[AV]Surface Microseismic Monitoring of Hydraulic Fracture Stimulations, Bakken Formation, Nesson Anticline, Williston Basin, North Dakota

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Abstract

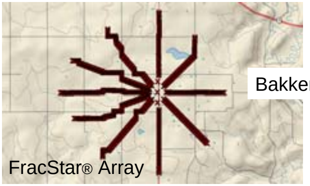
A surface microseismic methodology was utilized to perform hydraulic fracture diagnostics during stimulation of the XTO Energy Nesson State 41X-36 and 44X-36 wells, Bakken Formation, Williston Basin, Williams County, North Dakota. Analysis of the surface microseismic data was carried out for seven (7) hydraulic fracture stages performed in the 41X-36 and 44X-36 wells to: (1) determine the applicability of the surface microseismic approach for fracture stimulations in the Bakken; and (2) characterize fracture azimuth, length,and symmetry with respect to rock properties.

The surface microseismic data were of sufficient quality to enable successful interpretations of hydraulic fracture geometries. Induced fracture azimuths and lengths were estimated for all 7 hydraulic fracture stages. Induced fractures were observed to form complex networks along primary azimuths of 55-60 degrees and secondary azimuths of 145-150 degrees. Fracture half-length varied from stage to stage but on average was 1000 feet for the 41X-36 and 750 feet for the 44X-36. A regional geologic study of the Williston Basin provided structural evidence to support geometries observed from the surface microseismic data.

References

Heck, T.J., LeFever, R.D., Fischer, D.W. and LeFever, J., 2002. Overview of the petroleum geology of the North Dakota Williston Basin: North Dakota Geological Survey, Bismarck, ND.

LeFever, Julie, 2005, Oil production from the Bakken Formation: A short history: North Dakota Geological Survey newsletter, v. 32, no. 1, p. 5-10.



Bakken Consortium

Surface Microseismic Monitoring of Hydraulic Fracture Stimulations, Bakken Formation, Nesson Anticline, Williston Basin, North Dakota

David Abbott, Sherilyn Williams-Stroud, MicroSeismic, Inc.

Ron Shaffer, XTO Energy Inc.

AAPG 2009 Annual Convention & Exhibition, Denver, Co, June 9, 2009

PASSIVE SEISMIC MONITORING

Note of Presenter:

-Welcome, I appreciate your interest in hearing about surface based microseismic monitoring.

-As indicated by the title we shall review a surface microseismic project conducted in the Williston Basin North Dakota.

-I would like to thank my co-authors Sherilyn Williams-Stroud of MicroSeismic and Ron Shaffer of XTO Energy; without their help this wouldn't be as compelling a presentation.

Outline

- Bakken Consortium Project
  - Objectives
  - Project Layout/Design
- Regional/Local Geology
- FracStar®/PSET® Methodology
- Results
- Fracture Interpretation
- Conclusions

Bakken Consortium Project

- Test Multiple Drilling Techniques
- Optimize Completion Practices
- Determine Productive Area Utilizing Microseismic Methods
- Employed Four Separate Microseismic Arrays As Part of the Consortium
- The Focus of this talk will be on the Surface Microseismic implementation and interpretation

PASSIVE SEISMIC MONITORING

Note of Presenter:

-The Bakken Consortium is a group of seven companies who together conceived an idea to deploy the most advanced available technology to investigate opportunities to optimize the drilling, completion and production of horizontal Williston Basin Bakken formation wells. Of special significance was the implementation of microseismic technology to monitor fracture initiation and growth.

-The data to be shown today was acquired as part of the Bakken Consortium Project

-Members of the consortium will be listed at the end of the talk

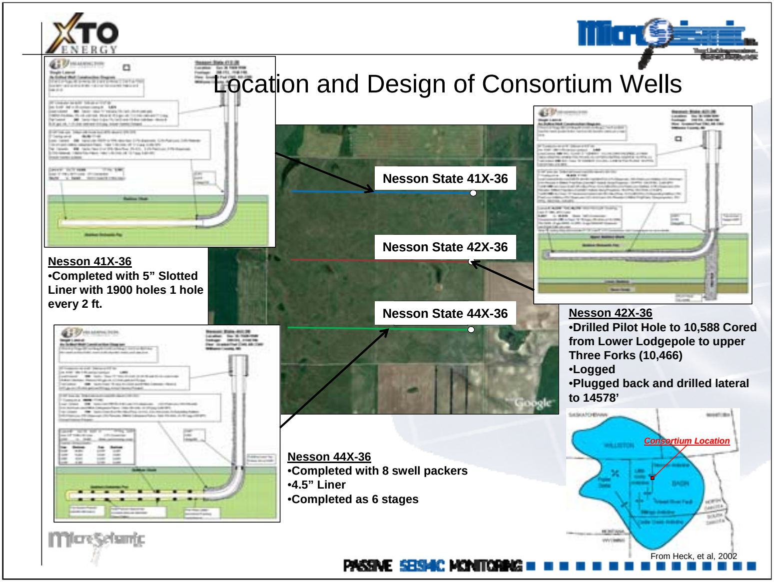
-Project objectives include

 -Drilling and completion optimization

 -Testing microseismic monitoring for fracture treatments in the Bakken

 -4 microseismic arrays were employed

 -The focus of this presentation will be on the surface based implementation



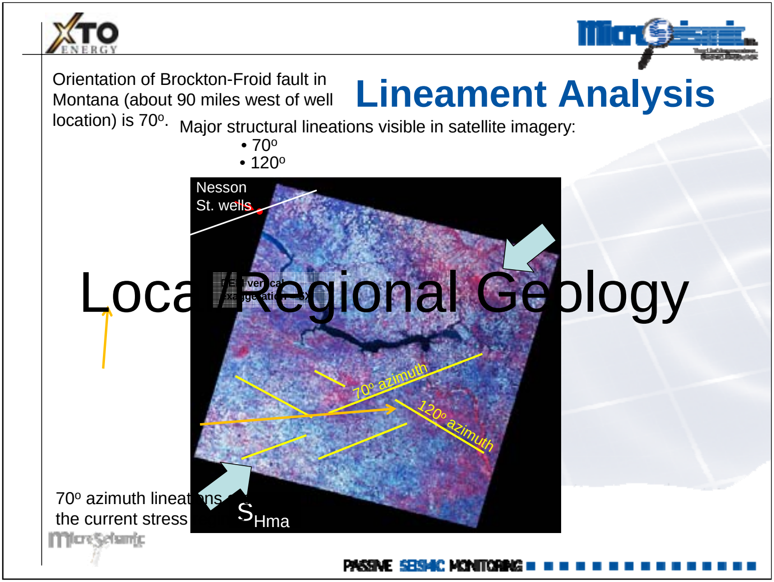
Note of Presenter:

The consortium project area is located on the east flank of the Nesson Anticline in NW North Dakota as shown on the index map.

3 wells were drilled for the project. The 42X was drilled primarily as a “data well.” Pilot hole drilled through the Bakken section. Well was cored from the Lower Lodgepole to the Upper Three Forks. Pilot hole was logged. Pilot hole was plugged and drilled lateral. The lateral section was utilized by Schlumberger for the downhole monitor array.

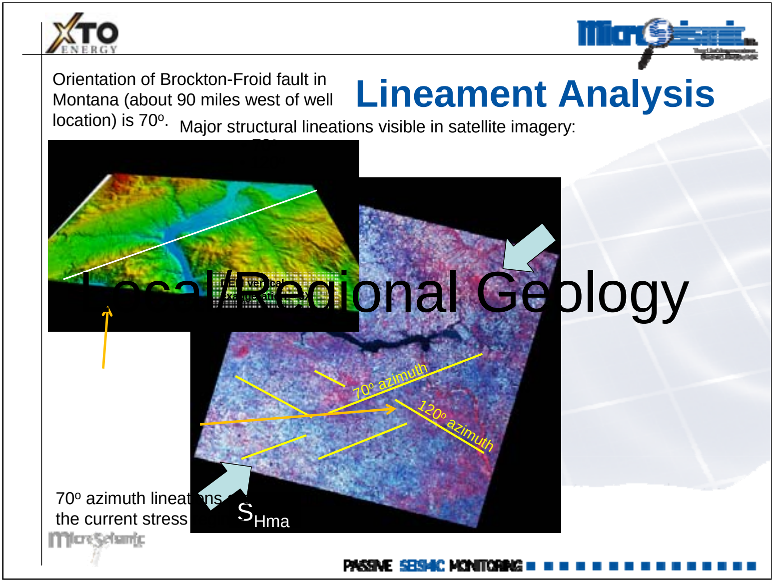
The 41X is the northern producer. It was completed with a 5” slotted liner, 1 hole/2 feet. One fracture treatment stage lasting ~2 hours.

The 44X is the southern producer. It was completed with a 4.5” liner. 8 Swell Packers were used to isolate treatment zones. 6 stages were treated.



Note of Presenter:

Major structural lineaments observed on the landsat image shown have orientations of 70 degrees and 120 degrees. Surface lineaments indicate active or recently active fault movement along the lineaments. The lineaments are surface expressions of major structural features in basement rocks of the Williston Basin. World Stress Map data indicate maximum horizontal stress is NE-SW. Stress anisotropy is low in the Williston Basin explaining why fault motion is observed in 2 orientations.



Note of Presenter:

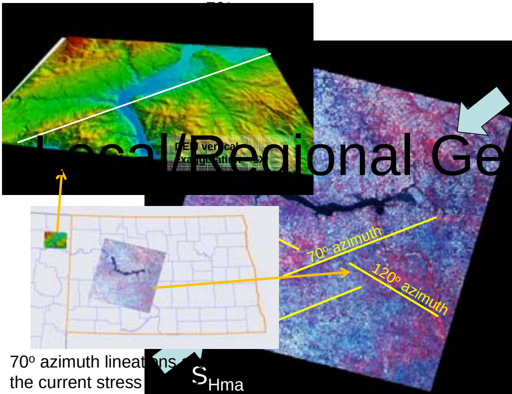
The 70 degree trend is expressed as a major feature in other parts of the Williston Basin, in particular in the Brockton-Froid strike-slip fault in Montana.

Lineament Analysis

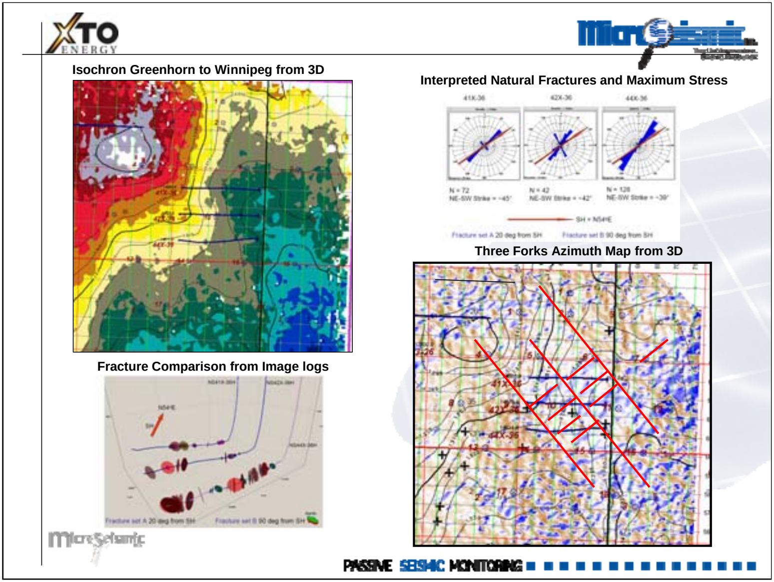
Orientation of Brockton-Froid fault in Montana (about 90 miles west of well location) is 70º.

Major structural lineations visible in satellite imagery:

Local/Regional Geology



70º azimuth lineat ns the current stress



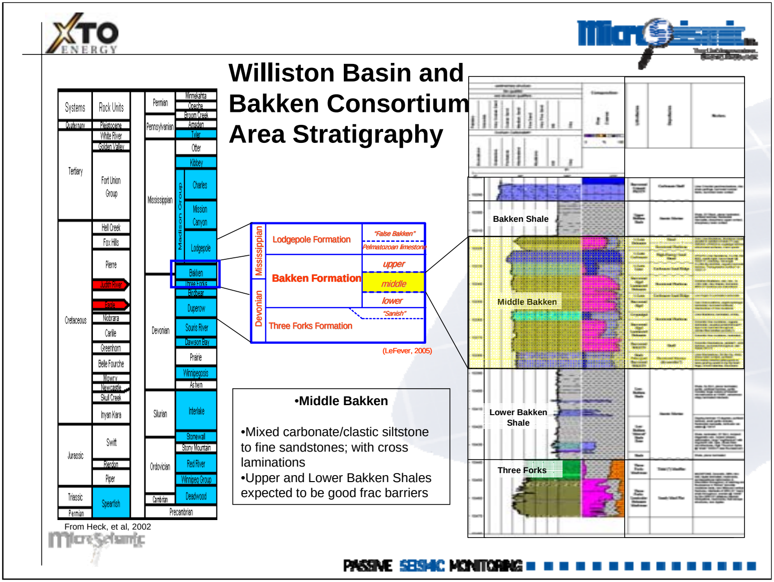
Note of Presenter:

The upper left map is an Isochron from Greenhorn to Winnipeg showing local structure in the Consortium area to be a low-relief anticline/syncline pair with axes oriented at approximately N15W. No significant faulting is evident in this area

The lower left and upper right figures summarize the fracture density and orientation identified in each of the 3 laterals drilled in the Consortium.

There are two directions of natural fractures evident in these wells with difference in stress magnitude. Orientations of the natural fractures are 39-45 degrees and ~145 degrees. Shmax was measured to be oriented at 54 degrees.

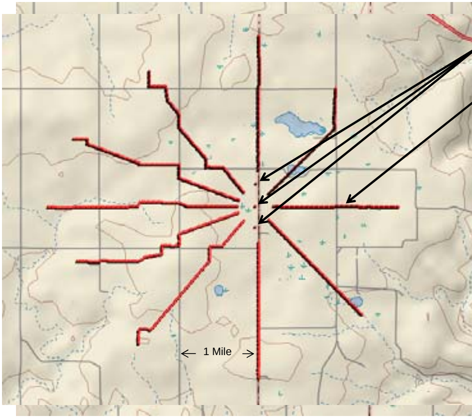
The lower right map shows interpreted lineaments from the Three Forks azimuth map from the 3D which show similarity to the local grain as depicted in the image log data.



Note of Presenter:

The wells are completed in the Middle Bakken. The Middle Bakken is mixed carbonate/clastic siltstone to fine sandstones. The Upper and Lower Bakken shales are expected to be frac barriers.

FracStar/PSET Methodology



FracStar Array

- •Array centered on well surface locations
- •10 Radial Lines
- •962 Total Stations
- •24 Vertical Component Geophones per Station
- •23,088 Total Geophones

PSET

- •Microseismic Event Imaging
- •“Beam Steer” Algorithm
- •Power of Stack

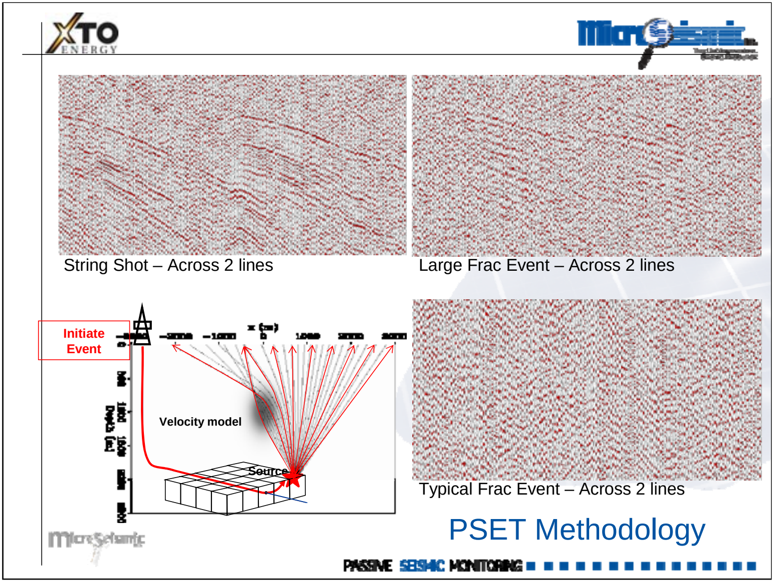
Note of Presenter:

Next let us look briefly at the surface microseismic methodology. Shown is the FracStar utilized for the consortium project

The array is centered on the surface locations. The pumps are the largest noise source and centering the array on this noise source helps with noise reduction filters.

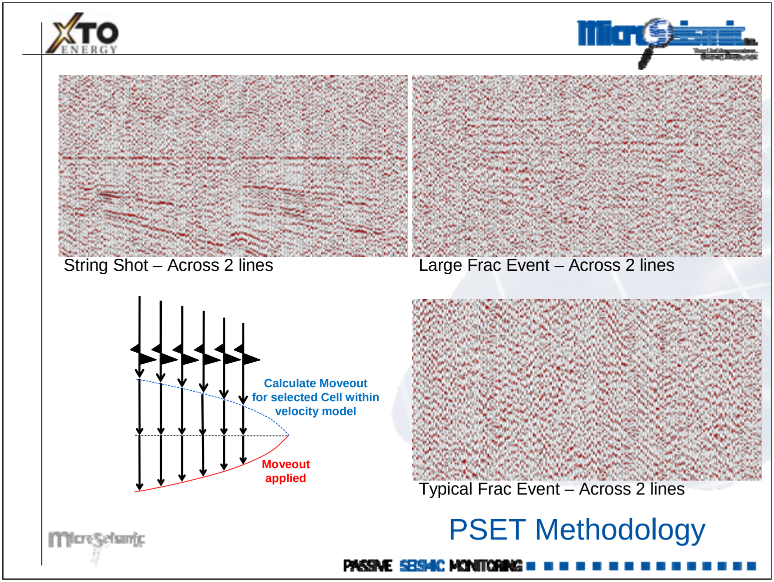
The array has 10 radial lines with 962 total stations. Each station has 24 vertical component geophones meaning over 23,000 geophones were deployed for this project.

PSET is the proprietary software system used for event location. PSET utilizes a “Beam Steer” algorithm and relies on the “Power of Stack” for event detection.



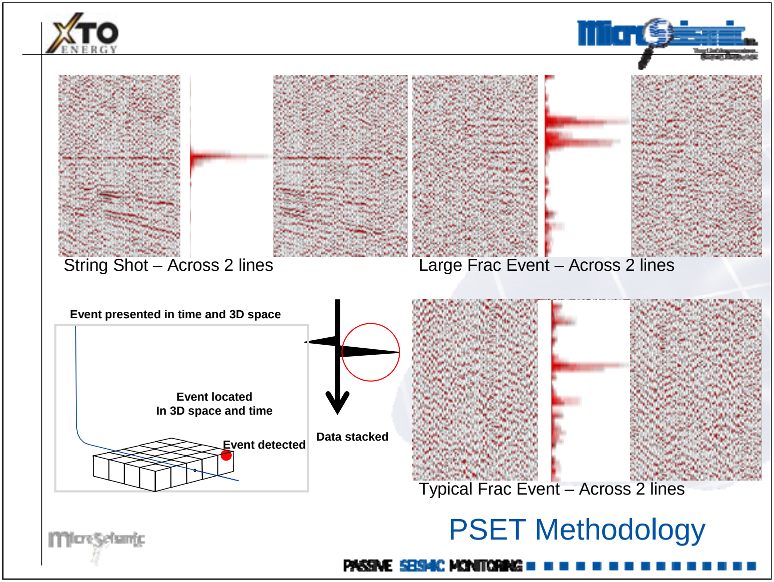
Note of Presenter:

Events are initiated in the subsurface and recorded along the FracStar array. Shown here are 3 examples of events detected during this project – shown along 2 of the FracStar lines. String Shot detonated in the 41X used for velocity model calibration. Large frac induced microseismic event. Typical frac induced microseismic event.



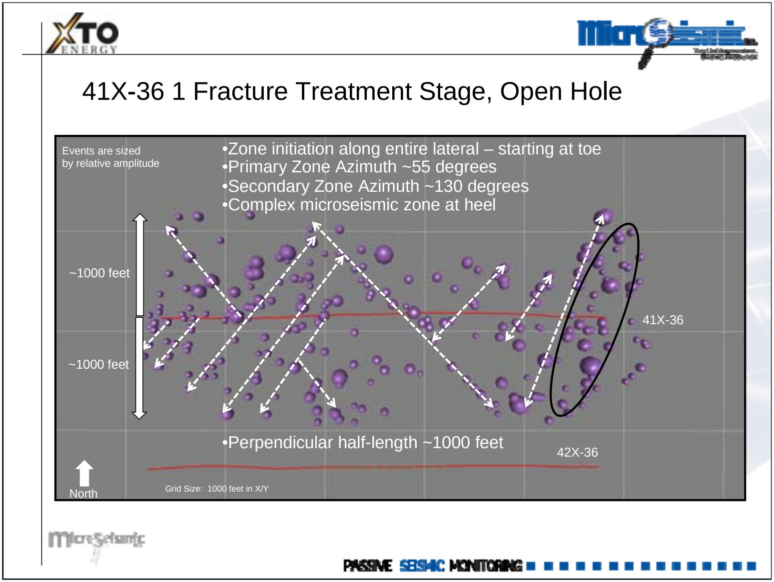
Note of Presenter:

PSET calculates travel times from a regular grid of subsurface cells. The moveout correction is applied for each of these subsurface cells.



Note of Presenter:

The data are stacked at each subsurface cell. PSET scans each subsurface cell for spikes in seismic energy. The event is located in the cell which has the highest energy for a given time period. In our examples we can see that spikes in seismic energy are observed for each event.



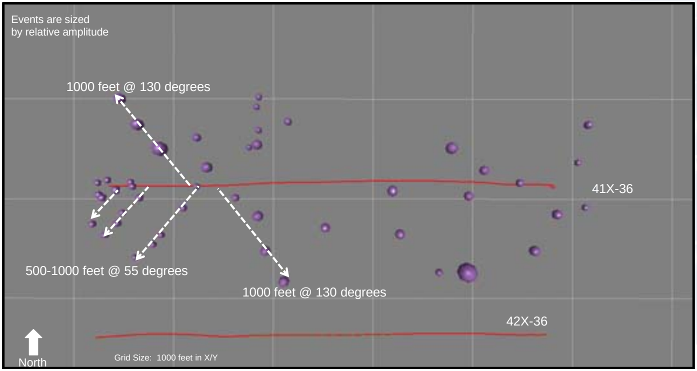
Note of Presenter: Results--

Shown here is the entire microseismic data set for the single fracture treatment in the 41X. Microseismic event locations are represented by spheres whose size represents the relative amplitude of the Microseismic event. The grid on all displays is 1000’ in X/Y.

Some general observations are: Zone initiation occurs along the entire lateral starting at the toe; Primary zone azimuth is ~55 degrees; Secondary zone azimuth is ~130 degrees; Complex microseismic zone appears at the heel of the well; Perpendicular half-length ~1000 feet; Vertical resolution is not sufficient for meaningful interpretation; therefore, all results will show horizontal geometries only.

41X-36 1 Fracture Treatment Stage, Open Hole

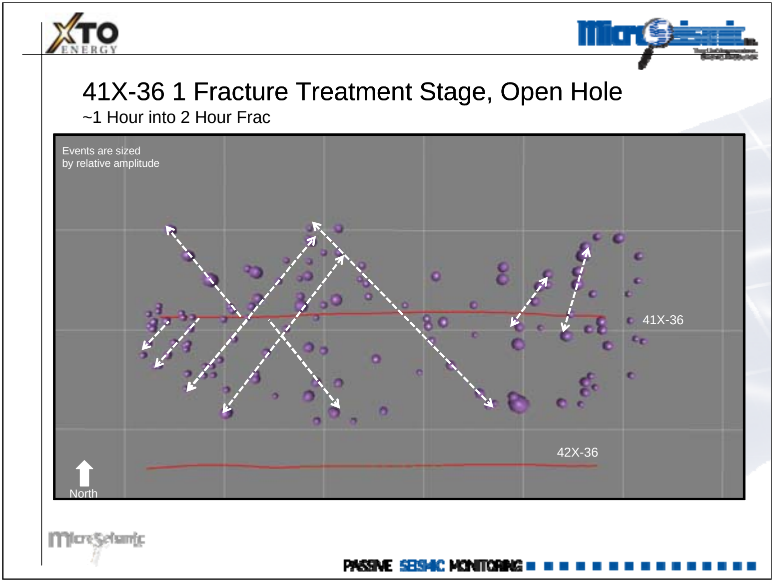
~20 minutes into 2 Hour Frac



PASSIVE SEISMIC MONITORING

Note of Presenter: Time series animations showing microseismicity as it occurs during the frac:

During the first 20 minutes of the frac we observe well defined zones at the toe of the well. Microseismicity is observed along the entire lateral but at the heel end zone geometries are not obvious at this point.

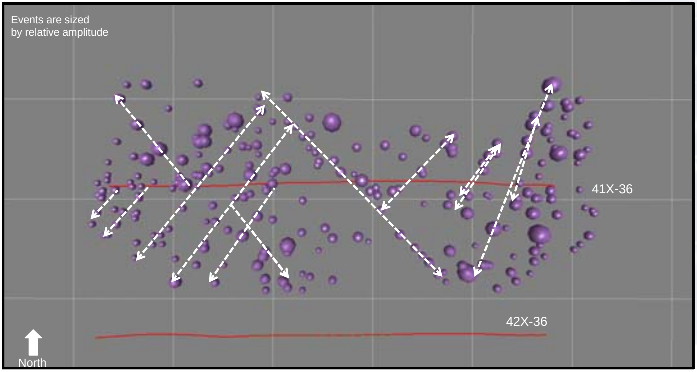


Note of Presenter:

After an hour we observe zones along the entire lateral; Complexities within the zone network are becoming more evident.

41X-36 1 Fracture Treatment Stage, Open Hole

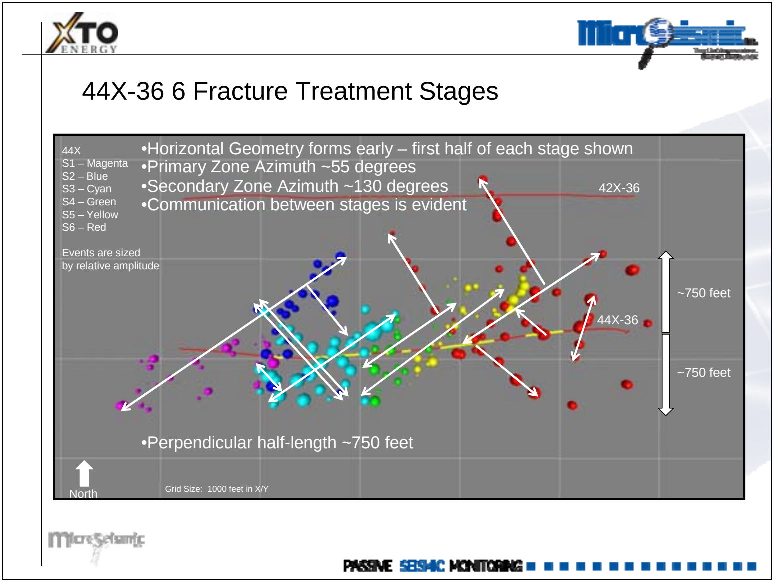
~2 Hours into 2 Hour Frac



PASSIVE SEISMIC MONITORING

Note of Presenter:

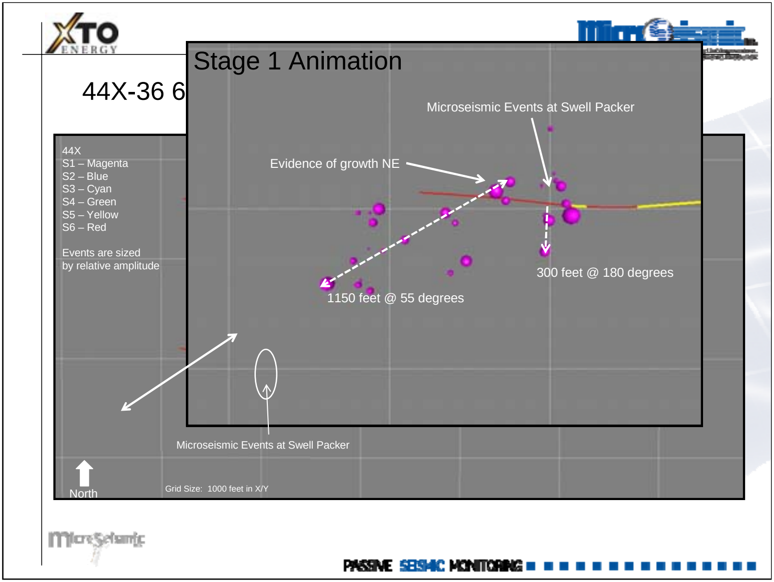
This is the entire data set showing well defined zones along the entire lateral with added complexity to all zones.



Note of Presenter:

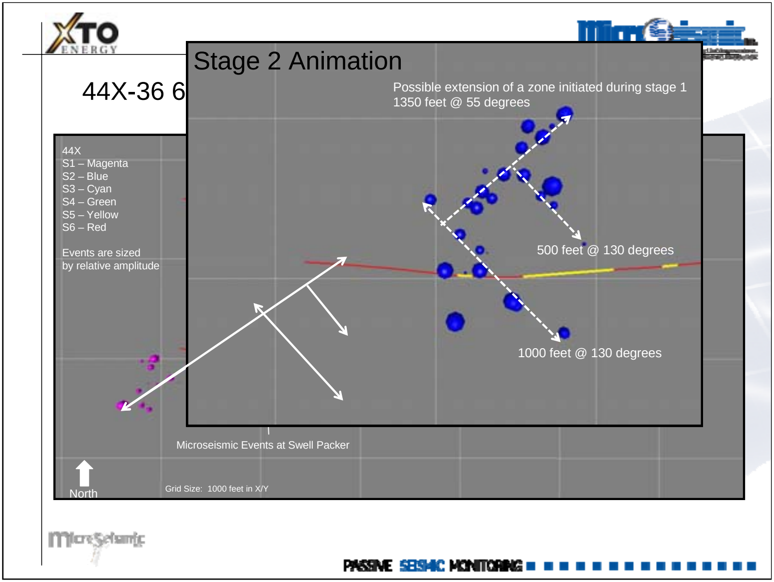
Shown here is a composite of microseismicity observed during all 6 stages of the 44X fracture stimulation. Each stage is a different color – shown in the legend at left.

Some general observations: Horizontal geometry forms early – data shown therefore is for the first half of each stage; Primary zone azimuth is ~55 degrees; Secondary zone azimuth is ~130 degrees; Communication between stages is evident by observing zones occupied by multiple colors; Perpendicular half-length is in general ~750 feet; Vertical resolution is not sufficient for meaningful interpretation.



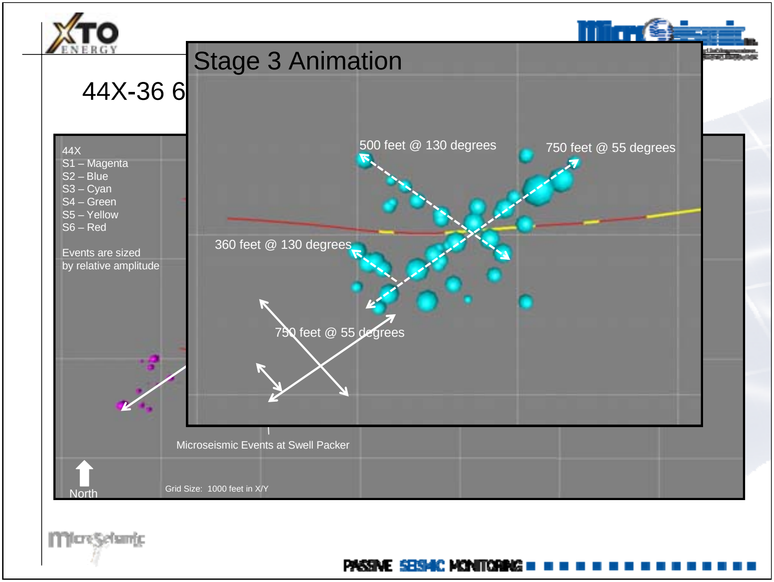
Note of Presenter: Time series animations of each stage:

During stage 1 we observe microseismicity along the primary orientation with a clustering of events at the swell packer between Stage 1 and Stage 2.



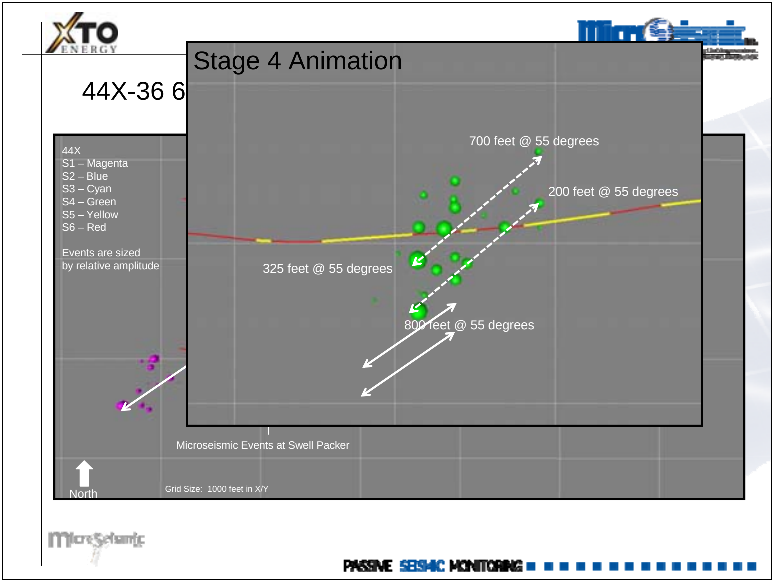
Note of Presenter:

Stage 2 is dominated by what appears to be an extension of the zone initiated during Stage 1 along the primary zone orientation. Zones are also observed in the secondary orientation.



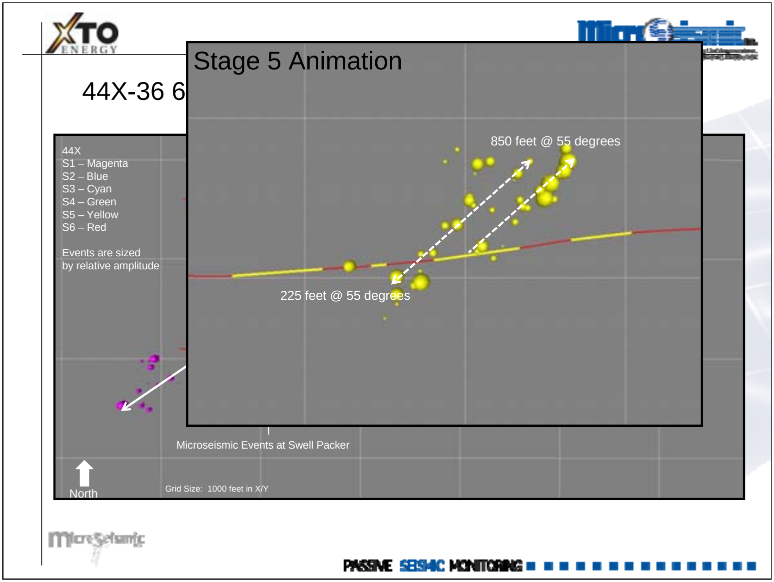
Note of Presenter:

Stage 3 microseismicity is a bit more complex but still is dominated by zone initiation in the primary orientation. Zones are also observed in the secondary orientation.



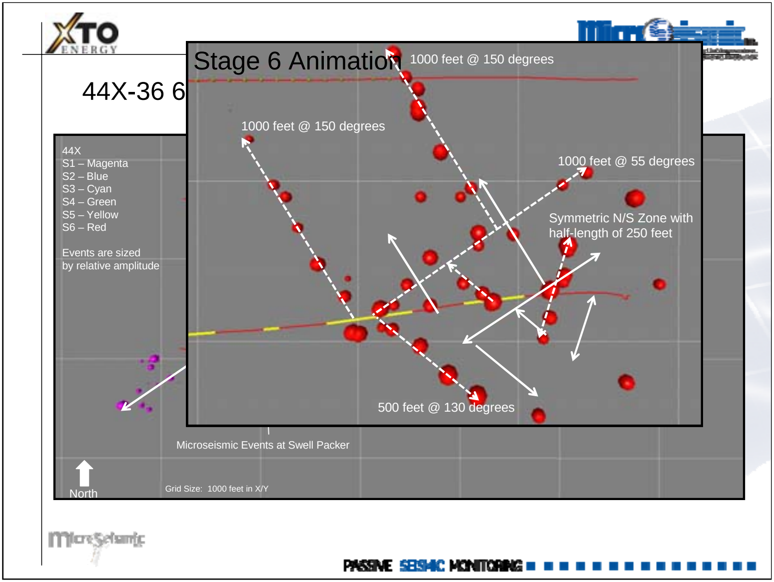
Note of Presenter:

Stage 4 microseismicity is basically along 2 zones in the primary orientation.



Note of Presenter:

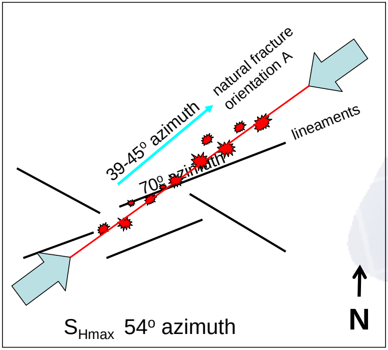
Stage 5 microseismicity is also along 2 zones in the primary zone orientation.



Note of Presenter:

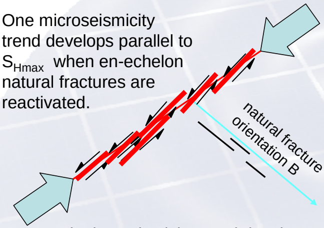
Stage 6 is dominated by long well defined zones in both orientations. A curiosity of the Stage 6 result is zone initiation at the Stage 5 interval indicating a possible breach in the plug or packers between Stage 5 and Stage 6.

Regional Lineaments and Microseismicity Trends



Fractures and lineaments are not parallel to S_{Hmax}.

One microseismicity trend develops parallel to S_{Hmax} when en-echelon natural fractures are reactivated.



A second microseismicity trend develops parallel to existing natural fractures because $S_{Hmax} - S_{hmin}$ is small.

Lineaments could also be reactivated in current stress regime.

Conclusions

- FracStar/PSET methodology successfully imaged frac induced microseismicity
- Horizontal zone geometry well defined for all 7 stages
  - Primary zone azimuth ~55 degrees
  - Secondary zone azimuth ~130 degrees
  - Perpendicular half-length 750-1000 feet
- Zones initiate along entire lateral of 41X-36 open hole frac
- Zone geometry established early during 44X-36 staged fracs
- Geologic lineaments and natural fracture orientations differ from stress orientation
- Microseismicity trends are showing reactivation of the natural fractures in direction parallel to stress orientation

Consortium Members

Working Interest Partners

- XTO (Headington)
- Continental
- Hess
- Brigham
- Encore
- Petro-Hunt
- Whiting

Secondary Technical Partners

- Schlumberger/Terrascience
- MicroSeismic Inc
- United States Department of Energy

Primary Technical Partner

- Schlumberger

Grant Assistance

- North Dakota Oil and Gas Research Council

North Dakota Website
http://www.nd.gov/ndic/ogrp-publications.htm

Note of Presenter:

Would like to acknowledge the consortium members and thank those involved for granting permission to show these results.