TexNet

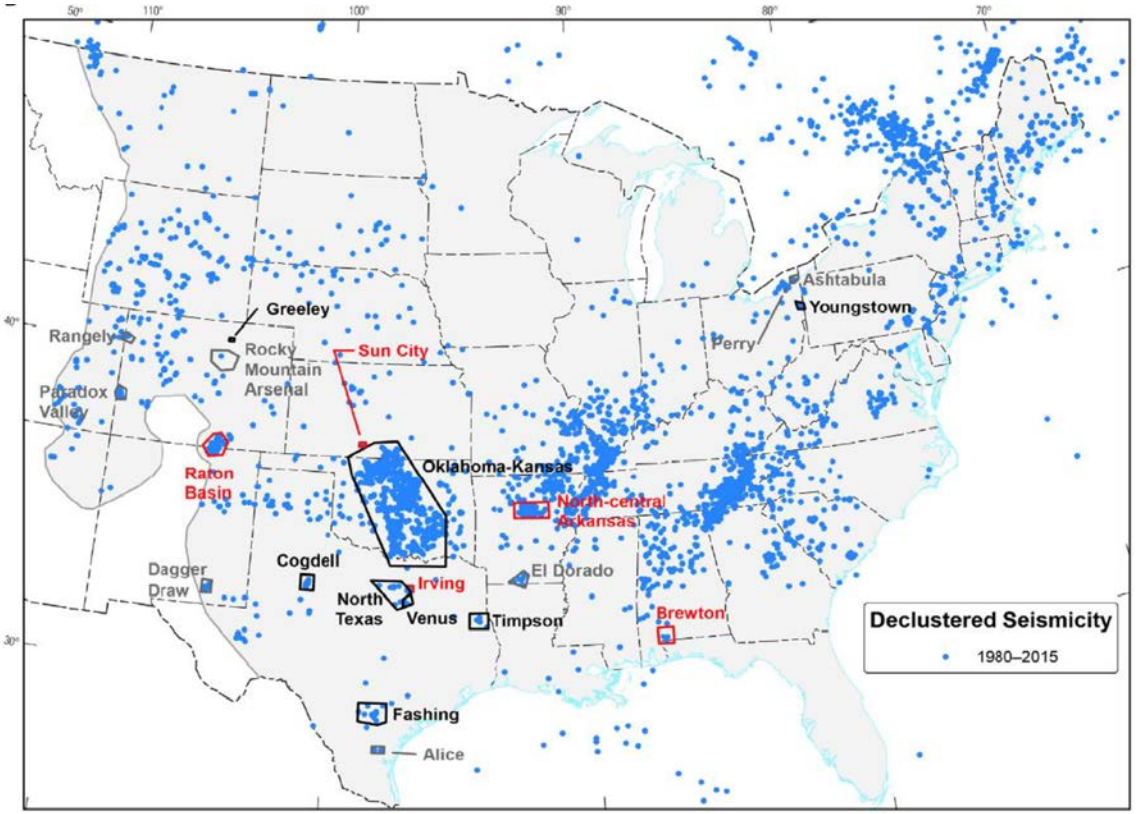
Technical Advisory Committee Meeting

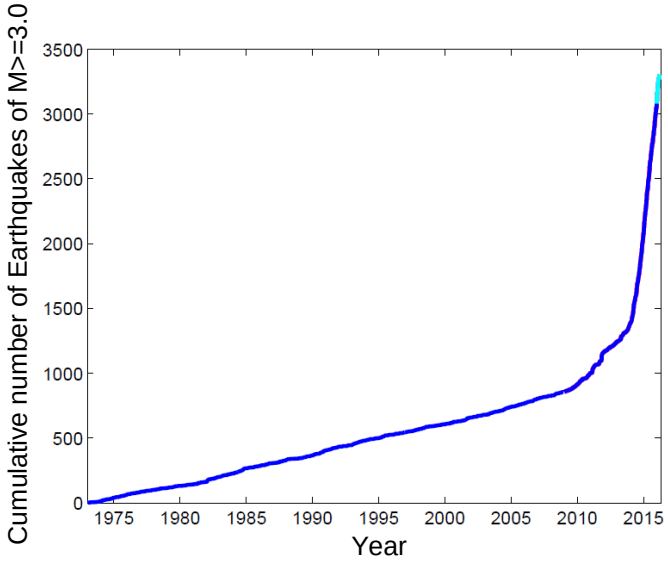
June 7, 2016

Bureau of Economic Geology
University of Texas at Austin

Introduction

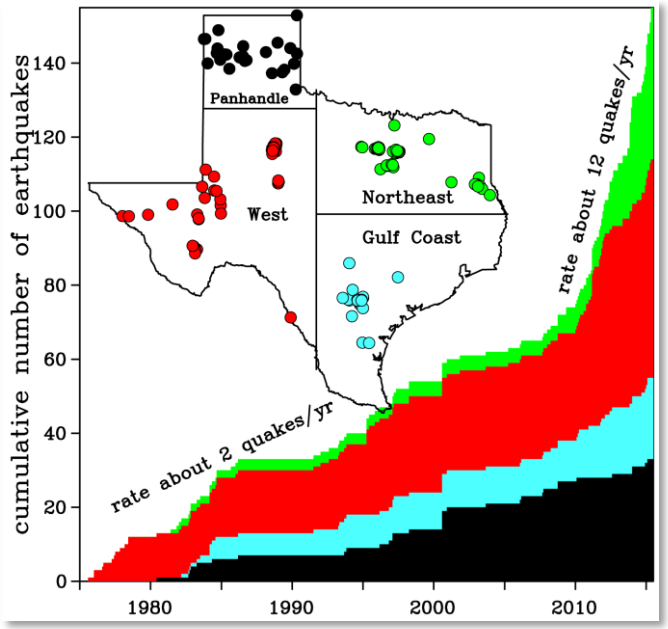
Seismic Activity in the Central and Eastern US





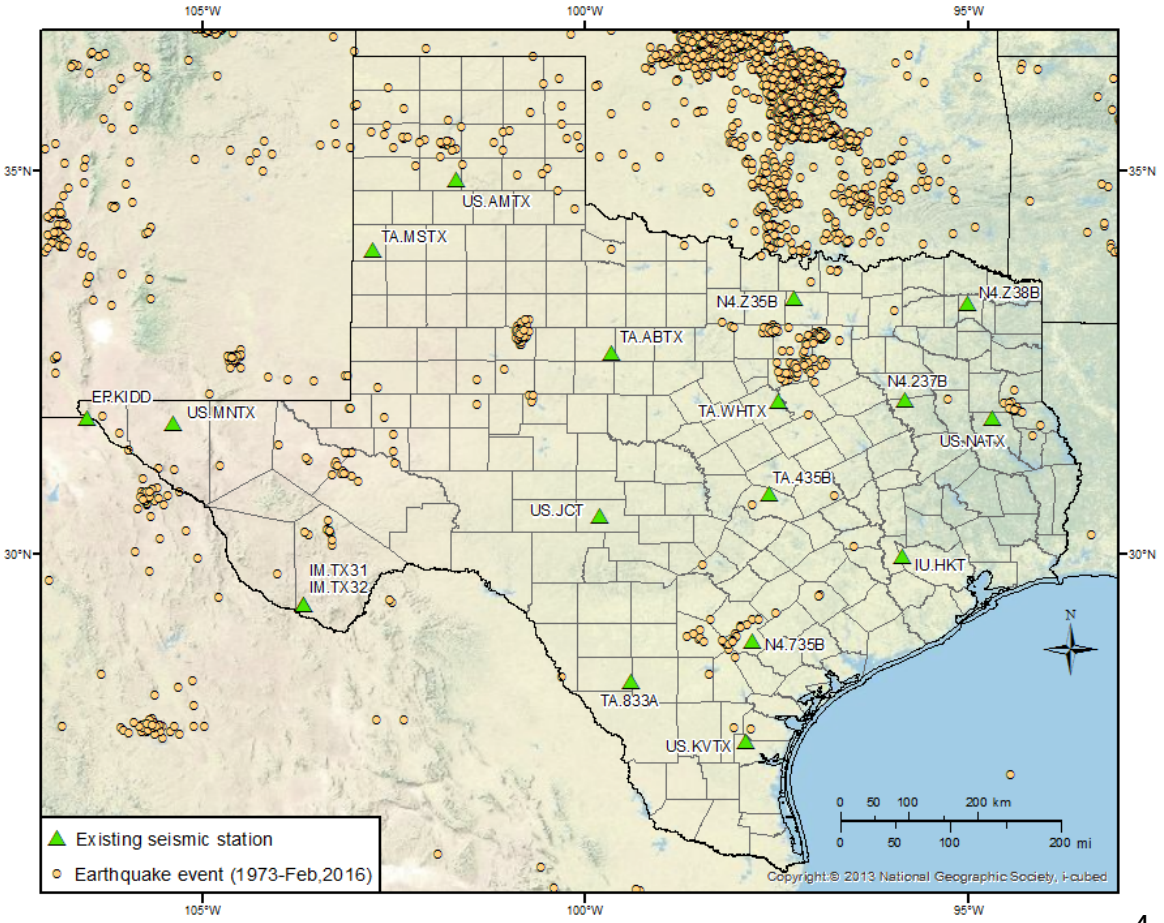
All earthquakes in the last 35 years believed to be primary events (e.g. not aftershocks)

Seismic Activity in Texas and Elsewhere

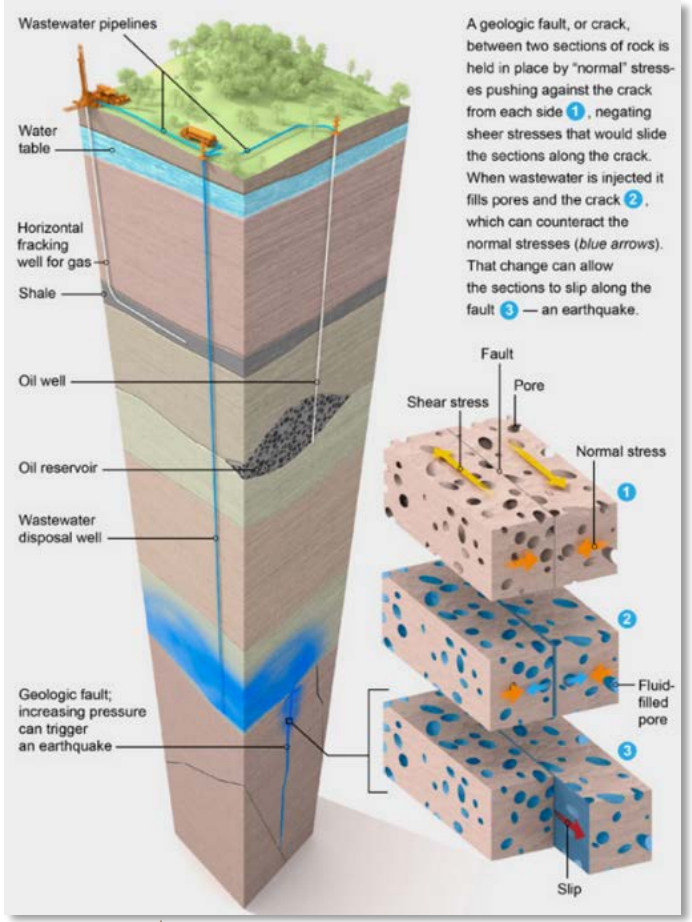


Frohlich, University of Texas

All earthquake epicenters in the modern USGS-ANSS catalog

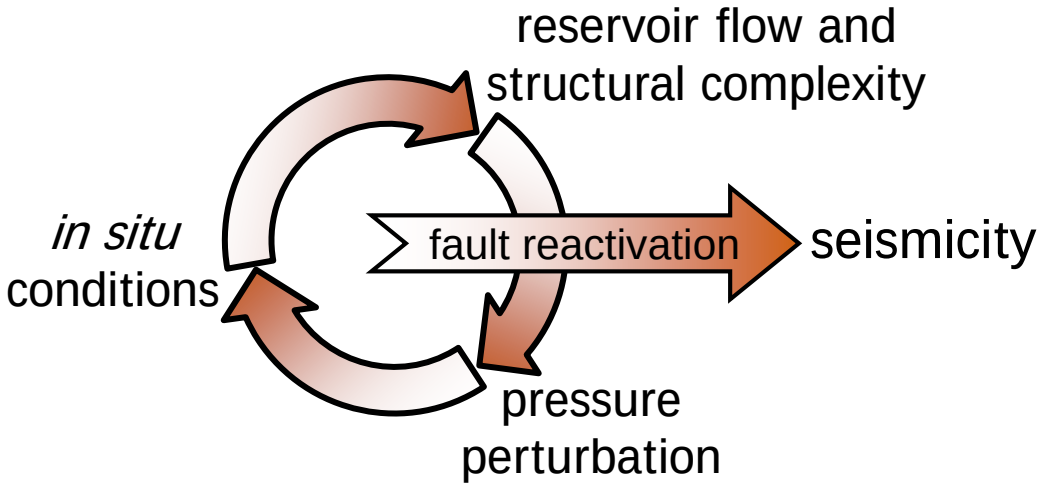


Fluid injection can cause Earthquakes



KEY FACTORS:

- fault system characteristics and geologic history
- *in situ* stress state
- reservoir hydraulic continuity and capacity
- fluid budgets and pressure
- these factors are dynamically coupled…



TexNet CISR Scientific American, Anne Kuchment, 2016

What we think we know about injection EQs

- Some of the anomalous seismicity in the central US is associated with injection
- Geologic and Geophysical aspects:
  - larger earthquakes occur in the crystalline basement
  - faults being triggered are well-oriented for failure in today's tectonic stress field
  - ground motion is strong but is peaked directly above the earthquakes
- Hydrologic aspects:
  - the association between injection and triggering is statistically strongest for injection rate
  - pressure changes in the injection interval move fast and far
  - seismicity generally dies down quickly when injections are halted but can linger for decades
  - disposal into sub-normally pressured zones can induce earthquakes
- Some important facts:
  - the vast majority of wastewater wells do not produce earthquakes
  - injected wastewater comes from lots of sources, not just from flow-back of fracking fluids
  - fracking is rarely the cause of damaging earthquakes but can generate moderately sized ones

TexNet

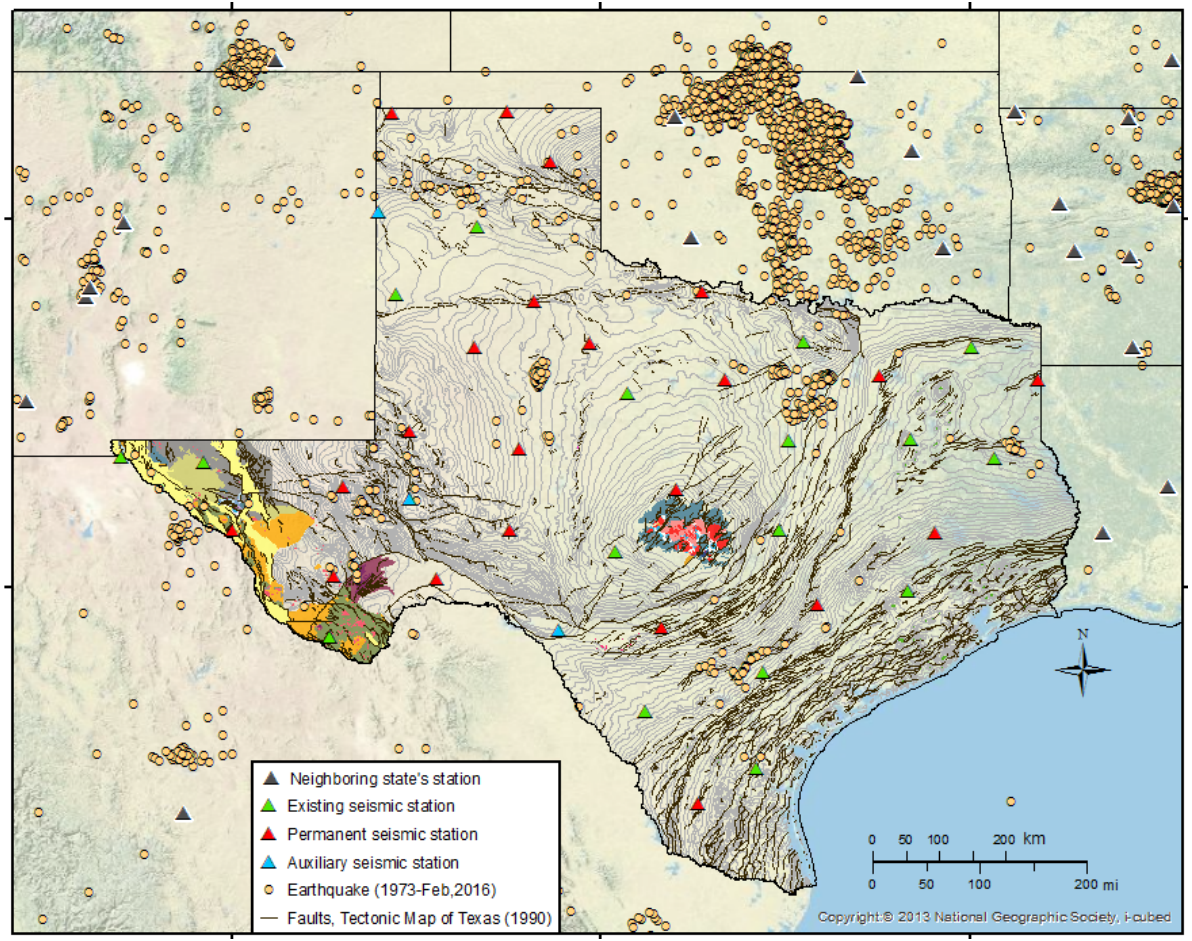
Texas is Geologically Diverse

Bureau of Economic Geology

12+ distinct tectonic areas

- Anadarko Basin
- Amarillo Uplift
- Palo Duro Arch
- Midland Basin
- Delaware Basin
- Trans-Pecos/Marathon
- Val Verde
- Gulf Coast
- Talco/Mexia/Balcones
- East Texas Basin
- Sabine Uplift
- Ft Worth Basin
- Llano/Bend Arch

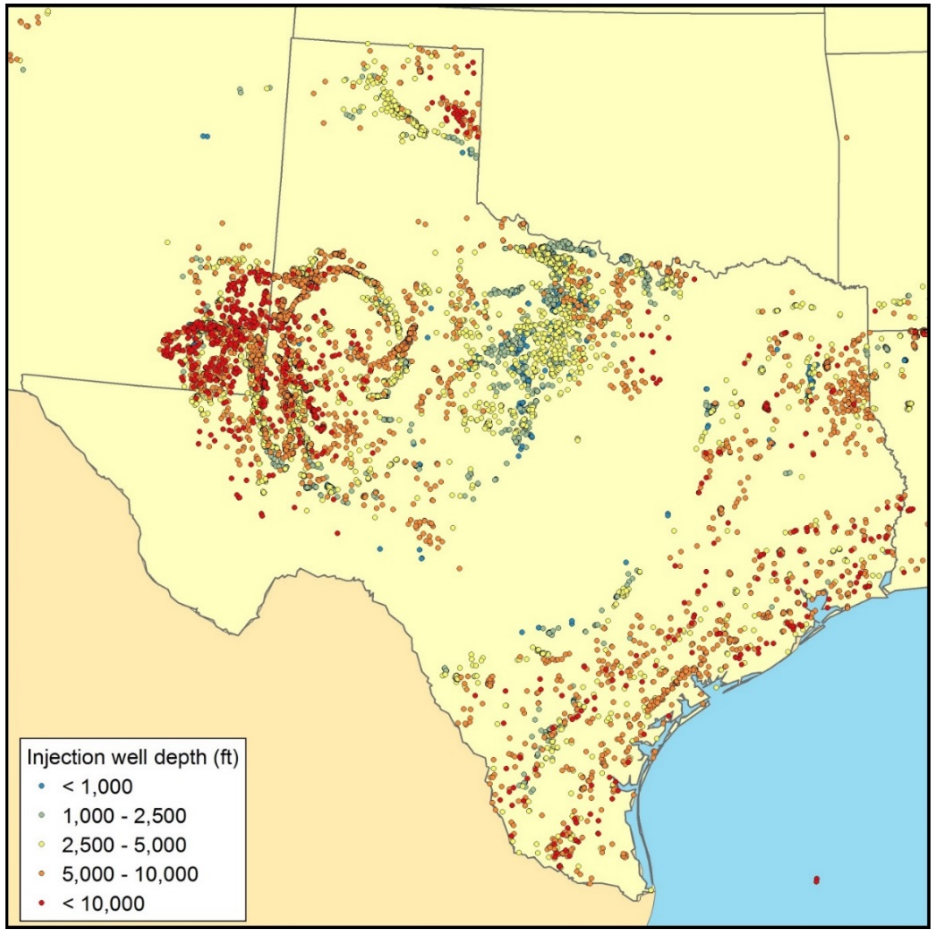
Many known fault systems that are poorly constrained in the subsurface



TexNet CISR

Injection History is Diverse

- ~50,000 injection wells permitted since 1930's
- ~34,000 active injection wells associated with enhanced oil production
- ~8,000 permitted disposal wells (UIC Class II)



TexNet Organization

Governor – Legislature

Bureau Directorship

Scott Tinker, Michael Young

Technical Advisory Committee

Robie Vaughn - Chair

Dan Hill, Hal Macartney, Brian Stump, Chris Hillman, Kris Nygaard, Scott W. Tinker, Dana Jurick, Craig Pearson

TexNet Network and Research*

PIs: Peter Hennings, Ellen Rathje, Alexandros Savvaidis

TexNet Seismic Network

Alexandros Savvaidis[B]
Tania Murkherjee[B]
Bissett Young[B]

Seismology

Cliff Frohlich[I]
Jake Walter[I]
Taylor Borgfeldt[I,3]
Alexandros Savvaidis[B]
Heather DeShon[S]
Kevin Kwong[S,2]
Oner Sufri[S,1]

Hydrology, Faults, Geomodels

Peter Hennings[B]
Julia Gale[B]
Chris Zahm[B]
Casee Lemons[B]
Fault Interpretation Tech[B]
Bridget Scanlon[B]
JP Nicot[B]
Robin Dommisse[B]

Geomechanics and Reservoir Modeling

Jon Olson[P]
Rich Schultz[P]
Peter Eichhubl[B]
Mohsen Babazadeh[P,2]
Valerie Gono[P,2]
Zhiqiang Fan[B,1]
Akhil Datta-Gupta[T]
Michael King[T]
Jihoon Kim[T]

*petroleum operators provide supplemental funding through BEG IA membership

[B] Bureau of Economic Geology
[I] UT Institute for Geophysics
[P] UT Petroleum Geosystems and Engineering
[T] Texas A&M Petroleum Engineering
[S] SMU Seismology
[1]Post Doc [2]PhD student [3]MS student

Science Themes

- **TexNet Permanent and Transportable Array Products**

  network; earthquake data, locations, calibrated magnitudes, catalog

- **Seismology**

  earthquake sequences, source characterizations, triggering analysis

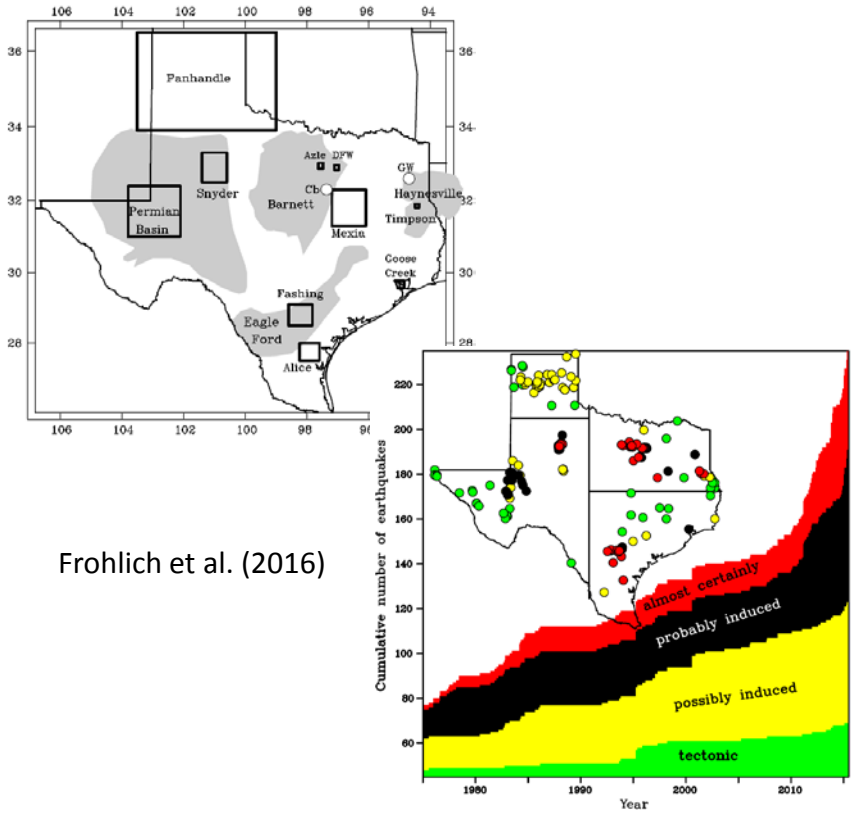
- **Geologic Characterization**

  in situ stress, fault system characteristics, fluid data and budgets, reservoir- to basin-scale geomodels

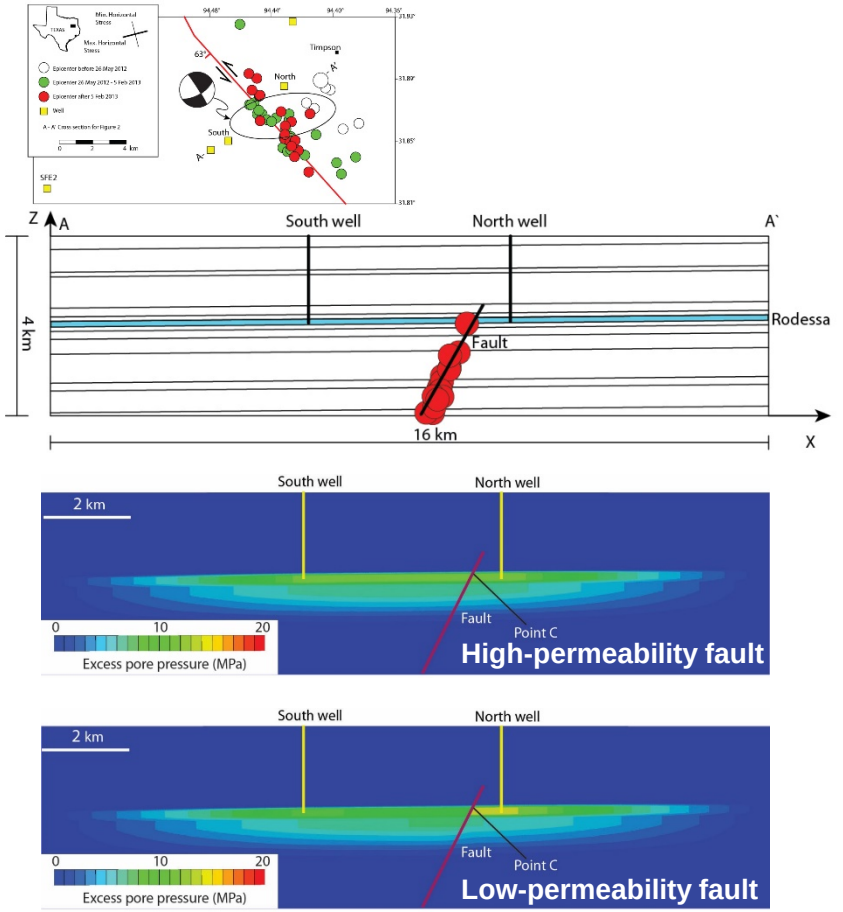
- **Geomechanics and Reservoir Engineering**

  pore pressure estimations, reservoir hydraulic continuity, fault triggering analysis, fault rupture mechanics

Moving from Associative to Mechanistic Analysis



Frohlich et al. (2016)

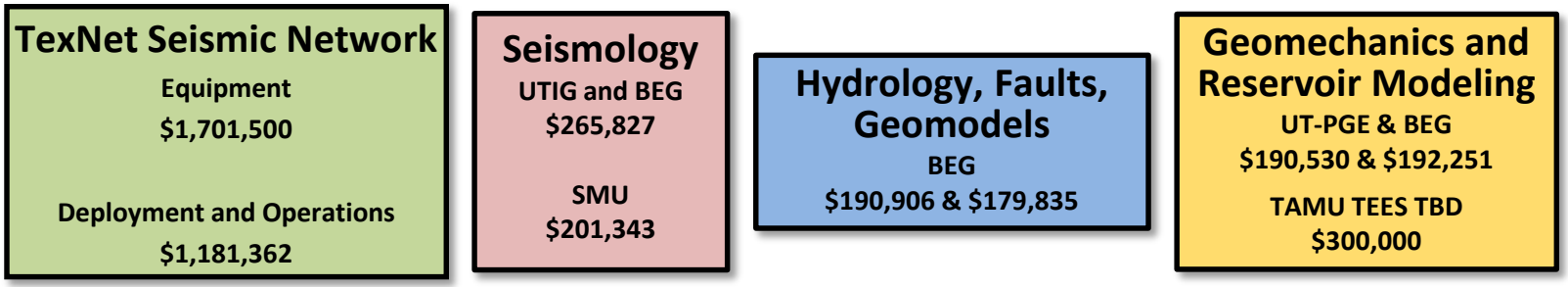


Fan et al. (2016)

TexNet Research Over-Arching Goals

- accurate and detailed seismicity/ground-shaking data in Texas
- understanding fault-triggering mechanisms
- assessing the seismogenic potential of Texas basins
- research that can be used to improve fluid disposal operations

TexNet Network and Research Proposed Funding



TexNet Network and Research Budget

TexNet Seismic Network	Equipment		Deployment and Operations						SubTotals by Cost
	Seismic Stations and Installation	TexNet HUB Hardware	Software	Borehole Subcontract	Materials & Services	Personnel	Computer Usage	Travel	
Nanometrics (one time cost)	$1,636,500		$23,420	$317,900	$18,700				$1,996,520
TexNet (one time cost)		$65,000							$65,000
TexNet Year 1 Cost					$61,500	$210,875	$8,700	$41,100	$322,175
TexNet Year 2 Cost					$128,100	$312,867	$13,200	$45,000	$499,167
SubTotals by Category	**$1,636,500**	**$65,000**	**$23,420**	**$317,900**	**$208,300**	**$523,742**	**$21,900**	**$86,100**	
Totals	**$1,701,500**							**$1,181,362**	**$2,882,862**

TexNet Research Projects

Fiscal Biennium 2016-2017

Theme	Project Title	Institution/Unit	PI	Personnel	Materials and Services	Computer Charges	Tuition	Equipment	Travel	Total
Seismic Network	TexNet Deployment and Operations	UT-BEG	Savvaidis	$ 523,742	$ 549,620	$ 21,900	$ -	$ 1,701,500	$ 86,100	$ 2,882,862
Seismology	Texas Seismologic Studies	UT-IG	Walter	$ 236,930	$ 4,200	$ 4,800	$ 11,425	$ -	$ 8,472	$ 265,827
Seismology	Ft Worth Basin Earthquake Characterization	SMU	DeShon	$ 180,909	$ 2,900	$ -	$ 6,912	$ 1,000	$ 9,622	$ 201,343
Hydrology	Hydrology: Fluid Budget Protocols, Data and Analysis	UT-BEG	Scanlon	$ 162,486	$ 3,100	$ 22,920	$ -	$ -	$ 2,400	$ 190,906
Faults and Geomodels	Fault Characterization and Reservoir Model Inputs	UT-BEG	Hennings	$ 166,735	$ 2,500	$ 6,600	$ -	$ -	$ 4,000	$ 179,835
Geomechanics	Geomechanics of Fault Reactivation	UT-BEG	Eichhubl	$ 165,931	$ 1,400	$ 16,920	$ -	$ -	$ 8,000	$ 192,251
Reservoir Modeling and Geomechanics	Pore Pressure Estimation and Fault Rupture Modeling	UT-PGE	Olson	$ 134,130	$ 400	$ -	$ 48,000	$ -	$ 8,000	$ 190,530
Reservoir Modeling and Geomechanics	Coupled Fluid Flow and Geomechanical Modeling	TAMU-TEES	Datta-Gupta	$ 259,033	$ 6,000	$ 3,000	$ 22,967	$ -	$ 9,000	$ 300,000
									Total	**$ 4,403,554**
									HB2 Budget	**$ 4,471,800**
									Contingency	**$ 68,246**
									Contingency	**2%**

TexNet Timeline 2015-2016

	2015			2016			
TASK or EVENT	June	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Sep-Dec
Texas House Bill 2 Supplemental Appropriation to BEG							
seismic network initial design and preliminary costing							
research program design and vesting of research contributors							
RFP posted, proposals reviewed and ranked							
recruitment of TexNet Manager, Research Principal Investigator							
negotiations with leading vendor							
commence research (UT and SMU)							
contract negotiations with leading vendor							
TexNet Network Manager and Principal Investigator hired							
seismic network design revised (installation method upgraded)							
TexNet permanent site locations identified and vetted							
identification of suitable site landowners							
vendor contact executed							
revise research plans, receive Texas A&M research scope							
develop strategy for temporary station deployment							
Governor's Technical Advisory Committee seated							
TexNet Technicians hired							
commence receiving network and hub equipment							
conduct initial site evaluations							
perform final site evaluations							
contracting with site landowners							
permanent station installation							
temporary station installation							
2016 report to Governor and Legislative Committees							

TexNet: Longer-Term Science and Timing

Bureau of Economic Geology

State-Wide and General Topics

1. network procurement and installation
2. network management and data stream
3. R&D products to improve network performance
4. EQ compilations and characterizations
5. stress and fault mapping
6. outreach

Ft Worth Basin Integrated Study

1. local seismic networks and EQ studies
2. basin-scale fluid budgets and pore pressure
3. stress characterization (Stanford)
4. fault characterization
5. 3D basin geo and hydrologic and modeling
6. fault reactivation analysis and mapping
7. reservoir modeling of seismicity mechanics
8. assessment of basin seismogenic potential

*

Panhandle Seismicity Study

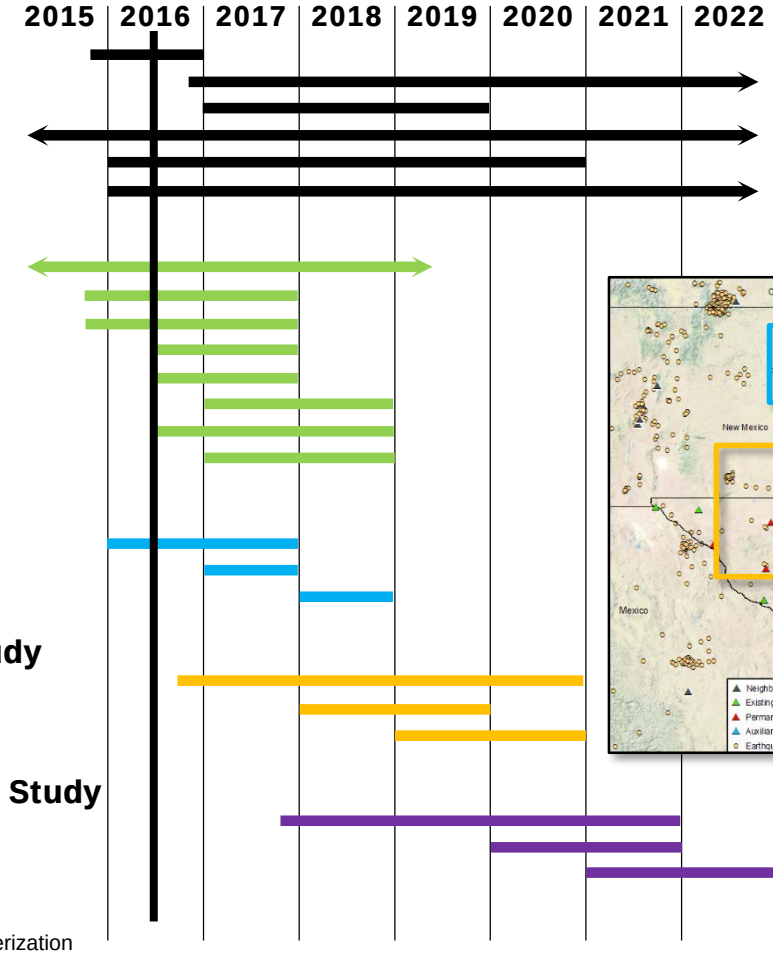
1. seismicity analysis (existing and TA stations)
2. *integrated geological characterization
3. assessment of basin seismogenic potential

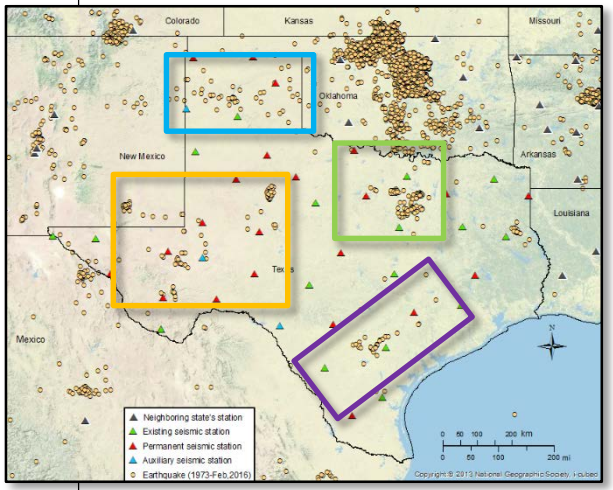
Greater Permian Basin Integrated Study

1. local seismicity base-line studies and analyses
2. *integrated geological characterization
3. assessment of basin seismogenic potential

Eagle Ford Operating Area Integrated Study

1. numerous local seismicity acquisitions and analyses
2. *integrated geological characterization
3. assessment of basin seismogenic potential





TexNet
Texas Seismological Network

Alexandros Savvaidis, PhD, and Peter Hennings, PhD

Bureau of Economic Geology
University of Texas at Austin

Overview

- TexNet Management
- TexNet Hardware
- Site Assessment
- TexNet Operational Services
- TexNet Products

TexNet Team

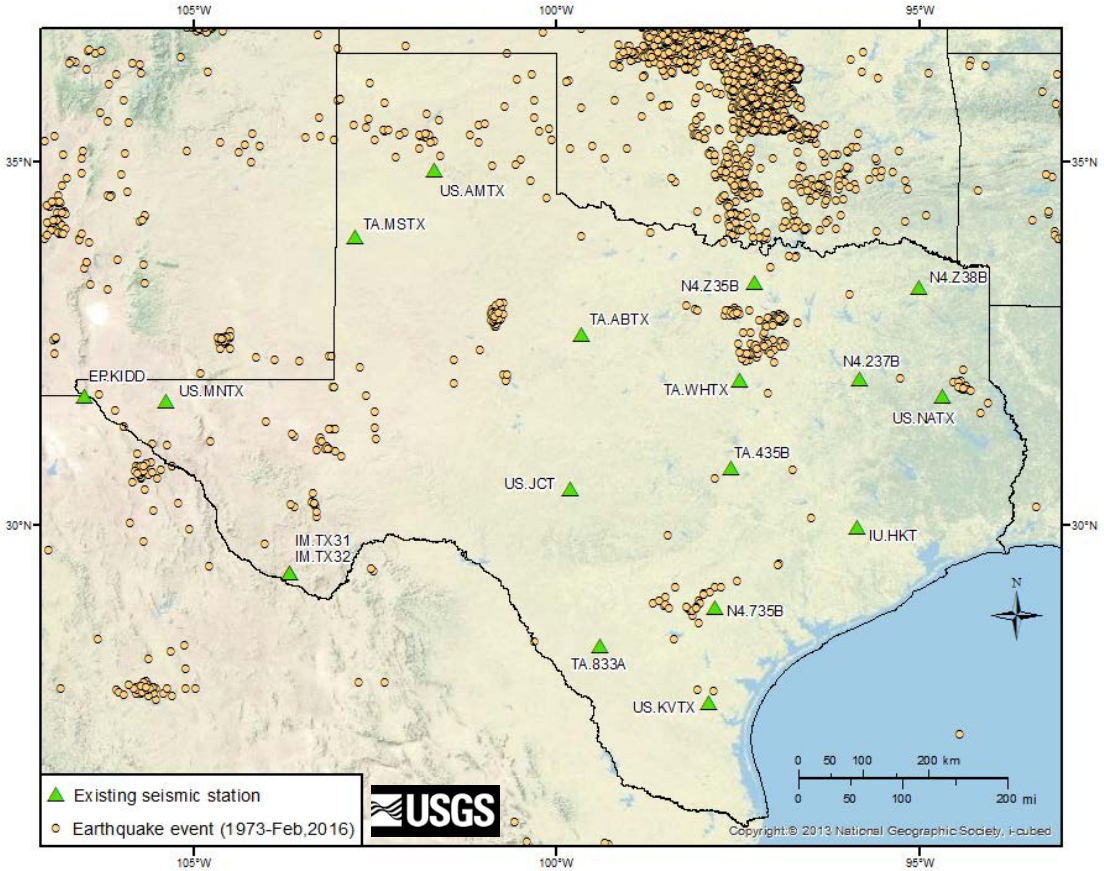
- Alexandros Savvaidis, PhD, BEG, Project Manager
- Peter Hennings, PhD, BEG, PI of CISR
- Ellen Rathje, PhD, CAEE, PI of CISR
- Bissett Young and Tania Murkherjee, BEG, Research Scientist Assoc
- Mark Blount, BEG, External Affairs
- Cliff Frohlich & Jake Walter – Univ. Texas Institute for Geophysics
- Heather De Shon, Chris Hayward & Brian Stump – SMU
- Scott Tinker, BEG, Director and Texas State Geologist
- Michael Young, PhD, BEG, Associate Director for Environment

TexNet Goals

- To monitor, locate, and catalog seismicity across Texas, capable of detecting and locating earthquakes with magnitudes ≥M2.0 (aka—Backbone)
- To improve investigations of ongoing sequences by deploying temporary seismic monitoring stations and conducting site-specific assessments, especially for
  - Events >M3.0 in or near urban areas, or
  - Events co-located where ongoing human activities may be related to earthquake activity

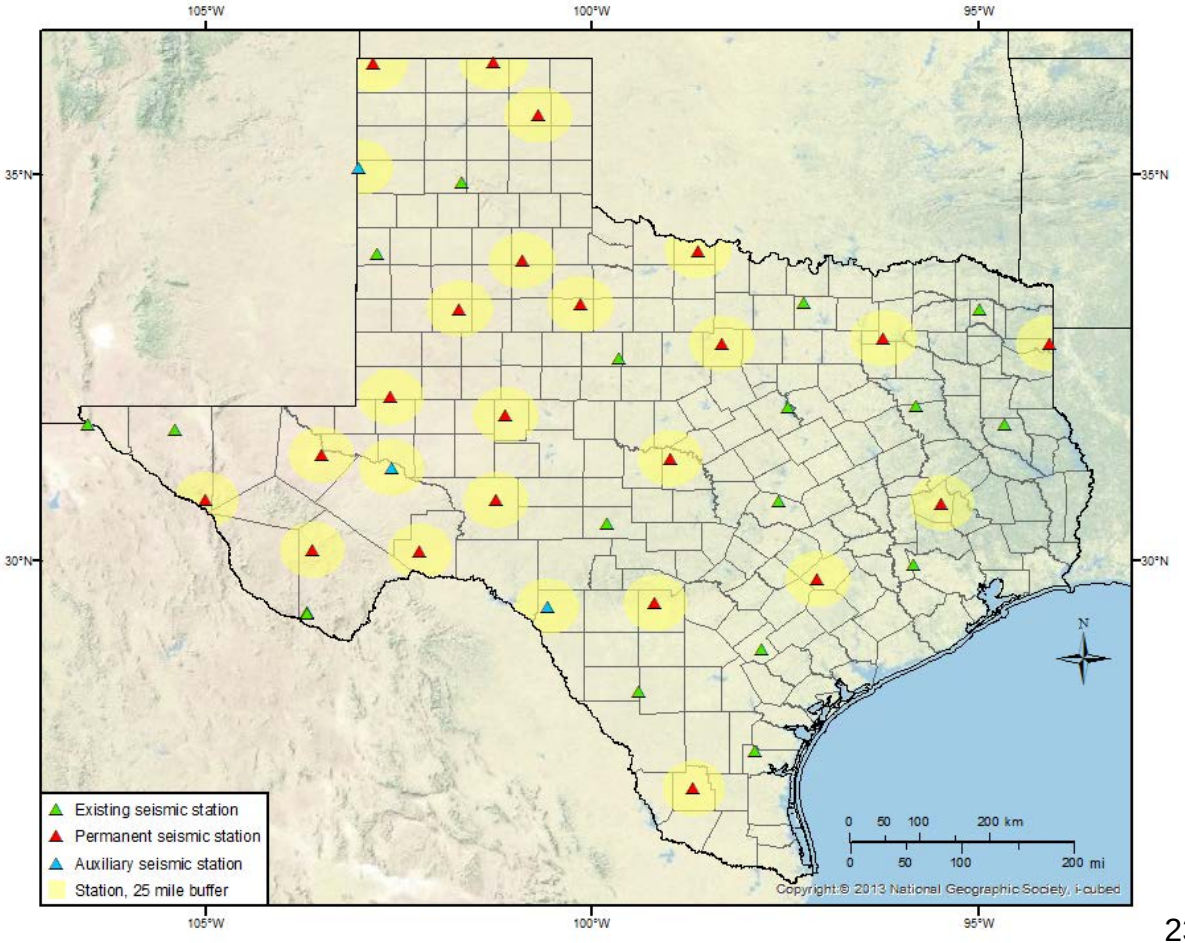
Challenge for Texas

- Existing network infrastructure is not sufficient to fully identify hypocenter depths of earthquakes in Texas
- Earthquake activity scattered across the State
- Network needs to be densified



Solution – Expand Monitoring Network

- Fill in the gaps
- Add 22 additional stations, providing 40 station backbone
- The ~36 temporary stations will densify areas of Texas that need special focus



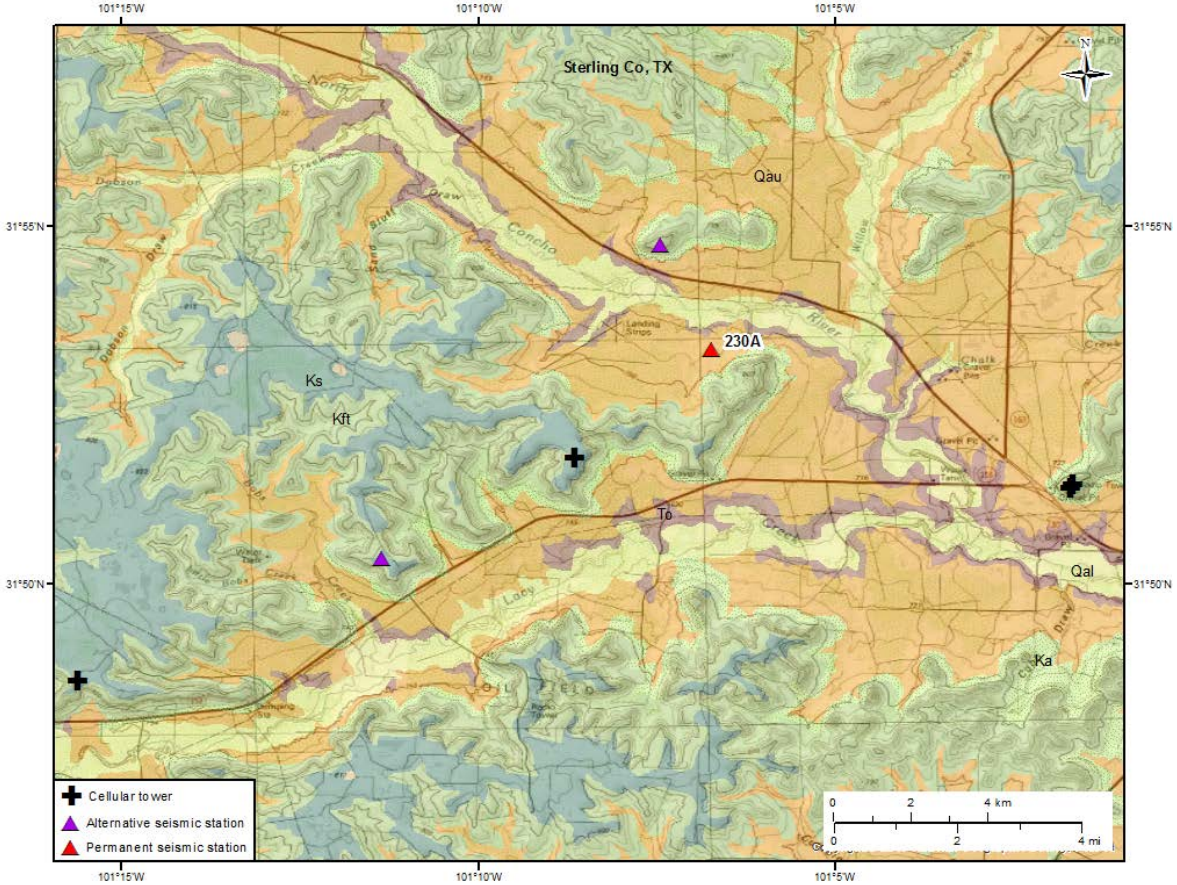
Factors to Assess Possible Station Locations

- Seismicity
- Existing broadband real-time stations
- Existing information from TA Seismological Stations
  - Noise level (Power Density Function)
  - Soil amplification (Noise and Earthquake Data)
  - Shear wave velocity (Vsz)
- Site Geology - Topography
- Tectonics
- Location of oil & gas wells
- Cell coverage

Example of Factor: Site Geology &Topography

Higher elevation areas are prioritized

- **Stiff material**
- **Isolated**
- **Cell coverage**



Importance of loose (younger) versus stiff (older) formations

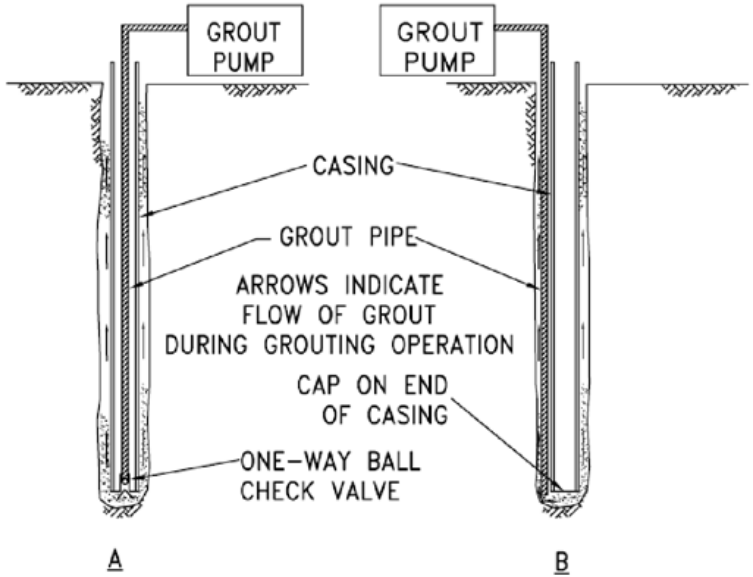
Permanent Station Setup

Pole mount hardware Installation:

- 6 Channel Datalogger
- Wireless Modem
- 200Ah Battery
- 150W Solar Panel, and
- 120sec – 3 Component Post-Hole Seismometer

Borehole Setup

- Cased posthole up to 20 feet
- Steel casing with a welded flat base plate on the bottom
- Borehole preparation will follow ASTM DH Seismic (D74000)



CROSS-SECTION VIEW

Portable Station Setup

Direct Burial Installations

- 3 Component, 20 sec Seismometer
- 3 Component Accelerometer

Station components (data logger, solar panels, etc.) will be identical to permanent stations

TexNet Services on Recorded Data

- TX is the TexNet Code on the International Federation of Digital Seismograph Networks
- DOI (Digital Object Identifier) http://dx.doi.org/doi:10.7914/SN/TX
- Data Provider Agreement in place with IRIS for archiving TexNet data collected from permanent and portable stations
- Time Series Data available to the public through IRIS and TexNet Hub

TexNet Operational Services

- Permanent and portable station deployment
- Data acquisition
- Local data archiving
- Network monitoring (QC,QA)
- Real-time earthquake information
- Updated manual earthquake information
- Monthly earthquake catalog
- Web portal

TexNet Products (Up to 3yrs)

- Earthquake Source Information (Real Time and Manual)
  - Minimizing the hypocenter uncertainties
  - Local and moment magnitude
  - Fault plane solutions
- Updated velocity model
- Shakemaps (real-time)

Data & Hardware Management

We have established a process for data and hardware management

- **Data from all stations will be transferred to TexNet HUB and used directly in TexNet operations**
- **Data and corresponding analysis results will be available to the public**
- **An individual can adopt a station or share data**
- **Portable installations managed by TexNet Team**

Portable Installations

- Areas of deployment based on:
  - Spatiotemporal (Accelerated/Decelerated) Seismicity Distribution
  - Societal / Infrastructure Risk
  - Baseline Seismicity Studies
  - Specific Scientific Questions Related to Research Products
- Provisional areas
  - Ft Worth Basin
  - Snyder area
  - Permian Basin region
  - Eagle Ford Play area
  - Panhandle
  - East Texas

Current Status

- Nanometrics (Ontario, Canada) awarded contract after public bidding process. Hardware delivery expected by the end of June, 2016
- We have identified provisional locations for each seismometer, both permanent and auxiliary. Site visits are ongoing.
- We have established our leadership team for TexNet
- Current expectation is for system to be operational and to begin streaming data by Summer 2016
- Critical issue – identifying landowners and securing lease agreements

Summary and Update of Earthquake Activity in Texas

Alexandros Savvaidis[1], PhD and Jacob Walter[2], PhD

[1]Bureau of Economic Geology
[2]Institute of Geophysics
University of Texas at Austin

Overview

- Tectonic Regime
- Historical Seismicity
- Instrumental Seismicity

Tectonic Regime of Texas

12+ Distinct Tectonic Areas

- Anadarko
- Amarillo Uplift
- Palo Duro Arch
- Midland Basin
- Delaware Basin
- Trans-Pecos/Marathon
- Val Verde
- Gulf Coast
- Talco/Mexia/Balcones
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- Ft Worth Basin
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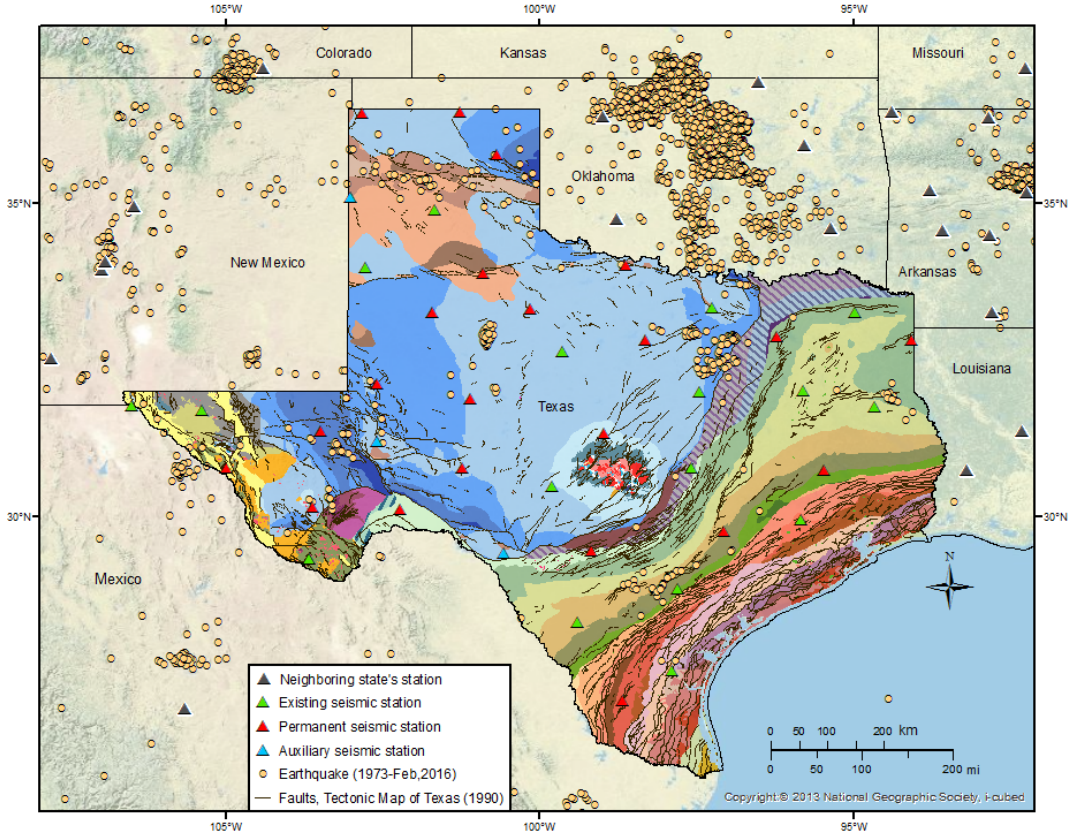


Historical Seismicity… before 1973

Major events with felt M > 5

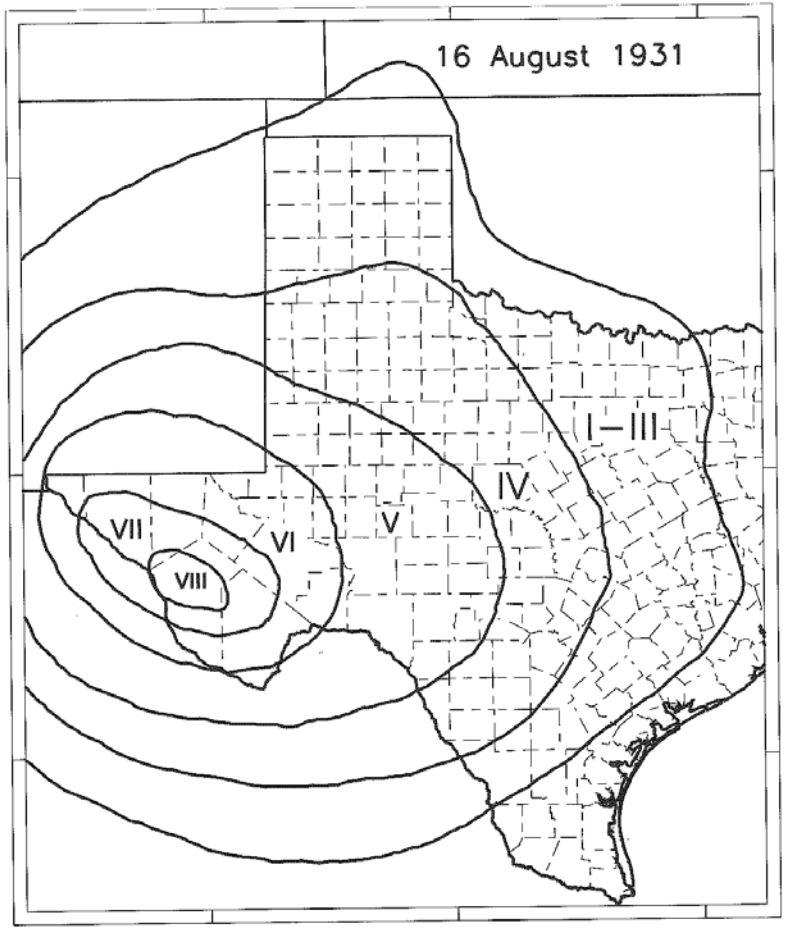
- 30th July 1925, M = 5.4 - Panhandle
- 16th August 1931, M = 6.0 - Valentine
- 20th June 1936, M = 5.0 - Borger
- 12th March 1948, M = 5.2 – Dalhart

Magnitude	Typical Maximum Modified Mercalli Intensity	
1.0 - 3.0	I	*Not Felt
3.0 - 3.9	II - III	
4.0 - 4.9	IV - V	
5.0 - 5.9	VI - VII	
6.0 - 6.9	VII - IX	
7.0 and higher	VIII or higher	*Considerable – Total Damage

Magnitude derived from Macroseismic Intensities (perceived ground motion in the Modified Mercalli Intensity Scale)

http://earthquake.usgs.gov/learn/topics/mag_vs_int.php

16th August 1931, M = 6.0 - Valentine

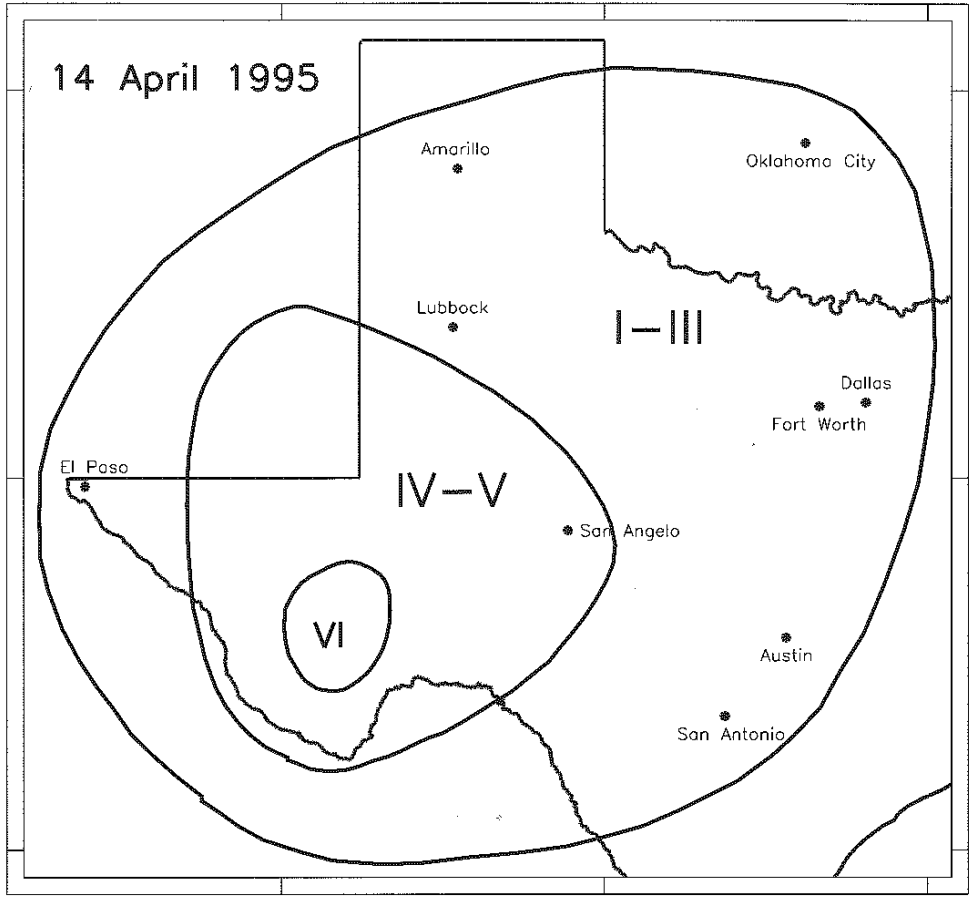


Frohlich & Davis, 2002

Instrumental Seismicity, 1973 … today

One event with M > 5

- 14th April 1995, M_w = 5.7 – Alpine



Frohlich & Davis, 2002

Instrumental Seismicity, 1973 … today

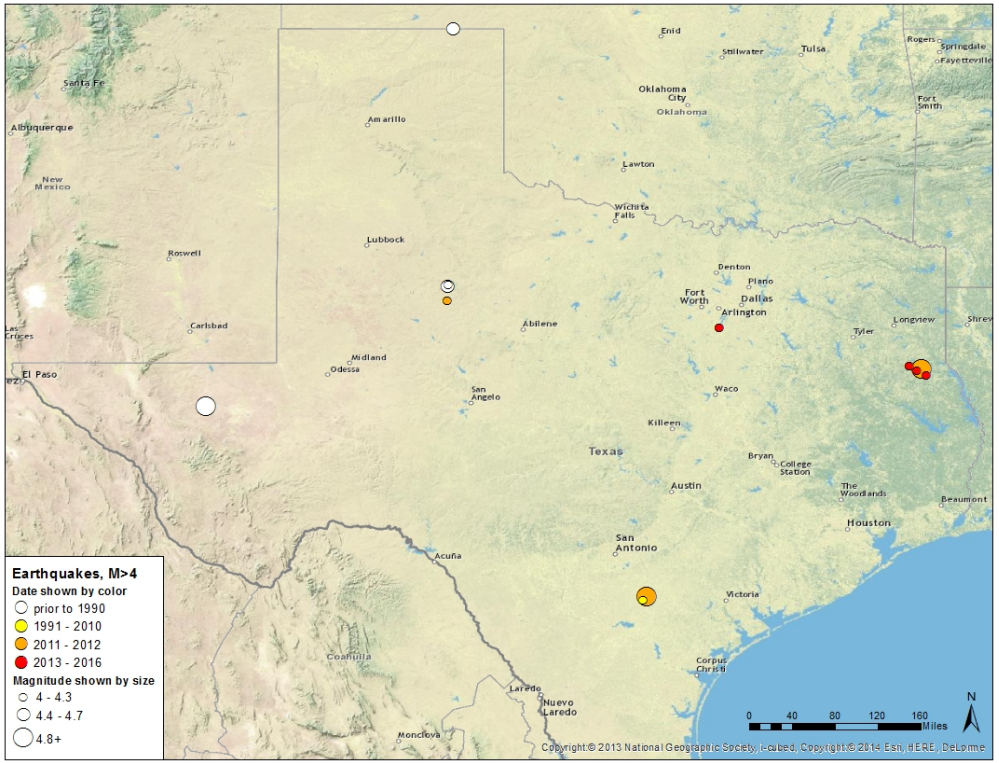
Bureau of Economic Geology

Events with M>=4.0

- 15th February 1974, m_b=4.5 – Perryton
- 1st August 1975, m_b=4.8 – Delaware
- 7th June 1977, M_L=4.0 - Snyder
- 16th June 1978, m_{bLg}=4.6 – Snyder
- 9th April 1993, m_{bLg}=4.3 – Fashing
- 11th September 2011, M_w=4.3 - Snyder
- 20th October 2011, M_w=4.8 - Fashing
- 17th May 2012, M_w=4.8
- 25th January 2013, M_w=4.1
- 2nd September 2013, M_w=4.2
- 2nd September 2013, M_w=4.3

Timpson

- 7th May 2015, M_w=4.0 - Venus



References of Recorded Instrumental Seismicity

- Ft Worth Earthquake Sequence 2008-2009 (m_b<3.4) – (Frohlich et al., 2011)
- 9th June 2009, m_{bLg}=2.8 – Cleburne (Fort Worth) – (Justinic et al., 2013)
- North Texas 2009-2011 (M_w<3.1) – (Frohlich, 2012)
- East Texas Earthquake Sequence 2010-2012 (Walter et al., 2016)
- 17th May 2012, M_w=4.8,
- 25th January 2013, M_w=4.1
- 2nd September 2013, M_w=4.2 & M_w=4.3

} Timpson - (Frohlich et al., 2014)

- 20th November 2013, M_w=3.6 – Azle - (Hornbach et al., 2015)

Recent Recorded Seismicity in Ft Worth Basin

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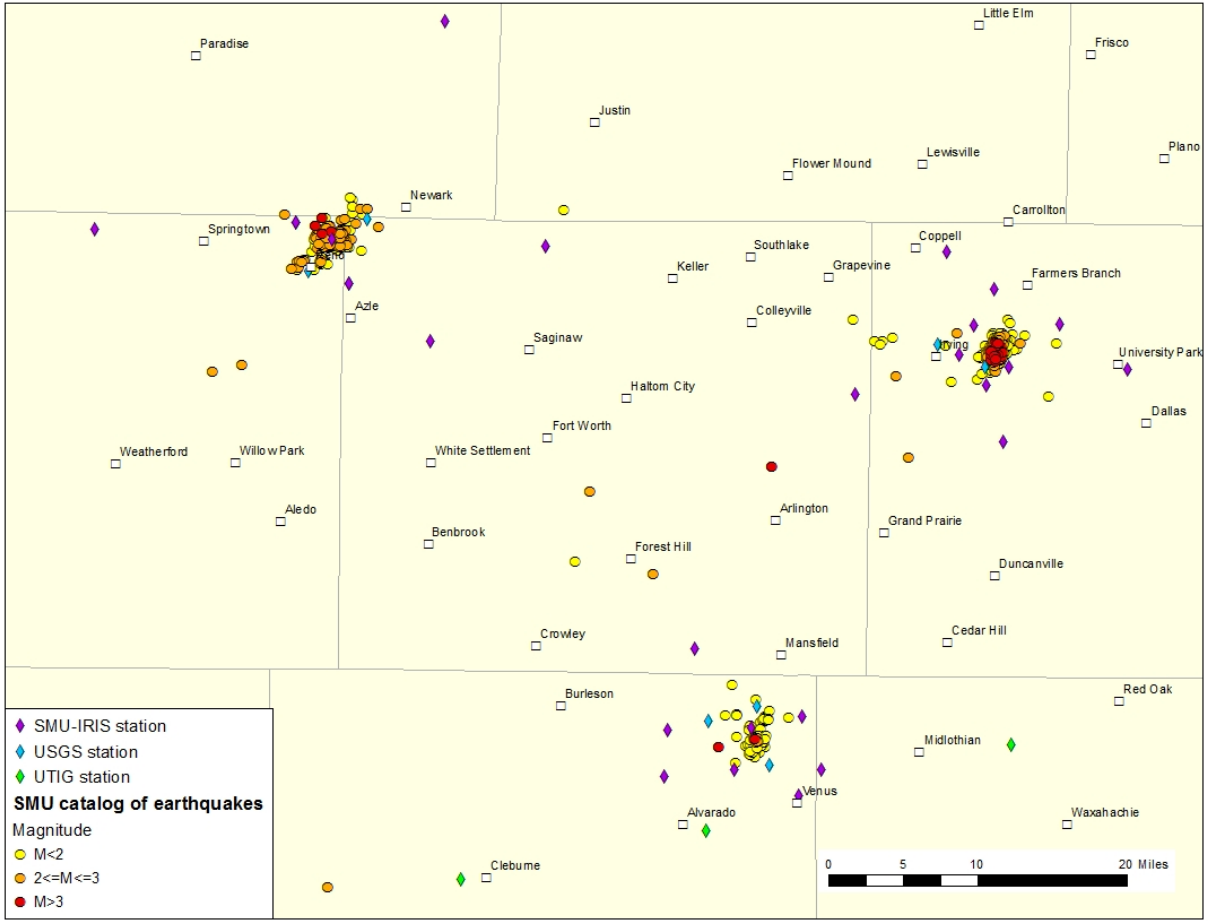
Three Distinct Areas

- Azle
- Irving
- Venus

Studied Seismicity based on portable network array



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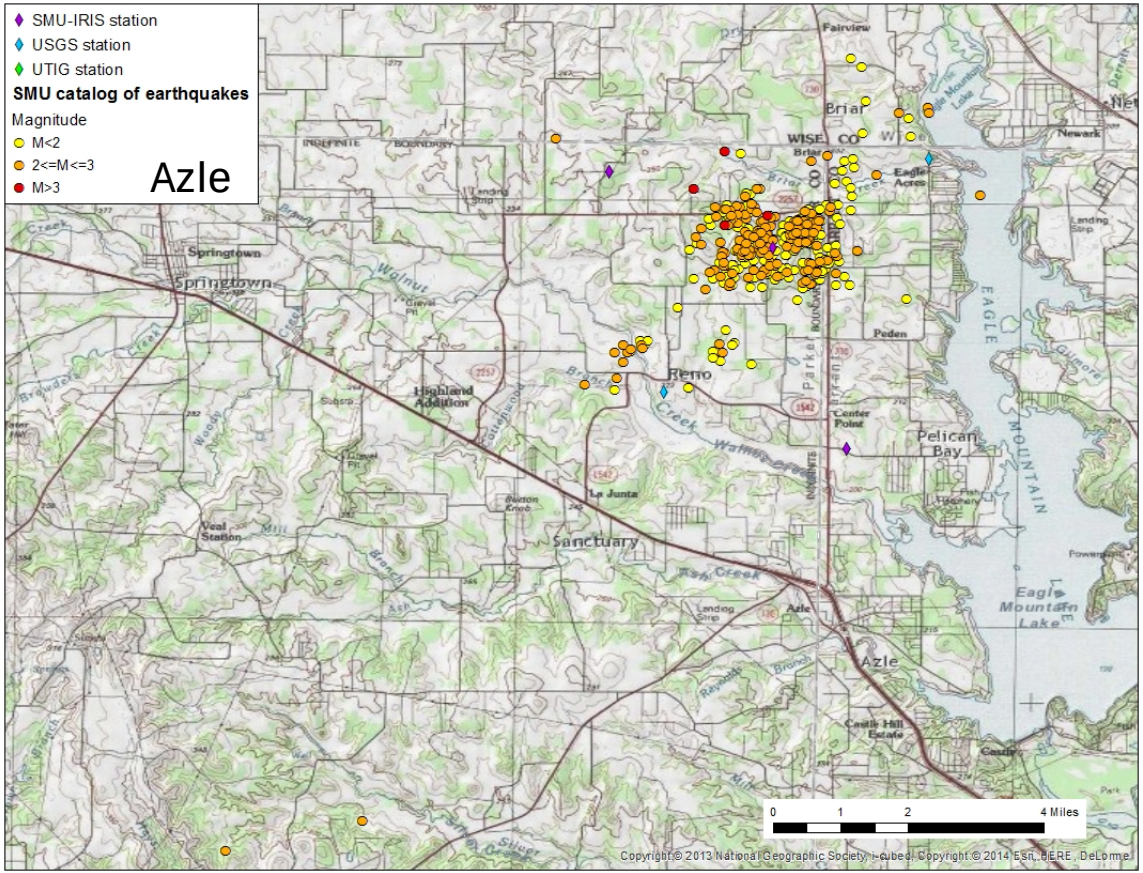
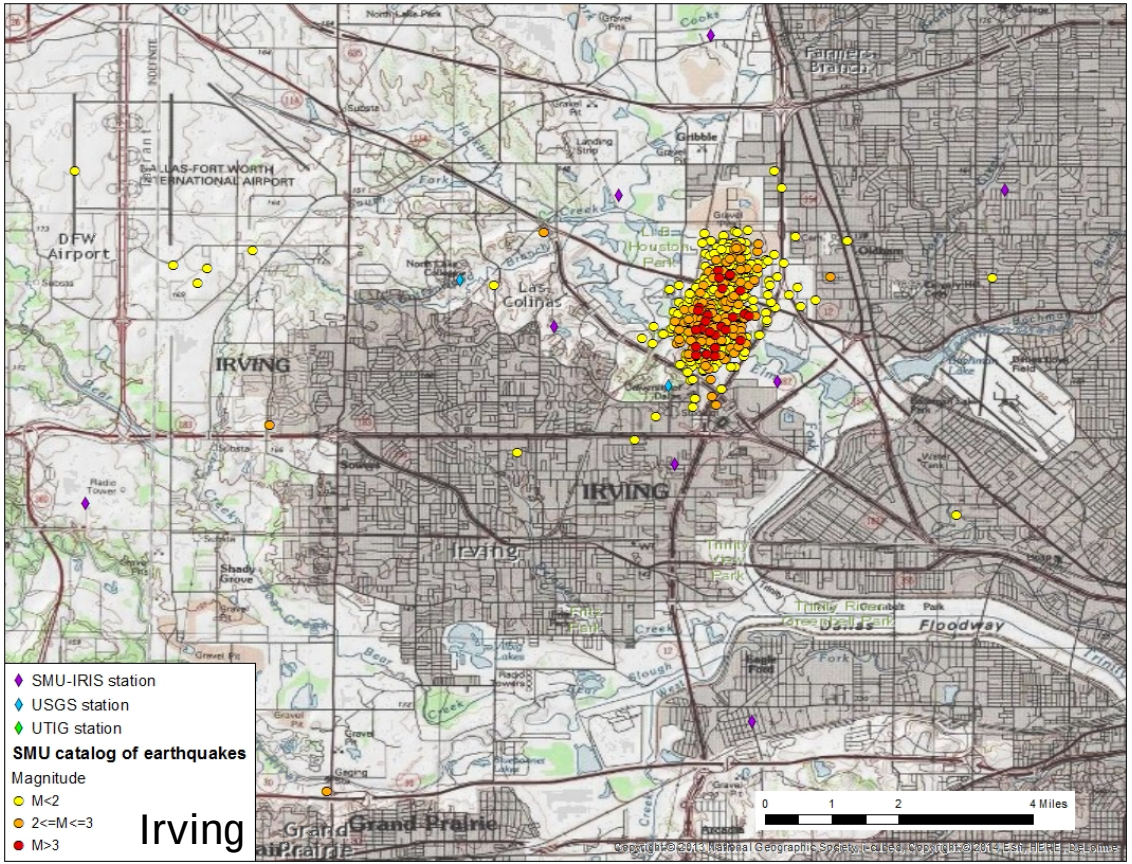
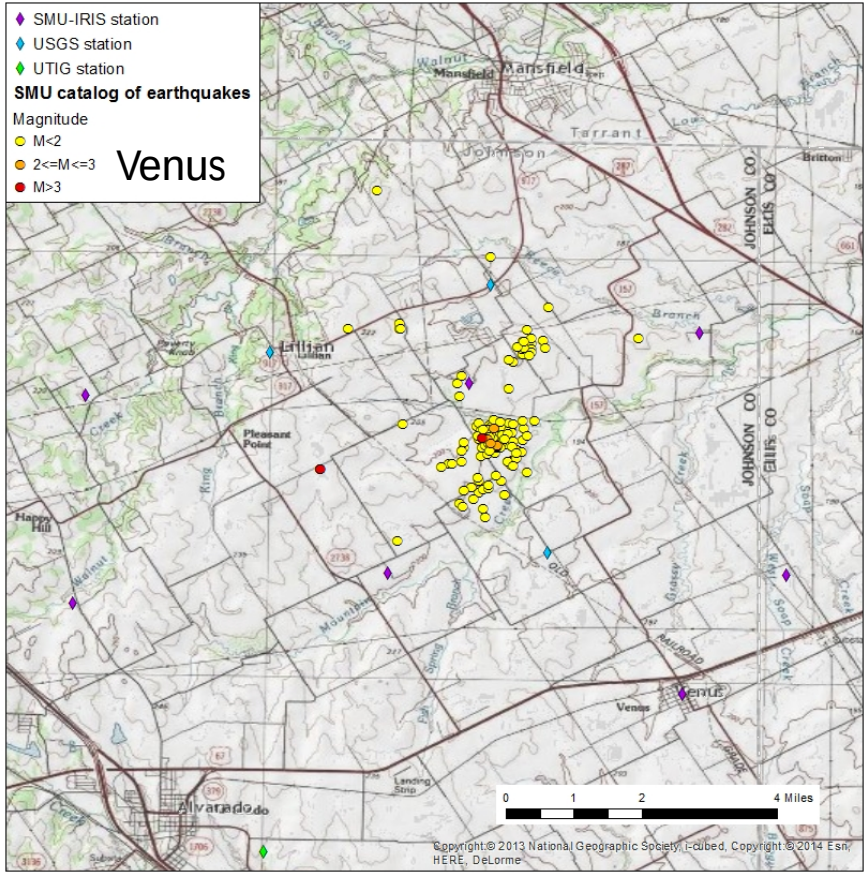
Installations in FW Basin



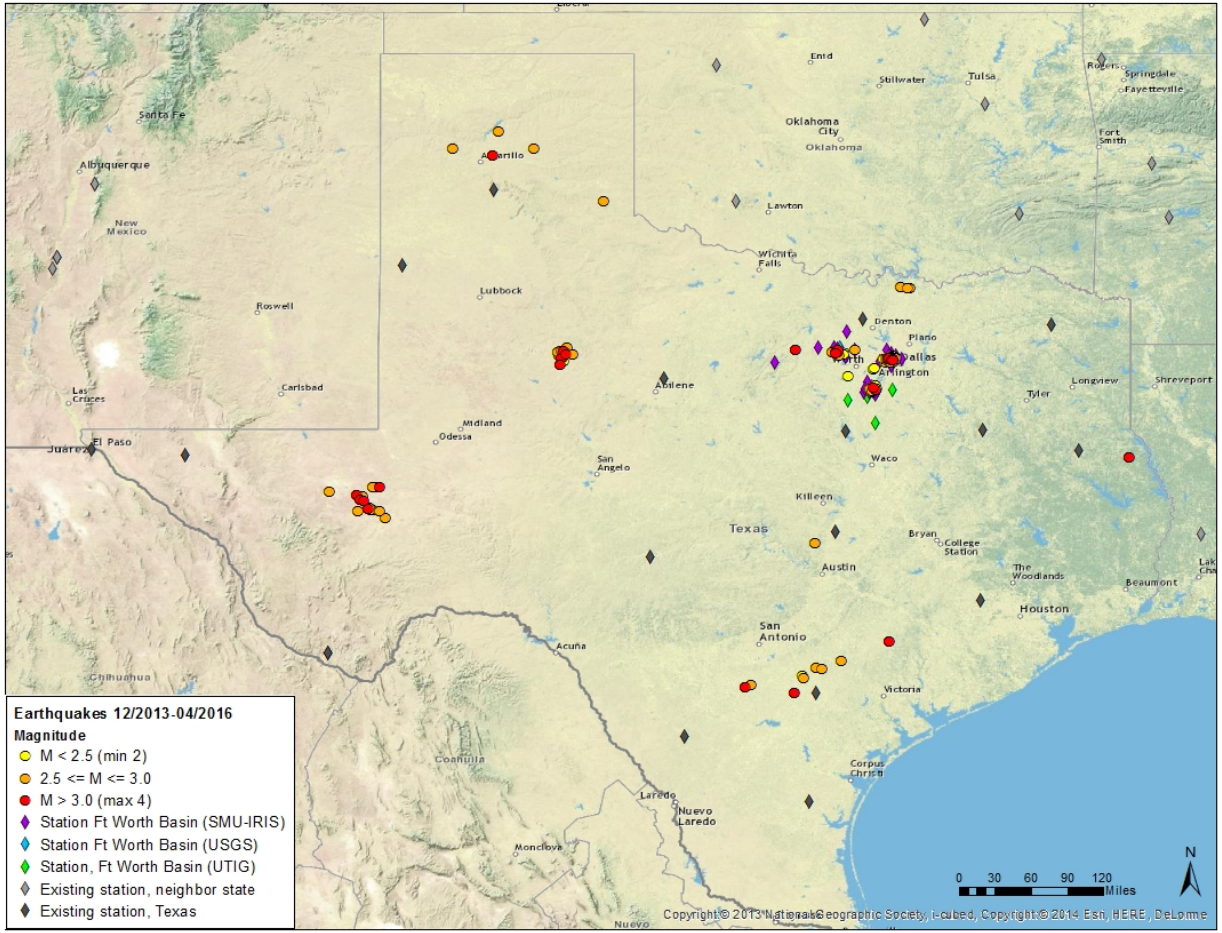
Installations in FW Basin



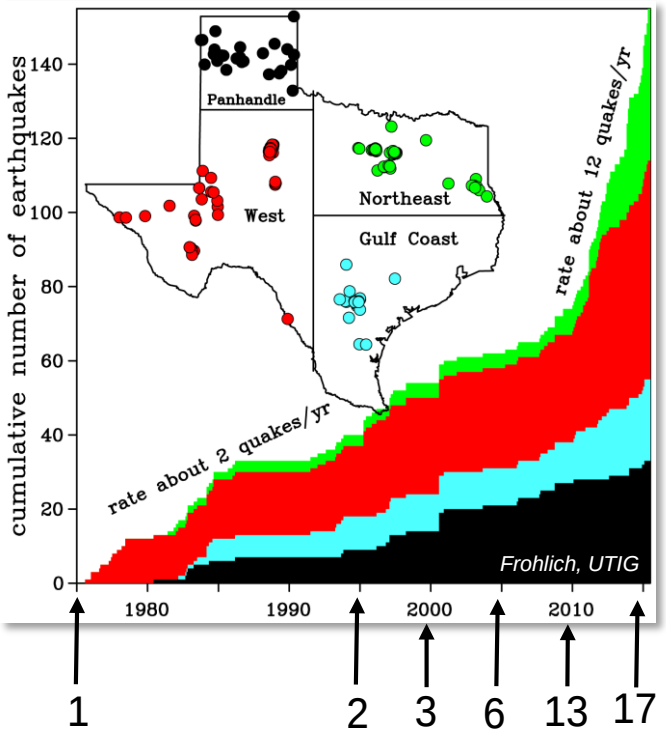
Installations in FW Basin



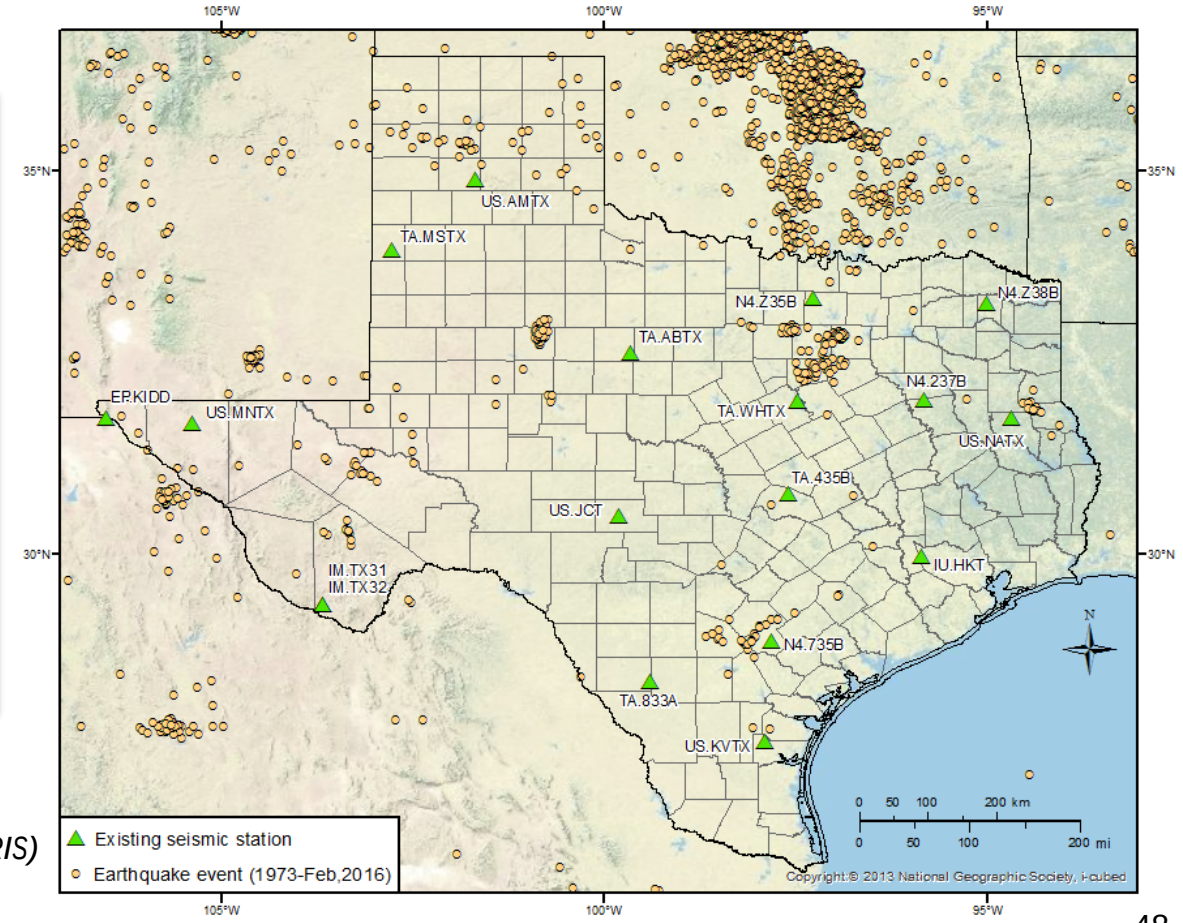
Overview of Seismicity - 2013 to 2016



Seismic Network from 1973 to 2015



Cumulative Number of Permanent Stations *(IRIS)*



Seismic Network Expansion 2016 - TexNet

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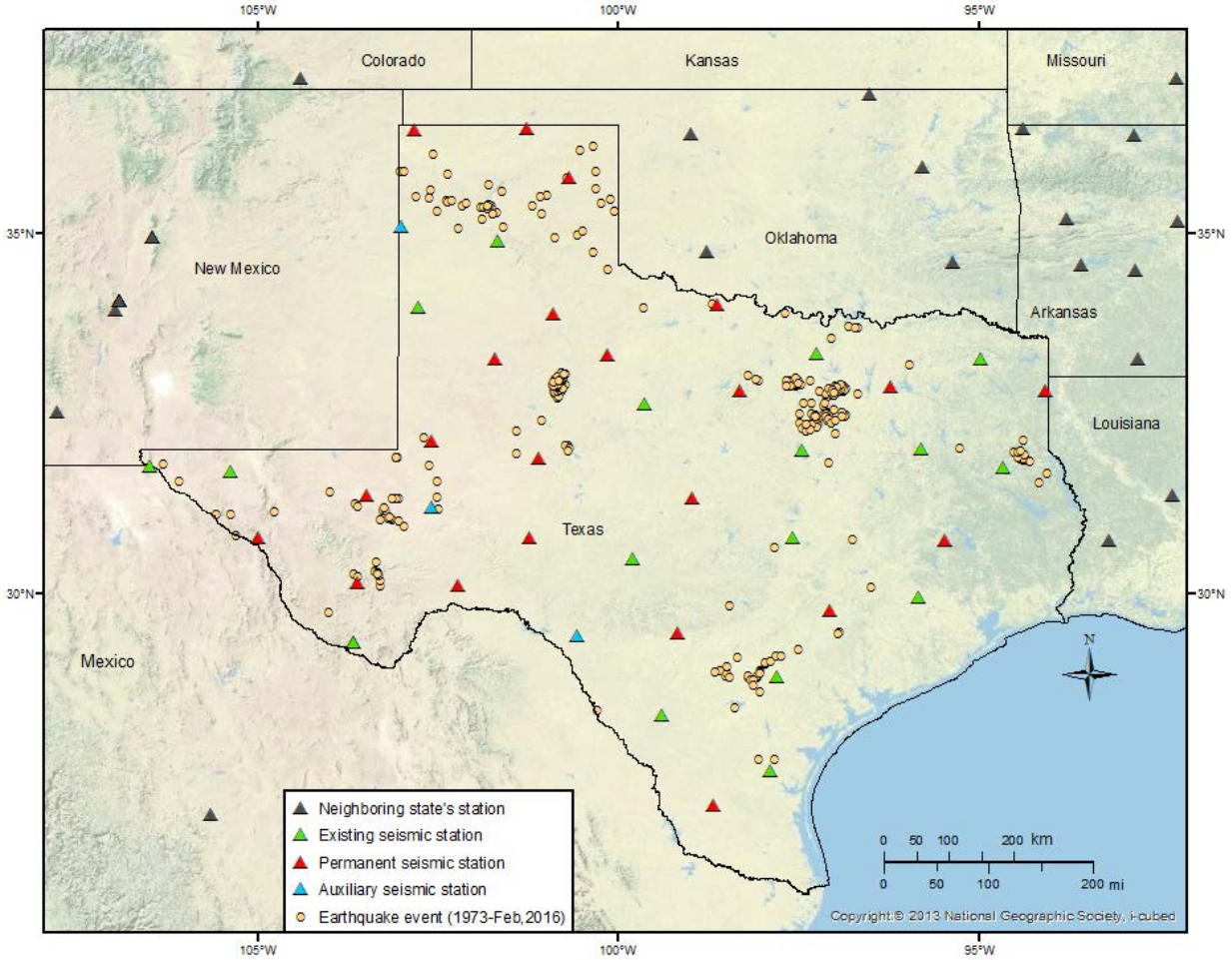
- Permanent Stations (22)
- Auxiliary Semi-Permanent Stations (3)

Portable Stations (33)



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Concluding Statement

- **Recorded** seismicity has shown that small magnitude earthquakes events occur throughout the State
- **TexNet** will provide:
  - The spatial distribution of seismicity in Texas, and
  - Minimize uncertainties in earthquake locations (position and hypocentral depth)

Thank you!

TexNet

Technical Advisory Committee Meeting

June 7, 2016

Bureau of Economic Geology
University of Texas at Austin