DAVID PORTER, CHAIRMAN
CHRISTI CRADDICK, COMMISSIONER
RYAN SITTON, COMMISSIONER

RYAN D. LARSON, DIRECTOR

RAILROAD COMMISSION OF TEXAS

HEARINGS DIVISION

Date: August 31, 2015 **Oil & Gas Docket No. 09-0296411**

NOTICE TO THE PARTIES

The attached document is a Proposal for Decision and recommended Final Order issued by the examiner(s) in this case. Under Section 1.141 of the Commission's General Rules of Practice and Procedure, we are required to circulate the document to each party or its authorized representative. This is only a proposal and is not to be interpreted as a final decision unless an official order adopting the proposal is signed and issued by the Commission.

Under Section 1.142 of the General Rules of Practice and Procedure (16 T.A.C. §1.142), you have the right to file a written statement disagreeing with the proposal and setting out your reasons for this position. This document is referred to as "Exceptions" and must be filed with the Docket Services Section of the Hearings Division (Room 12-123 within 15 days of the date above. You have the right to respond in writing to any exceptions filed by another party. This document is referred to as "Replies to Exceptions" and must be filed with the Docket Services Section of the Office of General Counsel (Room 12-123) within 10 days after the deadline for filing exceptions.

In addition to written exceptions and replies, the parties may file with the Commission a one page summary of the case. The summary shall be filed with the Commission **at the time exceptions are due**. The summary is specifically limited to one page and shall contain only information of record or argument based on the record. The summary shall not be submitted in reduced print. If the summary contains any material not of record, has reduced print, or exceeds one page (8-1/2" x 11"), the examiner(s) will reject the summary and it will not be submitted to the Commissioners for their review.

The summary shall contain the name of the party, the status of the party, the name and docket number of the case, the issue(s), the key facts, the legal principles involved (including proposed conclusions of law), and the action requested. (See enclosed form.)

In view of the due dates stated above, all parties are reminded that pleadings are considered filed only upon **actual receipt by the Docket Services Section of the Hearings Division** (Room 12-123). Furthermore, each pleading must be served upon all Parties of Record and a statement certifying such and giving complete names and addresses must be included. Exceptions and replies may not be filed by telephonic document transfer unless otherwise directed by the examiner(s). **An original plus THIRTEEN copies of exceptions, replies and summaries should be submitted to the Commission. PLEASE DO NOT STAPLE.** Further, a copy of these pleadings **must be submitted to each party. IN ADDITION, IF PRACTICABLE, PARTIES ARE REQUESTED TO PROVIDE THE EXAMINERS WITH A COPY OF ANY FILINGS IN DIGITAL FORMAT. THE DIGITAL FORMAT SHOULD BE LABELED WITH THE DOCKET NUMBER, THE TITLE OF THE DOCUMENT, AND THE FORMAT OF THE DOCUMENT.**

The proposal for decision, and all exceptions and replies will be submitted to the Commissioners for their consideration at one of their regularly scheduled conferences. The agenda for the scheduled conferences will be published in the *Texas Register* and posted in the office of the Secretary of State. The conferences are open meetings; you may attend and listen to the presentation of the case.

Via Fax and First Class Mail
Tim George
Representing XTO Energy, Inc.
McGinnis, Lochridge & Kilgore
600 Congress Avenue Suite 2100
Austin TX 78701
Fax No. 512/495-6093

Via Fax and First Class Mail
David Gross
Representing XTO Energy, Inc.
12400 Hwy 71 West Suite 350-230
Austin TX 78738
Fax No. 512/263-2702

Via Hand-Delivery and Email
Lindil Fowler
General Counsel
RRC - Austin

Via Hand-Delivery and Email
David Cooney
Director, Enforcement
General Counsel Division
RRC - Austin

Via Inter-Agency EMail:
David Hill, UIC - RRC, Austin
Lori Wrotenbery - RRC, Austin
Leslie Savage - RRC, Austin

CASE SUMMARY

PREPARED BY: STATUS:

EXAMINER(S):

DOCKET NO./CASE NAME:

ISSUE(S):

KEY FACTS:

LEGAL PRINCIPLES INVOLVED:

ACTION REQUESTED:

RAILROAD COMMISSION OF TEXAS

HEARINGS DIVISION

PROPOSAL FOR DECISION

OIL AND GAS DOCKET NO. 09-0296411

COMMISSION CALLED HEARING TO CONSIDER WHETHER OPERATION OF THE XTO ENERGY, INC., WEST LAKE SWD, WELL NO. 1 (API NO. 42-367-34693, UIC PERMIT NO. 12872), IN THE NEWARK, EAST (BARNETT SHALE) 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:	
Tim George	XTO Energy, Inc.
David Gross	
William Duncan	
Andrée Griffin	
Timothy Tyrrell	
INTERVENOR:	
David Cooney	Oil & Gas Division

PROCEDURAL HISTORY

Notice of Hearing:	April 24, 2015
Date of Hearing:	June 10, 2015
Transcript Received:	June 22, 2015
Proposal For Decision Issued:	August 31, 2015

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 West Lake Salt Water Disposal (SWD) Well No. 1 (API No. 42-367-34693) operated by XTO Energy, Inc. (XTO).[1] The West Lake SWD Well No. 1 injects produced salt water into the Ellenburger Formation in the depth interval from 8,064 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 XTO's West Lake SWD 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 Briar Well No. 1 (API No. 42-49736875) operated by EnerVest Operating LLC, for which a similar hearing was held on June 15, 2015 (Oil & Gas Docket No. 09-0296410).

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:*
>
> *(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;*
>
> *(ii) freshwater is likely to be polluted as a result of continued operation of the well;*
>
> *(iii) there are substantial violations of the terms and provisions of the permit or of commission rules;*
>
> *(iv) the applicant has misrepresented any material facts during the permit issuance process;*
>
> *(v) injected fluids are escaping from the permitted disposal zone;*
>
> *(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 XTO, 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.

Parties

The hearing was called to order on June 10, 2015. At the call of the hearing, two entities requested party status in the proceeding: XTO and the Railroad Commission's Oil & Gas Division. Several other persons were present to observe the hearing but did not request party status. The Examiners granted XTO's motion to set the parties as XTO and the Commission's Oil & Gas Division.

Burden of Proof

The Respondent, XTO, has the burden of proof to show that the injected fluids from its West Lake SWD 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 is a case of first impression before the Commission. 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 likely contributing 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.[4] 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.

Matters Officially Noticed

XTO did not offer the Causal Factors Study into evidence. At the hearing the Examiners did, however, take official notice of the study, to which XTO objected. The Examiners believe the claims made in the Causal Factors Study to be essential to establishing the context of XTO's evidence in response to the study. XTO objected as the

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4 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))

Causal Factors Study was not sponsored by a party or witness who could defend it and be subject to cross-examination. Therefore, XTO argues that the study should be regarded as hearsay and not admissible. The Examiners overruled XTO's objection.[5]

In addition, the Examiners take official notice of the following:

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. 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.

5. 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/).

6. 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).

By letter dated July 31, 2015, the Examiners notified the parties of their intention to take official notice of these documents, incorporate them into the record, and afford the parties an opportunity to contest the materials.[6] By letter dated August 14, 2015, XTO 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.

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

6 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).

Limitations

The purpose of the present matter is to evaluate the evidence in the record to determine whether XTO's West Lake SWD 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 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.

XTO was the only party offering direct evidence into the record in this case–several hours of expert witness testimony and 38 exhibits, including late-filed supplements. XTO's evidence challenged the findings of the Causal Factors Study. The Commission's Oil & Gas Division cross-examined XTO's witnesses and offered one exhibit into the record–the injection permit file for the subject well–but did not otherwise offer a direct case or take a position on the matter. The Commission's seismologist did not participate in the hearing. No evidence was offered in support of the Causal Factors Study.

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 XTO West Lake SWD Well No. 1 as a cause of the recent earthquakes in the Azle-Reno area. 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. 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.[7] 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. The primary fault (identified as the Azle Fault by XTO's witnesses) is about 2 miles east-southeast of the injection well, 2 to 3 miles long and extends into the crystalline basement rock that underlies the sedimentary Ellenburger Formation. The antithetic fault is about 1.2 kilometers southeast of the West Lake SWD well and is less

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7 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.

than a mile long. The antithetic fault cuts across the Ellenburger Formation and penetrates into the crystalline basement rock (see Attachment 1).[8]

The study identifies several natural and anthropogenic (originating in human activity) factors that may reactivate faults and cause earthquakes. These factors alter the stress regime of the subsurface and may include: (1) natural tectonic processes;[9] (2) water table fluctuations; and (3) the removal and the 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).[10]
- 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.[11]
- 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 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

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

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

10 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.

11 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.

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) west 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 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) to contribute to seismic activity. 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.[12] 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 brine. 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 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 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.

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

- 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 the XTO West Lake SWD Well No. 1 and EnerVest Operating LLC's Briar Well No. 1 were obtained from Commission records and based on monthly averages.

- 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).[13] The study states, "*Although uncertainty exists, model-predicted pressure changes are consistent with values that are known to trigger earthquakes on critically stressed faults.*"[14] 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).[15] 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.[16] 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.*"[17] This hypothesis was not explored.

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13 Causal Factors Study, Table 1.

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

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

16 Causal Factors Study, Figure 4.

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

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.*"[18] 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.

XTO'S EVIDENCE

Three witnesses testified for XTO. William Duncan is a reservoir engineer who currently serves as an environmental and regulatory advisor for XTO. Mr. Duncan's testimony focused on the West Lake SWD Well No. 1, including the injection permit, well construction, and operational history. The testimony of Andrée Griffin, XTO's Vice President of Geology and Geophysics, focused on the geology of the Fort Worth Basin in general, the geology of the Azle-Reno area (within the Fort Worth Basin) in particular, and on the regional Barnett-Paleozoic total petroleum system. Timothy Tyrrell, a geoscience and technical manager for XTO, testified about his analysis of the earthquakes in the Azle-Reno and Irving, Texas, areas.

XTO's Evidence – West Lake SWD Well No. 1

On February 19, 2009, the Commission issued Permit No. 12872 to XTO for its West Lake SWD Well No. 1 to dispose of non-hazardous oil and gas waste by injection into a porous formation not productive of oil and gas. The permit authorizes disposal of salt water into the Ellenburger Formation in the subsurface depth interval from 8,064 feet to 9,329 feet. The maximum permitted injection volume is 25,000 barrels per day (bpd), and the maximum operating surface injection pressure is 2,600 psi. The permit application was initially protested by the Upper Trinity Groundwater Conservation District and Devon Energy Production Company, L.P. XTO reduced its initial requested maximum surface injection pressure from 3,800 psi to 2,600 psi, and the protests were withdrawn. Absent protests, Commission staff administratively approved the application and issued the permit.

The well was completed to a total depth of 9,334 feet on May 23, 2009. XTO stated a show of natural gas in the Ellenburger Formation was observed while the West Lake SWD Well No. 1 was being drilled. XTO reports the base of usable quality ground water is at a depth of 620 feet. Surface casing (9 5/8-inch) was set at a depth of 756 feet with cement circulated to the surface. The production casing (7-inch) was set to a depth of 9,329 feet. A differential valve (DV) tool at 7,991 feet was used to cement the production casing from 9,329 feet to 5,730 feet, which was confirmed by a cement bond log. The production casing was perforated from 8,064 feet to 9,250 feet in the Ellenburger Formation. The original Form W-14 indicated 4 1/2-inch injection tubing would be used in the well, but a Form G-1 filed after well completion in 2009 indicated 2 3/8-inch injection

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[18] Causal Factors Study, p. 1 (emphasis added).

tubing set with a packer at a depth of 7,964 feet. A Form G-1 filed on June 3, 2015, corrected the well completion to indicate 4 1/2-inch tubing set at 7,967 feet.

Injection began in June 2009. The maximum daily average injection volume was 16,977 bpd in September 2009. The maximum average monthly surface injection pressure was 1,198 psi in August 2010. In July and August, 2010, the maximum surface injection pressure was measured at 1,740 psi. Through May 2015, the well has injected 22,622,904 barrels of salt water into the Ellenburger Formation.[19] Three events in the history of the injection well are of note:

- In the third quarter of 2012, XTO reported the well developed mechanical problems with one of the injection pumps, resulting in decreased injection capacity for a period of time–about six to nine months. Daily injection volume during this time was about 8,000 bpd and the average surface injection pressure about 500 psi.

- In August 2013, XTO began to produce about seven wells in its Indian Hills unit, increasing the salt water volume sent to the West Lake SWD Well No. 1 for disposal from about 8,000 to 12,000 bpd with a parallel increase in the average surface injection pressure from about 600 to 800 psi.

- From about mid-December 2014 through mid-February 2015 the well was shut in for tubing replacement. The well resumed service in late February 2015, following a successful Form H-5 mechanical integrity test that was witnessed by Commission staff from the Abilene District (7B) Office.

On February 13, 2015, after the well had been shut in for 53 days for tubing replacement, XTO measured the stabilized bottom hole pressure at the mid-perforation depth (8,656 feet) to be 4,393 psi. Based on an analysis of the drilling mud weight records from 2009, XTO estimates the initial reservoir pressure of the Ellenburger Formation at the mid-perforation depth to be about 4,400 psi. XTO concludes that injection of salt water into the Ellenburger Formation has not resulted in a change in reservoir pressure.

The well currently serves 233 XTO gas wells completed in the Newark, East (Barnett Shale) Field. Combined, these gas wells currently produce 5,000 to 10,000 bpd salt water requiring disposal. From March through May 2015, the well injected an average of 6,646 bpd. The average daily surface injection pressure during this time was 442 psi.

The West Lake SWD Well No. 1 shares a well pad with XTO's Wilkerson Olsovsky Unit A 1H, a horizontal well completed in the Newark, East (Barnett Shale) Field, which directly overlies the Ellenburger Formation in this area. The Wilkerson Olsovsky well entered production service prior to the commencement of injection activities on the West

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[19] Exhibit No. 9.

Lake SWD Well No. 1. Gas and water decline curve analysis from the Wilkerson Olsovsky well indicates there is no fluid communication between the two formations at this location.

XTO'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.[20] XTO provided extensive testimony and exhibits characterizing the basin in terms time, stratigraphy, tectonics, structure, erosion, and the total petroleum system resulting through the interplay of these combined geologic elements. XTO's analysis of the Basin was based on 2-D and 3-D seismic data, well data, and published literature.

Attachment 4 depicts a portion of the Fort Worth Basin area from Azle in the west to Irving in the east, including mapped faults in the Azle-Reno and Irving areas.[21] An associated cross section illustrating the interpreted structure and stratigraphy of the Fort Worth Basin is presented on Attachment 5.[22]

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.[23] 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 (~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 (these faults are evident in the Irving area on Attachment 4). The Ouachita uplifting also stimulated the erosion of source rock

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20 Exh. No. 14.

21 Exh. No. 16.

22 Exh. No. 17.

23 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.

ultimately deposited in the basin as the extensive sequence of Pennsylvanian-aged formations.

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-aged 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 system (as shown on Attachment 3) strikes southwest to northeast across the northern half of the basin. 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).[24] The Newark East fault system has a normal disposition that is down-thrown on the northwest side. Notably, as shown on Attachment 4, 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 3,000 feet thick and extends across the entire basin. In the West Lake SWD Well No. 1 the top of the Ellenburger was encountered at a depth of 7,064 feet and the top of the Ordovician unconformity was reported at a depth of 7,059 feet. The base of the Ellenburger/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 perforated injection interval. The carbonate Ellenburger was

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[24] Exh. No. 24A, p. 6.

deposited as a limestone but 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. Mapped karst features are illustrated (small, irregular red shapes) on Attachment 6.[25] The Ellenburger Formation is not indicated to be a hydrocarbon source rock.[26]

The Mississippian-age Barnett Shale Formation extends across the entire basin. The Barnett Shale is considered to be the source rock for nearly all of the hydrocarbons in the Basin. Deposited in a low-energy environment, the high organic content Barnett Shale increases in thickness from about 50 to 1,000 feet as one travels from west to east across the basin. The formation has an average porosity of 6 percent and nano-darcy permeability. In the West Lake SWD Well No. 1 the top of the Barnett Shale was encountered at a depth of 6,715 feet.

Pennsylvanian-age formations (Marble Falls, Bend, Strawn, Canyon and Cisco) form 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.[27] Geologic process acting upon the highly organic Barnett Shale provided the conditions necessary and optimal 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

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[25] Exh. No. 20.

[26] Exh. Nos. 24 & 24A.

[27] Exh. No. 24A.

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.[28] According to XTO, 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 is 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.

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

The geologic structure of the Azle-Reno area is dominated the Mineral Wells-Newark East normal fault system (the entire trend is shown on Attachment 3; the eastern Newark East segment is shown on Attachment 4). The Newark East fault zone impacts hydrocarbon production in the area. As shown on Attachment 4, the fault zone has resulted in a halo-zone devoid of wells. Ms. Griffin stated that some areas the fault zone adversely affect hydrocarbon production.[29] XTO interprets the Newark East Fault to be splaying–or breaking into a related series of smaller faults–in the Azle-Reno area. The Azle Fault, as illustrated on Attachment 6, is a deep-seated splay fault of the Newark East fault system that is rooted in the Precambrian crystalline basement. The Azle Fault is also accompanied by a shallow antithetic fault.

The Ellenburger Formation in the Azle-Reno area is marked by many karst-collapse structures. These structures developed in the late Ordovician time–or perhaps Silurian or Devonian, for which there is no stratigraphic record–when the Ellenburger 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. The karst collapse structures are limited to the carbonate Ellenburger Formation; some are mapped on Attachments 4, 5 and 6. The Ellenburger Formation porosity averages 5.5 percent and ranges from 1 to 20 percent. The average permeability is 10 md to 100 md, and ranges from 1 md to 1,000 md.

There is some production of natural gas from the Ellenburger in the area. The Barnett Shale is considered to be the source rock for Ellenburger hydrocarbons.[30] XTO identified three wells located from eight to 10 miles north and west of the West Lake SWD that have produced a combined 1.2 billion cubic feet (BCF) of gas from the Ellenburger Formation. As mentioned, a gas show was encountered in the Ellenburger while drilling

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28 Exh. No. 24. Tr. pg. 124, lns. 1-8.

29 Tr. pg. 167, lns. 4-9.

30 Exh. Nos. 24 & 24A.

the West Lake SWD Well No. 1. XTO asserts the Ellenburger 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.

XTO's Evidence – Earthquake Activity

On November 11, 2013, a M2.8 seismic event was felt by persons in the Azle-Reno area and recorded by the USGS National Earthquake Information Center (NEIC) regional seismograph network. Similar events were experienced on November 13, 19, 26, and December 3, 2013. From November 2013 through January 2014, the USGS NEIC catalogued 27 earthquakes in this area, including two M3.6 events.[31]

In response to the earthquake activity in November and early December 2013, seismologists at SMU and USGS deployed a temporary seismic network to the area. The addition of the temporary network provided the ability to improve knowledge of event locations horizontally (to about 1 kilometer, or 0.6 miles) and vertically, refine event magnitudes, and characterize the subsurface fault geometry associated with the events. The most recent recorded felt event in the Azle-Reno area was M2.5 and occurred on April 12, 2014. The temporary array allowed for detection of events that were too small to be felt. XTO provided data from the SMU temporary network of nearly 400 earthquakes through January 12, 2015, indicating continued seismic activity at magnitudes below the sensation threshold.[32]

XTO provided evidence of two historical records of felt earthquake activity in the region. On September 18, 1985, a M3.3 to M3.4 event located near Valley View, Cooke County, about 42 miles northeast of the West Lake SWD Well No. 1, was catalogued by the USGS NEIC and felt by persons in the area. XTO locates this event in the Sherman Marietta Basin, which is northeast of the Muenster Arch and outside of the Fort Worth Basin.[33]

Second, on March 20, 1950, an earthquake was reported near Chico, Texas, which is about 25 miles north-northwest of the West Lake SWD 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.*"[34] The magnitude was later estimated to

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31 Causal Factors Study, p. 3.

32 Exh. No. 36.

33 Exh. Nos. 25 & 26; tr. pg. 72, lns. 5-6.

34 Exh. No. 26 (emphasis added).

be M3.3 to M3.8. According to XTO Exhibit No. 26, the location of the Centerville Powerhouse Camp is unknown.

XTO's Evidence – Analysis of Azle-Reno Area Seismic Activity

XTO analyzed the Azle-Reno area seismic data as a sequence of events in time and space, yielding an interpretive picture distinct from that presented by the Causal Factors Study. The first five recorded events were detected by the USGS NEIC regional network from November 11, 2013, through December 3, 2013. The data quality of these recordings was not sufficient to locate the event hypocenters more accurately than 5 to 10 kilometers (3 to 6 miles) horizontally. For vertical resolution, standard 5 kilometer depths were assigned per USGS practice.

XTO's Exhibit No. 33 provided a time step sequence illustrating the progression of earthquakes over time and distributed vertically near the Azle Fault, the antithetic fault, the West Lake SWD well, and two nearby producing Barnett Shale gas wells. The graphical data presentation indicates the following (Attachment 7[35]):

- Time Step 3 (initial events from November 11, 2013 through December 15, 2013): The first six events, the last of which was the first event to be accurately located with the local network.
- Time Step 6 (all events through January 27, 2014): Most of the events concentrated on the parent Azle Fault within the crystalline basement rock. More than half of the recorded events were estimated to occur at depths greater than 20,000 feet.
- Time Step 7 (all events through January 28, 2014): on January 28, 2014, 77 events were recorded, most of which (about 51 events) occurred along the antithetic fault above 10,000 feet, in the Ellenburger or higher strata, above the crystalline basement rocks. Only 26 events were estimated at depths below 10,000 feet, the deepest being estimated at 12,457 feet.
- Time Step 31 (all events through January 15, 2015): Depicts all recorded event data provided at the hearing; the last felt event occurred on April 12, 2014.

Stepping through the data as a time sequence of events, XTO demonstrated that the early events occurred deep on the parent fault within the crystalline basement rock. The deeper events represented tectonic stress release in the basement and, at least in part, transferred to the antithetic fault. On January 28, 2014, stress accumulated on the antithetic fault was released by an earthquake swarm.

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35 Exh. No. 33.

XTO testified to data developed by EnerVest that 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. XTO argues that EnerVest's analysis demonstrates that the five earliest recorded events were, in fact, deep events originating in the crystalline basement. Thus, the earliest evidence of felt events originated in the crystalline basement rocks underlying the Ellenburger Formation disposal zone.

XTO's Evidence – Faults and Seismic Activity in the Irving, Texas, Area

XTO's geological and geophysical testimony gave significant attention to the Irving, Texas, area, which is about 40 miles to the east-southeast of the Azle-Reno area. According to the testimony, the Irving area is: (1) also in the Fort Worth Basin; (2) overlies known normal faulting similar to the Azle area; (3) has experienced recent seismic activity; but (4) does not have a history of significant nearby petroleum production or deep injection activities. Therefore, XTO asserts, the Irving area is a model demonstrating ongoing normal tectonic stresses and resultant seismic activity in the Fort Worth Basin that is unrelated to deep well injection.[36]

Attachment 4 illustrates a series of parallel *en echelon* normal faults located from the Dallas-Fort Worth (DFW) International Airport to west Dallas. The normal faults are generally parallel to the Ouachita Front. Several of the normal faults are accompanied by antithetic normal faults. Three faults with apparent strike-slip (wrench) motion (primarily lateral displacement) are shown in black.

A sequence of earthquakes began in the Irving area on April 17, 2014, marked by a felt earthquake of M2.4 event on that day. Seismologists at SMU and USGS installed a local network of seismograph stations following a M3.3 event on November 23, 2014. The rate of earthquakes increased significantly in January 2015. SMU and USGS have recorded five events greater than M3 during this sequence. On February 26, 2015, the SMU and USGS researchers issued a preliminary report on the Irving sequence, which documented efforts to study the recent seismicity. The preliminary report concludes: "*Most of the earthquakes are located in the shallow crystalline basement (granites) below the sedimentary rocks...*"[37] The events occurred at depths of 4.5 to 7 kilometers (about 14,800 to 23,000 feet), and follow linear trends consistent with fault traces. The preliminary report did not reach conclusions about causation.

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36 As shown on Attachment 4, the Azle-Reno and Irving areas are separated by a large area with no mapped faults. According to XTO, the gap in interpreted structural features across northern Tarrant County is due to the lack of quality seismic data and deep well control in the mid-cities area, and is not interpreted to be an area without faulting.

37 Exh. No. 29.

XTO obtained refined seismic event location information from the SMU and USGS seismologists. XTO plotted this information on its interpretation of geologic structure based two- and three-dimensional seismic exploration data. Most of the refined seismic event locations fall along three strike-slip faults (Attachment 8).[38] XTO did not offer a map of the Irving area depicting the surface distribution of earthquake epicenters, nor did XTO offer a time-sequence analysis of the Irving events, as it did for those in the Azle-Reno area.

XTO asserts the Irving earthquake activity is unrelated to oil and gas activity because there is no significant oil and gas activity in the area. XTO stated that the nearest deep injection well to the Irving seismic activity to be located at the north end of DFW Airport, about 9 miles northwest of the center of Irving seismic activity. Further, XTO identified two gas wells near the center of the Irving seismic activity, UD Gas Unit Well Nos. 1H and 2H (API Nos. 42-113-30147 and 42-113-30189, respectively). These two wells–one of which never produced and the other was marginal–were completed in the Barnett Shale in 2009. The cumulative production was about 400 million cubic feet of gas, ending in 2012.

XTO's Evidence – Critique of the Causal Factors Study

XTO'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 XTO's injection and seismicity in the Azle-Reno area.

1. Absence of Historical Earthquakes

XTO believes the Causal Factors Study did not adequately consider the potential for natural seismicity in the Fort Worth Basin, and did not thoroughly characterize the basin in terms of structure and tectonics. XTO asserts the Irving earthquake sequence beginning in 2014 demonstrates the Fort Worth Basin continues to experience seismic activity caused by natural tectonic processes. And, at least anecdotally, the 1950 and 1985 events affirm recent historical activity. Further, the Newark East and Irving fault systems indicate a long geologic history of tectonic activity–which was not considered by the Causal Factors Study. In the case of the Newark East fault system, these tectonic processes were essential for the formation of the enormous gas reserves in the Boonesville (Bend Conglomerate, Gas) and Newark, East (Barnett Shale) fields.

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38 Exh. No. 28.

2. *Earthquake Sequence*

XTO understands the Causal Factors Study to conclude the earthquake events first occurred on the antithetic fault in the Ellenburger Formation.[39] Further, XTO asserts the Causal Factors Study's graphical representation of individual events misrepresents the spatial location of the faults with respect to the West Lake SWD Well No. 1 (see Attachment 1). The Causal Factor Study's Figure 2a identifies events clustered between the antithetic fault and the disposal well, but does not accurately represent the dip of the faults or the spatial and temporal distribution of events on them as they occurred. Figure 2b does not adequately clarify the sequencing, either. XTO contends the Causal Factors Study does not accurately represent the progression of earthquakes, which originated on the primary Azle fault at depths of about 20,000 feet, and then generally spread to shallower locations on the antithetic fault.

3. *Fluid Pressure Modeling*

XTO identified a number of deficiencies in the modeling program undertaken by the Causal Factors Study. These deficiencies are summarized below:

- 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 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.

- 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 include stimulation flow-back, not connate water production.

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39 Tr. pg. 222, ln. 22 to pg. 223, ln. 5.

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

XTO asserts the Causal Factors Study's pressure model contained severe flaws in design and scope. Even with these flaws, the model does not estimate pressure changes due to injection at the location of initial rupture.

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.[40]

Therefore, the Examiners conclude that the evidence in the record does not support a finding of fact that XTO's West Lake SWD Well No. 1 is likely contributing to seismic activity. The Examiners recommend entry of an order maintaining XTO's current disposal permit for its West Lake SWD 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 elements of this system are the Ellenburger Formation and the existing fault structures (Attachment 9).[41]

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 22 million barrels of water from XTO's West Lake SWD well,

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40 The record, however, does not support a finding that injection activity is definitively unrelated to XTO's injection activities. XTO, for its part, was successful in identifying several significant deficiencies in the Causal Factors Study's modeling methodology and results. XTO 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.

41 Modified from Exh. No. 21.

and after an extended shut-in period there was no evidence of residual formation pressure above initial conditions at the West Lake SWD Well No. 1. 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
- Potential porosity and permeability development along the faults and fault zones which transect the formation.

XTO estimates the average porosity of the formation to be about 5.5 percent and the average permeability ranges from 10 md to 100 md. 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.

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 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. XTO's Exhibit Nos. 25 & 26 identified two events occurring in 1950 and 1985. The Examiners have taken official notice of documents that undermine the reliability of the 1950 earthquake reported to occur in Chico, Texas:

- Exhibit No. 26, an excerpt from a 2002 book entitled <u>Texas Earthquakes</u>, 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.[42]

- 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.

The Examiners conclude the reported 1950 event near Chico, Texas (25 miles north-northwest of Azle-Reno), most likely occurred in Chico, California, and was mis-reported in the records of the US Coastal and Geodetic Survey (precursor agency to the USGS).

XTO also reported a M3.3 to M3.4 event occurred on September 18, 1985, near Valley View in Cooke County, about 42 miles northeast of the West Lake SWD Well No. 1. This event was catalogued by the USGS NEIC network and felt by persons in the area. The Valley View earthquake was a single felt event reported by multiple sources. It did not occur–or at least was not reported–as a sequence or swarm of felt events such as those experienced in Azle-Reno and Irving. The Examiners conclude this event was not located in the Fort Worth Basin. Instead, it was located in the Sherman Marietta Basin, which is northeast of the Muenster Arch (see Attachment 3).

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 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 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:

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42 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.

- 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 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 XTO'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 10; it is close to the Airport Fault.[43] 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 XTO 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 injection zone. Shallow events 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

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[43] XTO Exhibit No. 18.

a preliminary conclusion that most of the earthquakes in the Irving area are located in the shallow crystalline basement rocks.[44]

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.[45]

- 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 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*

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44 Exh. No. 29.

45 39 Tex. Reg. 8990 (2014).

per square inch as a conservative number." 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.[46]

- 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."* 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.[47]

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*," 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 XTO in the Causal Factors Study's modeling are generally legitimate. The modeling effort 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.)

Examiners' Analysis – Formation Pressure in the Ellenburger Formation

XTO asserts the formation pressure within the Ellenburger has not changed since the well was completed. XTO estimates the initial formation pressure based on drilling mud weight to be 4,400 psi. In February 2015, the formation pressure following a 53-day shut-in period was 4,393 psi. The difference in these two values, the Examiners agree, is within the margin of error for the measurement methodologies.

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46 39 Tex. Reg. 8995-8996 (2014).

47 39 Tex. Reg. 8990 (2014).

While this information is useful, it is not necessarily conclusive. The second measurement followed a 53-day shut-in period in which injection activities were suspended. 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?

The evidence in the record is not sufficient to evaluate a temporal correlation, if any, between injection and seismicity following the 53-day shut-in period in early 2015. The last seismic event in evidence occurred on January 12, 2015. The Examiners requested XTO provide available Azle-Reno area seismic data from January 12, 2015, through May 31, 2015. XTO responded that the January 12, 2015, event was the most recent data it had received from researchers at SMU.

XTO 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 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. For example, the surface injection volume and pressure increase from August to October 2013 preceded the onset of seismicity in November 2013, by which time about 19 million barrels had been injected. Whether a local rate and pressure increase could cause a pressure disturbance at the location of rupture is a relevant question.

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

XTO 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.[48] In addition, the Newark East Fault dips to the northwest, while the Irving area normal faults dip to the east-southeast. The area between the two zones did not have sufficient data to map.[49] The Examiners conclude there is insufficient evidence

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48 Tr. pg. 87, lns. 14-22; Tr. pgs. 95-96; Exh. No. 24A.

49 Tr. pgs. 163-164.

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.

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 do not know enough about the stress regime to anticipate which areas are near failure. Injection-induced seismic events are generally recognized to result when a pressure disturbance caused by injected fluid is the stimulus that brings a fault that was already critically-stressed by natural processes to failure. 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 start toward understanding this issue, 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 XTO West Lake SWD 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 XTO West Lake SWD 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 XTO's' disposal permit for its West Lake SWD 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 XTO's West Lake SWD 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.

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 West Lake SWD 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 XTO's West Lake SWD 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 XTO's West Lake SWD 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 XTO's current disposal permit for its West Lake SWD 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.

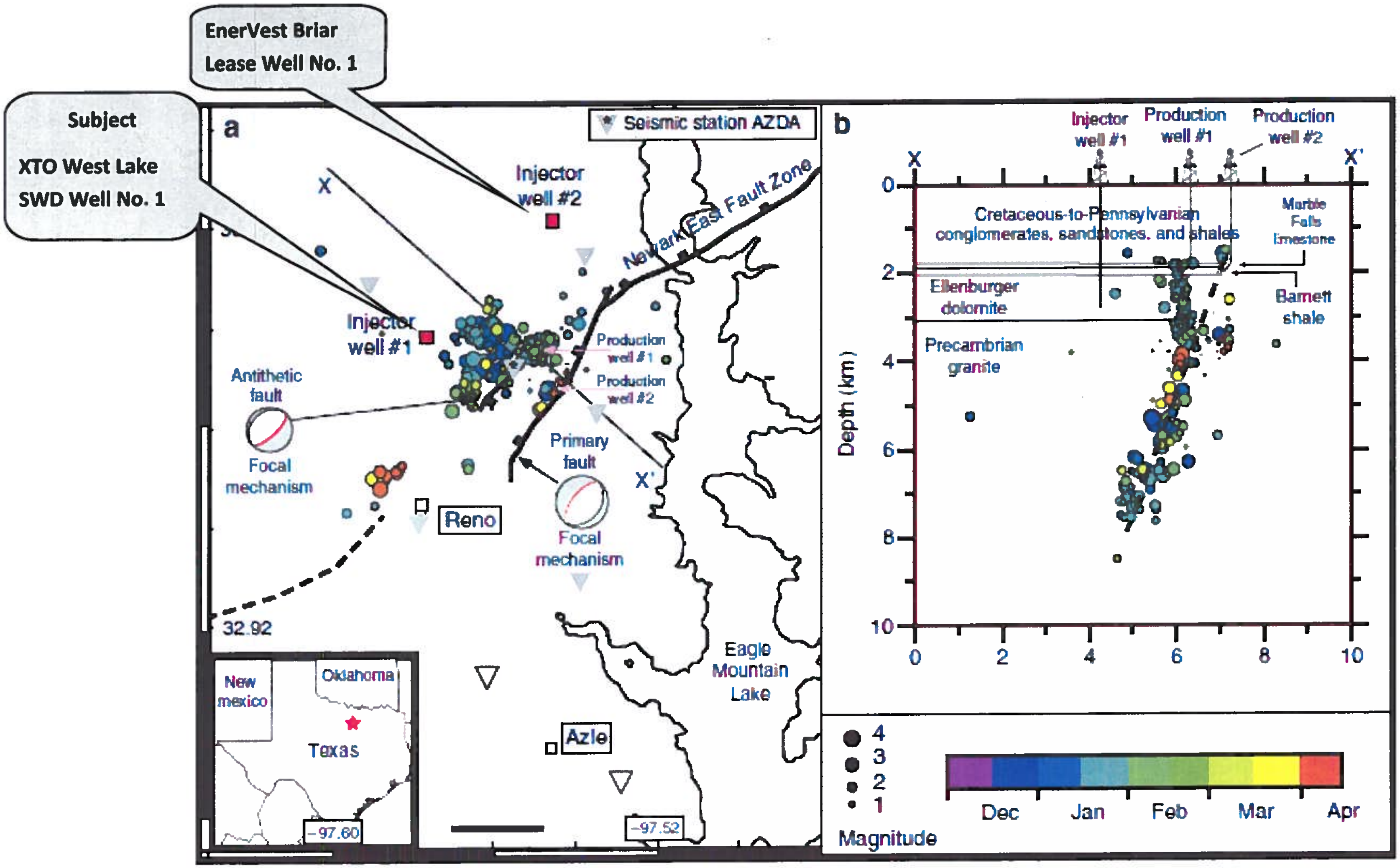


Figure 2 | Azle Earthquake locations and regional geologic structure. Map showing the location of NEFZ (black) at the top of the Ellenburger formation, inferred faults (dashed) at the top of the Ellenburger formation, injection wells (red squares), two production wells (API 36734045 and 36734139) with 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 **09-0296411**

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 zoon 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.

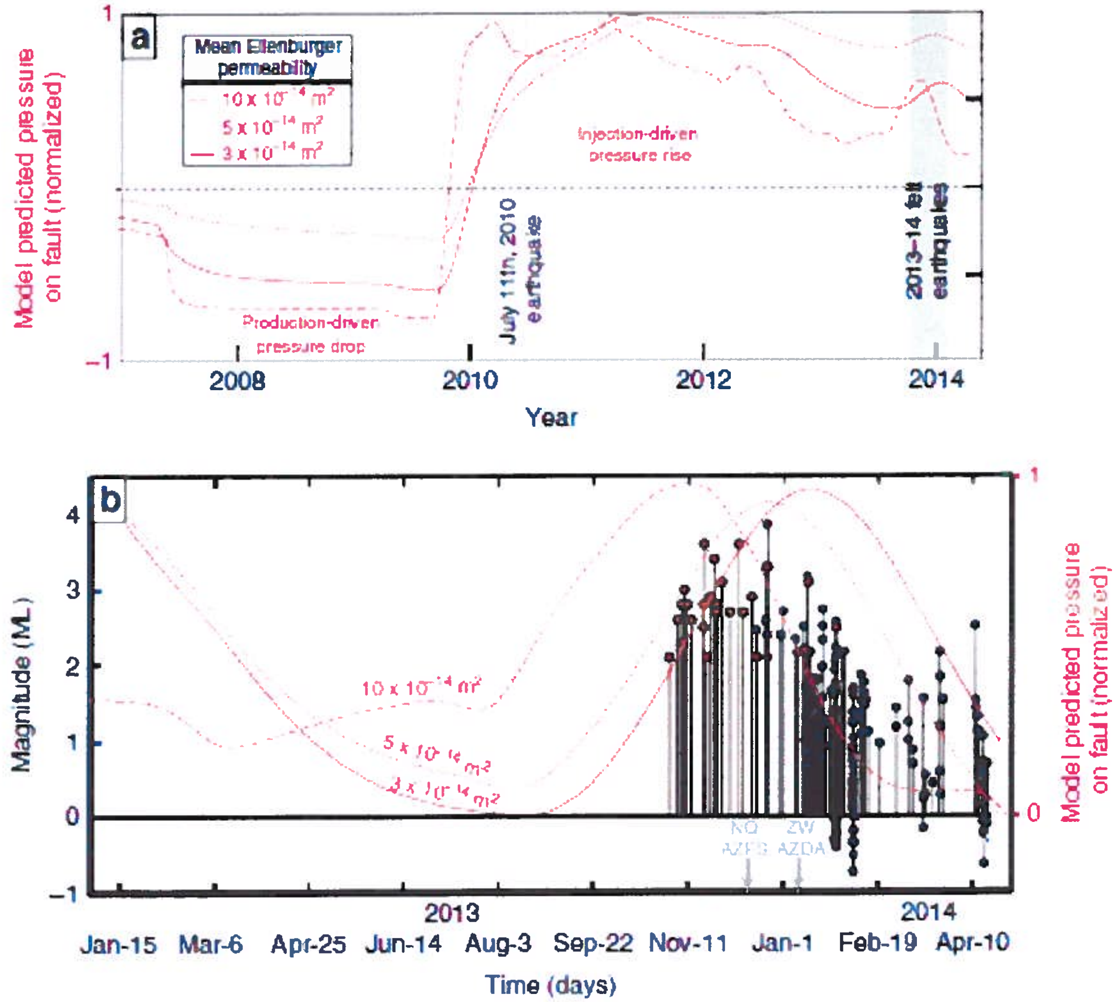


Figure 4 | Pressure at the antithetic fault versus time. Modelled pressure versus time at the antithetic fault, directly below seismometer AZDA (Fig. 2a) (**a**). Results include three different mean Ellenburger permeability values and demonstrate earthquake activity correlates in time with a local pressure 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 **09-0296411**

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.

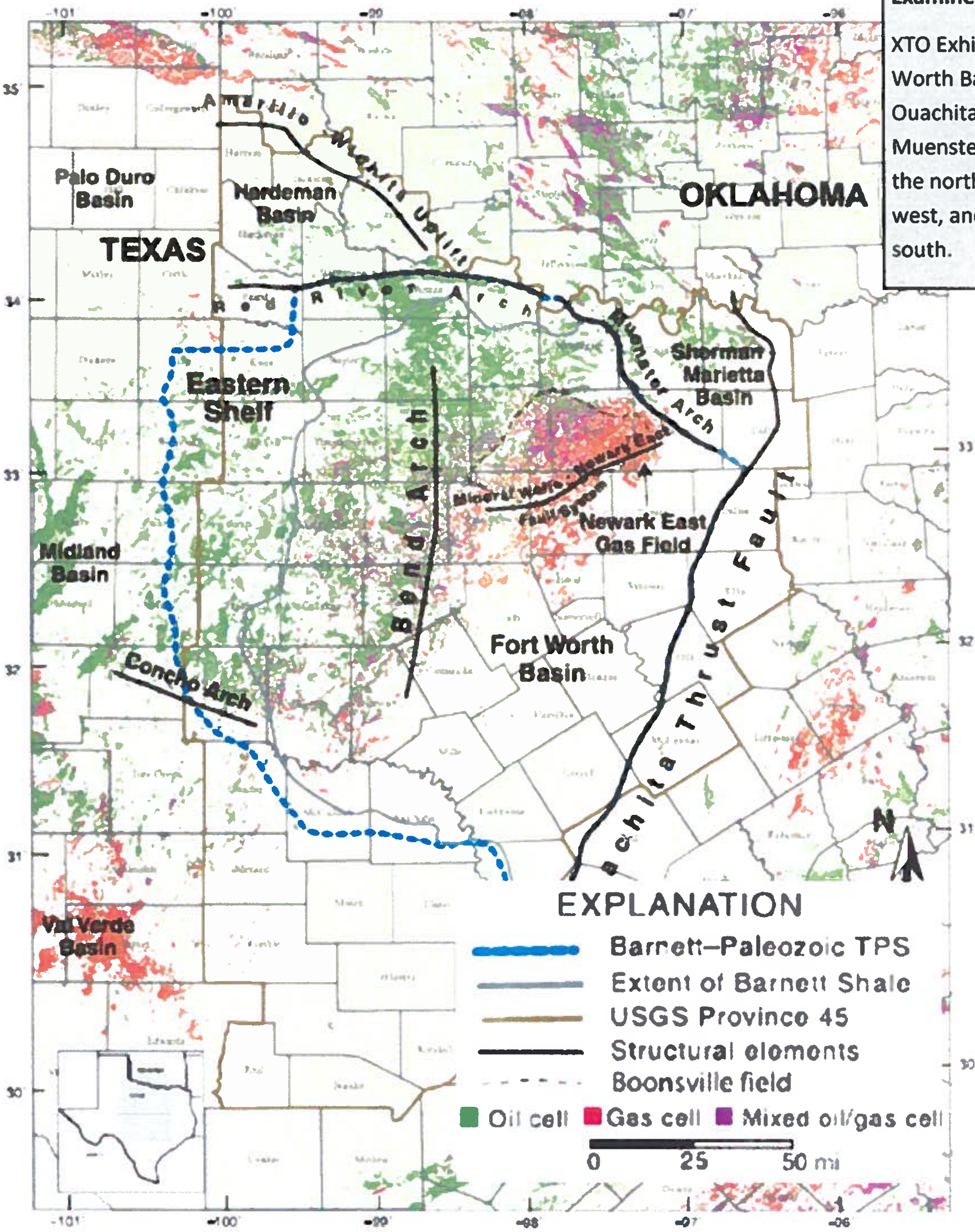
Exhibit No. 14
XTO Energy Inc.
O&G Docket No. 09-0296411
Hearing Date: June 10, 2015

Geologic Framework Map
Fort Worth Basin

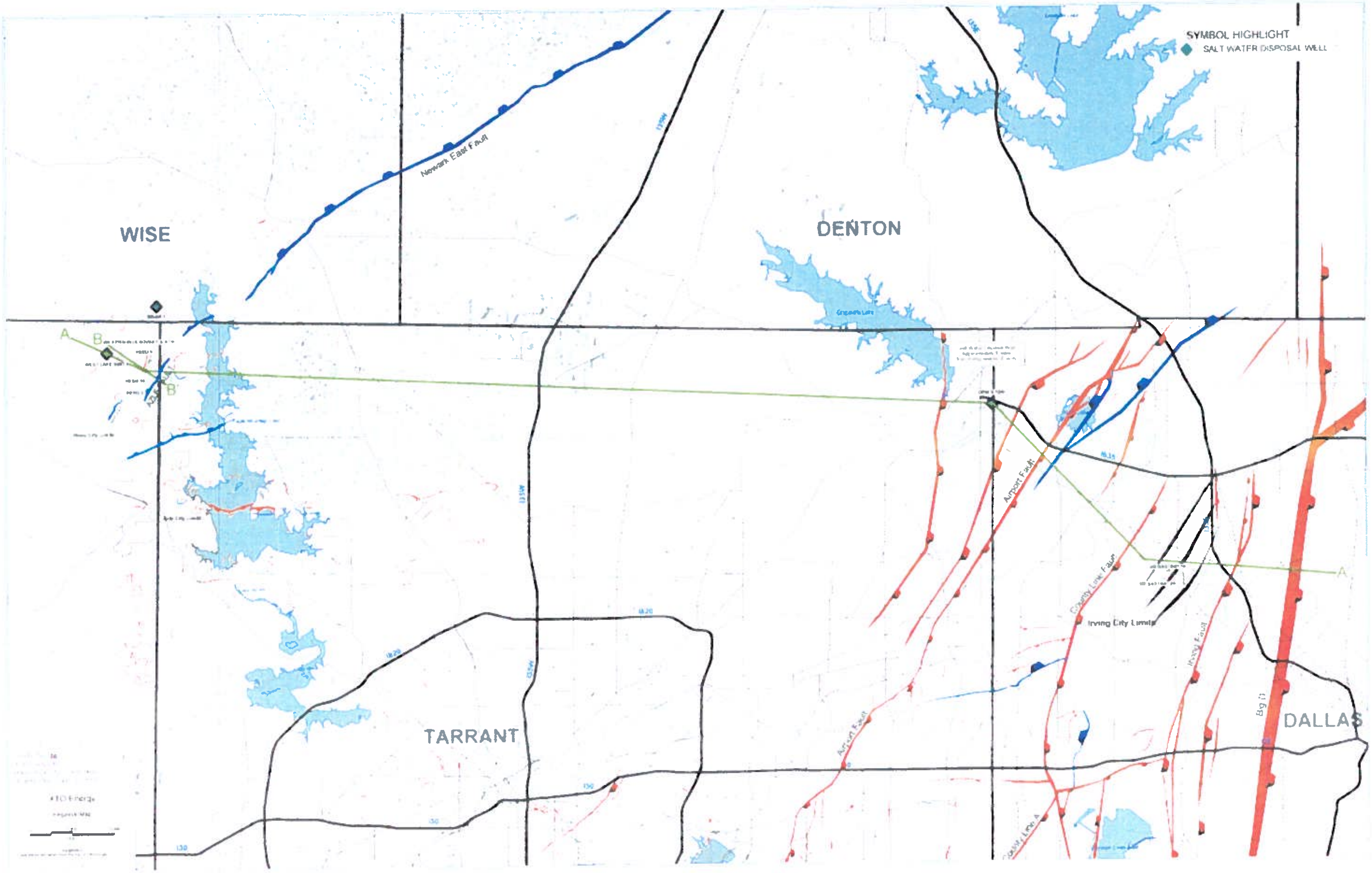
ATTACHMENT 3 09-0296411

Examiners' Notes:

XTO Exhibit No. 14. 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.



Reference cited Pollastro, Richard M., Jarvie Daniel M., Hill, Ronald J., and Adams, Craig W., 2007, Geologic framework of the Mississippian Barnett Shale, Barnett-Paleozoic total petroleum system, Bend Arch – Fort Worth Basin, Texas, AAPG Bulletin, V.91,
No.4 pp.405-436.



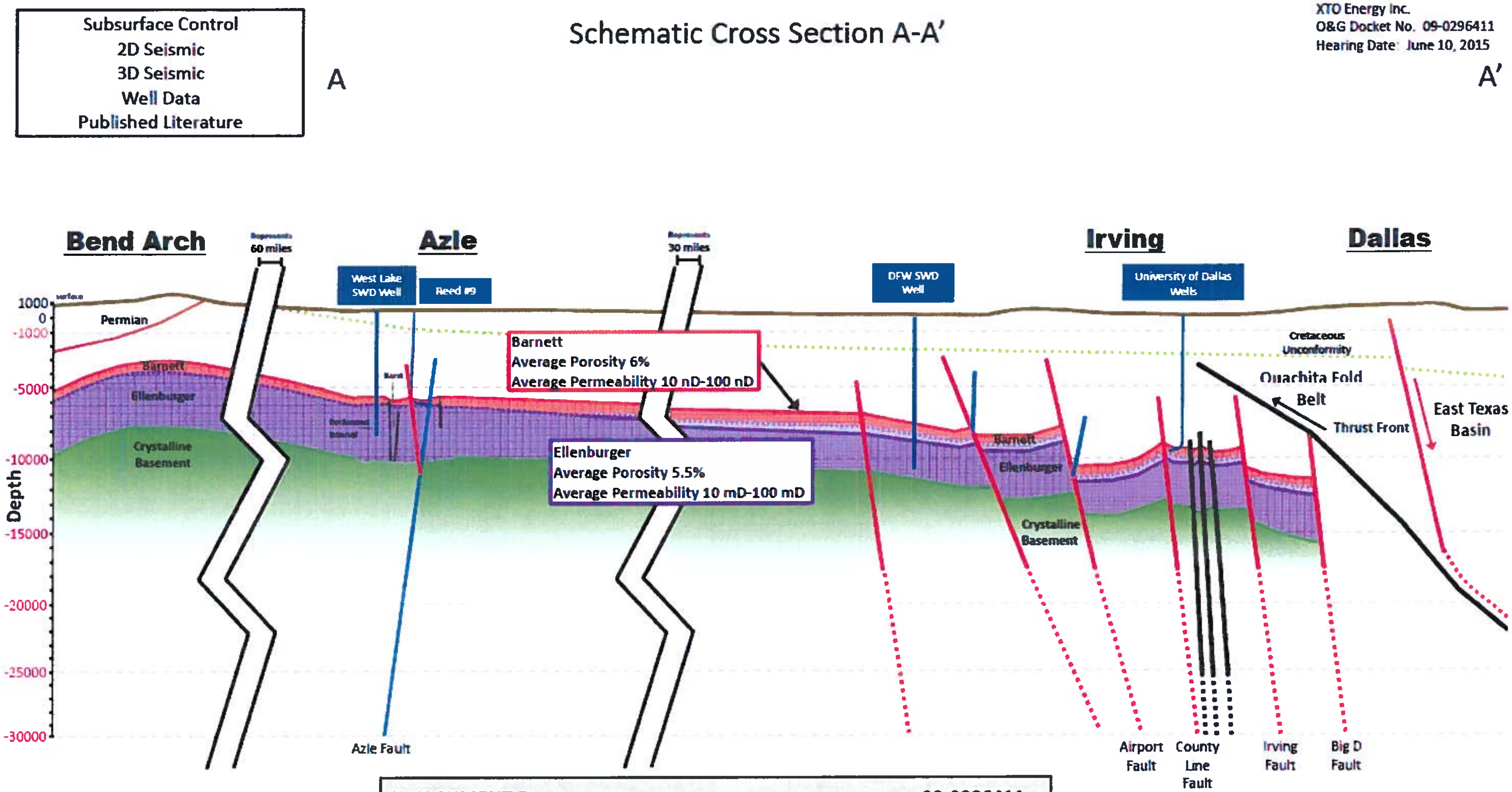
ATTACHMENT 4 **09-0296411**

Examiners' Notes: XTO Exhibit No. 16.

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

Exhibit No. 17
XTO Energy Inc.
O&G Docket No. 09-0296411
Hearing Date: June 10, 2015

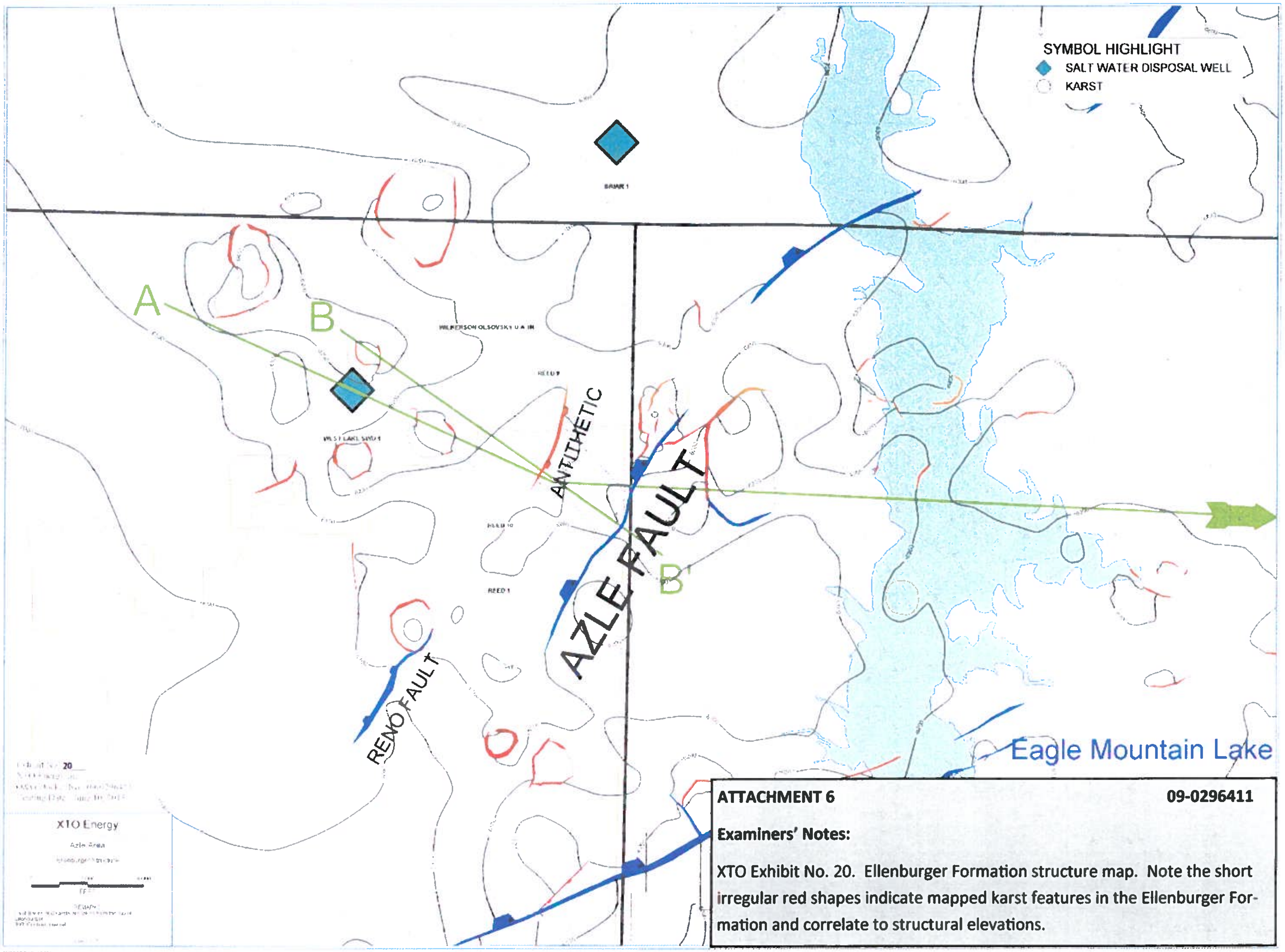
Schematic Cross Section A-A'



ATTACHMENT 5 **09-0296411**

Examiners' Notes:

XTO Exhibit No. 17. Note (1) the Fort Worth Basin thickens and deepens to the east; (2) the location of the *en echelon* normal faults near Irving; and (3) the location of the Airport Fault.



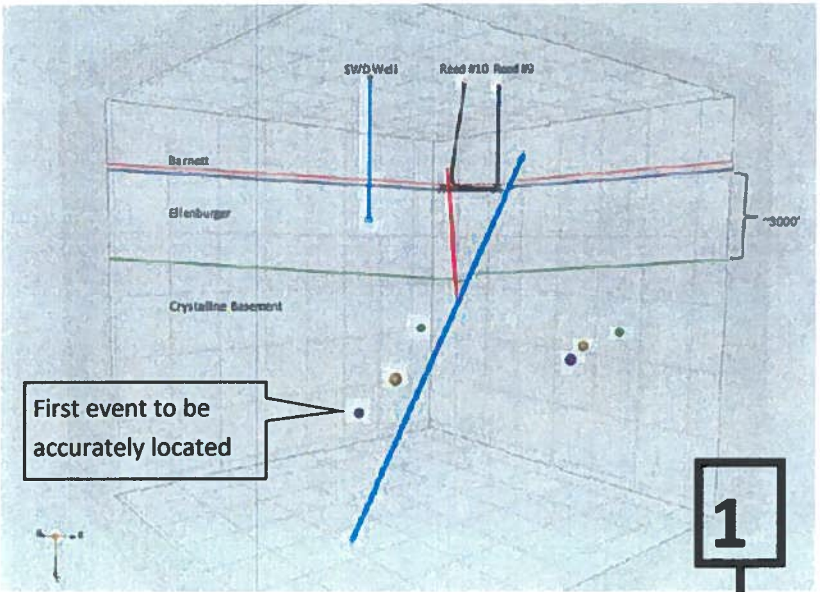
ATTACHMENT 6 **09-0296411**

Examiners' Notes:

XTO Exhibit No. 20. Ellenburger Formation structure map. Note the short irregular red shapes indicate mapped karst features in the Ellenburger Formation and correlate to structural elevations.

C C′

Sequence of Events – Time Step 3 (11/11/13-12/15/13)

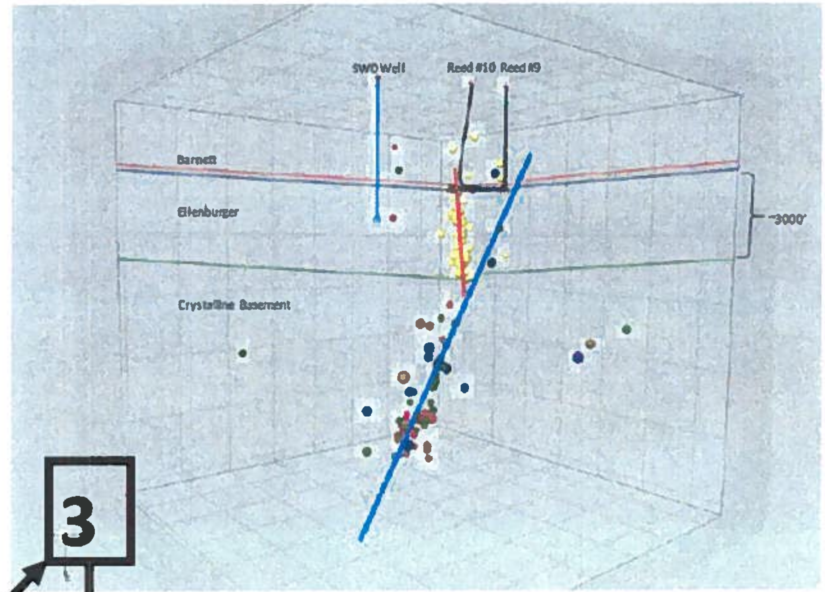


Diagrammatic Cross-section – Cumulative Sequences

Exhibit No. ___
XTO Energy Inc
O&G Docket No 09-0296411
Hearing Date June 10, 2015

C C′

Sequence of Events – Time Step 7 (11/11/13-01/28/14)



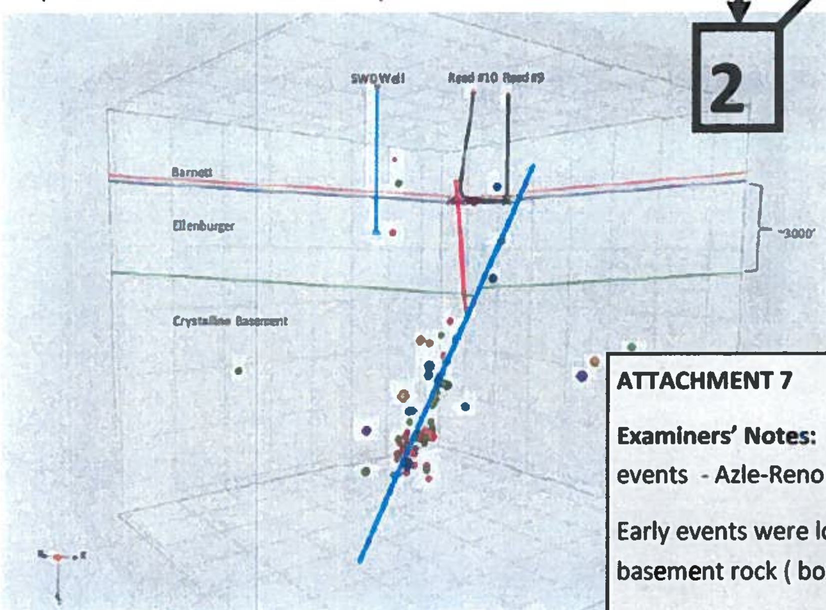
Diagrammatic Cross-section – Cumulative Sequences

Exhibit No ___
XTO Energy Inc
O&G Docket No 09-0296411
Hearing Date: June 10, 2015

1 → 2 → 3 → 4

C

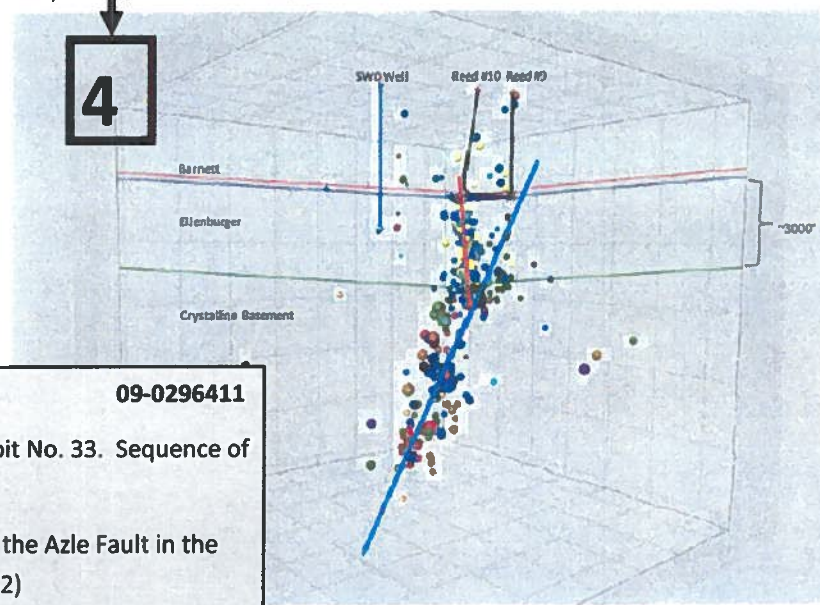
Sequence of Events – Time Step 6 (11/11/13-01/27/14)



Diagrammatic Cross-section – Cumulative Sequences

C C′

Sequence of Events – Time Step 31 (11/11/13-01/15/15)



…n – Cumulative Sequences

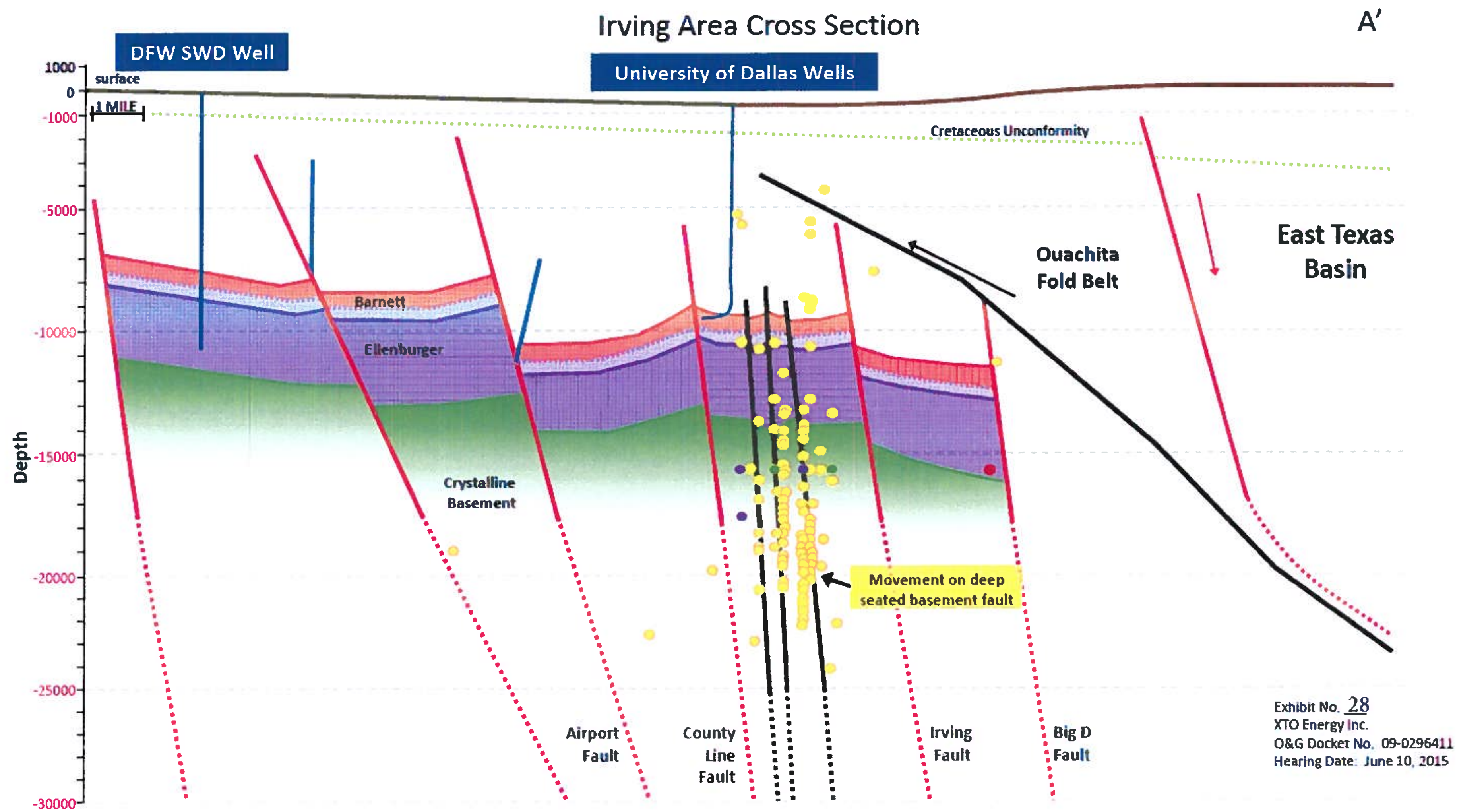
Exhibit No 33
XTO Energy Inc
O&G Docket No 09-0296411

ATTACHMENT 7 **09-0296411**

Examiners' Notes: XTO Exhibit No. 33. Sequence of events - Azle-Reno Area

Early events were located on the Azle Fault in the basement rock (boxes 1 and 2)

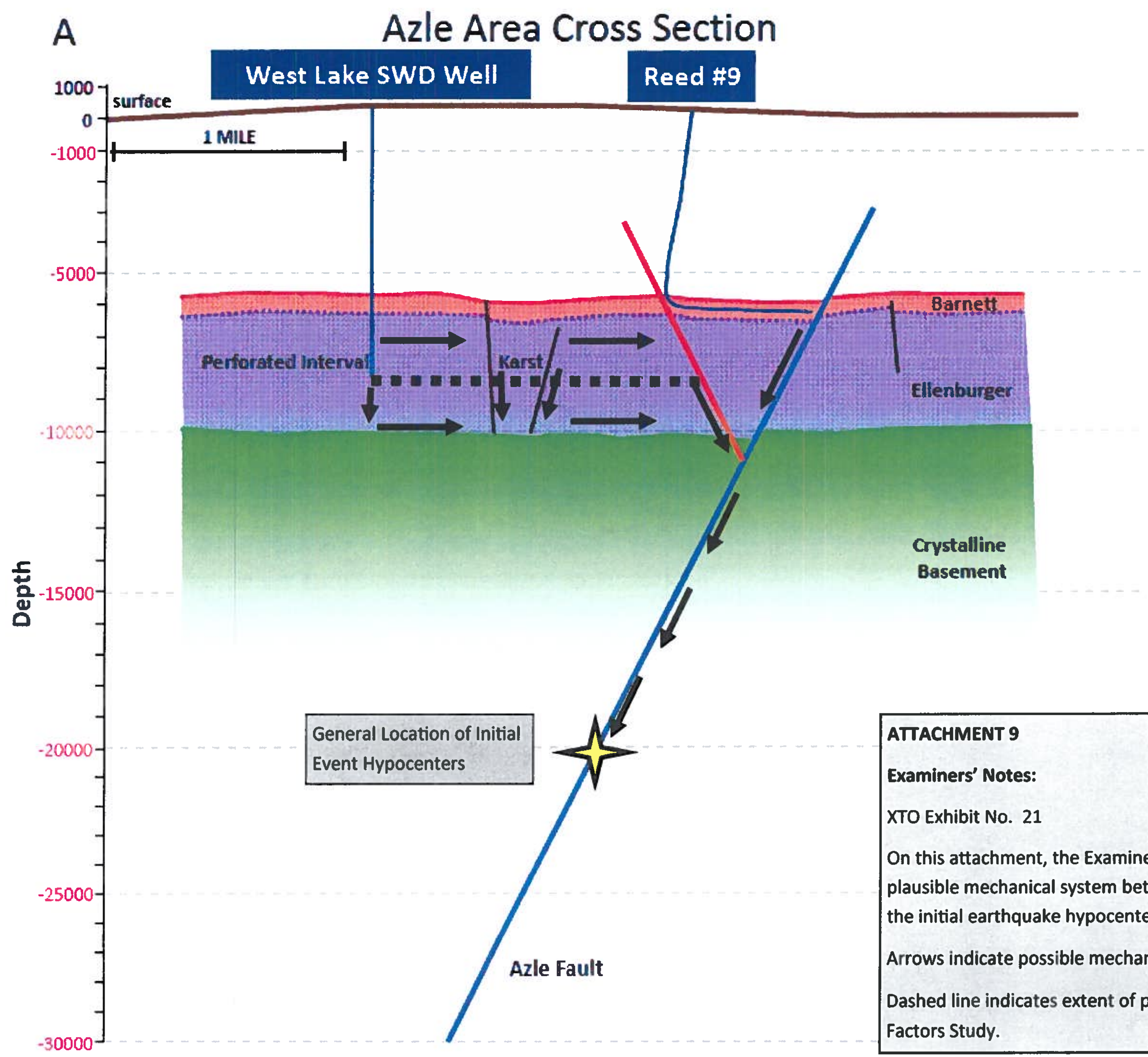
On January 28, 2014, 51 events occurred on the



ATTACHMENT 8 **09-0296411**

Examiners' Notes: XTO Exhibit No. 28. Event location with depth - Irving

Unlike for the Azle-Reno sequence, A map view showing the location of events and an exhibit showing the time sequence of events were not offered into evidence. Most of the events appear to fall along one of three strike-slip (wrench-type) faults (nearly vertical black lines).



ATTACHMENT 9 **09-0296411**

Examiners' Notes:

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.

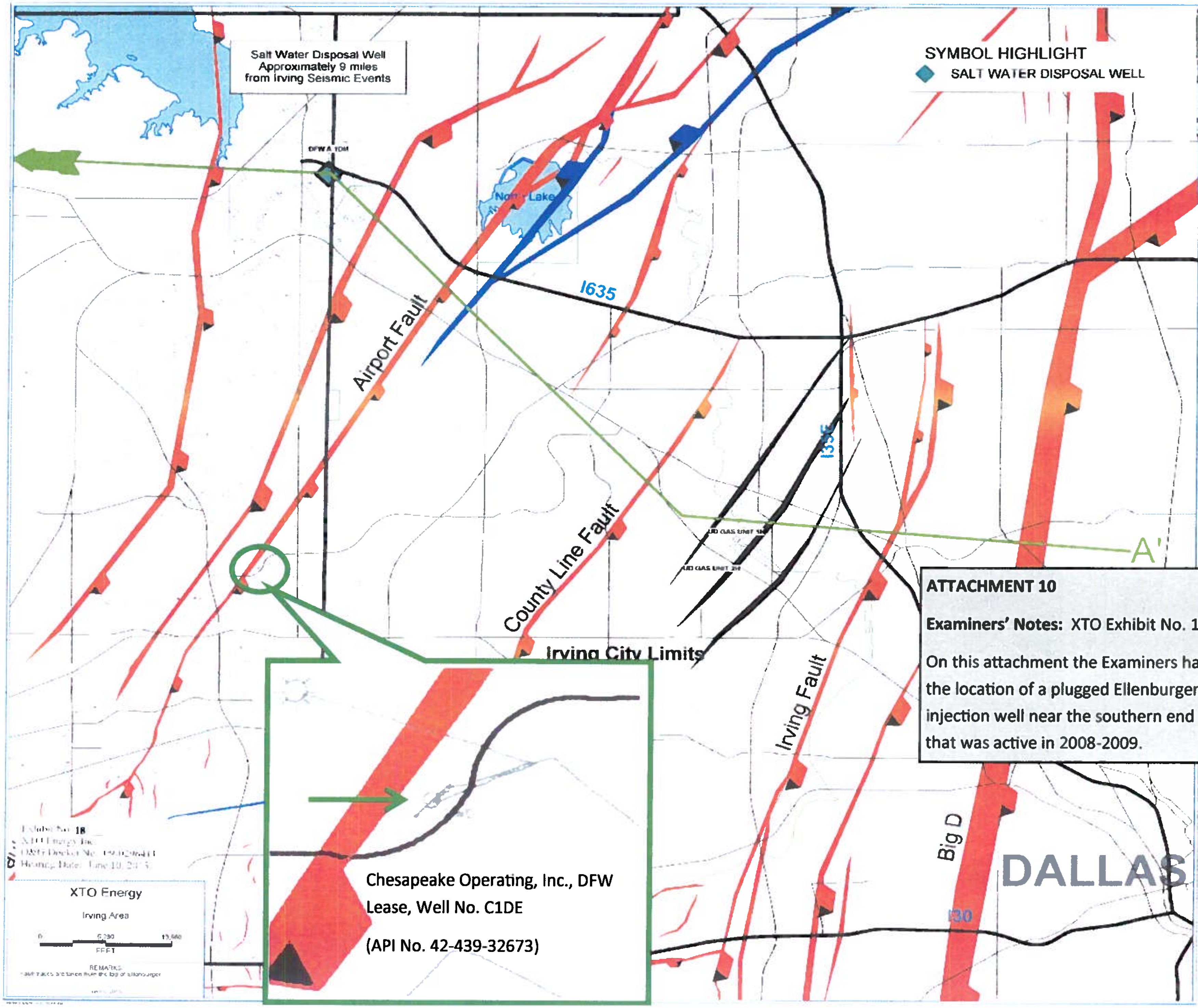
Arrows indicate possible mechanical pathways.

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

ATTACHMENT 10 **09-0296411**

Examiners' Notes: XTO Exhibit No. 18, Irving Area

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



RAILROAD COMMISSION OF TEXAS
HEARINGS DIVISION

OIL AND GAS DOCKET NO. 09-0296411

COMMISSION CALLED HEARING TO CONSIDER WHETHER OPERATION OF THE XTO ENERGY, INC., WEST LAKE SWD, WELL NO. 1 (API NO. 42-367-34693, UIC PERMIT NO. 12872), IN THE NEWARK, EAST (BARNETT SHALE) FIELD, IS CAUSING OR CONTRIBUTING TO SEISMIC ACTIVITY IN THE VICINITY OF RENO, PARKER COUNTY, TEXAS.

FINAL ORDER

The Commission finds that after statutory notice the captioned proceeding was heard by the examiners on June 10, 2015. The examiners have duly circulated a Proposal for Decision containing Findings of Fact and Conclusions of Law. Having been duly submitted to the Railroad Commission of Texas at conference held in its offices in Austin, Texas, those Findings of Fact and Conclusions of Law are hereby adopted and made part hereof by reference.

The Commission finds that a preponderance of the evidence supports a finding that the XTO West Lake SWD Well No. 1 was constructed and operated in accordance with its permit. Further, the Commission finds that the preponderance of the evidence does not support a finding that fluids injected into the Ellenburger Formation through the XTO West Lake SWD 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, it is hereby **ORDERED** by the Railroad Commission of Texas that UIC Permit No. 12872 for the XTO West Lake SWD Well No. 1 remain active and unamended.

It is further **ORDERED** by the Commission that this order shall not be final and effective until 20 days after a party is notified of the Commission's order. A party is presumed to have been notified of the Commission's order 3 days after the date on which the notice is actually mailed. If a timely motion for rehearing of an application is filed by any party at interest, this order shall not become final and effective until such motion is overruled, or if such motion is granted, this order shall be subject to further action by the Commission. Pursuant to Tex. Gov't Code §2001.146(e), the time allotted for Commission action on a motion for rehearing in this case prior to its being overruled by operation of law is hereby extended until 90 days from the date the parties are notified of this order in accordance with Tex. Gov't Code §2001.144.

Done this __th day of _______, 2015.

RAILROAD COMMISSION OF TEXAS

____
CHAIRMAN DAVID PORTER

____
COMMISSIONER CHRISTI CRADDICK

____
COMMISSIONER RYAN SITTON

ATTEST:

____
SECRETARY