constructed and operated in accordance with its permit.

3. There is no evidence in the record that injected fluids are escaping from the permitted disposal zone.

4. There is no evidence in the record of felt seismic events originating in the Fort Worth Basin prior to 2008.

5. Since 2008, seismic events have occurred in the Fort Worth Basin in the vicinity of Dallas-Fort Worth International Airport, Cleburne, Azle-Reno, and Irving, Texas.

6. The initial earthquake events in the Azle-Reno area in November and December 2013, occurred along the Azle Fault below the Ellenburger Formation injection zone in the Precambrian crystalline basement rock at a depth of about 20,000 feet.

7. The Causal Factors Study groundwater model estimated pore pressure changes at a depth of about 10,000 feet, at the base of the Ellenburger Formation.

8. The Causal Factors Study did not model pore pressures into the Precambrian crystalline basement rock and associated fault zones.

9. The evidence in the record is not sufficient to establish the operation of a mechanical system capable of transferring energy from the injection well to the location of initial rupture at a depth of 20,000 feet.

10. The evidence of record in this case does not support a finding of fact that EnerVest's Briar Lease Well No. 1 is likely to be or determined to be contributing to seismic activity.

CONCLUSIONS OF LAW

1. Resolution of the subject application is a matter committed to the jurisdiction of the Railroad Commission of Texas. Tex. Nat. Res. Code § 81.051

2. All notice requirements have been satisfied. 16 Tex. Admin. Code § 1.45

3. A material change of conditions has not occurred in the operation or completion of the disposal well, and there are no material changes in the information originally furnished. 16 Tex. Admin. Code §3.9(6)(A)(i)

4. The evidence in the record is insufficient to conclude that injected fluids are escaping from the permitted disposal zone. 16 Tex. Admin. Code §3.9(6)(A)(v)

5. The evidence in the record is insufficient to conclude that injection is likely to be or determined to be contributing to seismic activity. Tex. Admin. Code §3.9(6)(A)(vi)

RECOMMENDATION

The Examiners conclude that the evidence in the record does not support a finding of fact that EnerVest's Briar Lease Well No. 1 is likely to be or determined to be contributing to seismic activity according to 16 Tex. Admin. Code §3.9(6)(A)(vi). Therefore, the Examiners recommend entry of an order maintaining EnerVest's current disposal permit for its Briar Lease Well No. 1.

Respectfully submitted,

Paul Dubois
Technical Examiner

Marshall Enquist
Administrative Law Judge

APPENDIX

MECHANICAL FOUNDATION FOR INDUCED SEISMICITY

This is a case of first impression before the Commission. The Examiners find it helpful that a technical foundation be established forming an understanding of the mechanics by which injection may contribute to seismic activity, as currently understood by the scientific community.

The mechanics of injection-induced seismicity are well understood. The standard model for triggering slip on a fault–whether triggered by naturally occurring tectonic or induced causes–is expressed through the Coulomb failure criterion. Simply stated, a fault is stable when the shear stress–the driving force per unit area acting in the direction of potential movement–is less than the shear or frictional strength (resistance to slip) of the fault. Slip is triggered along a fault when the shear stress exceeds the shear strength. A fault can be thought of to be in a critical state (close to failure) when the shear stress acting on a fault is very near the shear strength resisting movement. In a critical state, either an incremental increase in the shear stress acting on the fault, or an incremental decrease in shear strength holding the blocks together, results in a slip of, or movement along, the fault.

The shear or frictional strength of a fault is proportional to the effective stress, which is the difference between the normal stress acting perpendicular to the fault (and holding it together) and the fluid pore pressure within the rock (exerting an outward force.)

Given the following parameters:

τ = shear stress
σ = normal stress
ρ = pore pressure
μ = friction coefficient

$\mu\ (\sigma - \rho)$ = shear or frictional strength
$\sigma - \rho$ = effective stress

A fault will be stable when: $\tau < \mu\ (\sigma - \rho)$

A fault approaches a critical state of stress when: $\tau \approx \mu\ (\sigma - \rho)$

And a slip will occur when: $\tau > \mu\ (\sigma - \rho)$

Thus, three independent stress conditions could result in slip:

- An increase in the shear stress
- A decrease in the normal stress
- An increase in the pore pressure

Conversely, stress changes in the opposite directions would tend to increase stability.

In the case of induced seismicity from fluid injection, the effective stress ($\sigma - \rho$) can be reduced by the increase in pore pressure from injection. This is the mechanism–an increase in pore pressure that reduces the effective stress and, consequently, the frictional strength of a fault–by which injection may induce seismic activity. Beyond the apparent simplicity of this criterion, however, the problem of actually determining the *in situ* state of stress on a particularly-oriented fault to assess the potential for stability or instability in the geomechanical system is very complex and fraught with difficulties and uncertainties.

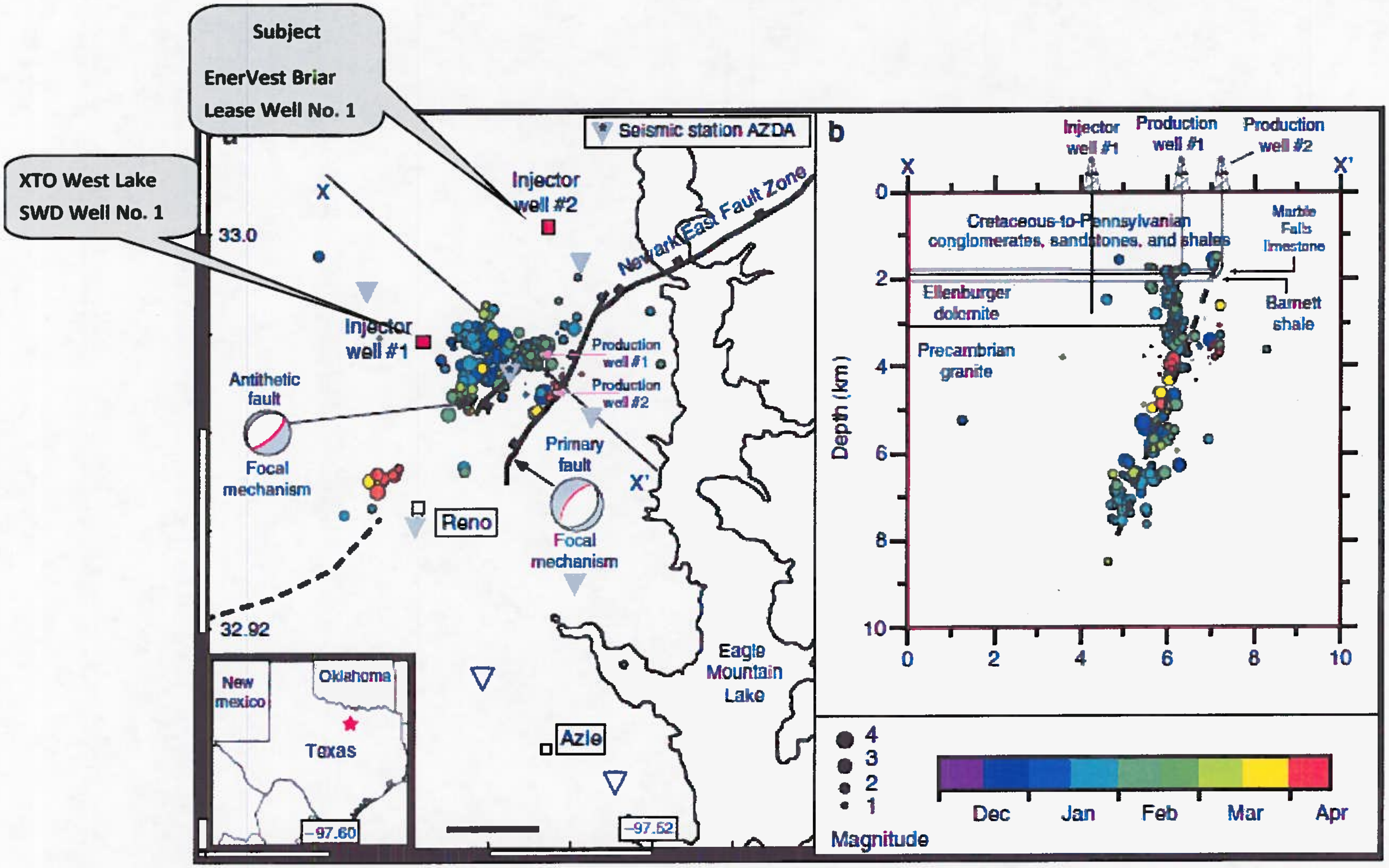


Figure 2 | Azle Earthquake locations and regional geologic structure. Map showing the location of NEFZ (black) at the top of the Ellenburger formation, inferred faults (dashed) at the top of the Ellenburger formation, injection wells (red squares), two production wells (API 36734045 and 36734139) with significant brine production near the faults (pink arrows) and earthquake epicentres (coloured circles) recorded by the temporary seismic network (triangles) (**a**). The red star in the inset of **a** shows the map location. The black scale bar in **a** is 2 km. Grey (white) triangles indicate the locations of active (inactive) seismic stations. Line X-X′ in **a** shows the location of the cross-section shown in (**b**). We interpret two faults based on earthquake location and consistent with industry interpretations: a primary normal fault and a shallower antithetic normal fault.

ATTACHMENT 1 **09-0296410**

Examiners' Notes: Causal Factors Study figures illustrating the spatial and temporal distribution and magnitude of detected events in the Azle-Reno area in (a) map view , and (b) cross-section view. Although difficult to discern on this image, one can zoom in on an electronic version of Figure 2b and see the earliest events (purple, dark blue and medium blue) occurred mostly within the Precambrian crystalline basement rock.

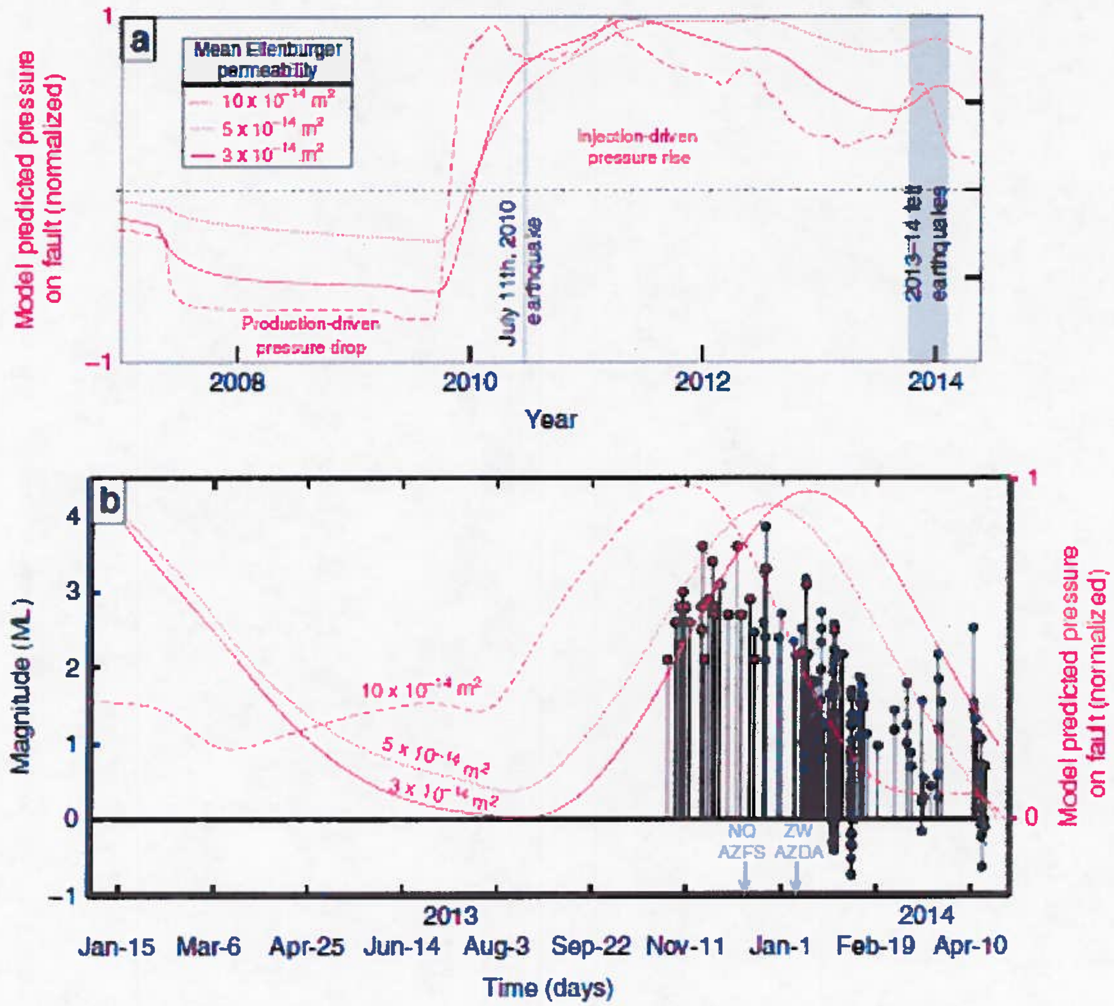


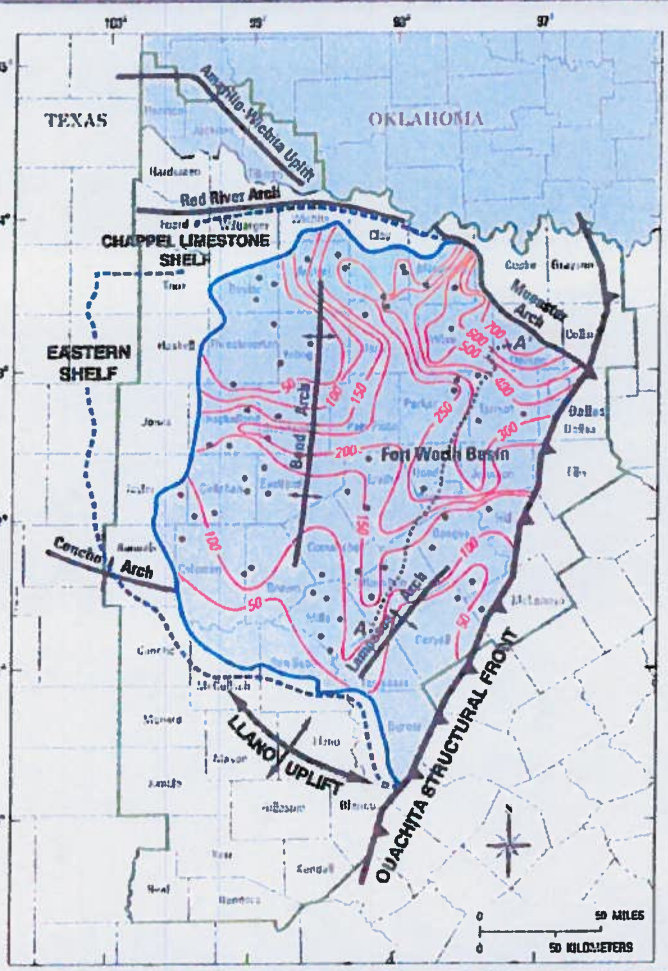
Figure 4 | Pressure at the antithetic fault versus time. Modelled pressure versus time at the antithetic fault, directly below seismometer AZDA (Fig. 2a) (**a**). Results include three different mean Ellenburger permeability values and demonstrate earthquake activity correlates in time with a local pressure maximum but not an absolute maximum at this site. Higher resolution time image of modelled injection pressures versus time at AZDA with earthquakes (stem and circle) coloured by network (NEIC-red; SMU-blue) (**b**). In 2010, one small (<M 2.5) earthquake was detected in the study area[17]. Event detection increases beginning on 15 December, the date when the first Netquakes station (NQ_AZFS) was deployed. Detection further improved when station ZW_AZDA was installed. Model results indicating pressures increase along the fault near the time of felt seismicity, with a 1-3-month delay between injection rate increase and pore pressure change at the fault based on permeability values measured at injector well #1.

ATTACHMENT 2 **09-0296410**

Examiners' Notes: Causal Factors study figures comparing (1) the temporal modeling of fluid pressure at the antithetic fault and (2) the occurrence of earthquakes in the Azle-Reno area.

Barnett Isopach

ENERVEST



ATTACHMENT 3 **09-0296410**

Examiners' Notes:

EnerVest Exhibit No. 26. The Fort Worth Basin is bounded by the Ouachita Thrust Fault to the east, Muenster and Red River Arches to the north, the Bend Arch to the west, and the Llano Uplift to the south.

EXPLANATION

- USGS PROVINCE 45 BOUNDARY–BEND ARCH-FORT WORTH BASIN
- GEOGRAPHIC EXTENT OF BARNETT SHALE IN THE FORT WORTH BASIN
- BARNETT-PALEOZOIC TOTAL PETROLEUM SYSTEM
- ISOPACH CONTOUR (INTERVAL 50 AND 100 FEET)
- STRUCTURAL FRONT
- WELL LOCATION

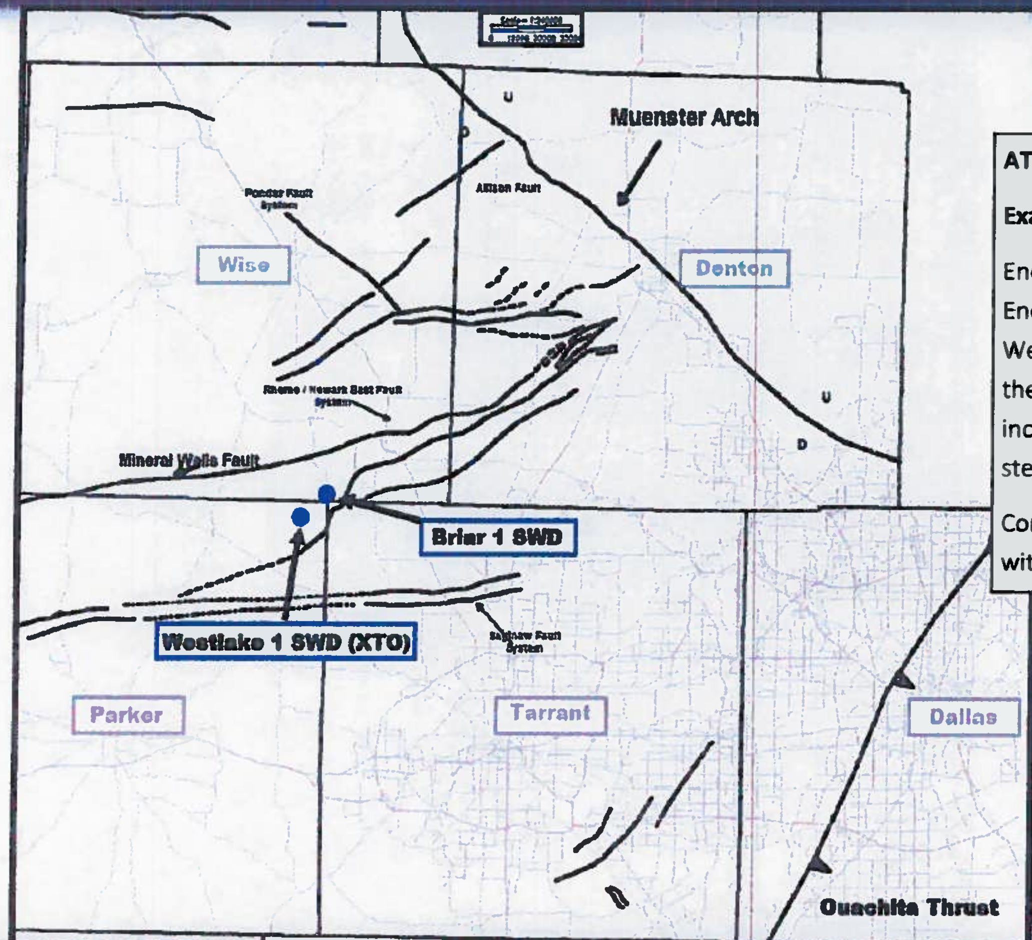
Modified from Bruner and Smosna 2011

ENERVEST OPERATING LLC
O&G Docket No. 09-0296410
June 15-16, 2015
Exhibit No. 26

BRINGING OUT THE BEST

Locator Map

ENERVEST



ATTACHMENT 4 **09-0296410**

Examiners' Notes:

EnerVest Exhibit No. 2. Location of the EnerVest Briar Well No. 1 and the Mineral Wells—Newark East Fault Systems, along with the nearby boundaries of the Fort Worth Basin including the Ouachita Thrust and the Muenster Arch.

Compare the interpreted faults on this figure with those presented on Attachment 5.

ENERVEST OPERATING LLC
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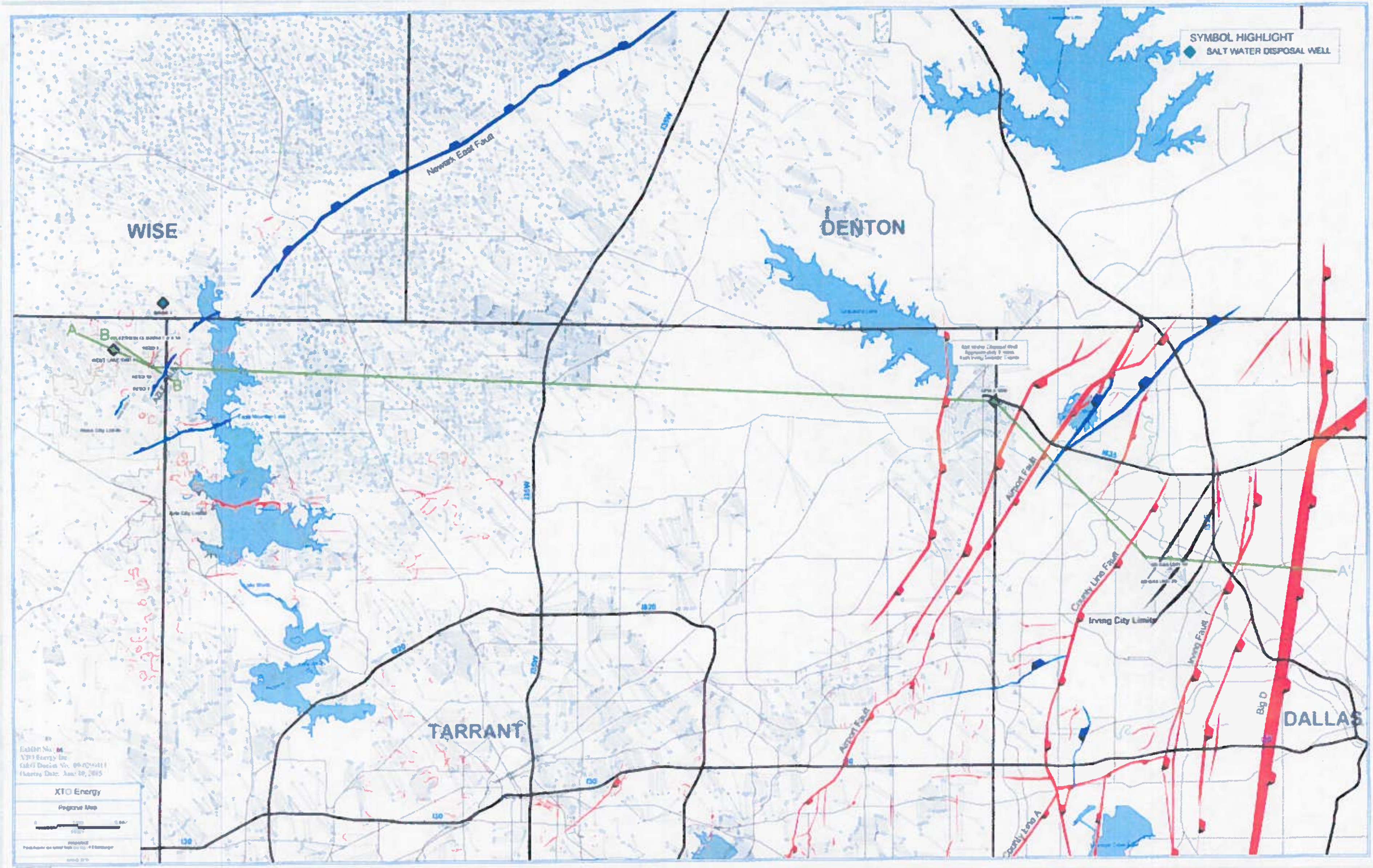
Exhibit No. - 2



ATTACHMENT 5 **09-0296410**

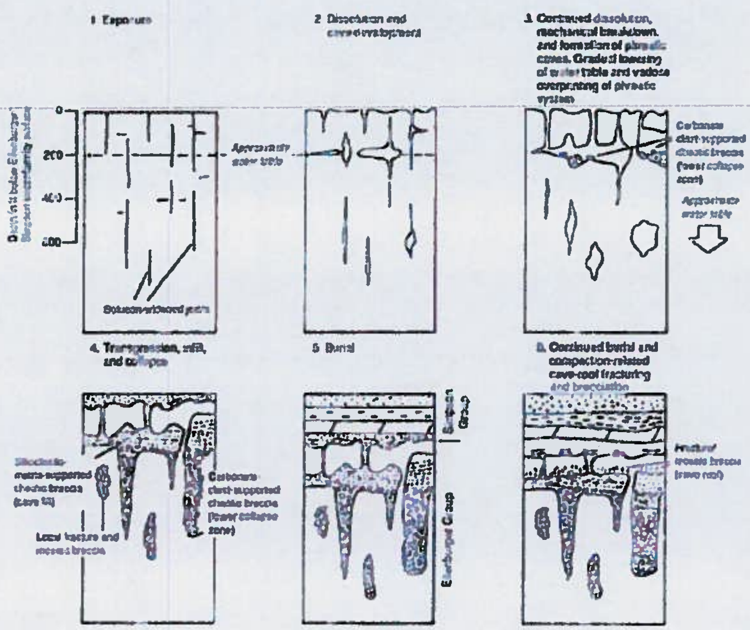
Examiners' Notes: EnerVest Exhibit No. 24 (XTO Exhibit No. 16.)

Note the absence of gas wells along the Newark East Fault. The short irregular red shapes indicate mapped karst features in the Ellenburger Formation.

Compare the interpreted faults on this figure with those presented on Attachment 4.

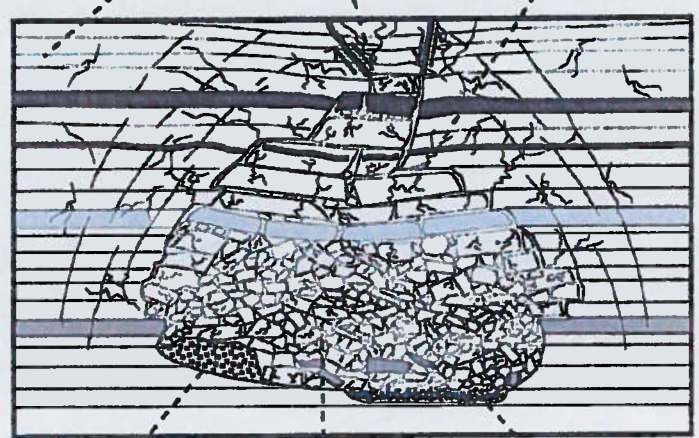
Ellenburger Karst Development

ENERVEST



Karst Development

(Kerans, SEPM 1993)



Karst Collapse Morphology

(Loucks et al, AAPG 2004)

ATTACHMENT 6 09-0296410

Examiners' Notes:

EnerVest Exhibit No. 29. This diagram illustrates the formation of karst and karst collapse structures in the Ellenburger Formation that may result in areas of very high porosity and permeability.

ENERVEST OPERATING LLC
O&G Docket No. 09-0296410
June 15-16, 2015
Exhibit No. 29

BRINGING OUT THE BEST

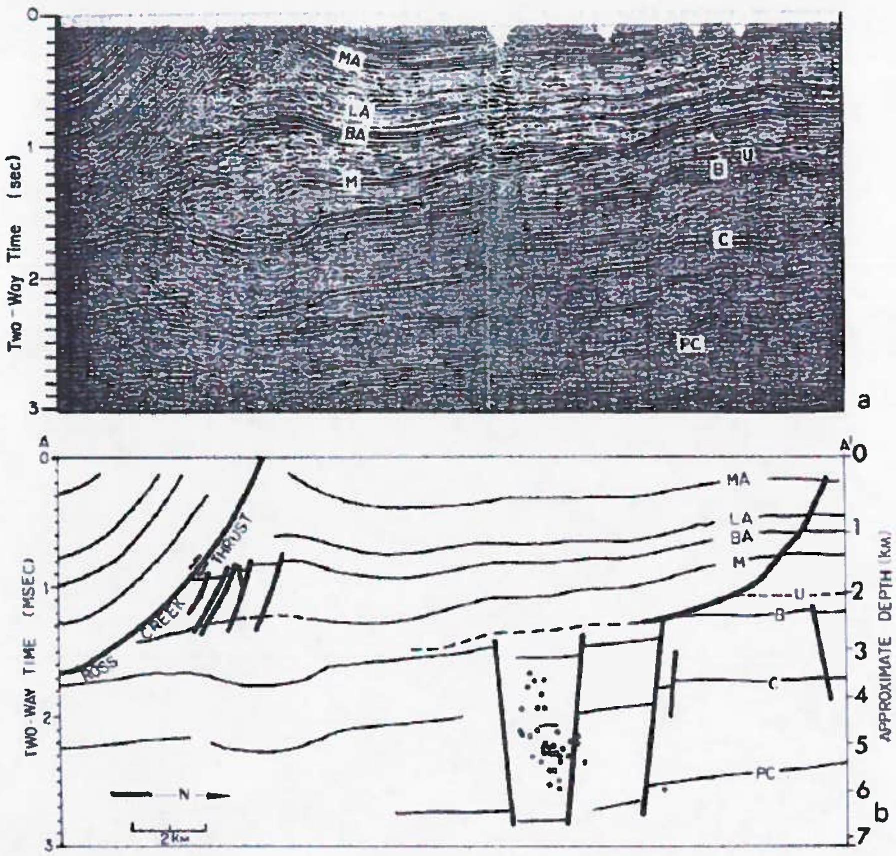


Fig. 3. Reflection seismic section *A–A'* and interpretation. Location of the seismic section shown on Fig. 4. Earthquakes are those relocated by Pujol (1989) and projected parallel to the WNW trending faults. Open circles represent U.S.G.S. data from 1982; closed circles, Portable Array for Numerical Data Acquisition (PANDA) data from 1987. Depths are approximate and were determined using the velocity model of Chiu et al. (ms. in prep.). Reflectors: *MA* = middle Atoka; *LA* = lower Atoka; *BA* = Basal Atoka; *M* = Morrowan; *U* = pre-Morrowan unconformity; *B* = Boone Formation; *C* = top of Cambrian clastics; *PC* = Precambrian reflector.

ATTACHMENT 7

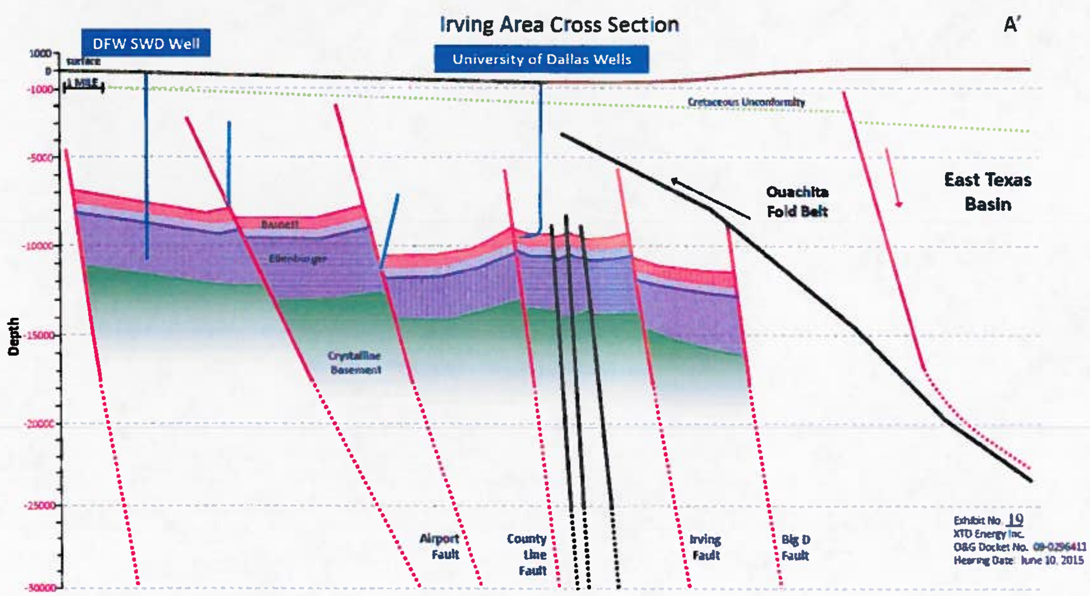
09-0296410

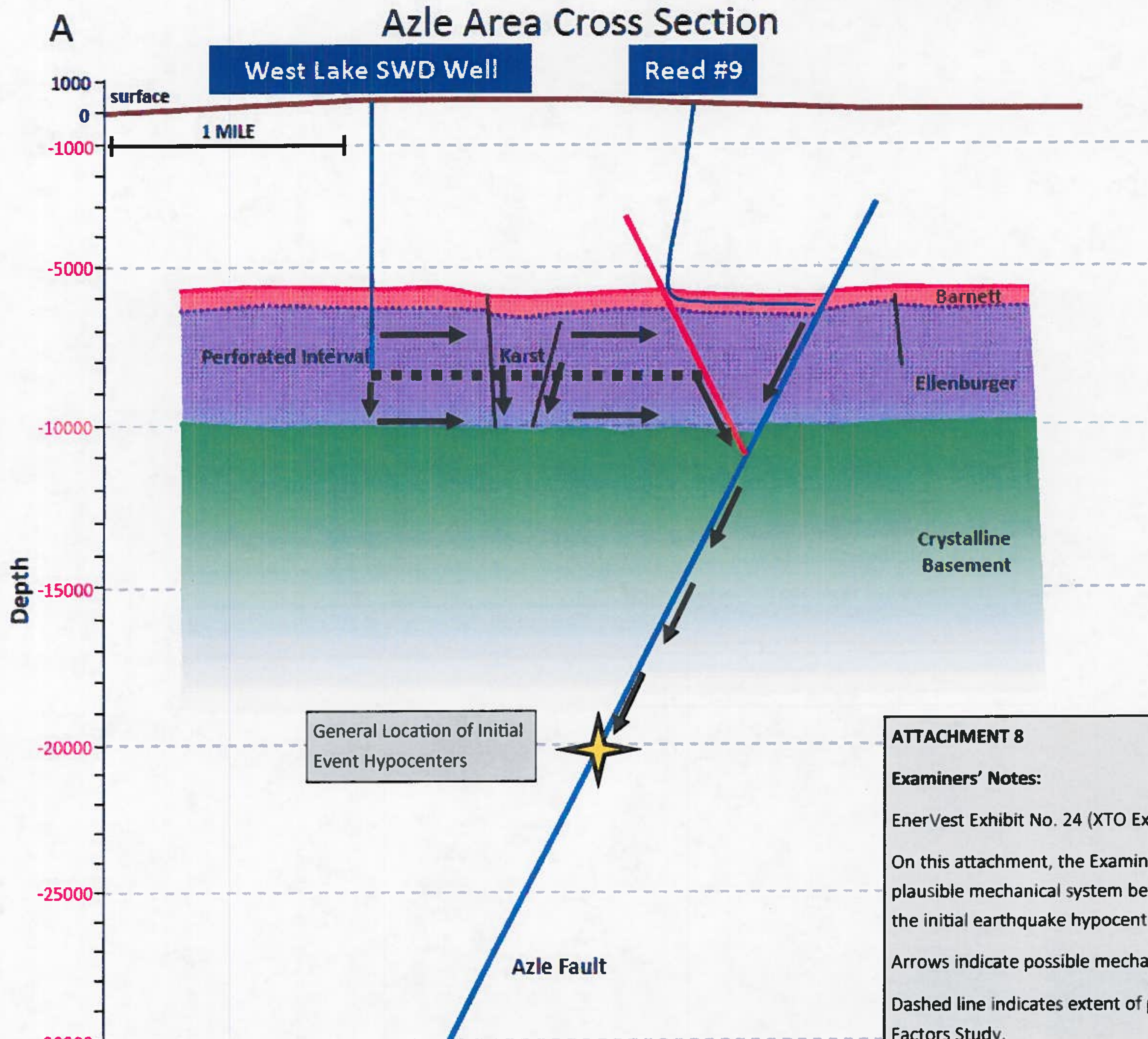
Examiners' Notes:

TOP: EnerVest Exhibit No. 46, illustrating structure in the Enola, Arkansas, area.

BOTTOM: EnerVest Exhibit No. 24 (XTO Exhibit No. 19.), illustrating structure in the Irving, Texas, area.

Note the similarities in structure, including thrust faulting, normal faults, and sedimentary strata from Cambrian through Pennsylvanian overlying Precambrian crystalline basement.





ATTACHMENT 8 **09-0296410**

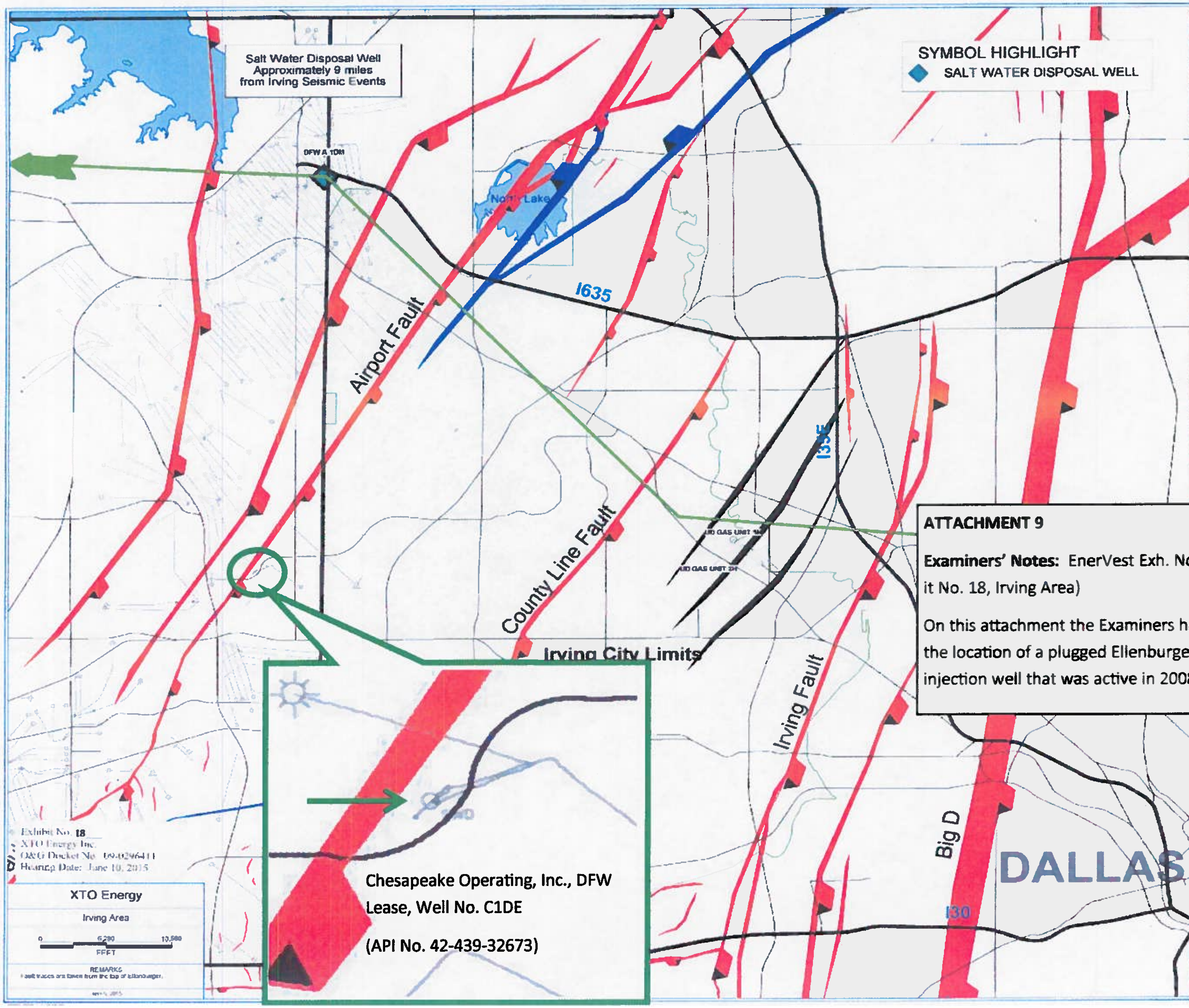
Examiners' Notes:

EnerVest Exhibit No. 24 (XTO Exhibit No. 21)

On this attachment, the Examiners have identified elements of a plausible mechanical system between the injection location and the initial earthquake hypocenter locations.

Arrows indicate possible mechanical pathways.

Dashed line indicates extent of pressure modeling in the Causal Factors Study.



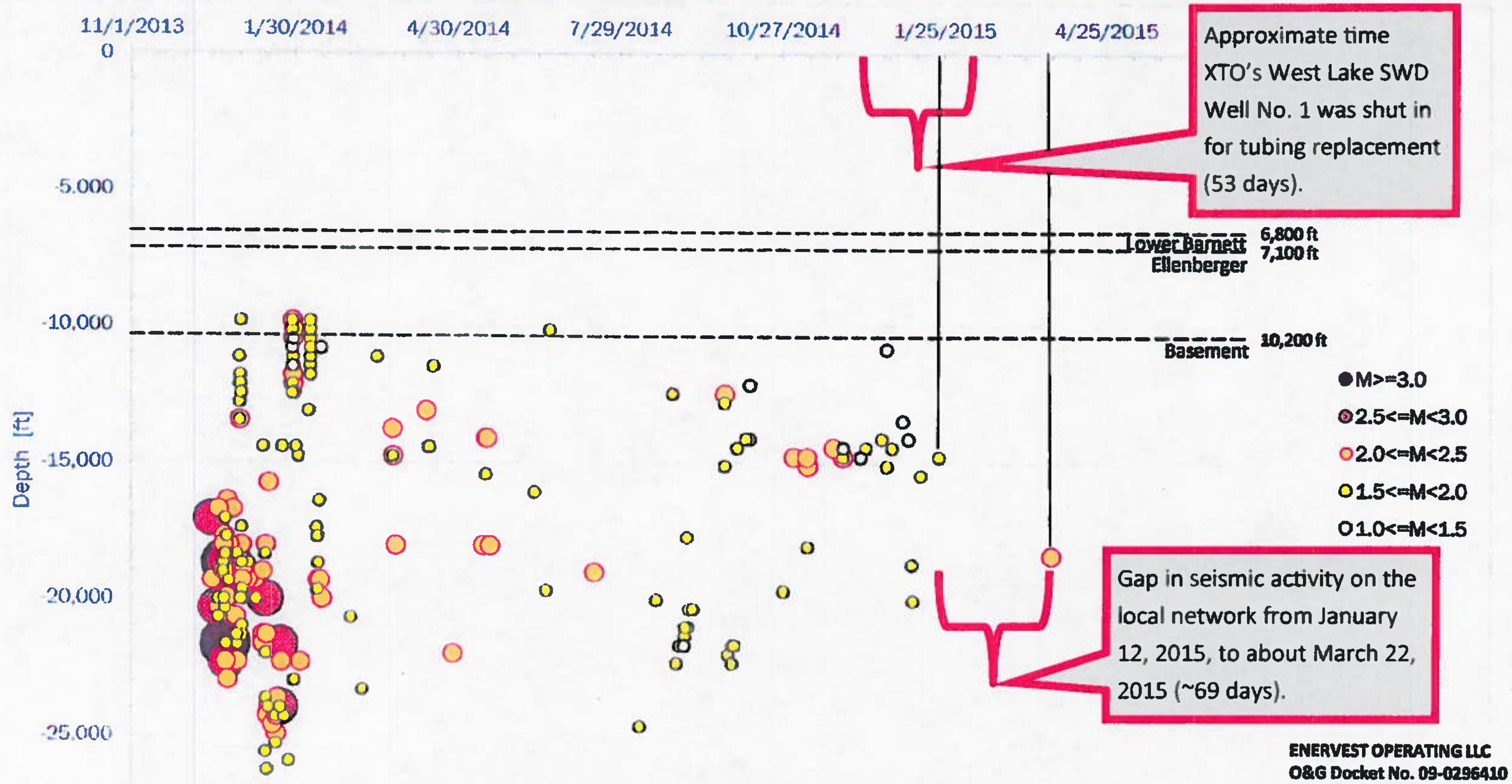
ATTACHMENT 9 **09-0296410**

Examiners' Notes: EnerVest Exh. No. 24 (XTO Exhibit No. 18, Irving Area)

On this attachment the Examiners have identified the location of a plugged Ellenburger Formation injection well that was active in 2008-2009.

Depth of Recorded Events Over Time
Located Using Local Network

ENERVEST



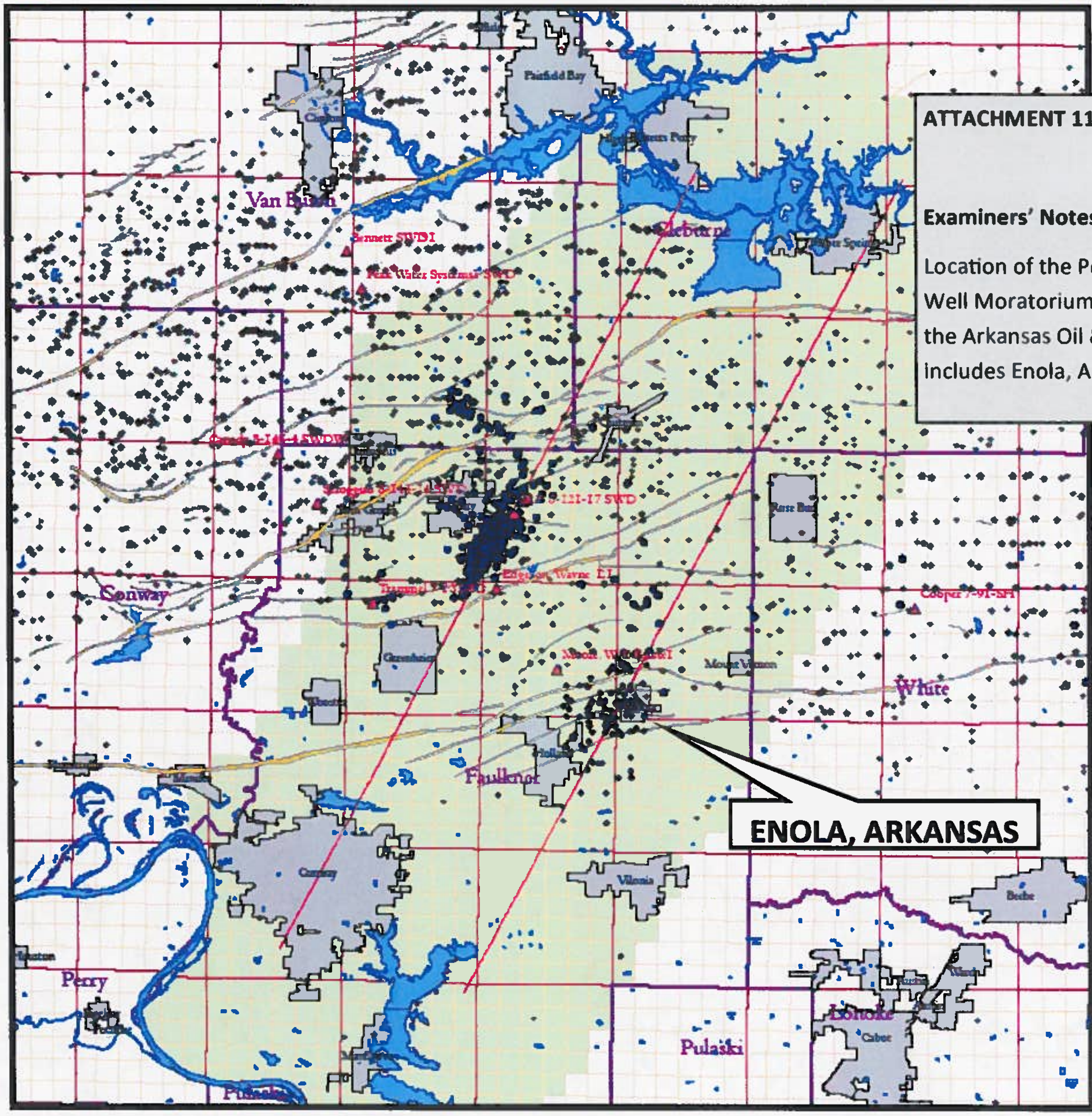
ENERVEST OPERATING LLC
O&G Docket No. 09-0296410
June 15-16, 2015
Exhibit No. 48

ATTACHMENT 10 **09-0296410**

Examiners' Notes: EnerVest Exh. No. 48

Exhibit No. 48 identifies one detected earthquake event on or about March 22, 2015. This event follows an approximately 53 day period in which the XTO West Lake SWD well was shut in. See Attachment No. 2, and the Causal Factors Study's statement about a one to three month delayed response time.

Permanent Disposal Well Moratorium Area



ATTACHMENT 11 **09-0296410**

Examiners' Notes:

Location of the Permanent Disposal Well Moratorium Area established by the Arkansas Oil & Gas Commision and includes Enola, Arkansas.

Arkansas Oil and Gas Commission
Lawrence Bengal, Director

Legend

- Disposal Wells
- Natural Gas Wells
- Enola1982_1989
- USGS_EVENTS_2010
- Proposed Moratorium Center lines
- Faults
- Moratorium Area
- ADMIN_CITY_LIMITS_AHTD_2005_poly

Scale 1:300,000