Seismic Expression of Shale Reservoirs
Opportunities for Technology Improvement

Kurt J. Marfurt (University of Oklahoma)

Outline

Review of workflows useful in the Barnett Shale

- Volumetric attributes
- Basement control of faulting and collapse
- Velocity anisotropy analysis
- Azimuthal AVO analysis
- Improved lateral resolution through innovative migration

Some flash images of preliminary application of these techniques to the Woodford Shale

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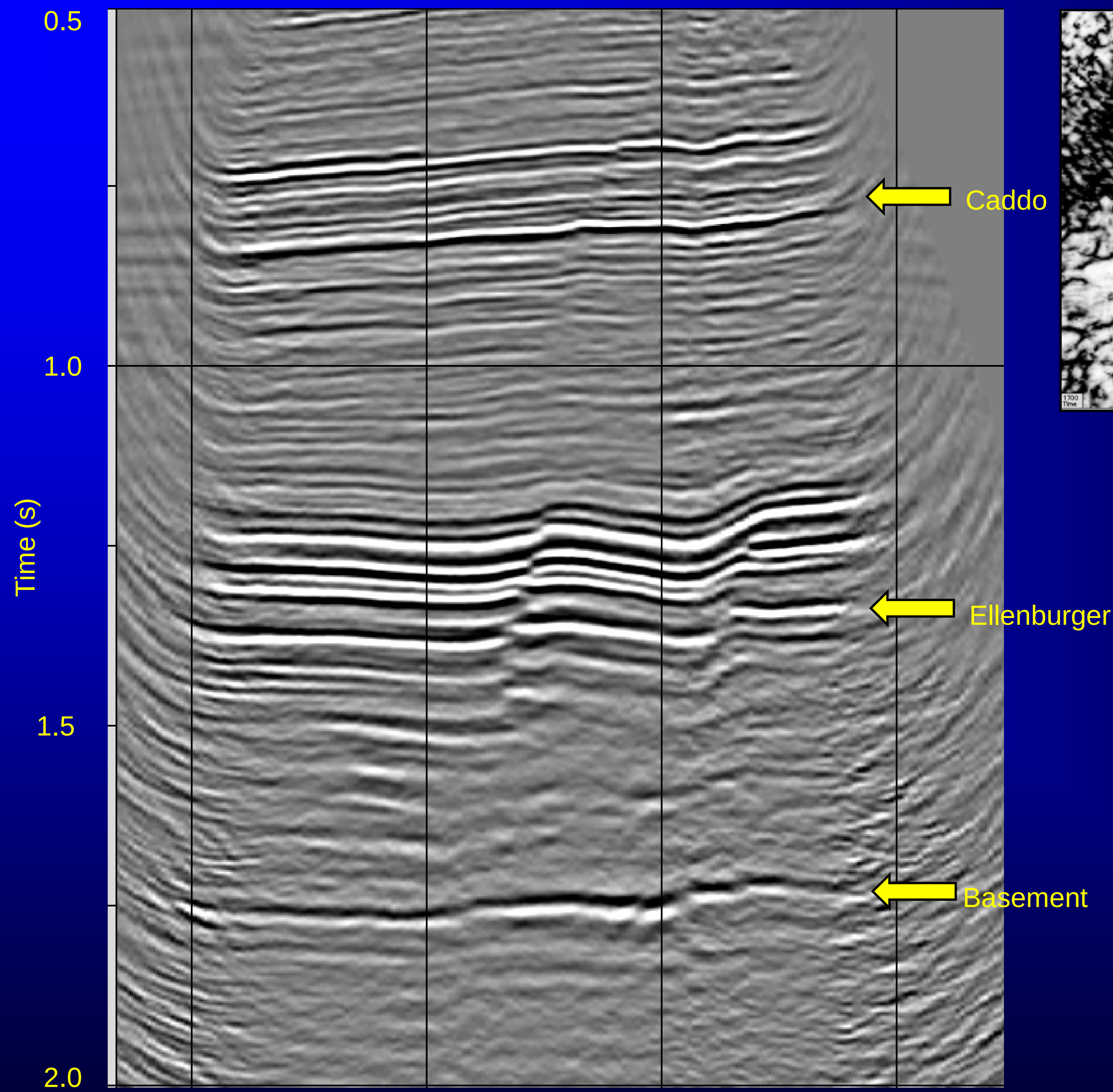
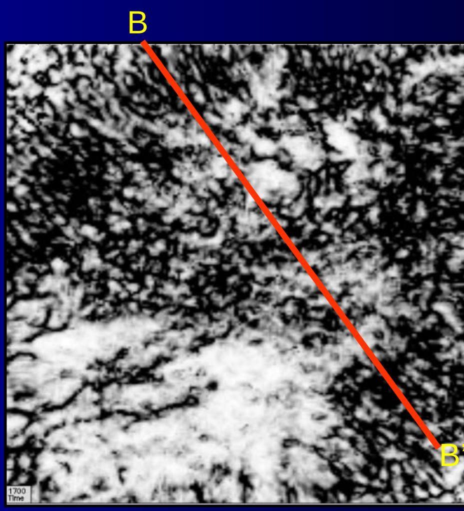
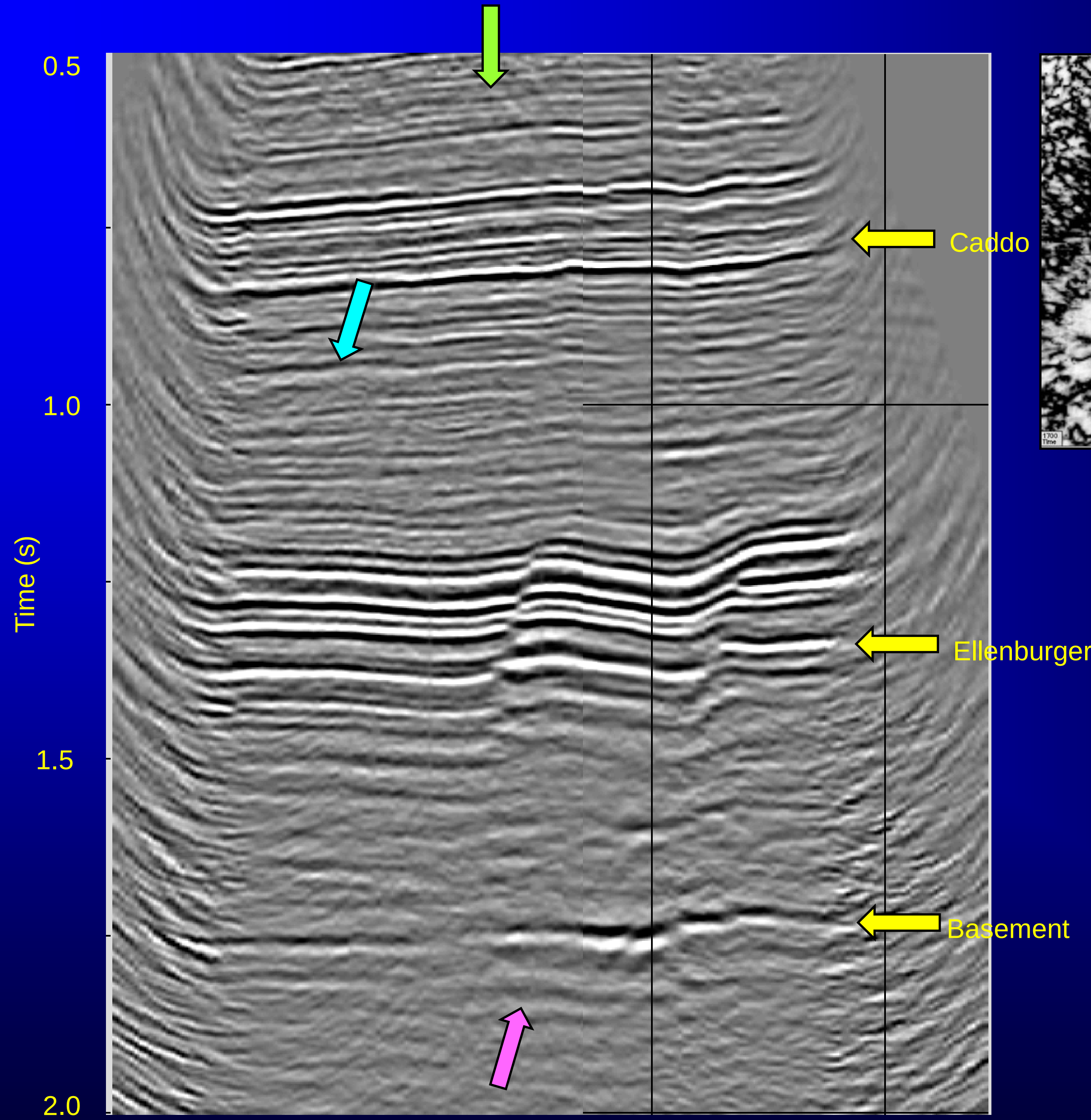
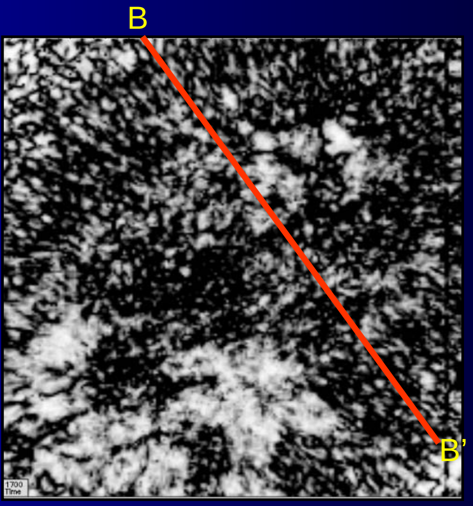




Post-stack time migration

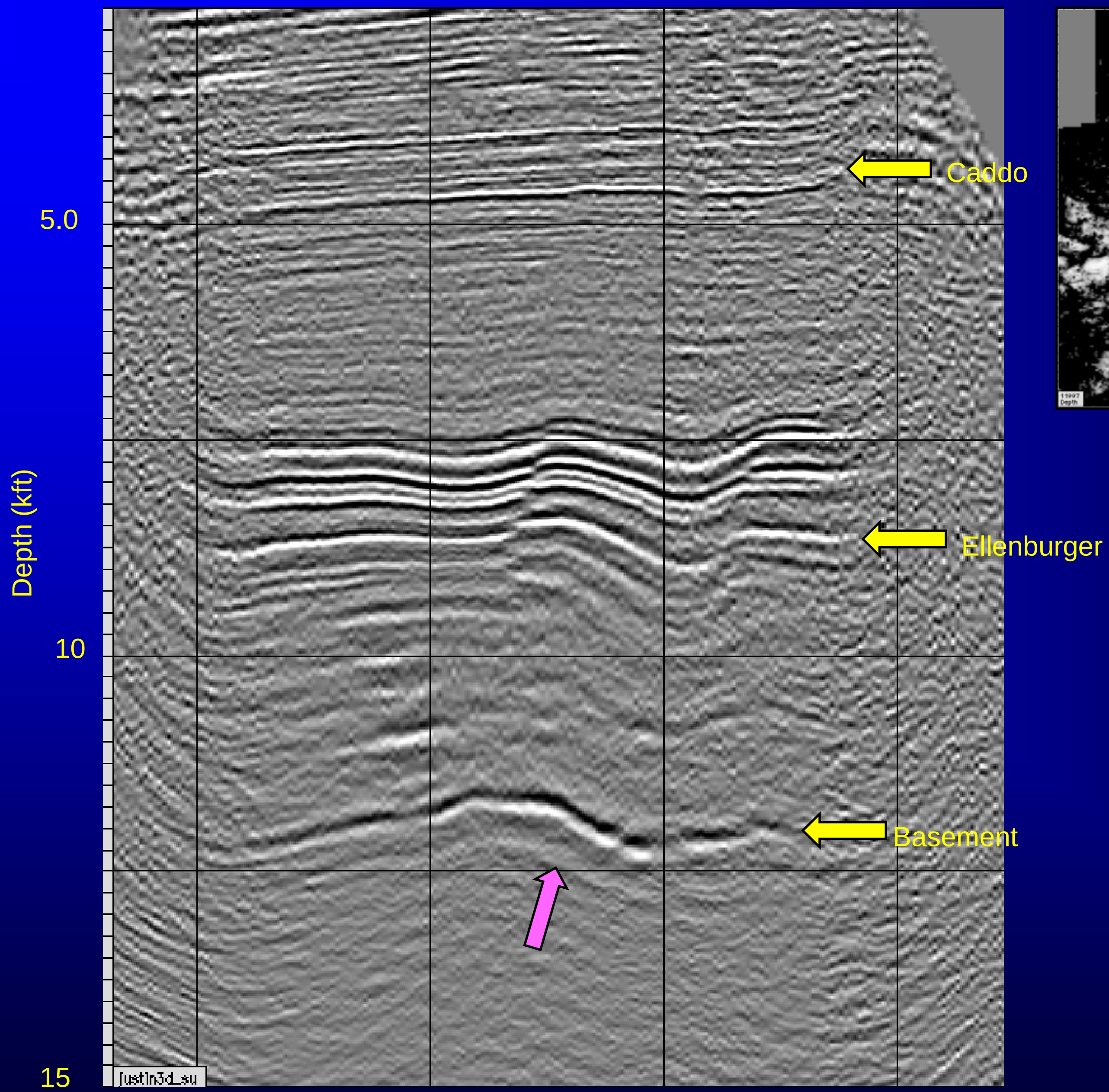
(Aktepe et al., 2008)

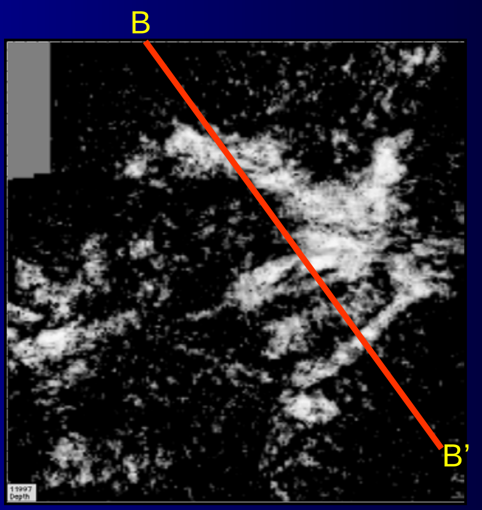




Pre-stack time migration

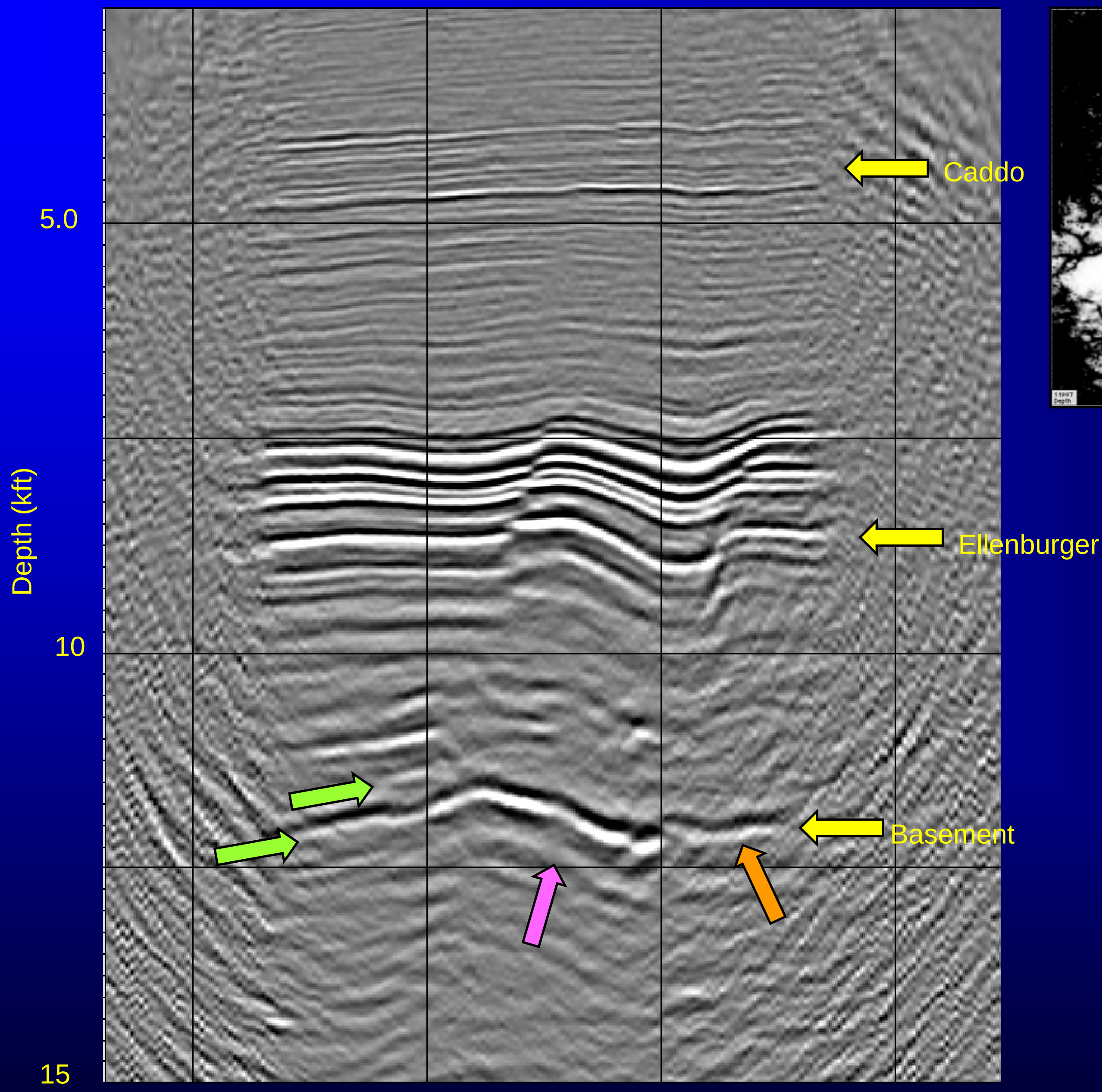
(Aktepe et al., 2008)

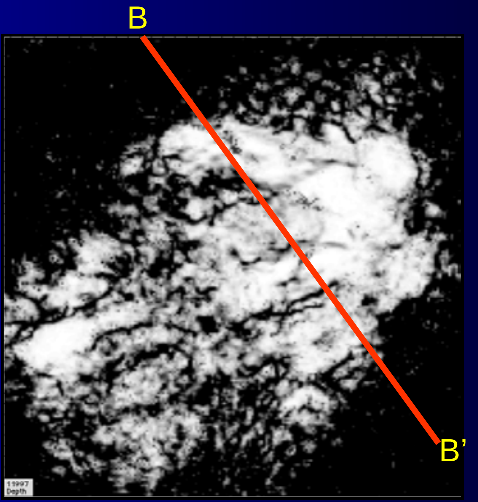




Post-stack depth migration

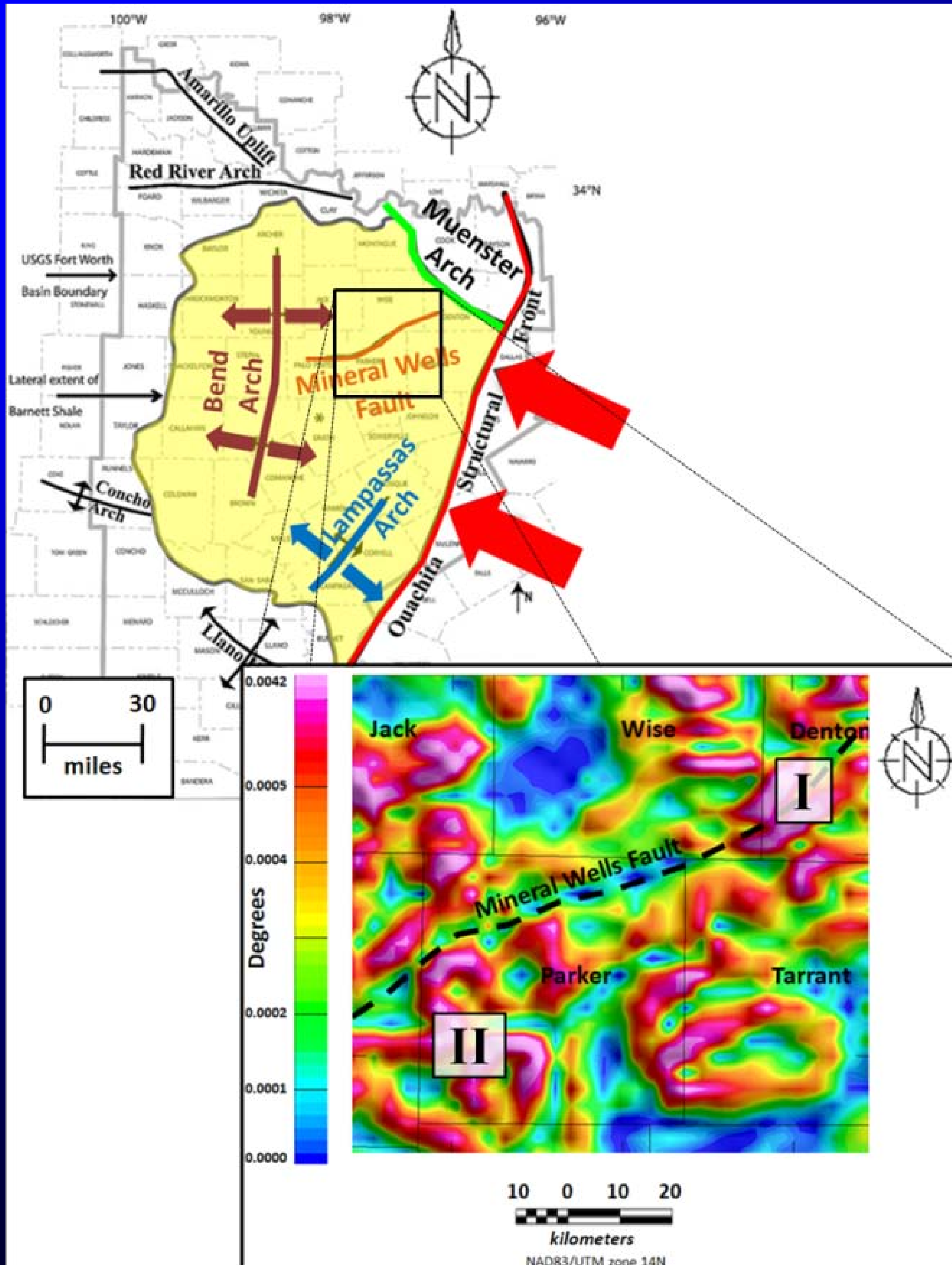
(Aktepe et al., 2008)





Pre-stack depth migration

(Aktepe et al., 2008)



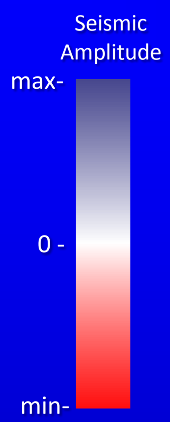
Structural components of the Fort Worth Basin

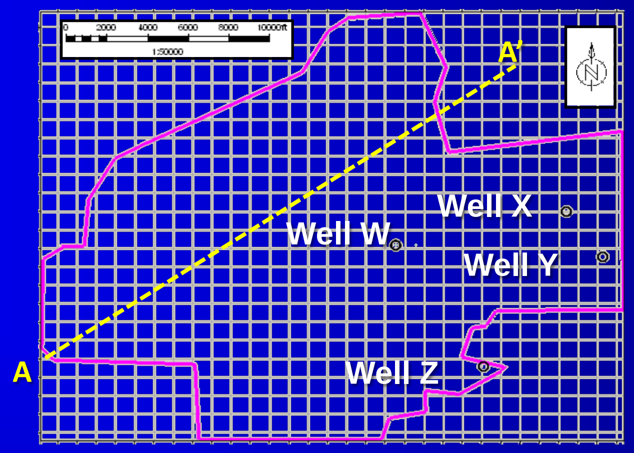
Magnetic tilt derivative map

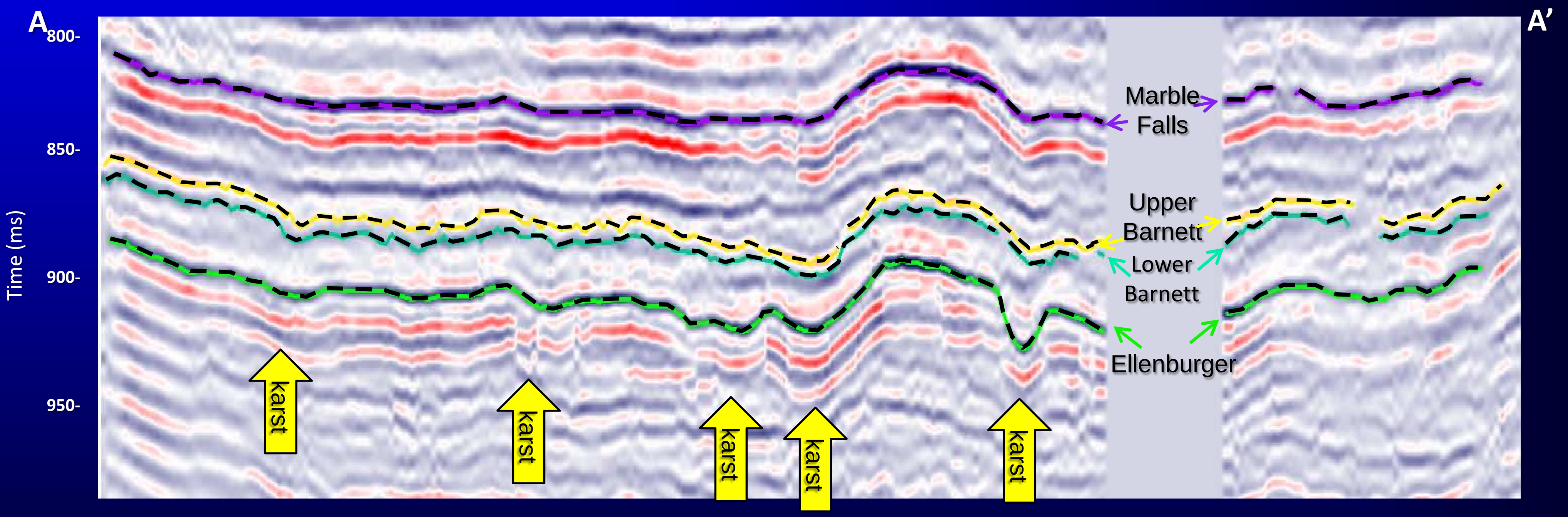
(Pollastro, 2007)

(Baruch et al., 2009)

Understaning the Ellenburger karstified topography







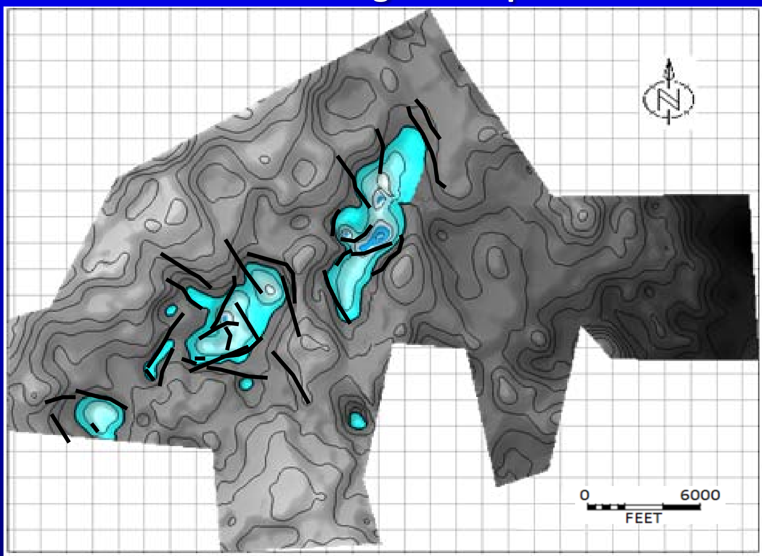
(Baruch , 2009)

Time-Structure Maps of Shale Sequencies

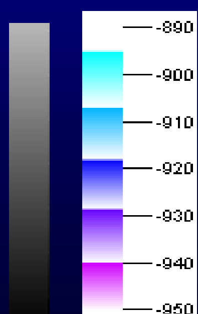
With fault interpretation

Faults and Fracture distribution within a Paleocave Collapse

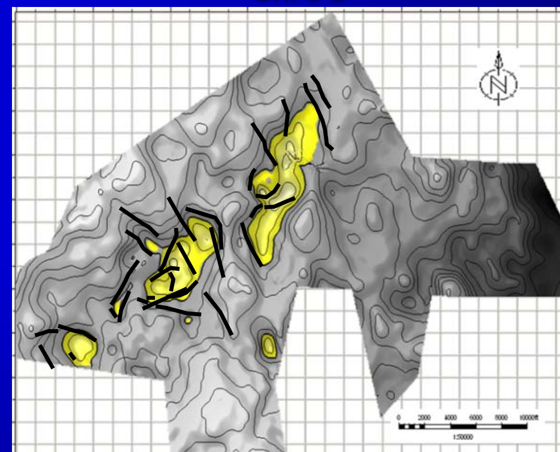
Ellenburger Group



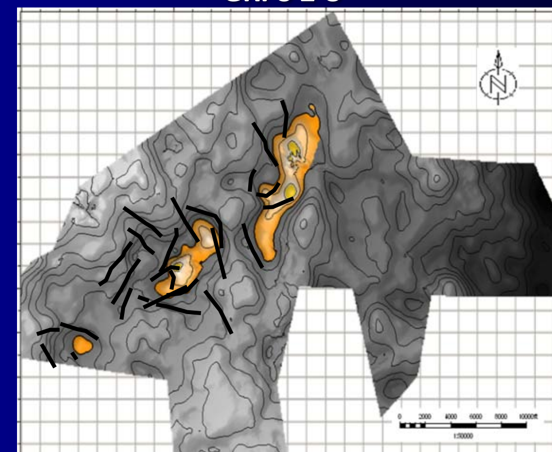
Time (ms)



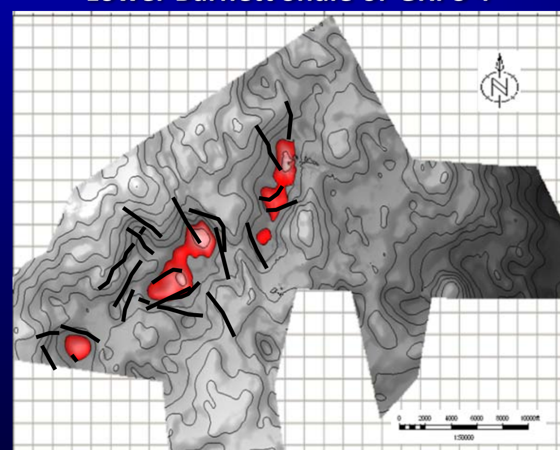
GRPS 1



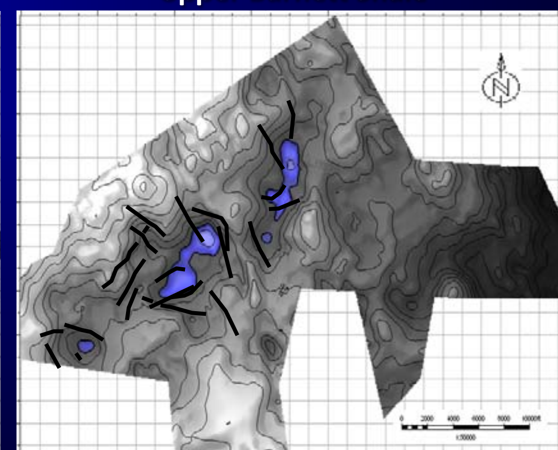
GRPS 2-3



Lower Barnett Shale or GRPS 4

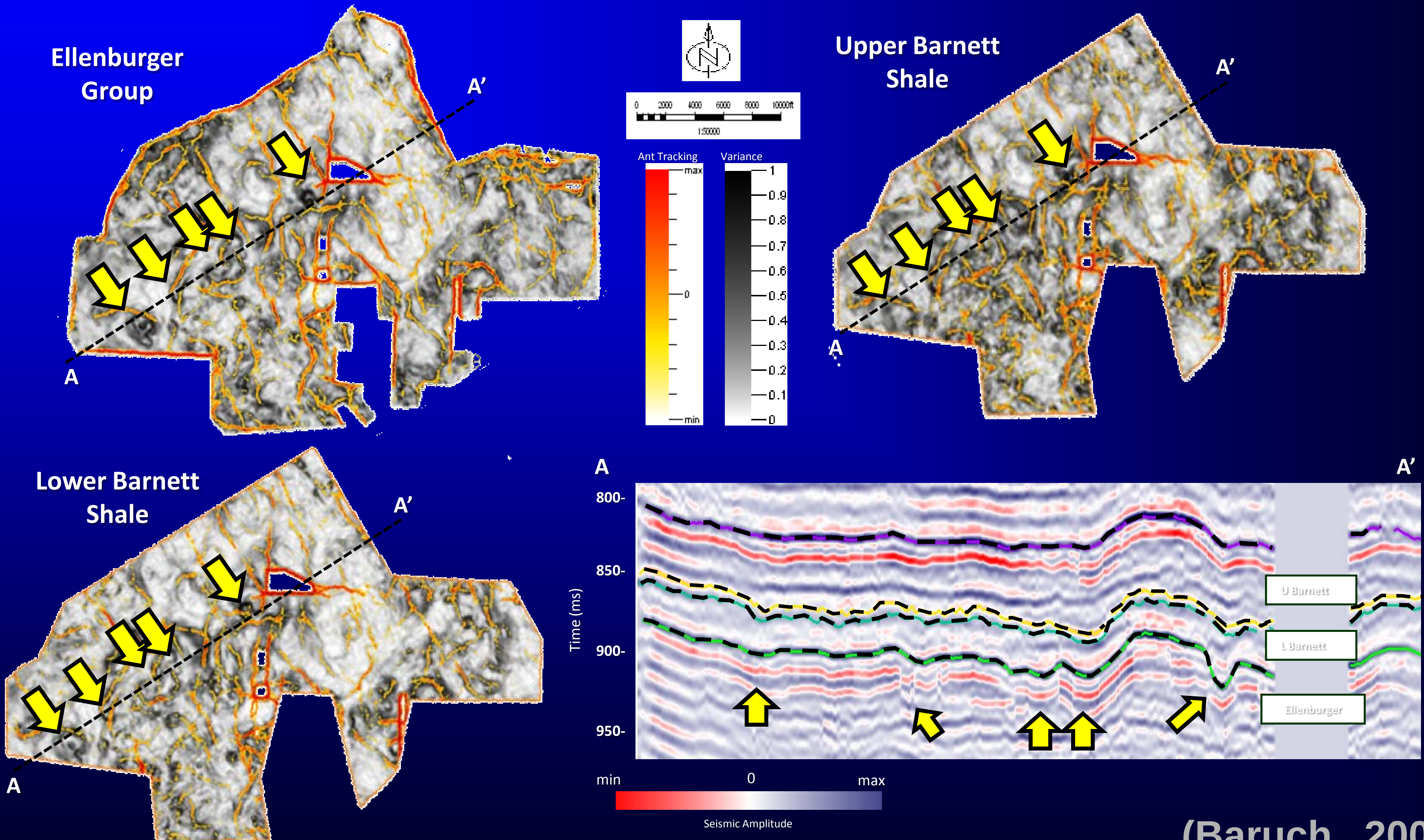


Upper Barnett Shale



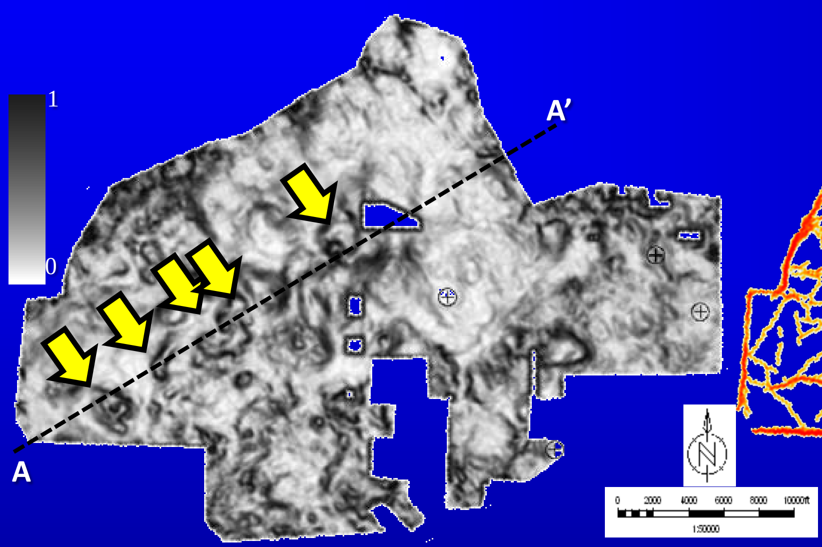
(Baruch , 2009)

Ant Tracking over Variance

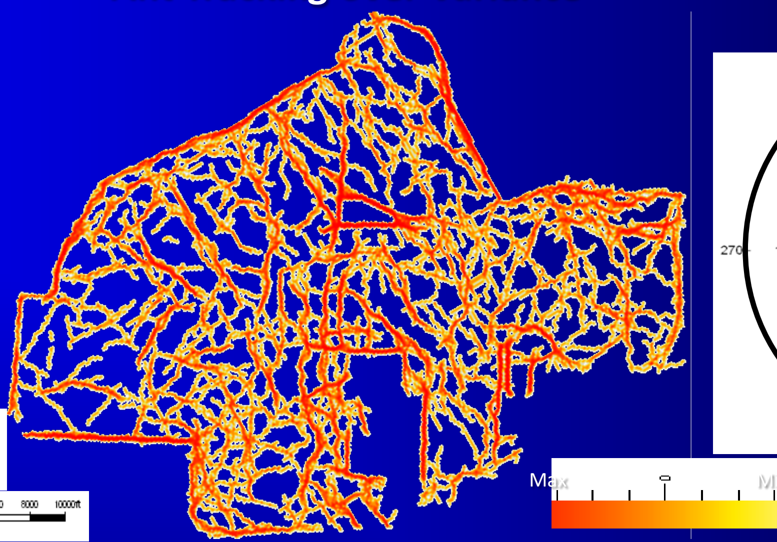


(Baruch , 2009)

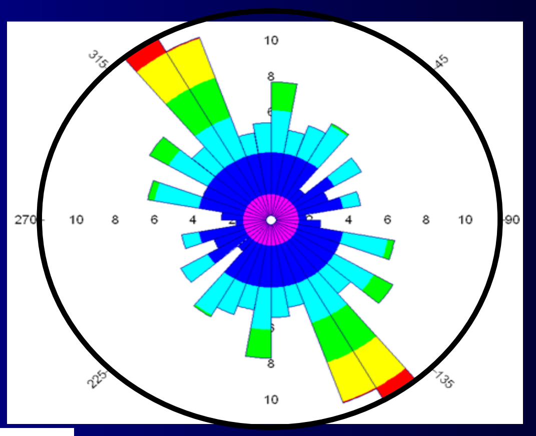
Variance



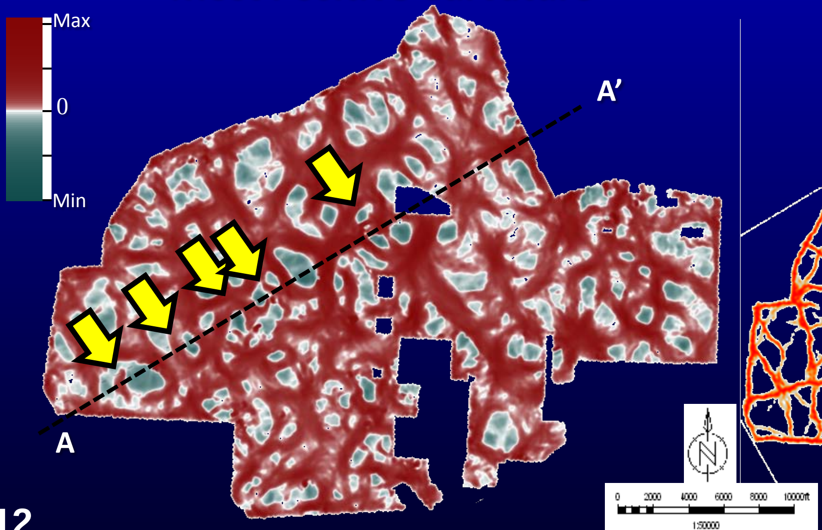
Ant Tracking over Variance



Rose Diagram



Most Positive Curvature



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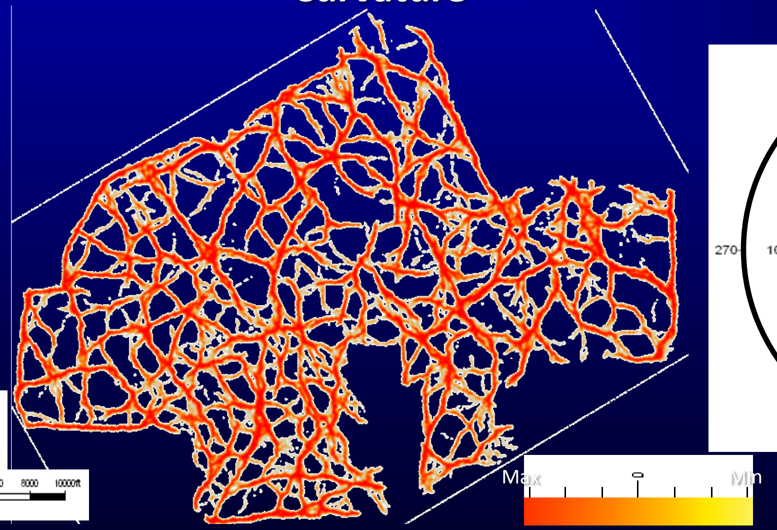
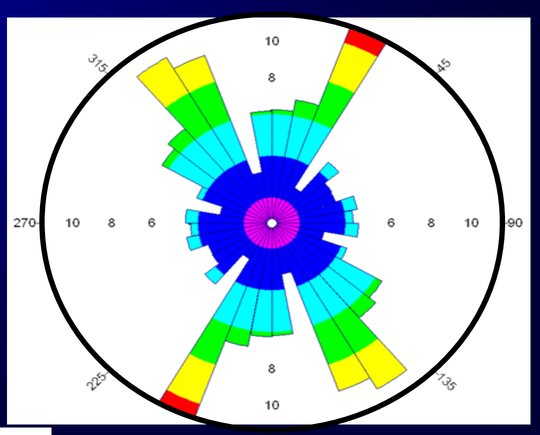


Rose Diagram



(Baruch , 2009)

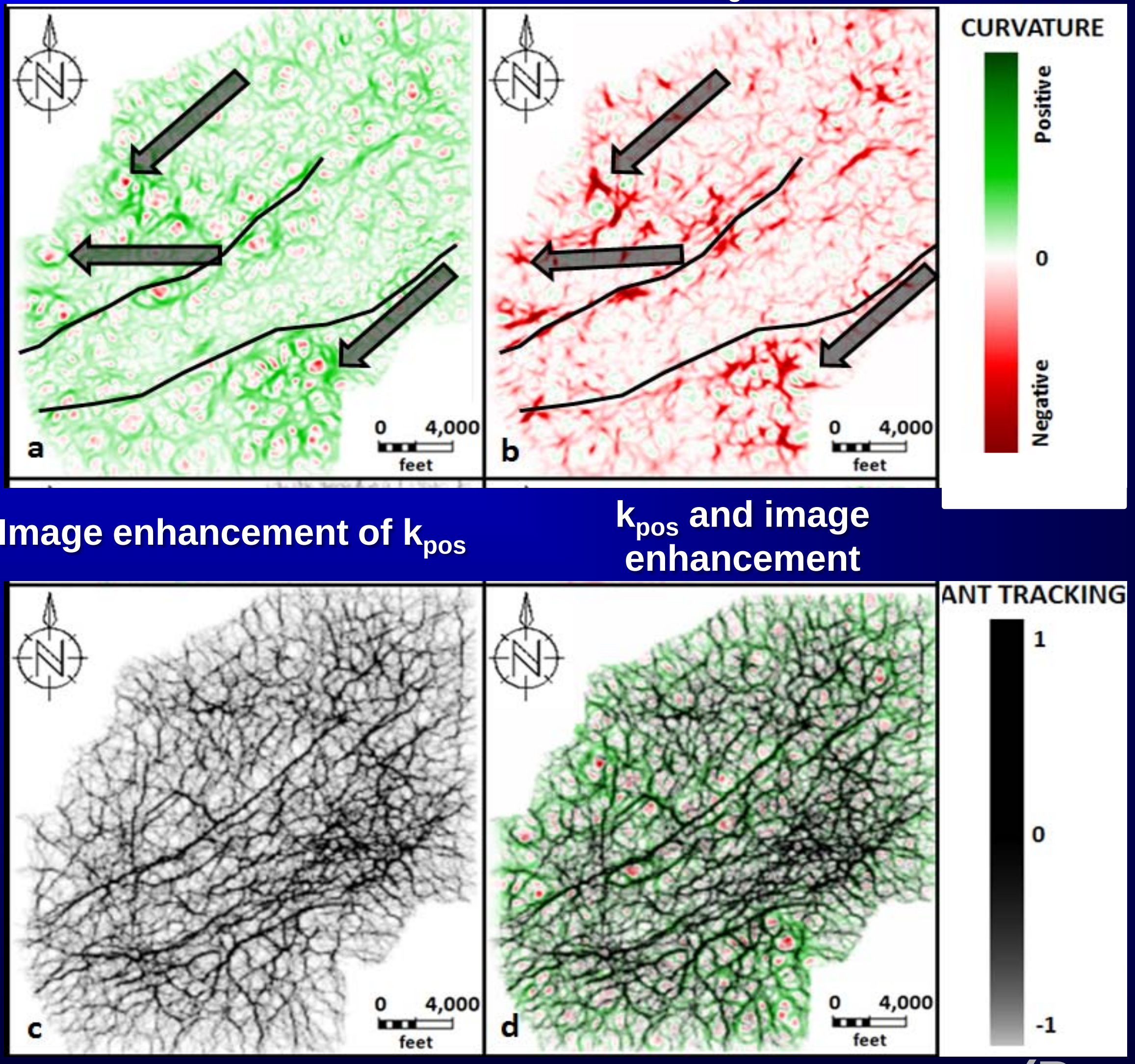
Curvature on Viola Limestone

Most-positive curvature, k_{pos}

Most-negative curvature, k_{neg}

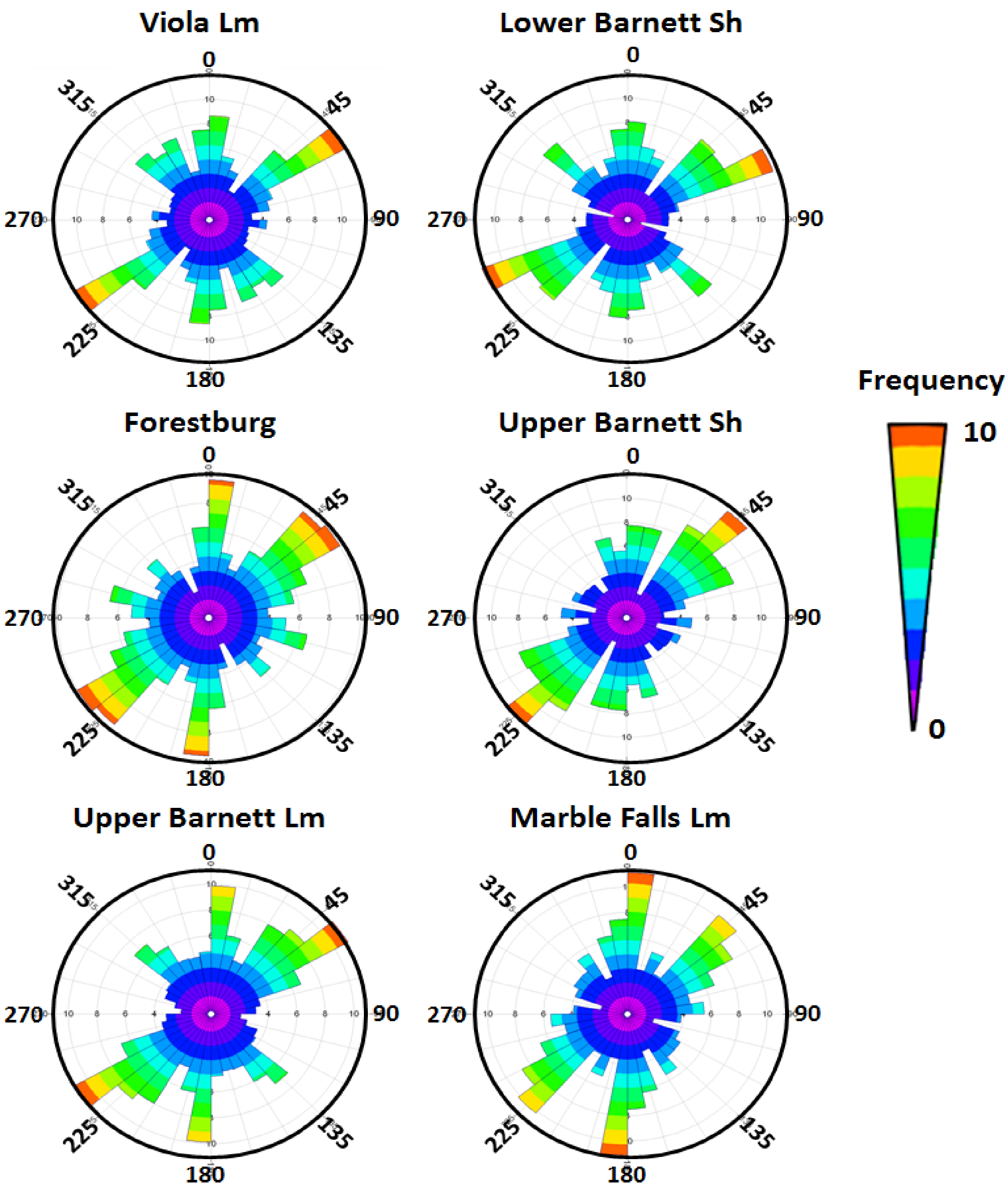
Image enhancement of k_{pos}

k_{pos} and image enhancement



(Perez , 2009)

Curvature lineaments at each horizon

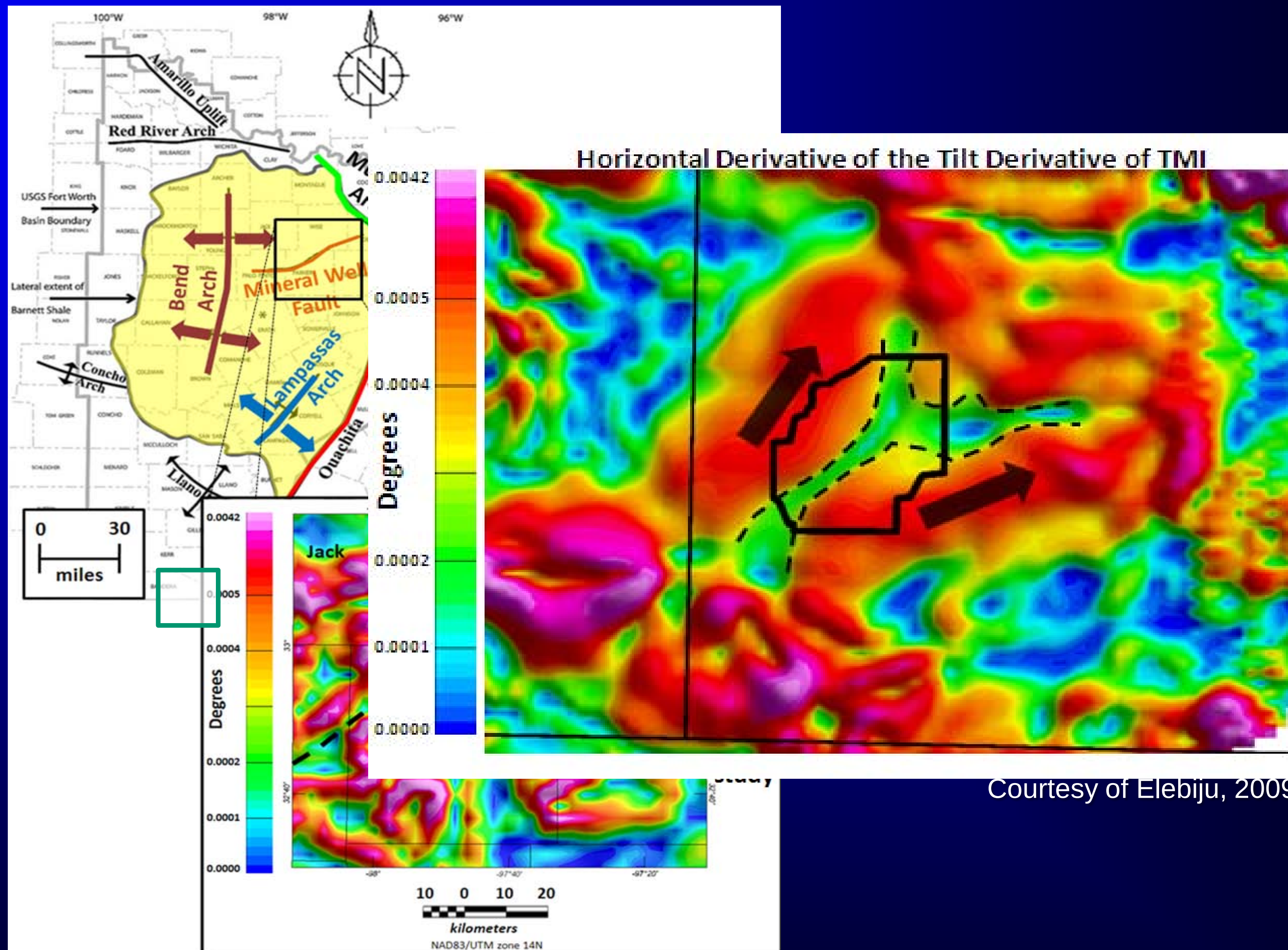


Stratigraphic column

AGE	Group or Form.
CRETACEOUS	Caddo Fm.
PERMIAN	
PENNSYLVANIAN	Marble Falls
MISSISSIPPIAN	Barnett Shale
ORDOVICIAN	Viola Lm. Simpson Group Ellenburger Group
CAMBRIAN	
PRECAMBRIAN	Basement

(Perez , 2009)

GEOLOGY BACKGROUND



Courtesy of Elebiju, 2009

(Perez , 2009)

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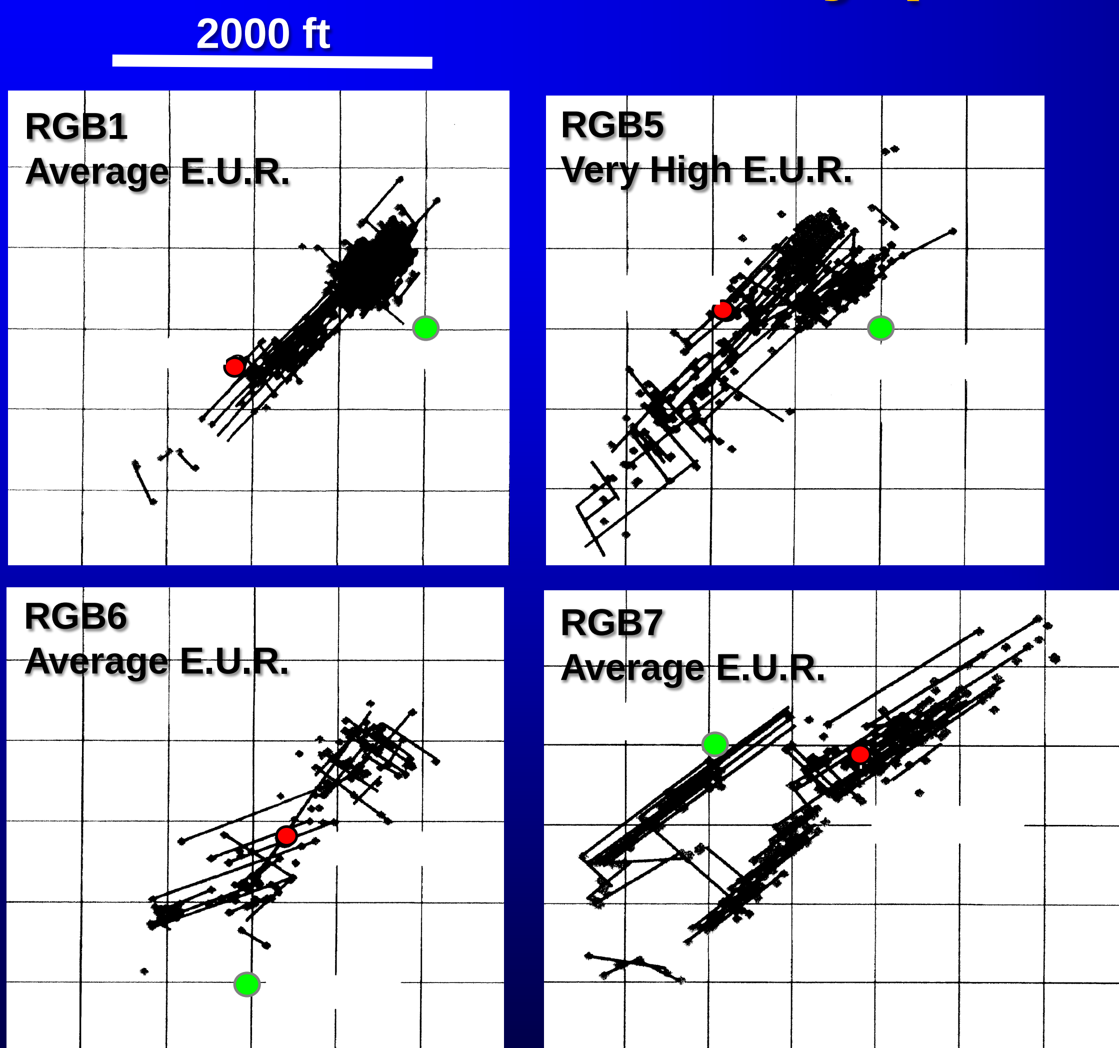
Induced fractures versus expected ultimate recovery (E.U.R.)

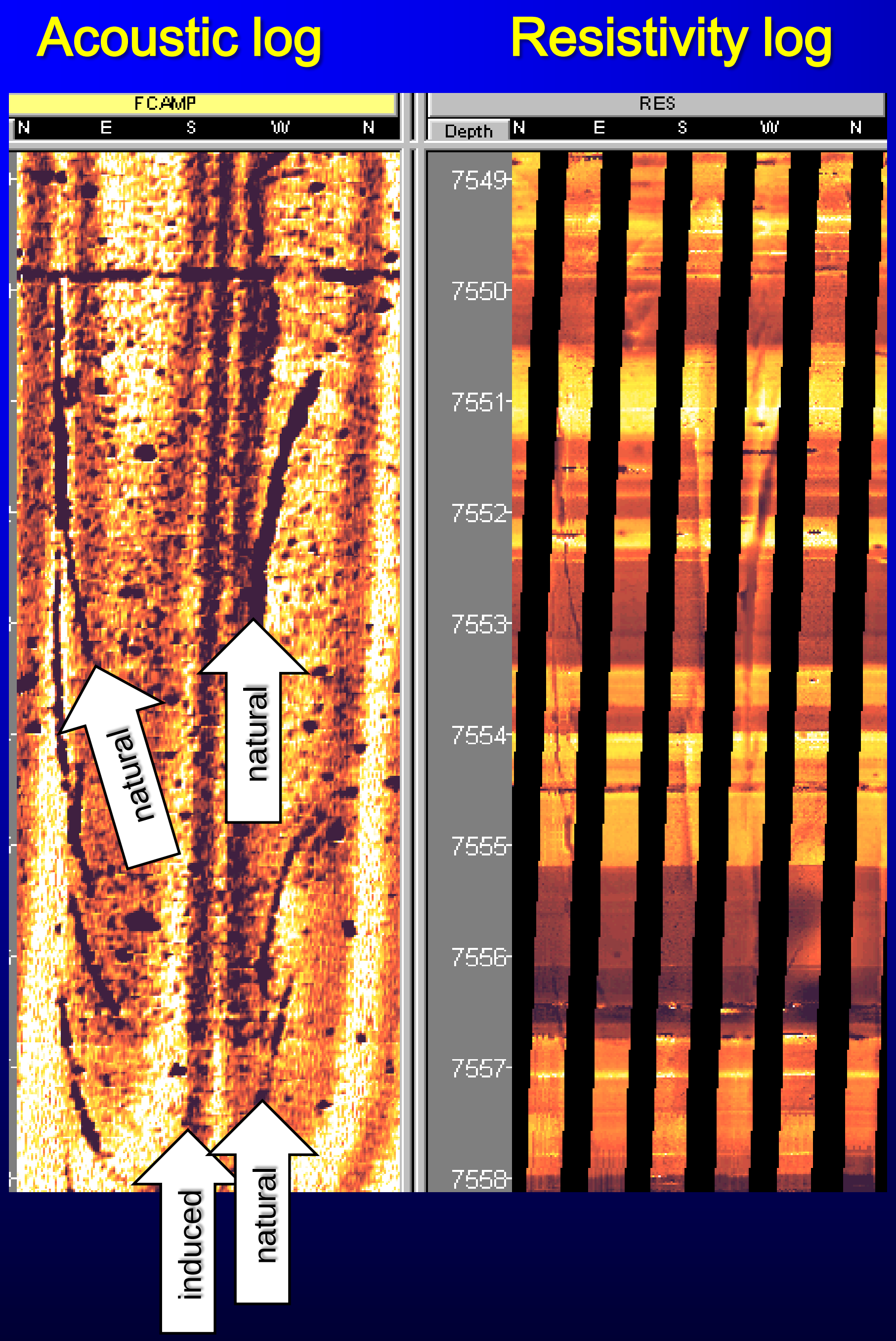


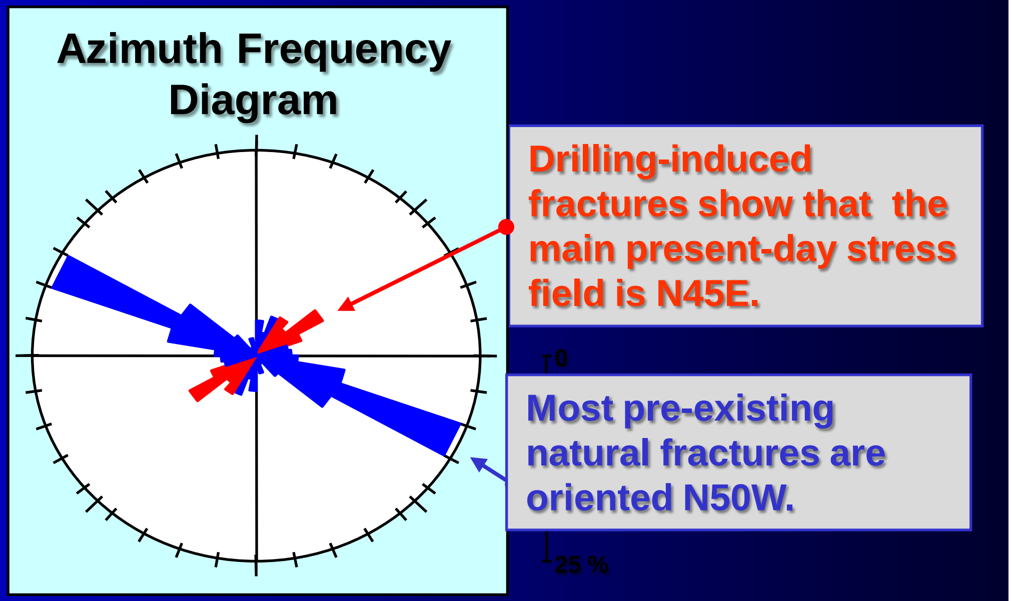
Injection wells

Observation wells

Micro-Seismic studies suggest that large E.U.R. depends on creation (by hydrofractures) of large network of multi-azimuth vertical fractures

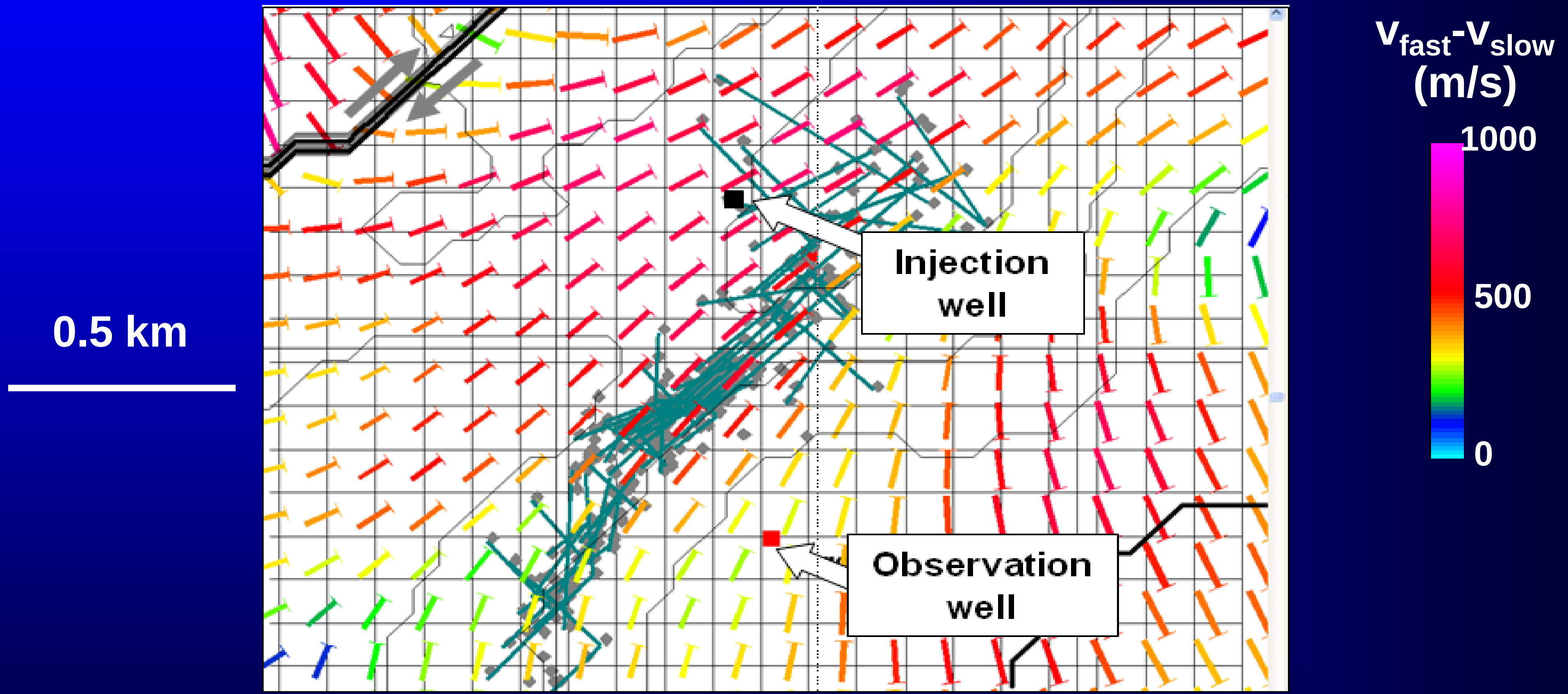
(Simon, 2005)


Acoustic log
Resistivity log
FCAMP
RES
N
E
S
W
N
Depth
7549
7550
7551
7552
7553
7554
7555
7556
7557
7558
natural
natural
induced
natural


Azimuth Frequency Diagram
0
25 %
Drilling-induced fractures show that the main present-day stress field is N45E.
Most pre-existing natural fractures are oriented N50W.

(Simon, 2005)

Azimuthal velocity anisotropy vs. induced fractures (Fort Worth Basin, Texas, USA)

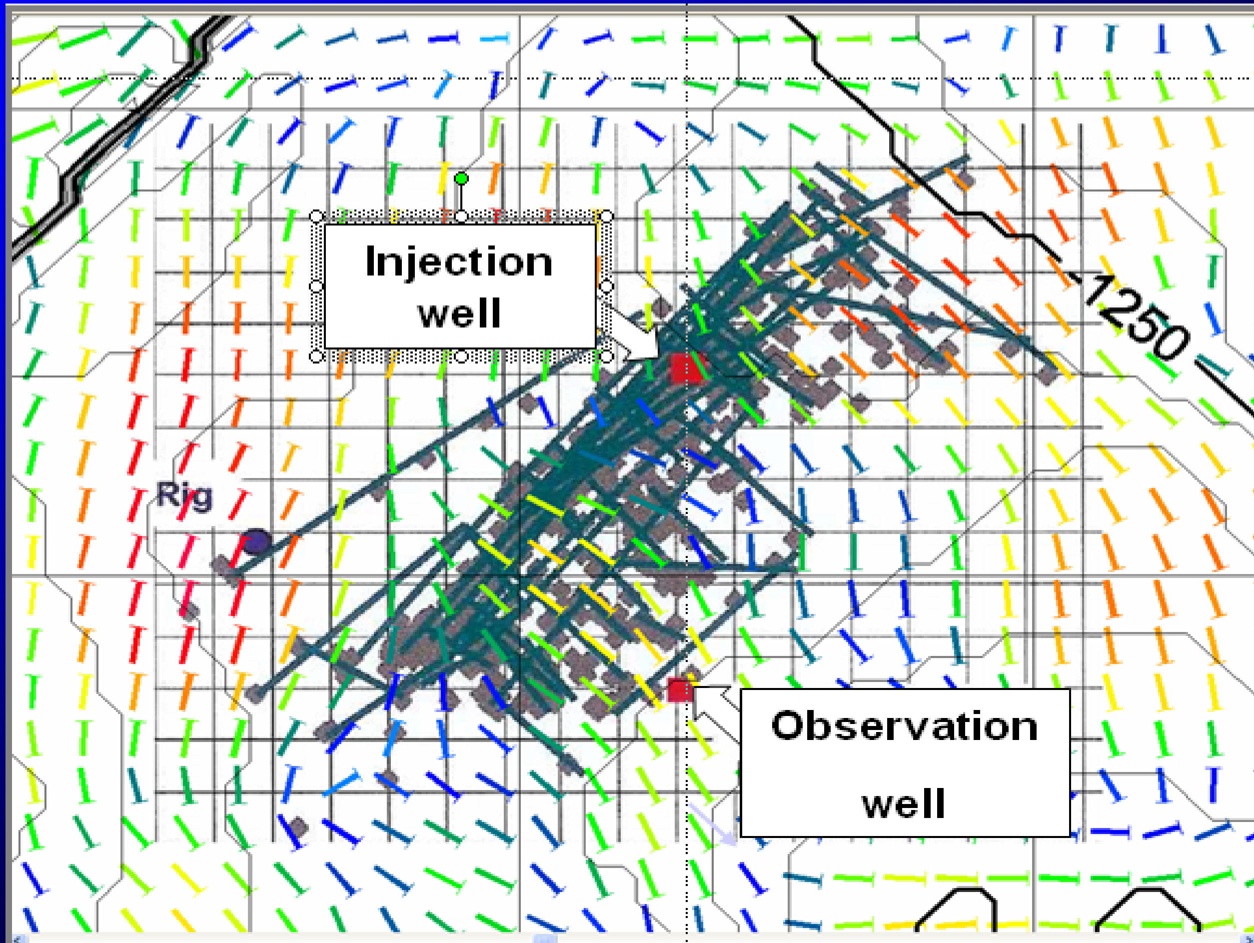


Poor well (fractures parallel)

(Simon, 2005)

Azimuthal velocity anisotropy vs. induced fractures (Fort Worth Basin, Texas, USA)

0.5 km

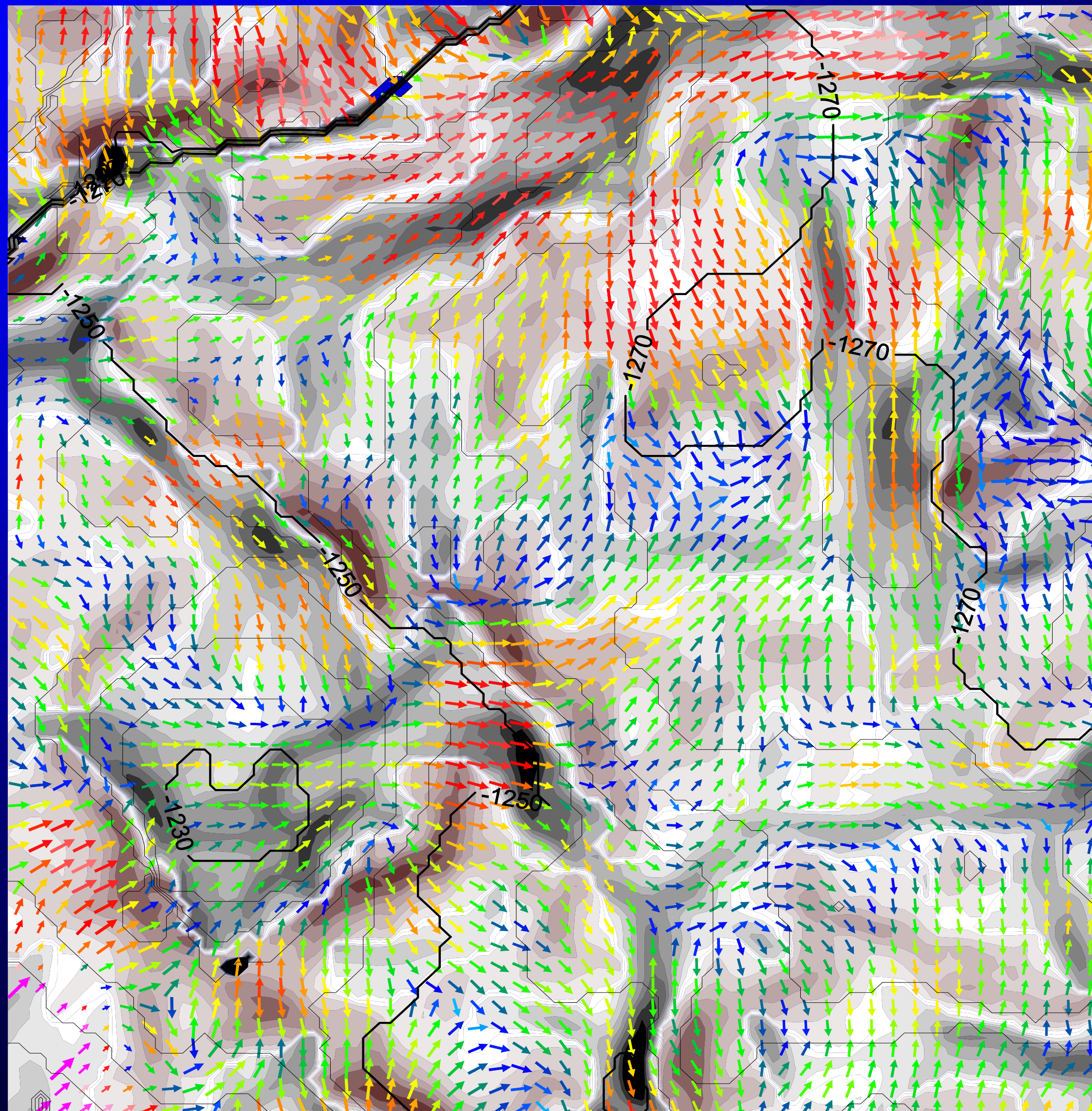


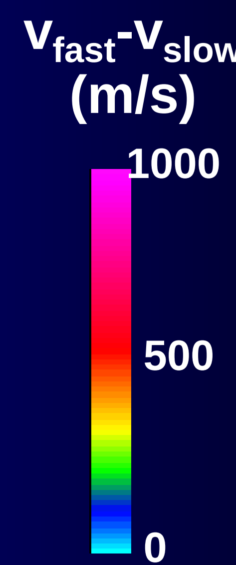
Good well (orthogonal fracture sets)

(Simon, 2005)

Azimuthal velocity anisotropy vs. most positive curvature (Fort Worth Basin, Texas, USA)

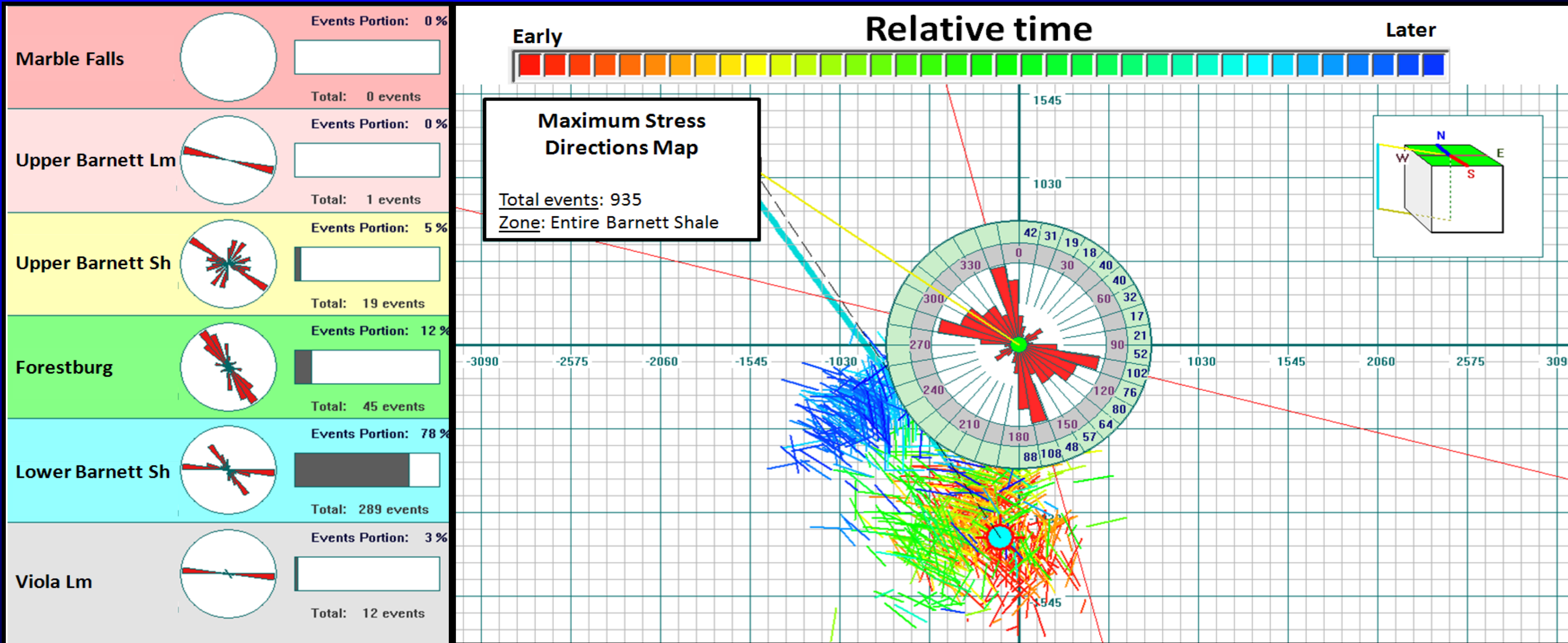
1 km





(Simon, 2005)

Curvature and microseismic?



Minimum Stress Direction Map of Microseismic events

(Awasekien , 2009)

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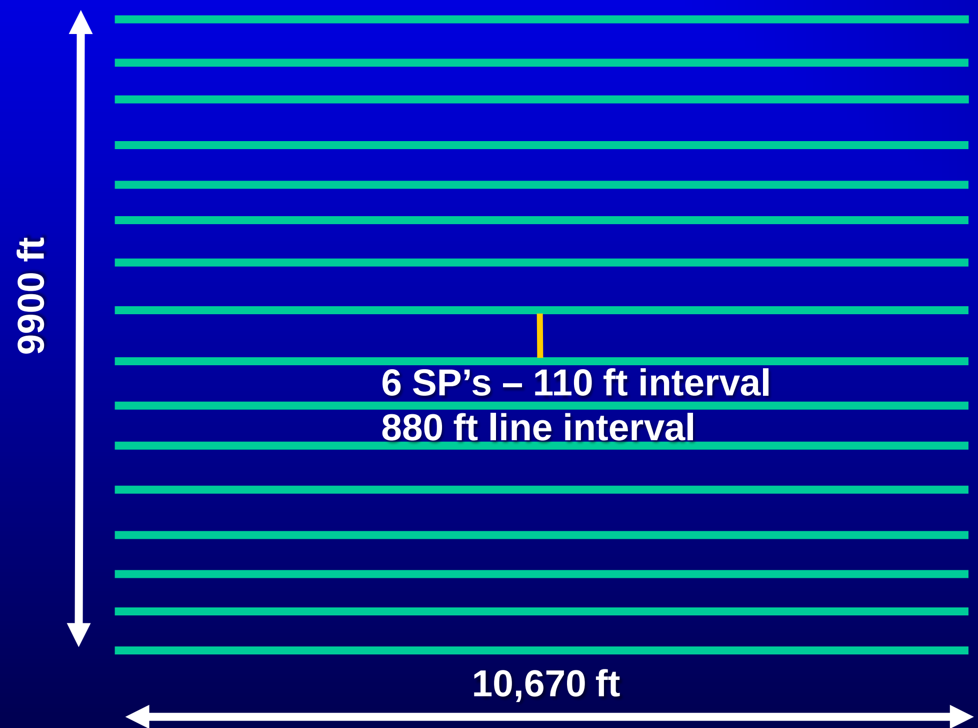
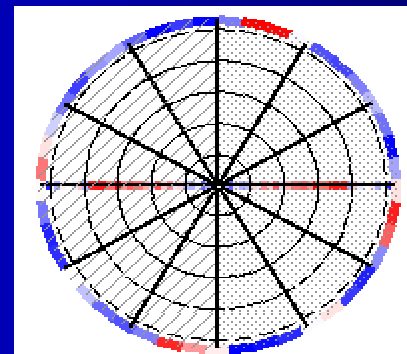
Azimuthal AVO:

~ 75 Square miles
16 receiver lines, 98 channels each,
21,750 SPs (290 / sq mi)
29,100 Rcvr Stns (388 /sq mi)
30 fold

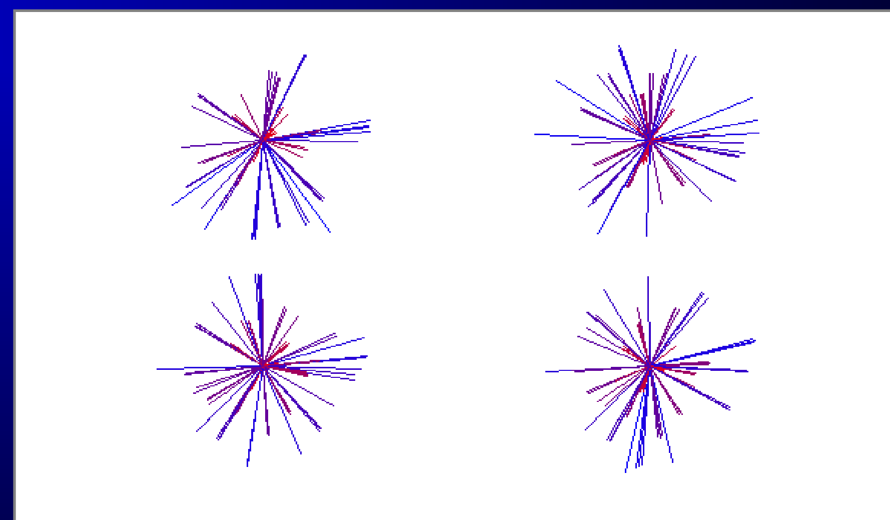


Acquisition parameters



6 sectors
250 ft offset classes
sector fold of 20
110 by 110 ft bins

13% empty bins

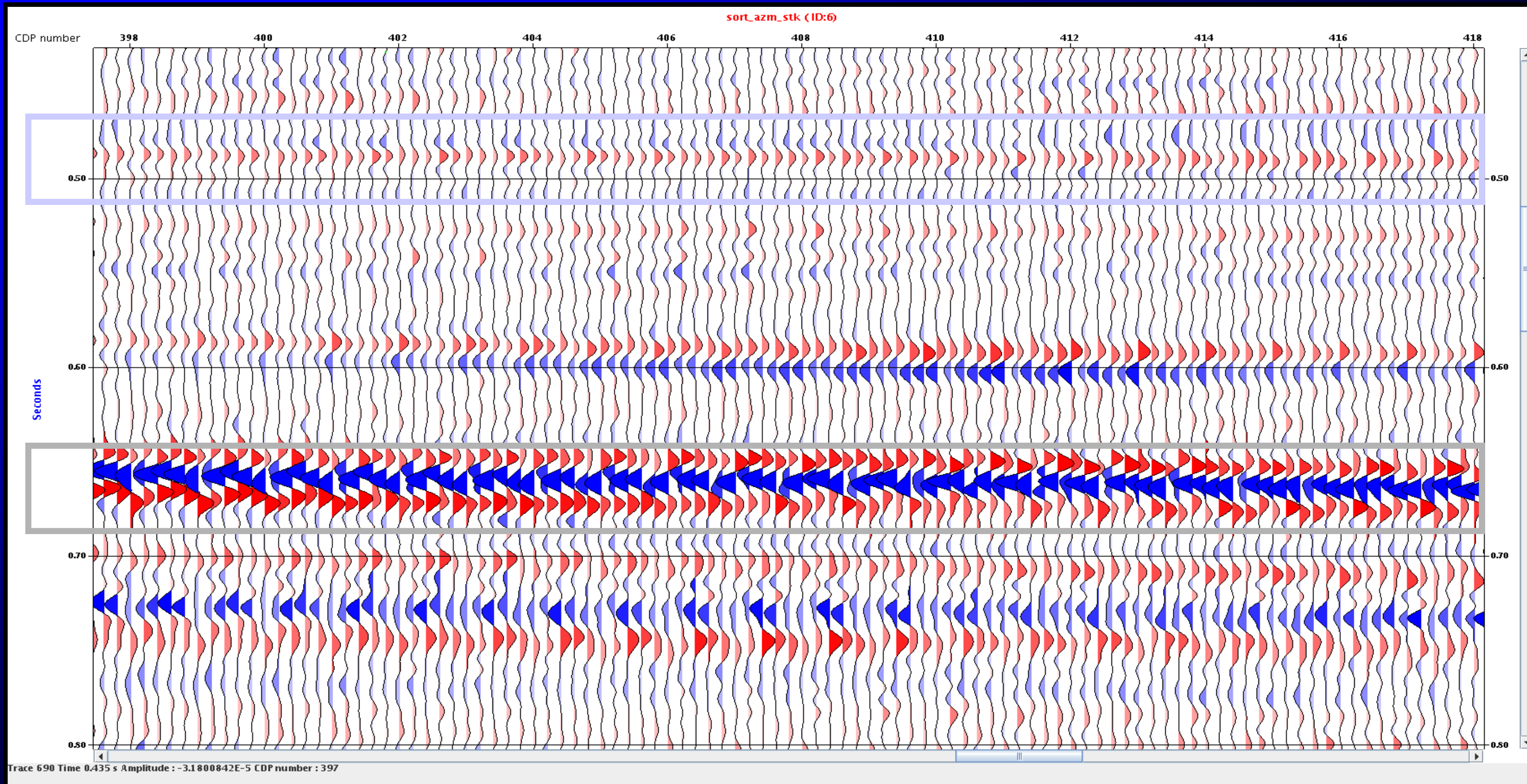


Spider plots

(Roende et al., 2008)

Stacked azimuth sector gathers

Anisotropy indicators



1 AZM Gather

Data aligns

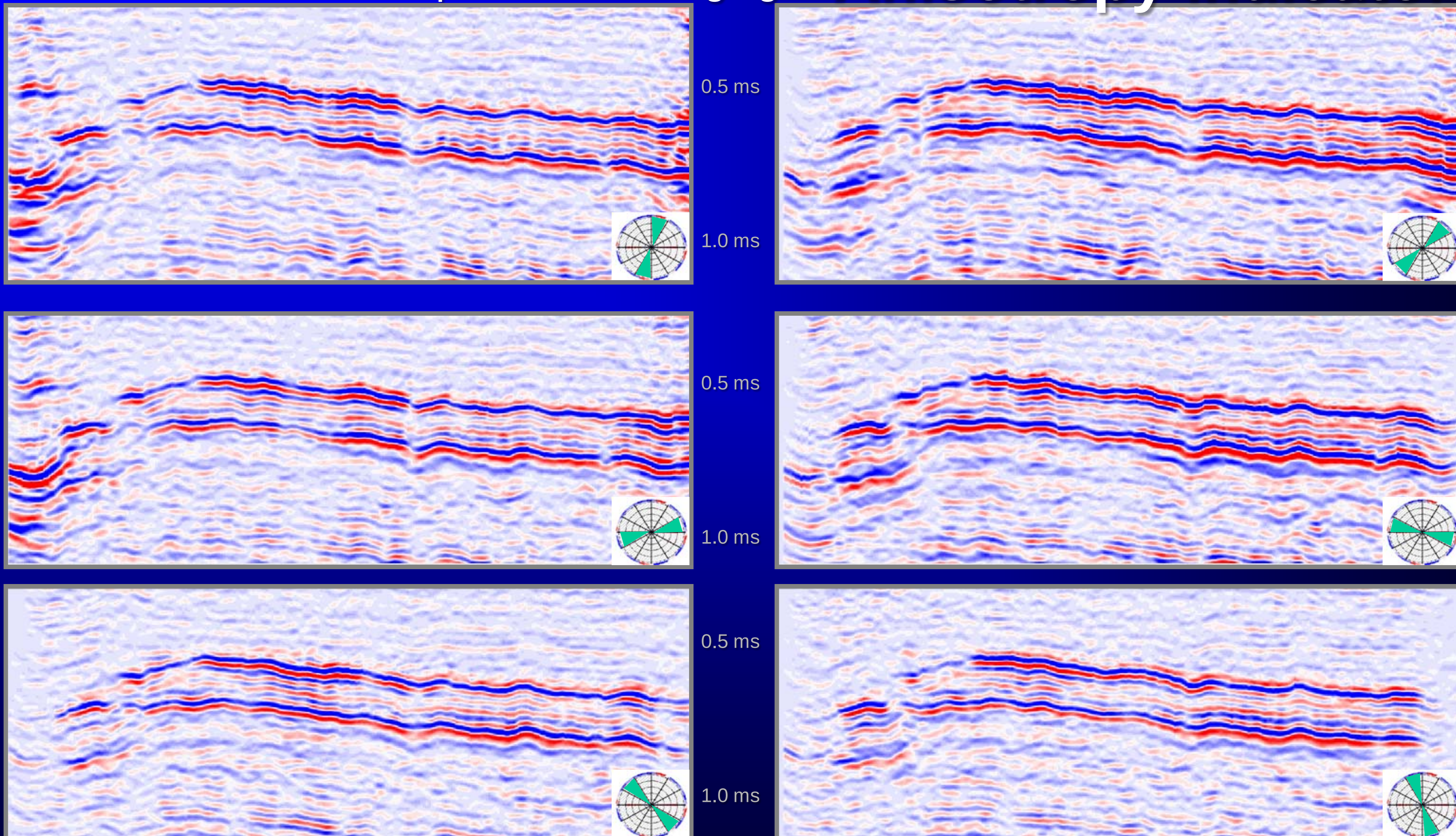
Data Jitters

(Roende et al., 2008)

6 Migrated Sectors:

NOTE differences in amplitude and imaging

Anisotropy indicators

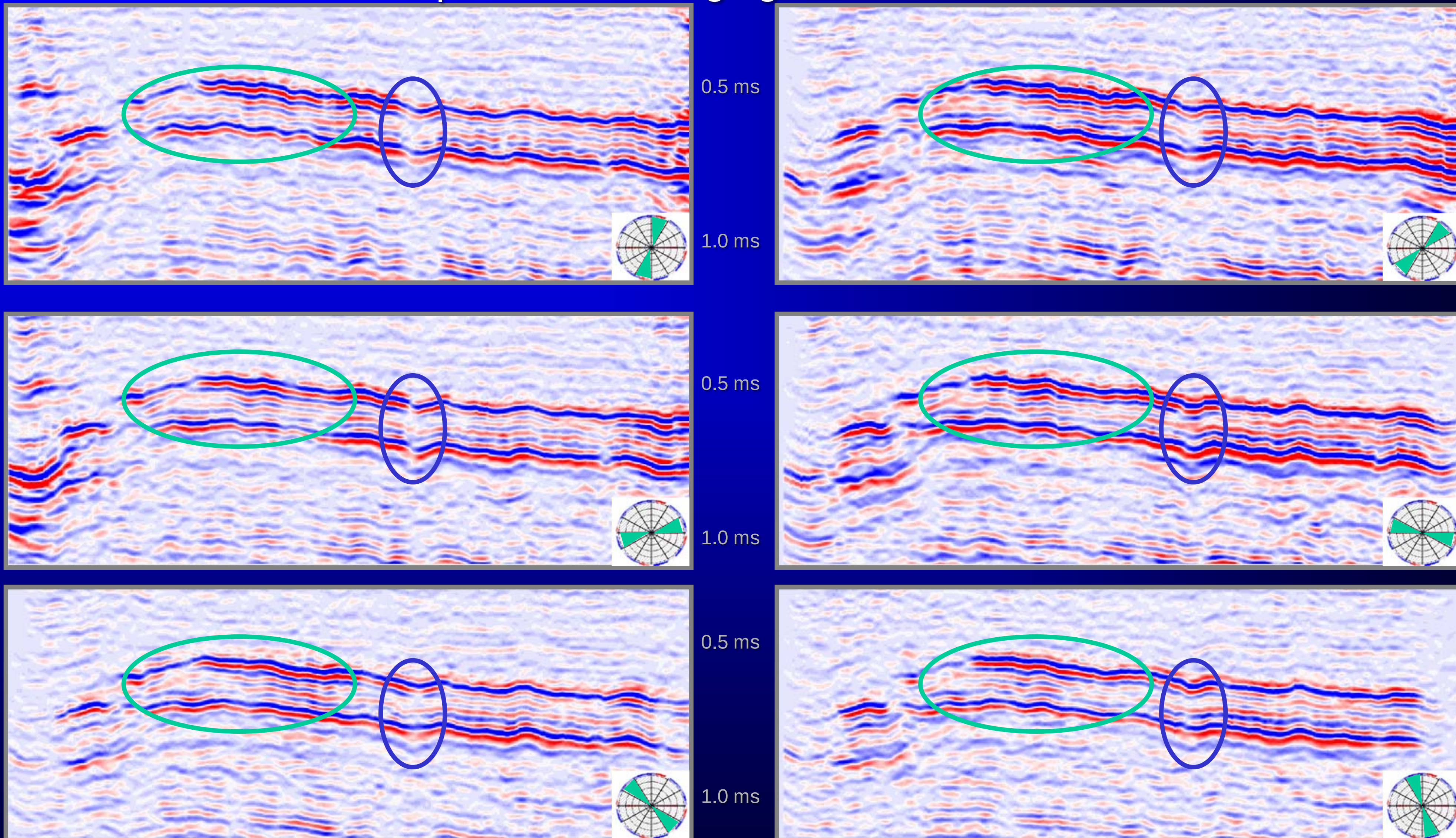


1 mile

(Roende et al., 2008)

6 Migrated Sectors:

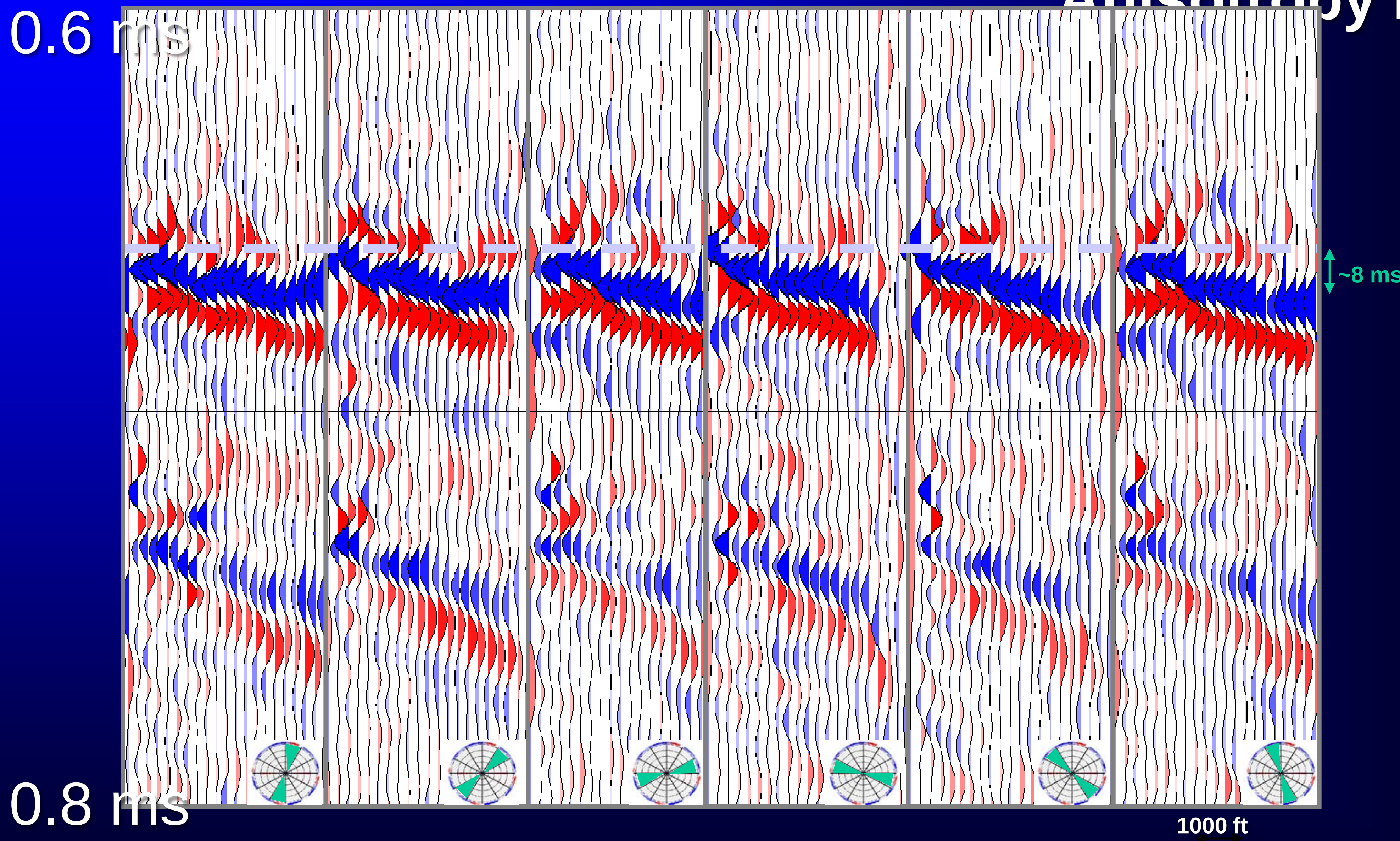
NOTE differences in amplitude and imaging



(Roende et al., 2008)

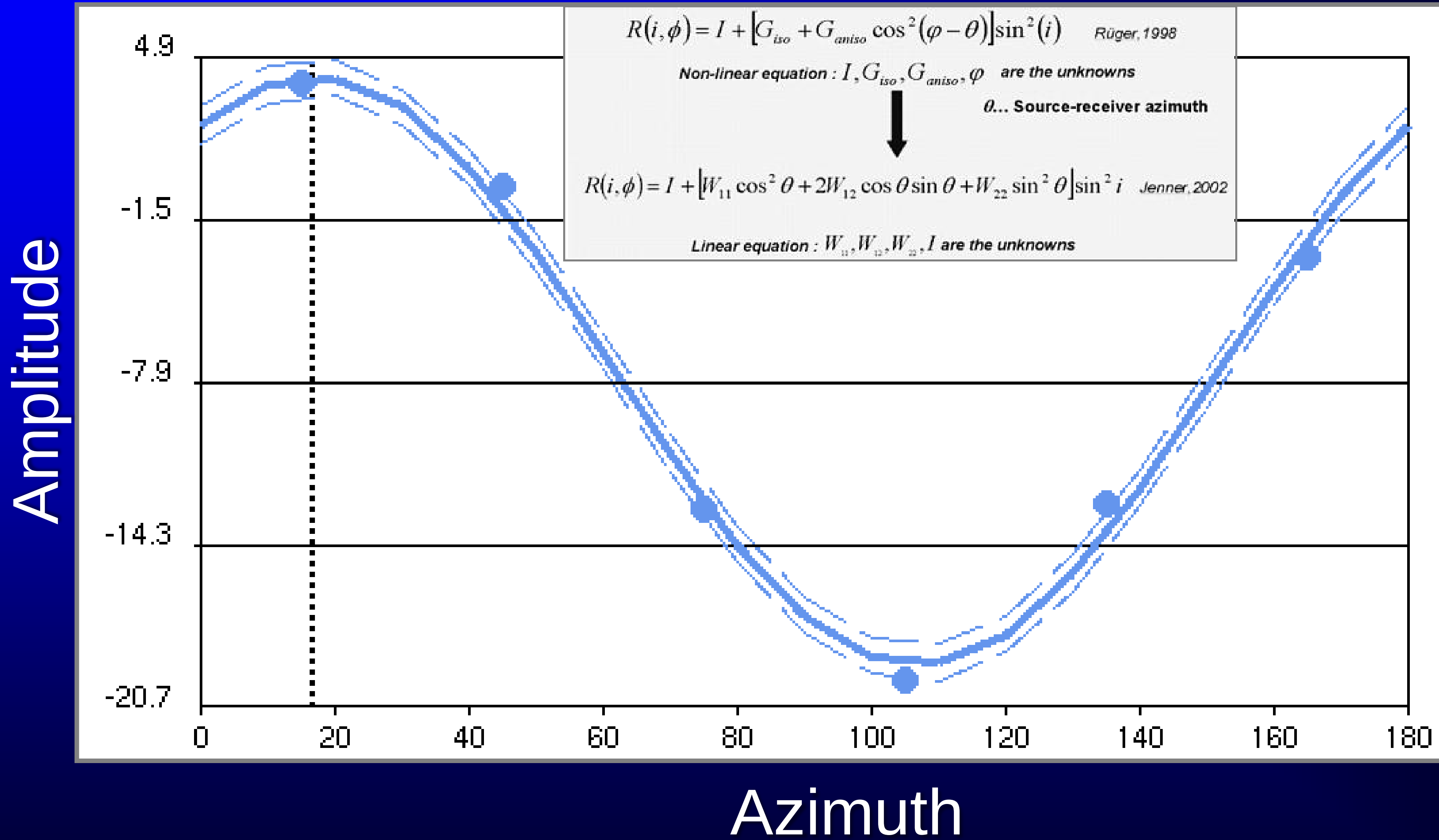
Prestack azimuth sectors

Anisotropy in



AVOZ analysis

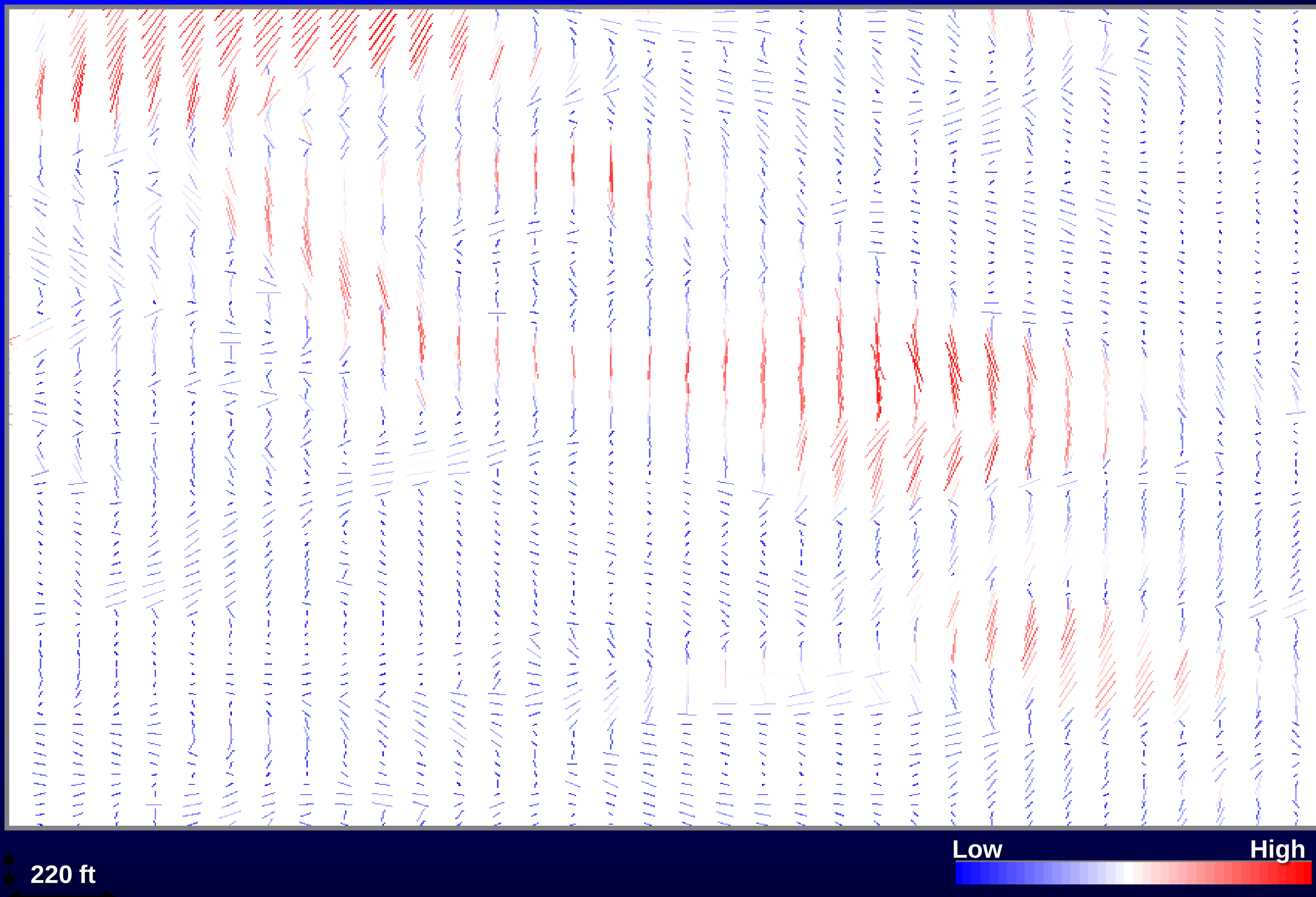
AVO



(Roende et al., 2008)

AVOZ Resulting maps

AVOZ



(Roende et al., 2008)

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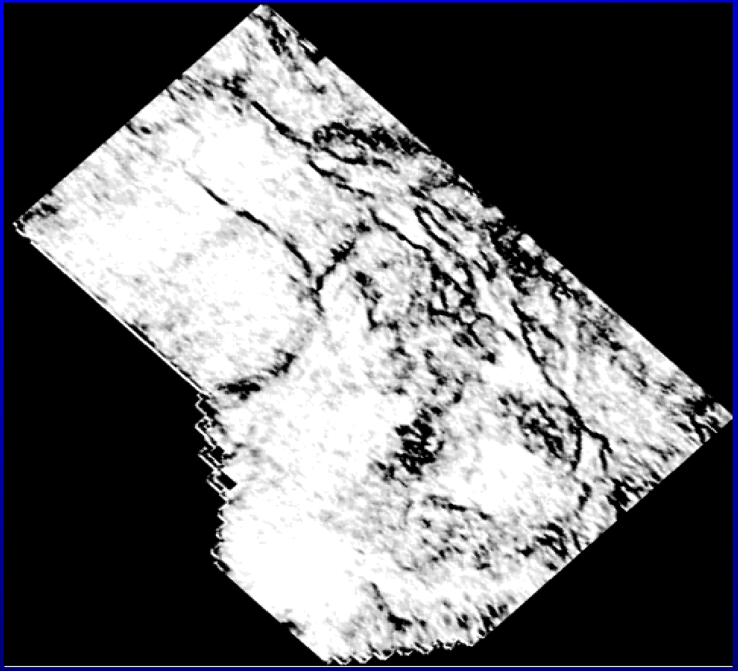
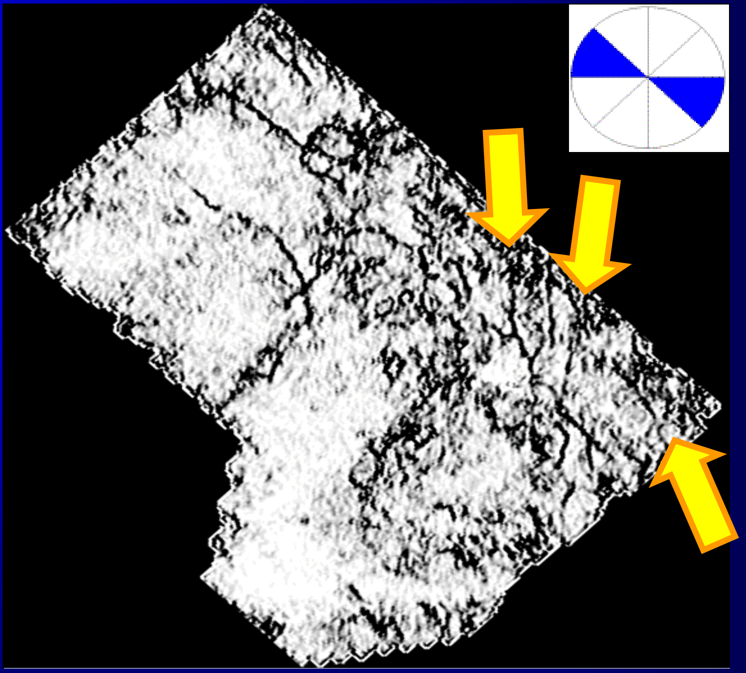
Coherence applied to Azimuthally-Limited Volumes





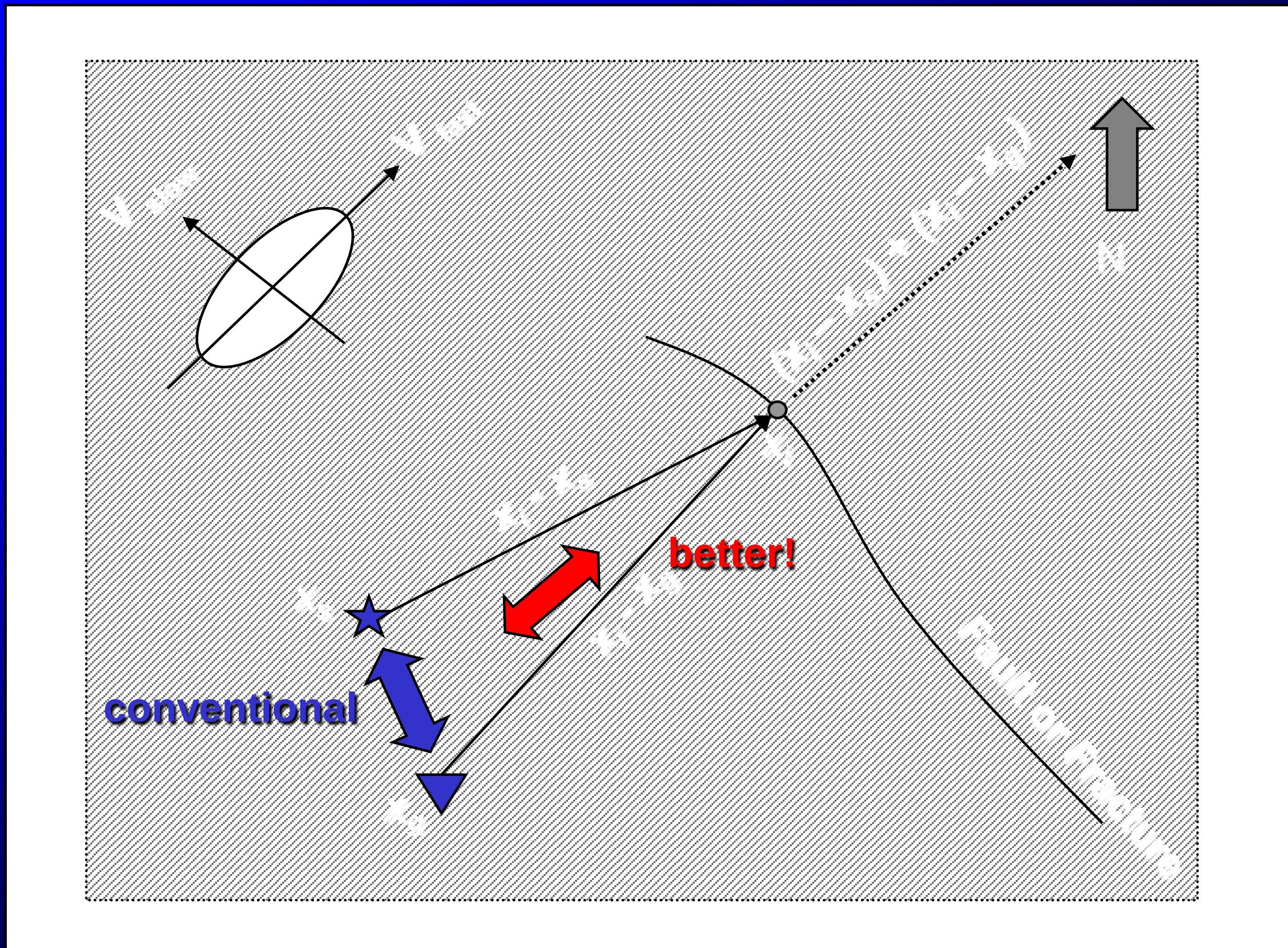
All-azimuth volume

Limited-azimuth volume

Time slices at 1.514 s

(Chorpa , 2005)

Azimuthal Binning to Better Image Fractures

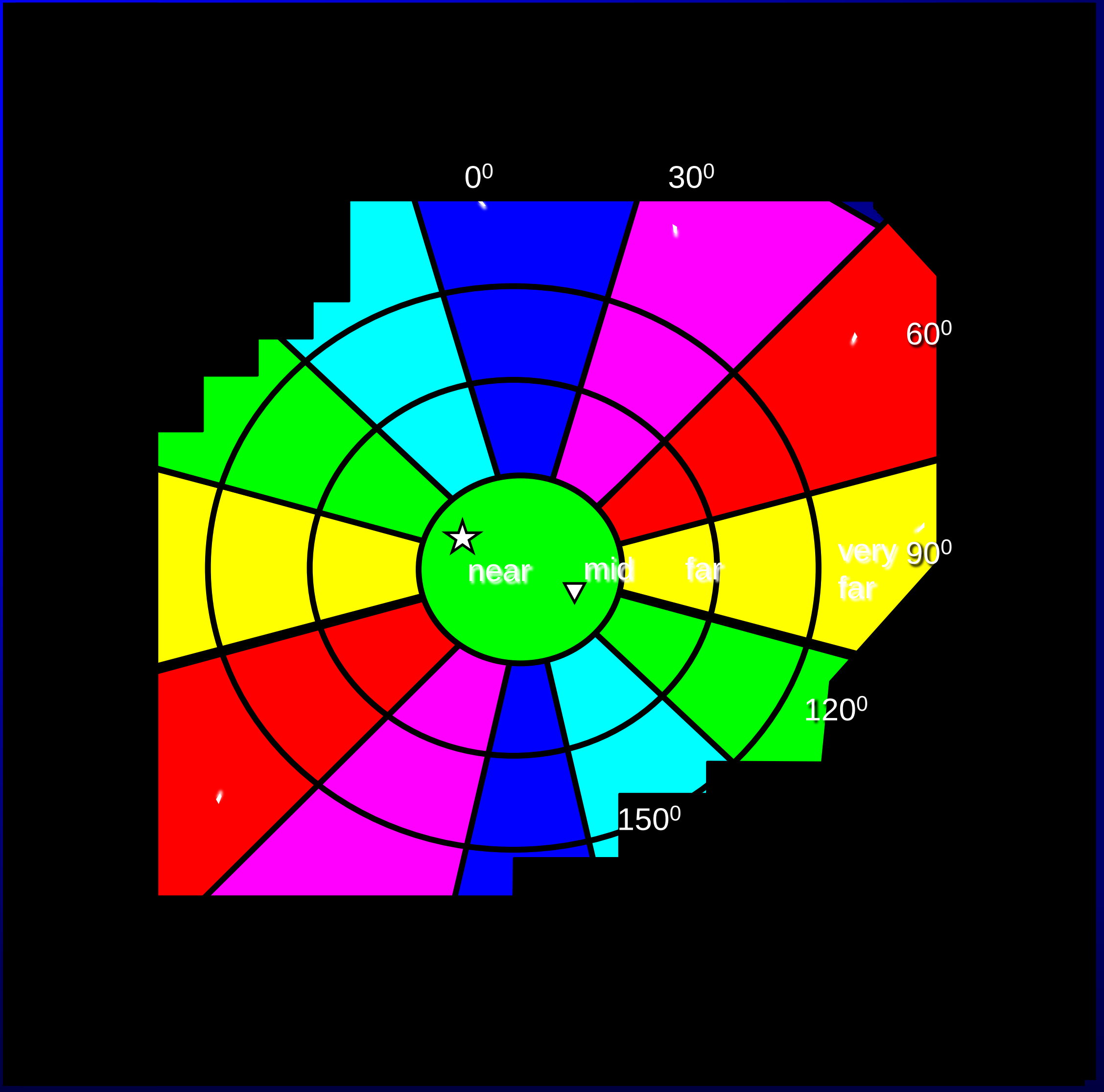


Kirchhoff migration

8-33

(Perez, 20

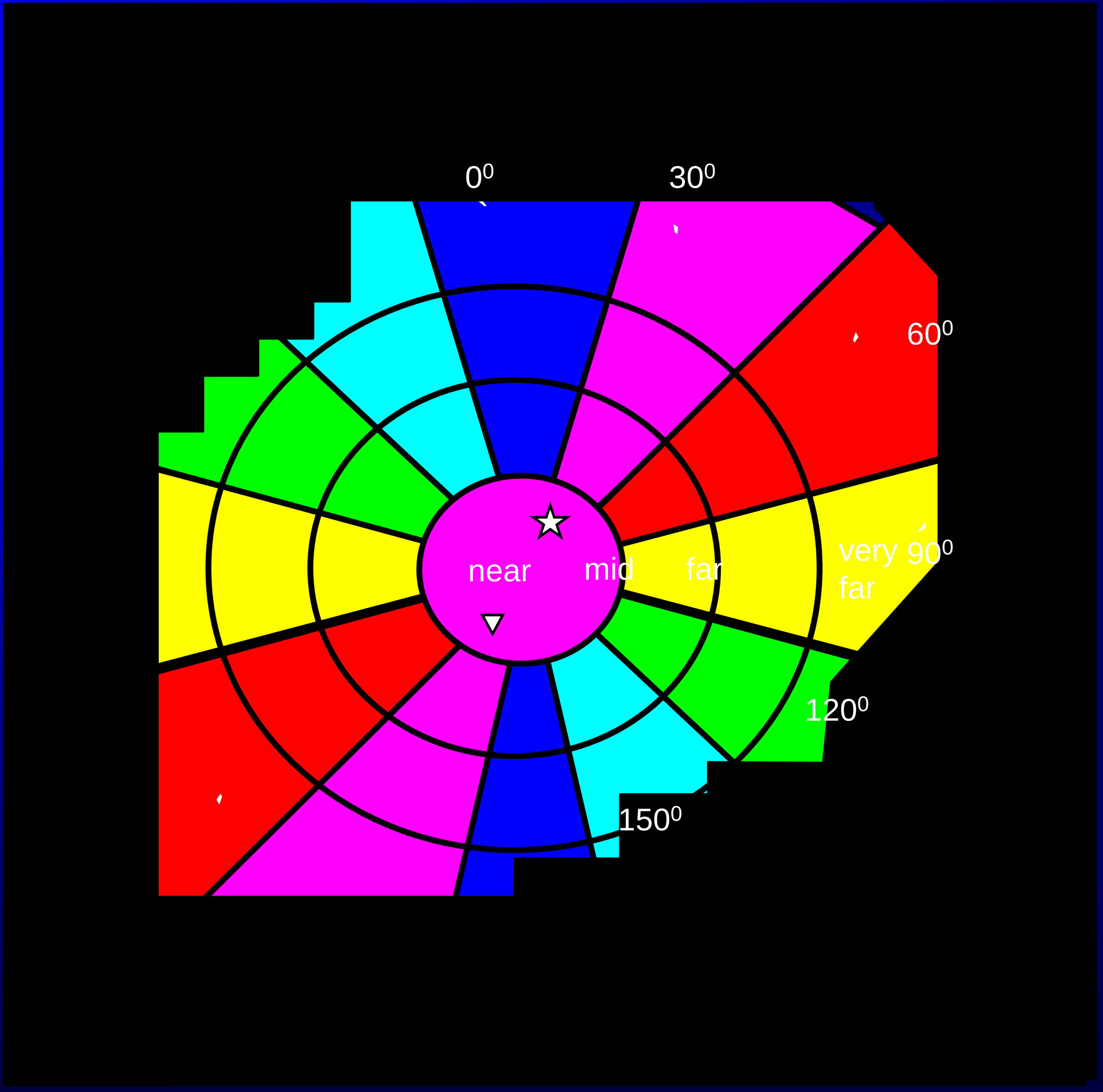
Azimuthal Binning:
Source-receiver azimuth = NW-SE



(Perez and Marfurt, 2008)

Azimuthal Binning:

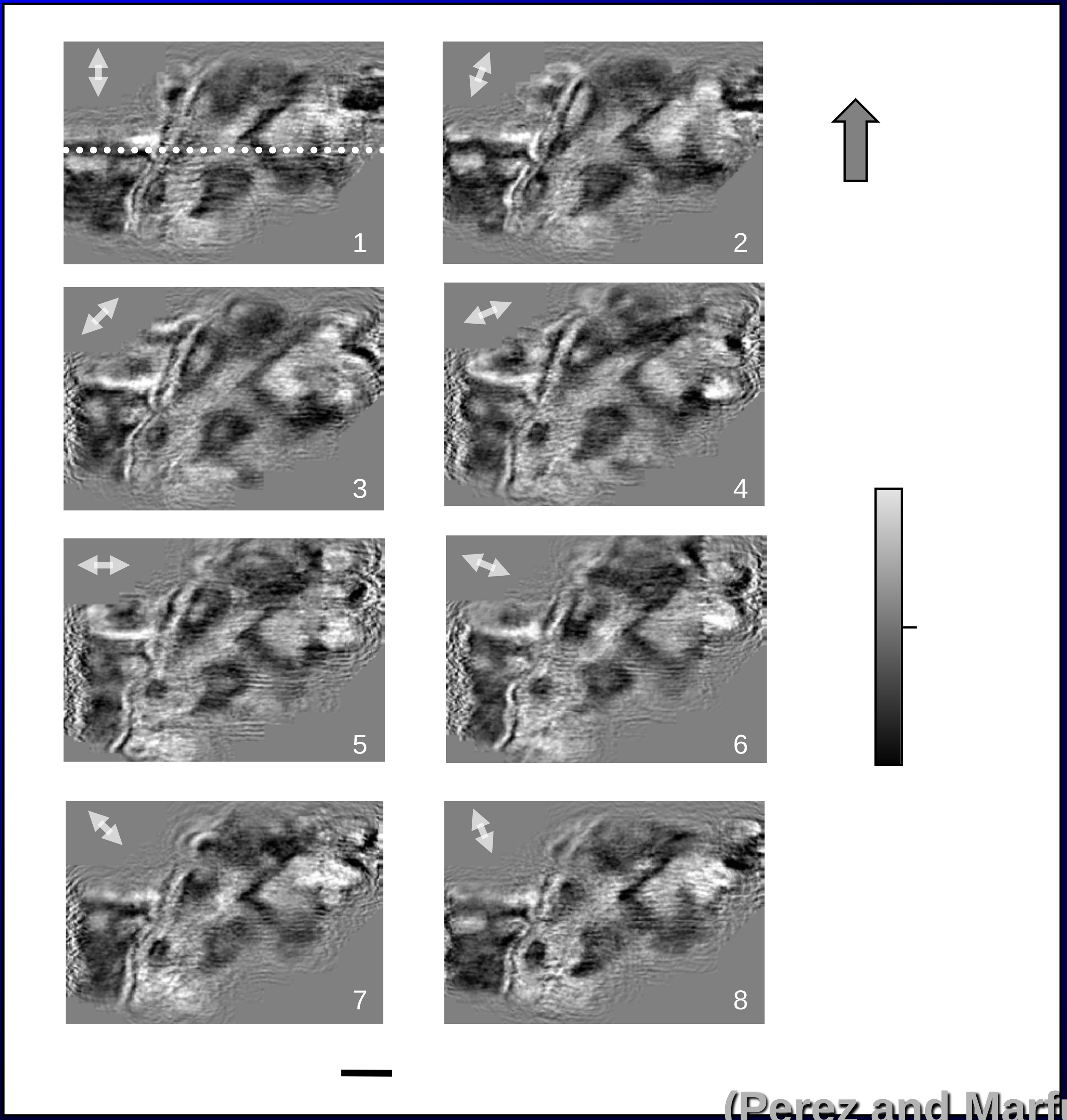
Source-receiver azimuth = NNE-SSW



(Perez and Marfurt, 2008)

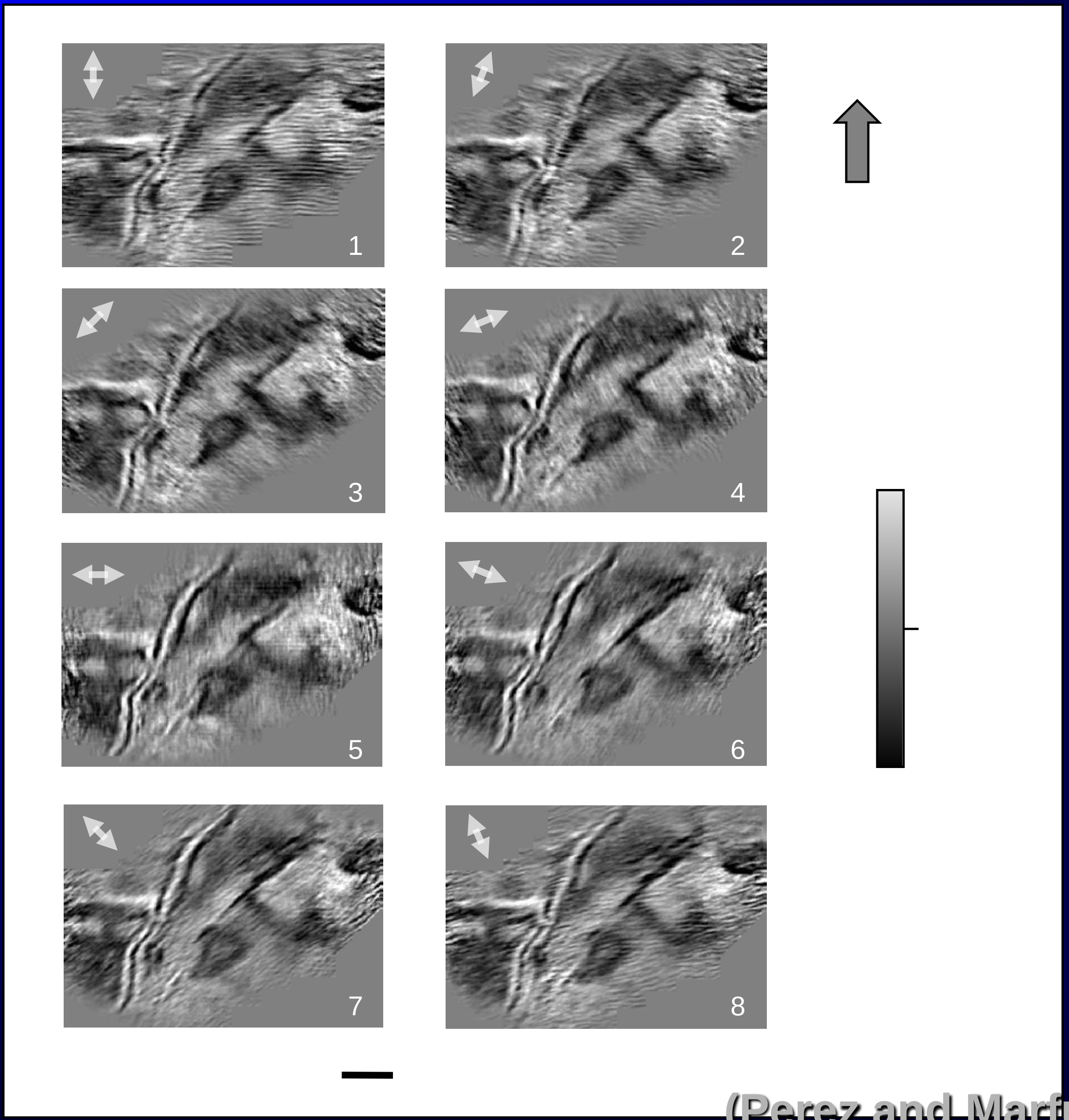
Conventional Azimuthal Binning

Data slices at
t = 1.24 s



(Perez and Marfurt, 2008)

New Azimuthal Binning



Data slices at
t = 1.24 s

(Perez and Marfurt, 2008)

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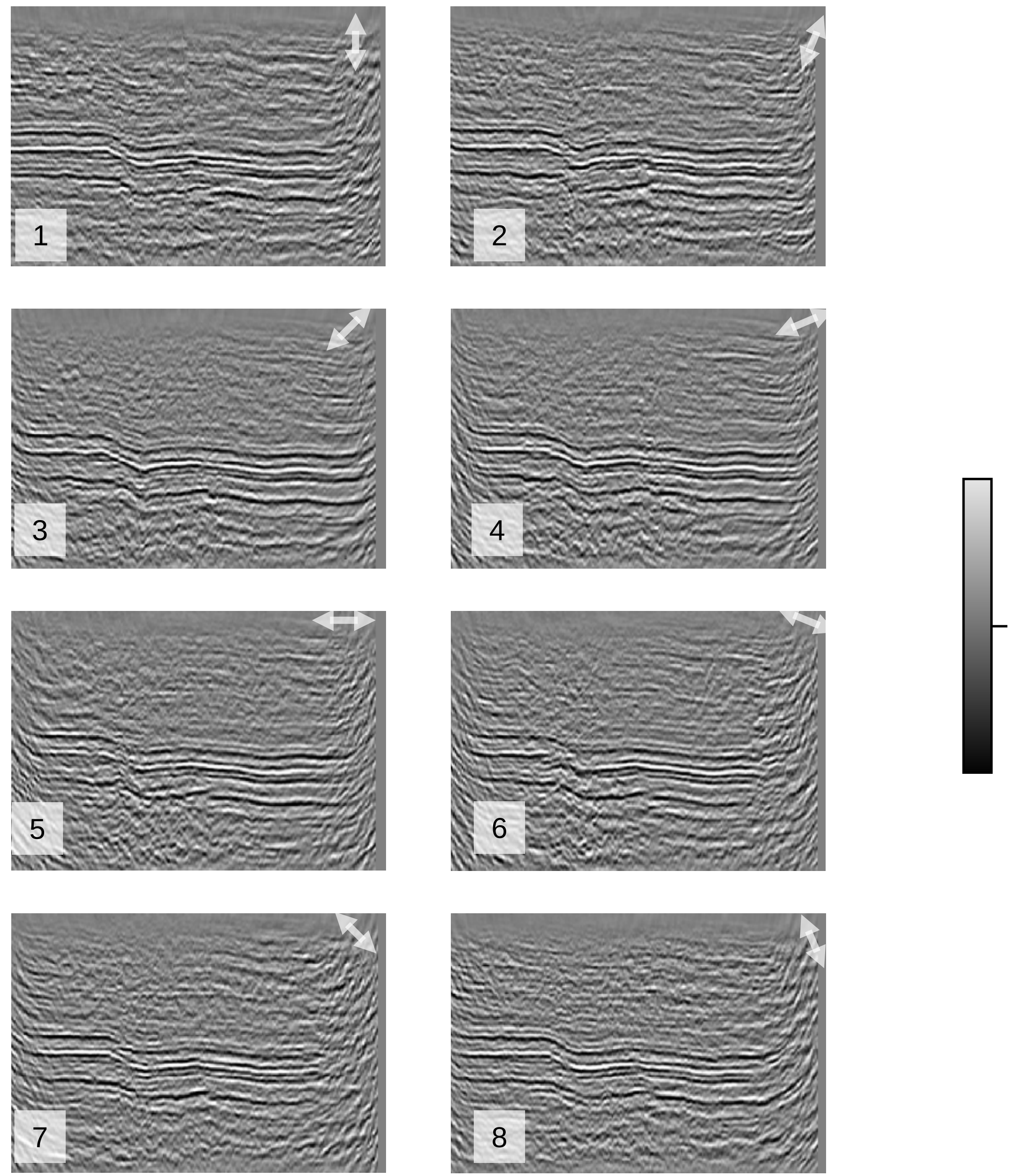
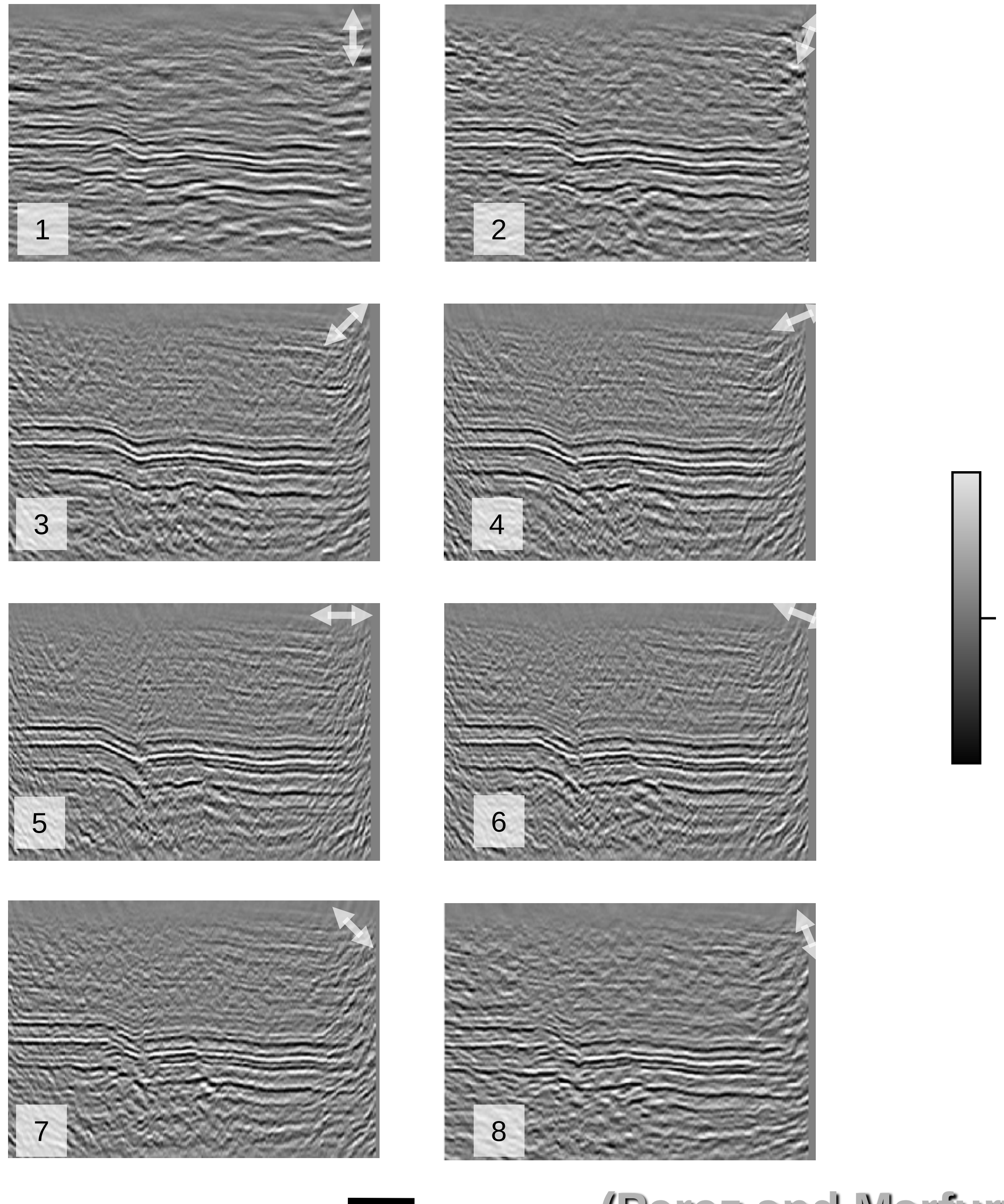


(Perez and Marfurt, 2008)

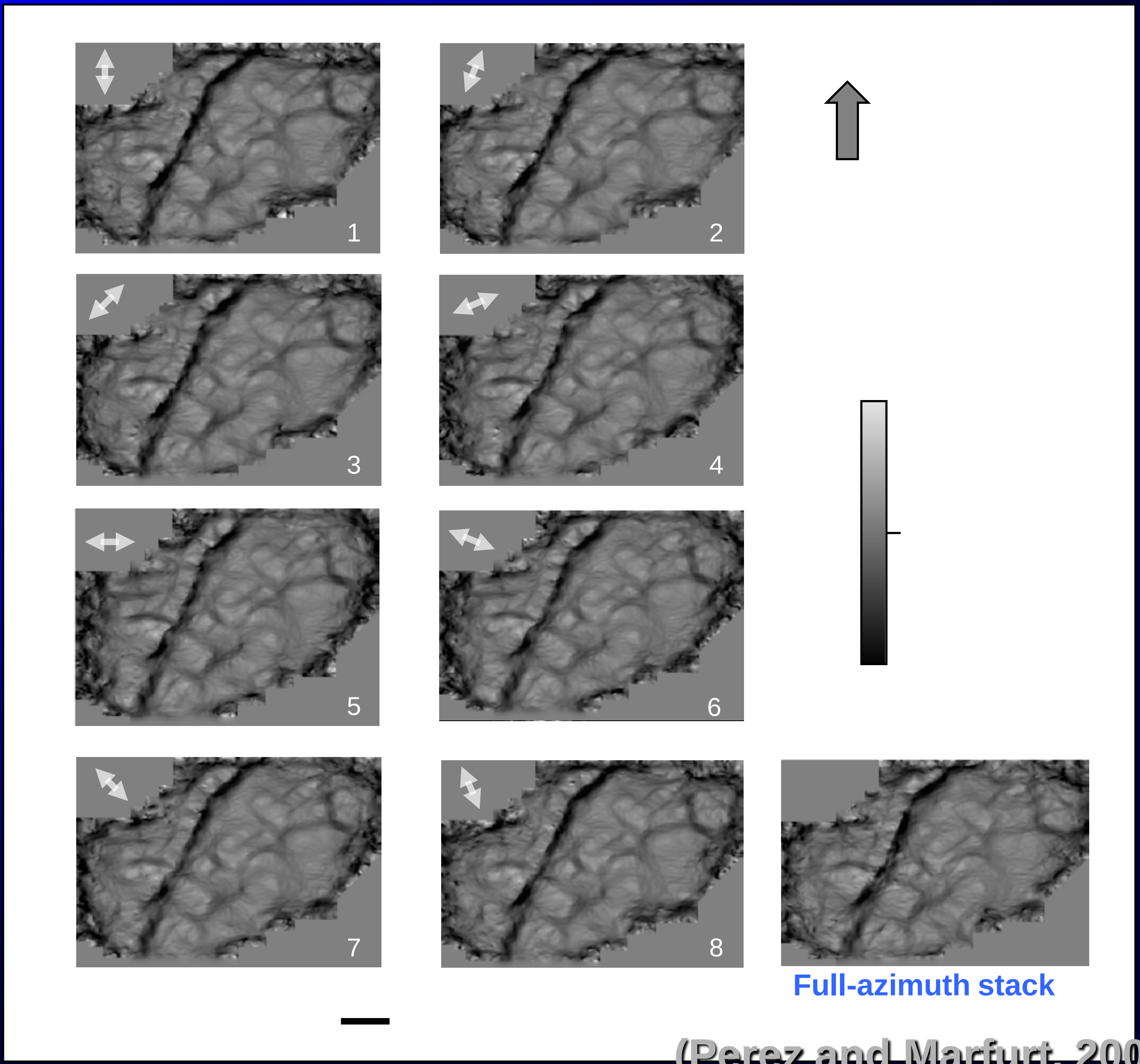
New Azimuthal Binning



(Perez and Marfurt, 2008)

Conventional Azimuthal Binning

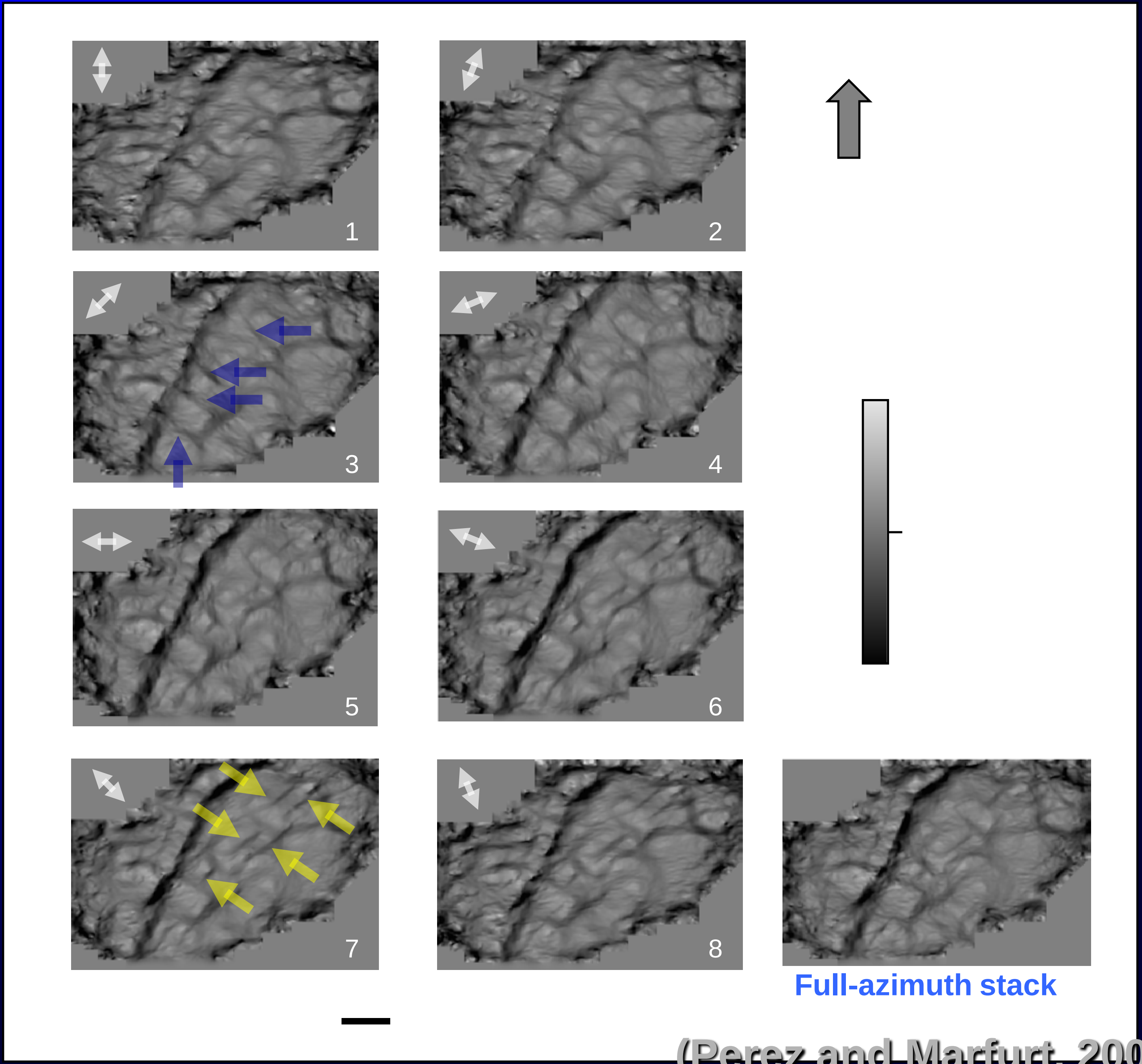
Kneg slices at
t = 1.36 s



(Perez and Marfurt, 2008)

New Azimuthal Binning

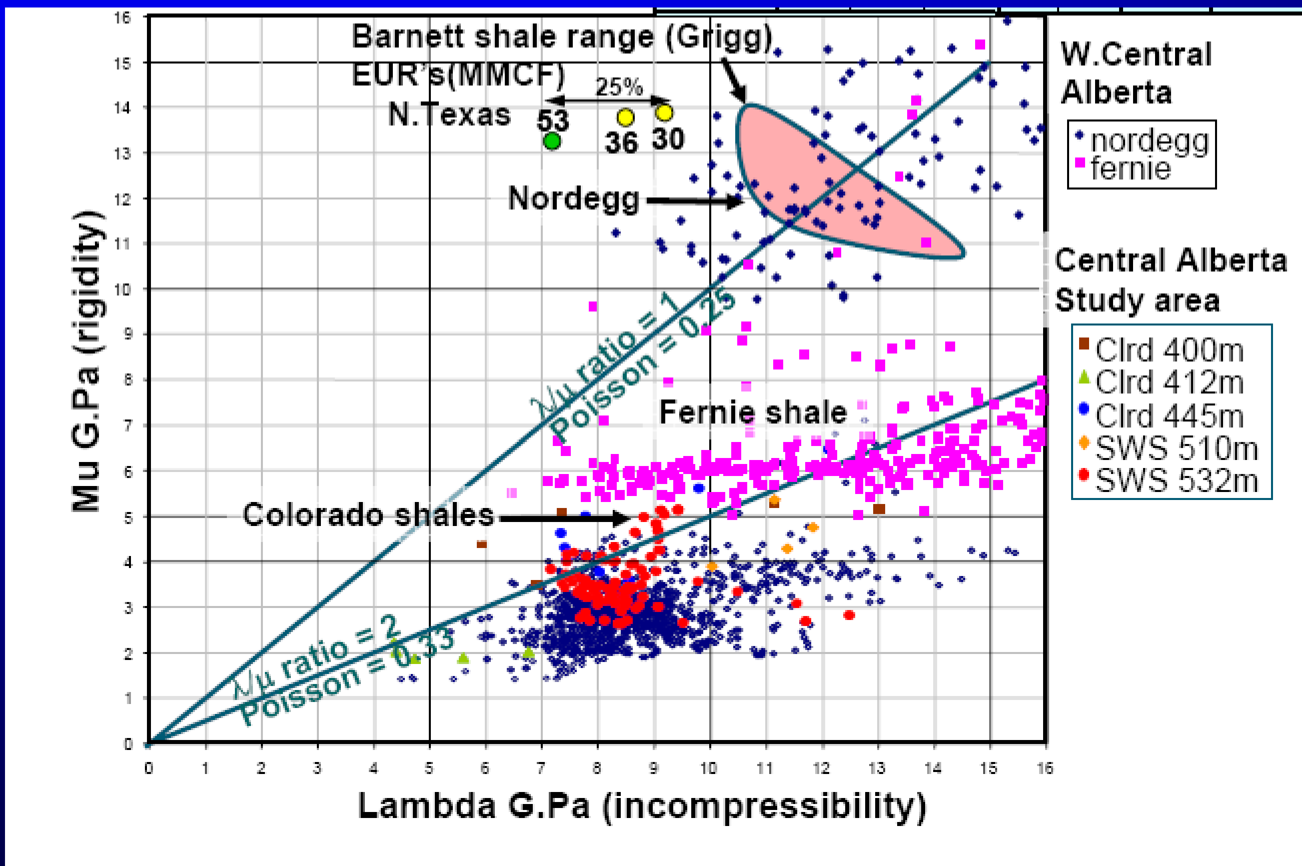
Kneg slices at t = 1.24 s



(Perez and Marfurt, 2008)

Can we predict 'fracability' from λ-μ cross plots of shales?

BARNETT WELLS	Vp	Vs	Rho	Lam	Mu	gr	poisson	EUR
S1	3687	2314	2.47	7.1	13.2	139.72	0.175	53
S2	3812	2358	2.49	8.5	13.8	129.08	0.190	36
S3	3850	2364	2.49	9.1	13.9	144.42	0.197	30



(Goodway et al. , 2007)

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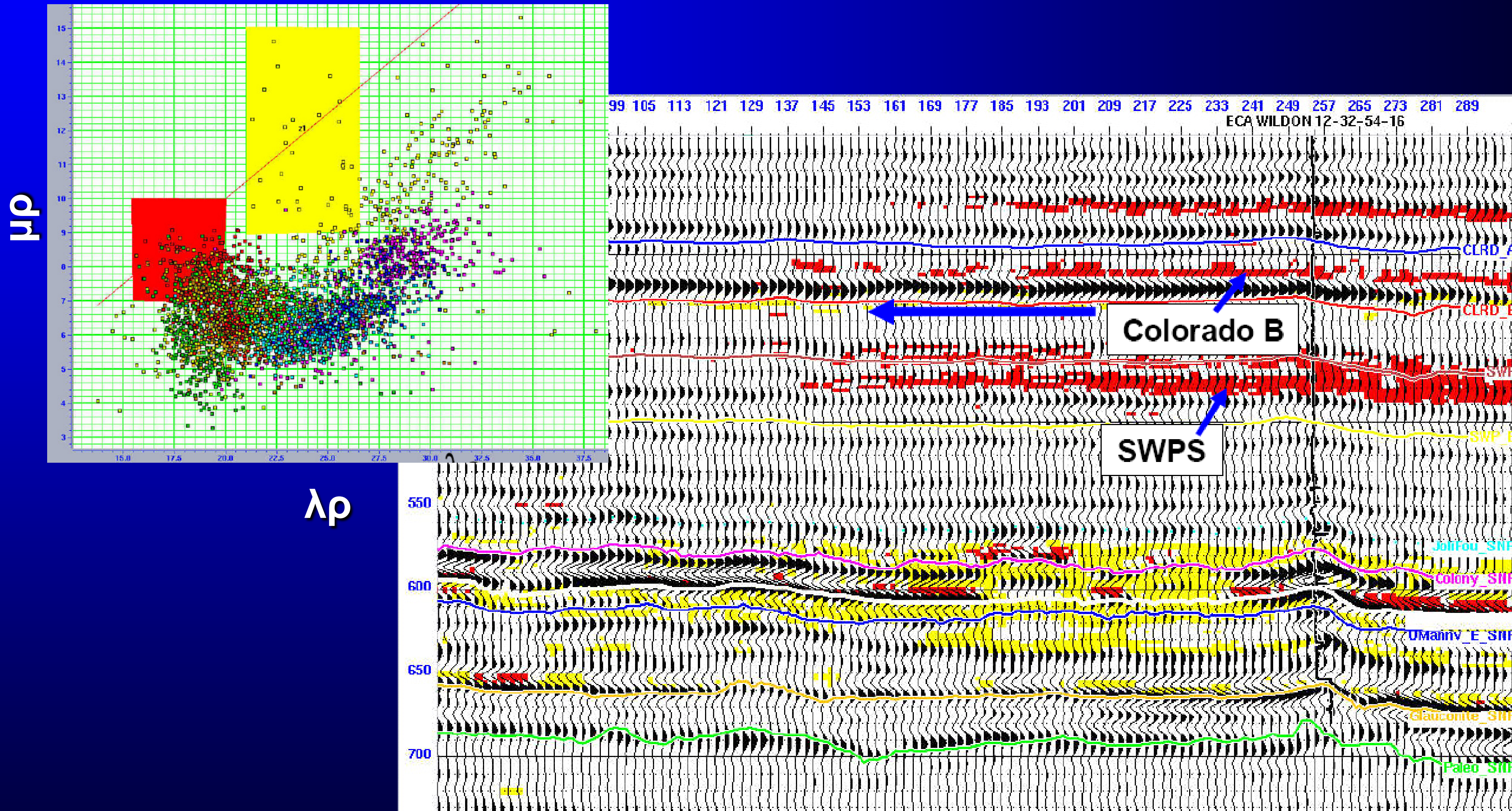

(Goodway et al. , 2007)

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Natural fractures in the Woodford Shale (Wyche shale pit, OK)

(Portas, 2009)

Summary

In the core area of the Fort Worth Basin:

- Large fractures and karst can be readily identified by using 3D wide-azimuth seismic volumes; these features often result in production of water from the Ellenberger
- Mapping fractures and karst can be facilitated by coherence and curvature
- Fractures at the target area correlate to those in the Basement
- Minor fractures are almost always healed and have been shown to be correlated to paleo-deformation. Induced fractures preferentially follow the direction of maximum horizontal stress

In other areas:

- Production (EUR) appears to be enhanced by natural fractures seen in curvature

Further development is needed in:

- Correlating surface seismic AVO and AVOA to core and EUR for a wider suite of shale reservoirs
- Improving resolution of anisotropy velocity analysis