3D Seismic Interpretation

Horizon and formation attributes

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Learner Objectives

After this section you will be able to:

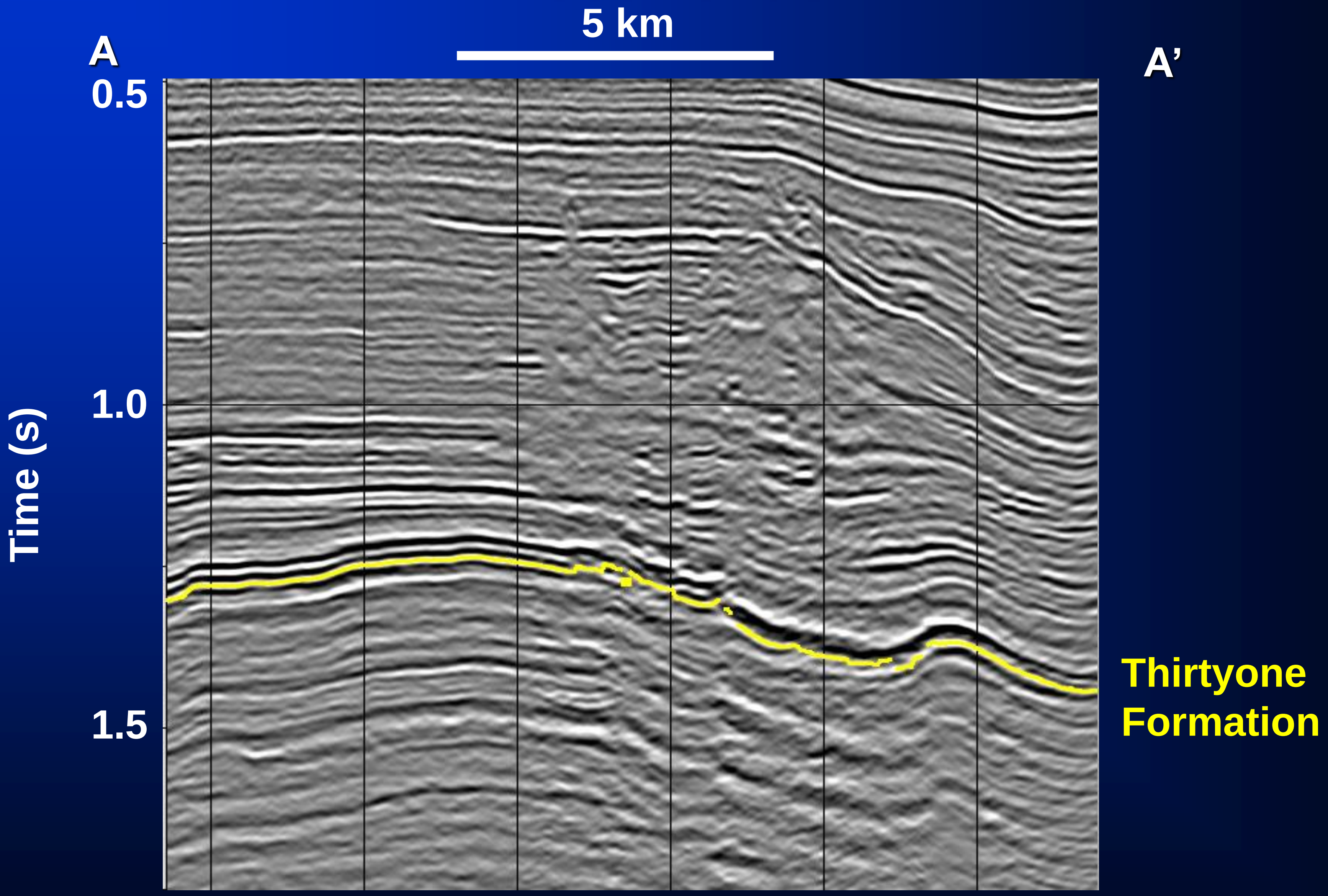
- use attributes computed from interpreted time-structure maps to enhance subtle faults and folds
- Choose the appropriate view of the data to enhance a feature of interest – vertical slices, time slices, horizon slices, phantom horizon slices, stratal slices through the data, or optical stacks and averages of the data measured between horizons of interest
- Use statistical measures of amplitude above or below picked horizons to map chaotic features that cannot easily be picked

Conventional interpretation work flow

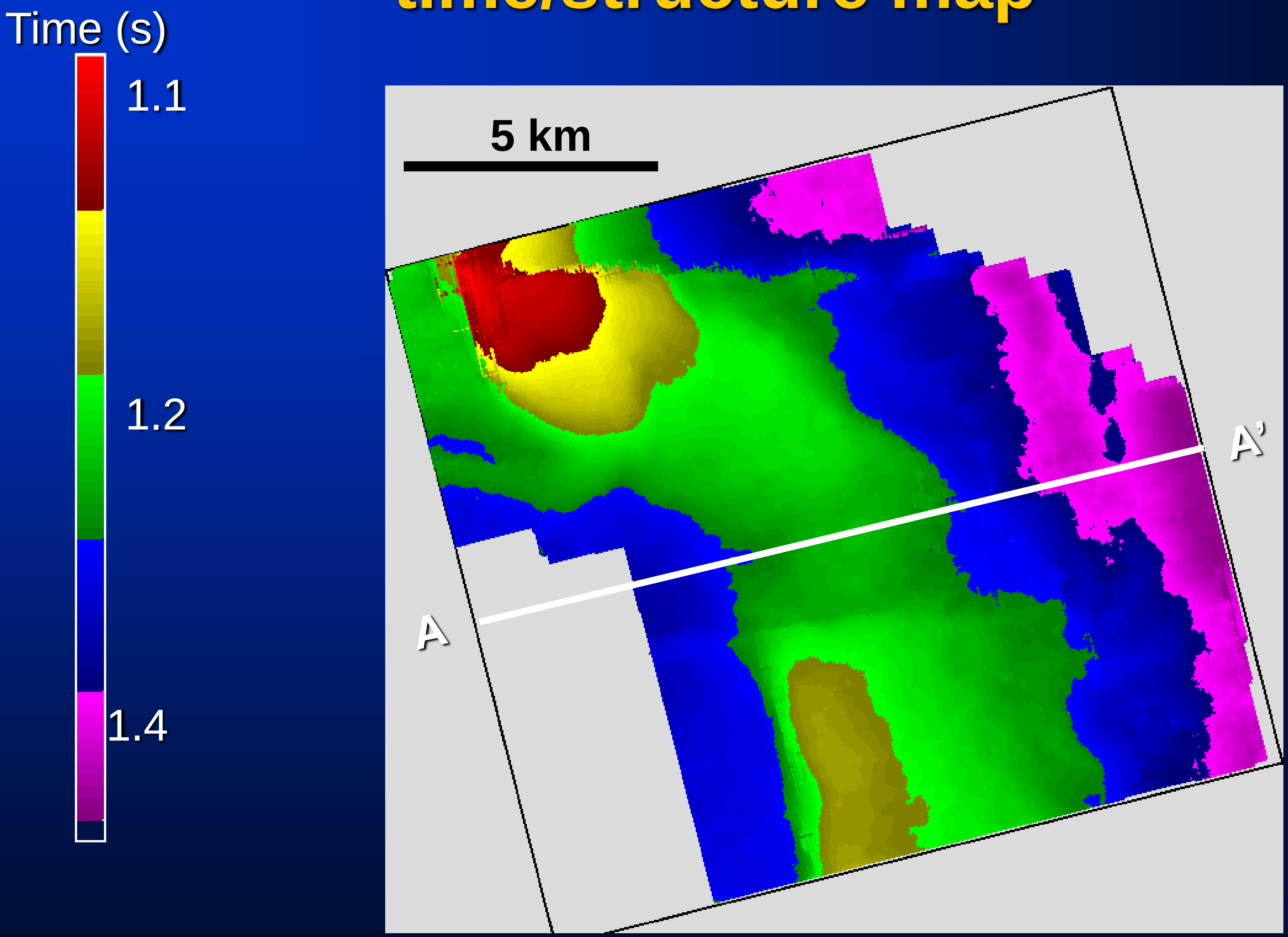
1. Identify horizon of interest
2. Pick horizon on a selected grid of lines
3. Pick all intermediate traces using an automatic picking algorithm
4. Extract horizon attributes:
    - Time structure
    - Amplitude extractions
    - Dip magnitude
    - Dip azimuth
    - Combined dip magnitude/dip azimuth
    - Interactive sun-shading of the picked horizon
    - Horizon-based curvature

(modified from Rijks and Jauffred, 1991)

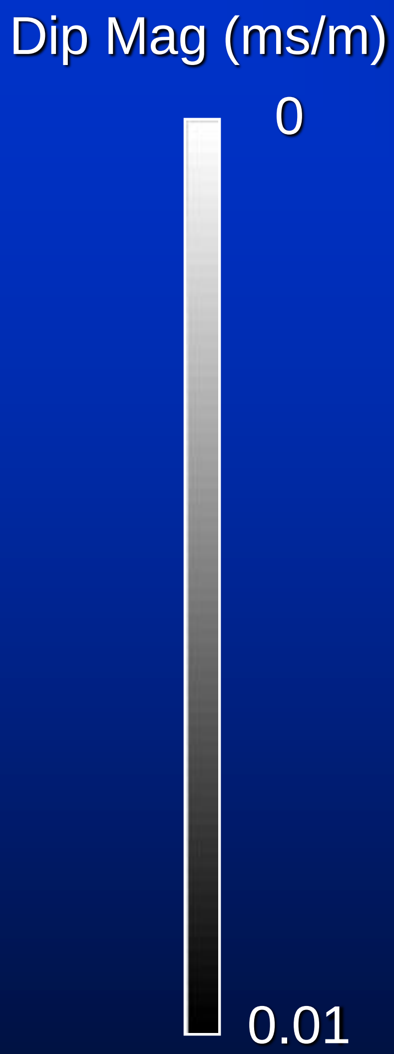
Example from Central Basin Platform west Texas

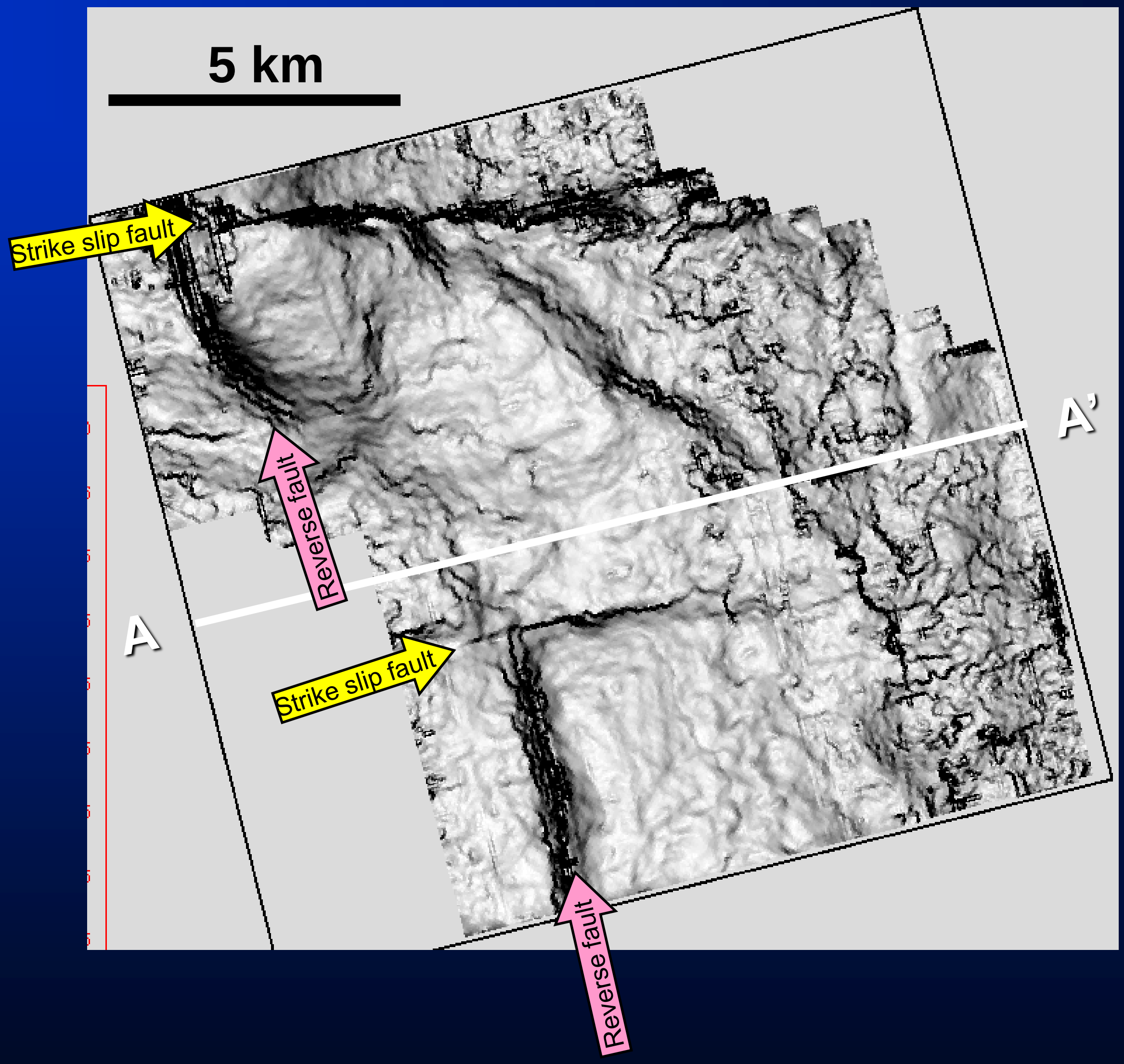


The simplest horizon attribute – a time/structure map

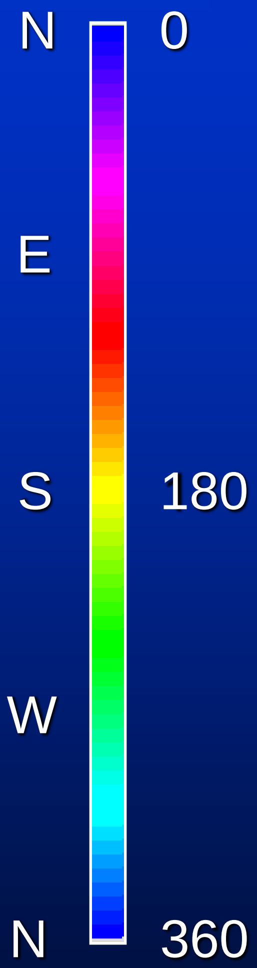


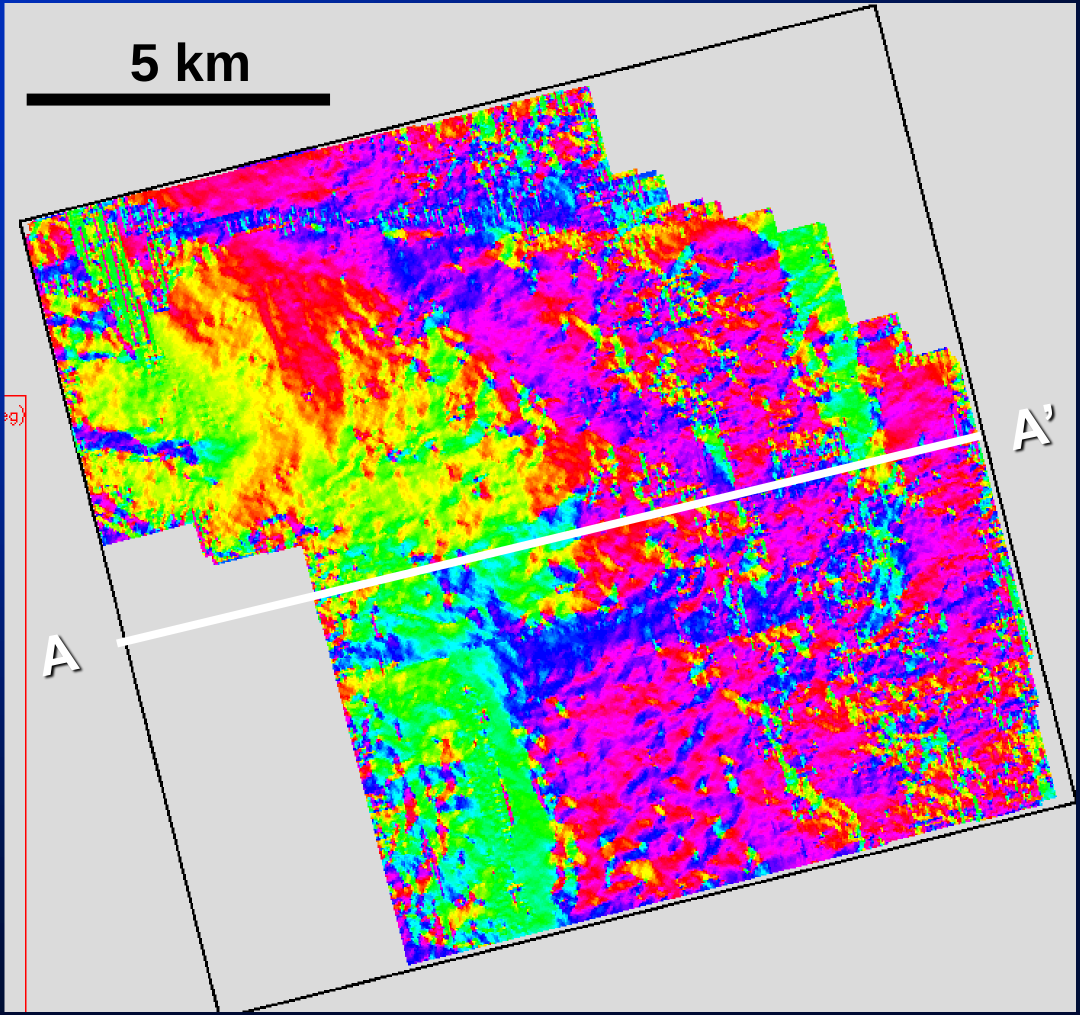
Dip magnitude of a picked horizon



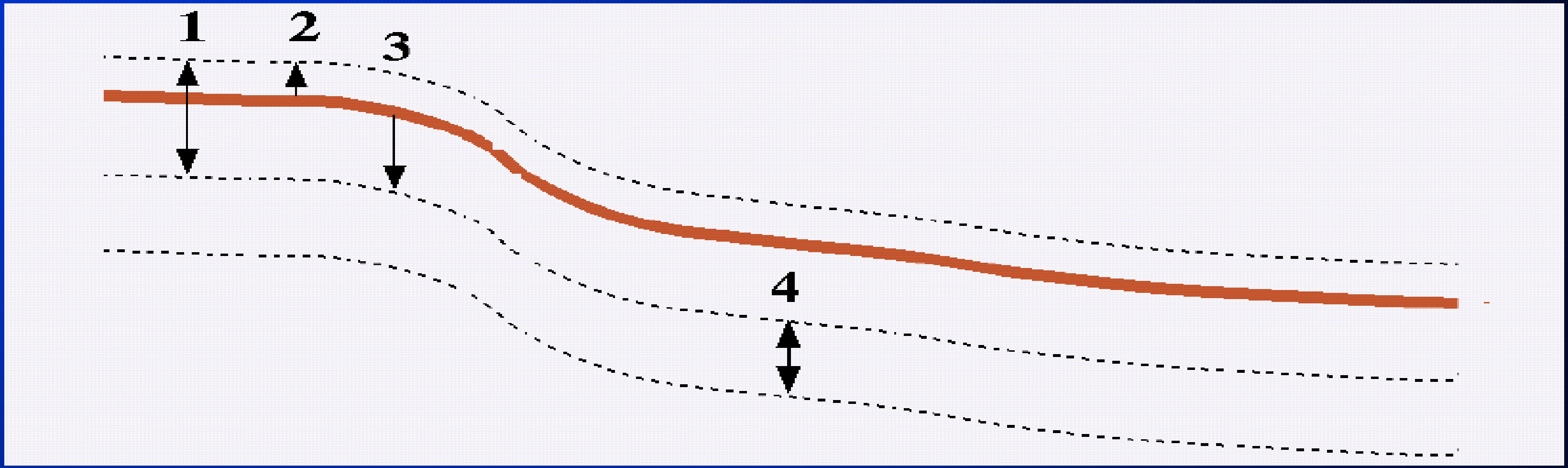


Dip azimuth of a picked horizon

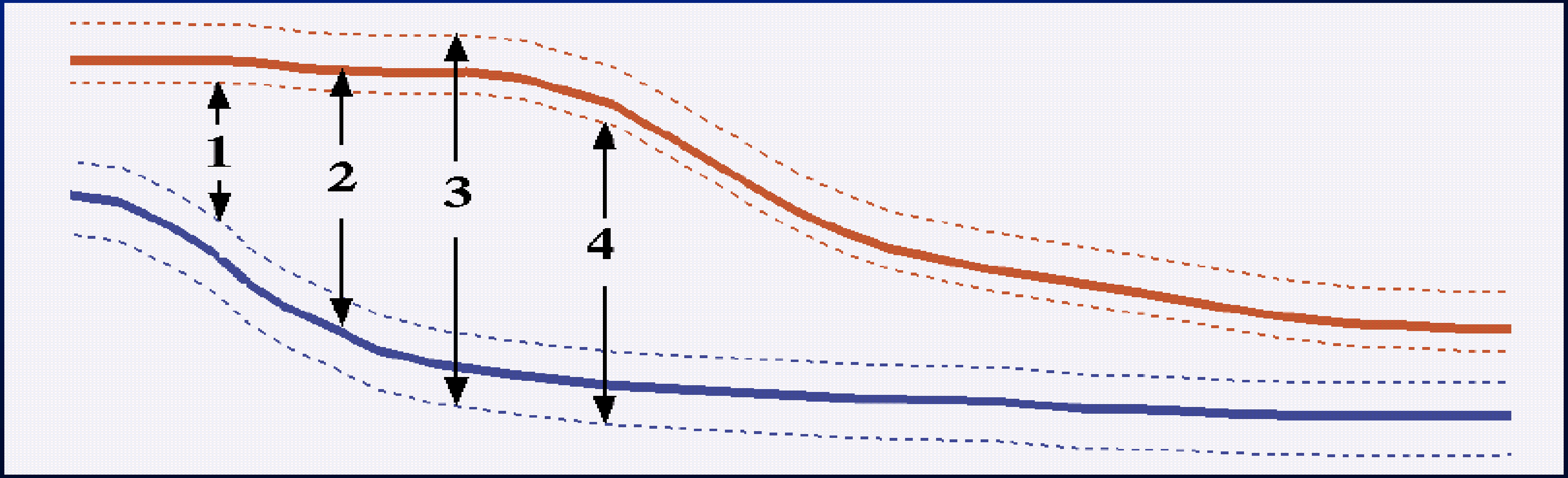




Attributes keyed to a horizon

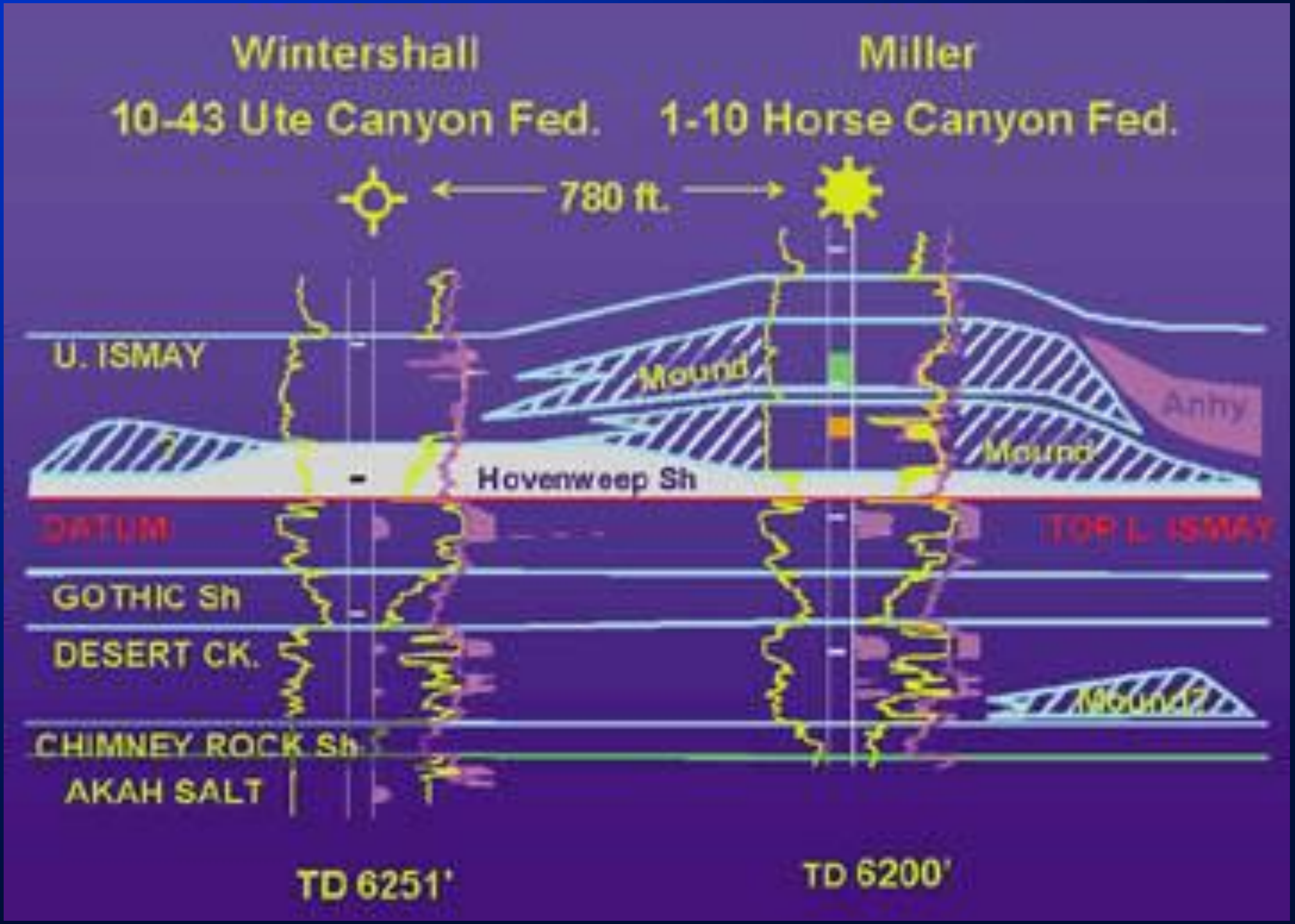


Attributes keyed to a formation or sequence



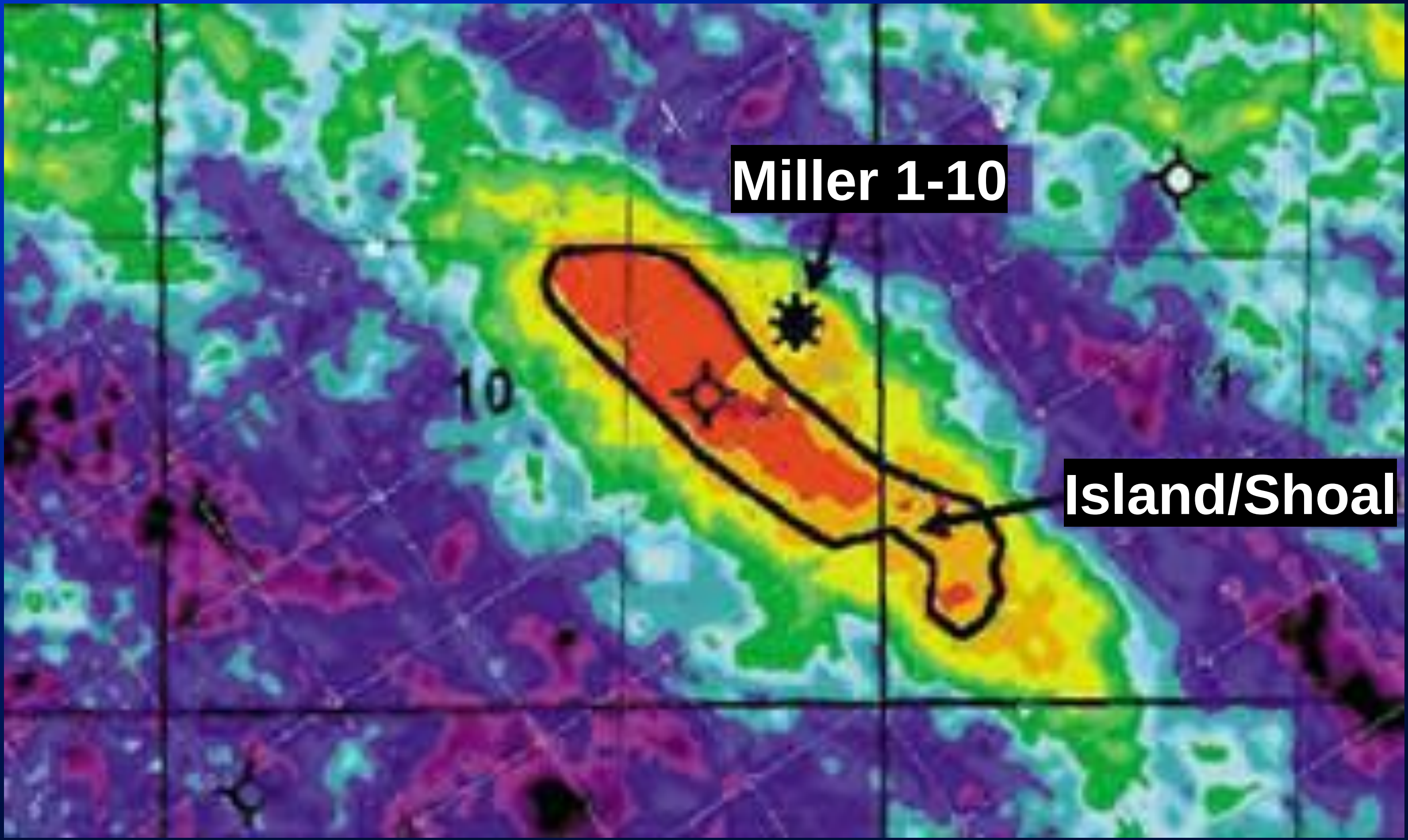
(Kidd, 1999)

Attribute expression of a Pennsylvanian algal mound, Paradox Basin, Utah



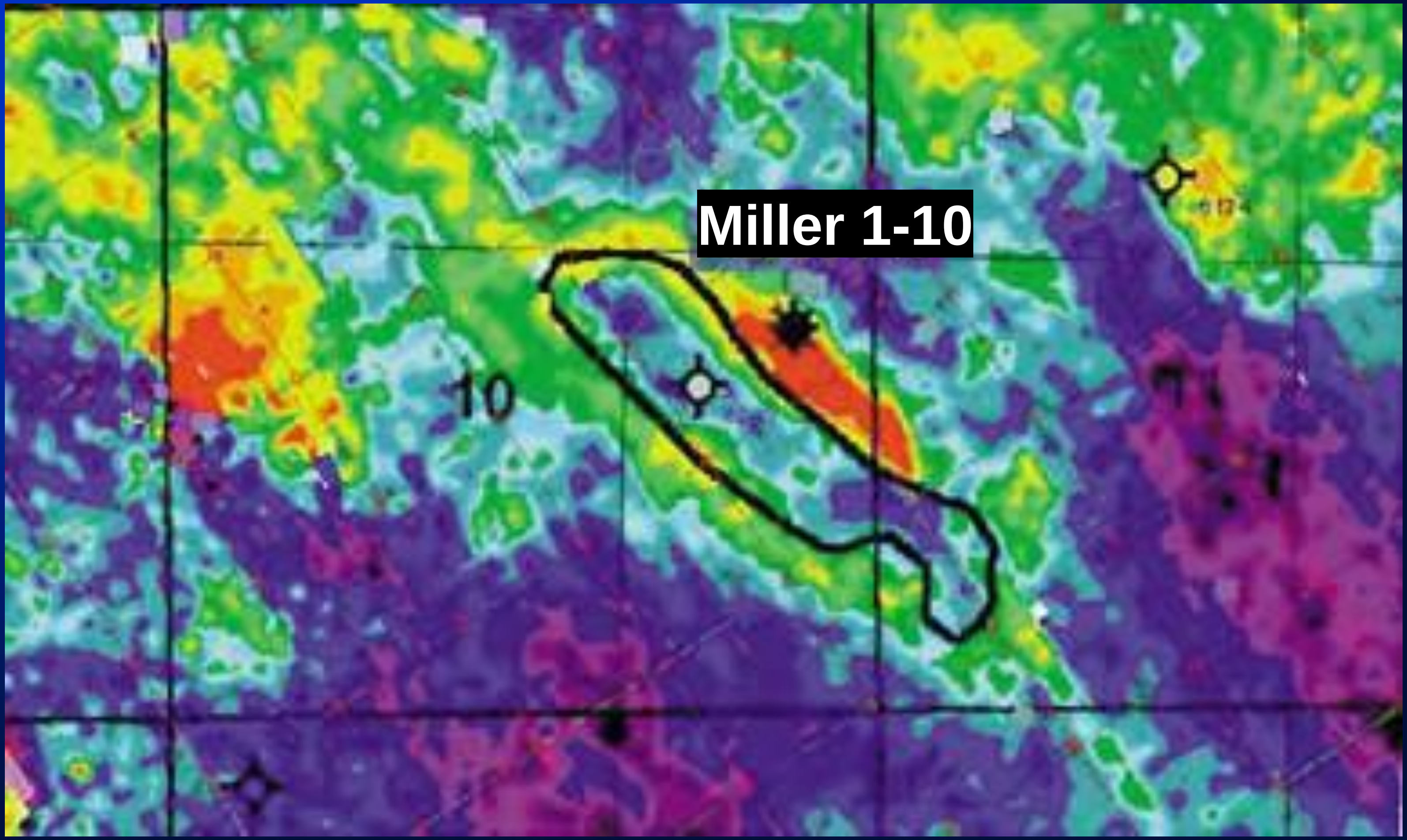
(Johnson et al., 2001)

Hovenweep amplitude extraction showing tuning



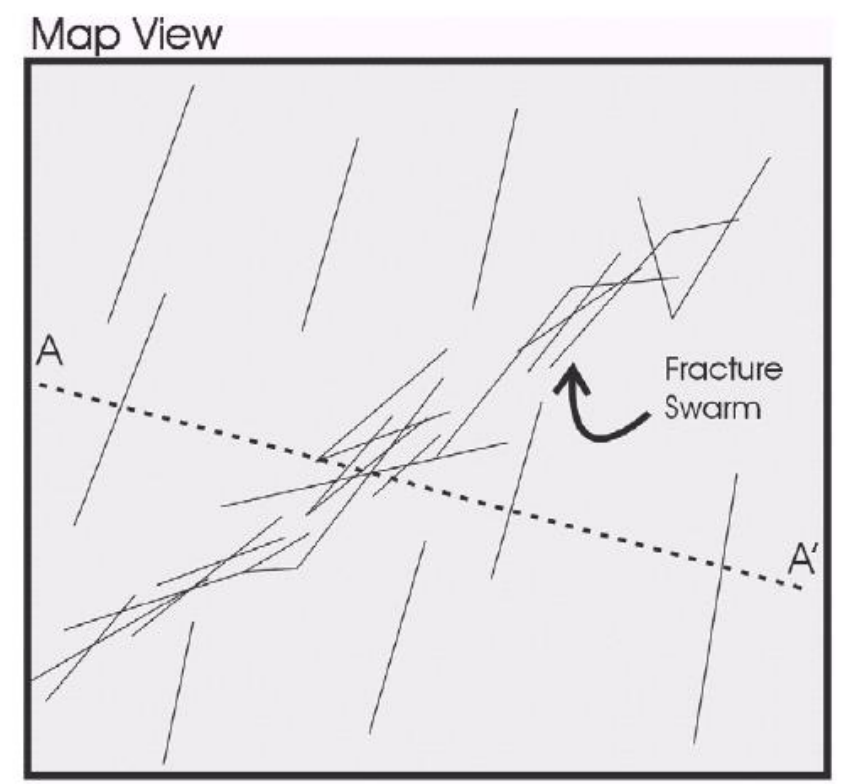
(Johnson et al., 2001)

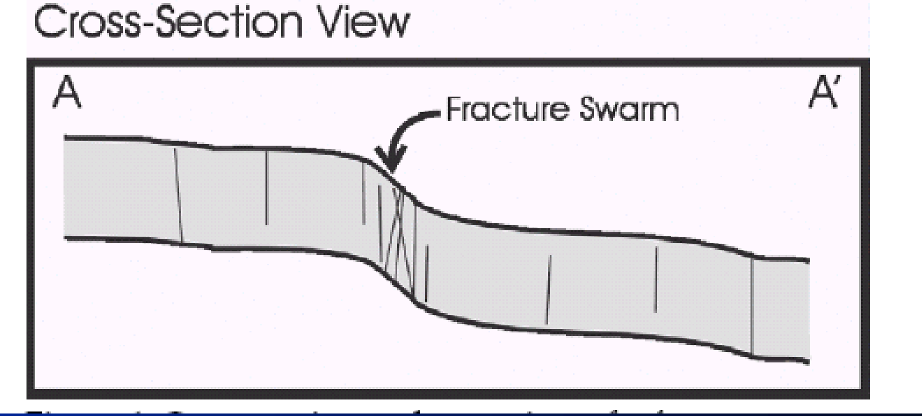
Upper Ismay Isochron
(thicker atoll around original island)



(Johnson et al., 2001)

Fracture detection

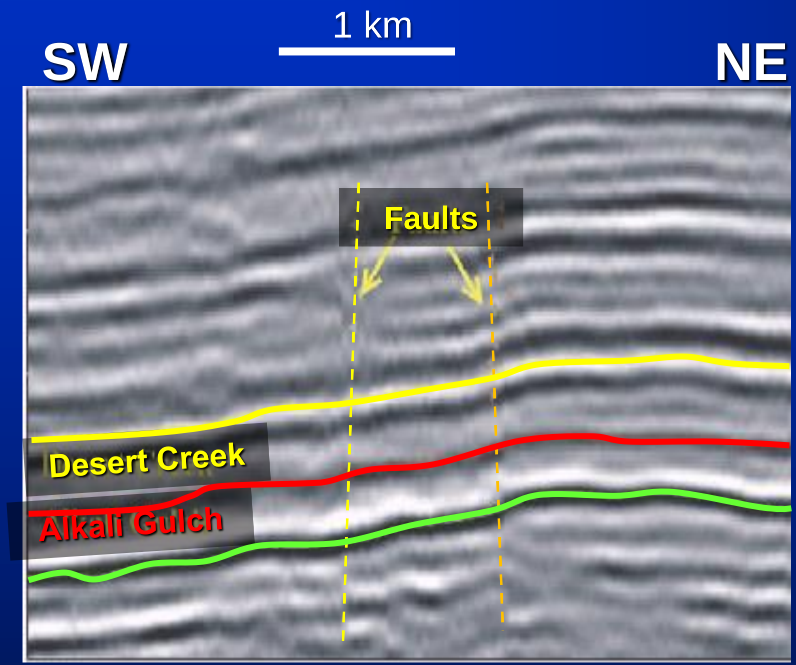


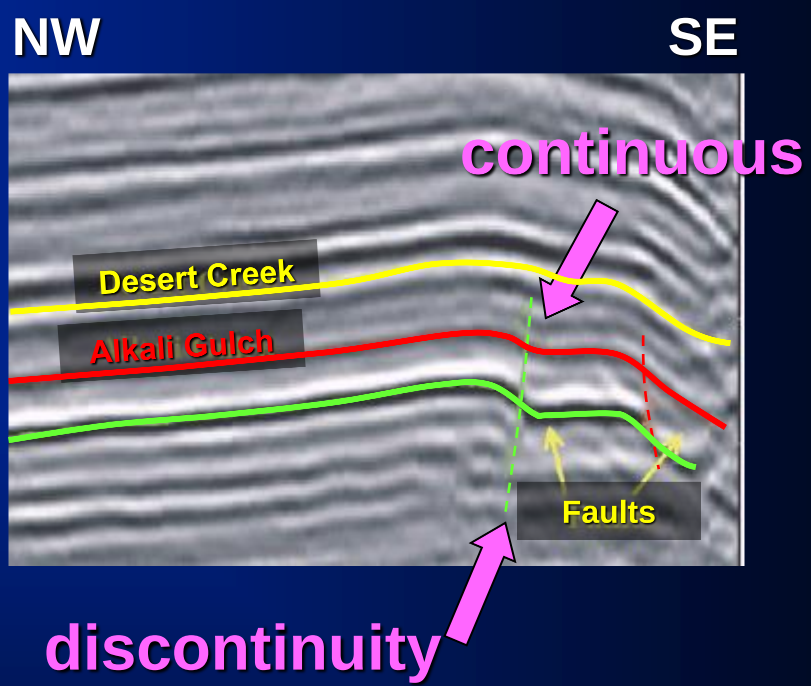


Cross-section and map view of a fracture swarm sweet spot associated with a flexure or fault that may be oriented at some angle to the trend of more pervasive "regional" fractures.

(Hart et al., 2002)

Fracture detection (carbonates - Paradox Basin, NM)





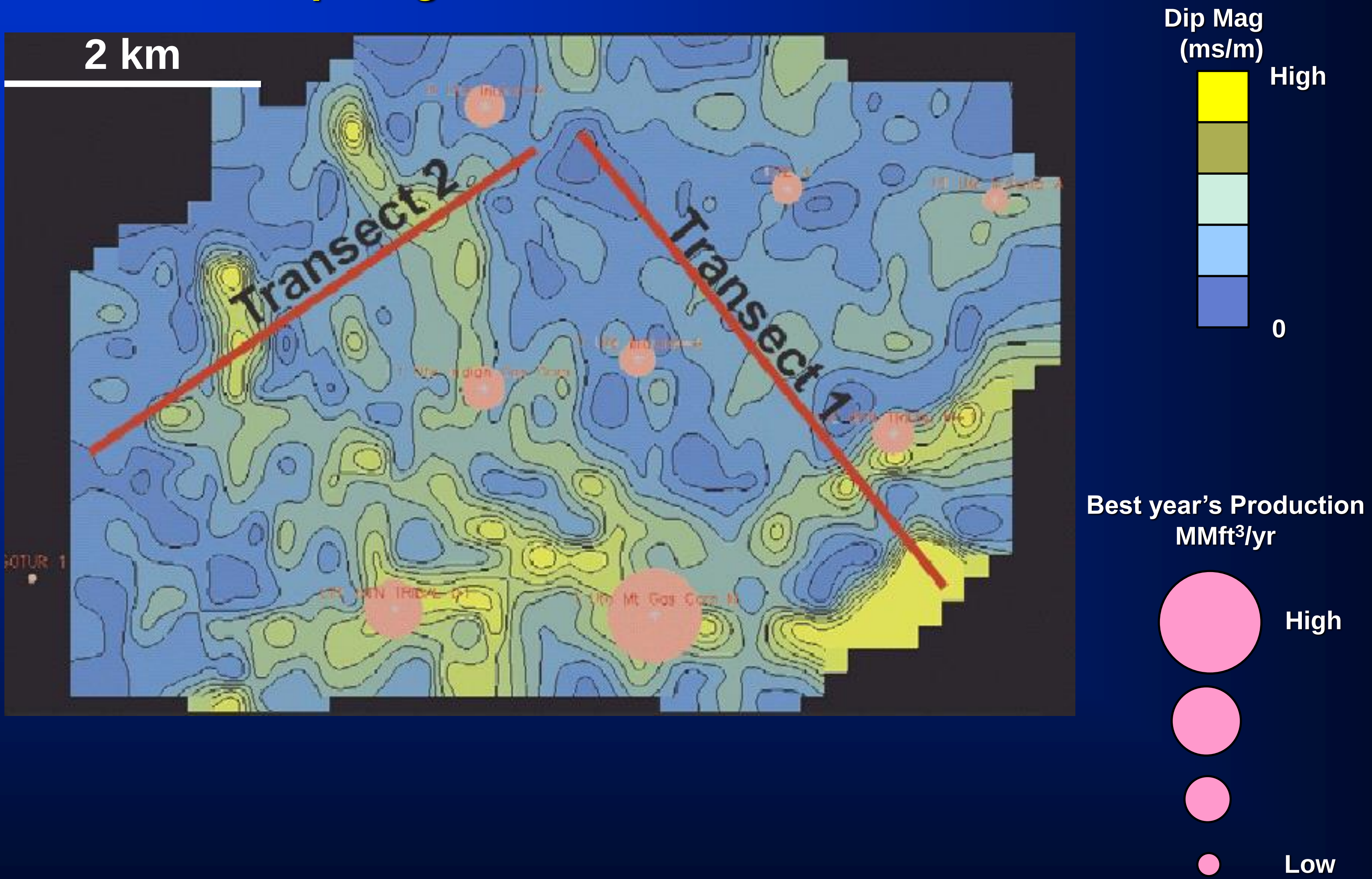
Transect 2: cuts NW-striking small-offset normal faults.

Transect 1 cuts NE-striking reverse faults

(Hart et al., 2002)

Fracture-enhanced permeability

Dip-magnitude of Alkali Gulch Horizon



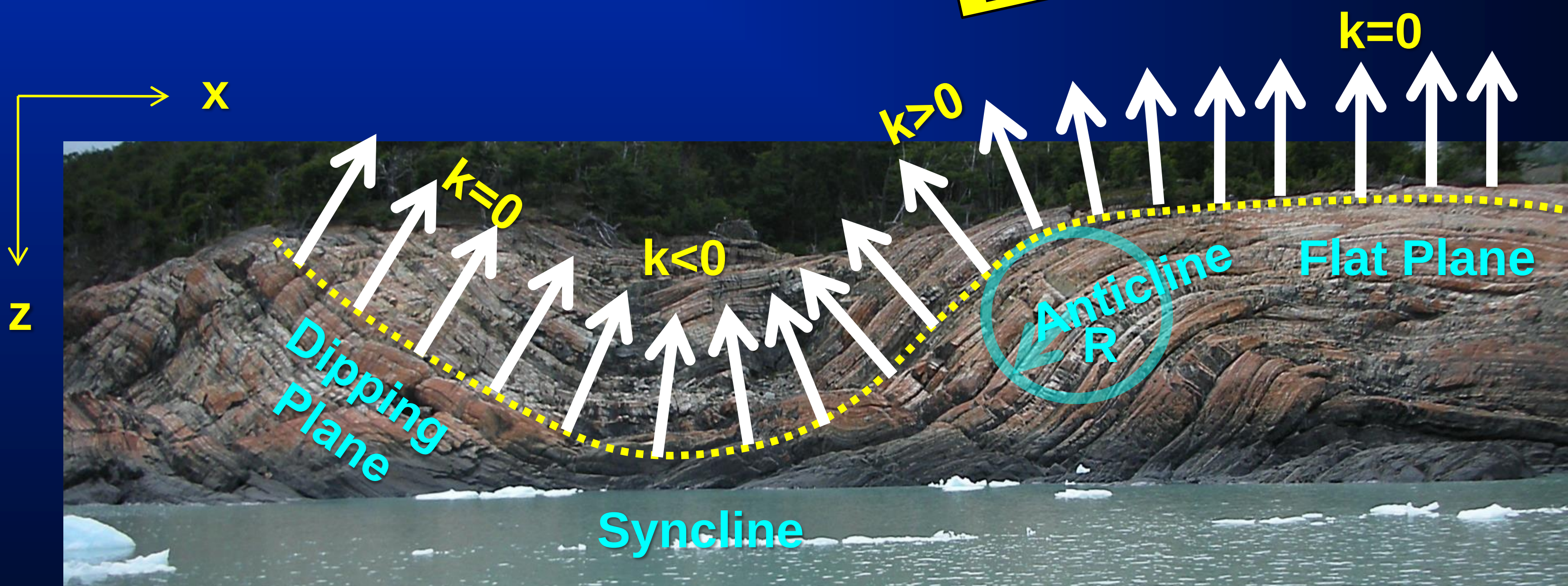
(Hart et al., 2002)

Sign convention for 2D curvature attributes:

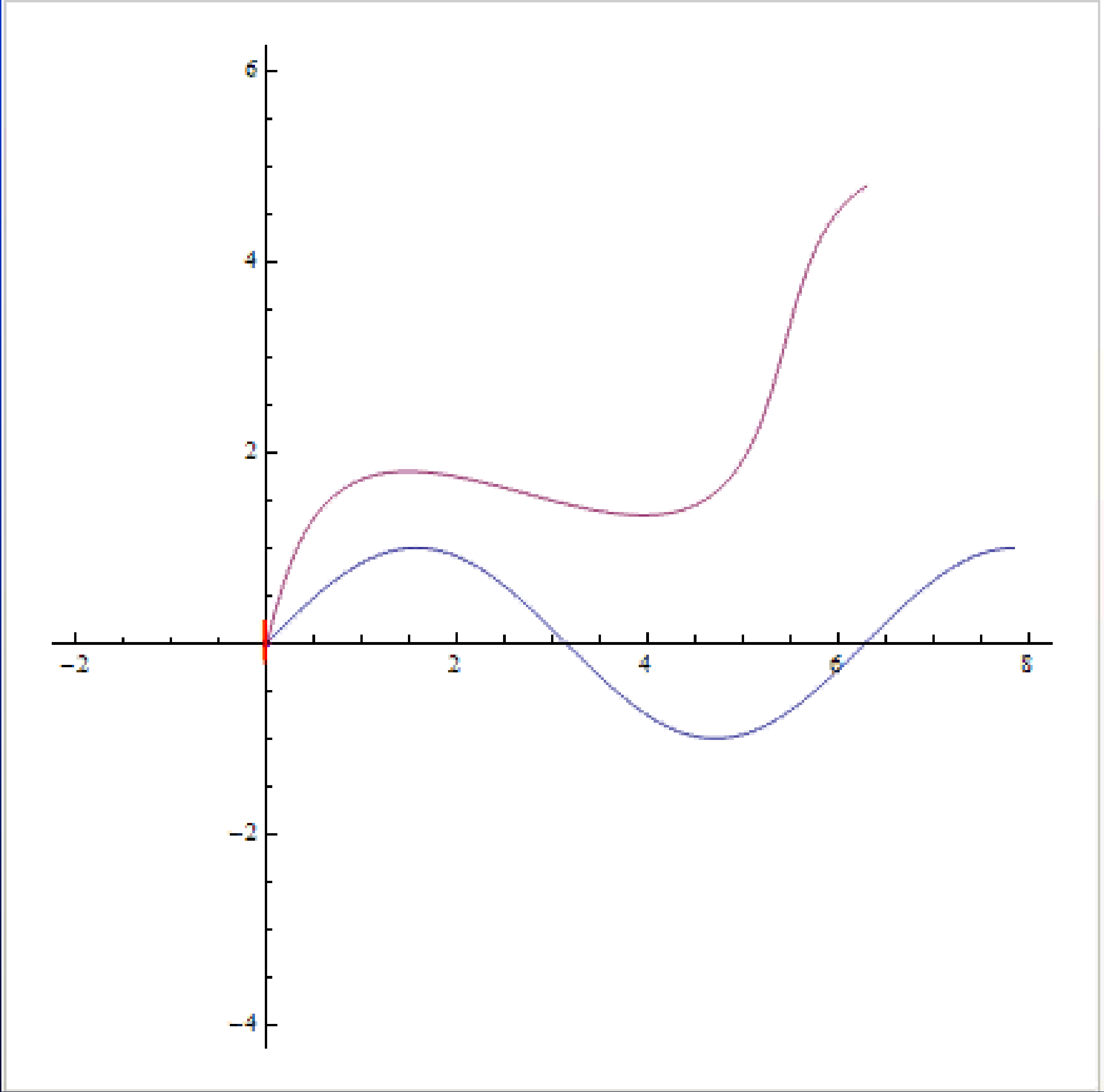
Anticline: k > 0
Plane: k = 0
Syncline: k < 0

$$k = \frac{1}{R} = \frac{d\theta}{ds} = \frac{dx}{ds}\frac{d}{dx}\left[\tan^{-1}\left(\frac{dz}{dx}\right)\right] = \frac{\dfrac{d^2z}{dx^2}}{\left[1+\left(\dfrac{dz}{dx}\right)^2\right]^{3/2}}$$

Dip of reflector



2D Maximum curvature, k_{max}



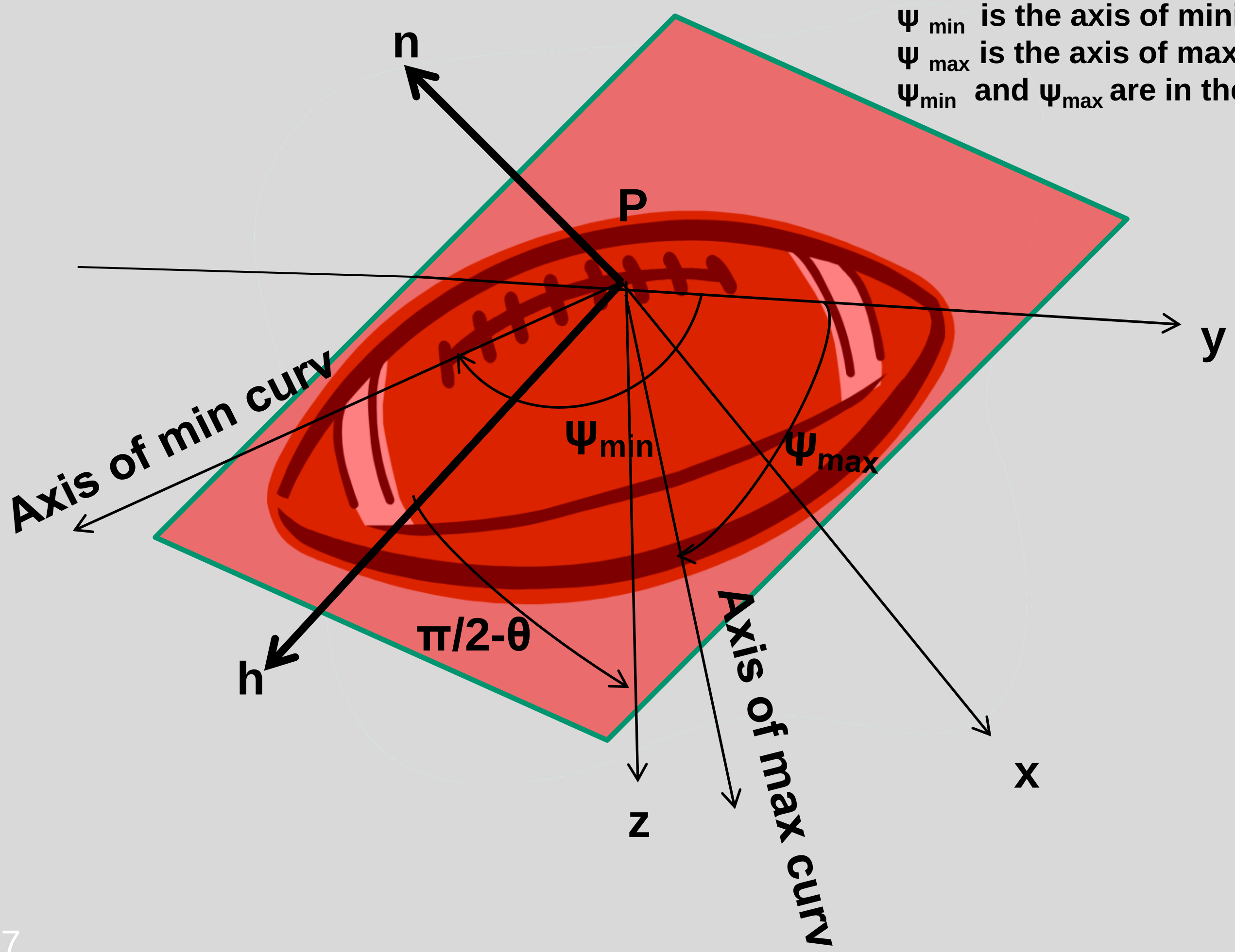
$z(x)$

$k_{max}(x)$

http://demonstrations.wolfram.com/OsculatingCircles

Principal Curvatures k_1 and k_2

n is the normal to the tangent plane
h is the vector dip of the tangent plane
θ is the dip magnitude of the tangent plane measured from the horizontal
φ is the dip azimuth of the tangent plane, measured from the y (North) axis
ψ_{min} is the axis of minimum curvature
ψ_{max} is the axis of maximum curvature.
ψ_{min} and ψ_{max} are in the plane containing the y axis and h



Curvature measures

Most-positive principal curvature , k_1

Most-negative principal curvature: k_2

Gaussian curvature: $k_{Gauss}=k_1k_2$

Mean curvature: $k_{mean}=(k_1+k_2)/2$

Minimum curvature: $k_{min}= \begin{cases} k_1 \text{ if } |k_1|<|k_2| \\ k_2 \text{ if } |k_1|>|k_2| \end{cases}$

Maximum curvature: $k_{max}= \begin{cases} k_2 \text{ if } |k_1|<|k_2| \\ k_1 \text{ if } |k_1|>|k_2| \end{cases}$

Curvedness: $k_c =(k_1^2+k_2^2)^{1/2}$

Dip curvature: $k_{dip}=k_1\sin^2\varphi+k_2\cos^2\varphi$

Strike curvature: $k_{strike}=k_1\cos^2\varphi+k_2\sin^2\varphi$

where φ =dip azimuth at P

Points of confusion:

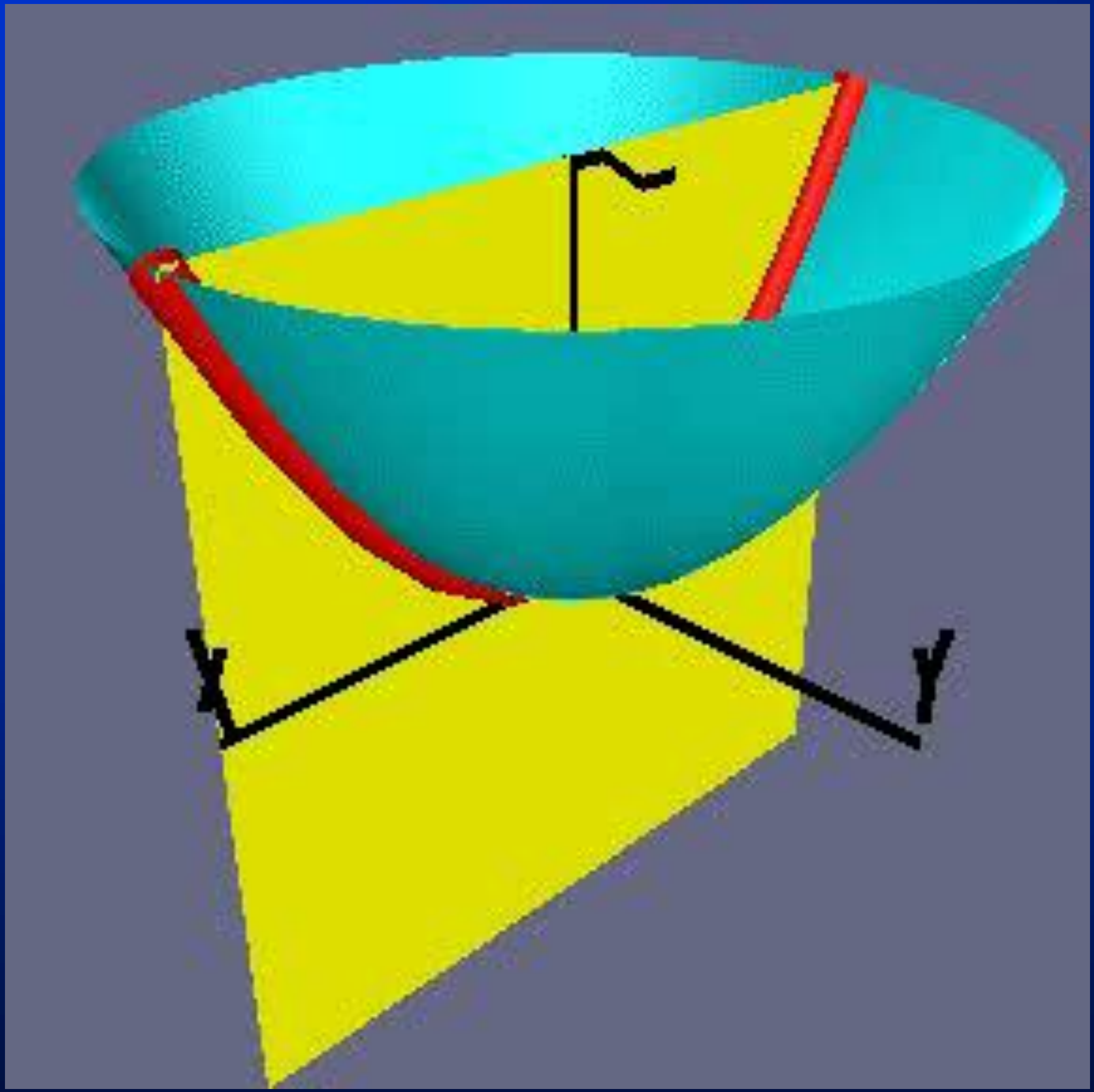
Most common definition of maximum vs. minimum curvature:

$$|k_{\max}| \geq |k_{\min}| \quad \textbf{\textit{NOT}} \quad k_{\max} \geq k_{\min}$$

If you want the behavior on the right, use the most-positive and most-negative principal curvatures

$$k_1 \geq k_2$$

bowl

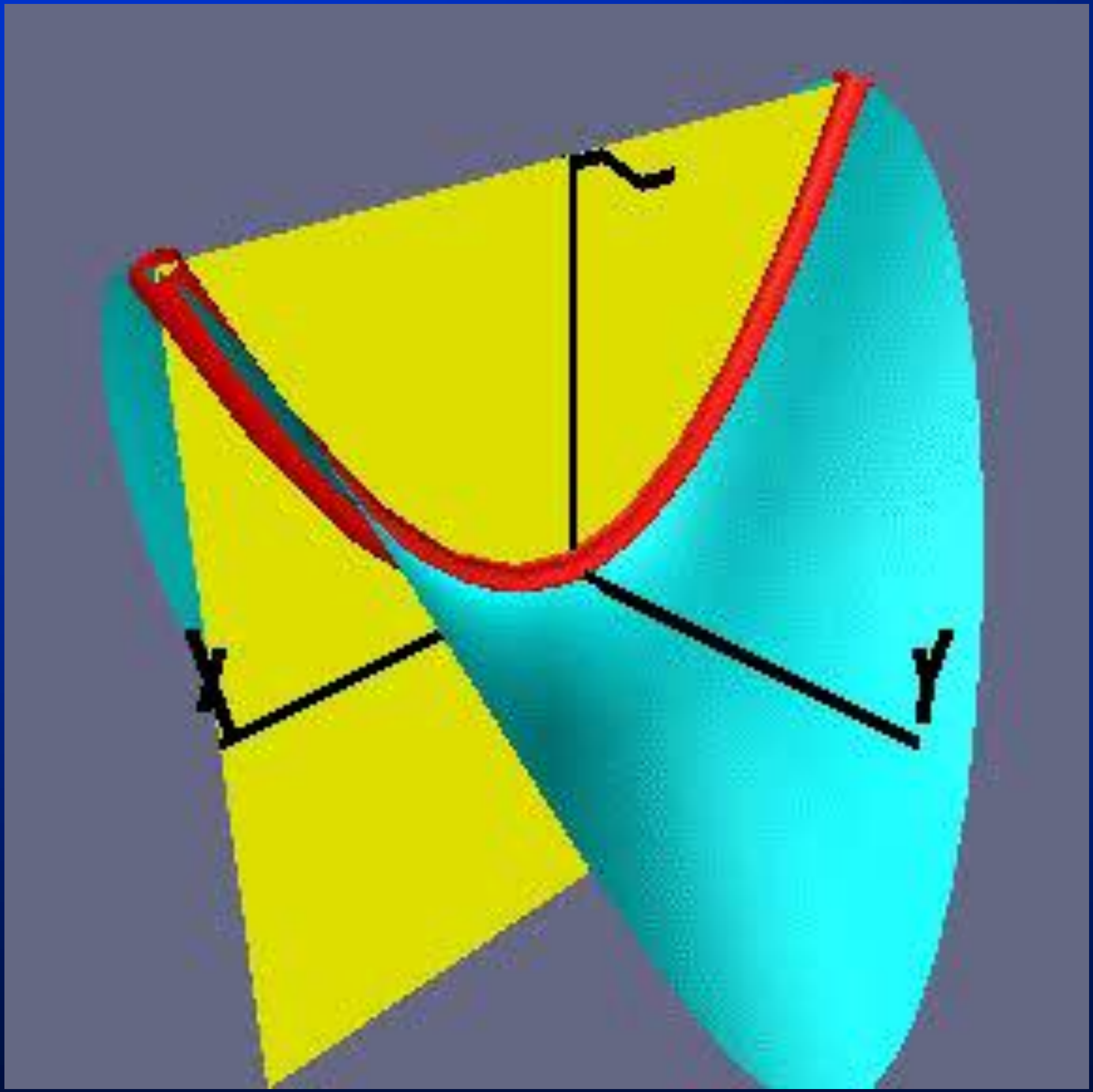


Most-negative principal curvature, k_1 *(in red)*

Most-positive principal curvature , k_2, is equal to and perpendicular to k_1

http://www.geom.uiuc.edu/zoo/diffgeom/surfspace/concepts/curvatures/prin-curv.html

Saddle

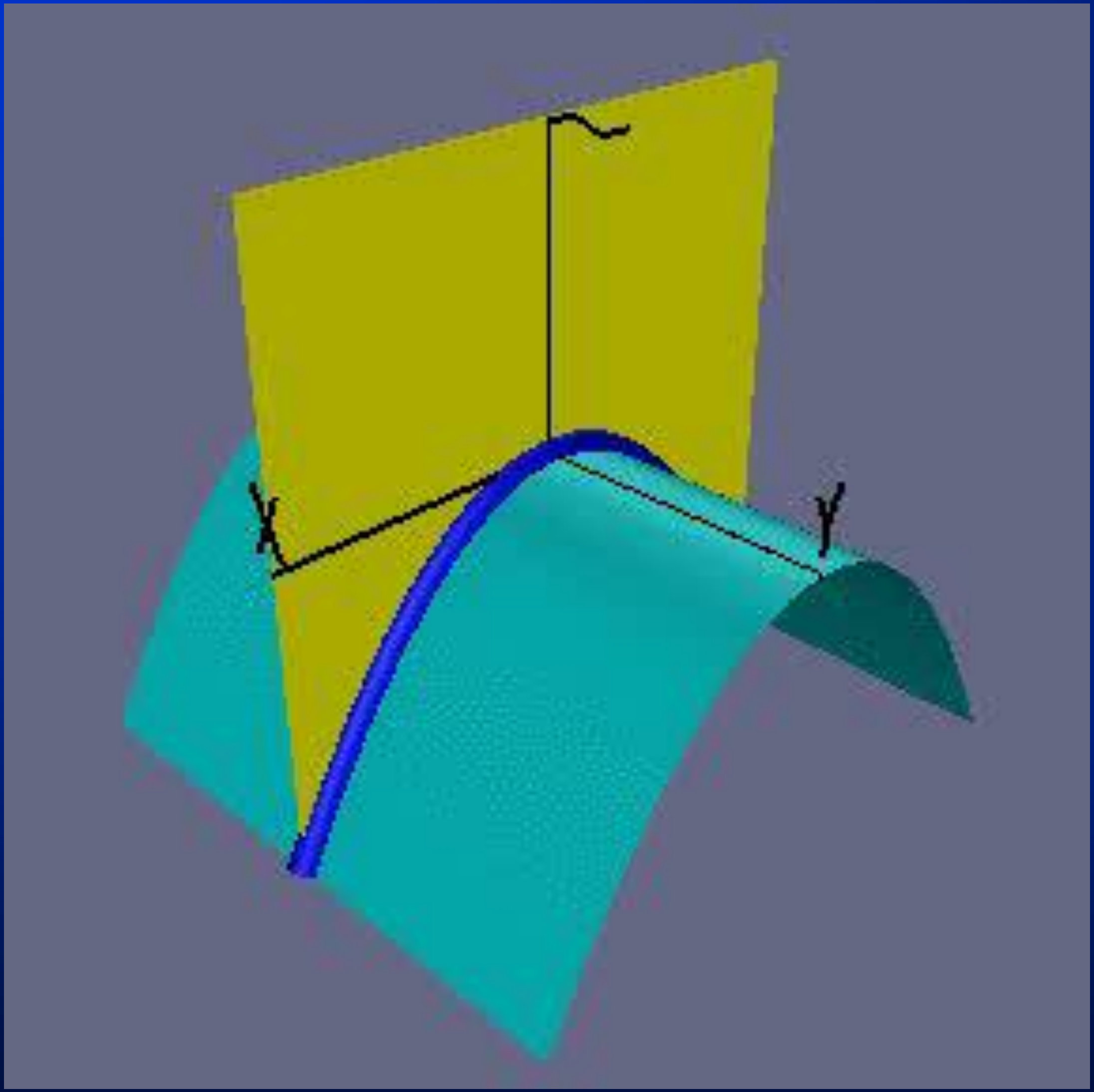


Most-negative principal curvature, k_1 (in red)

Most-positive principal curvature, k_2 (in blue)

http://www.geom.uiuc.edu/zoo/diffgeom/surfspace/concepts/curvatures/prin-curv.html

ridge

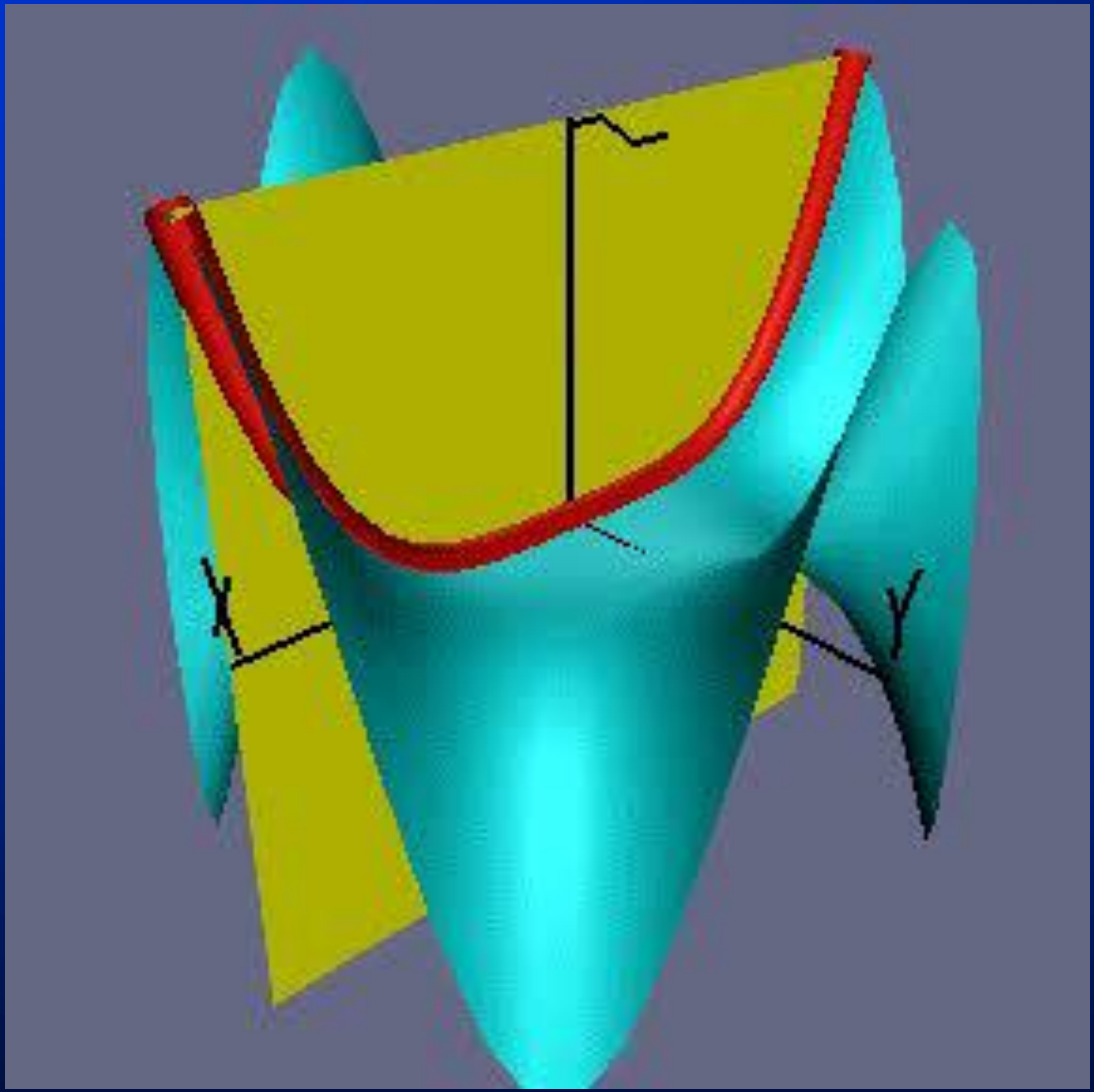


Most-negative principal curvature, k_1 (in red)

Most-positive principal curvature, k_2 (in blue)

http://www.geom.uiuc.edu/zoo/diffgeom/surfspace/concepts/curvatures/prin-curv.html

dog

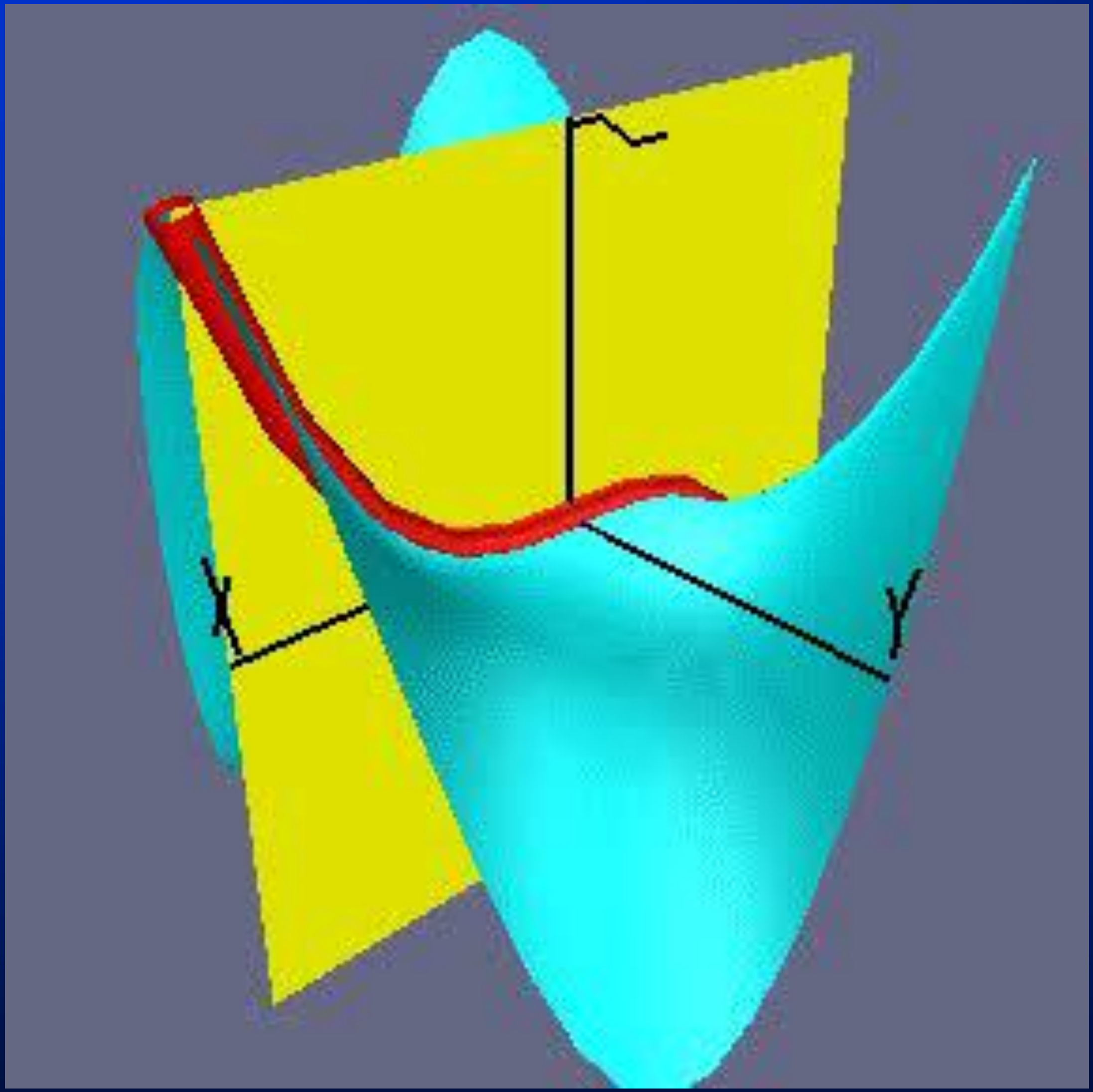


Most-negative principal curvature, k_1 (in red)

Most-positive principal curvature, k_2 (in blue)

http://www.geom.uiuc.edu/zoo/diffgeom/surfspace/concepts/curvatures/prin-curv.html

monkey



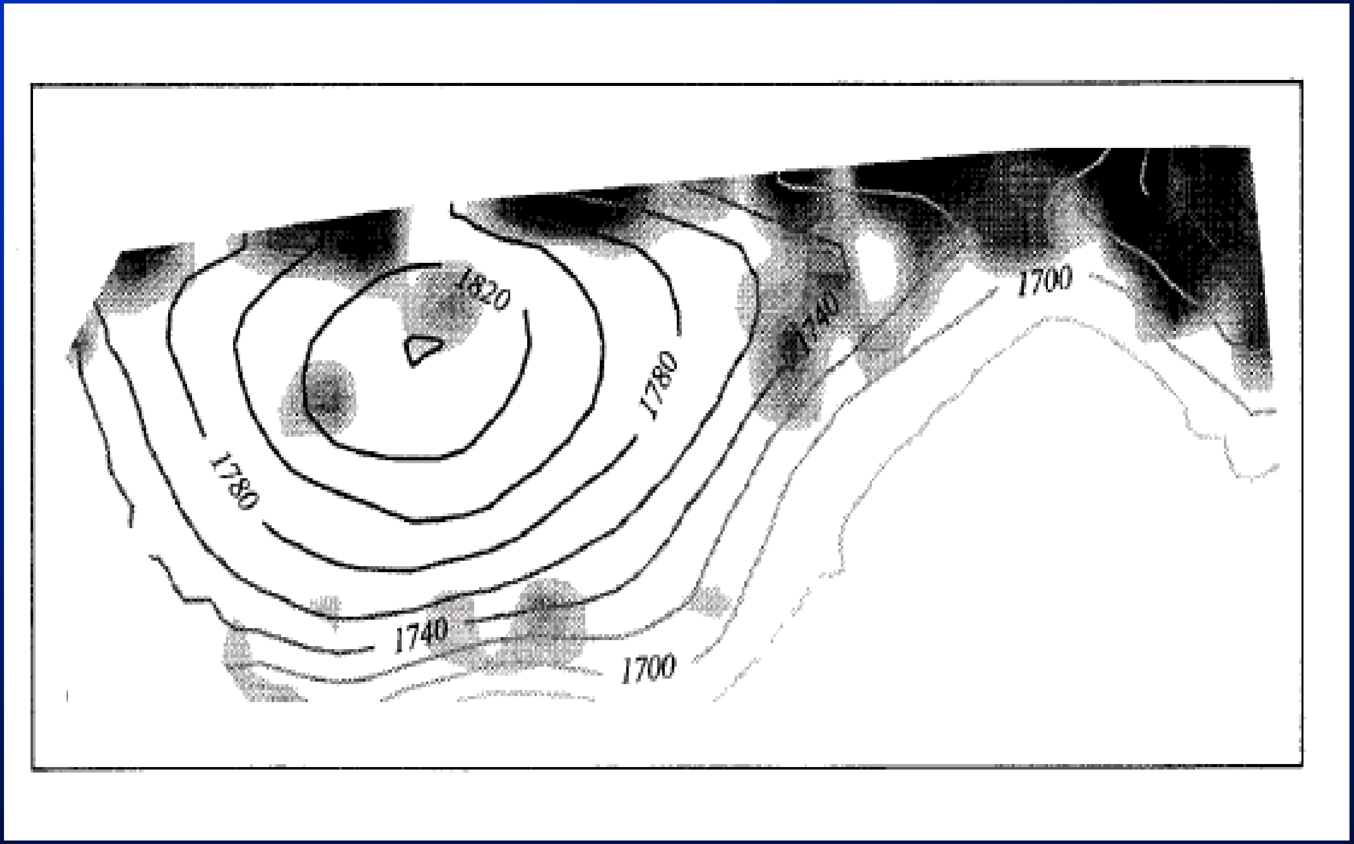
Most-negative principal curvature, k_1 (in red)

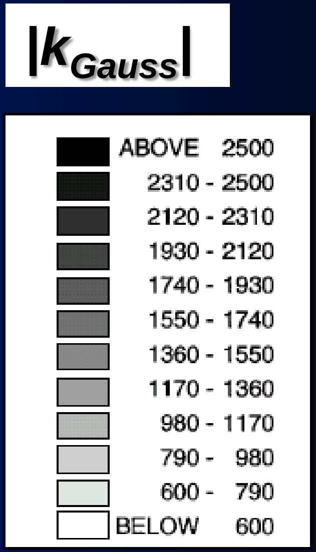
Most-positive principal curvature, k_2 (in blue)

http://www.geom.uiuc.edu/zoo/diffgeom/surfspace/concepts/curvatures/prin-curv.html

Curvature of picked horizons

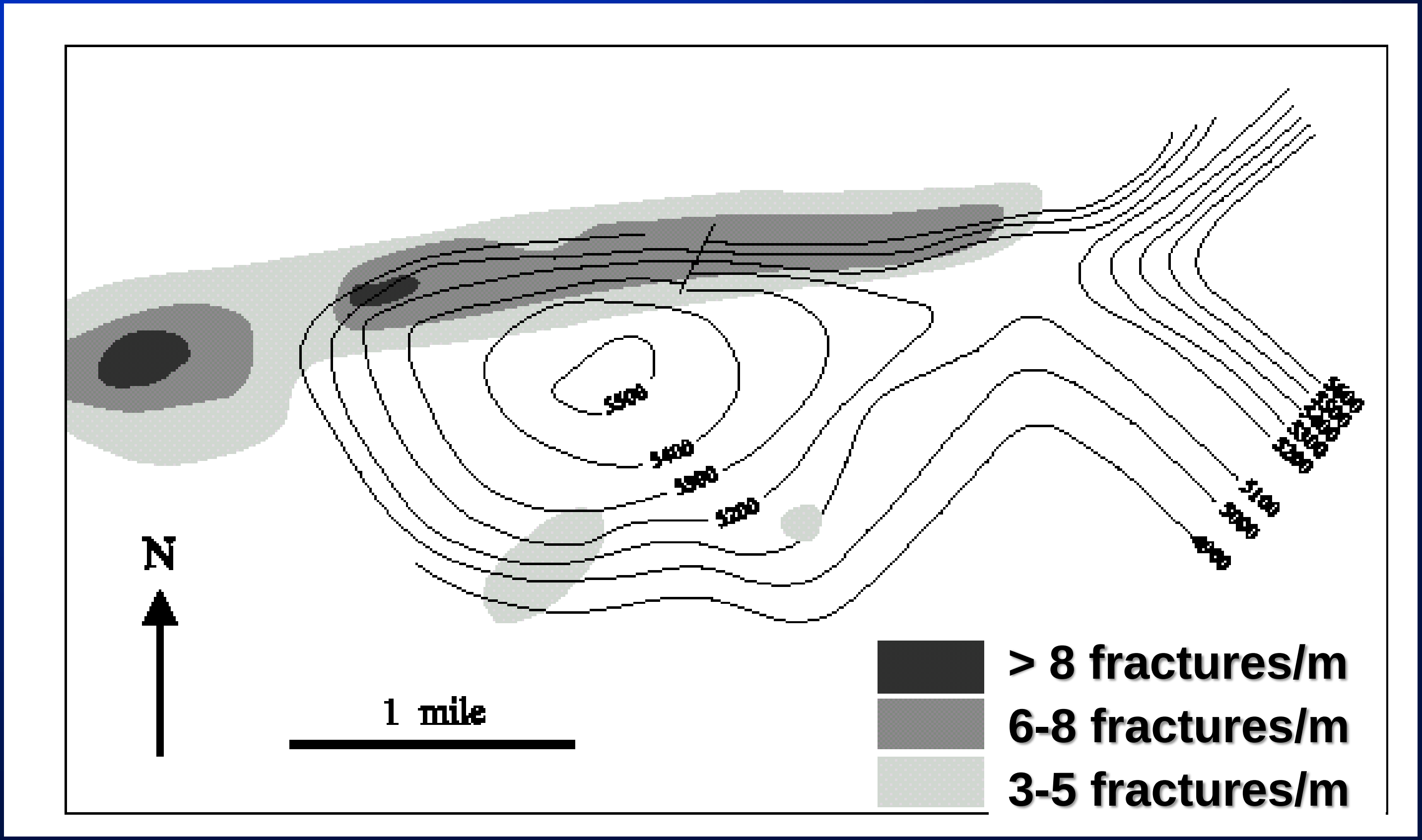
Gaussian curvature from outcrop
(Goose Egg Dome, WY, USA)





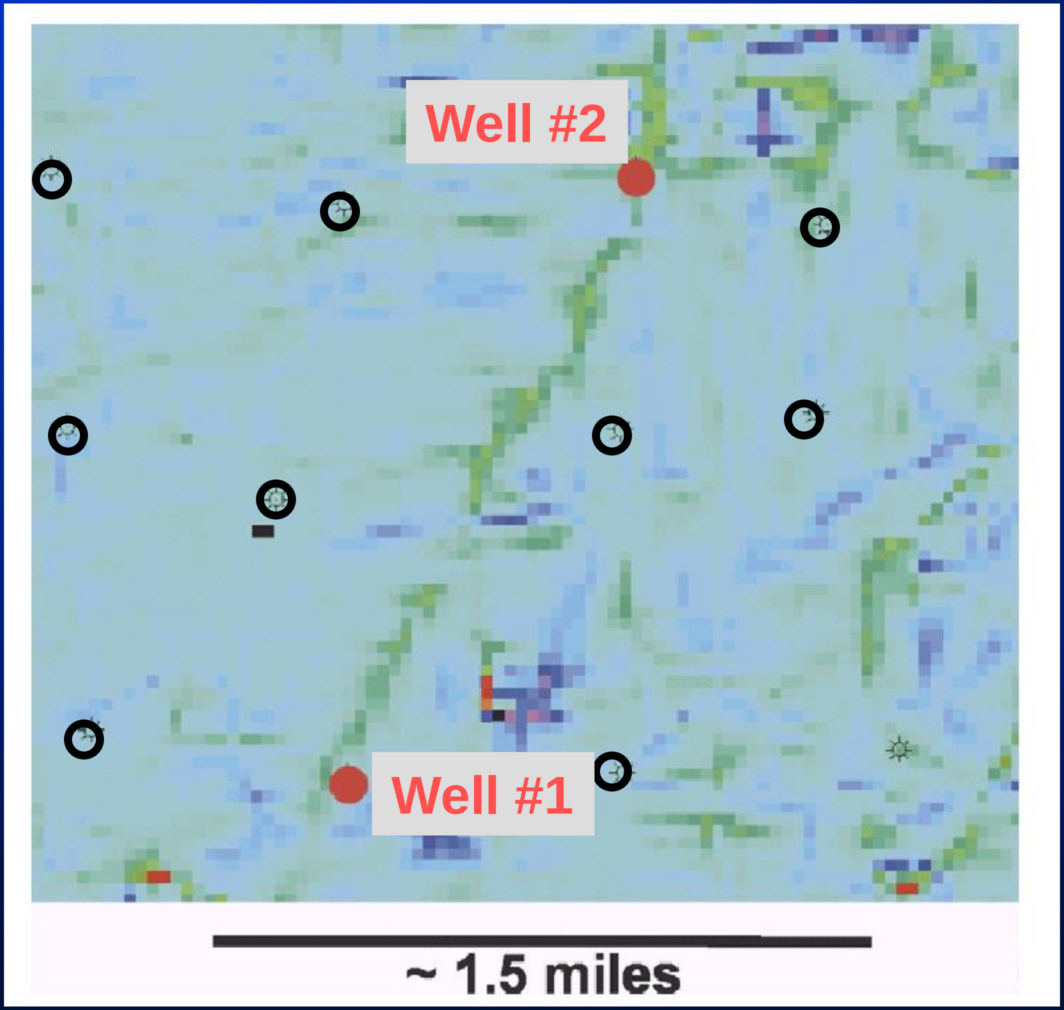
(Lisle, 1994)

Fracture density from outcrop
(Goose Egg Dome, WY, USA)



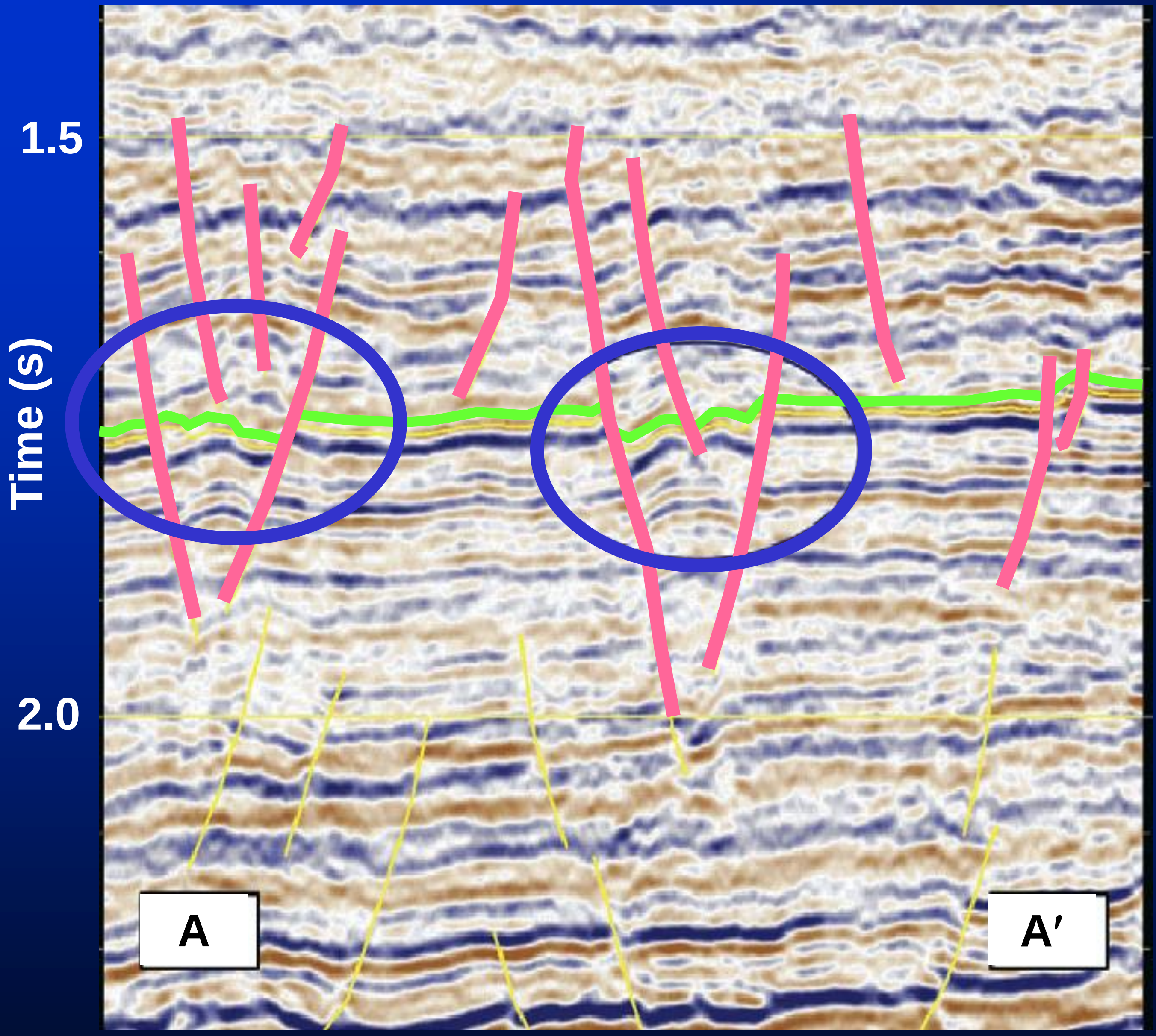
(Lisle, 1994)

Strike curvature and fracture detection (sandstones - San Juan Basin, NM)



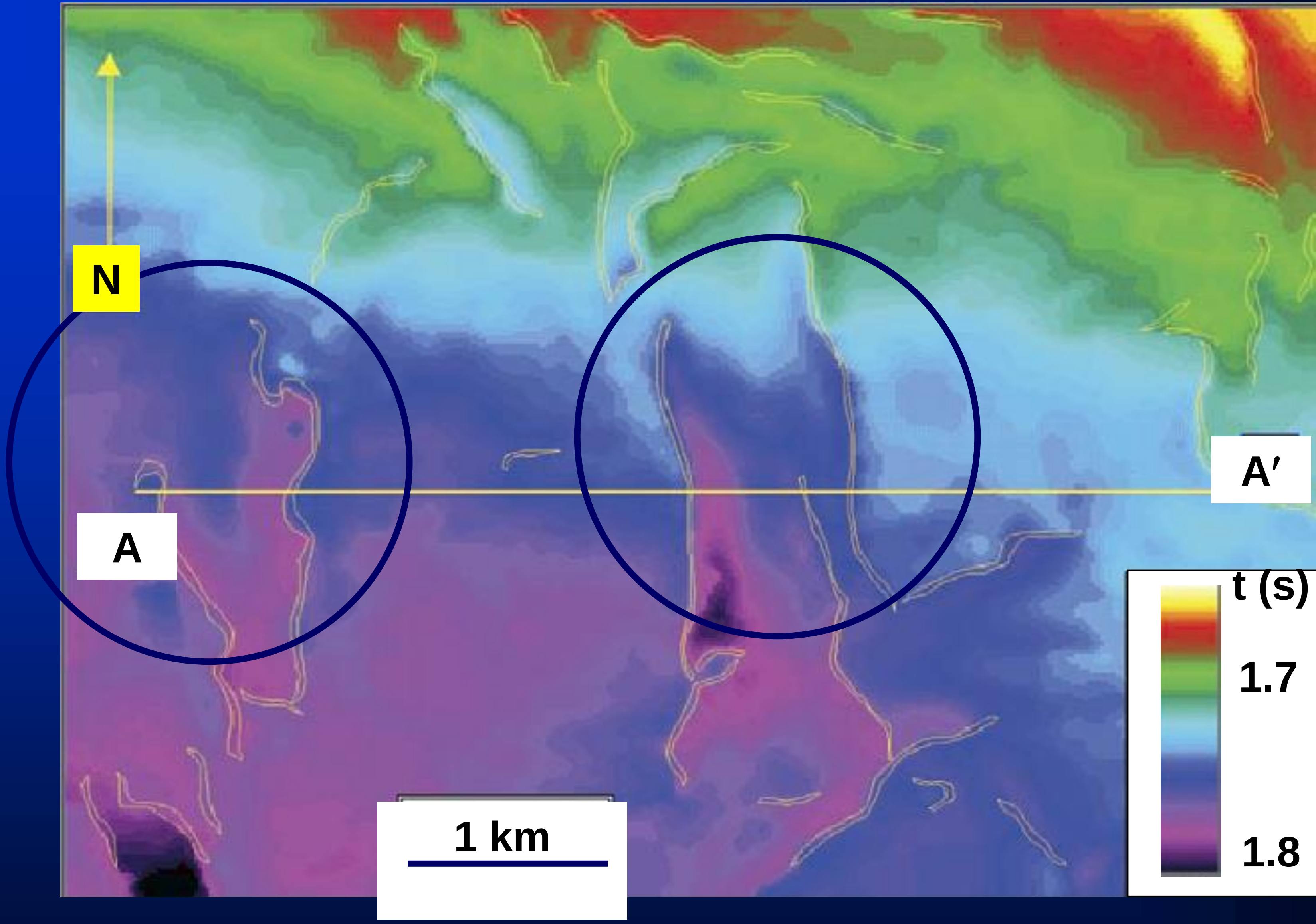
Wells 1 and 2 interfere with each other!

(Hart et al., 2002)



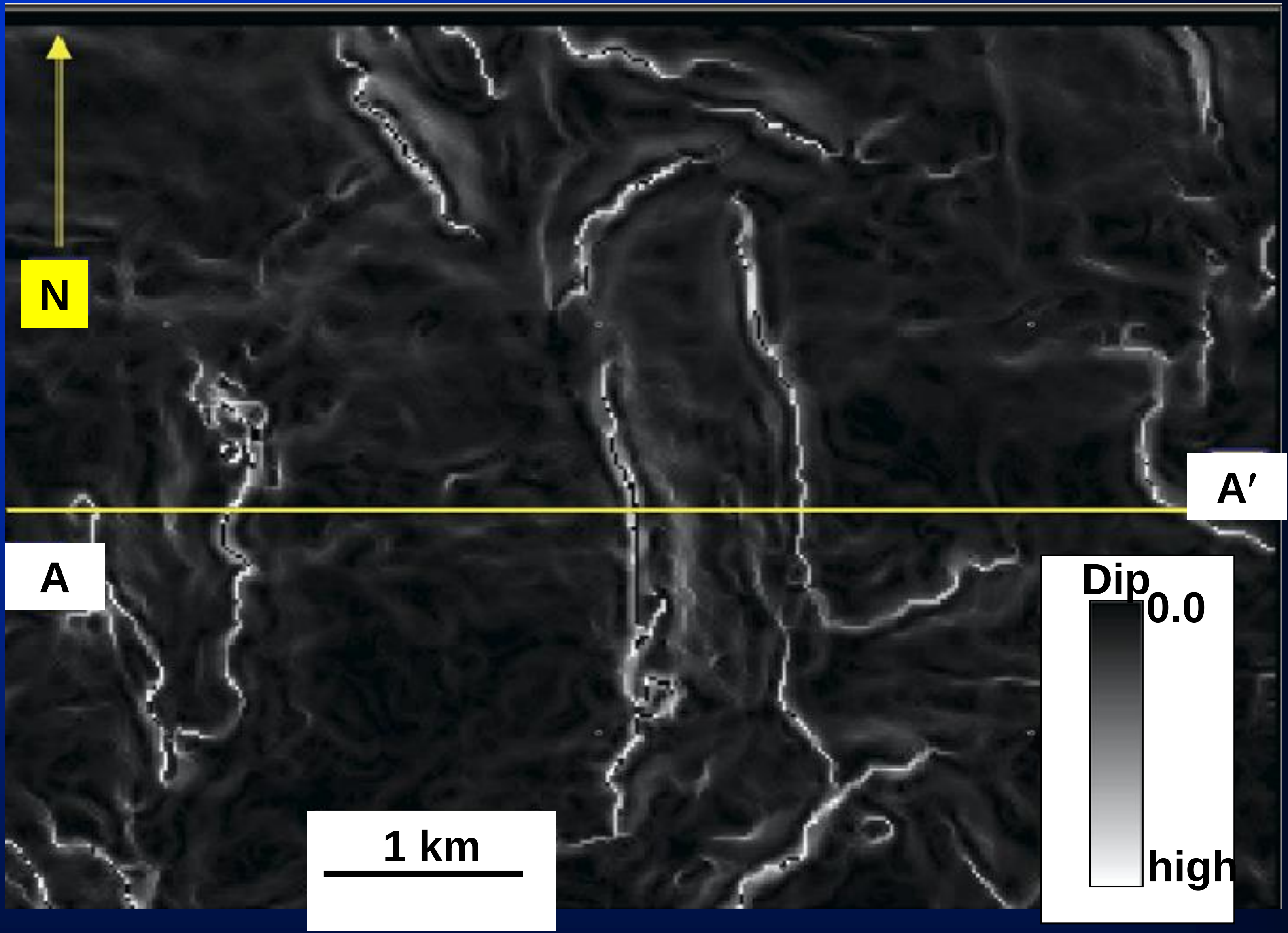
Seismic line through two grabens (Magallanes Basin, Argentina)

(Sigismondi and Soldo, 2003)



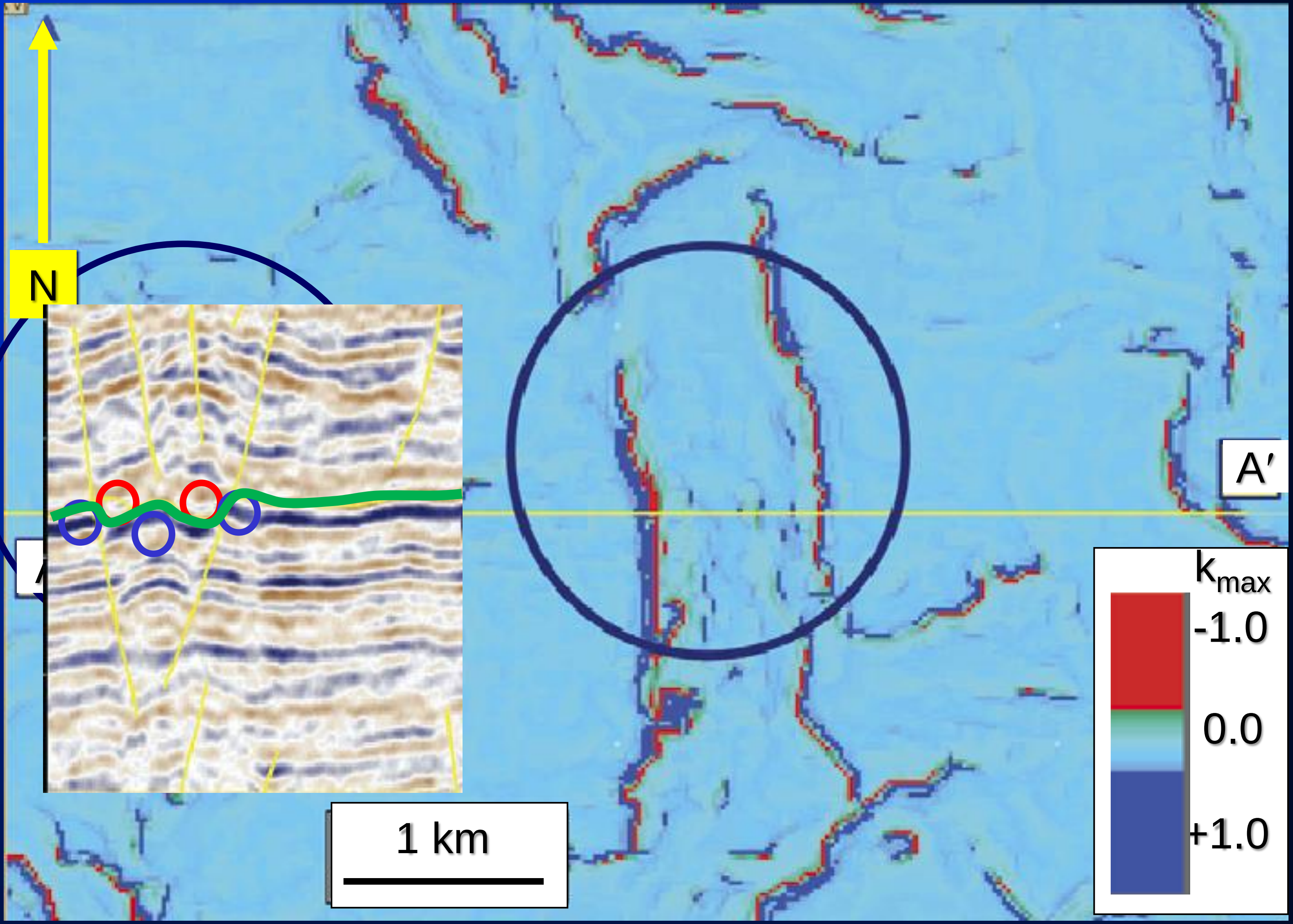
Time structure map. Line AA’ shown in previous figure.

(Sigismondi and Soldo, 2003)



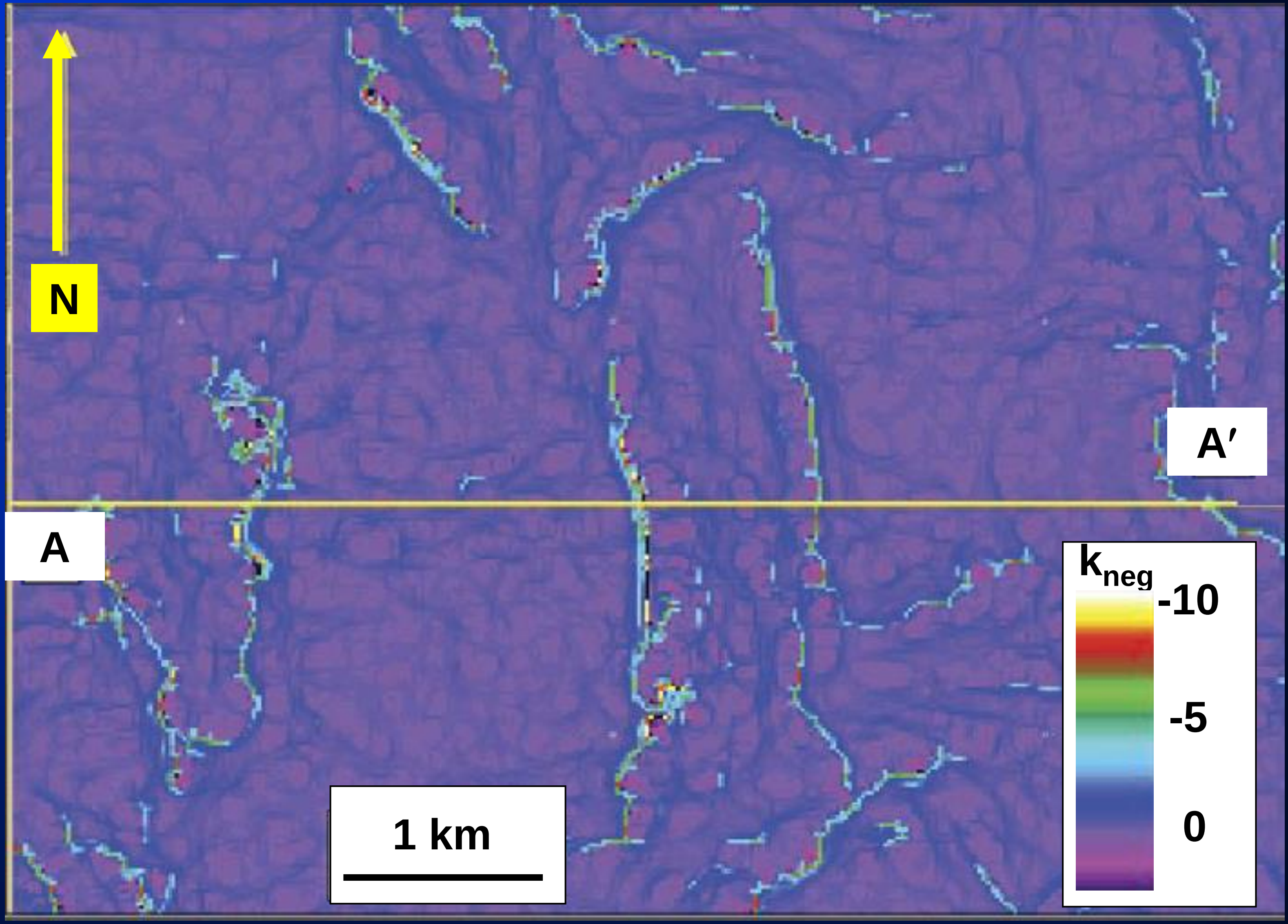
Dip magnitude calculated from the previous time structure map. Line AA’ shown in previous figure.

(Sigismondi and Soldo, 2003)



Maximum curvature calculated from time structure map. Circles indicates the grabens.

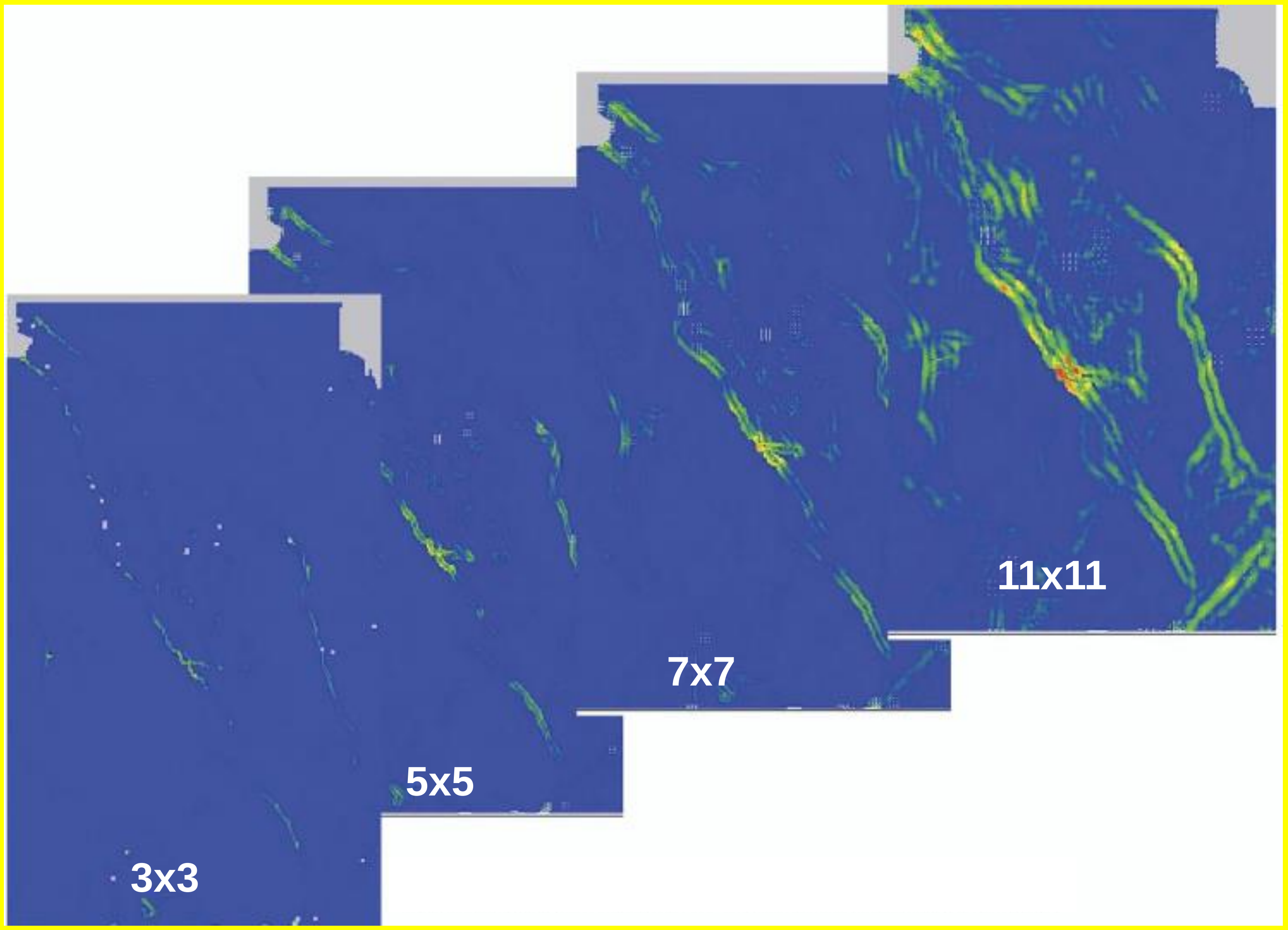
(Sigismondi and Soldo, 2003)



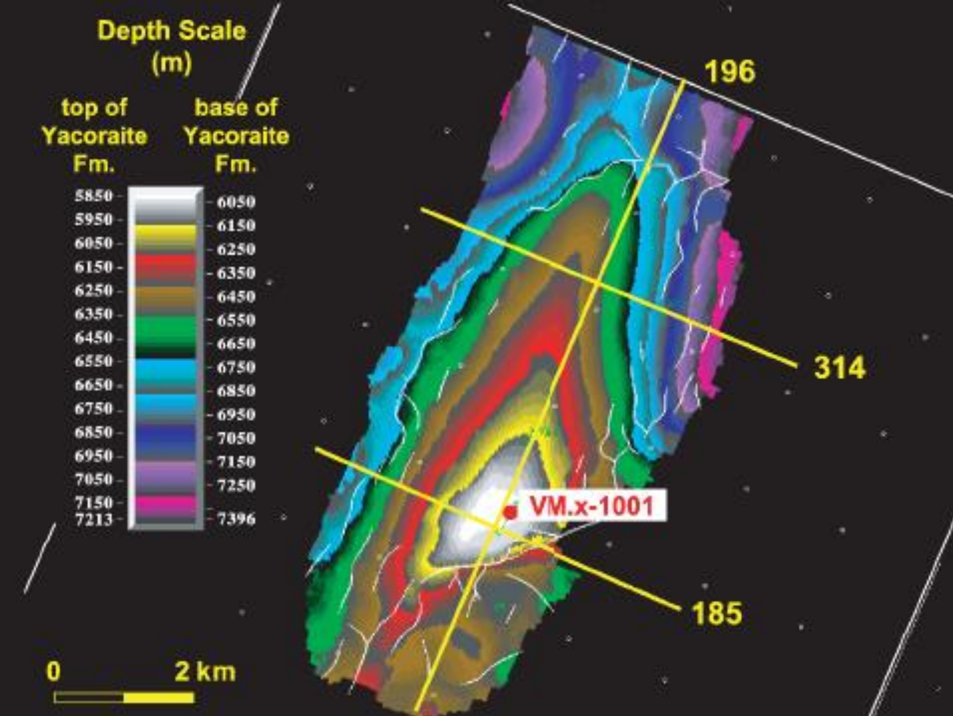
Most negative curvature corresponding to the interpreted horizon.

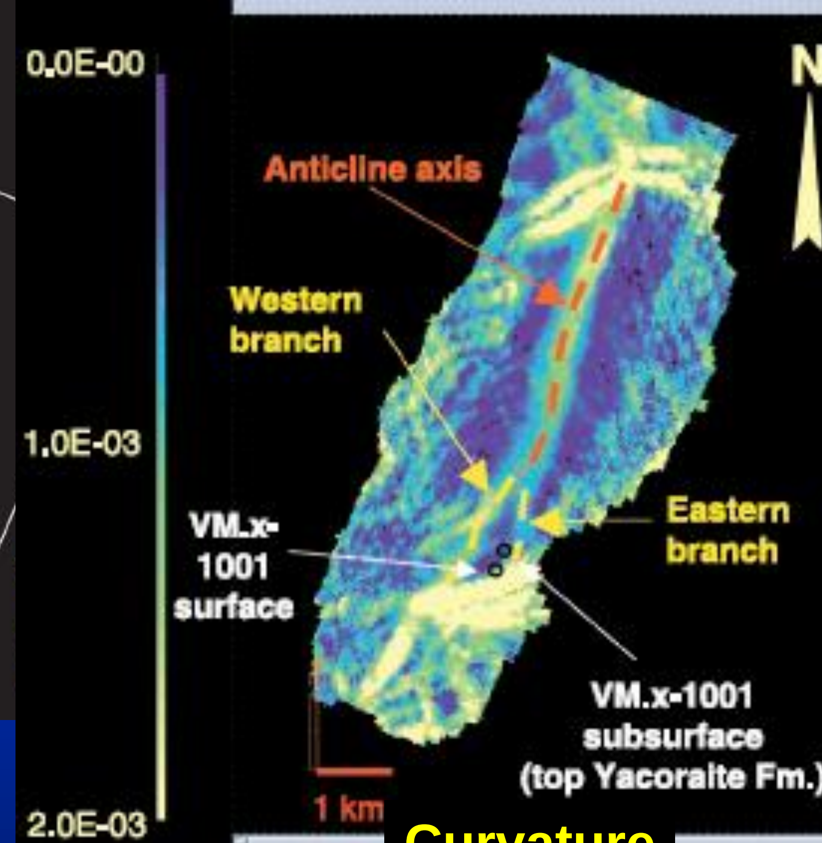
(Sigismondi and Soldo, 2003)

Curvedness using short to long analysis windows.

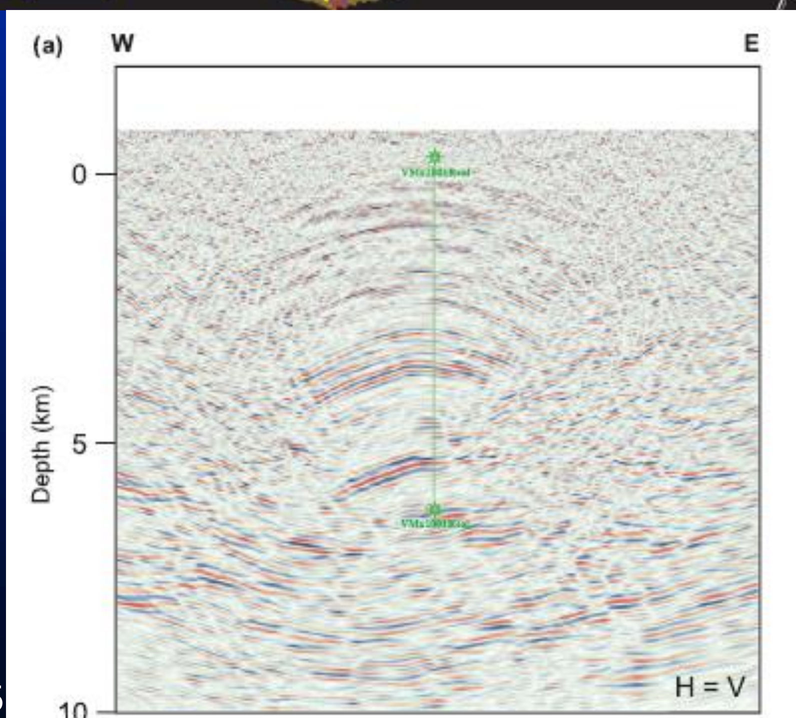


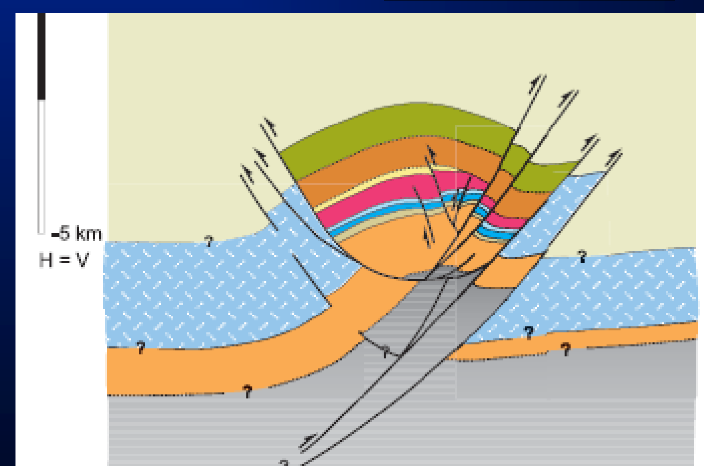
(Sigismondi and Soldo, 2003)





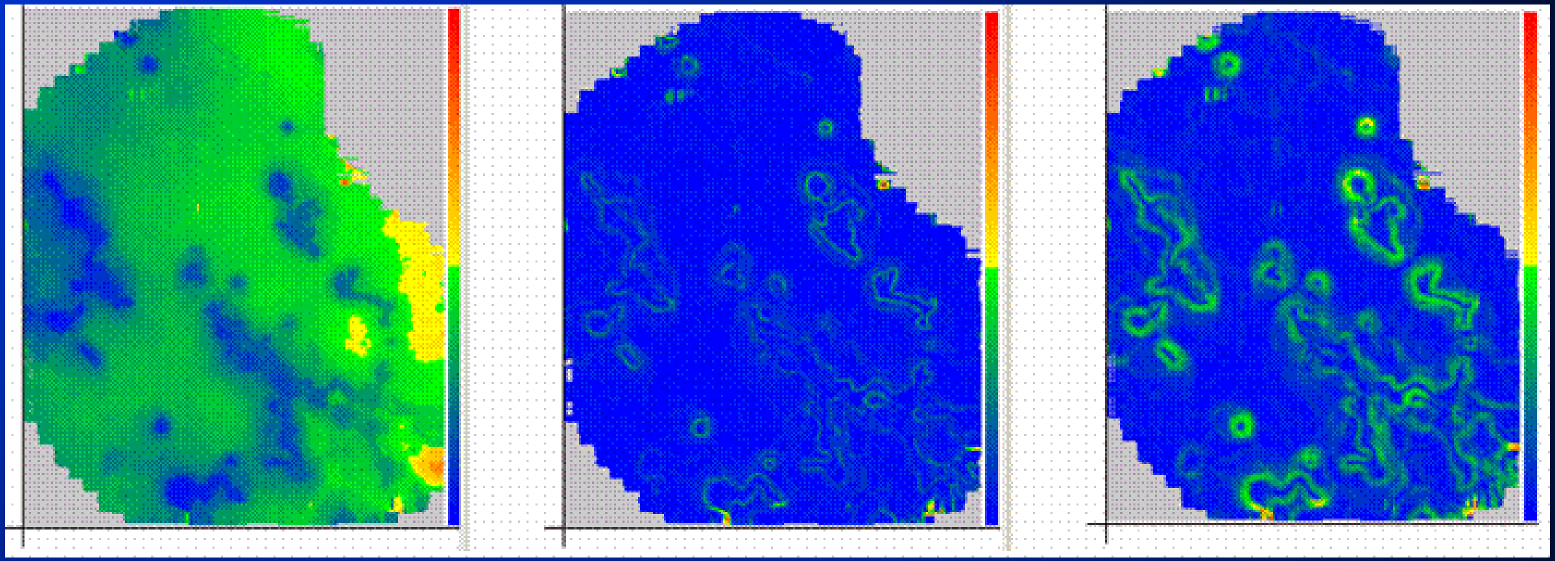
Curvature





(Masaferro et al., 2005)

Dip curvature at different scales



Time/structure

Dip curvature
Aperture=3x3

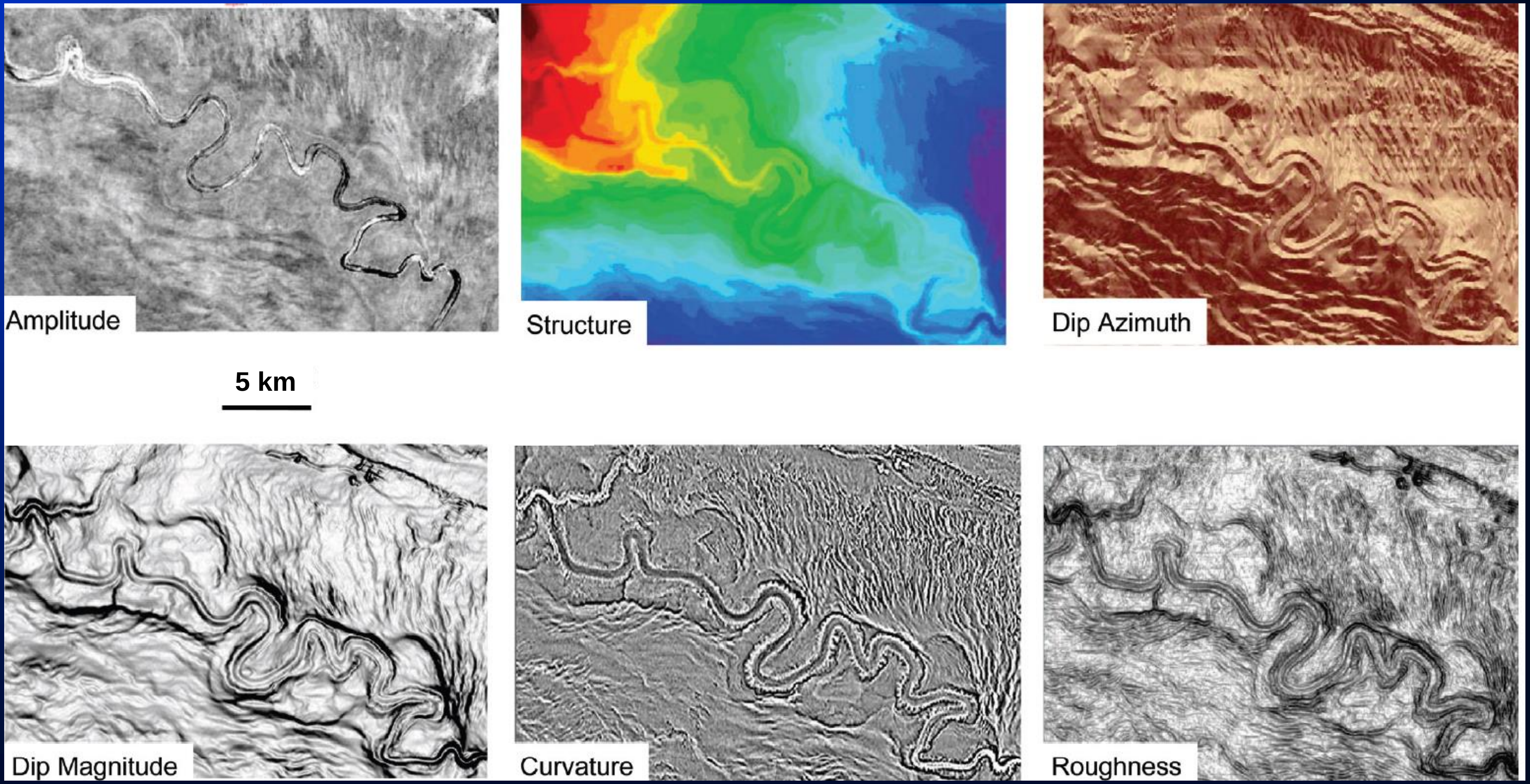
Dip curvature
Aperture=7x7

Devonian horizon with pinnacle build-ups from the Williston Basin. Changing the aperture on the curvature calculations improves definition of the pinnacles.

(Hart: http://www.eps.mcgill.ca/~hart/CURVZ_website.htm)

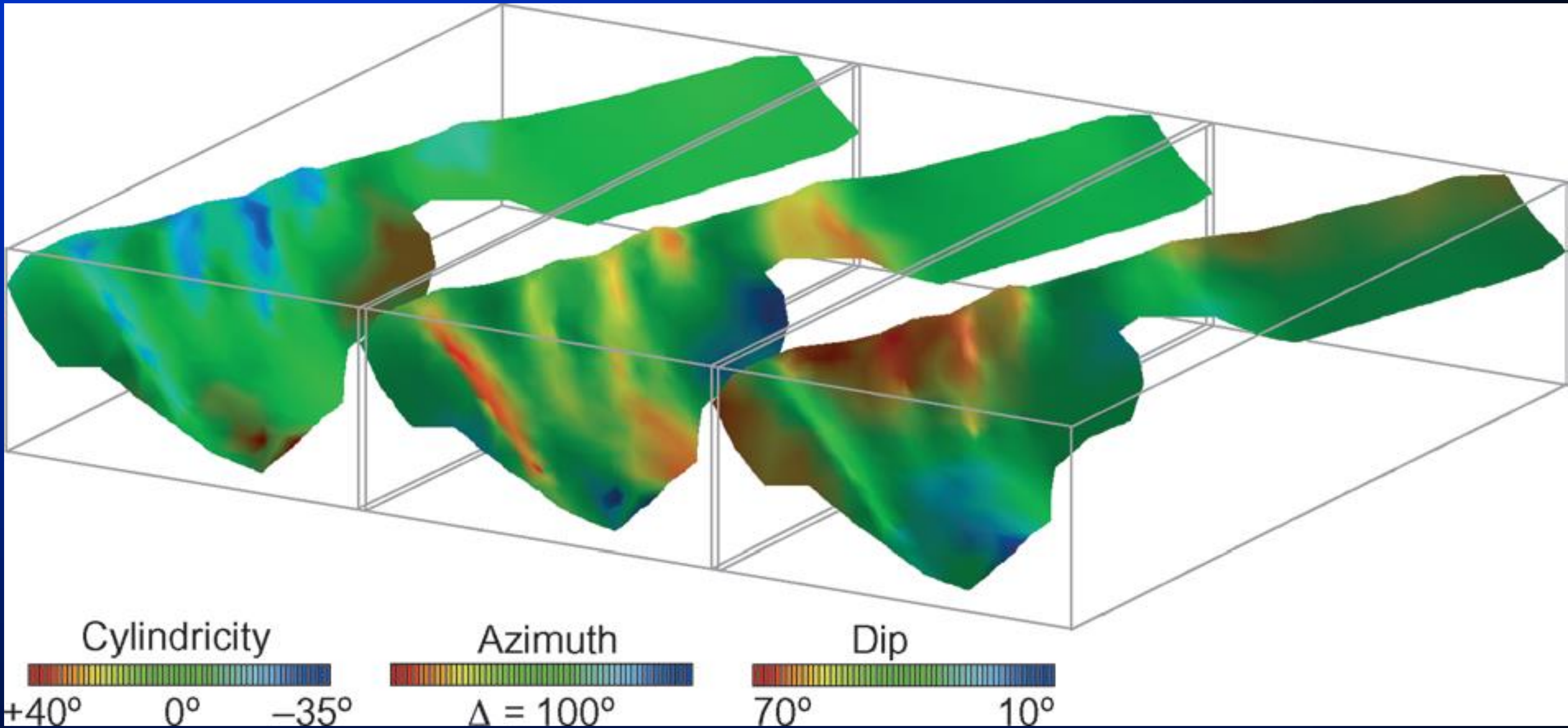
Horizon-based attributes applied to stratigraphic features

Desoto Canyon, Gulf of Mexico

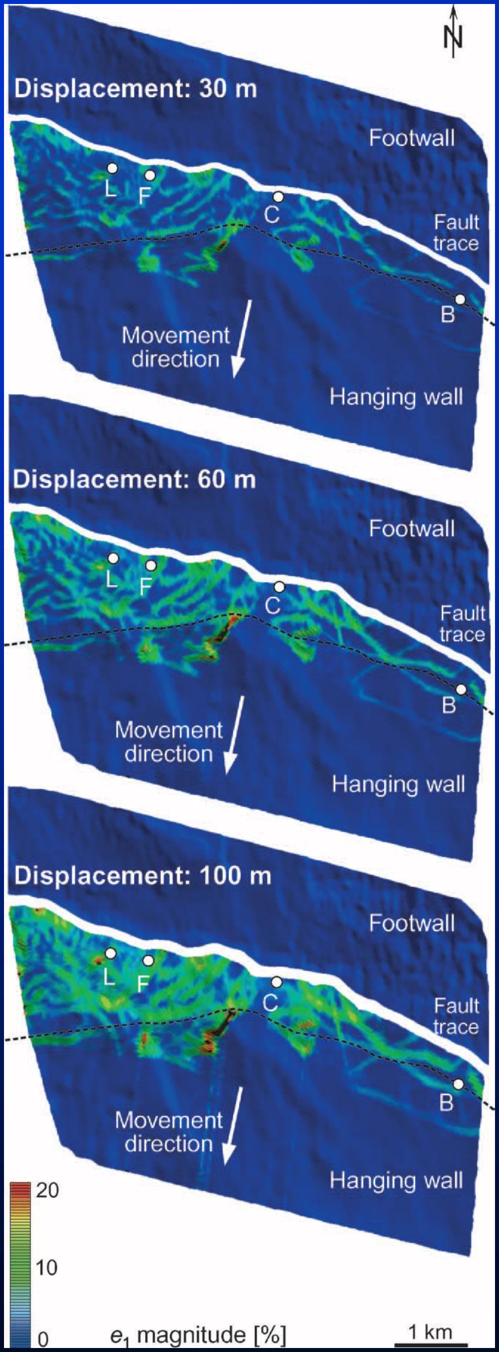


(Posamentier, 2005)

Attributes applied to fault surfaces. Axes of corrugations define direction of fault movement.



(Lohr et al., 2008)

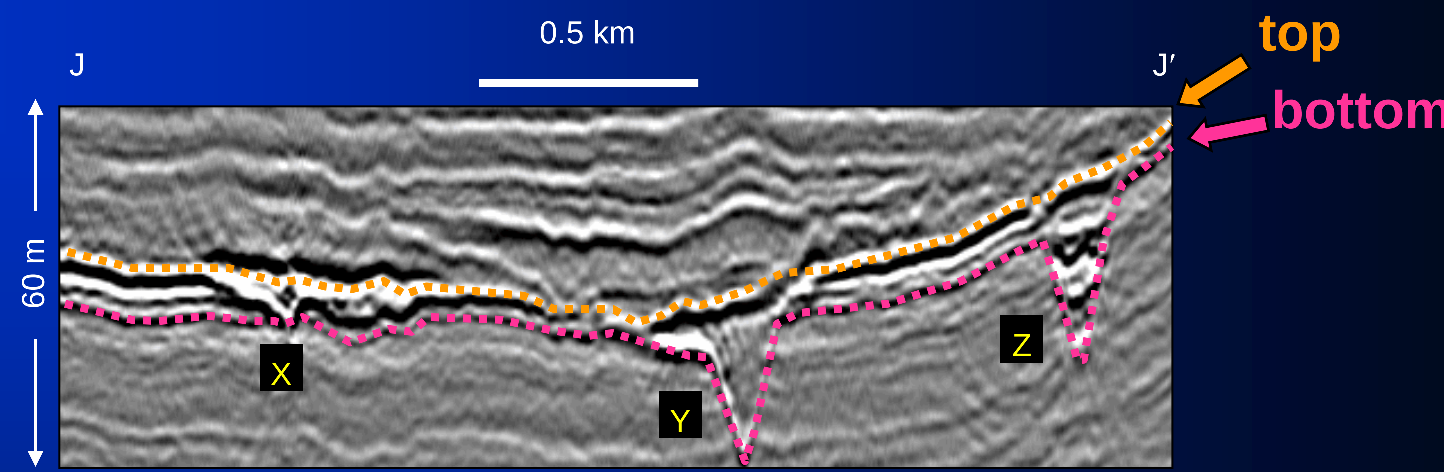


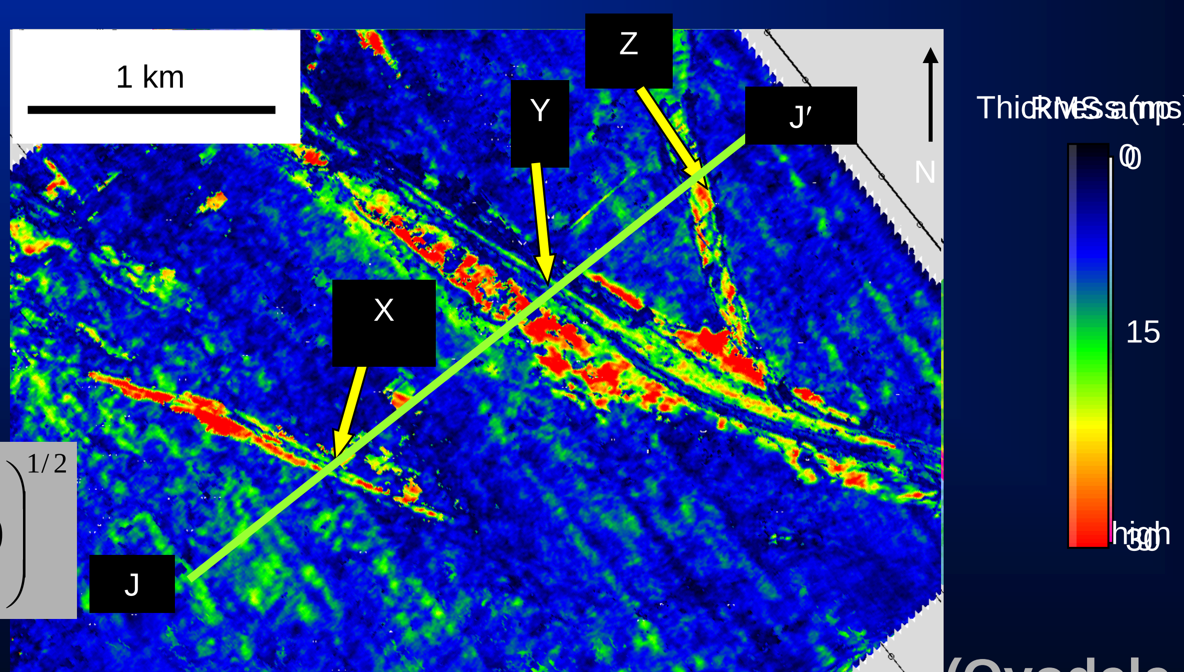
Using direction of fault movement to predict strain

(Retrodeformation modeling)

(Lohr et al., 2008)

Common Attributes Using an Analysis Window



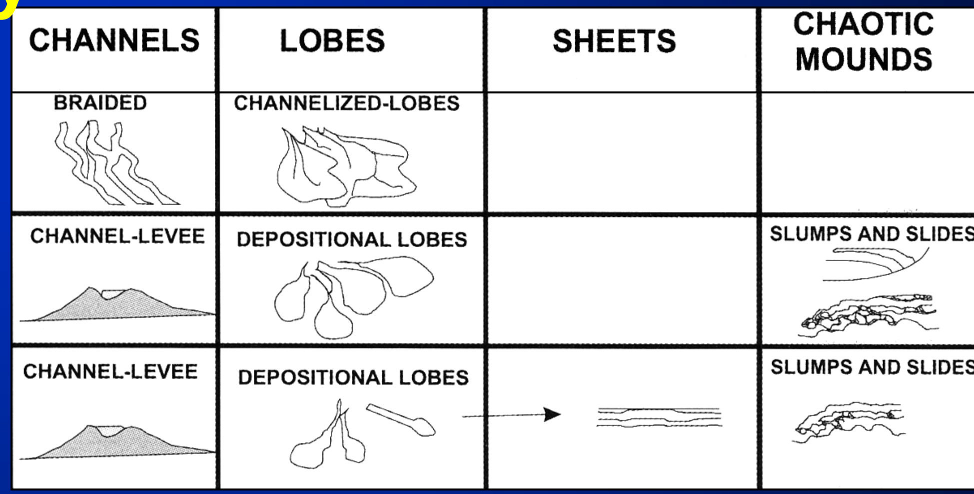


$$d_{RMS} = \left(\frac{1}{T_{bot} - T_{top}} \sum_{t=T_{top}}^{T_{bot}} d^2(t) \right)^{1/2}$$

(Oyodele, 2005)

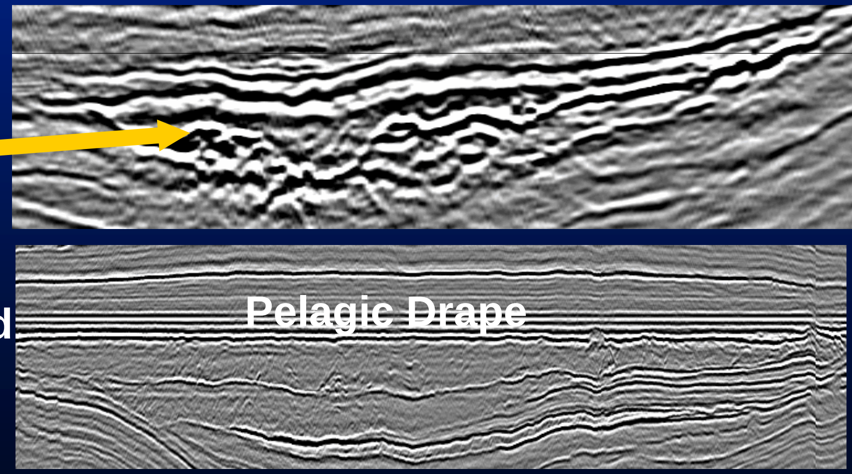
Seismic Facies description based on

- geometry



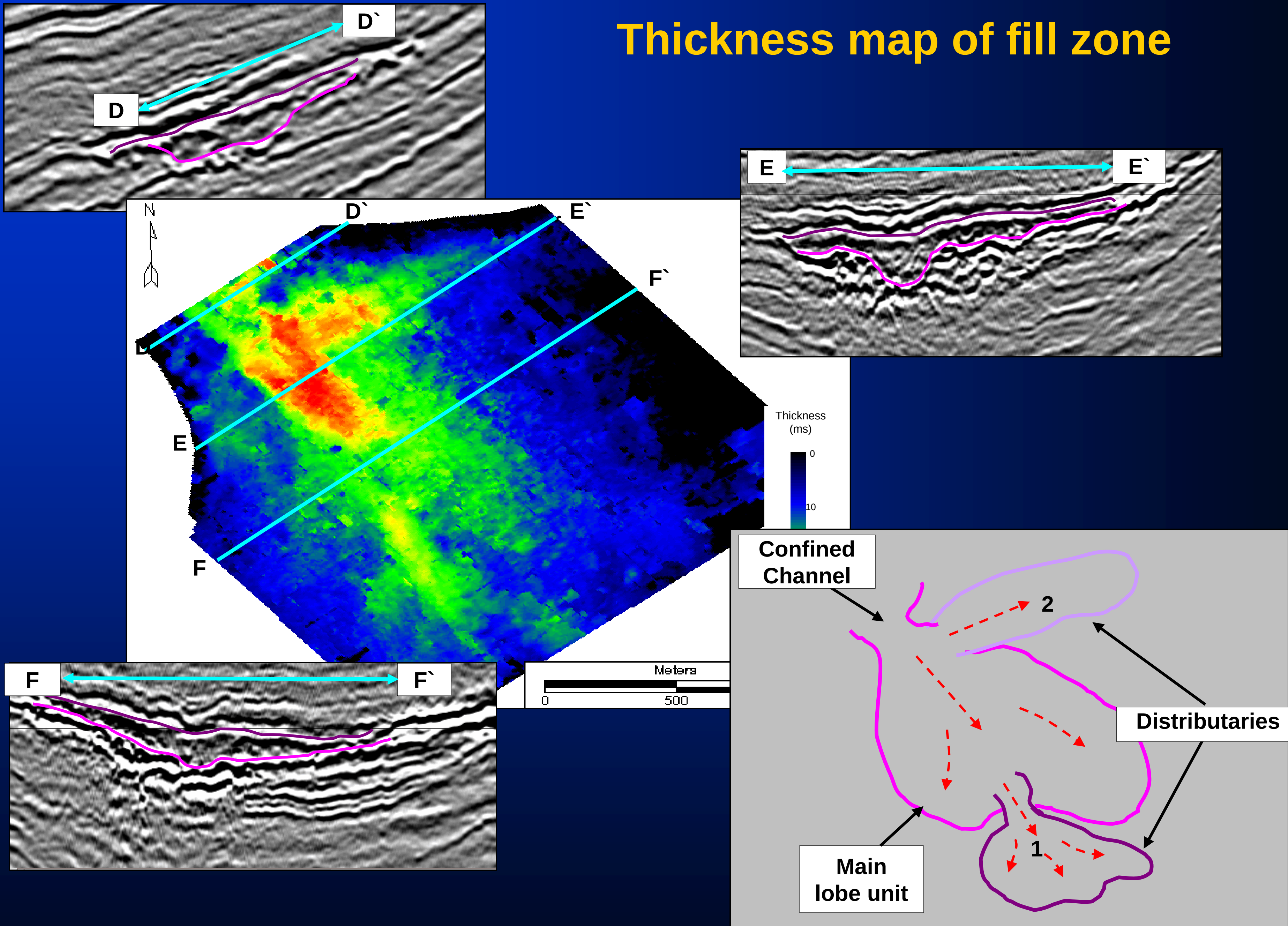
(Reading & Richards, 1998)

- reflection character



(Oyodele, 2005)

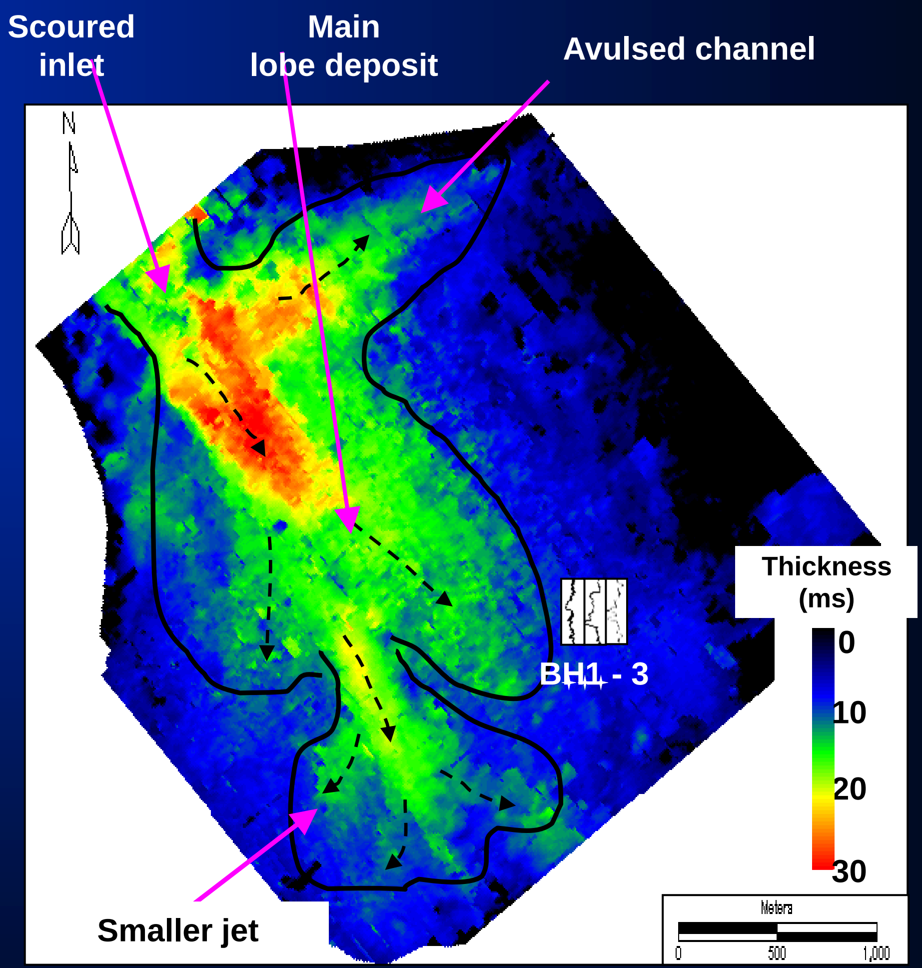
Thickness map of fill zone



(Oyodele, 2005)

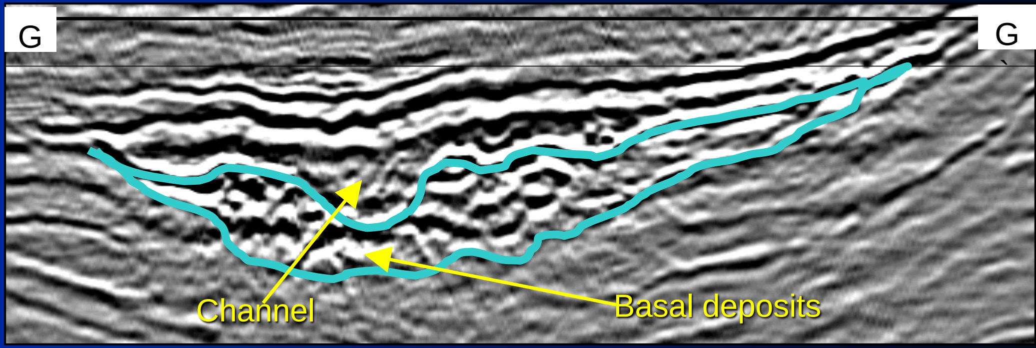
Thickness map of fill zone

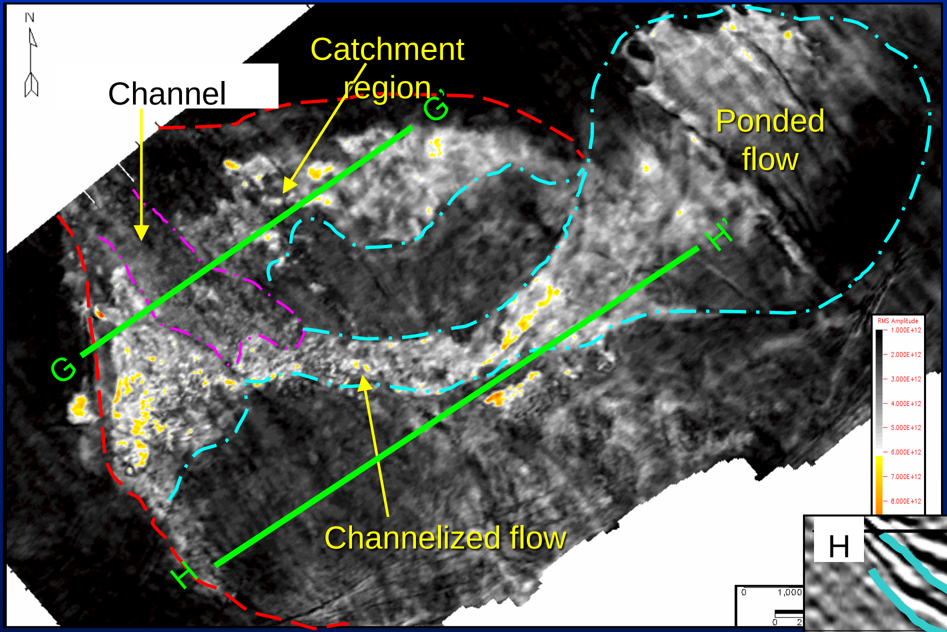
ExxonMobil URC Tank Experiment
(Van Wagoner et al, 2003)

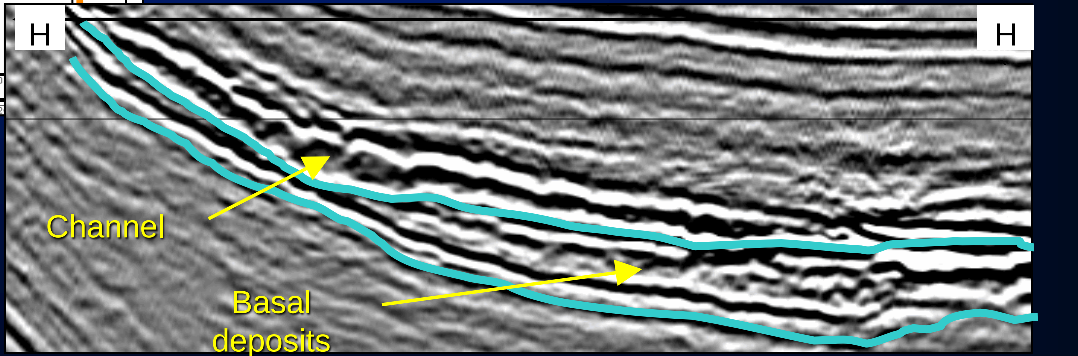


(Oyodele, 2005)

RMS amplitude map of a fill zone (20 ms)

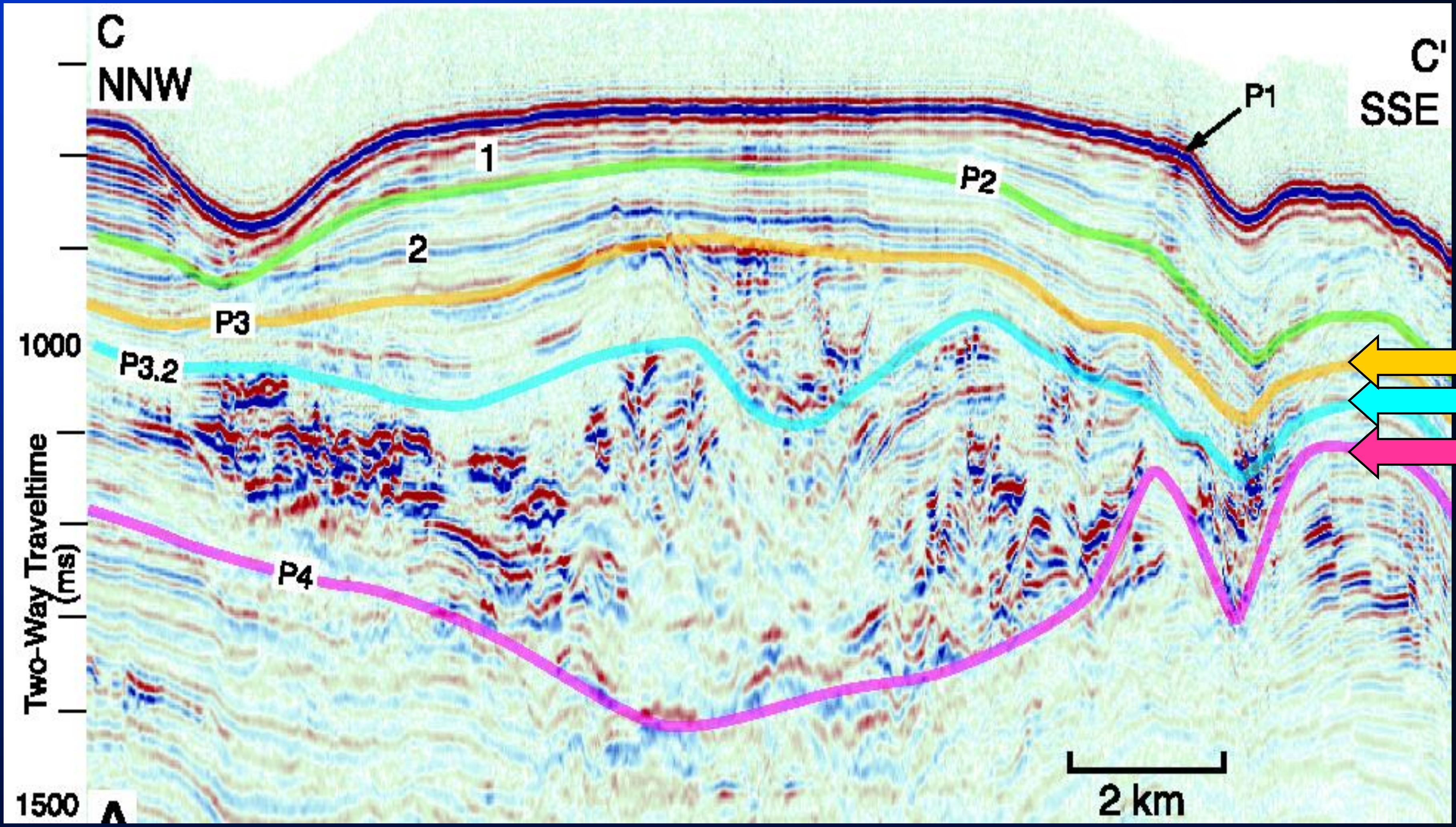






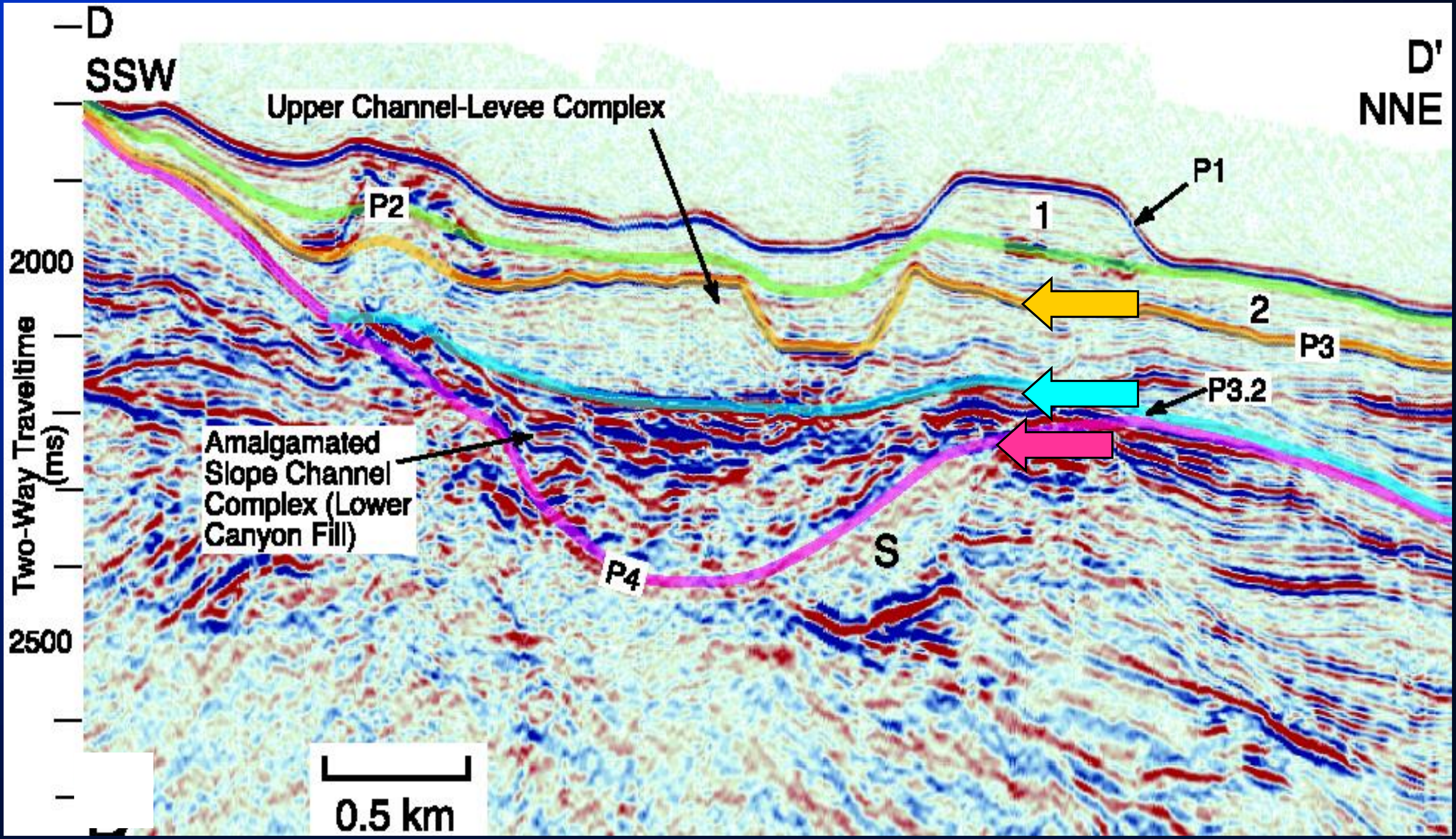
(Oyodele, 2005)

Lowstand delta front and slope
Offshore Kalimantan



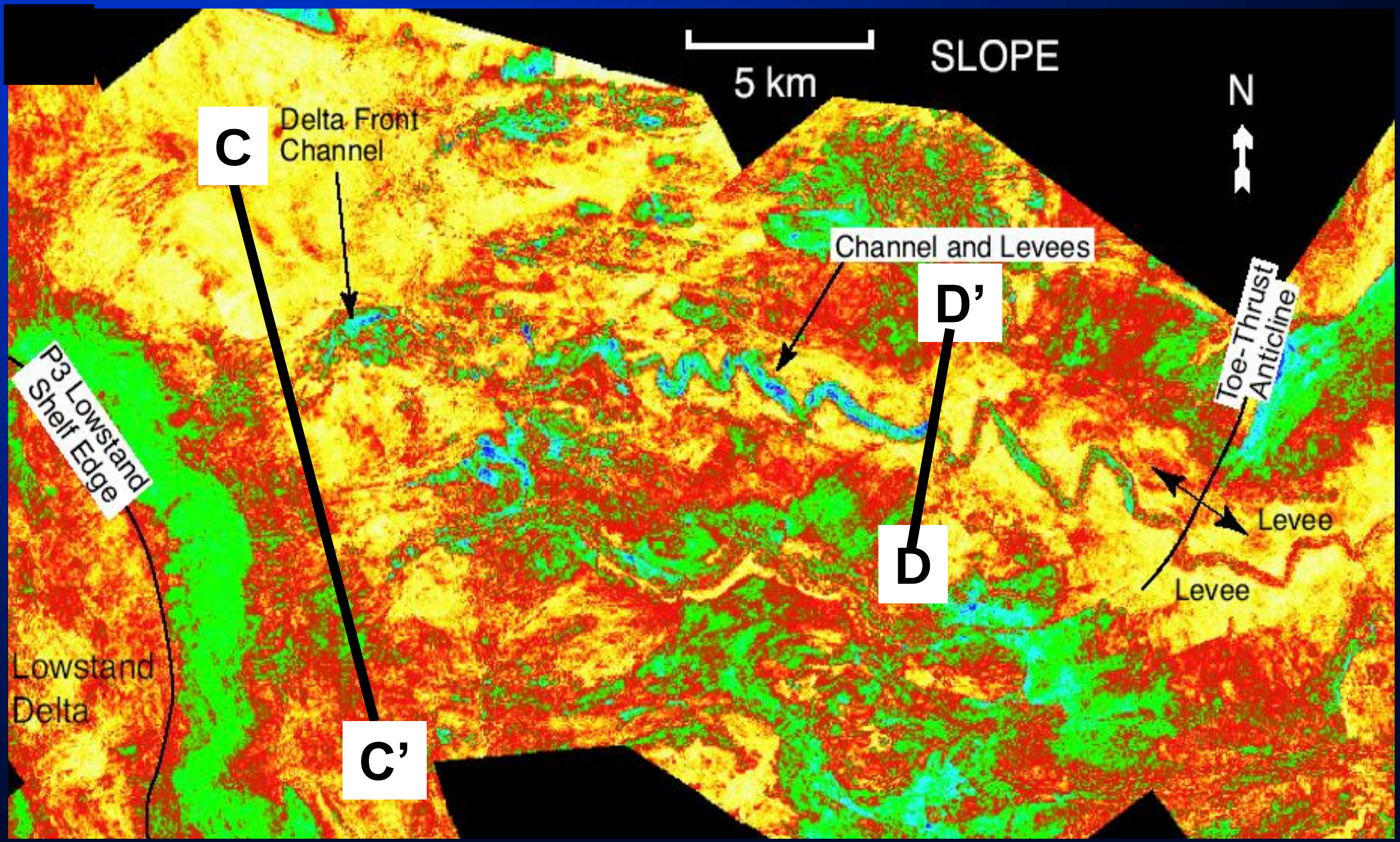
(Saller et al., 2004)

Lowstand delta front and slope
Offshore Kalimantan



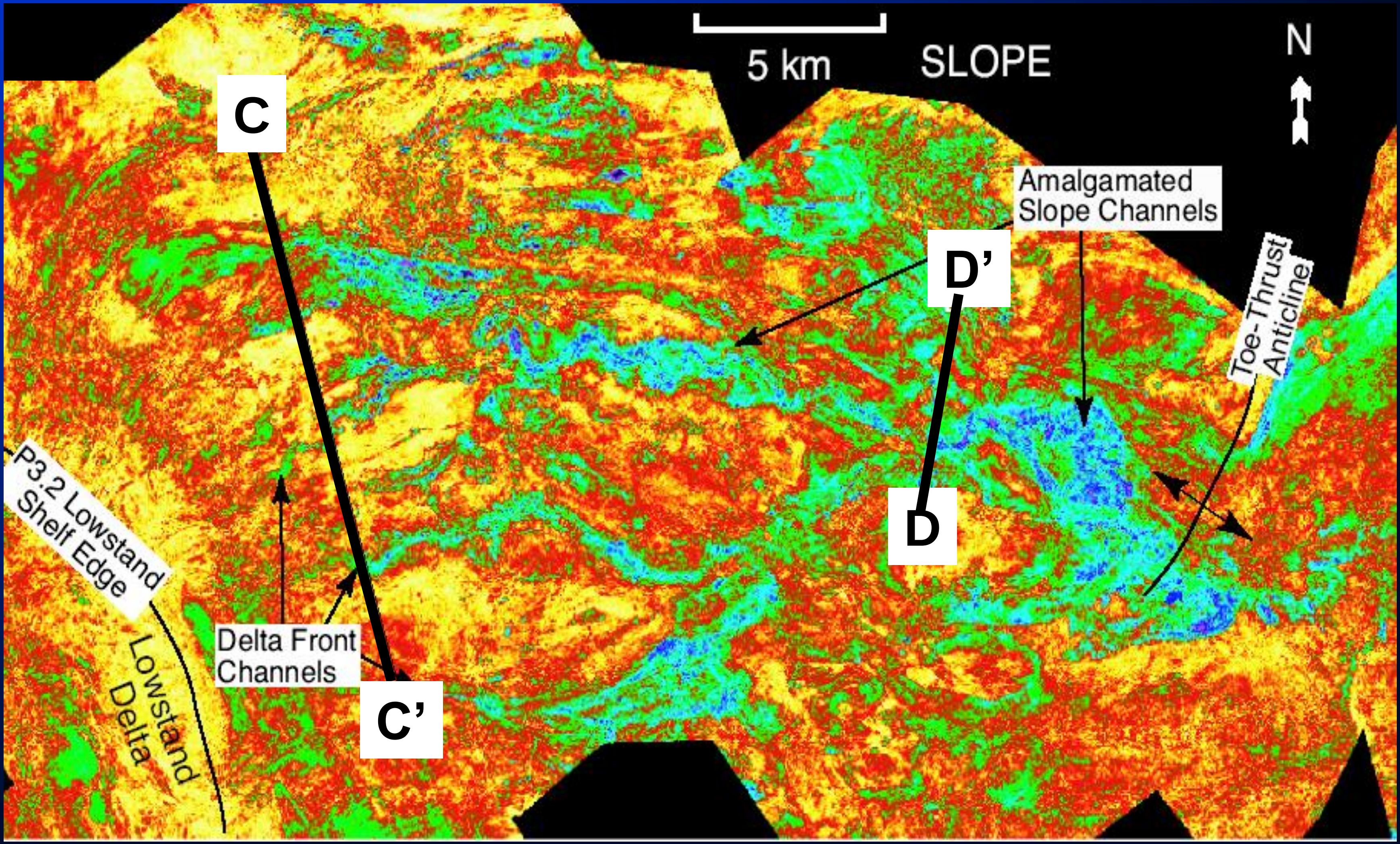
(Saller et al., 2004)

RMS amplitude between horizons P3 and P3.2
Higher amplitude channels inferred to be sandy



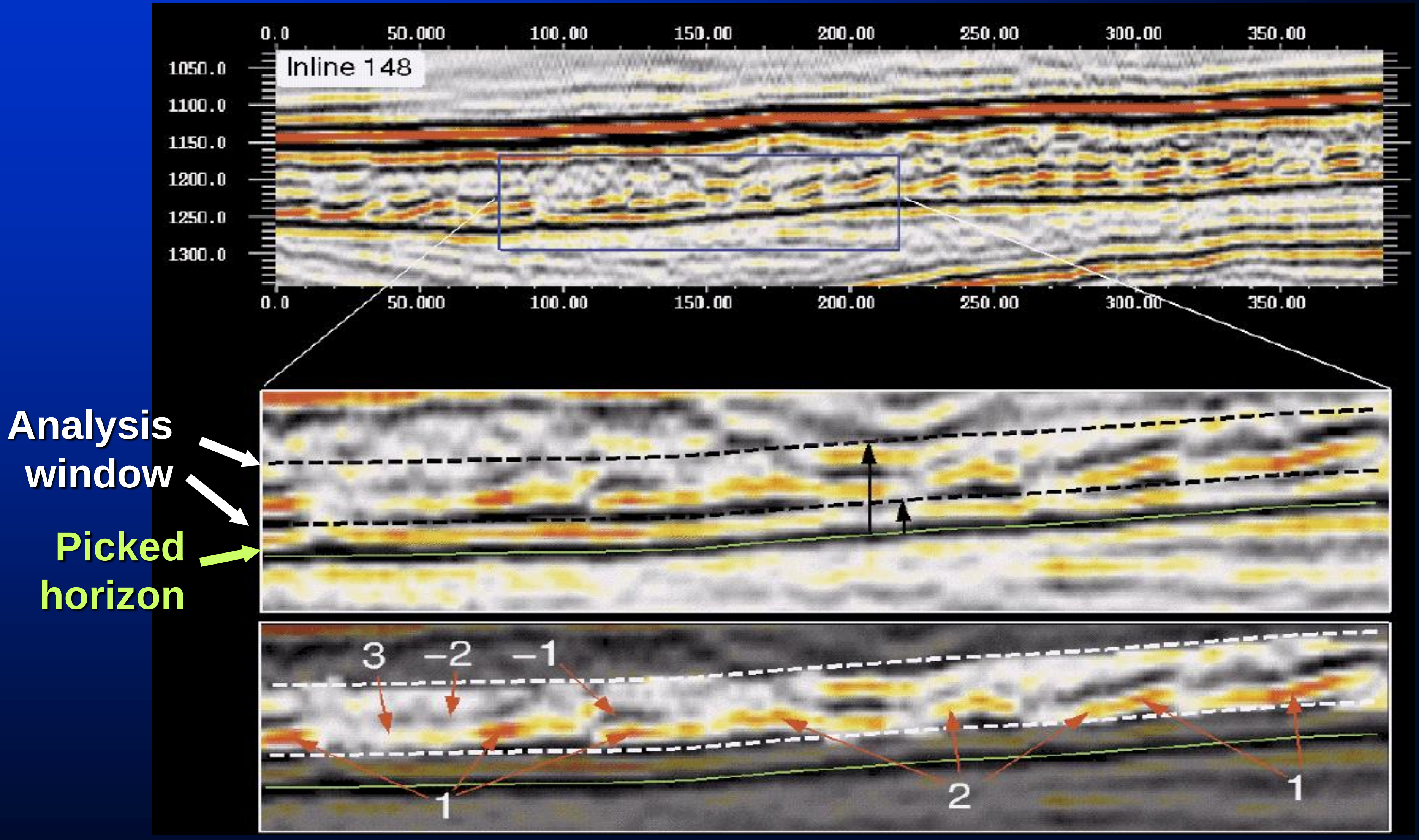
(Saller et al., 2004)

RMS amplitude between horizons P3.2 and P4. Channels coalesce into canyon.



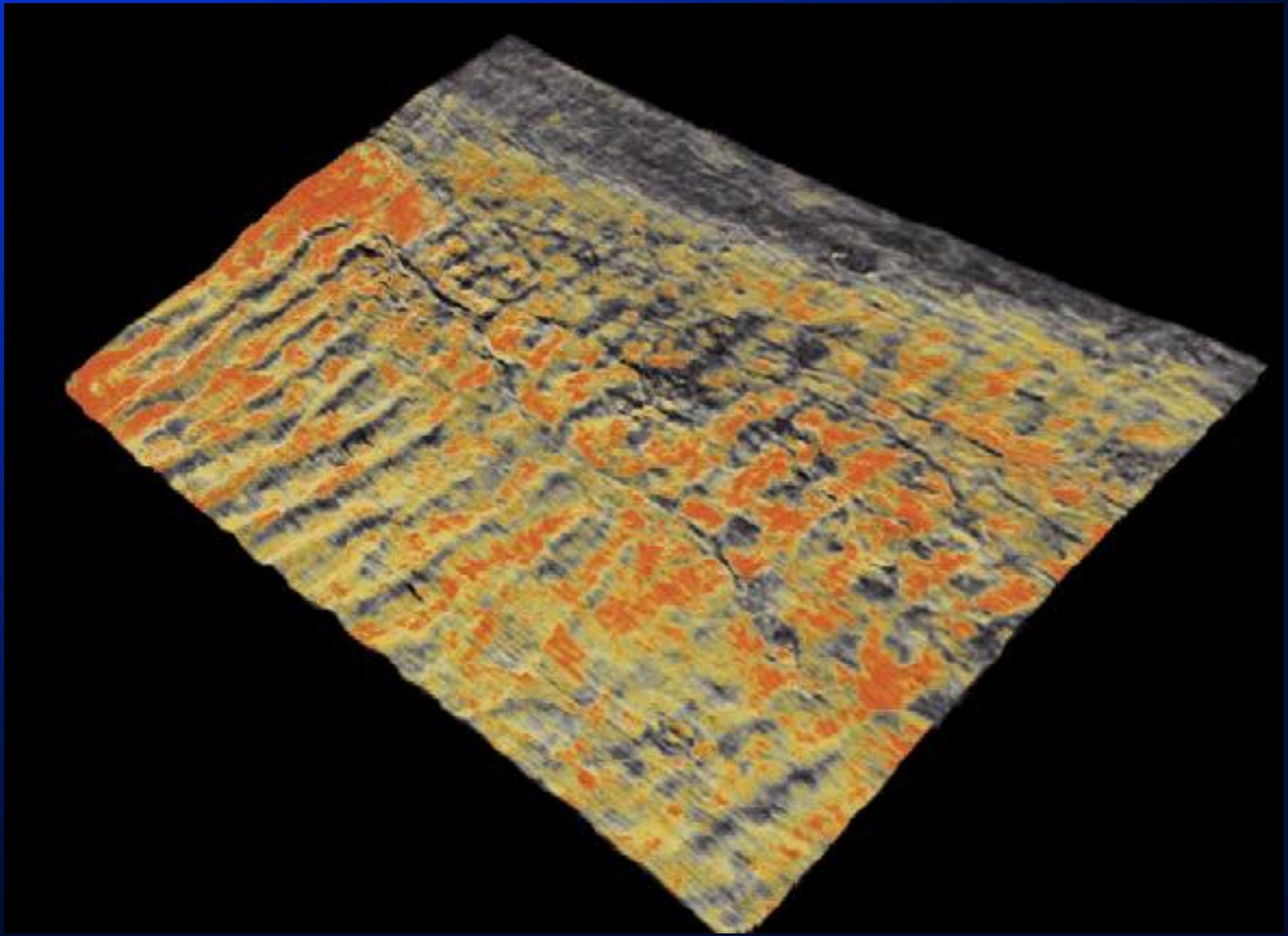
(Saller et al., 2004)

Optical stacking – the relation between formation attributes and 3D visualization



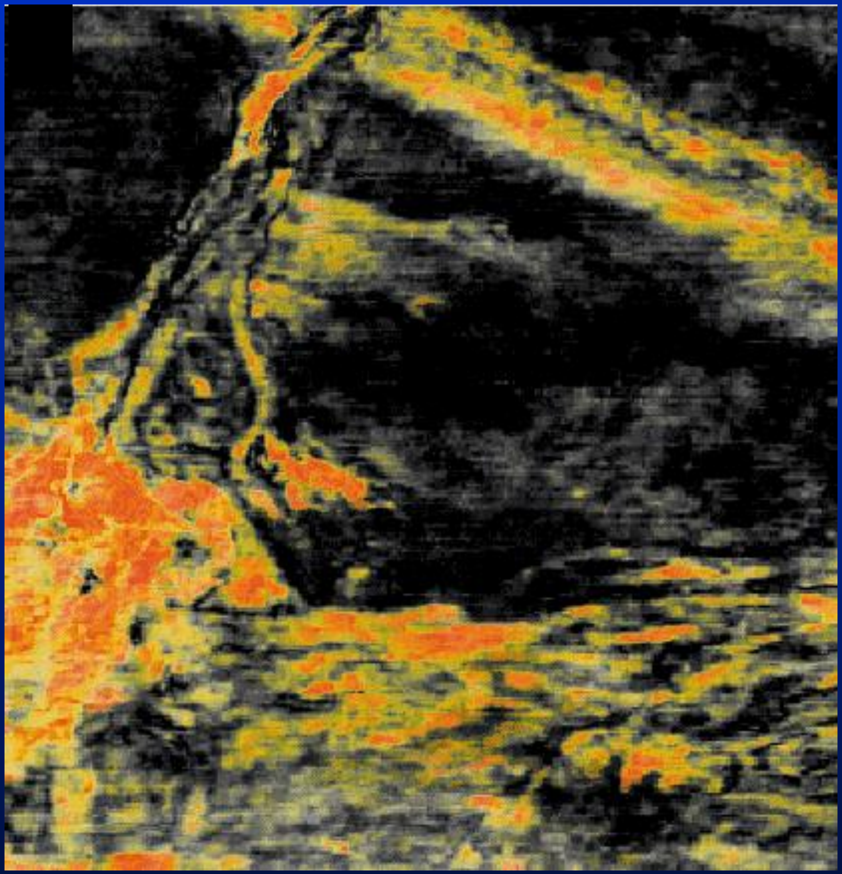
(Kidd, 1999)

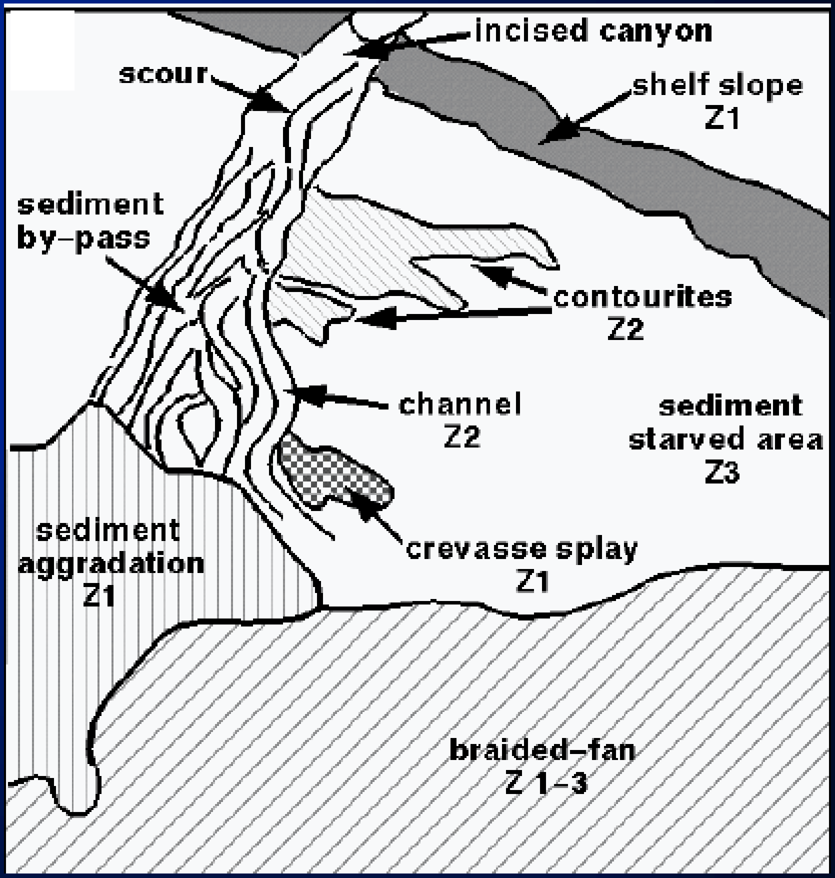
Optical stacking – the relation between formation attributes and 3D visualization



(Kidd, 1999)

Optical stacking – the relation between formation attributes and 3D visualization





Lowstand channel fan system

(Kidd, 1999)

Horizon, and Formation Attributes

In Summary:

- Horizon dip magnitude, dip azimuth, combined dip/azimuth, and shaded relief maps can exhibit subtle faults and channels not readily seen on the vertical seismic data itself

- Horizon curvature maps can be correlated to the presence of fractures.

- RMS, Average Absolute Amplitude, and other attributes sensitive to energy can characterize chaotic, high-energy features that cannot easily be picked

- Volume visualization using transparency ‘optically stacks’ the data resulting in images that are related to formation attributes