[AV]Structural Attribute Analysis Used in Barnett Resource Development*

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Abstract

Successful completions in the shale of the Barnett Formation require a combination of high quality geology and geophysics in association with high technology drilling and completion engineering. Large areas of the Barnett play contain challenging conditions that make economic completions more difficult. These challenges can be geological (faulting and karsting), geophysical (gas effects and velocities), and engineering (Barnett thickness and lack of frac barriers). Thus, the majority of the play area has more difficulties to overcome than in the core area (sweet spots) and requires the use of higher technology with respect to the geosciences and engineering. Success is not simply a matter of drilling a large number of wells into a uniform resource (as mistakenly applied to the Barnett), but one must both avoid drilling marginally or non-economic wells and drill more wells with significantly higher economic returns.

Important aspects related to the geology and geophysics for the drilling of successful Barnett gas wells are:

- Prediction and avoidance of Ellenberger karsts and both large- and small-scale faults that provide vertical conduits for water.
- Ability to define an objective zone within the Barnett and to maintain penetration within that zone.
- Ability to define “lateral” facies changes within the Barnett that may require different frac techniques from one zone to another.
- Improved frac designs to better contact the Barnett more efficiently.
- Anticipate conduits between wells to reduce problem communication.

We use detailed structural analysis and multi-attribute interpretation of 3D seismic data to aid in the drilling program. Karsts and major tectonic faults, both development hazards, are easily seen in dip-steered Similarity and Curvature attributes. The mid range of the Most Negative Curvature attribute shows a fine network of anomalies that can be correlated to natural fracture trends and small faults and that these are activated and accessed by fracture stimulation during well completions. Comparing micro-seismic fracture monitoring and visualization of the seismic-derived structural attribute volumes shows a clear relationship that allow us to predict reservoir presence as well as hazards. Clearly this is a broad multidisciplinary workflow that requires expertise from area of Geology, Geophysics, and Engineering that is somewhat unique to the play.

References

Al-Dossary, S., and K.J. Marfurt, 2006, 3D volumetric multispectral estimates of reflector curvature and rotation: Geophysics, v. 71, p.P41-P51.

King, G.E., L. Haile, J. Shuss, and T.A. Dobkins, 2008, Increasing Fracture Path Complexity and Controlling Downward Fracture Growth in the Barnett Shale: paper SPE 11986, SPE Shale gas Production Conference, Irving, TX, November 16-18.

Montgomery, Scott L., Daniel M. Jarvie, Kent A. Bowker, and Richard M. Pollastro, 2005, Mississippian Barnett Shale, Fort Worth basin, north-central Texas: Gas-shale play with multi – trillion cubic foot potential: AAPG Bulletin, v. 89, p. 155-175.

Roberts, A., 2001, Curvature attributes and their application to 3-D interpreted horizons: First Break, v. 19, p. 85-100.

Structural Attribute Analysis Used in Barnett Resource Development, Fort Worth Basin, Texas

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ACKNOWLEDGEMENTS

- Rimrock Energy

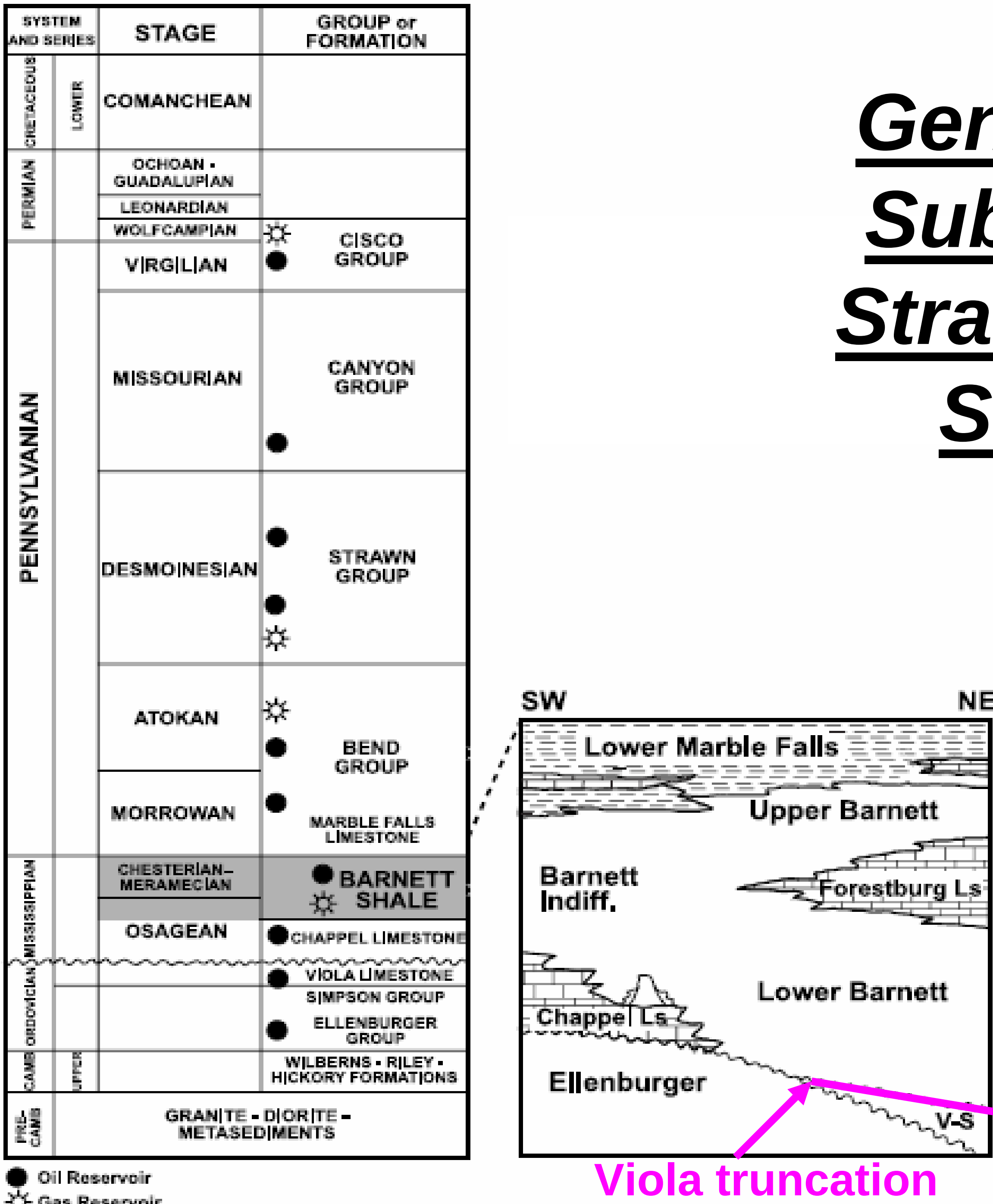
OUTLINE

- Basin Geology
- Geologic Hazards
- Completion Issues
- Geophysical Techniques
- Applications
- Fracing the Barnett
- Further efforts
- Conclusions

Basin Geology

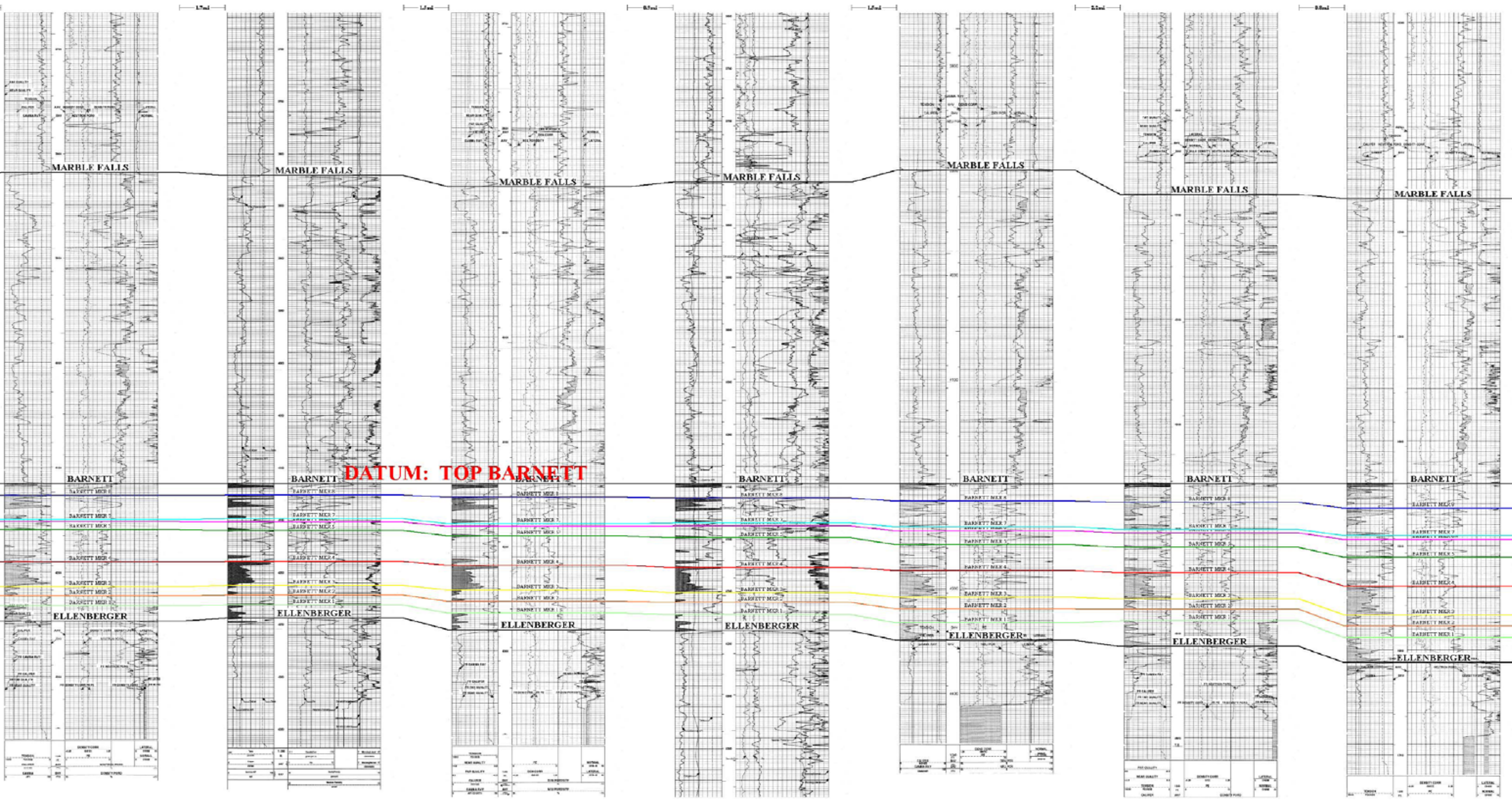
- Stratigraphy
- Structure
- Barnett Thickness
- Maturation
- Composition of Barnett

<u>Generalized Subsurface Stratigraphic Section</u>



From Montgomery, et al, 2005

BARNETT STRATIGRAPHIC CROSS SECTION

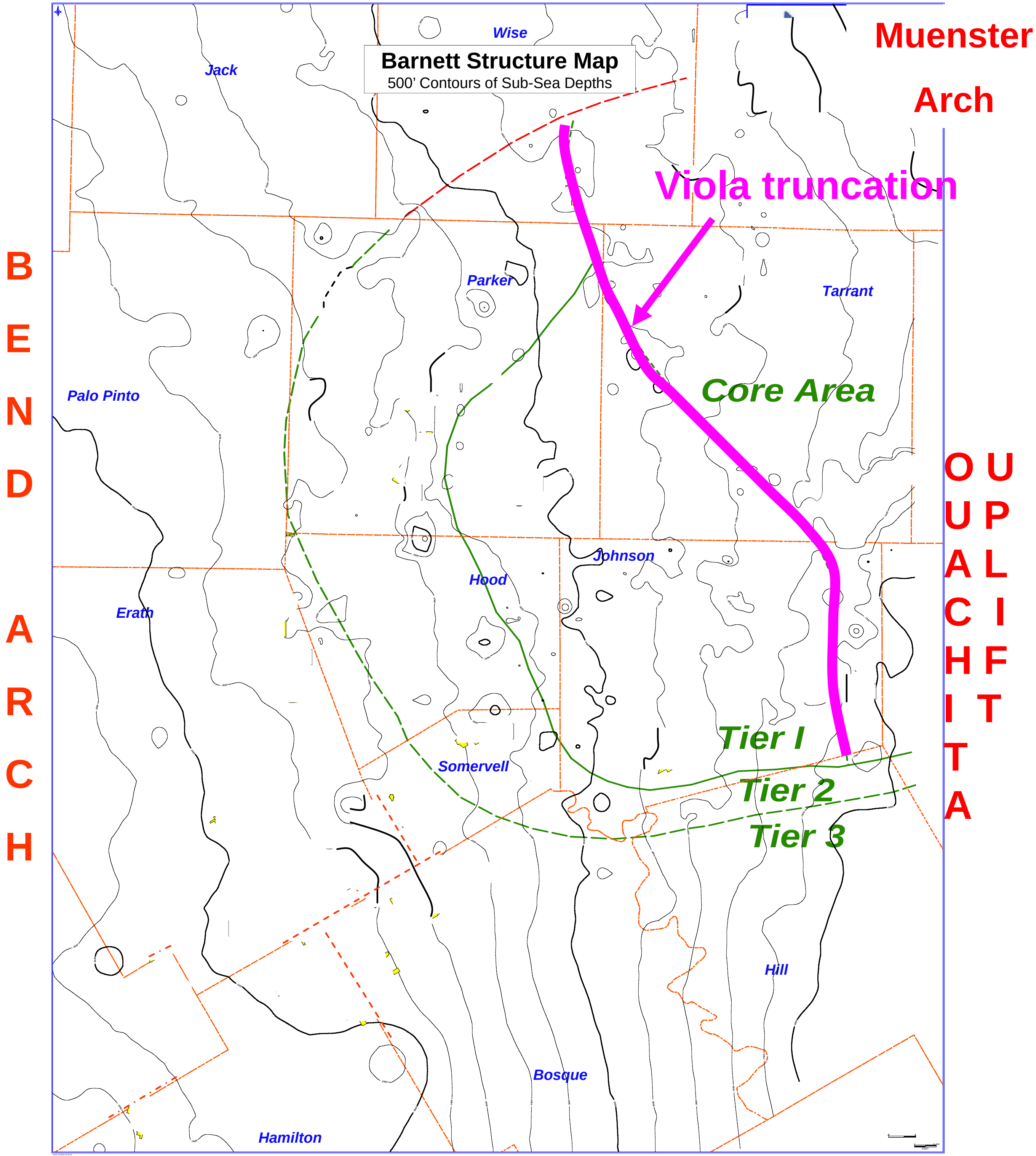


Approximate length of section = 9 miles

Top of Barnett Structure Contour Map

C.I. = 500 feet

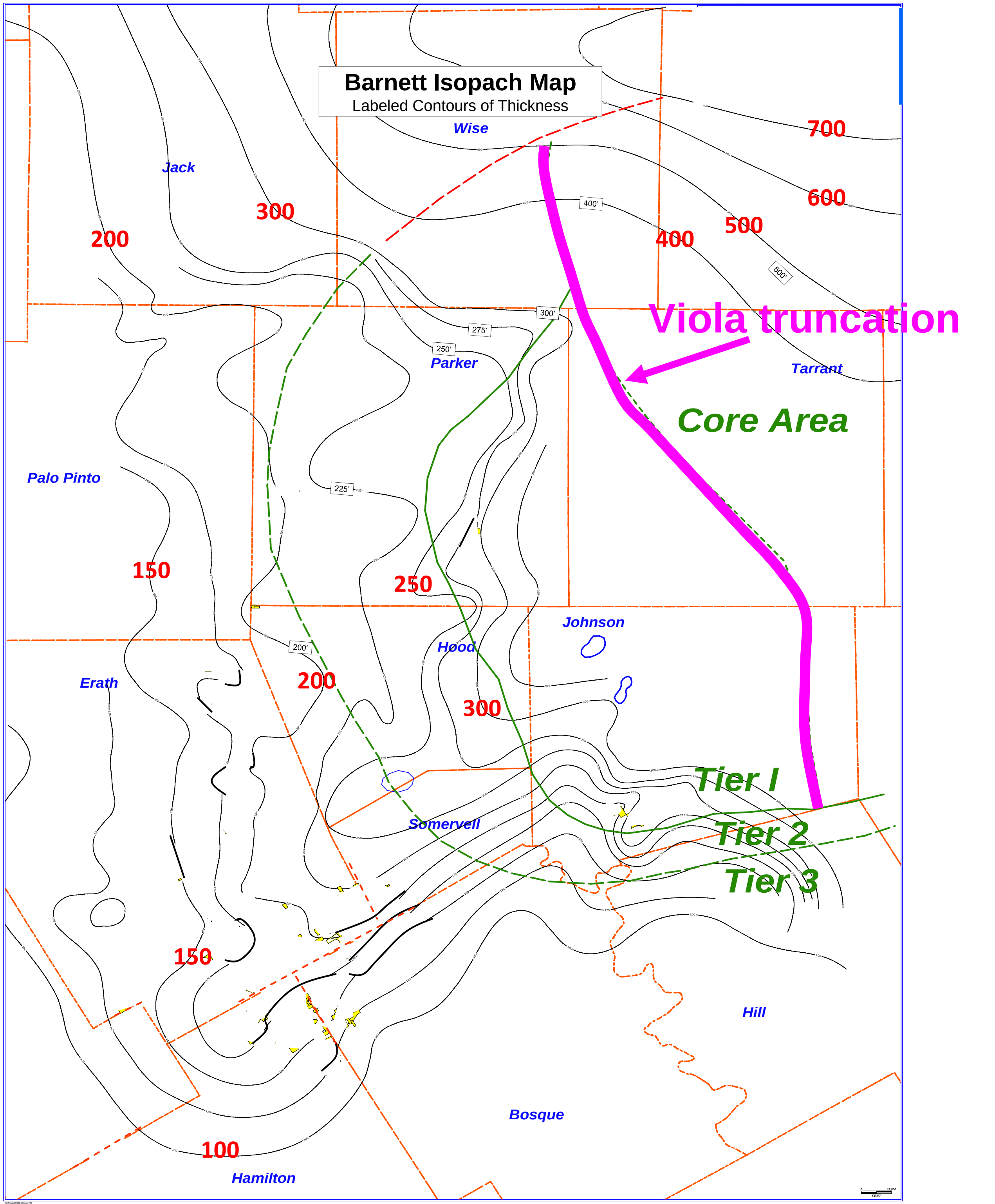
The Barnett in the Fort Worth Basin dips from west to east towards the Ouachita Thrust Belt and northeast to the Muenster Arch. Dips are approximately 1º to 2º.



Barnett Isopach Map

C.I. = 25 and 100 feet

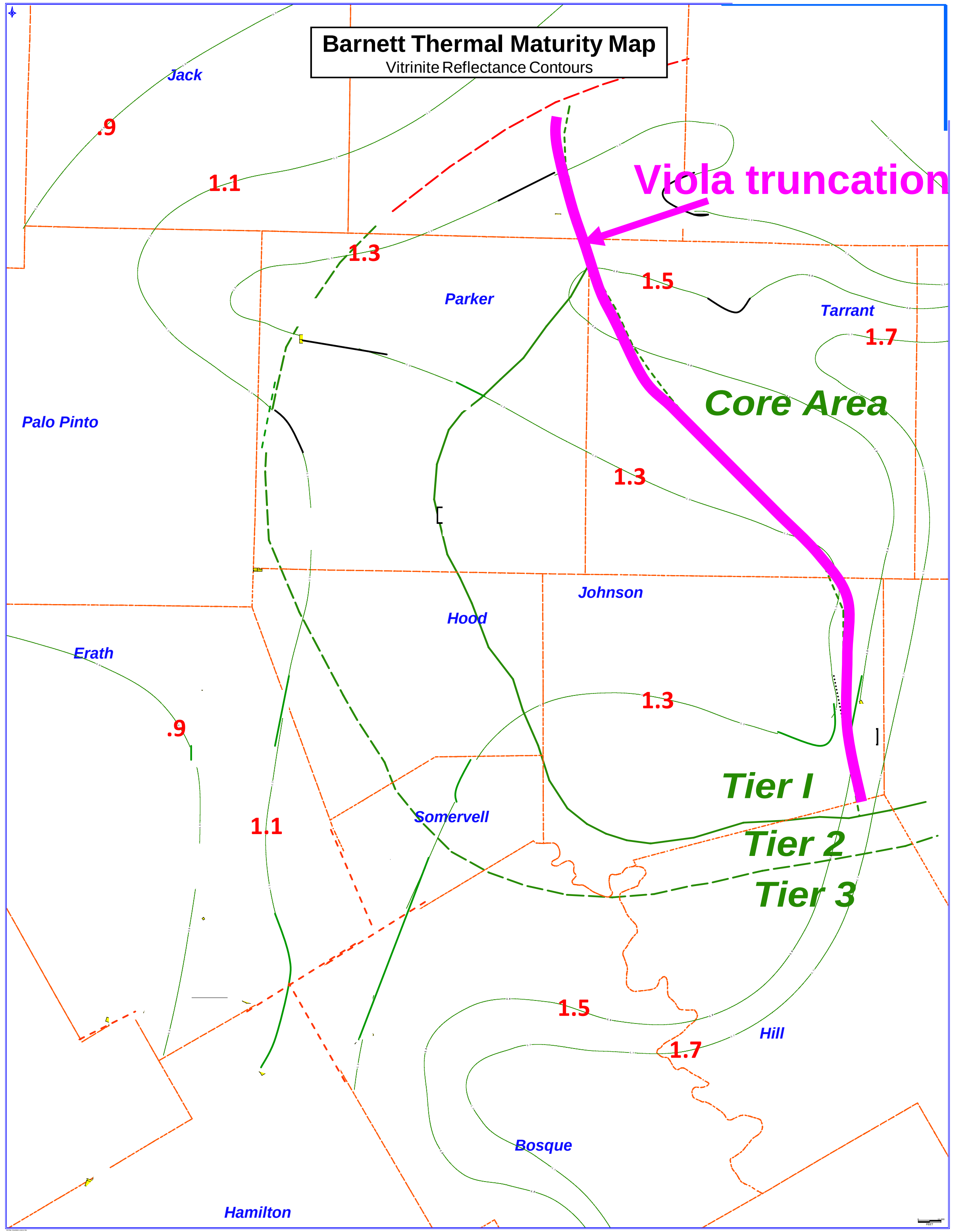
The Barnett thins from less than 100 feet to the west to over 700 feet in front of the Ouachita Thrust Belt to the northeast.



Barnett Ro Map

Ro's are high enough throughout the Fort Worth Basin area for gas generation.

1.3 **Ro Values**



Composition of the Barnett

- 35-50% quartz
- <35% clay
- <15% carbonate
- <15% other
- Original TOC >10%

High TOC and high quartz content provides an ideal situation for porosity filled free gas within the shale as well as sorbed gas that will be produced late in the production history of the well after the free gas is produced early in the well's history.

From Montgomery et al, 2005

Geologic Hazards

- Faults
    - Large (> 100 feet of throw)
    - Small (< 100 feet of throw to ~5 feet)
- Fracture zones connecting into the Ellenberger
- Ellenberger karsts and collapse features

• Problems

- **Faulting affects placement of horizontals bringing the Ellenberger closer to the wellbore**
- **Small faults and fracture zones taking fracs and bringing water into the wellbores**
- **Karsts affecting placements of horizontals**

Completion Issues

- Faults bringing the horizontal wellbore close to the top of the Ellenberger
- Small faults and fracture zones taking fracs that bring water from the Ellenberger into the wellbore
- Inconsistency in effective fracing along the wellbore within the Barnett, especially when using the same techniques in every frac

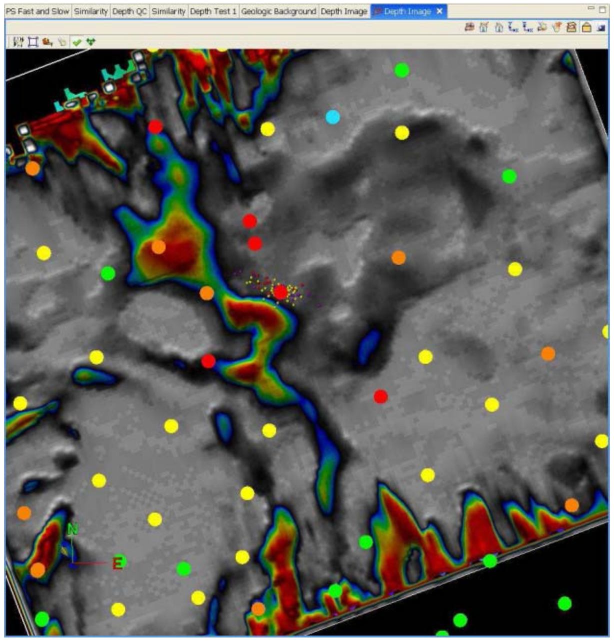
Geophysical Techniques

- **Similarity**

- **Curvature**

SIMILARITY

- Similarity measures the lateral seismic reflection variation and highlights discontinuities, i.e., faulting, facies changes, major fractures, etc.



What Is Curvature?

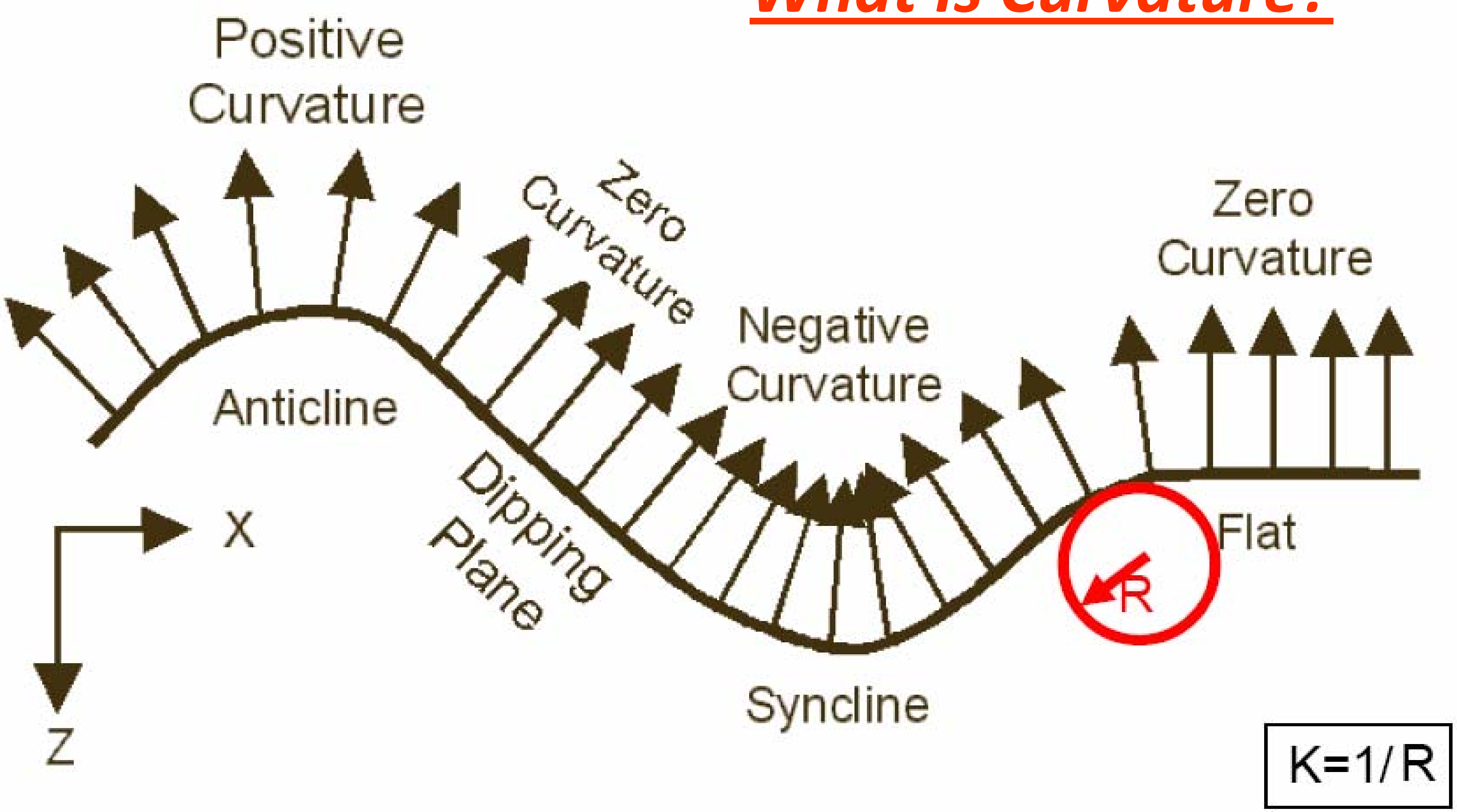


FIG. 1. Curvature in two dimensions. Note that curvature is defined as the inverse of the radius of a circle that is tangent to the surface at any point and that, by convention, positive curvature is concave downward and negative curvature is concave upwards. (After Roberts, 2001).

Types of Curvature

-Based on PSTM
-Requires Dip and Azimuth Cube (Dip Steering)

1) Dip Curvature
2) Strike Curvature
3) Minimum Curvature
4) Maximum Curvature
5) **Most Negative Curvature ***
6) Most Positive Curvature *
7) Mean Curvature
8) Gaussian Curvature
9) Contour Curvature

(* “most useful in delineating faults, fractures, flexures and folds.” Al-Dossary and Marfurt,2006, Geophysics)

APPLICATIONS

Three examples

- **1. Core/Tier 1 – Deepest and thickest Barnett**
- **2. Tier 2 – Intermediate depth and thickness of Barnett**
- **3. Tier 3 – Shallowest and thinnest Barnett**

Areas of seismic examples to be presented

Similarity

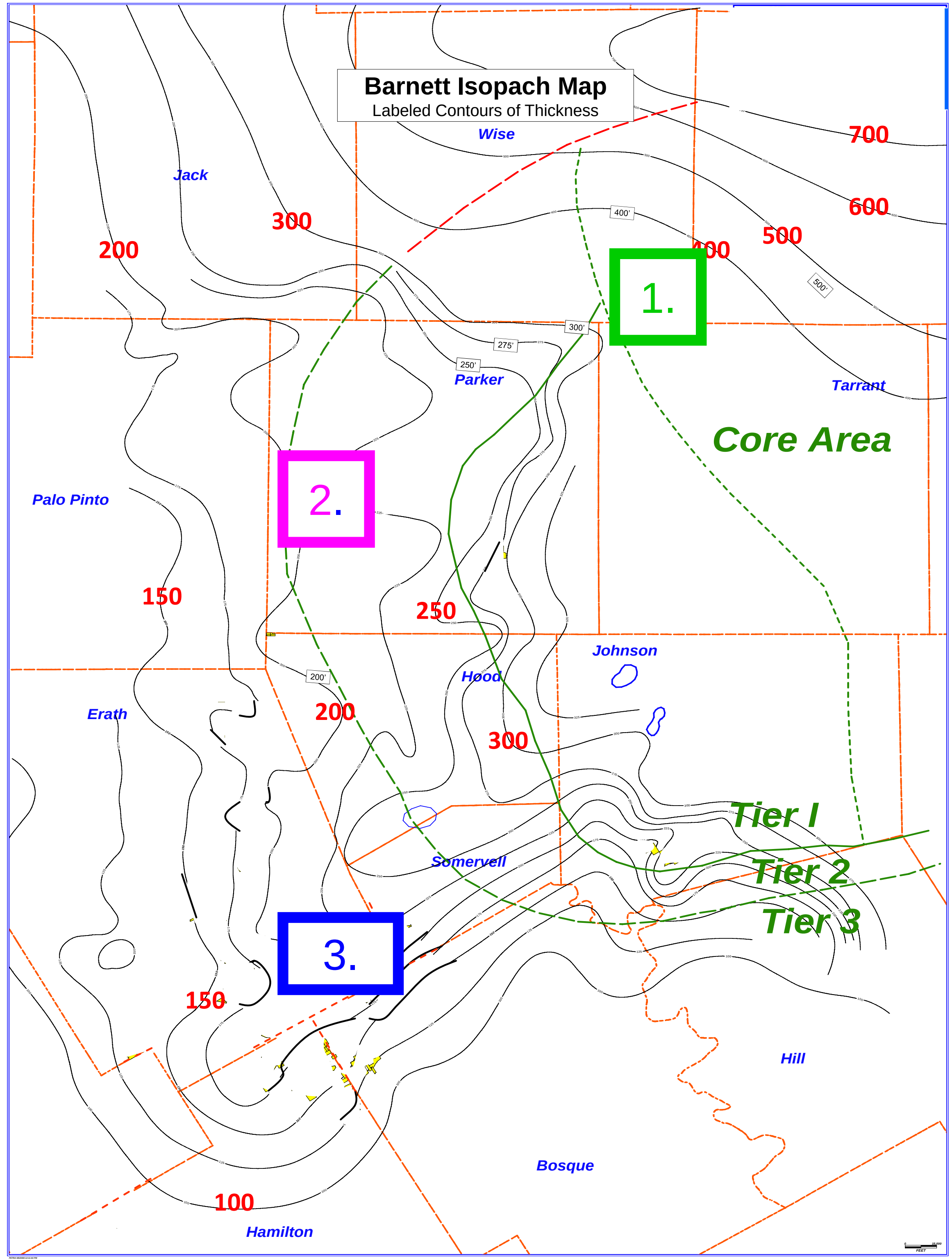
- Core/Tier 1
- Tier 2
- Tier 3

Neg. Curvature

- Core/Tier 1
- Tier 2
- Tier 3

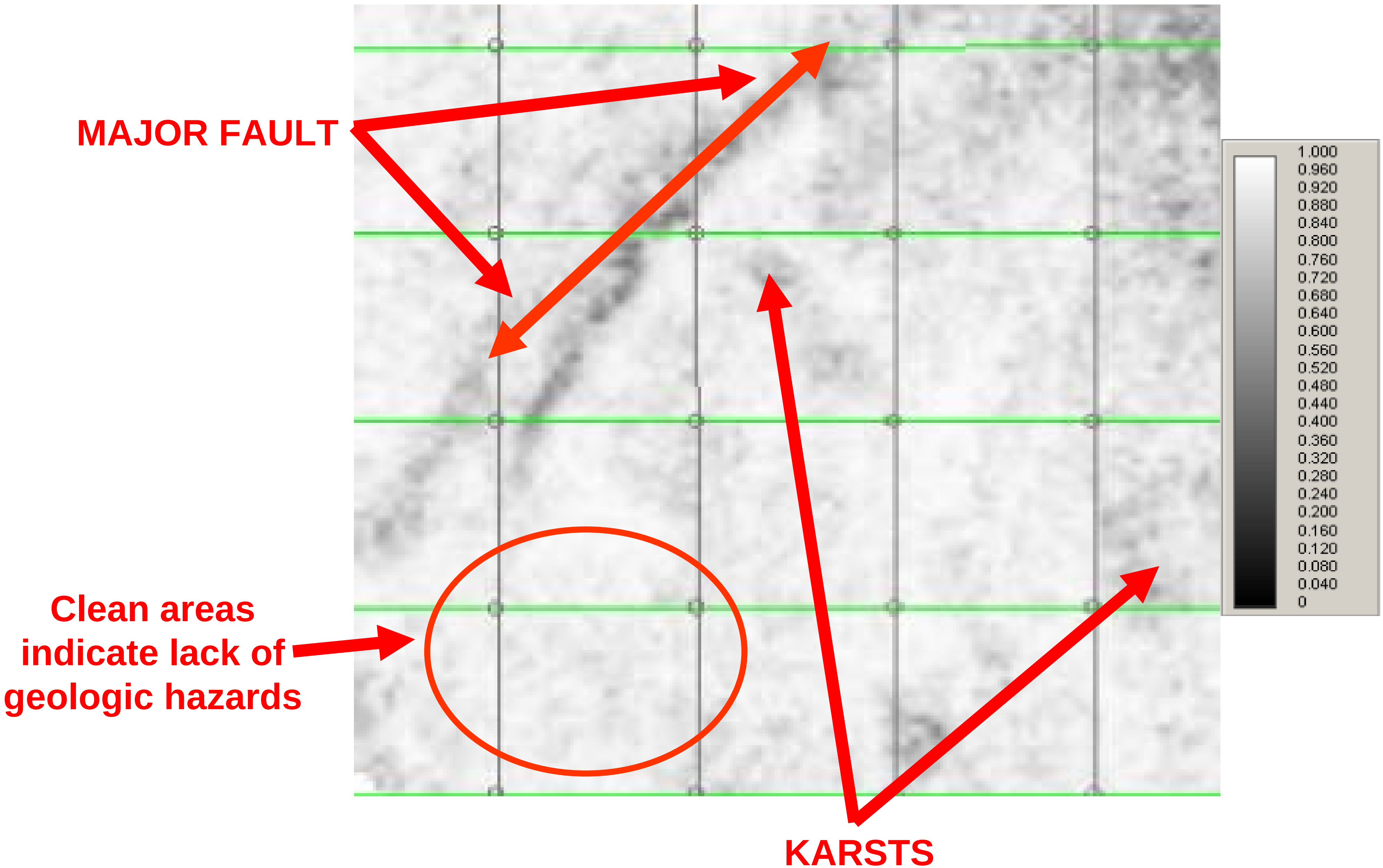
Barnett Isopach Map

C.I. = 25 and 100 feet

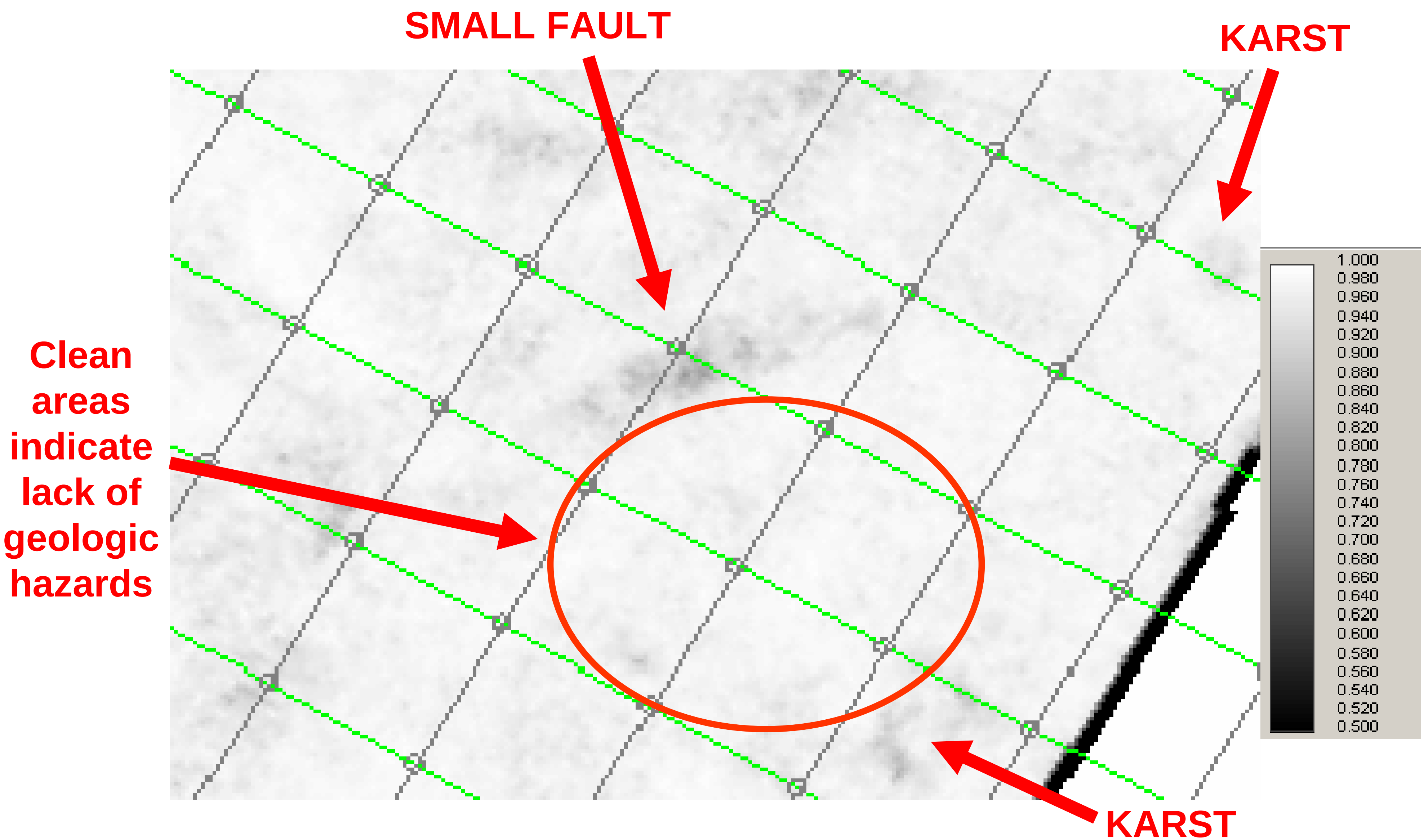


SIMILARITY IN THE THREE SEISMIC AREAS

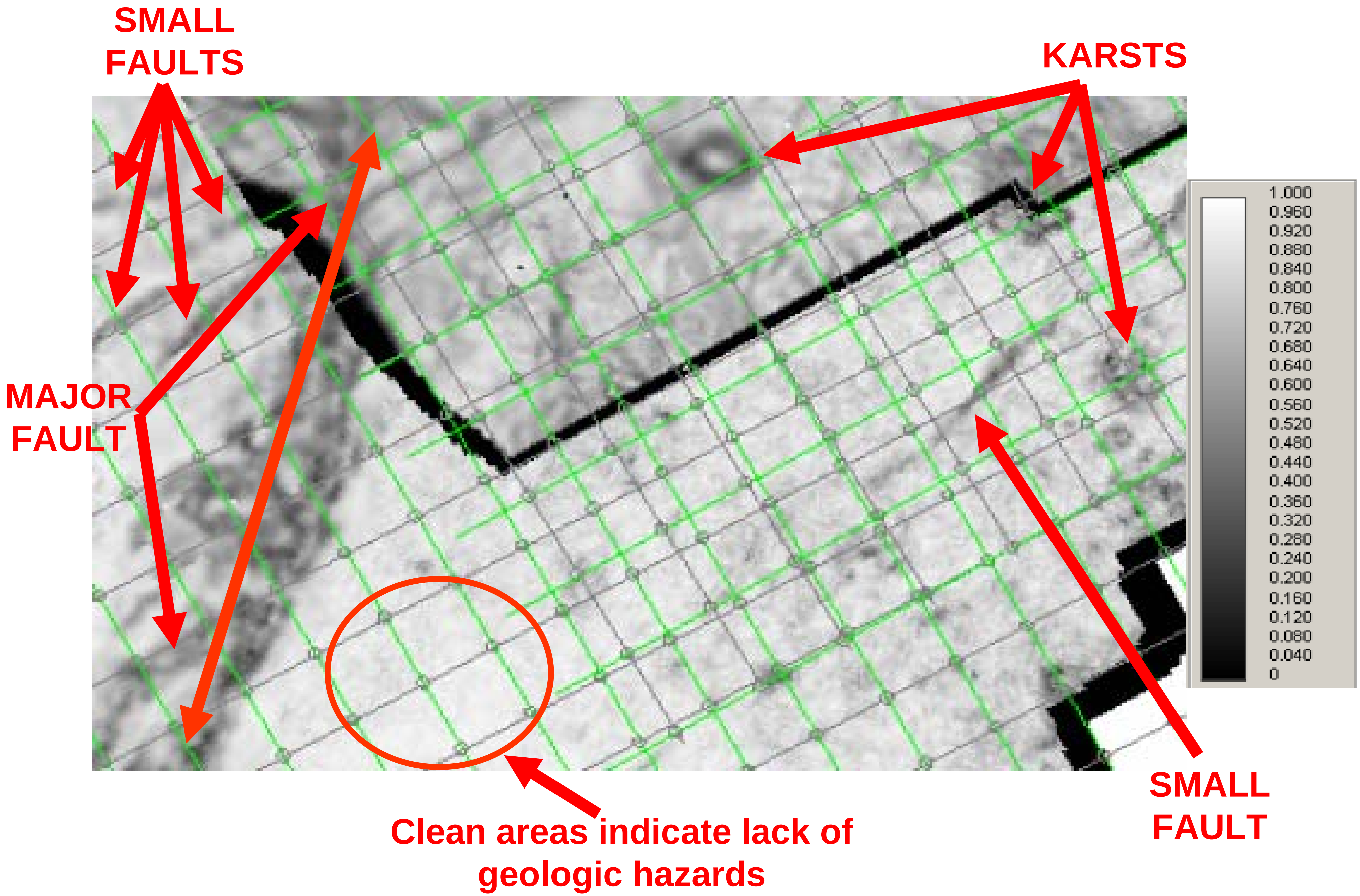
Core/Tier 1 Similarity



Tier 2 Similarity



Tier 3 Similarity

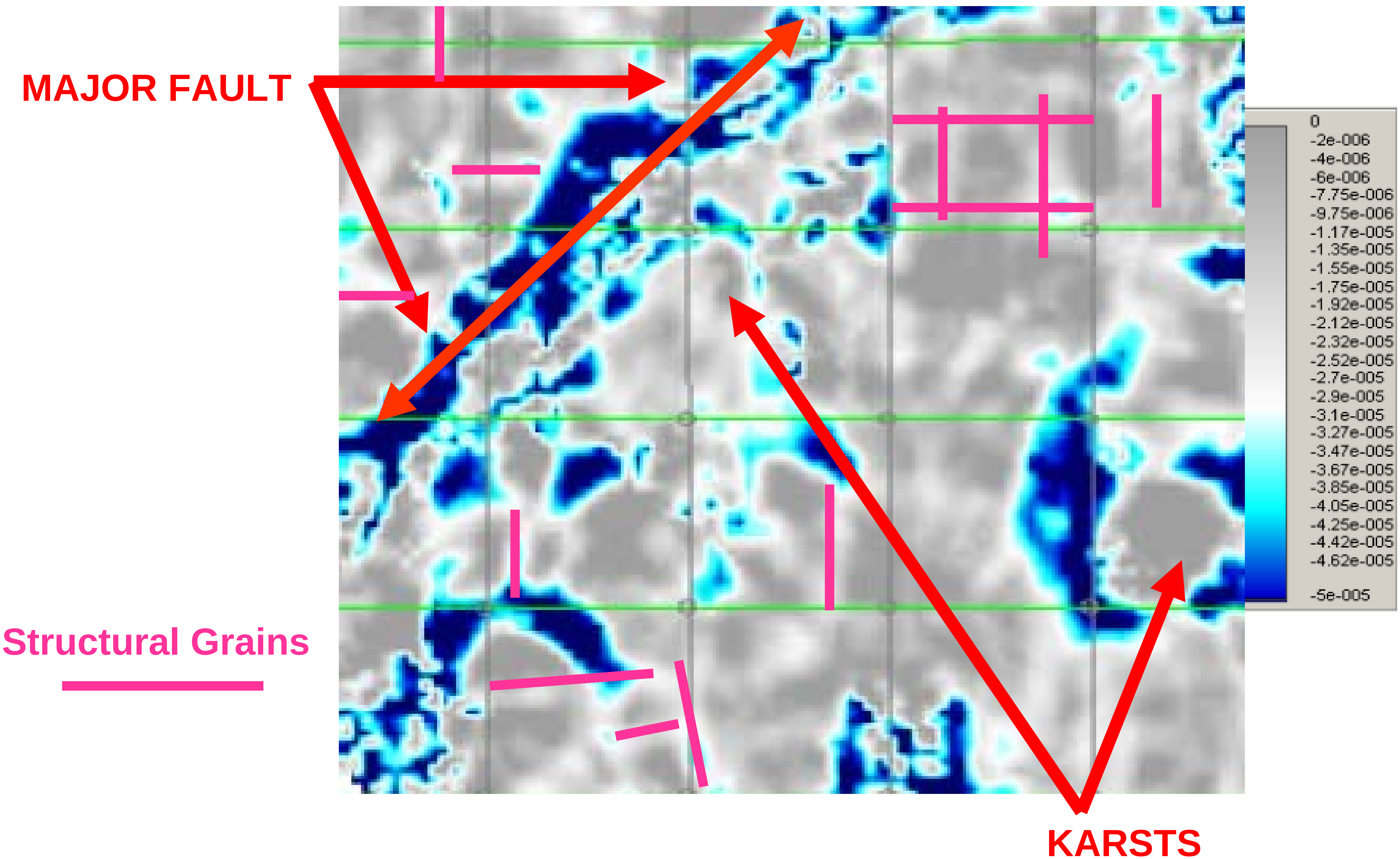


SIMILARITY

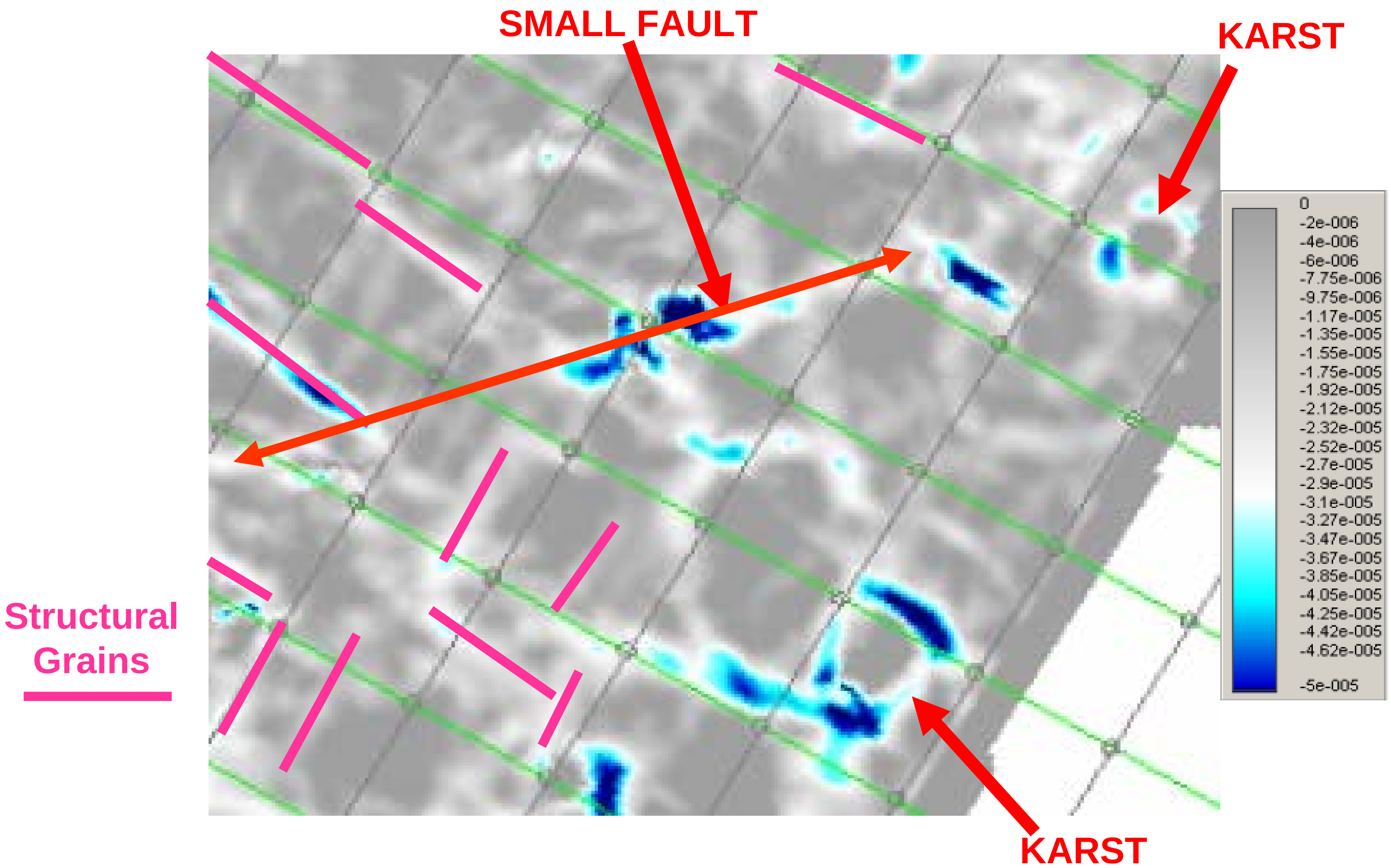
- Defines large faults and the extent of the fault complexity
- Defines smaller faults that more conventional seismic may not define
- Defines small and large karst features well
- Is very quiet when there are no geologic hazards present

MOST NEGATIVE CURVATURE IN THE THREE SEISMIC AREAS

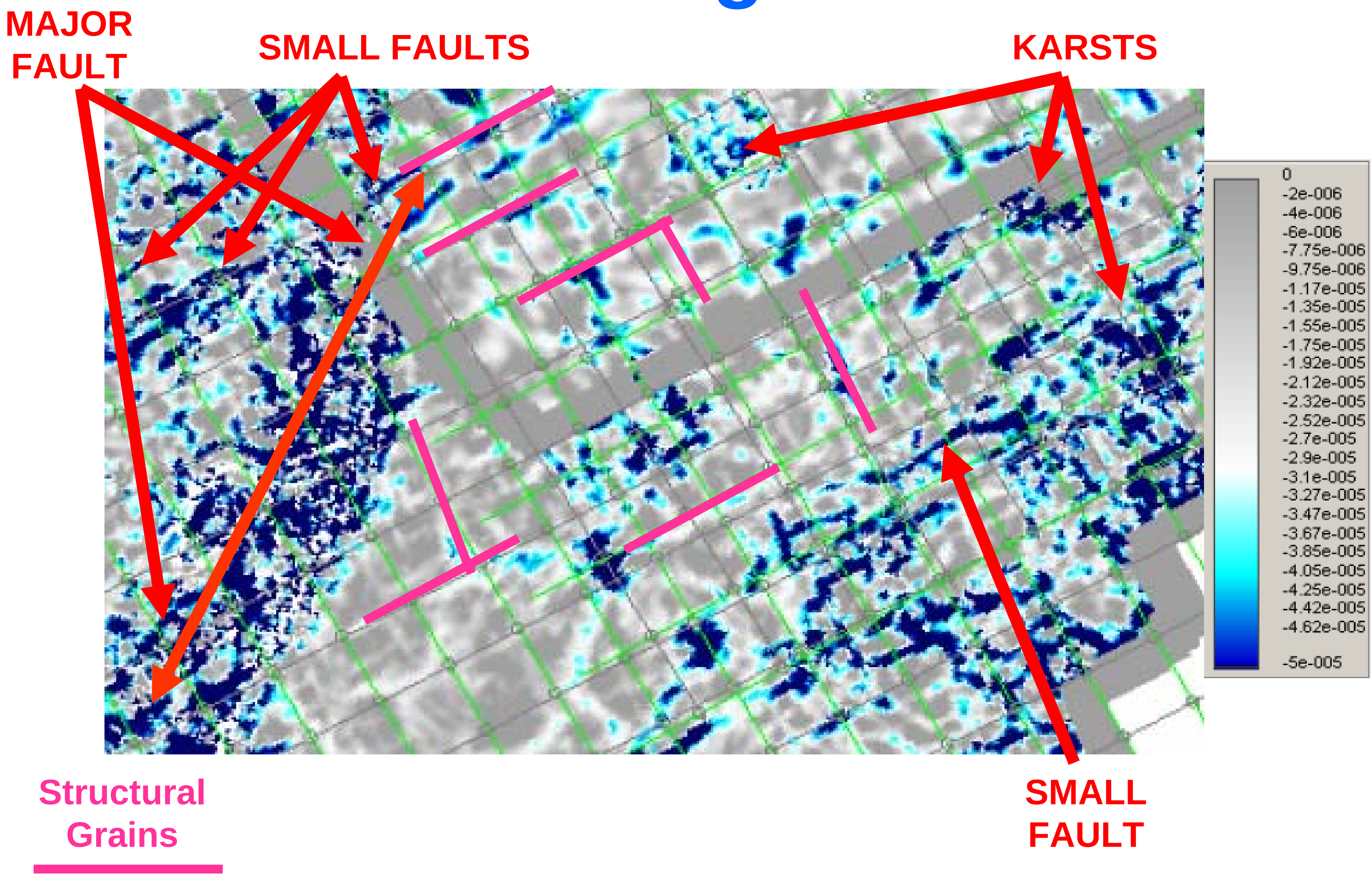
Core/Tier 1 Most Neg. Curvature



Tier 2 Most Neg. Curvature



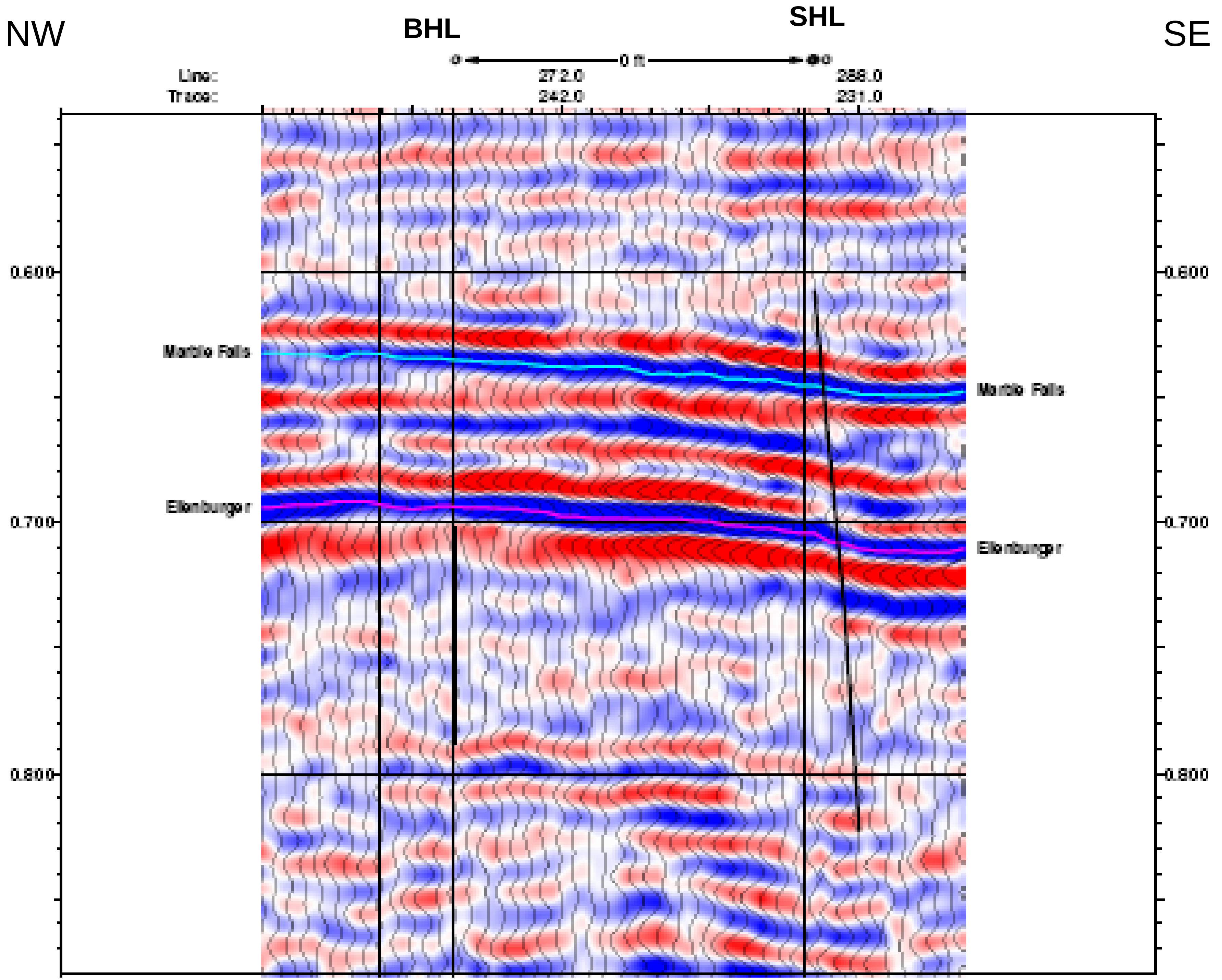
Tier 3 Most Neg. Curvature



Lateral changes within the Barnett and Maximum Negative Curvature

- Color variations in the Most Negative Curvature processing may indicate lateral changes in the Barnett that may indicate better targets for more effective frac design that “rubblizes” the Barnett creating better permeability to access more of the gas contained in the shales.

Tier 3, Good Well

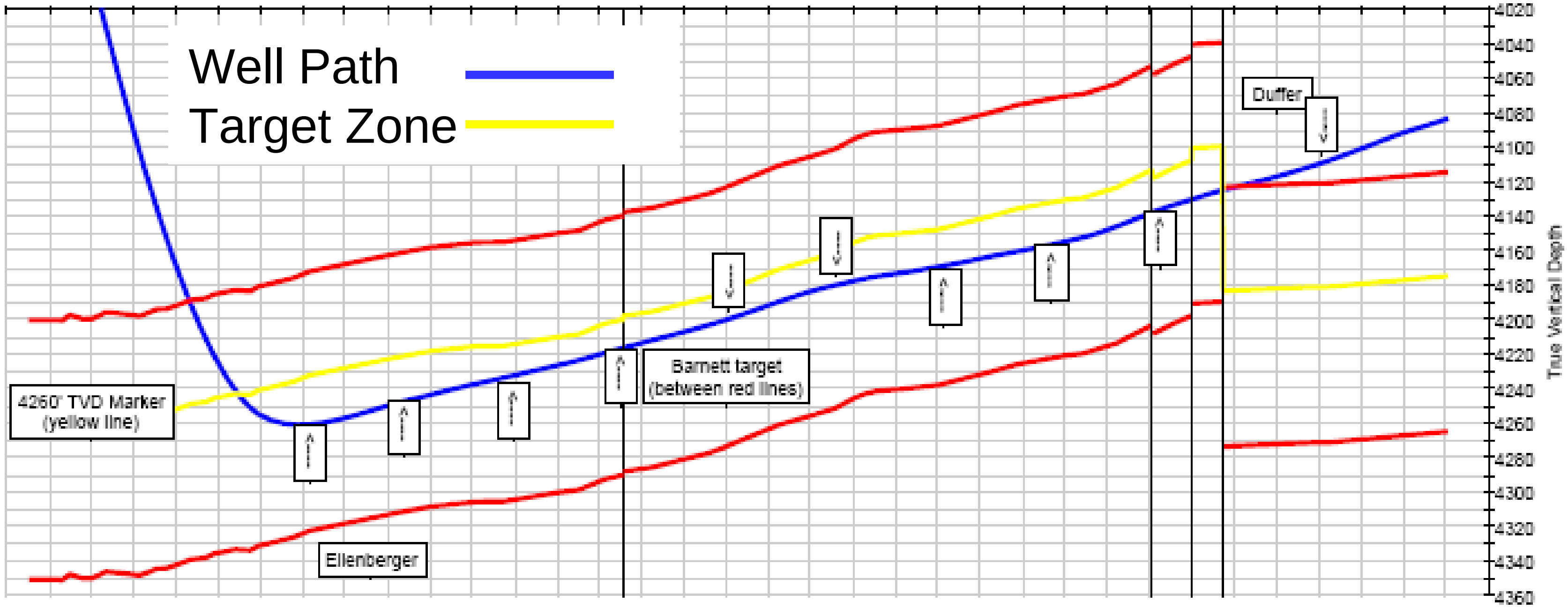


Tier 3, Good Well

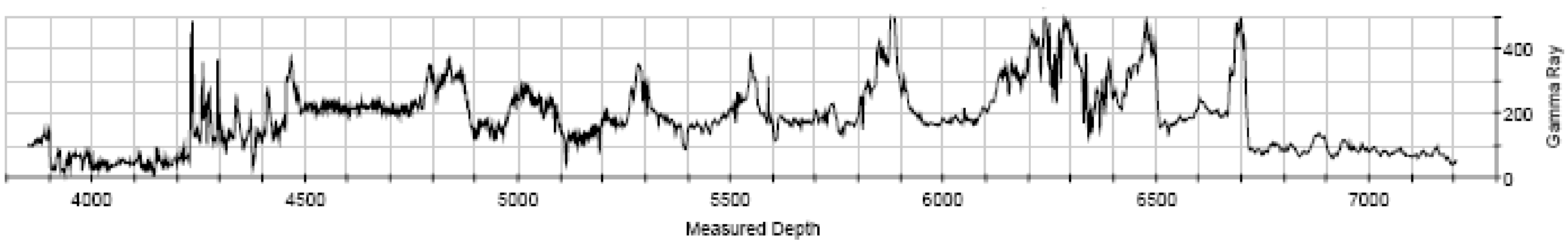
SE

NW

Note this profile orientation is reversed to the conventional seismic



Perf zones



Tier 3, Good Well 1

- **Barnett Thickness~150 feet**
- **# of faults 4 Min Throw 2’ Max Throw 84’ Ave. 24.5’**
- **# of Perfs 9**

# of Perfs ___ ft from faults	**<300’**	**<200’**	**<100’**	**<50’**
	5	**4**	**3**	**3**

Vert. Dist. of Perfs from Ellenberger <50’-0 <75’- 8 <100’-8

GAS SHOWS:	**Min.**	**Max.**	**Ave.**
	90	**1,300**	**350**

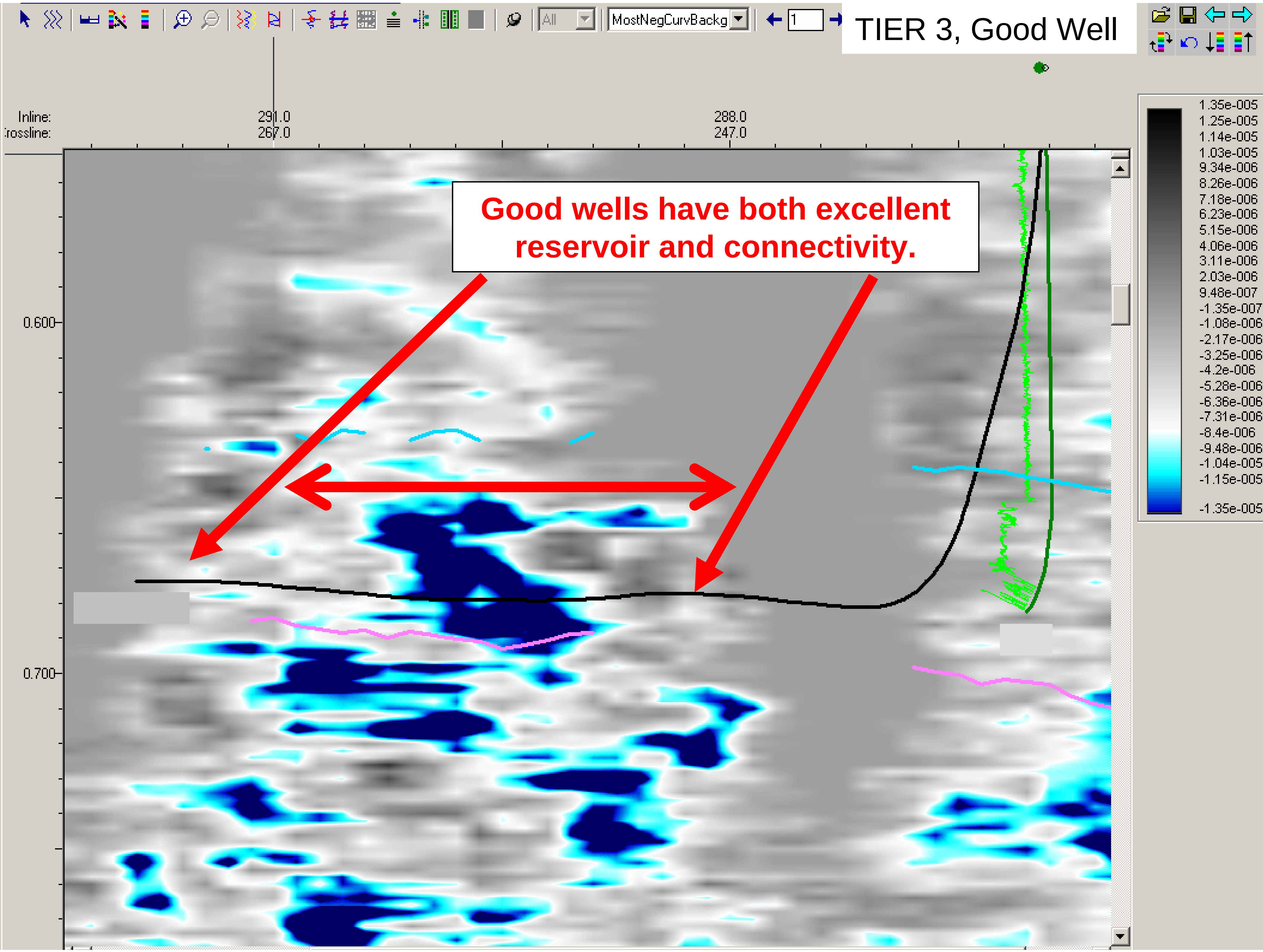
Ave. Prod. 445 mcf/d 45 bw/d <u>738 Days</u>

Total Frac Fluid Used 43,617 BW

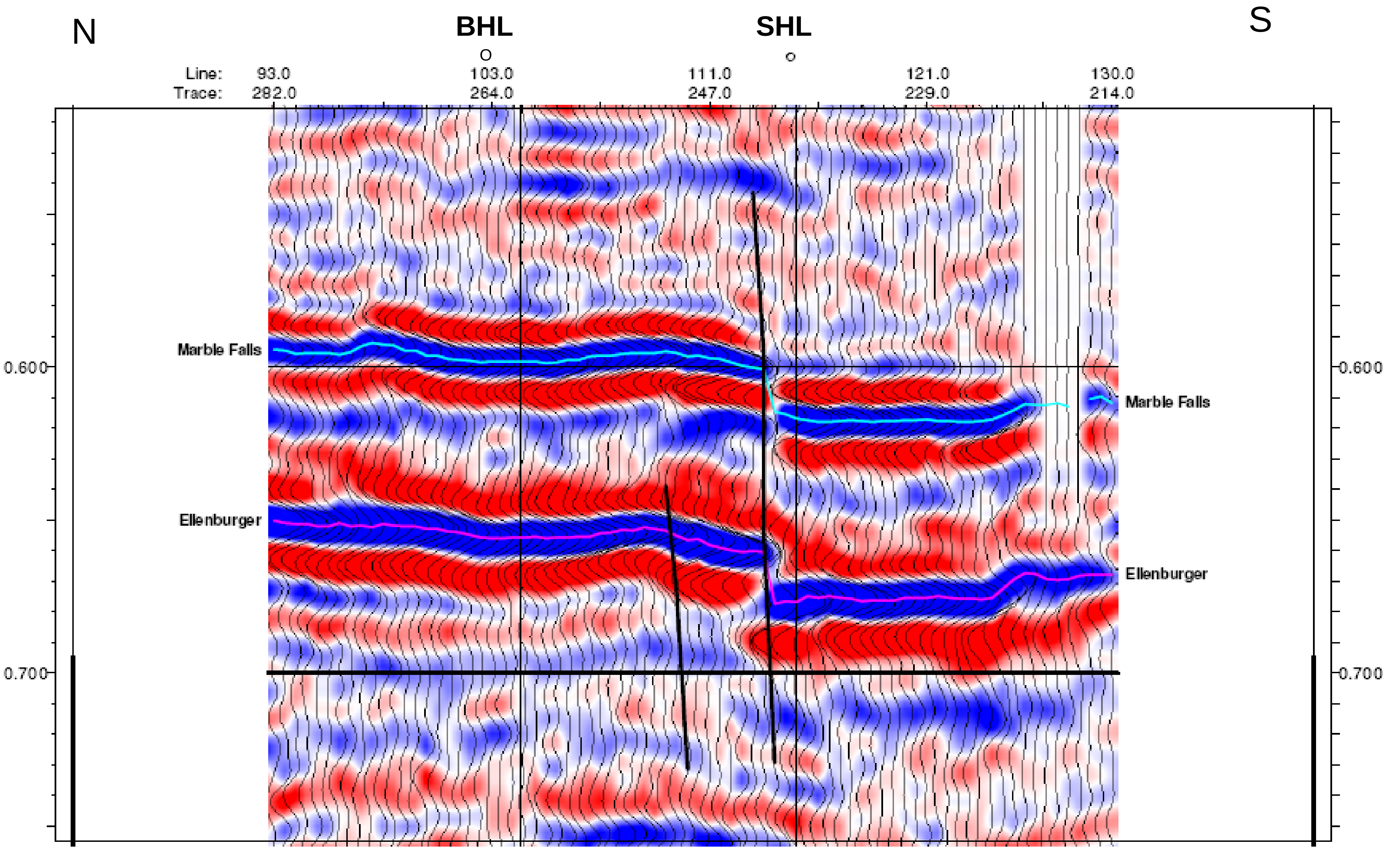
Total Water Produced 33,308 BW (76%)

Cum. Prod. 328,202 MCF, 33,308 BW .1 bw/mcf

TIER 3, Good Well



Tier 3, Poor Well

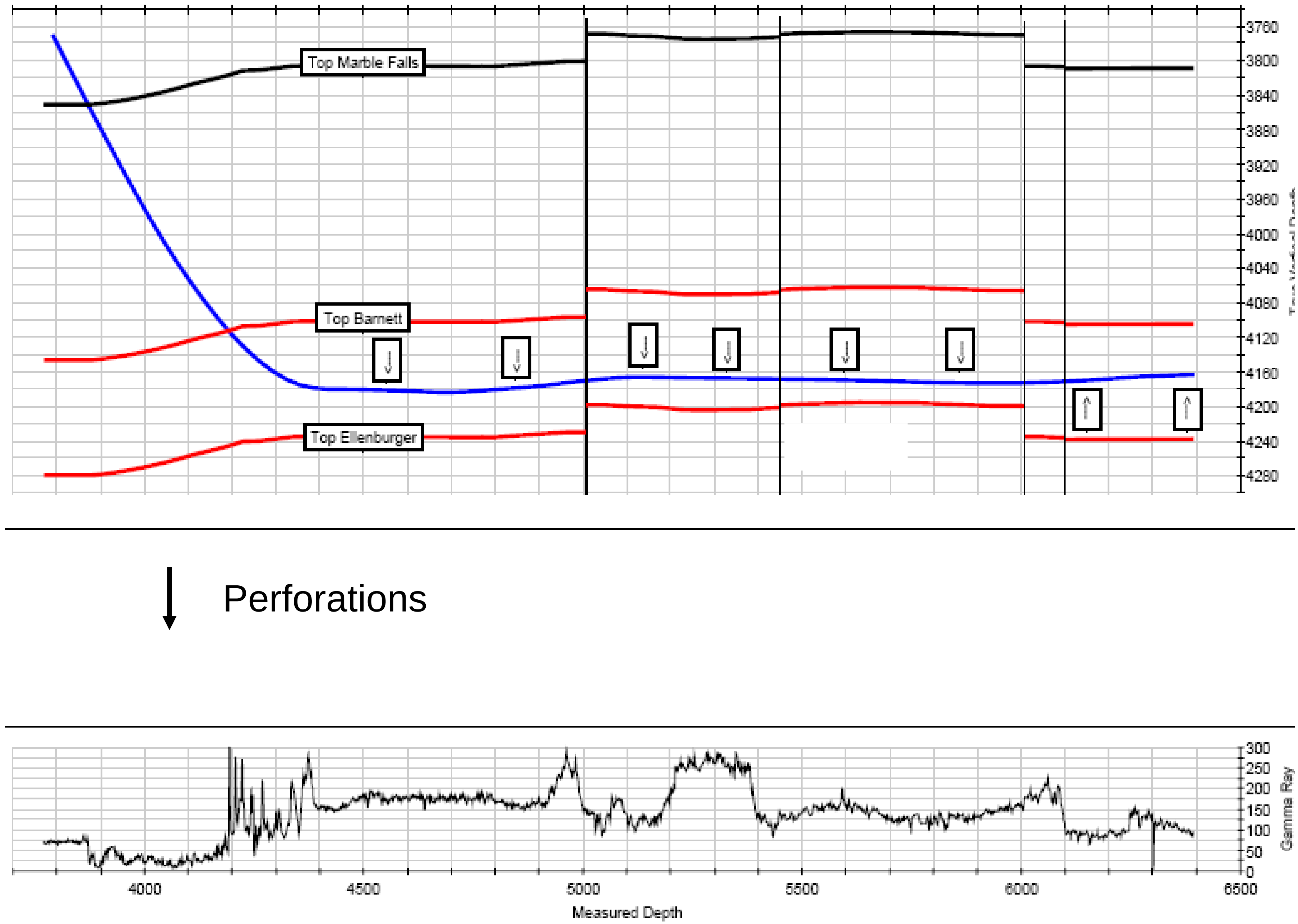


Tier 3, Poor Well

S

Note this profile orientation is reversed to the conventional seismic

N



Tier 3, Poor Well

- **Barnett Thickness~140 feet**
- **# of faults 4 Min Throw 2' Max Throw 36' Ave. 18.25'**
- **# of Perfs 8**

# of Perfs ___ ft from faults

	<300'	<200'	<100'	<50'
	9	7	1	1

Vert. Dist. of Perfs from Ellenberger <50'-4 <75'-8 <100'-8

GAS SHOWS:	Min.	Max.	Ave.
	0	3,100	1,700

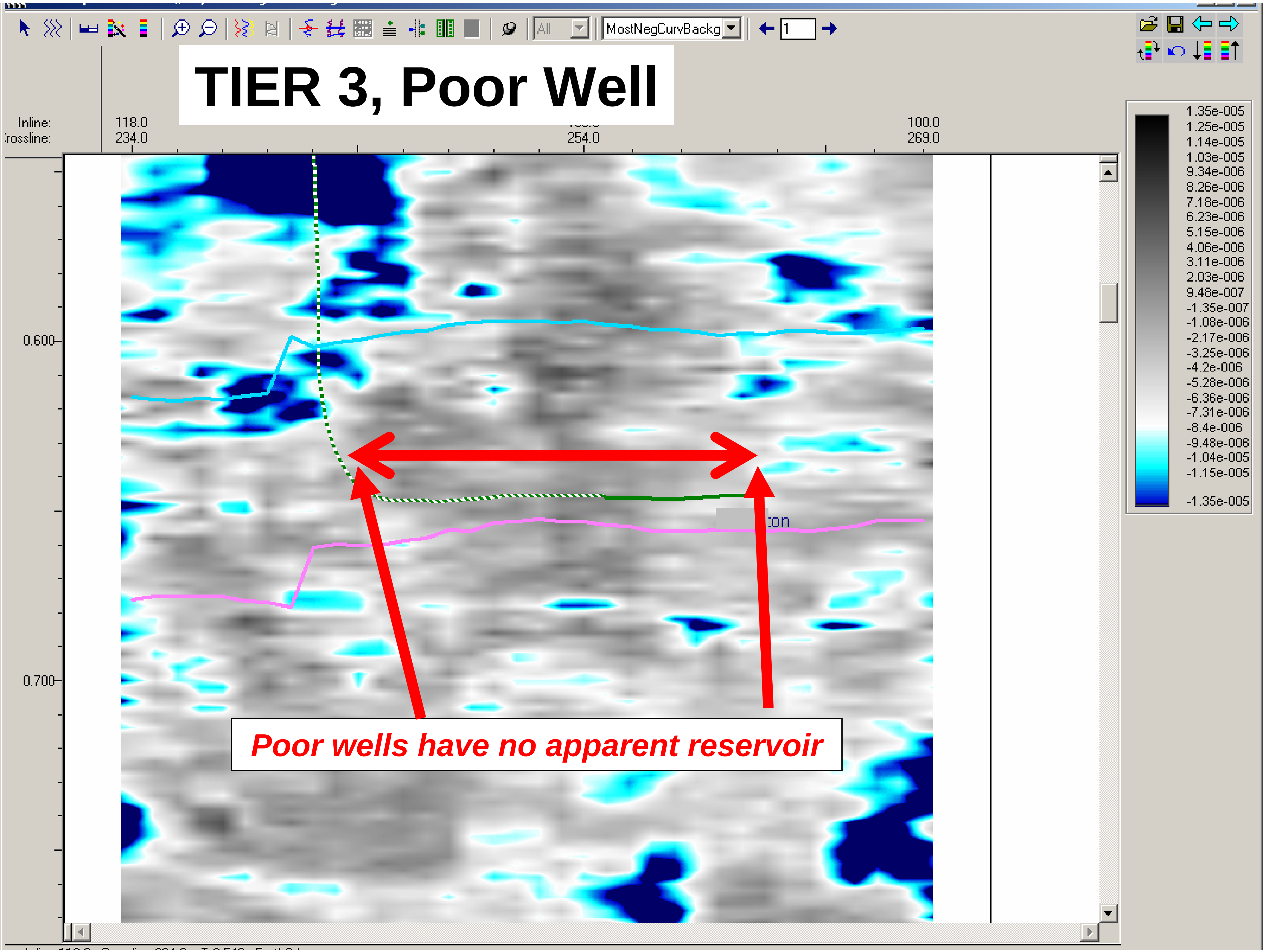
Ave. Prod. 174 mcf/d 797 bw/d 110 Days

Total Frac Fluid Used 46,205 BW

Total Water Produced 87,285 BW (189%)

Cum. Prod. 19,009 MCF, 87,285 BW, 4.6 bw/mcf

TIER 3, Poor Well



Poor wells have no apparent reservoir

FRACING THE BARNETT

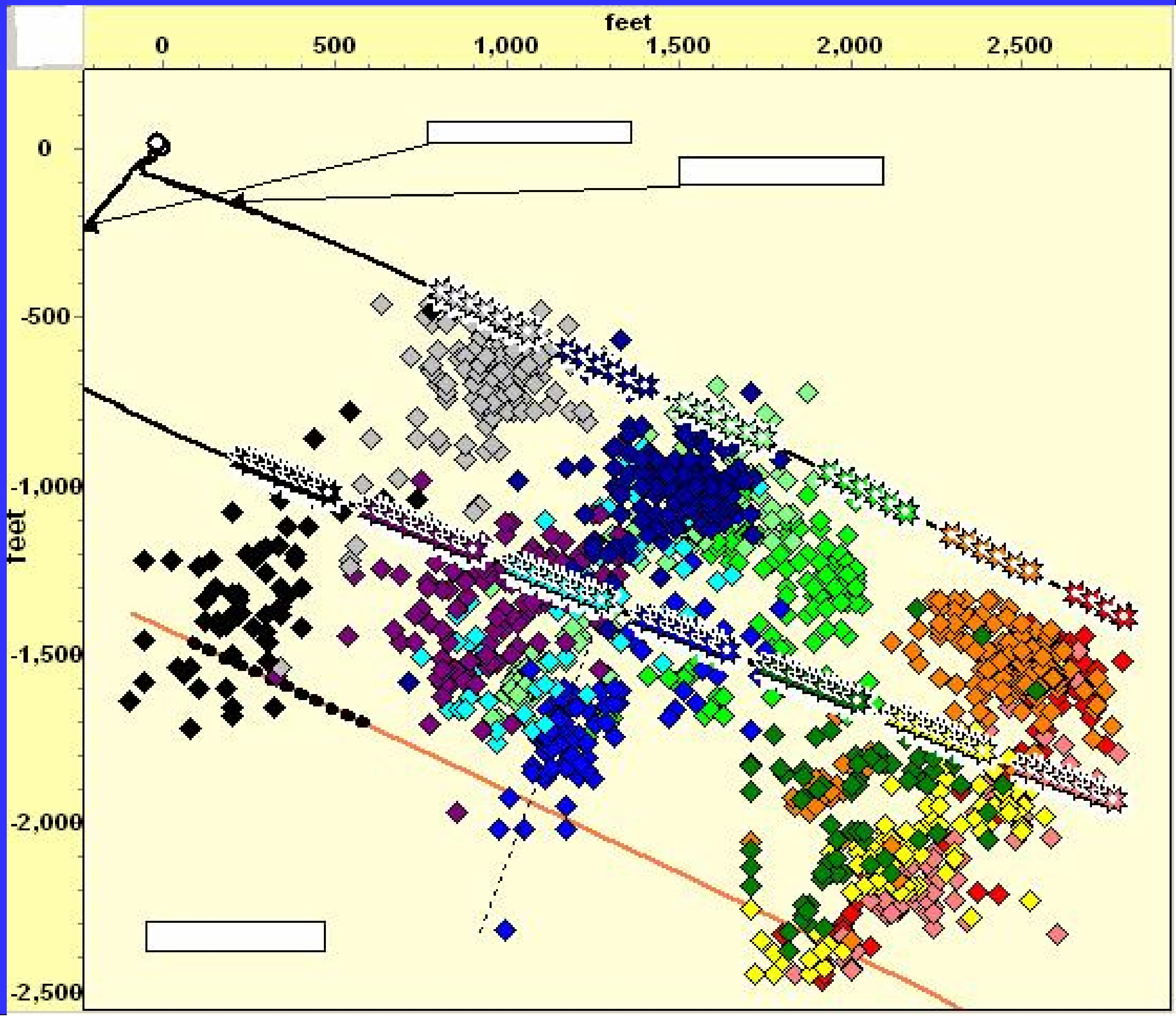
Most Neg. Curvature and Fracing

- **Tying the Most Negative Curvature to the fracing results in wells can give an indication of the efficiency of fracs and may lead to more efficient fracing techniques. Two examples follow. Fracs seem to be better in one shade of the colors and is less effective in another shade of colors.**

Complex Fracturing – the Key to Shale Contact

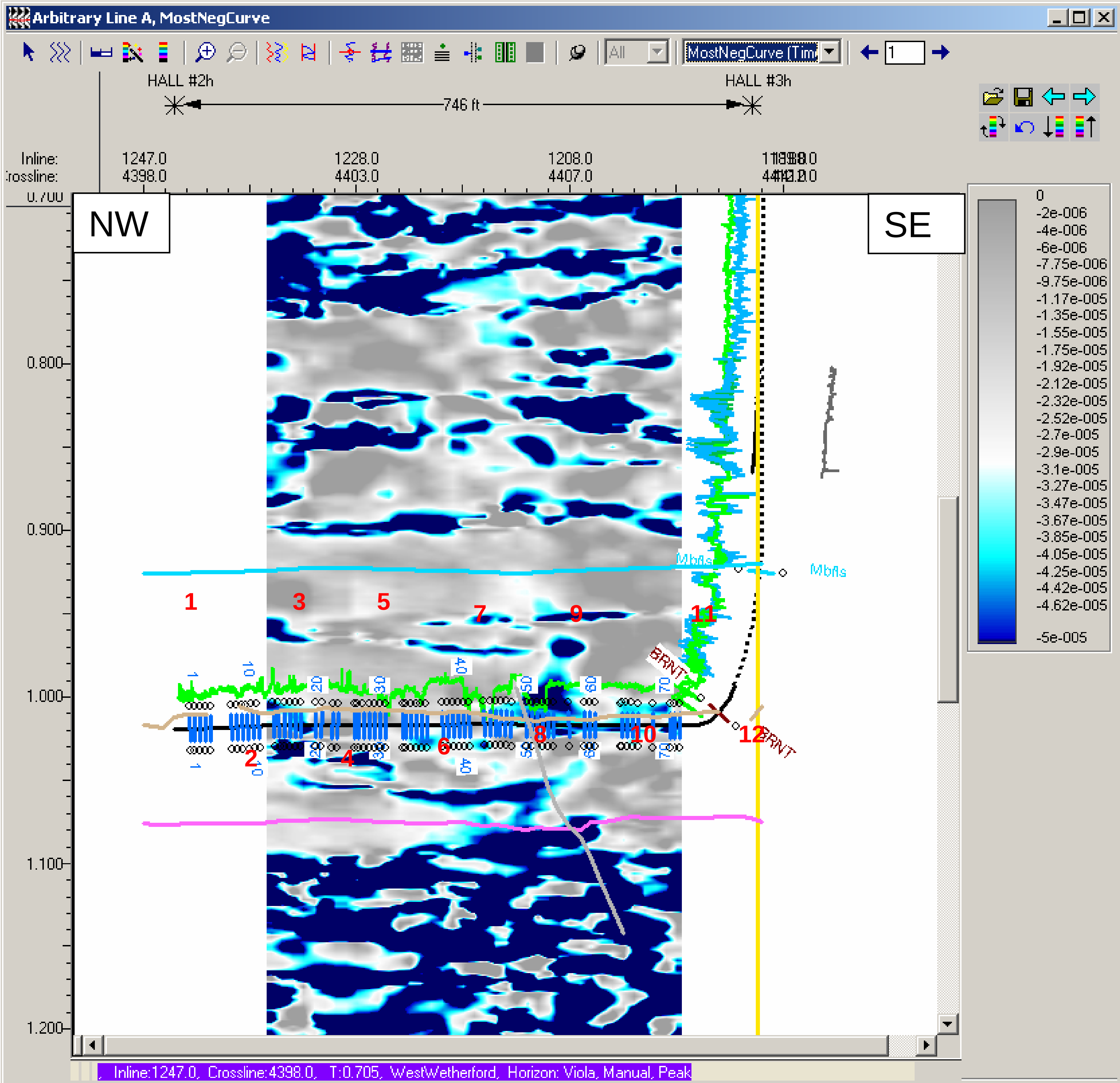
Microseismic spread usually an indication of increasing complexity and contact area.

What are the undisturbed areas?



From King, et al, 2009

Tier 2, 12 stage frac on Most Negative Curvature



Arbitrary Line A, MostNegCurve
MostNegCurve (Tim
HALL #2h
HALL #3h
746 ft
Inline:
1247.0
1228.0
1208.0
4398.0
4403.0
4407.0
0.800
0.900
1.000
1.100
1.200
NW
SE
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Mbfls
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BRNT
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2
3
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-6e-006
-7.75e-006
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-2.12e-005
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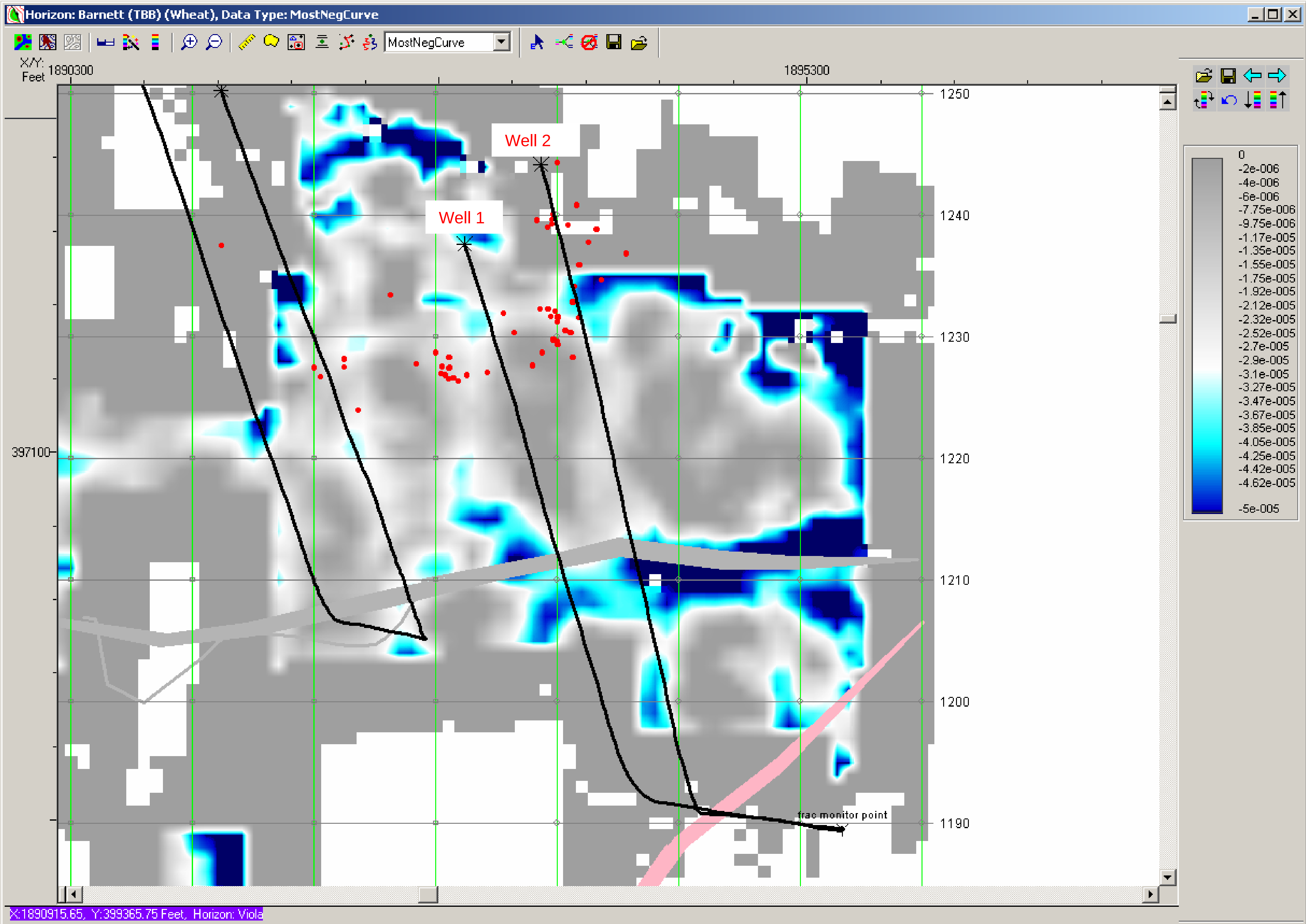
Inline:1247.0, Crossline:4398.0, T:0.705, WestWetherford, Horizon: Viola, Manual, Peak



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
1890300
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frac monitor point
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-6e-006
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-9.75e-006
-1.17e-005
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-3.85e-005
-4.05e-005
-4.25e-005
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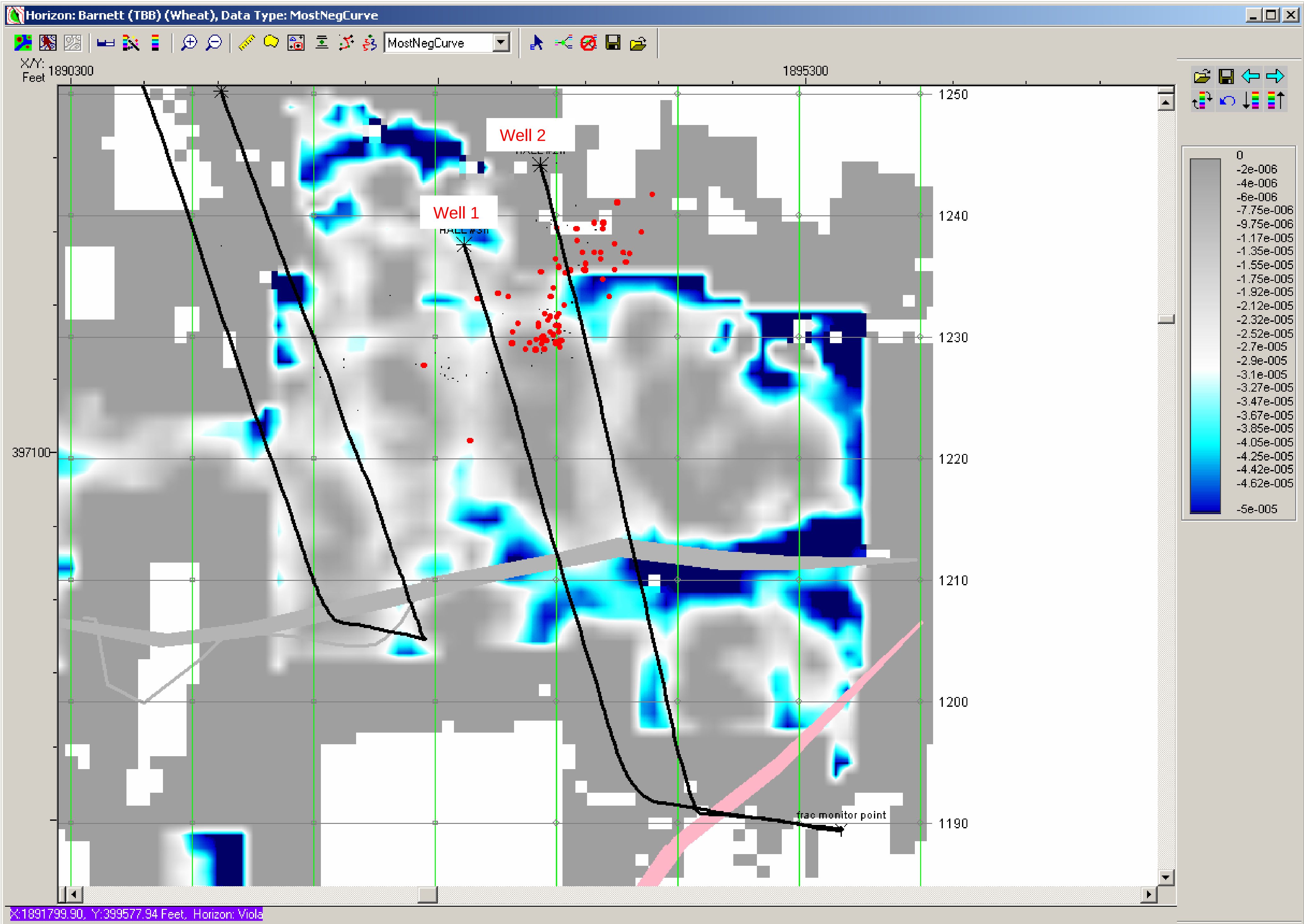
-4.62e-005
-5e-005
X:1890915.65, Y:399365.75 Feet, Horizon: Viola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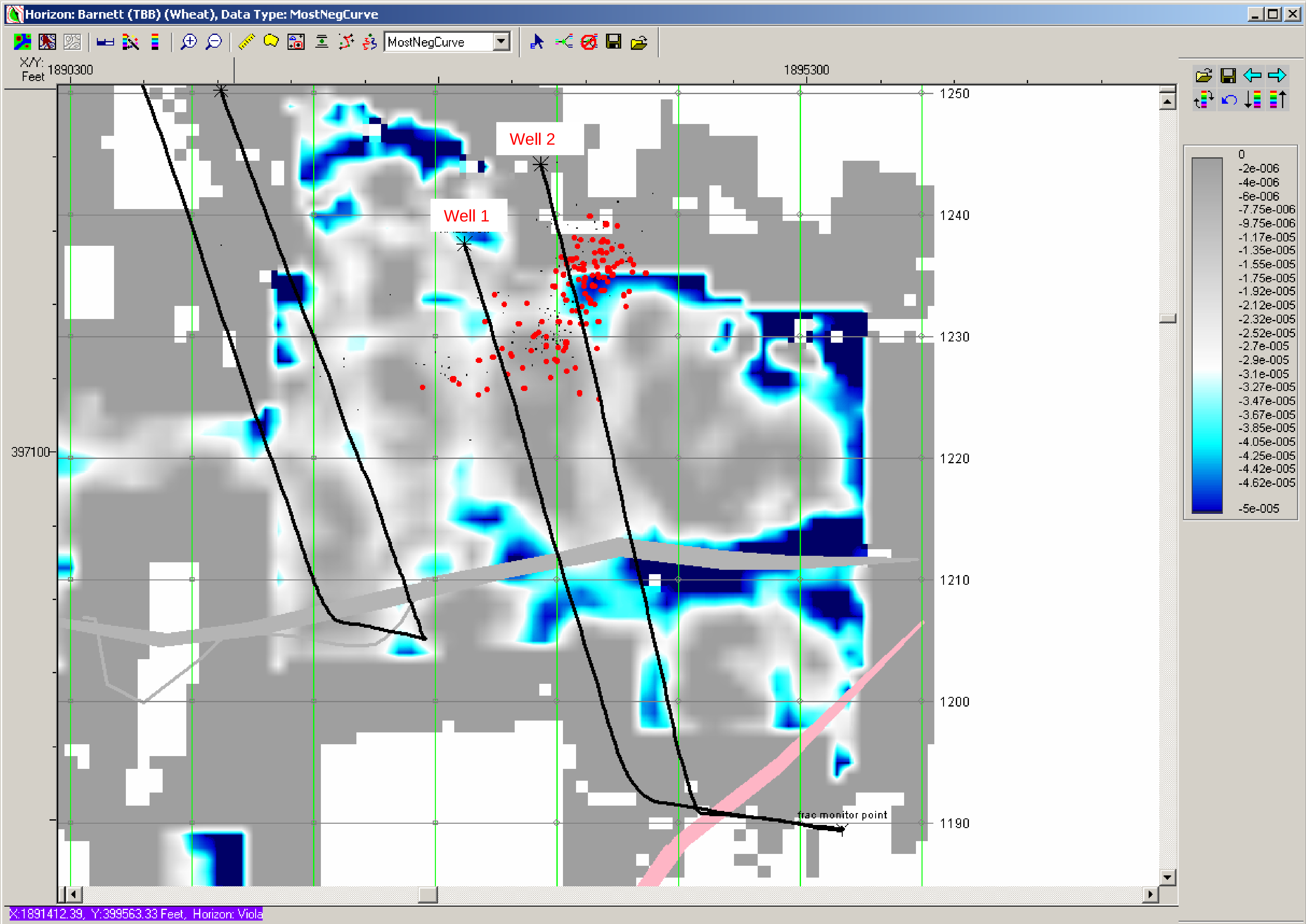
-5e-005
X:1891799.90, Y:399577.94 Feet, Horizon: Viola



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MostNegCurve
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-6e-006
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-9.75e-006
-1.17e-005
-1.35e-005
-1.55e-005
-1.75e-005
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-2.12e-005
-2.32e-005
-2.52e-005
-2.7e-005
-2.9e-005
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-3.85e-005
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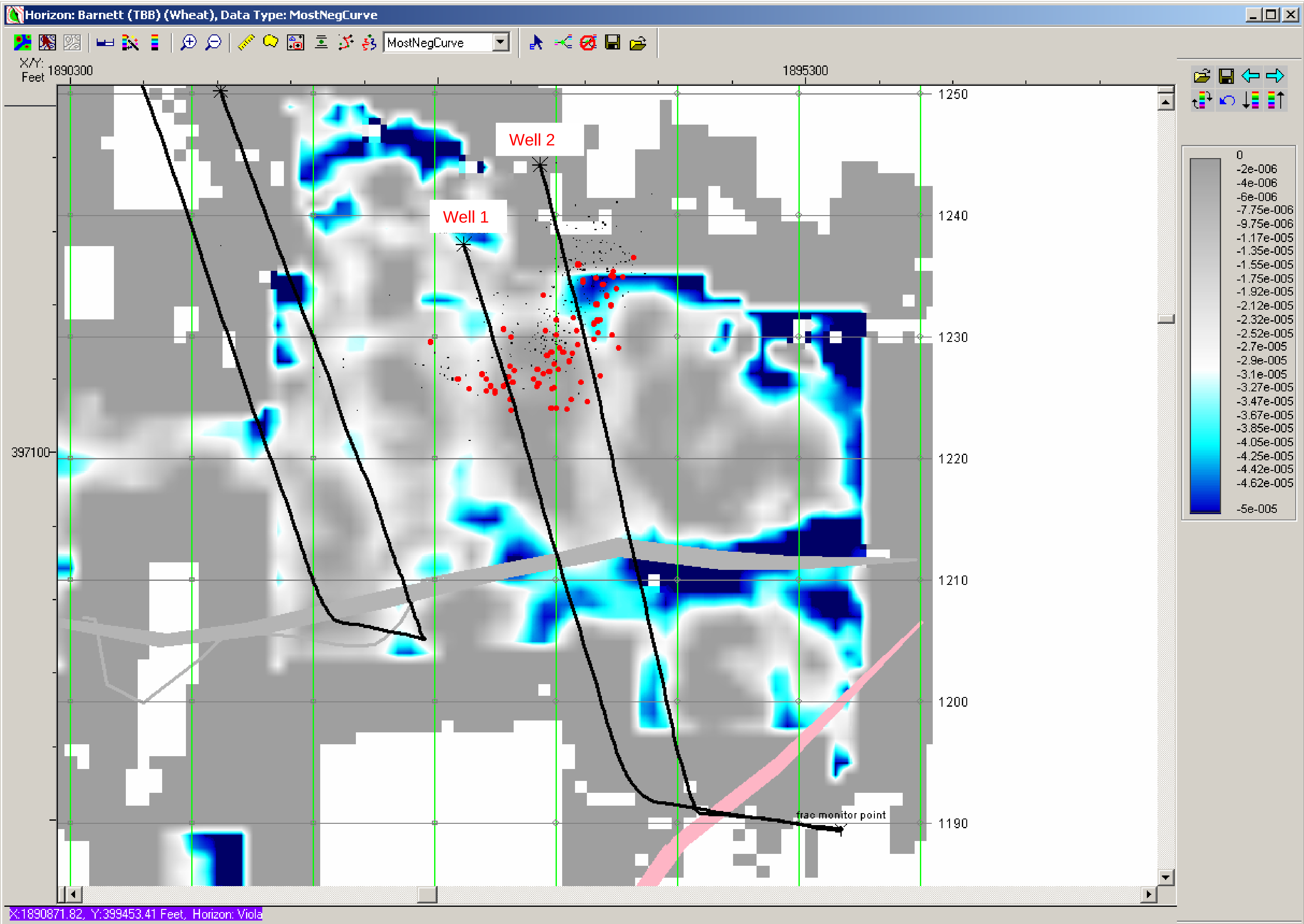
-5e-005
X:1891412.39, Y:399563.33 Feet, Horizon: Viola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MostNegCurve
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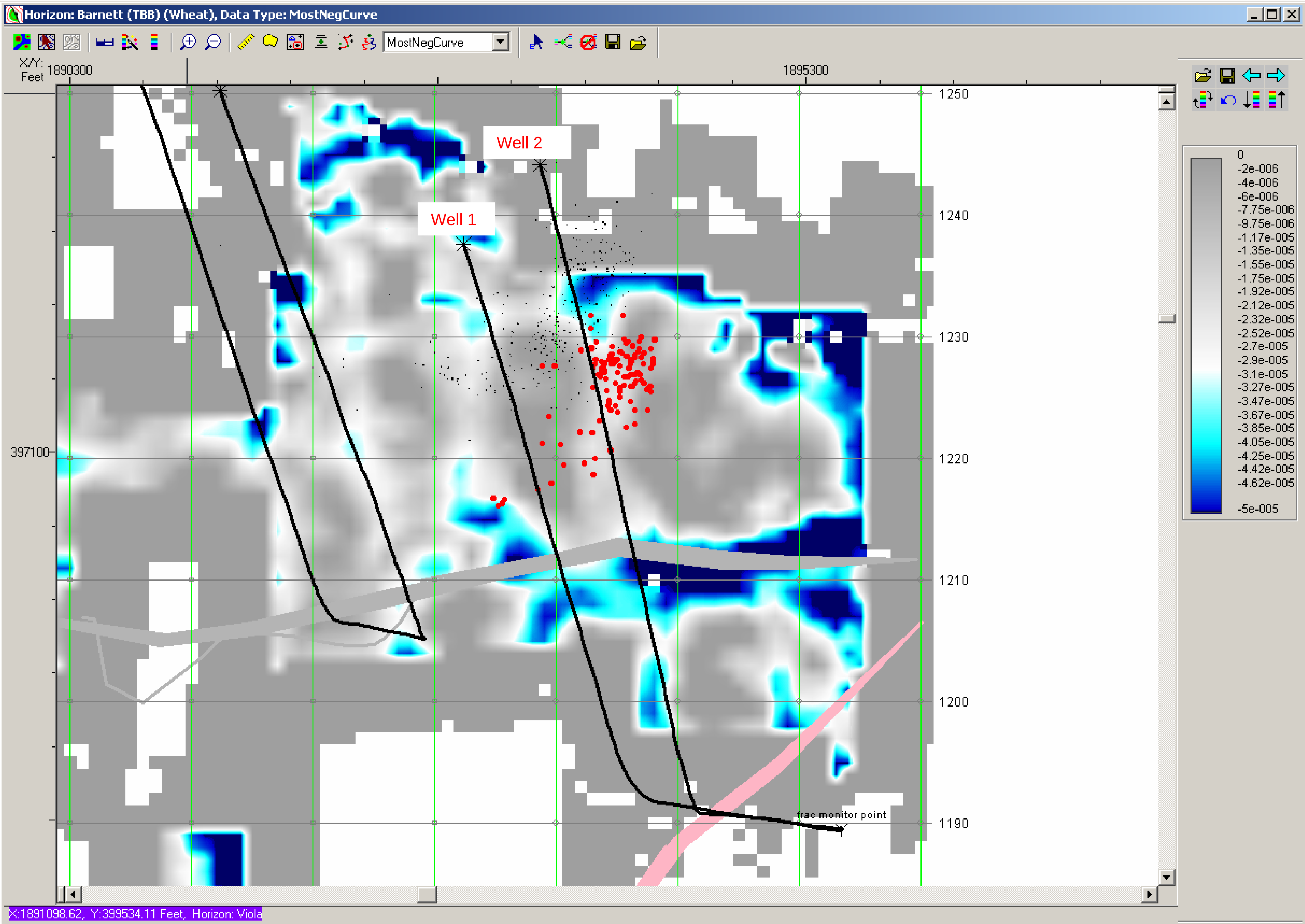
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-4e-006
-6e-006
-7.75e-006
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-2.9e-005
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-3.27e-005
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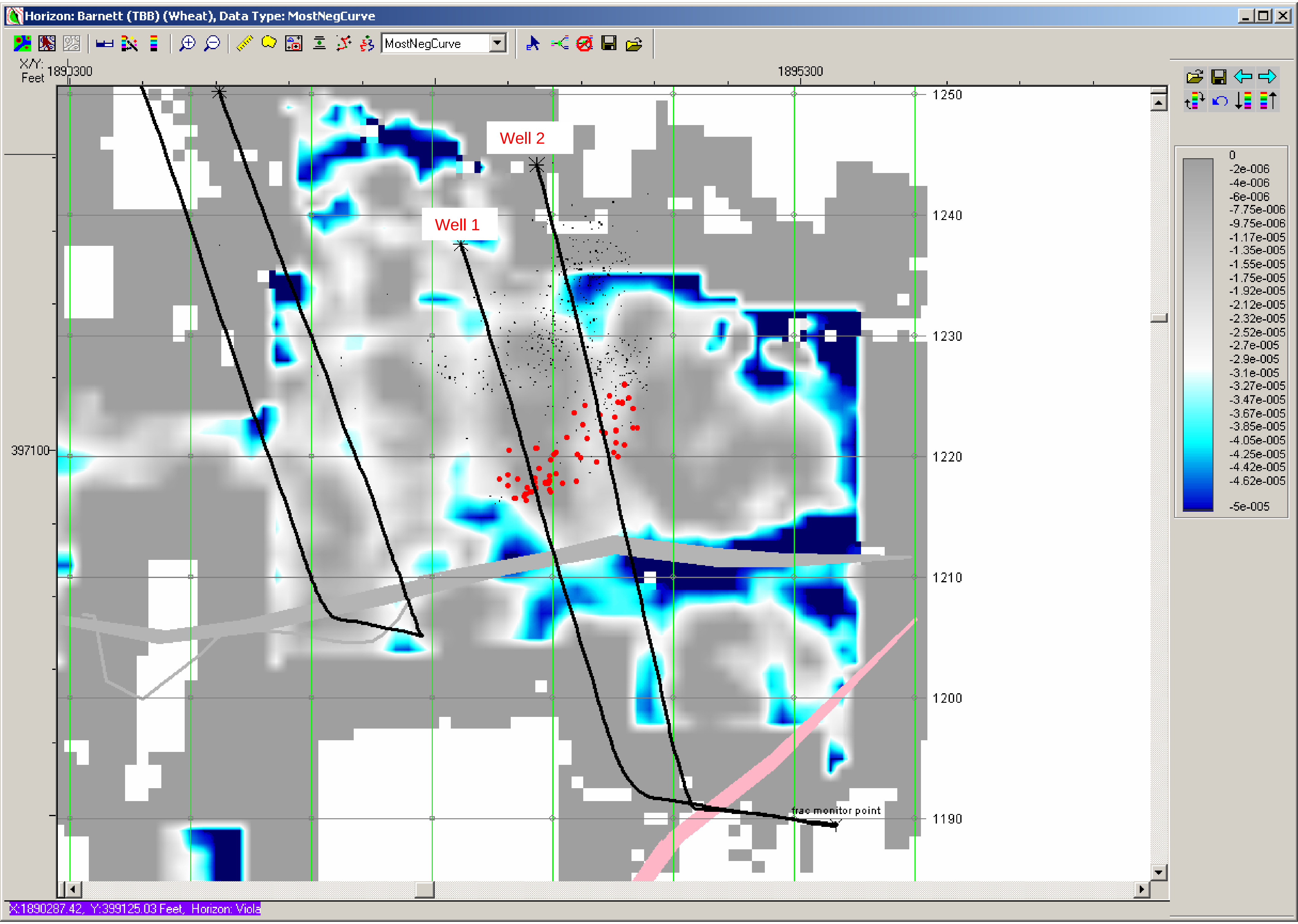
-3.67e-005
-3.85e-005
-4.05e-005
-4.25e-005
-4.42e-005
-4.62e-005
-5e-005
X:1891098.62, Y:399534.11 Feet, Horizon: Viola


Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
1890300
1895300
397100
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Well 2
frac monitor point
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-4e-006
-6e-006
-7.75e-006
-9.75e-006
-1.17e-005
-1.35e-005
-1.55e-005
-1.75e-005
-1.92e-005
-2.12e-005
-2.32e-005
-2.52e-005
-2.7e-005
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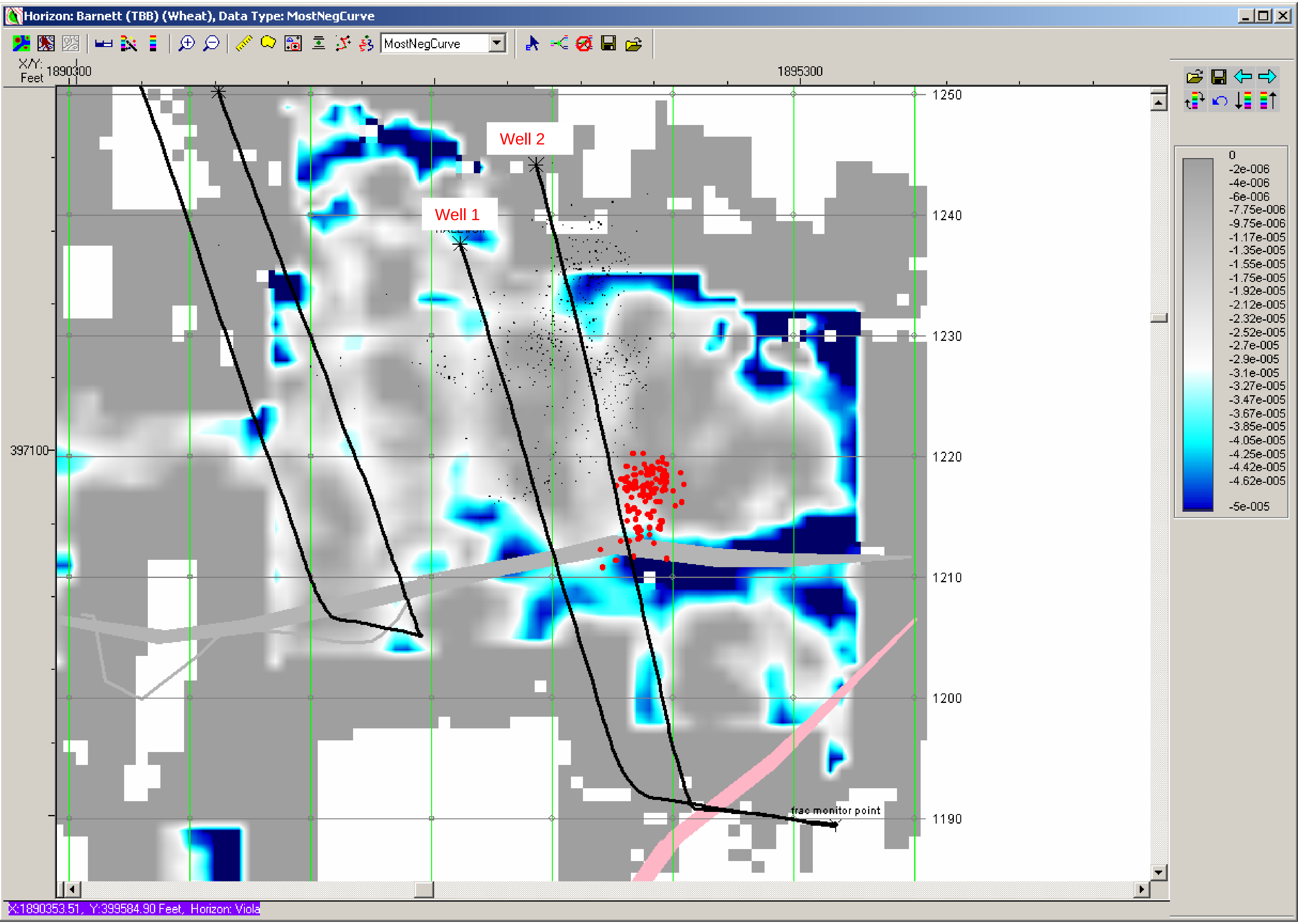
X:1890287.42, Y:399125.03 Feet, Horizon: Viola


Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
1890300
1895300
397100
1250
1240
1230
1220
1210
1200
1190
Well 1
Well 2
frac monitor point
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-4e-006
-6e-006
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-1.17e-005
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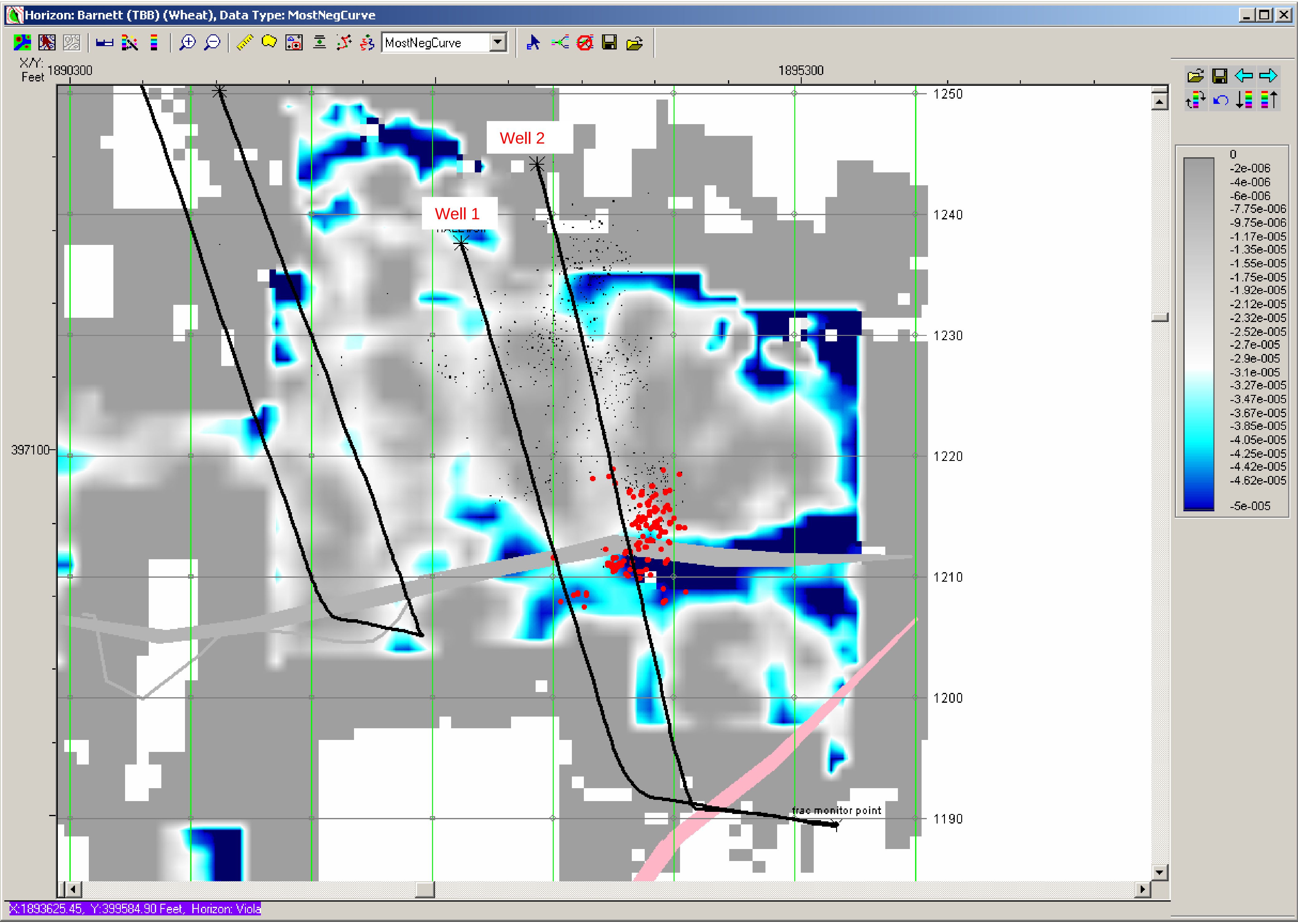
X:1890353.51, Y:399584.90 Feet, Horizon: Viola



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
1890300
1895300
397100
Well 2
Well 1
frac monitor point
1250
1240
1230
1220
1210
1200
1190
0
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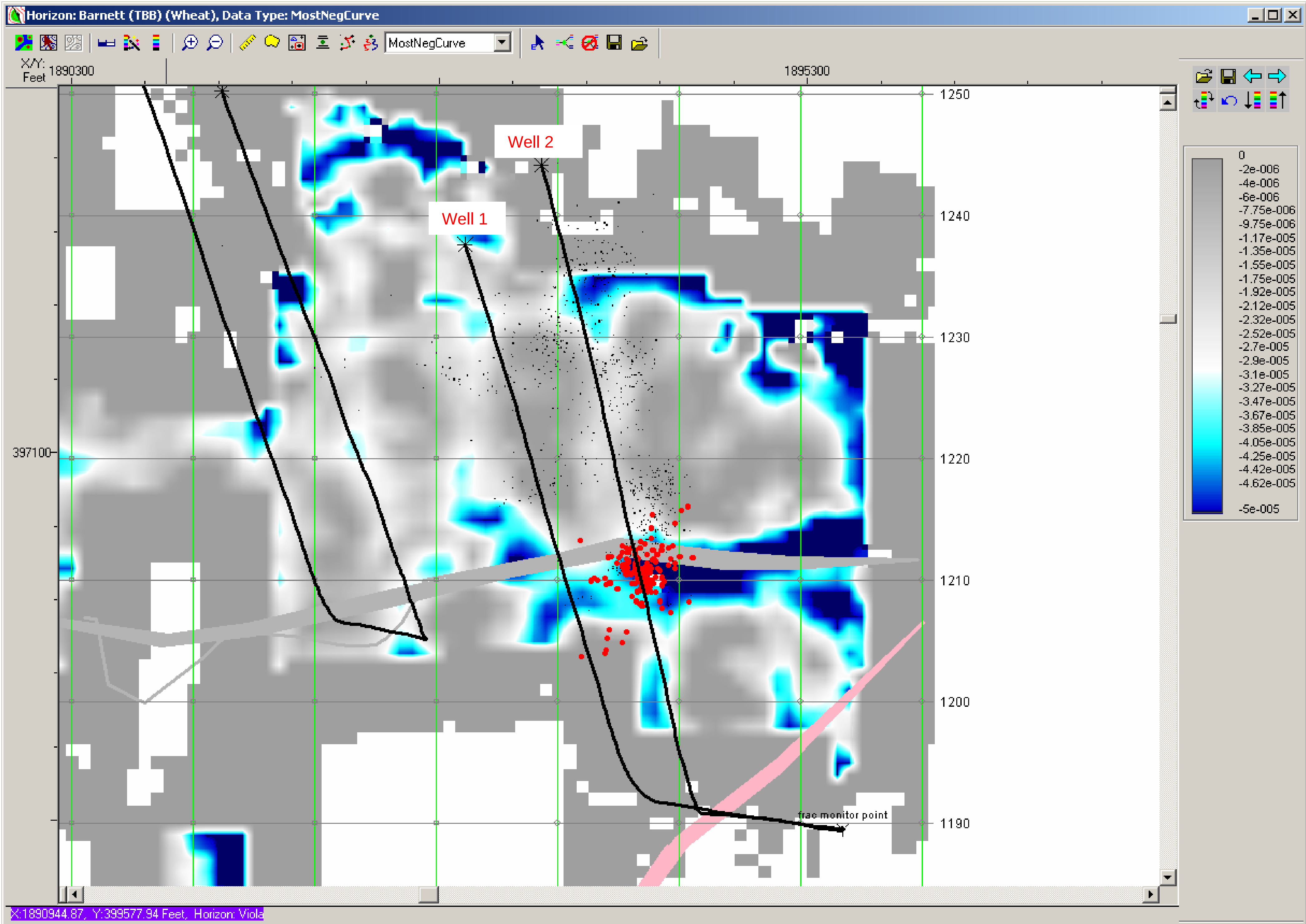
X:1893625.45, Y:399584.90 Feet, Horizon: Viola



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
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1895300
397100
1250
1240
1230
1220
1210
1200
1190
Well 1
Well 2
frac monitor point
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-4e-006
-6e-006
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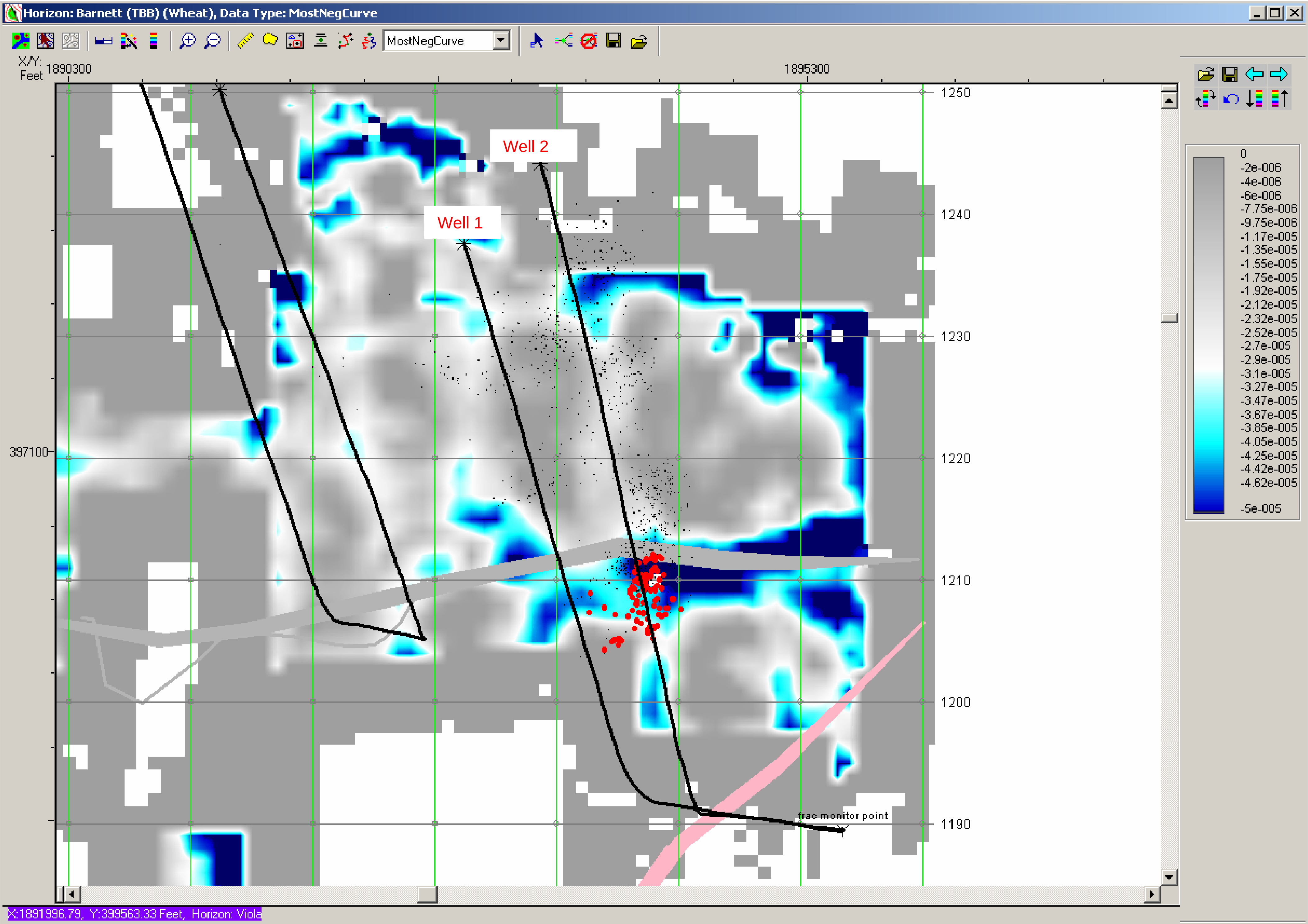
X:1890944.87, Y:399577.94 Feet, Horizon: Viola



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
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1895300
397100
1250
1240
1230
1220
1210
1200
1190
Well 1
Well 2
frac monitor point
0
-2e-006
-4e-006
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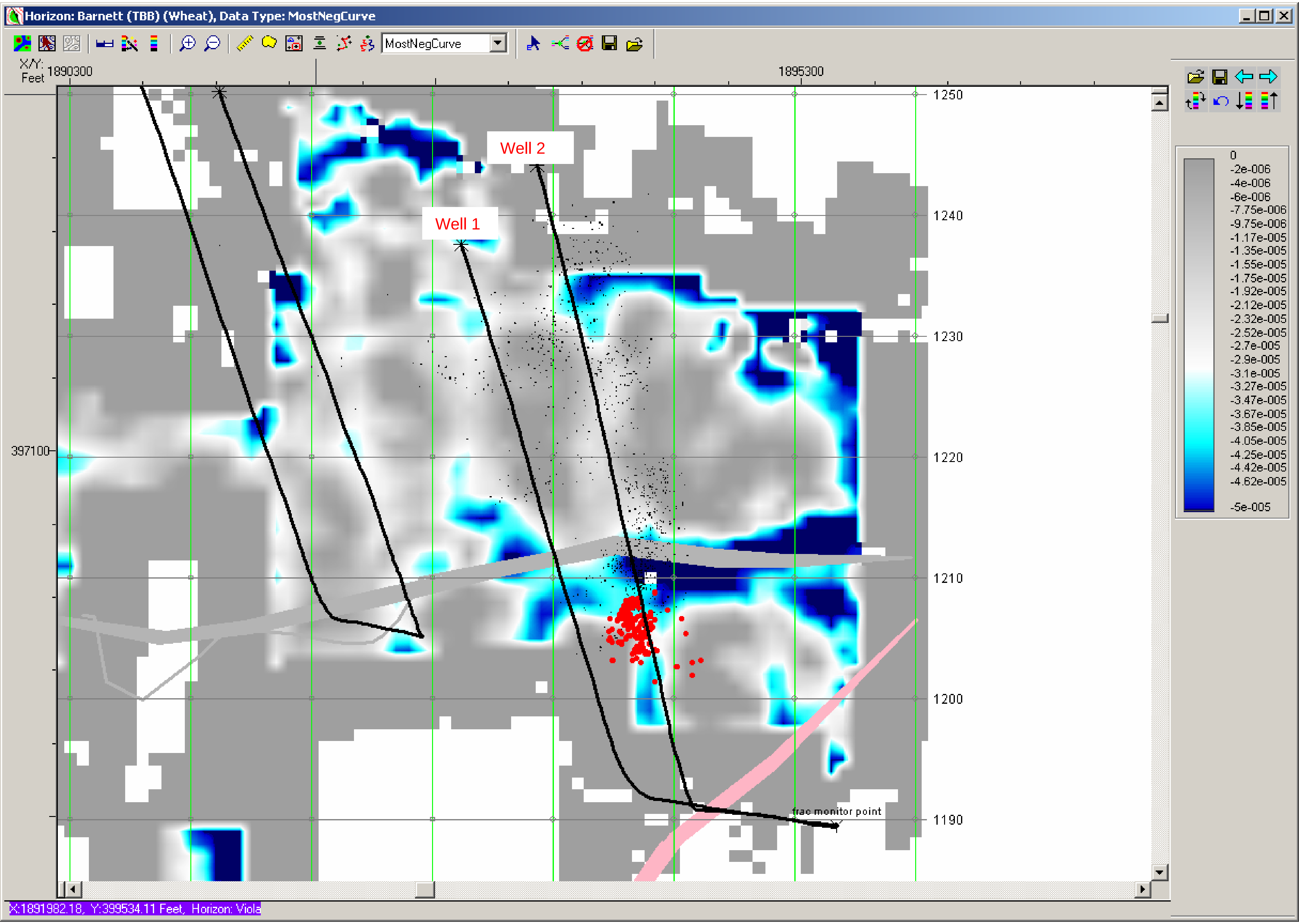
X:1891996.79, Y:399563.33 Feet, Horizon: Viola



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
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1895300
397100
1250
1240
1230
1220
1210
1200
1190
Well 2
Well 1
frac monitor point
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-4e-006
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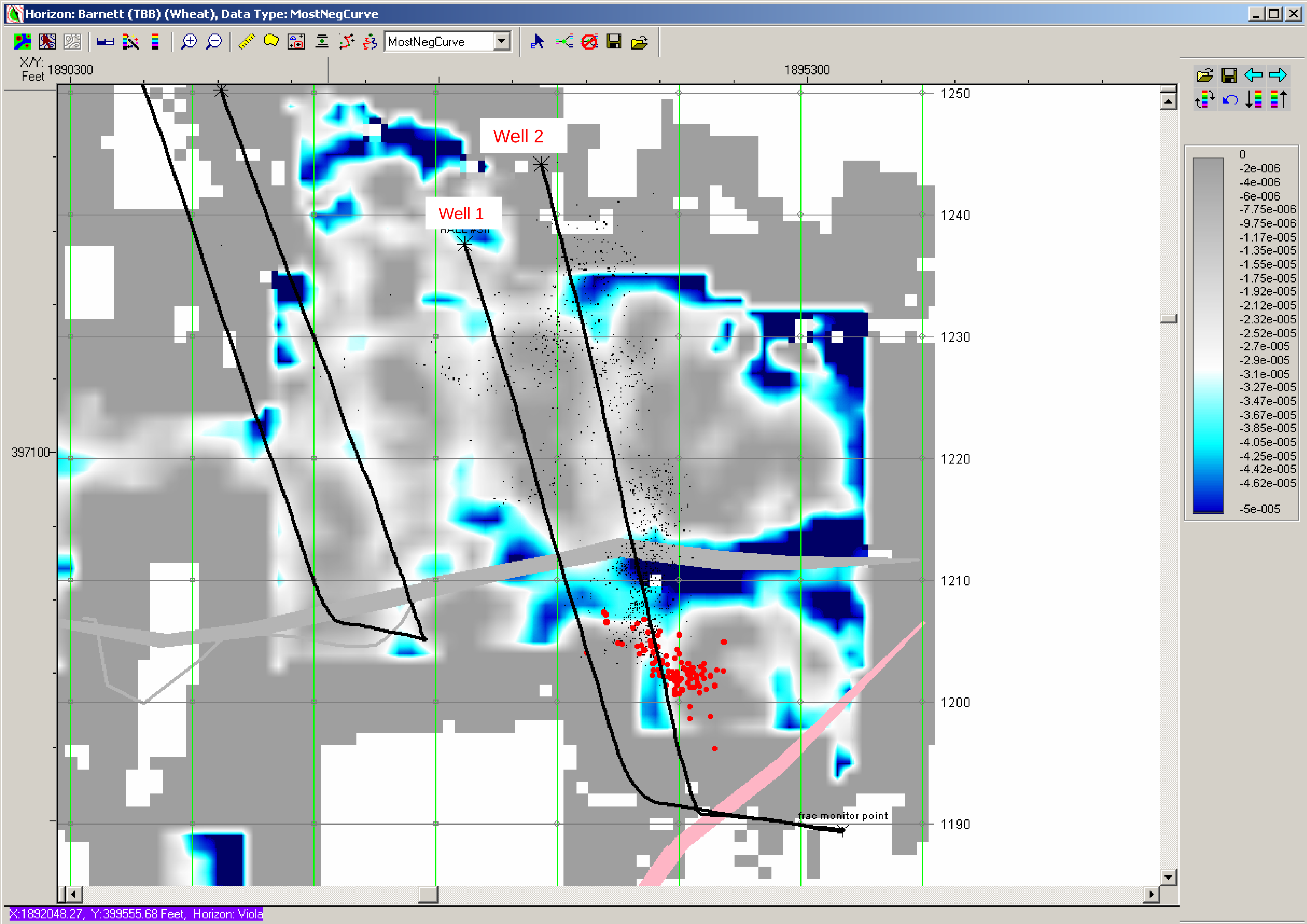
-5e-005
X:1891982.18, Y:399534.11 Feet, Horizon: Viola



Horizon: Barnett (TBB) (Wheat), Data Type: MostNegCurve
MostNegCurve
X/Y: Feet
1890300
1895300
397100
1250
1240
1230
1220
1210
1200
1190
Well 2
Well 1
frac monitor point
0
-2e-006
-4e-006
-6e-006
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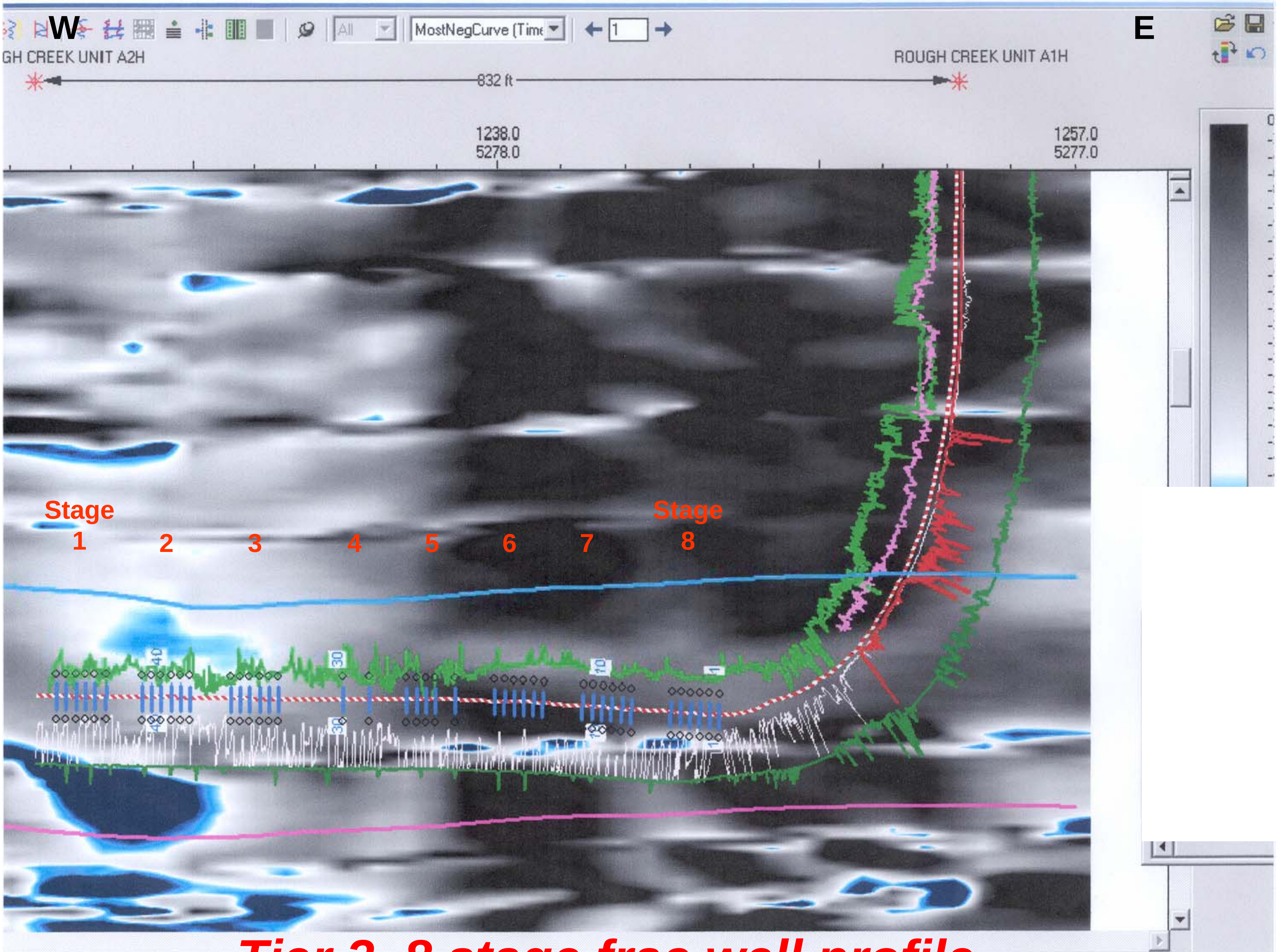
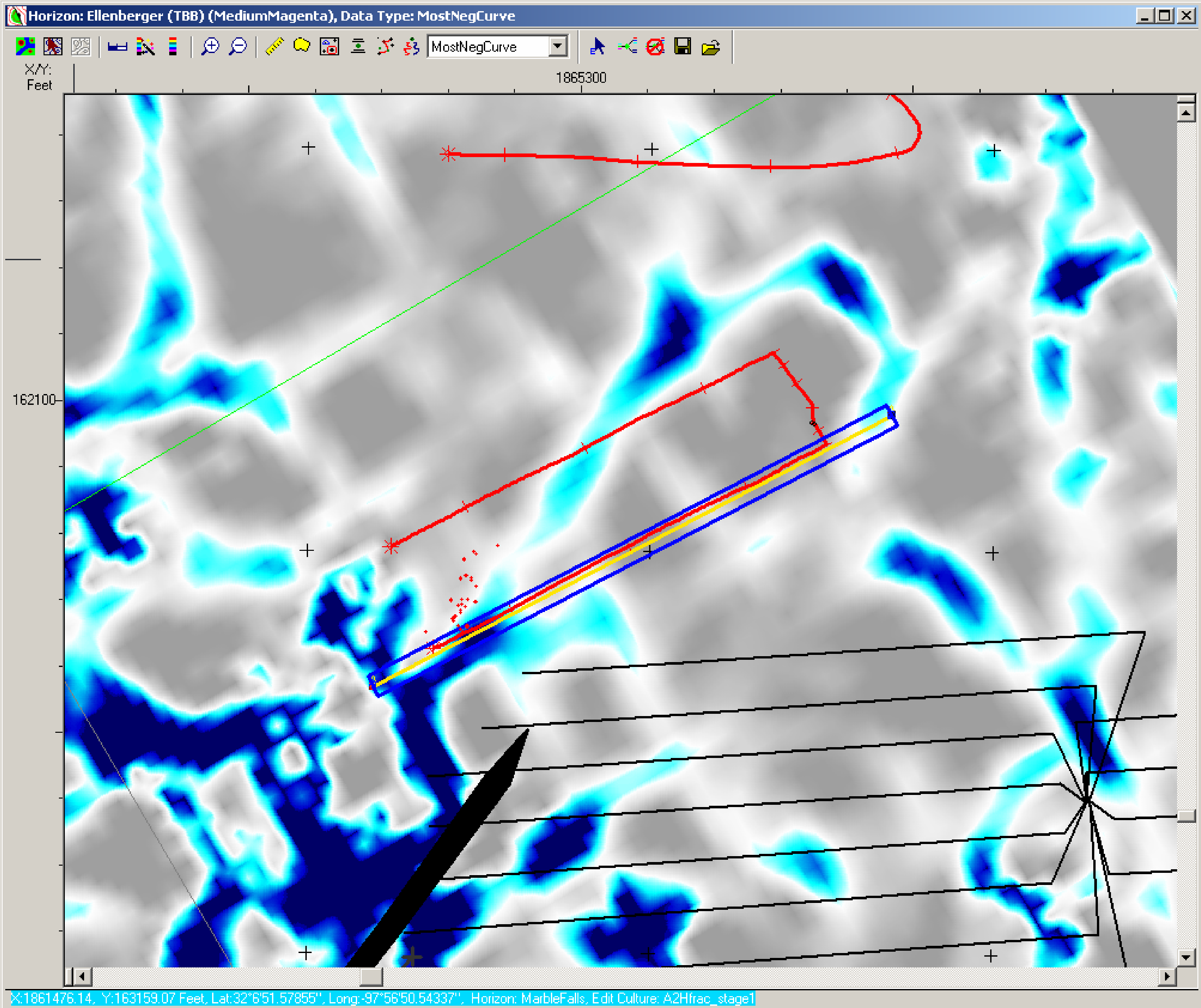
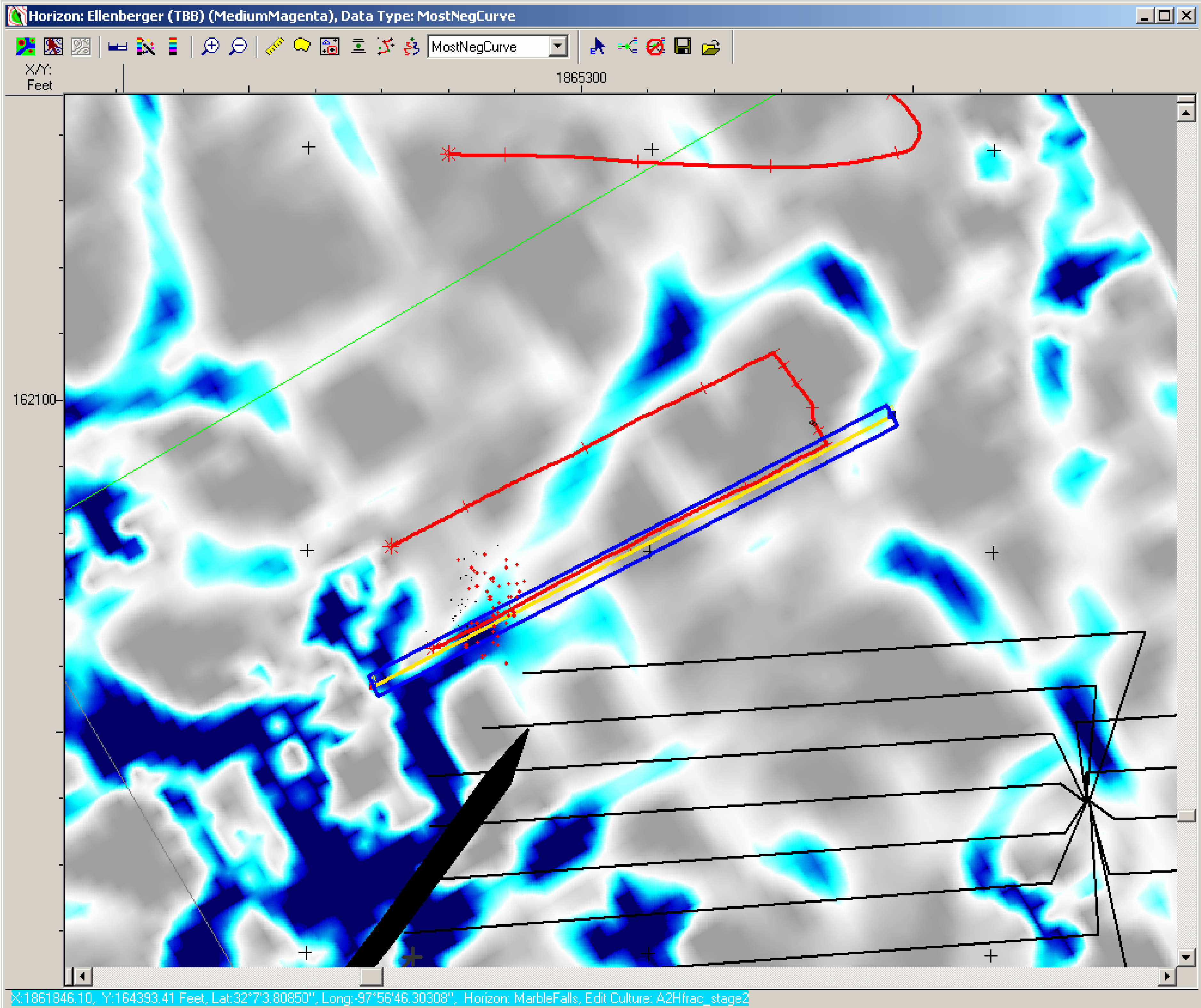
X:1892048.27, Y:399555.68 Feet, Horizon: Viola

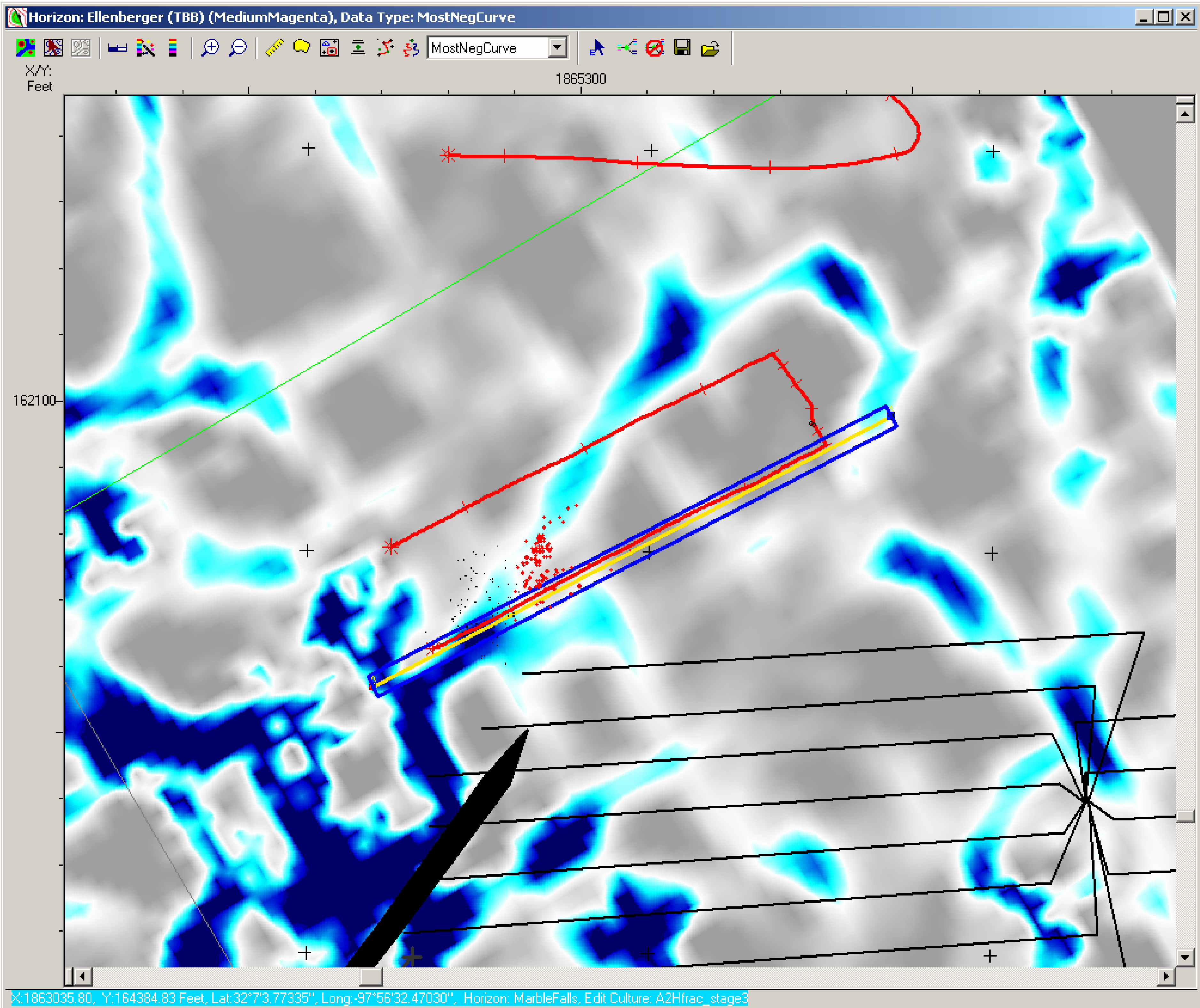
Tier 3, 8 stage frac on Most Negative Curvature



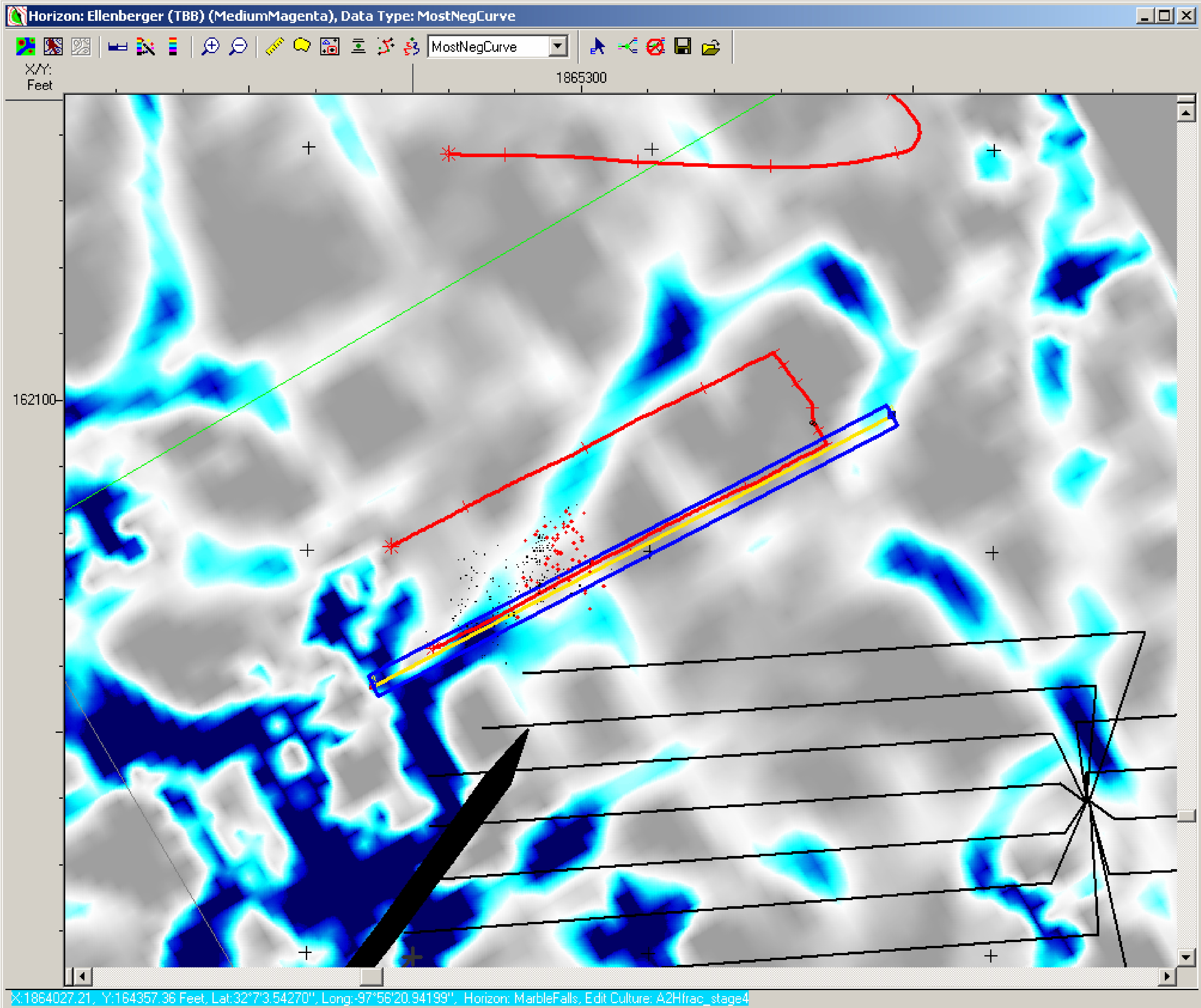
Tier 3, 8 stage frac well profile

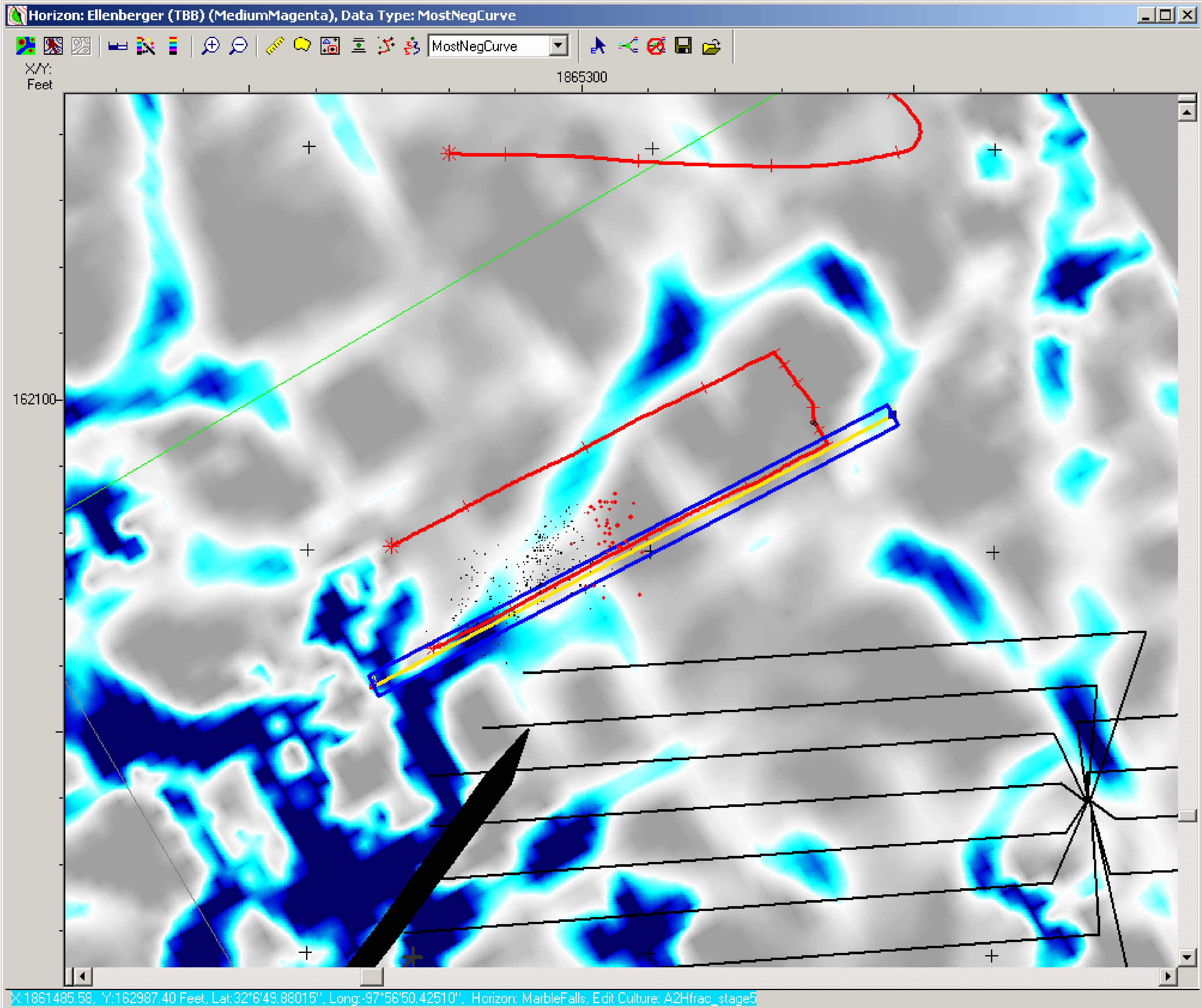

Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861476.14, Y:163159.07 Feet, Lat:32°6'51.57855", Long:-97°56'50.54337", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage1


Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861846.10, Y:164393.41 Feet, Lat:32°7'3.80850", Long:-97°56'46.30308", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage2

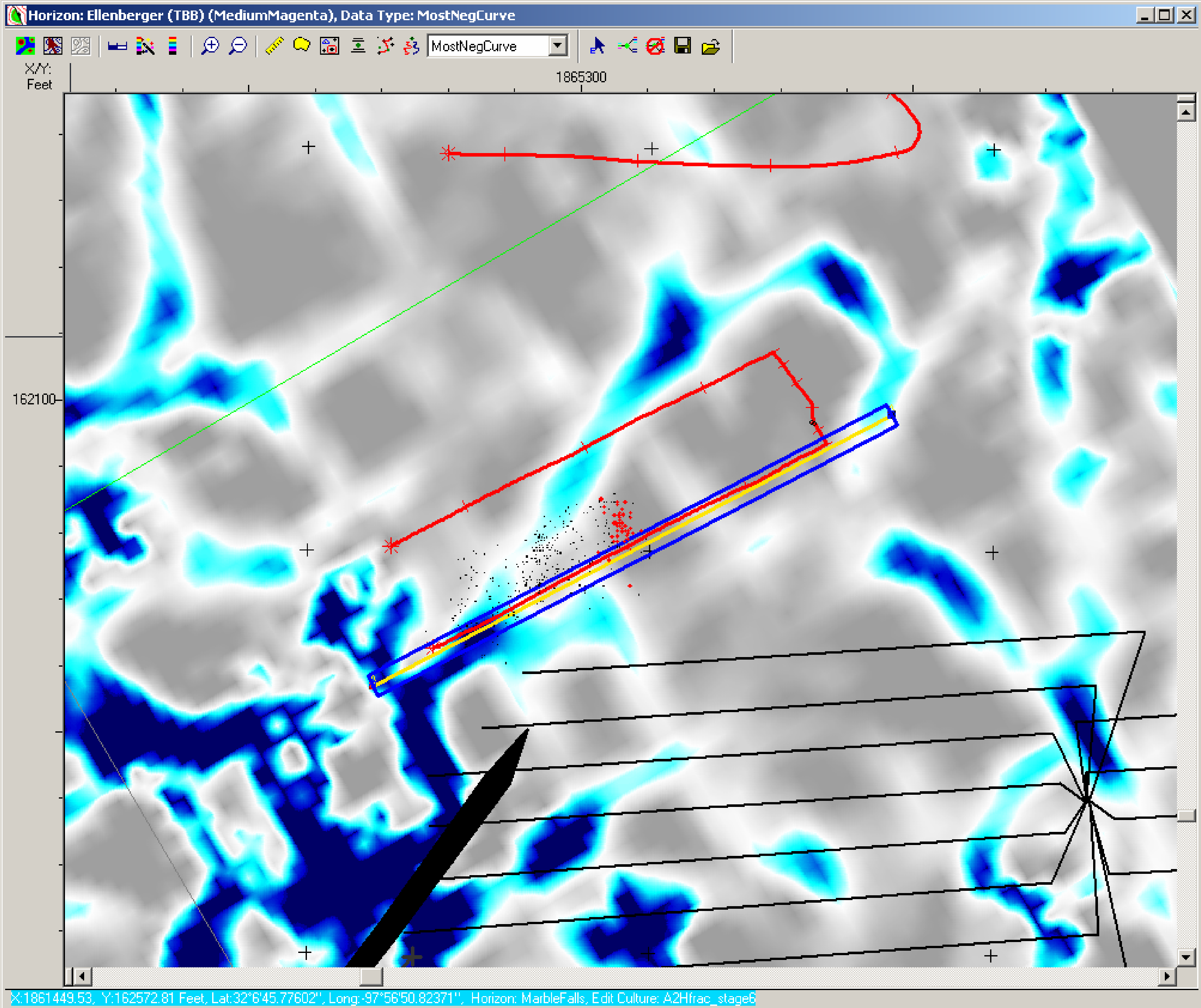


Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1863035.80, Y:164384.83 Feet, Lat:32°7'3.77335", Long:-97°56'32.47030", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage3

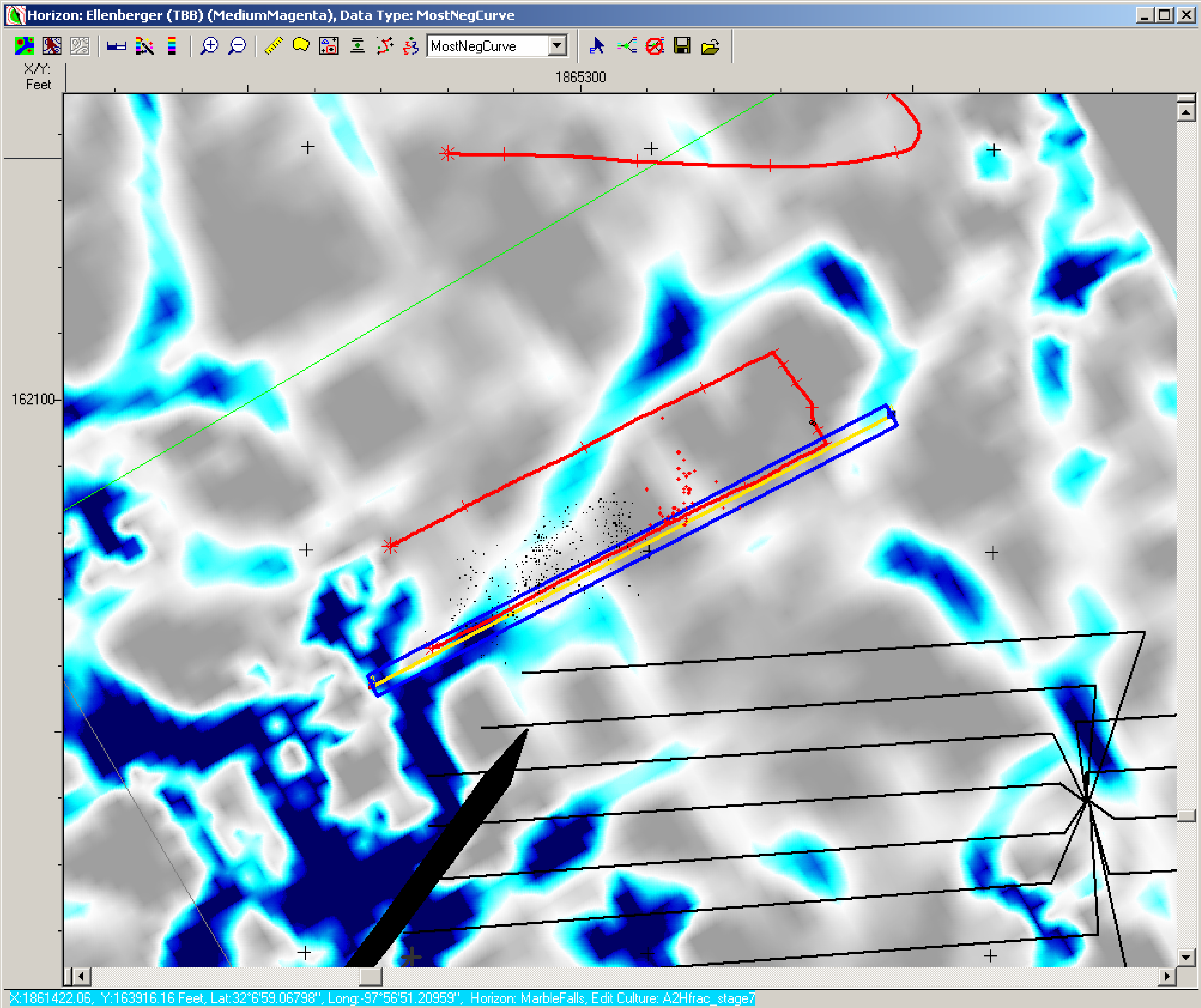

Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1864027.21, Y:164357.36 Feet, Lat:32°7'3.54270", Long:-97°56'20.94199", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage4

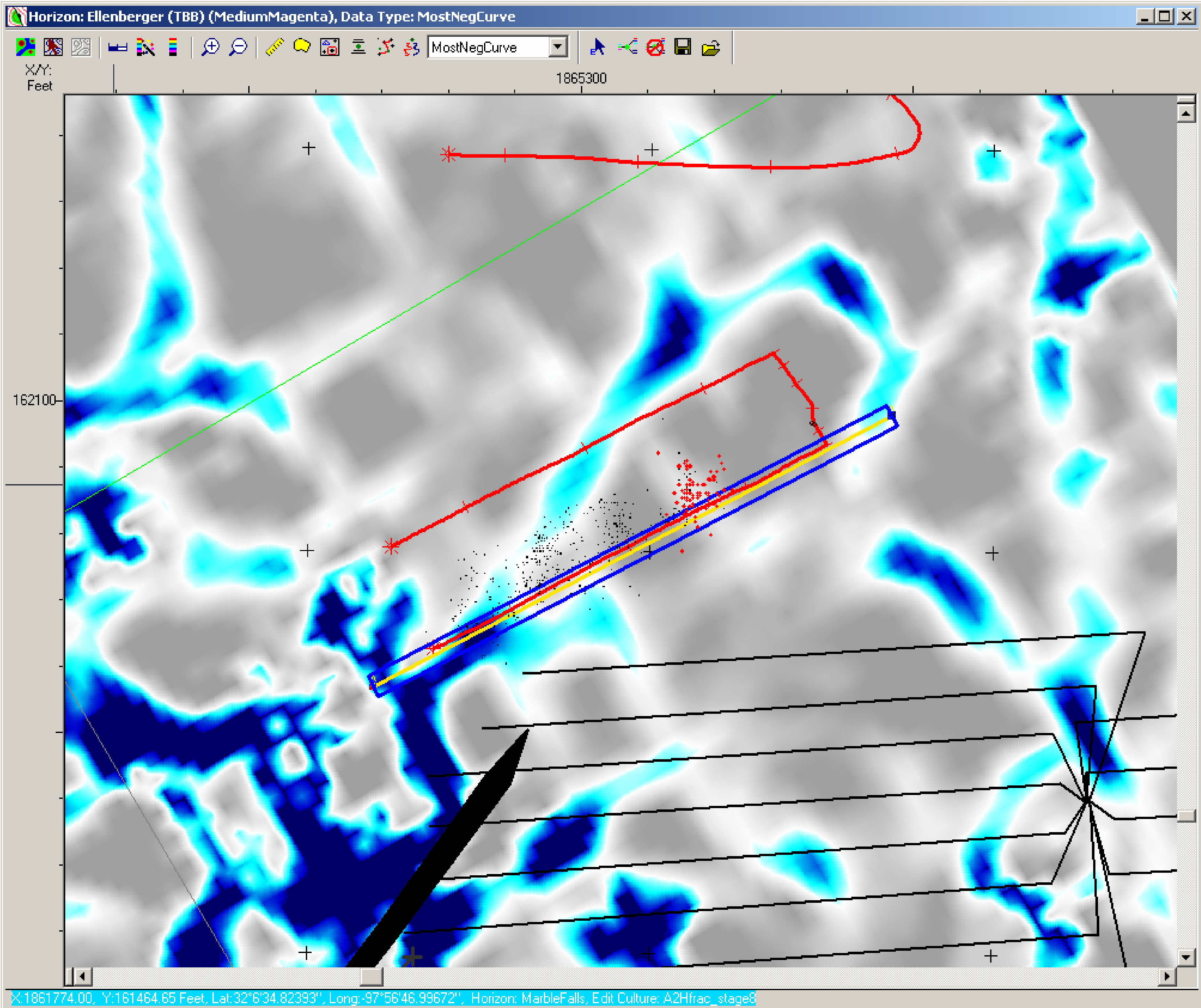


Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861485.58, Y:162987.40 Feet, Lat:32°6'49.88015", Long:-97°56'50.42510", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage5

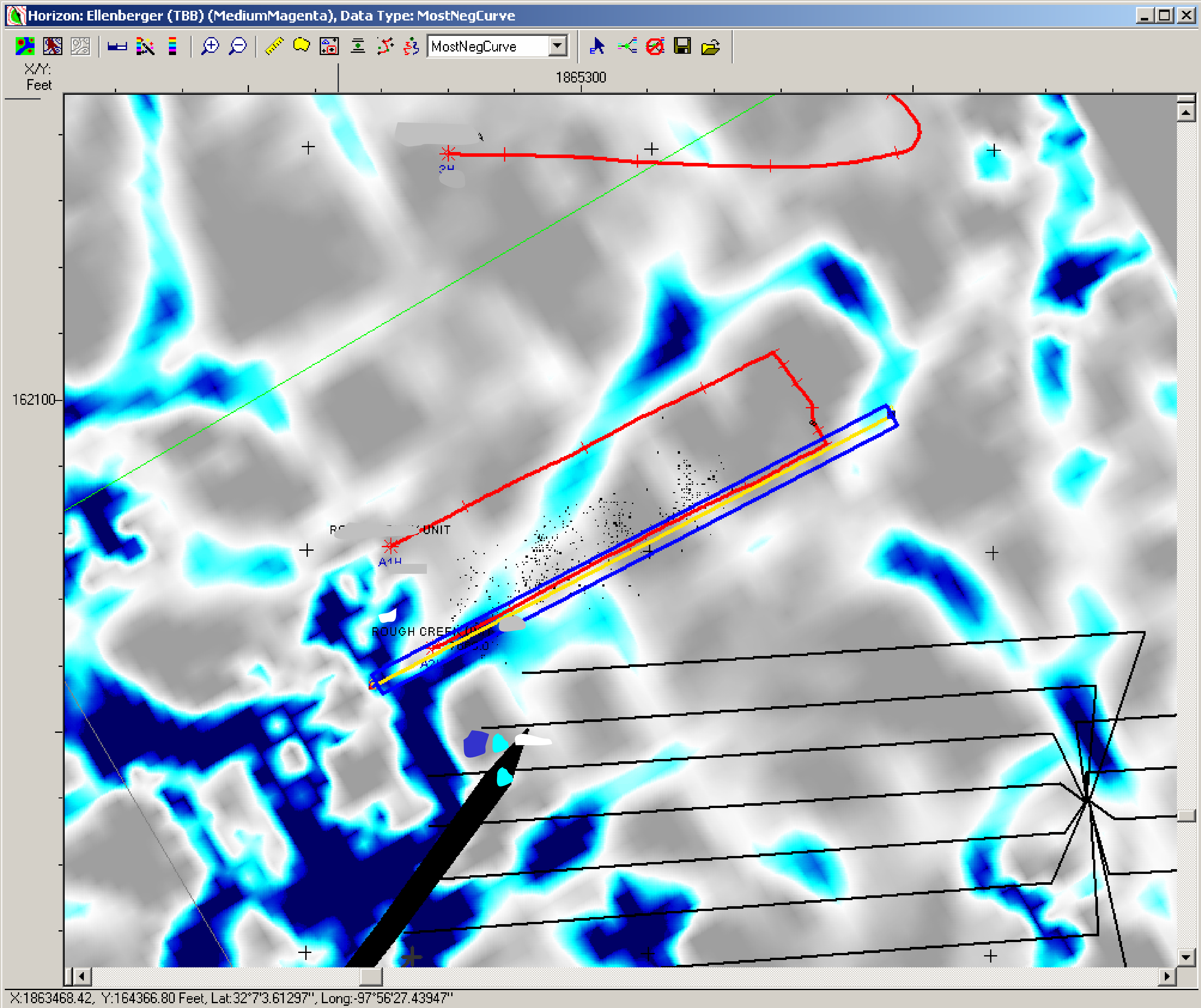


Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861449.53, Y:162572.81 Feet, Lat:32°6'45.77602", Long:-97°56'50.82371", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage6

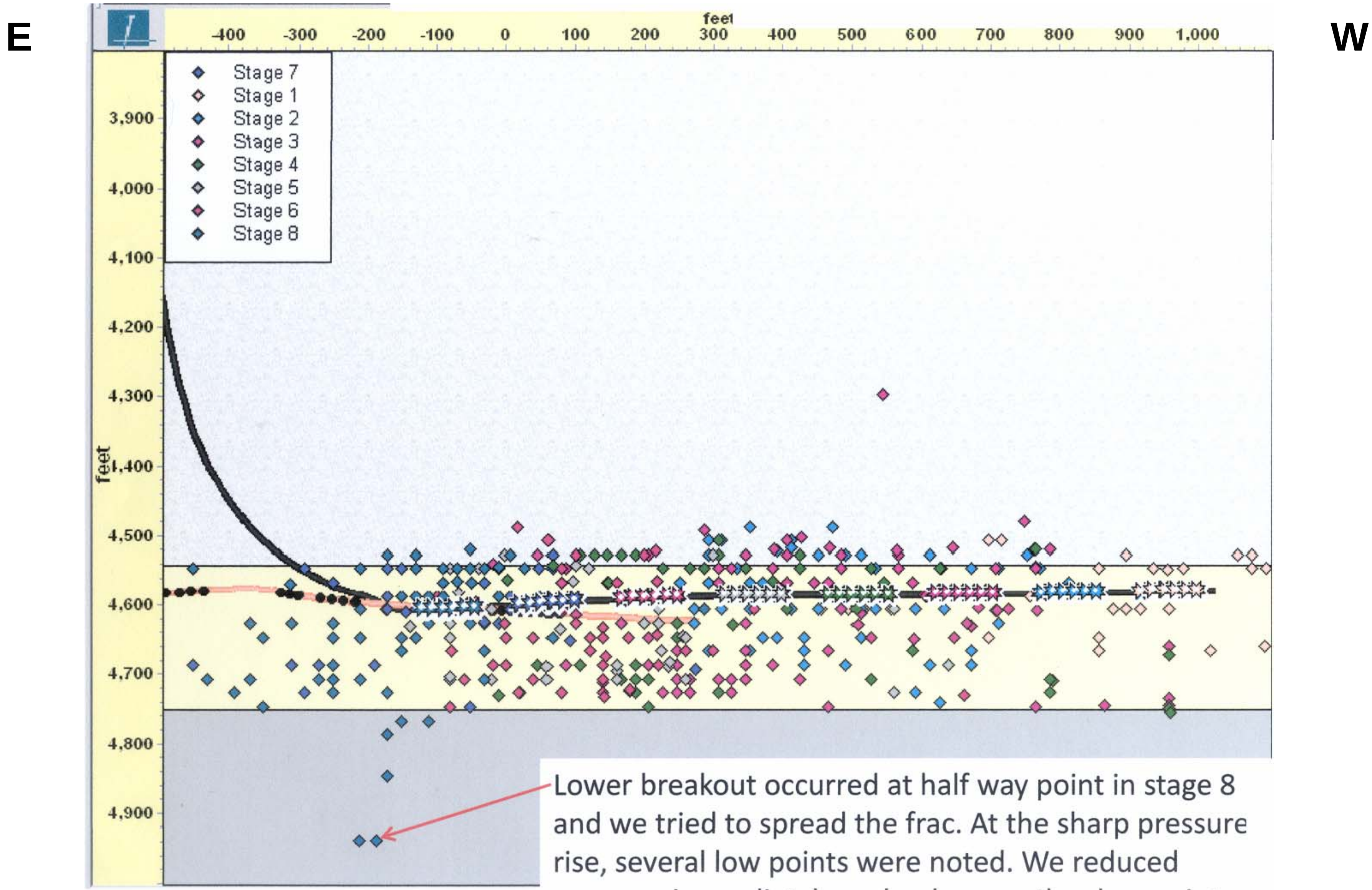

Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861422.06, Y:163916.16 Feet, Lat:32°6'59.06798", Long:-97°56'51.20959", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage7



Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
X:1861774.00, Y:161464.65 Feet, Lat:32°6'34.82393", Long:-97°56'46.99672", Horizon: MarbleFalls, Edit Culture: A2Hfrac_stage8

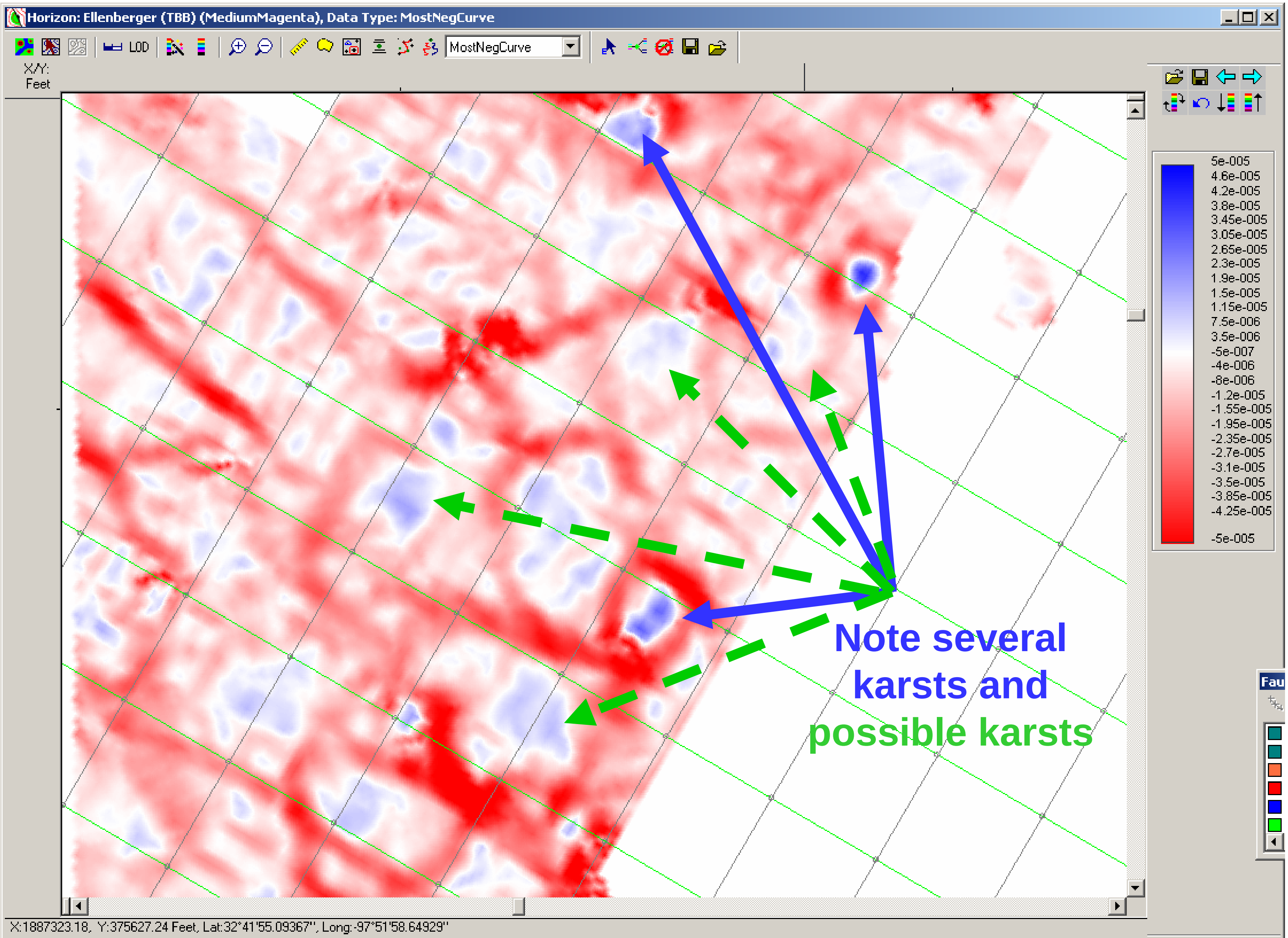

Horizon: Ellenberger (TBB) (MediumMagenta), Data Type: MostNegCurve
MostNegCurve
X/Y:
Feet
1865300
162100
UNIT
ROUGH CREEK
X:1863468.42, Y:164366.80 Feet, Lat:32°7'3.61297", Long:-97°56'27.43947"

Tier 3, 8 stage frac Pinnacle Data



Lower breakout occurred at half way point in stage 8 and we tried to spread the frac. At the sharp pressure rise, several low points were noted. We reduced pressure immediately and only one other low point was seen in the area.

Neg. Curvature can be a “Karst killer”



MOST NEG. CURVATURE

- Defines large faults and the extent of the fault complexity
- Better defines smaller faults that more conventional seismic may miss
- Defines small and large karst features well
- Defines structural grains that may allow better orientation of horizontal wells
- Perhaps indicates zones of fracturing that allows modification of fracs to avoid fracing downward into the Ellenberger
- May indicate lateral changes within the Barnett that affects the fracing of wells

FURTHER EFFORTS

- **Better understand the color variations of the similarity and negative curvature data related to the variations in Barnett rock properties laterally and vertically.**
- **Better understand the color variations of the similarity and negative curvature data to better identify fracture zones to avoid fracing down into the water-bearing Ellenberger.**
- **Need more understanding of the orientation of horizontal wellbores related to the structural grains shown in the negative curvature as to what orientation allows more efficient fracing and rubblizing of the objective Barnett.**

<u>CONCLUSIONS:</u>

These processing techniques of 3D data in the Fort Worth Basin:

- Are effective throughout the Barnett gas productive area of the Fort Worth Basin
- Identify large and small geologic hazards.
- Identify lateral changes in the Barnett
- Provide better control for horizontal orientation
- Provide insight into improving frac efficiency along single well bores
- Show that cookie cutter frac techniques applied in the same manner throughout the basin, and even along the same well bore, do not work.

AND

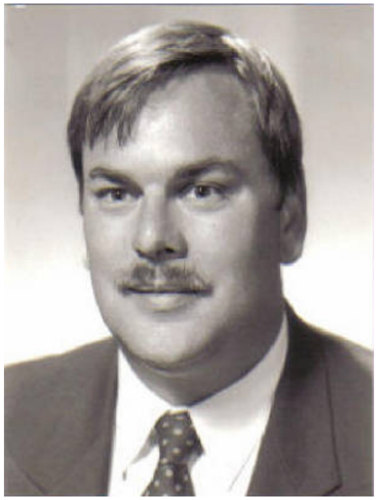
- ***MOST IMPORTANTLY*, INCREASE THE CHANCES OF DRILLING A LARGER PERCENTAGE OF GOOD WELLS AND DRILLING FEWER POOR, NON-ECONOMIC WELLS RESULTING IN HIGHER ECONOMIC RATES OF RETURN.**

AN DEIREADH

THE END

TAPADH LEIBH, GLÉ MHOR, A H-UILEDUINE

THANK YOU, VERY MUCH EVERYONE



MADAINN MHATH

GOOD MORNING

Garaidh agus Tim

Gary and Tim