Visualization in Geophysics

Recent advances in seismic volume rendering

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Visual Computing Forum

UNIVERSITAS BERGENSIS

Overview

This talk is divided in 3 parts

- Ground truth visualization of measured seismic data
- Automated object extraction/segmentation of important structures in the seismic data such as horizons and faults
- Perceptually aligned rendering of seismic data

Ground truth visualization of measured seismic data

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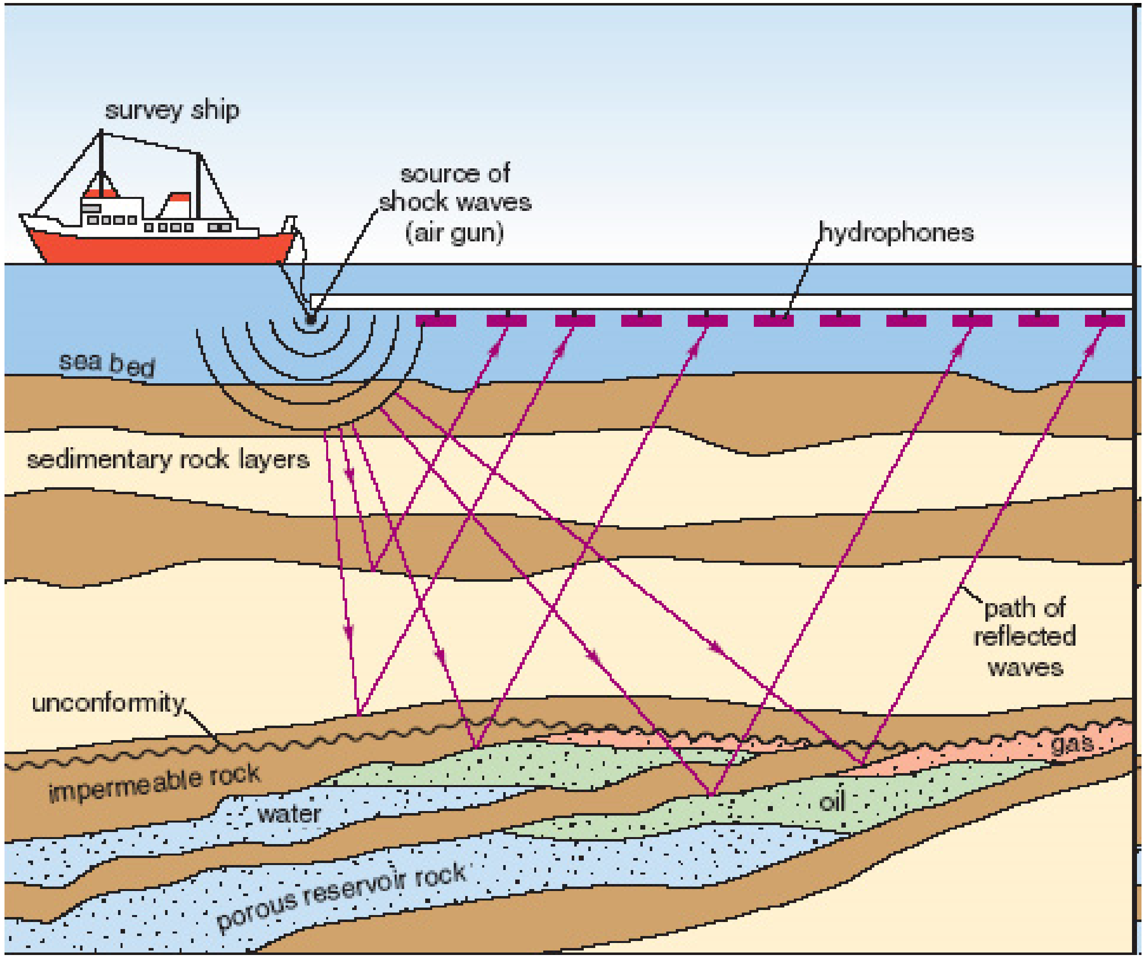
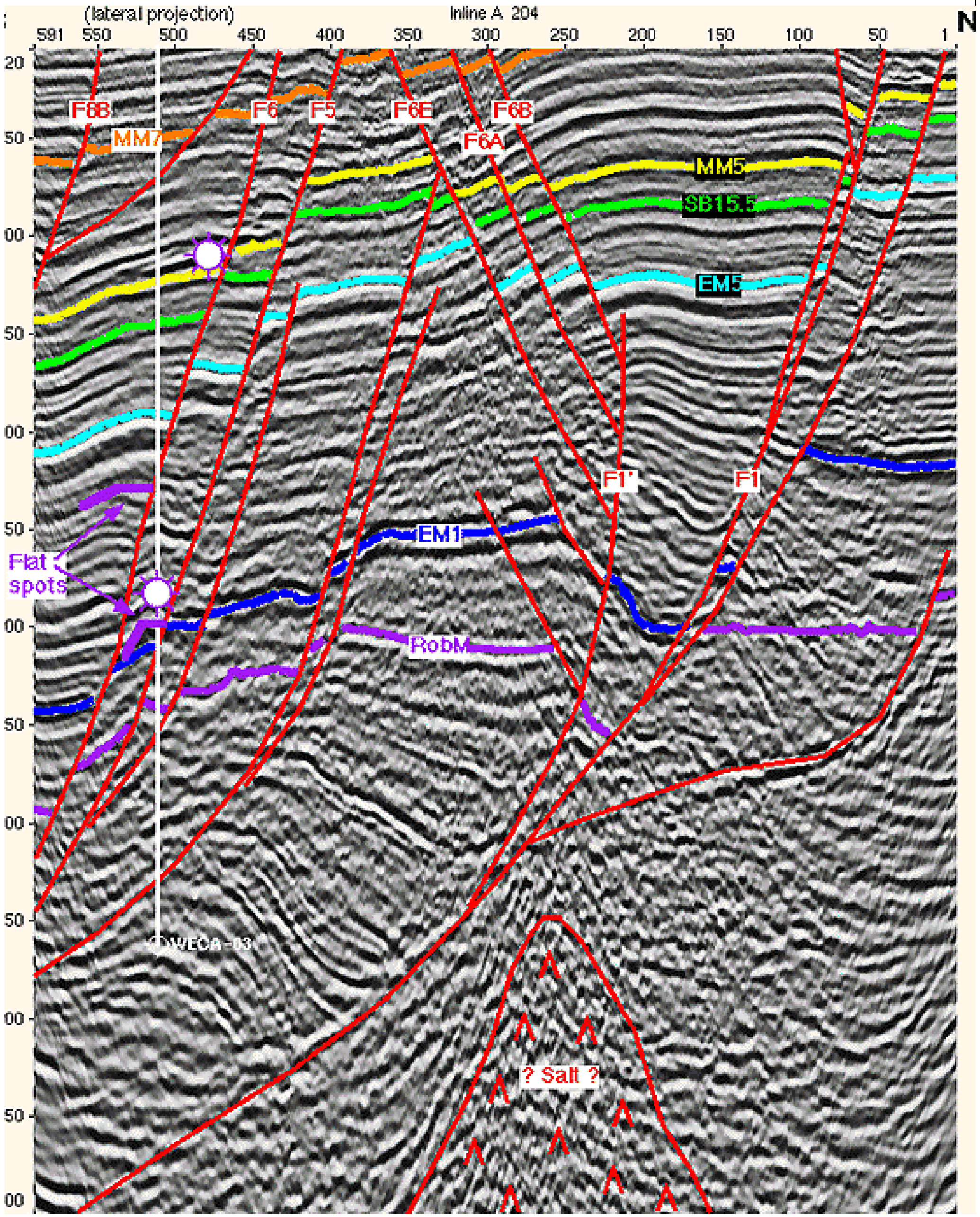
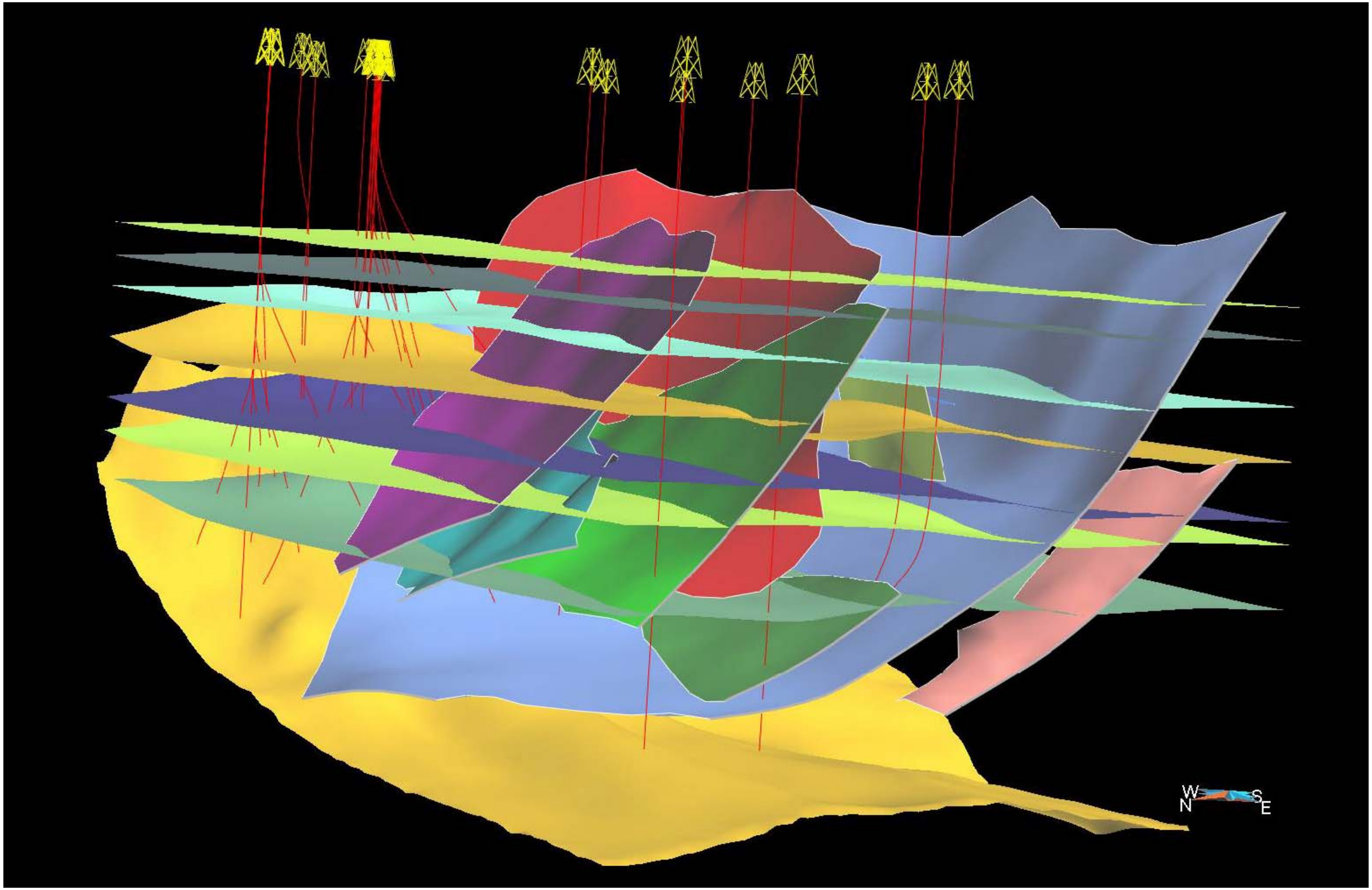
Seismic collection



Seismic interpretation



Resulting model



Visualizing large volumes

How to visualize data that doesn’t fit in gpu memory or in main memory = out of core visualization

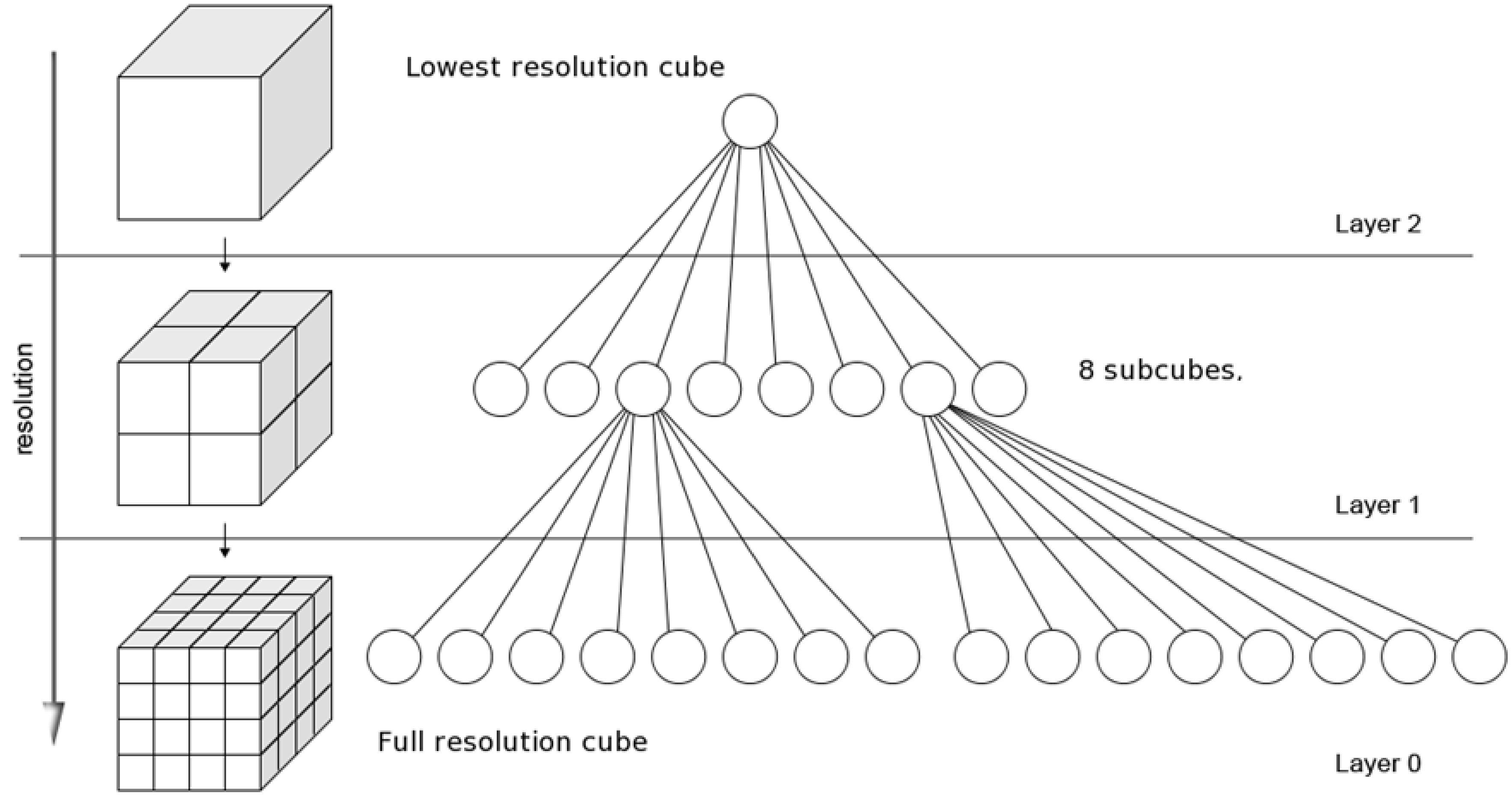
- *Reorganize data for fast access*
- *Send data to main memory on demand*
- *Send data to gpu memory on demand*

Octreemizer: A Hierarchical Approach for Interactive Roaming Through Very Large Volumes. John Plate et al. VISSYM '02 Proceedings of the symposium on Data Visualisation 2002

Reorganize data for fast access

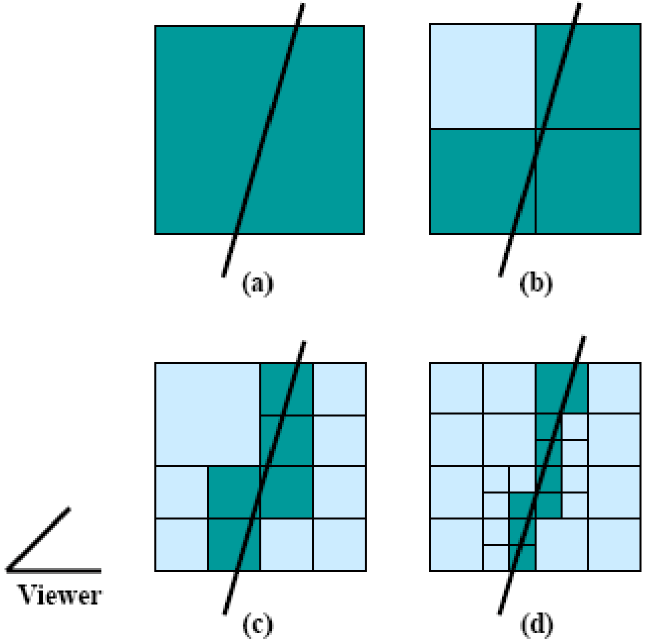
- The seismic data is reorganized on disk
- Define a brick size: nxnxn (n=32,64,.. must be tuned to bus speeds)
- It is fine to store data linearly when all fits in main memory and in texture memory
- Instead of storing it linearly it is stored as bricks, where each brick is stored linearly. This reduces disk access and jumps.
- Bricks are subsampled into parent bricks

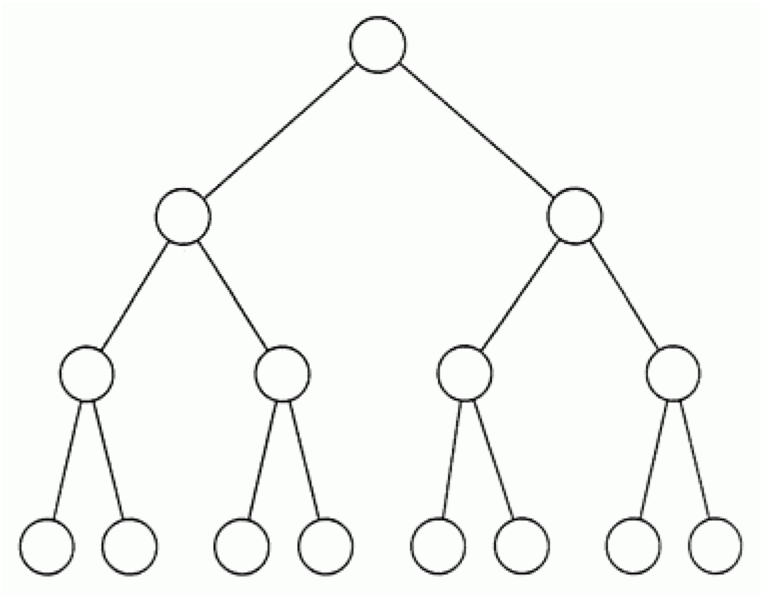
Reorganize data for fast access



Main memory to GPU

- Given a geometry/volume, identify the leaf nodes that cover it
- Find the parents also
- Upload from memory to GPU, top-down
- To maintain interactivity, have max brick upload





Disk to main memory

- Upload all leafnodes, if more space, upload neighbors until available memory is used

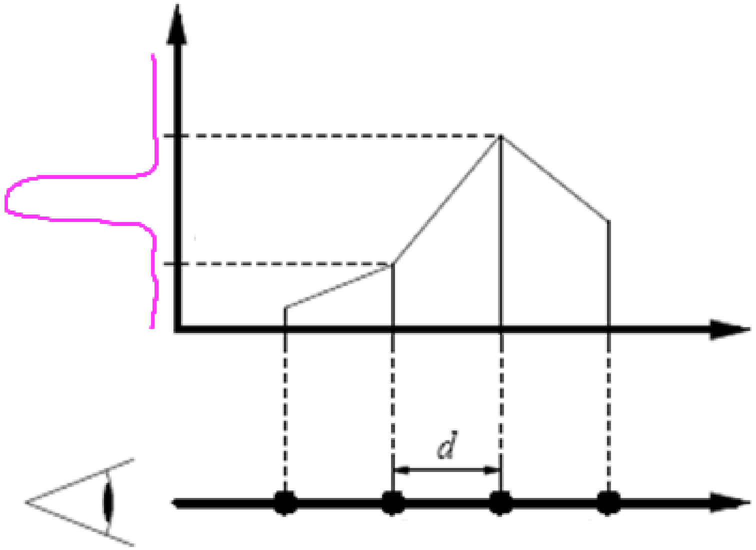
- Runs in a separate process from the memory to GPU transfer

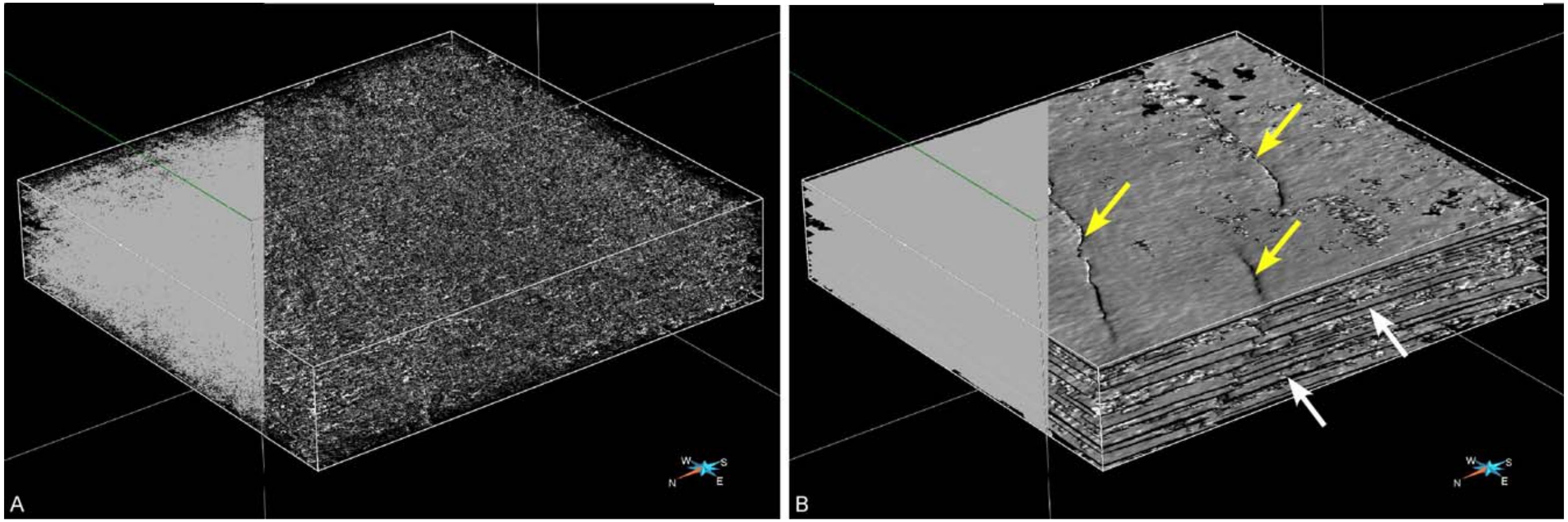
- Both processes check wether a brick is already uploaded before uploading it

- When overwriting unused bricks, the oldest are overwritten first

VolumeExplorer paper

- Preintegration

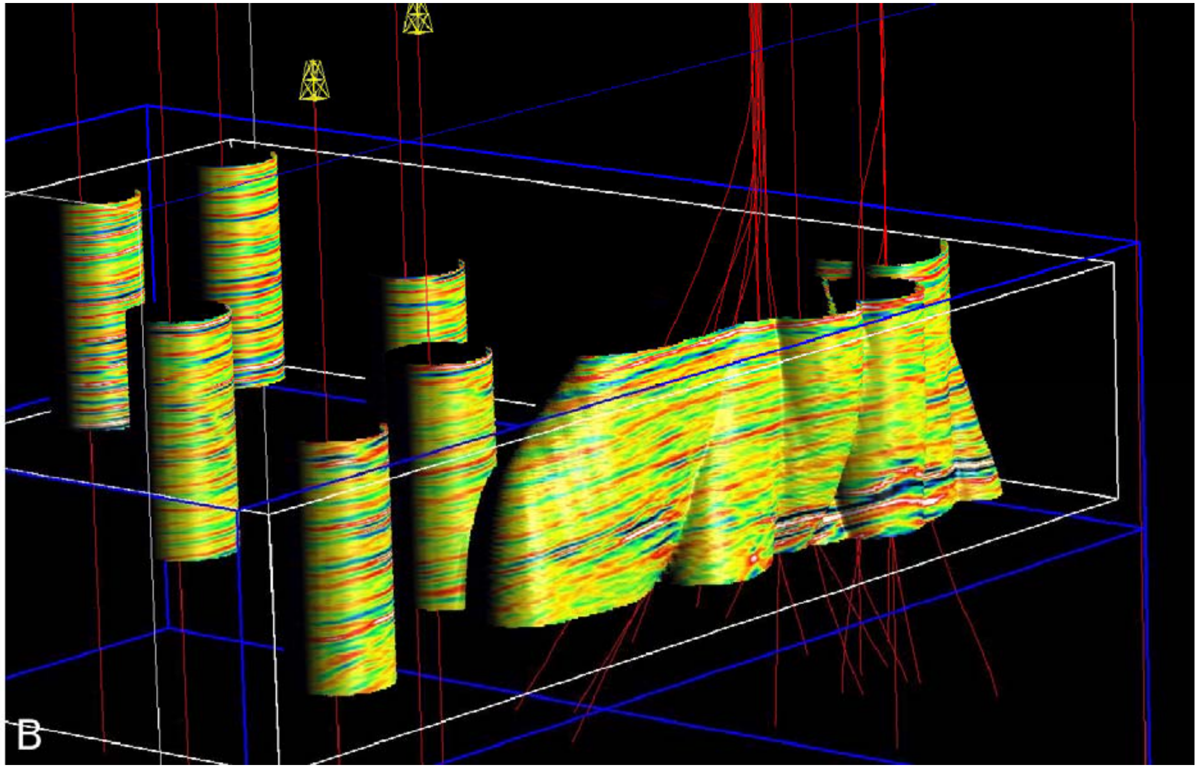




VolumeExplorer: Roaming Large Volumes to Couple Visualization and Data Processing for Oil and Gas Exploration. Laurent Castanie et al. Vis 2005

VolumeExplorer paper

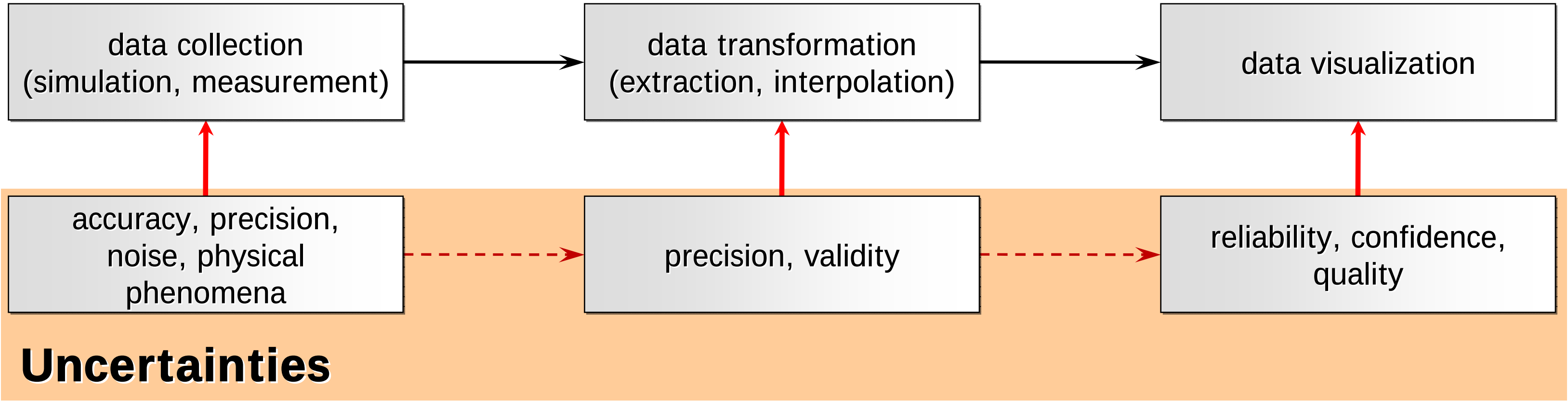
- Iso distant surfaces from wells



VolumeExplorer: Roaming Large Volumes to Couple Visualization and Data Processing for Oil and Gas Exploration. Laurent Castanie et al. Vis 2005

Visualizing Uncertainty

- Data Processing/Visualization Pipeline
  - errors and uncertainties introduced and derived at any stage



data collection (simulation, measurement)

data transformation (extraction, interpolation)

data visualization

accuracy, precision, noise, physical phenomena

precision, validity

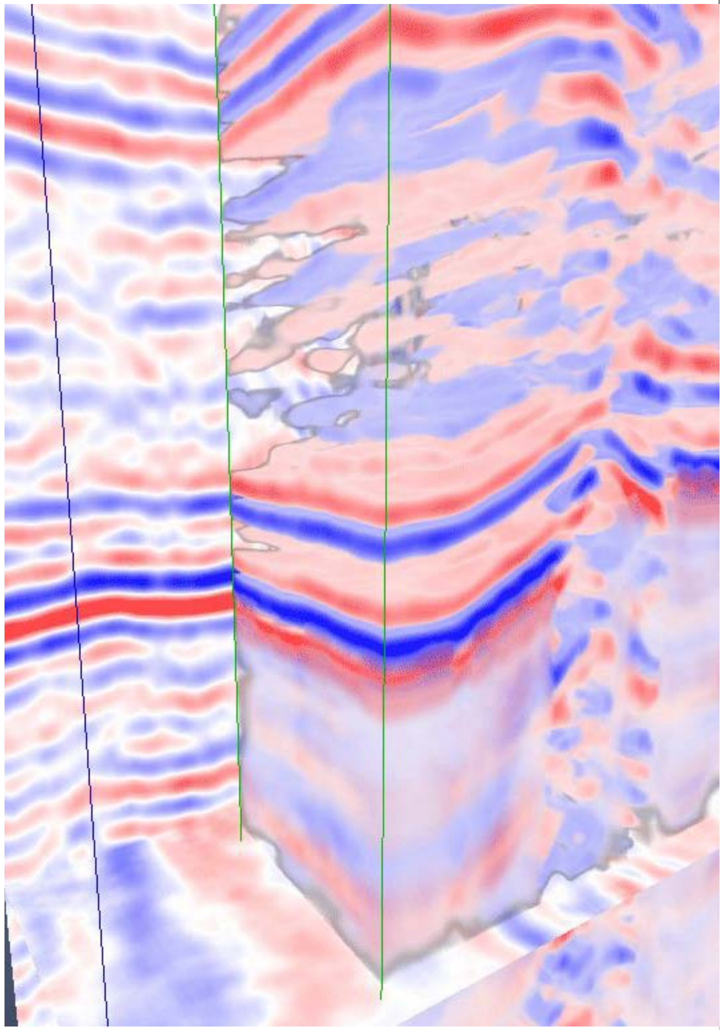
reliability, confidence, quality

Uncertainties

Christopher Lux, Bernd Fröhlich. Bauhaus-Universität Weimar
Faculty of Media | Virtual Reality Systems Group

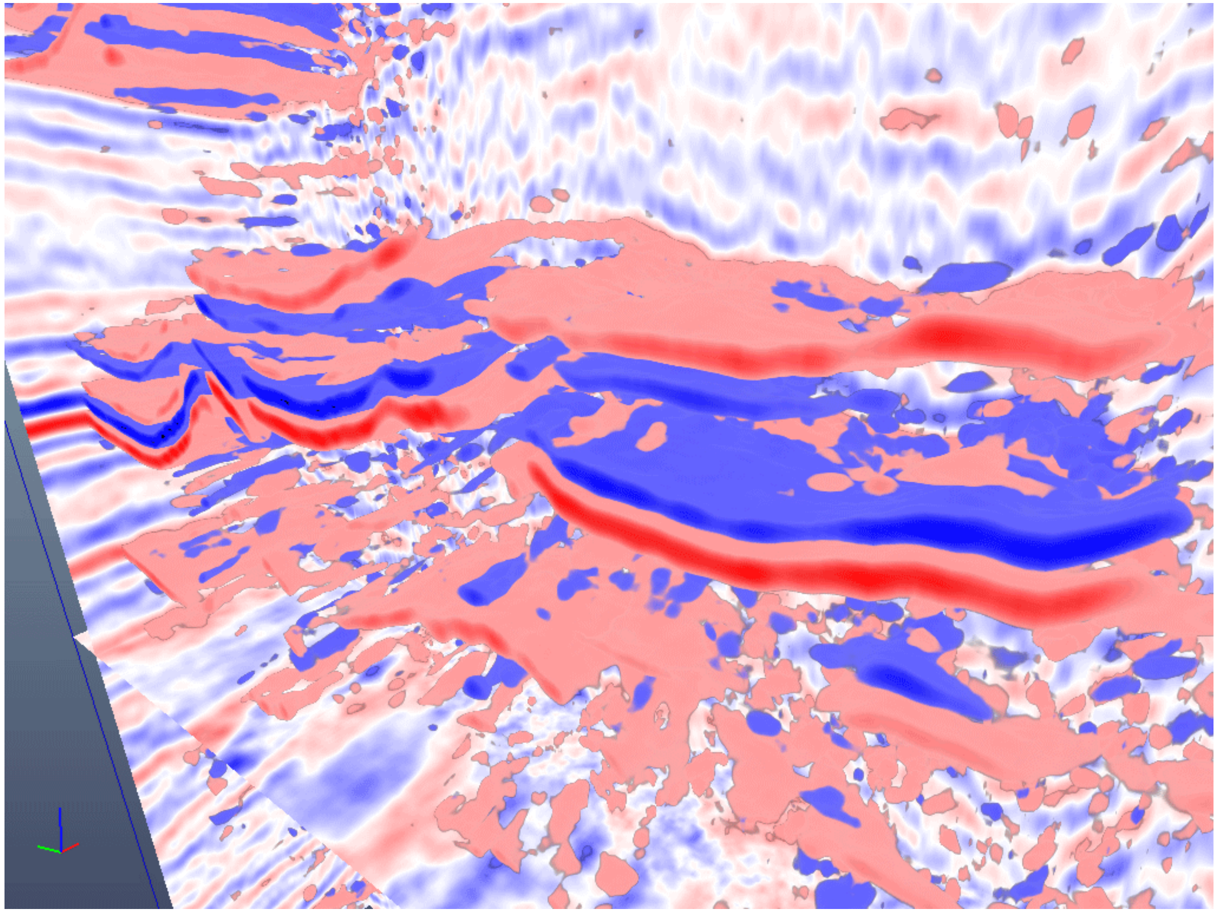
Visualizing Uncertainty of Surface Data

- Manipulation of color mapping
    - Transparency
    - Desaturation
    - Inversion
- Deformation
- Line Glyphs
- Volume Surface



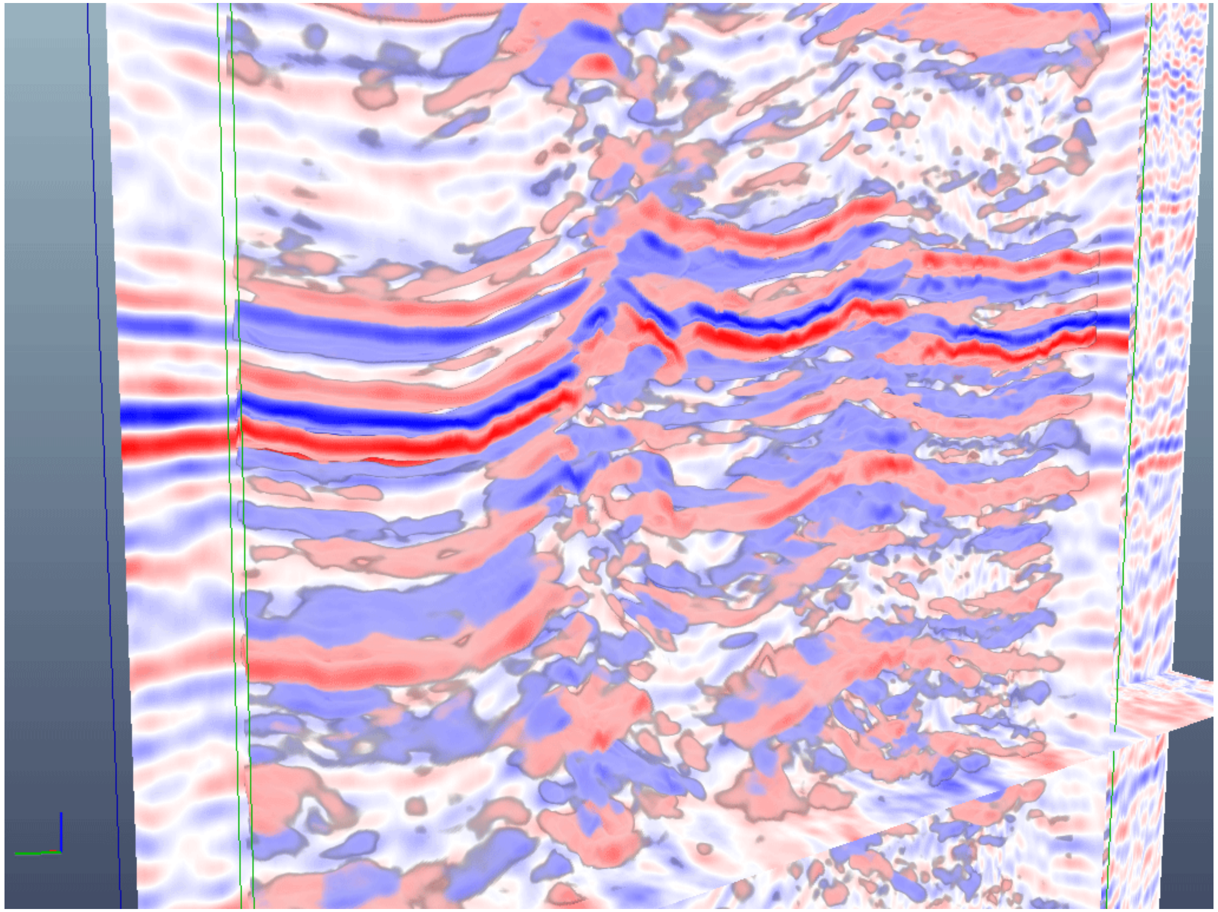
Visualizing Uncertainty of Volume Data

- Color Map Desaturation



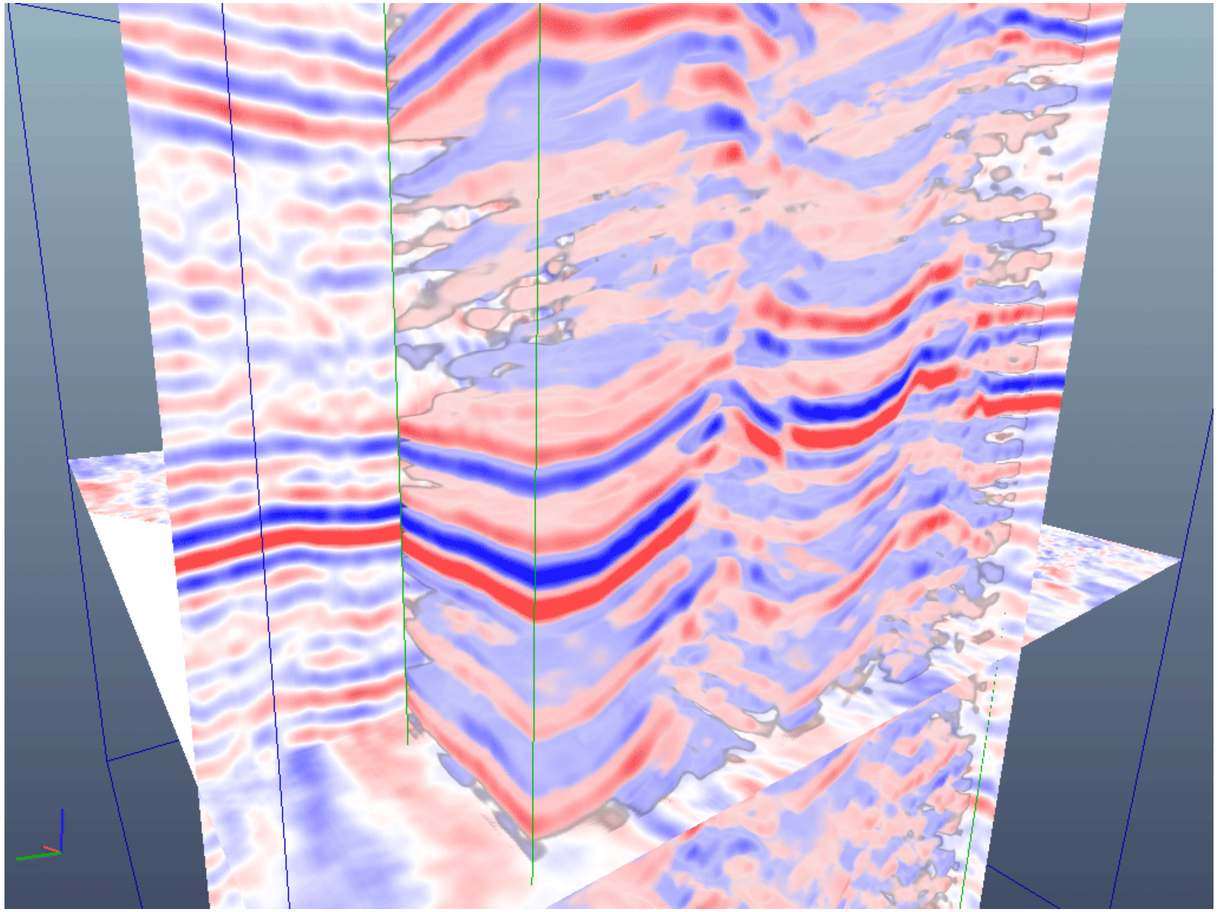
Visualizing Uncertainty of Volume Data

- Volume Deformation



Visualizing Uncertainty of Volume Data

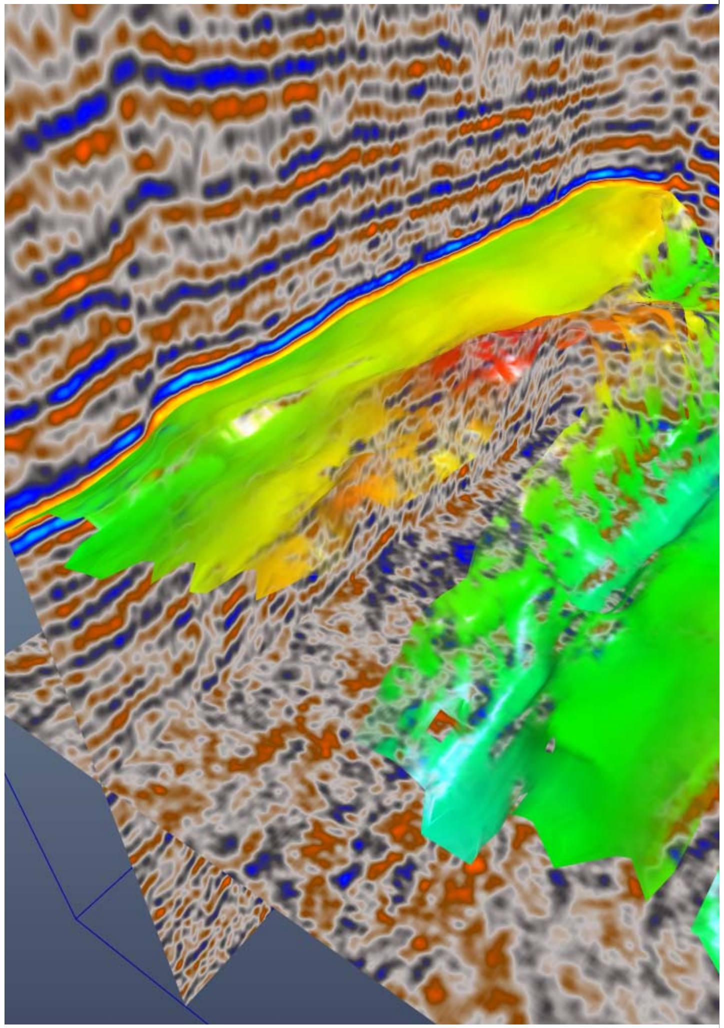
- Volume Blurring



Visualizing Uncertainty of Surface Data

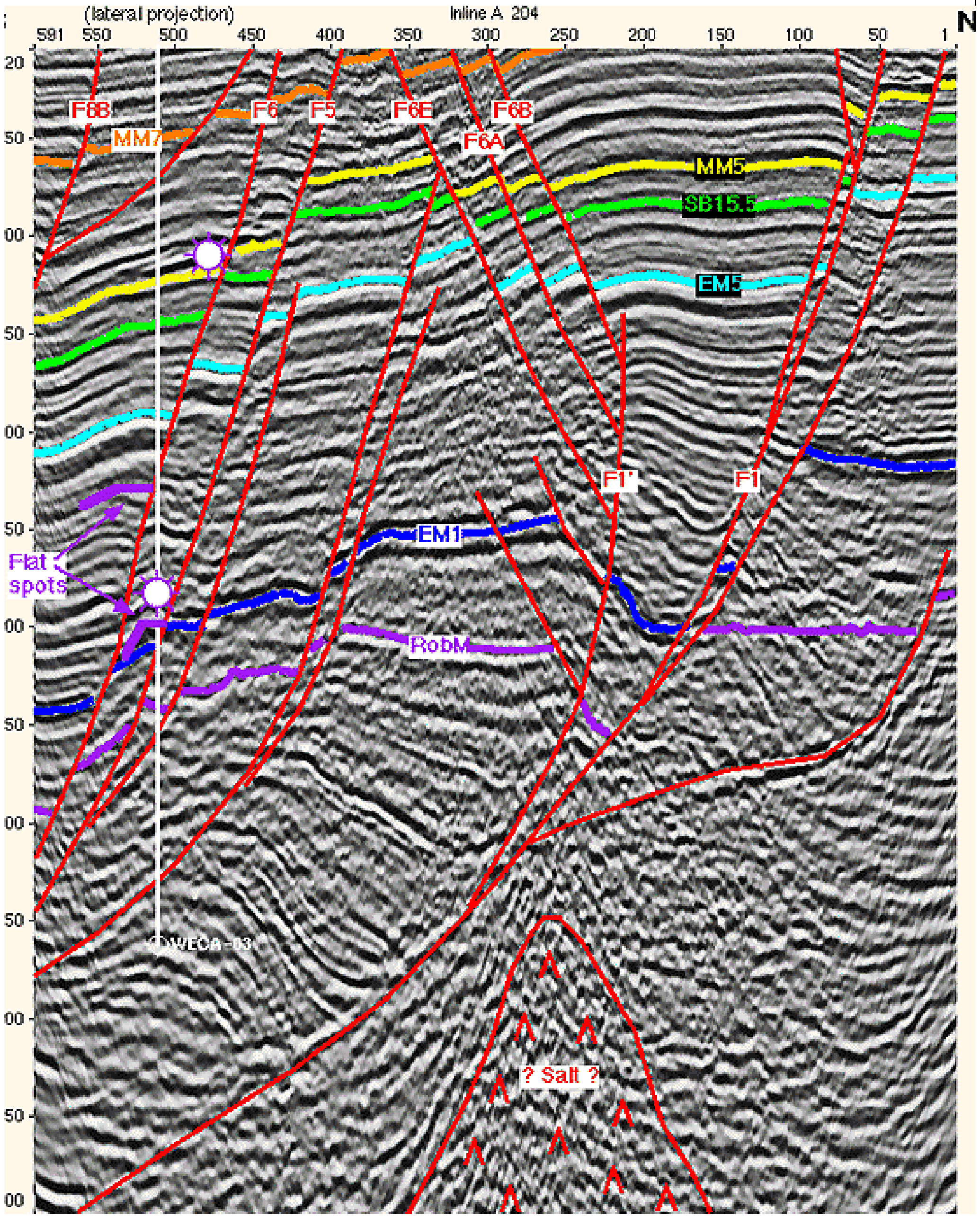
- Manipulation of color mapping
  - Transparency
  - Desaturation
  - Inversion

- Deformation
- Line Glyphs
- Volume Surface

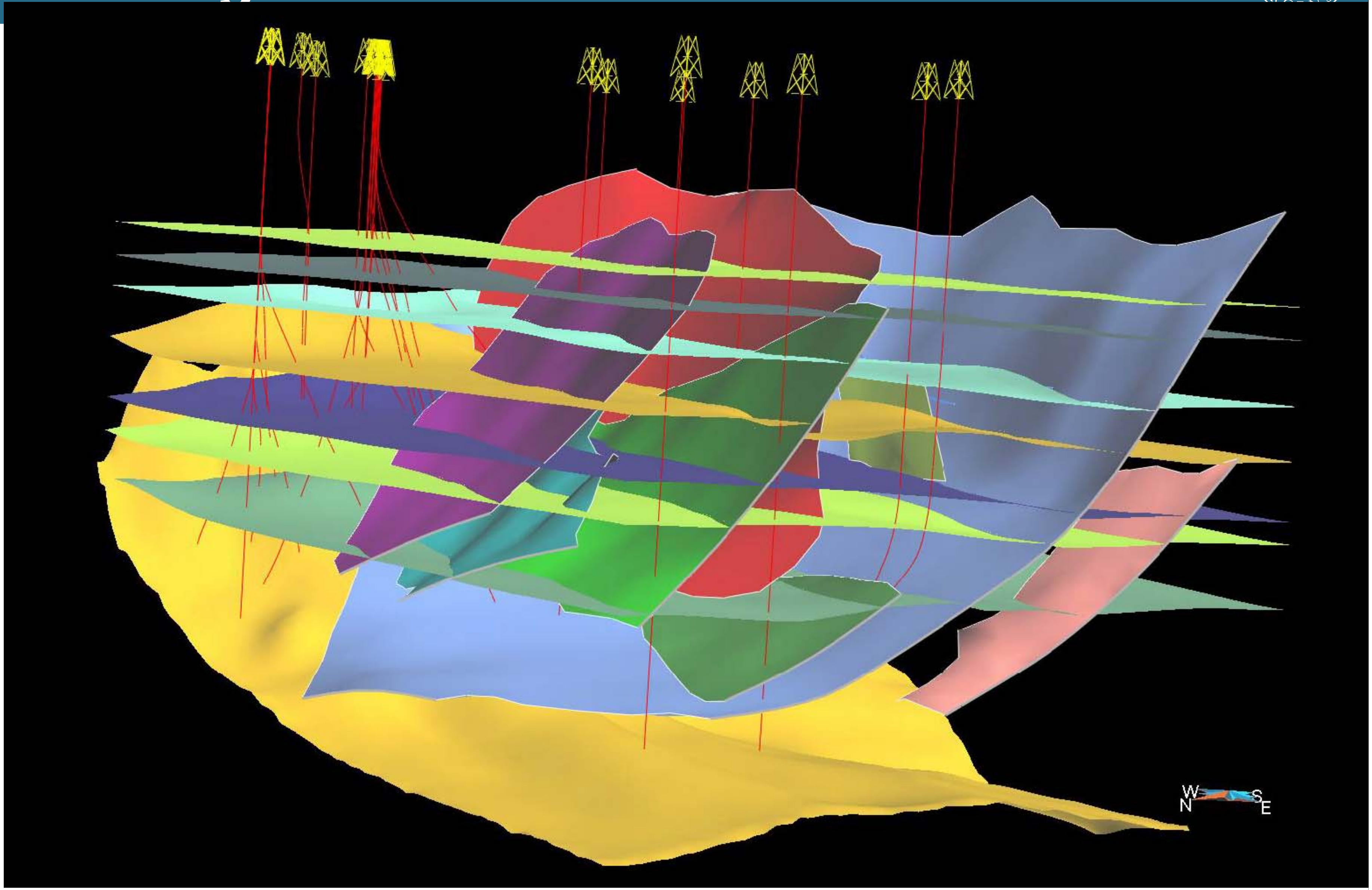


Automated object extraction/segmentation of important structures in the seismic data such as horizons and faults

Seismic interpretation



Resulting model



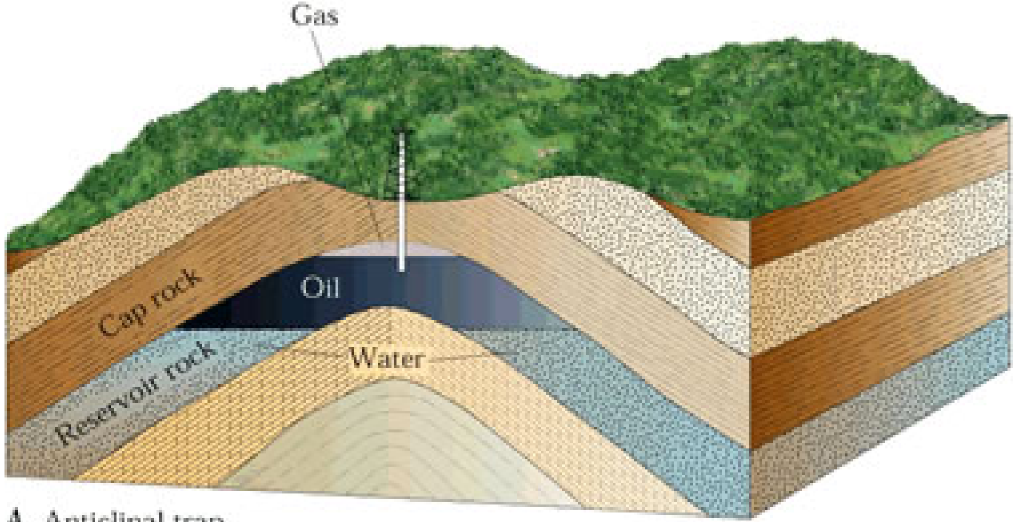
VolumeExplorer: Roaming Large Volumes to Couple Visualization and Data Processing for Oil and Gas Exploration. Laurent Castanie et al. Vis 2005

Seismic objects

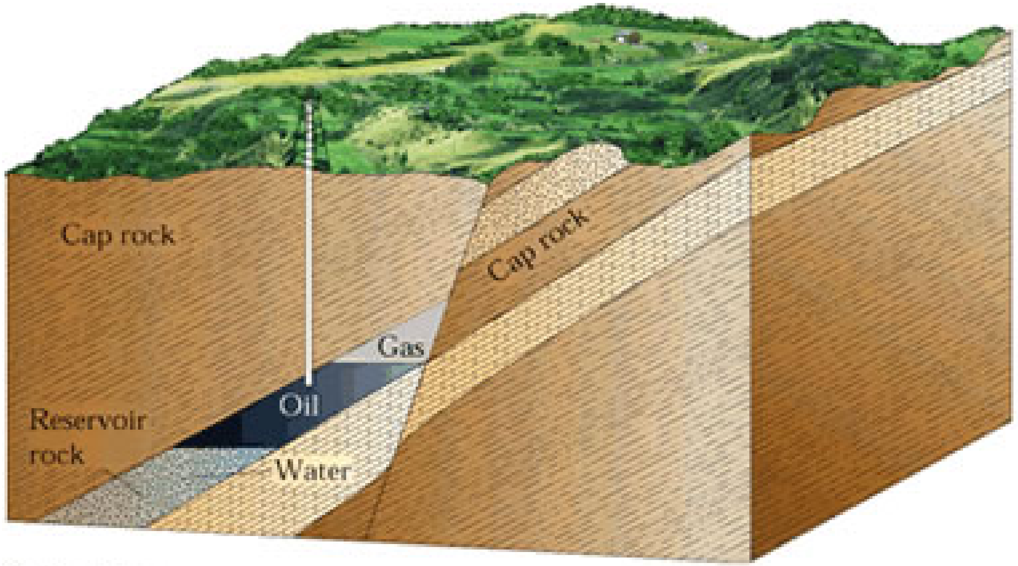
- Objects which can be detected in the collected data and can help indicate where oil is:

- Horizons
- Faults
- Channels
- Salt diapirs
- Mud diapirs
- Bright spots

Seismic objects: horizons and faults

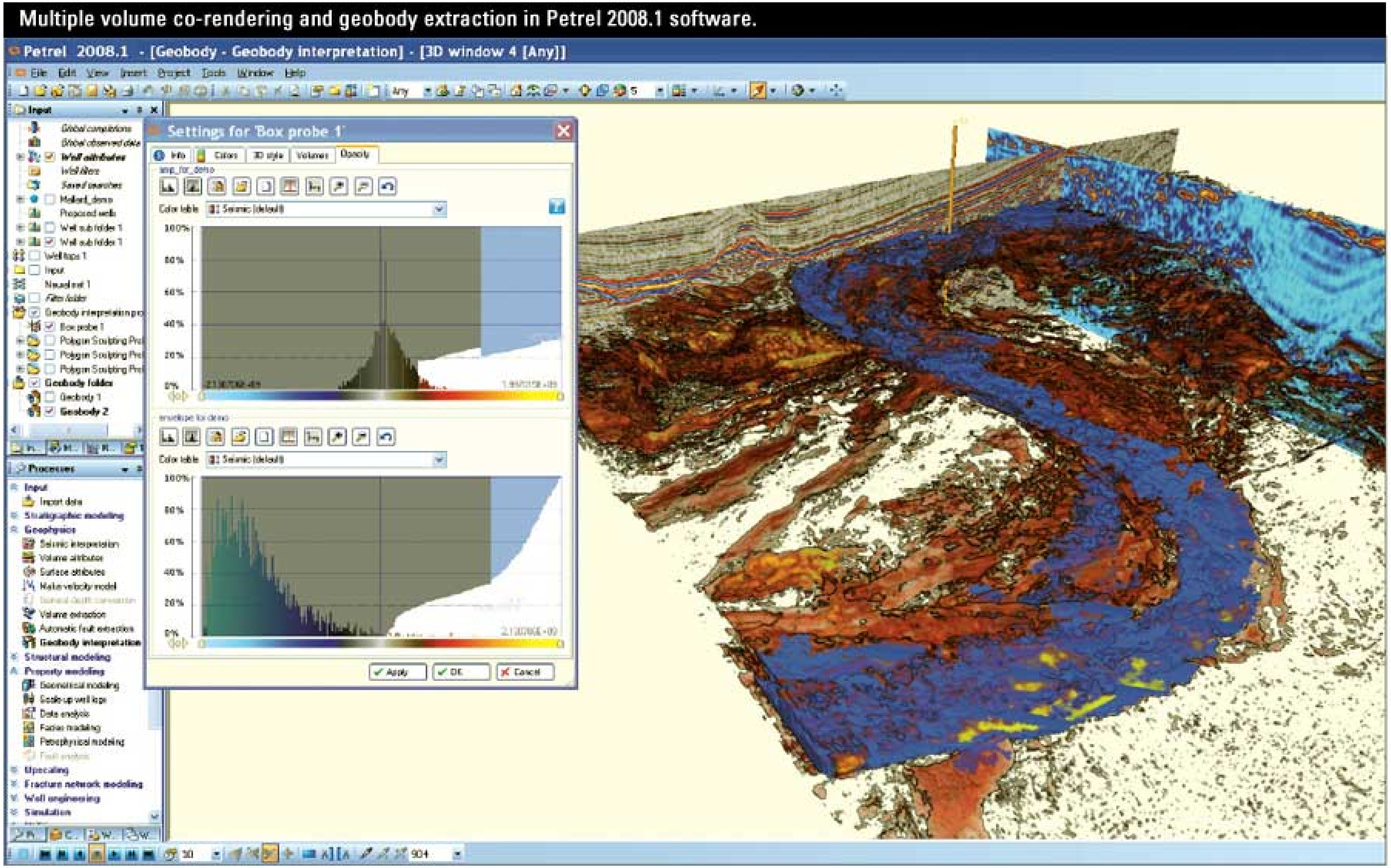


A. Anticlinal trap



B. Fault trap

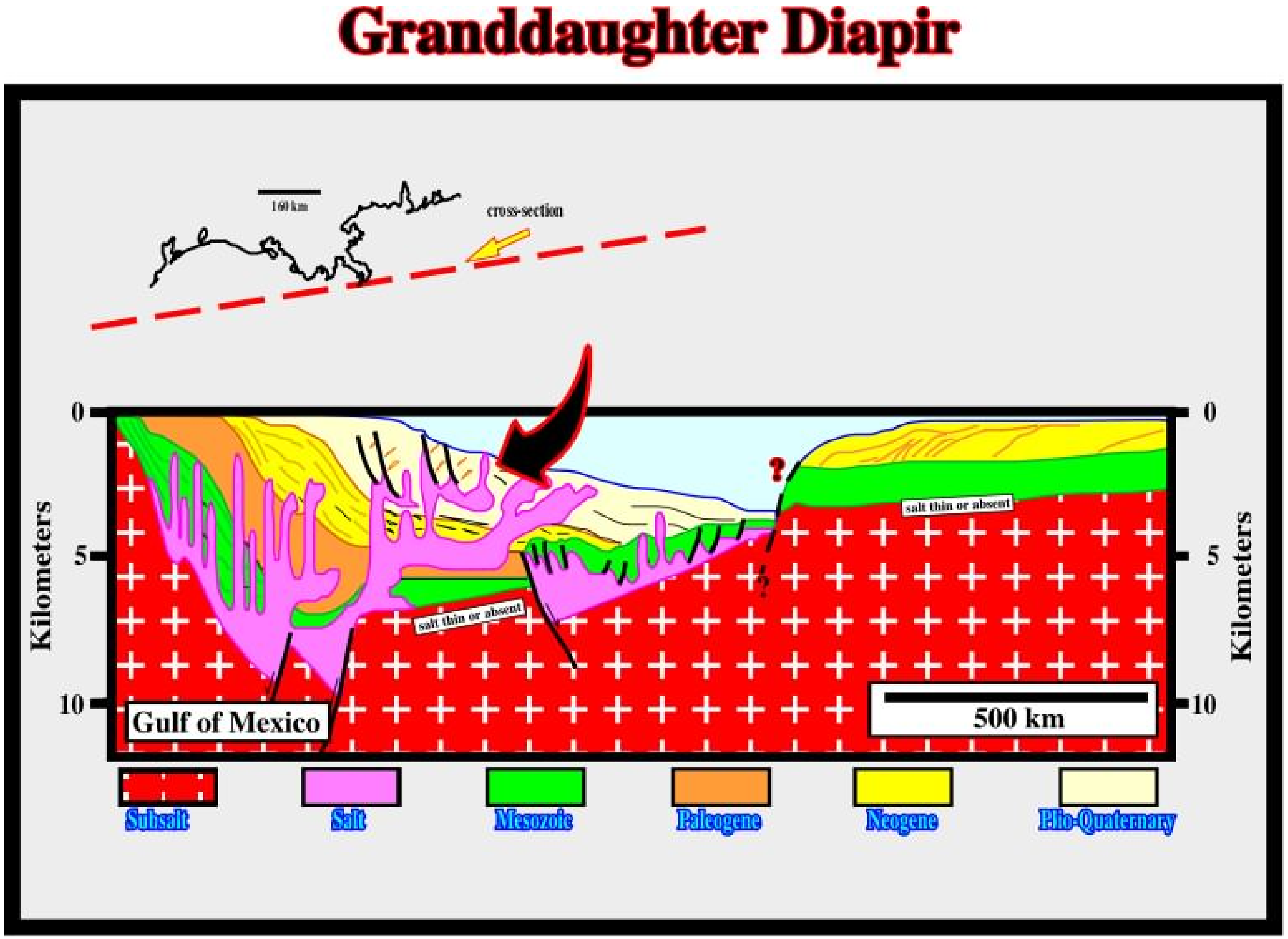
Seismic objects: channels



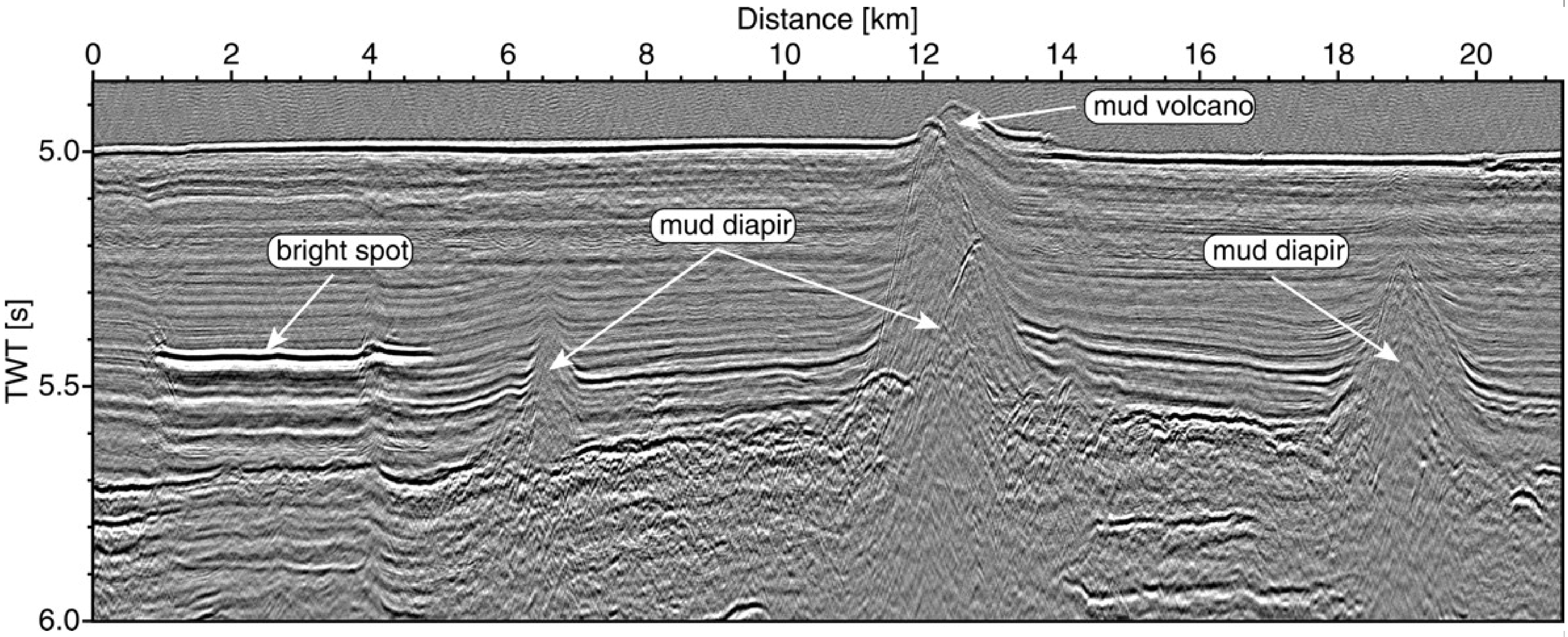
Multiple volume co-rendering and geobody extraction in Petrel 2008.1 software.

Schlumberger Petrel interpretation software

Seismic objects: salt diapirs


Granddaughter Diapir

Seismic objects: bright spots and mud diapirs



Seismic attributes

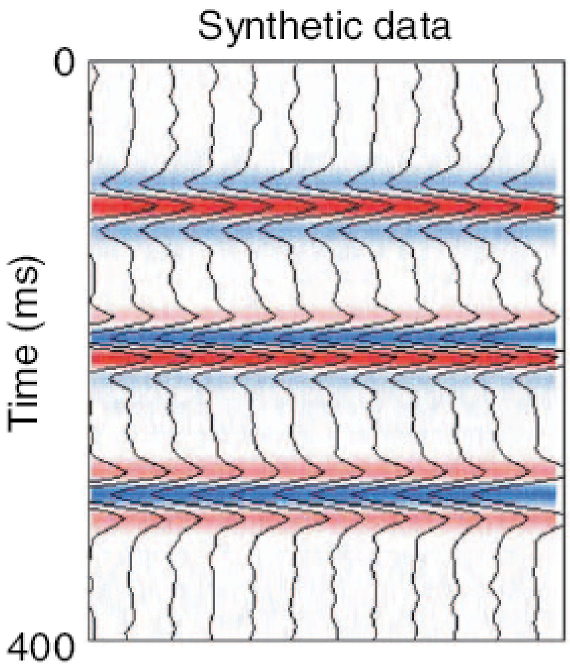
- There are different measured attributes
  - 3D: Reflection data, Vp/Vs data
  - 1D: Well logs
  - 2D: Ground measured data: gravity, magnetism

- There are many derived attributes
  - Chaos, dip, phase, frequency, impedance
  - Unlimited amount of derived attributes

Seismic measured attributes

- Reflection data
  - In time or in depth (depth converted)
- Vp/Vs data, pressure/shear wave ratio
- Going from recorded sound waves to the 3D data, called inversion, is an underdefined problem, many methods exist, several companies offer their ’superior’ inversion.

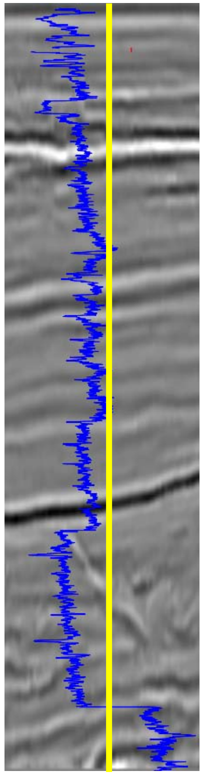
Seismic trace

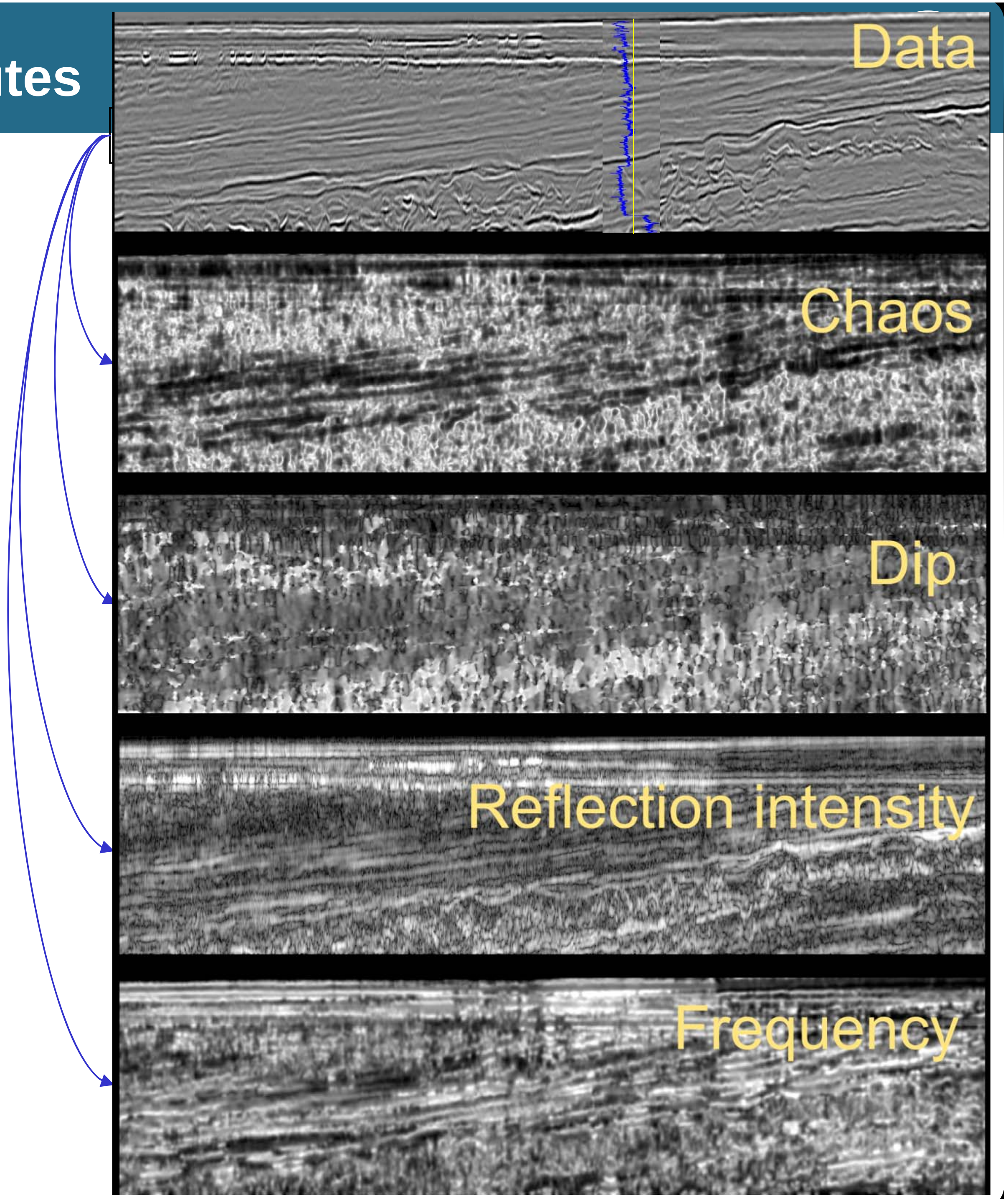


Seismic derived attributes

-derived attributes

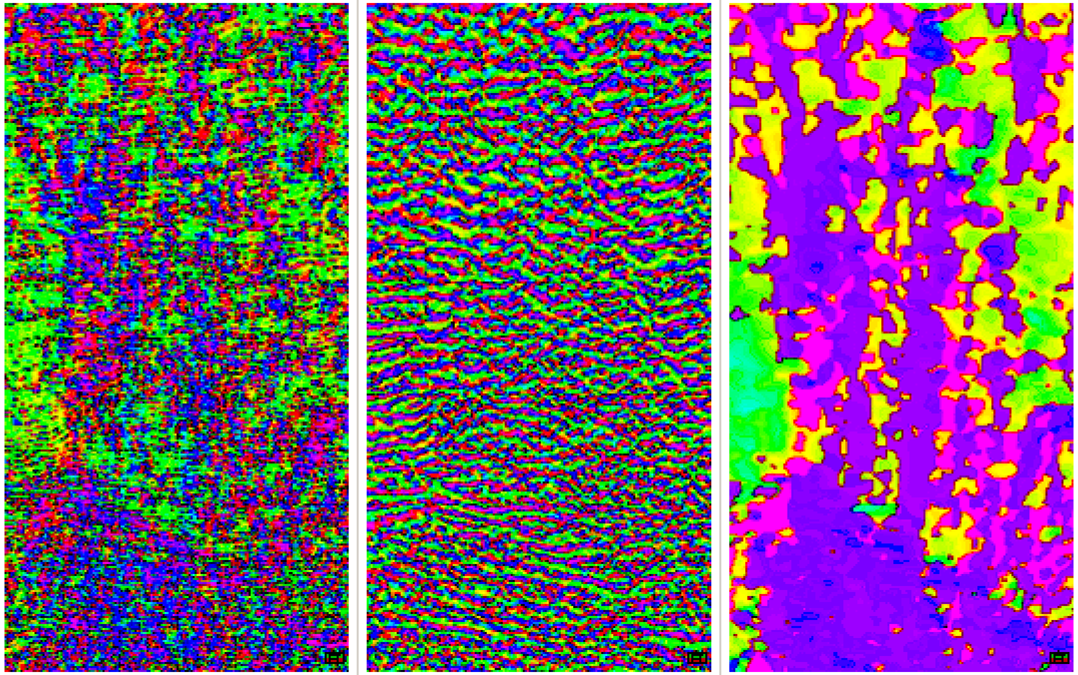
-well logs





Seismic derived attributes

- **Dip and azimuth**



Event Azimuth

Gradient Azimuth

Principle Component Azimuth

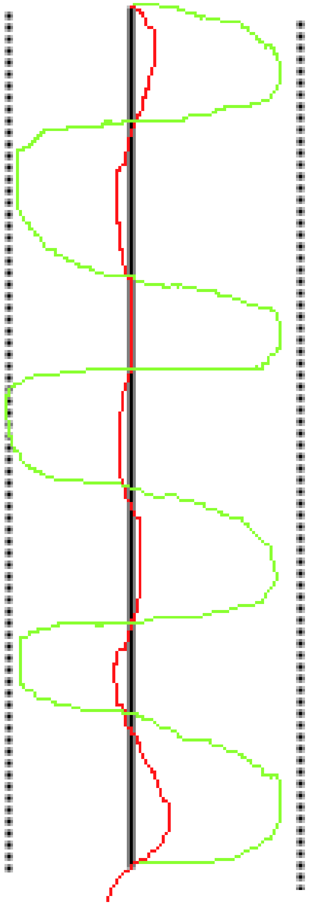
Schlumberger Petrel interpretation software

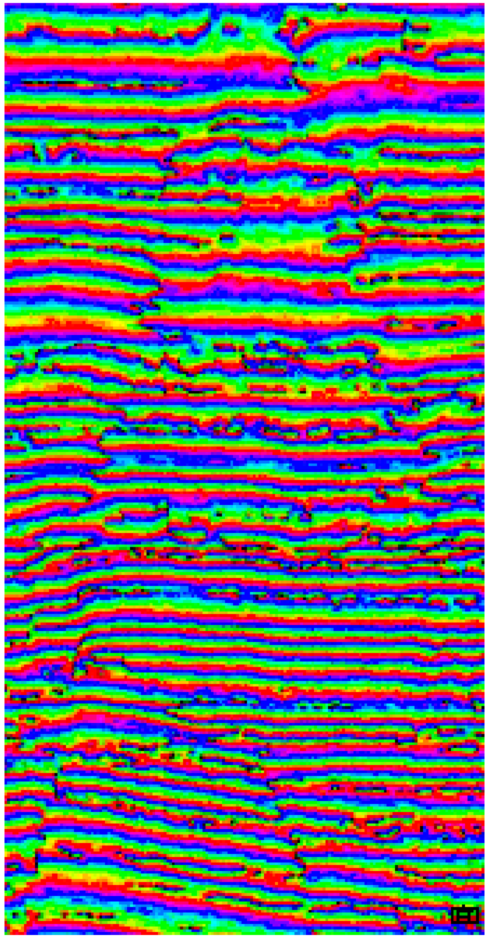
Seismic derived attributes

- Instantaneous phase

$$\theta = \tan^{-1}\left(\frac{g}{f}\right)$$

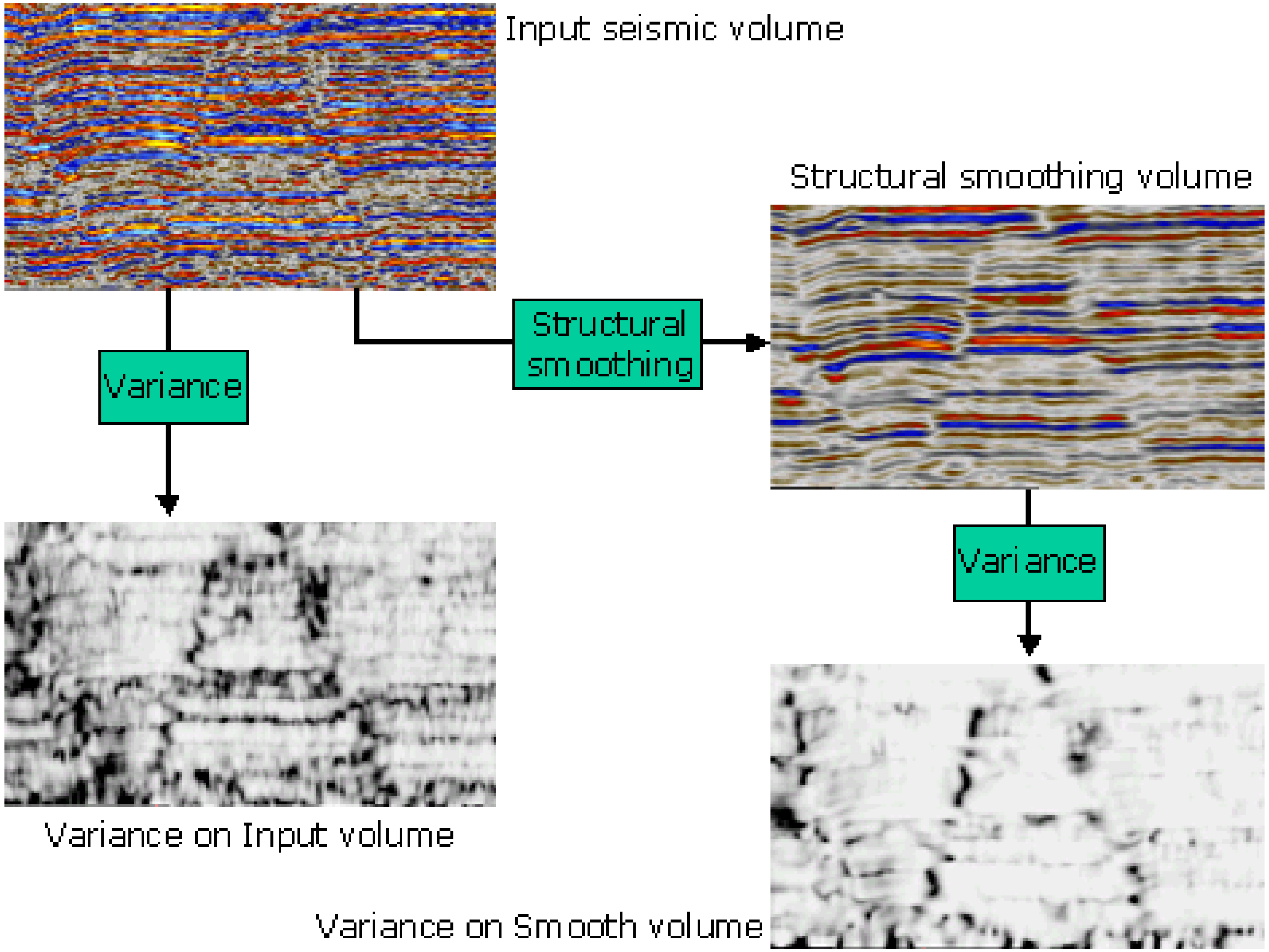
A window length parameter is available (default: 33).





Seismic derived attributes

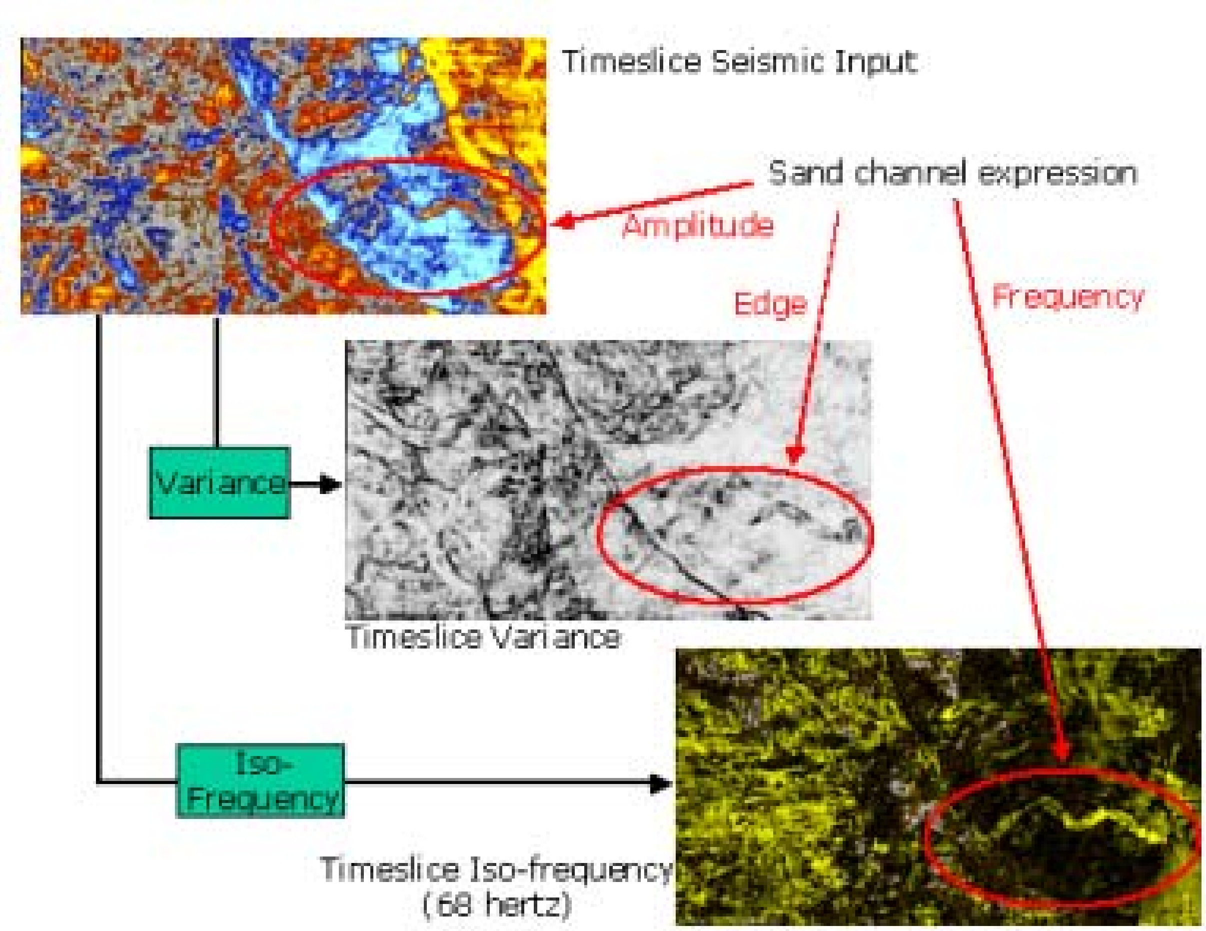
Structural Smoothing



Schlumberger Petrel interpretation software

Seismic derived attributes

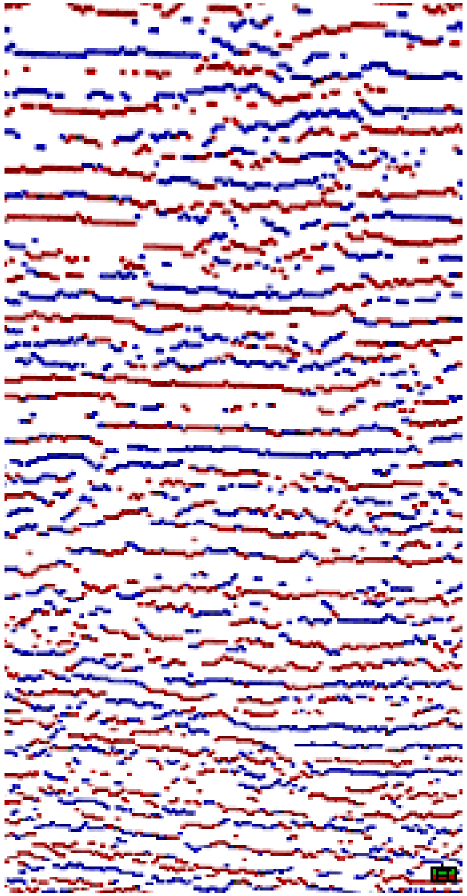
- Frequency



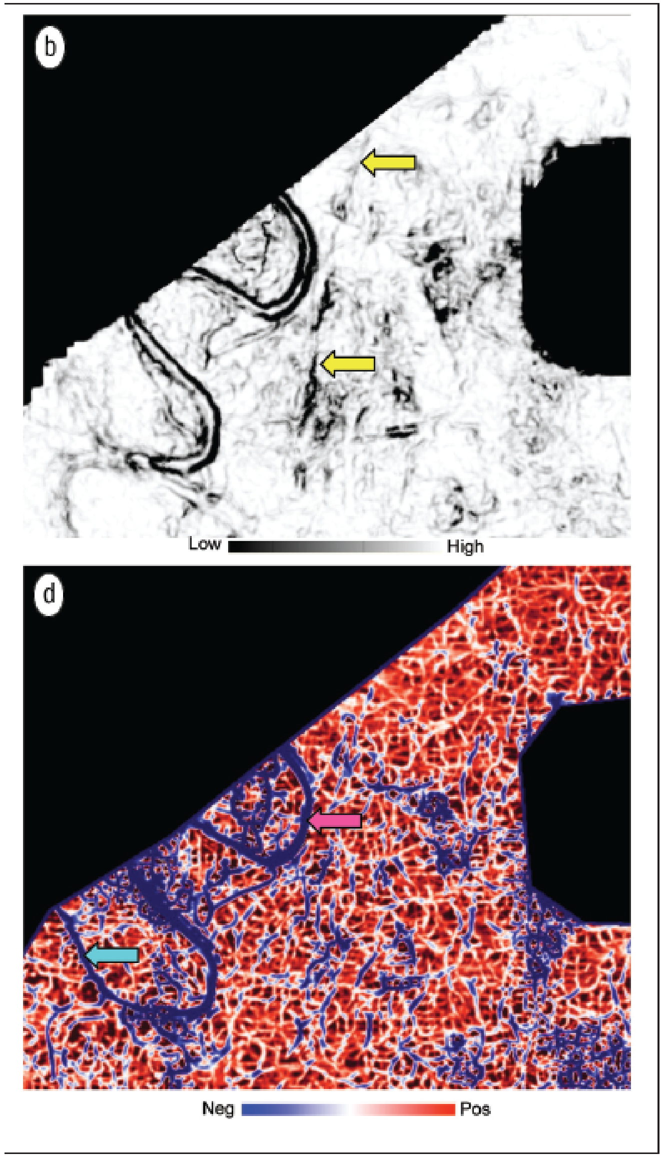
Schlumberger Petrel interpretation software

Seismic derived attributes

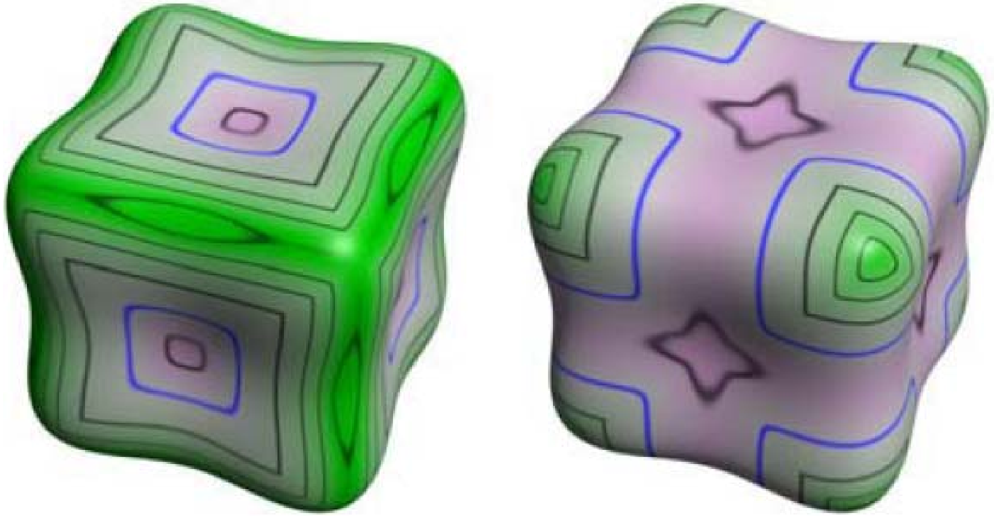
- Extremas

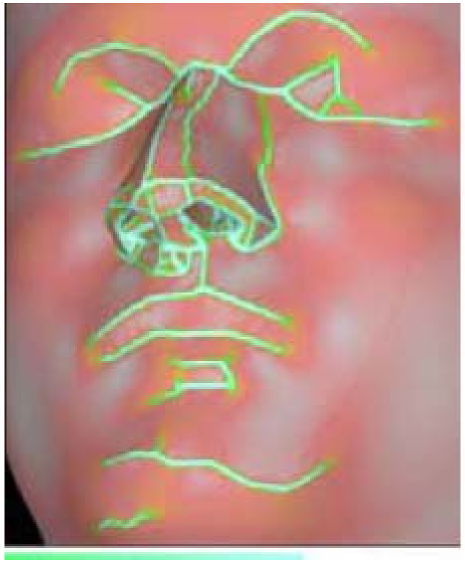


Curvature



Top:coherence, bottom:curvature





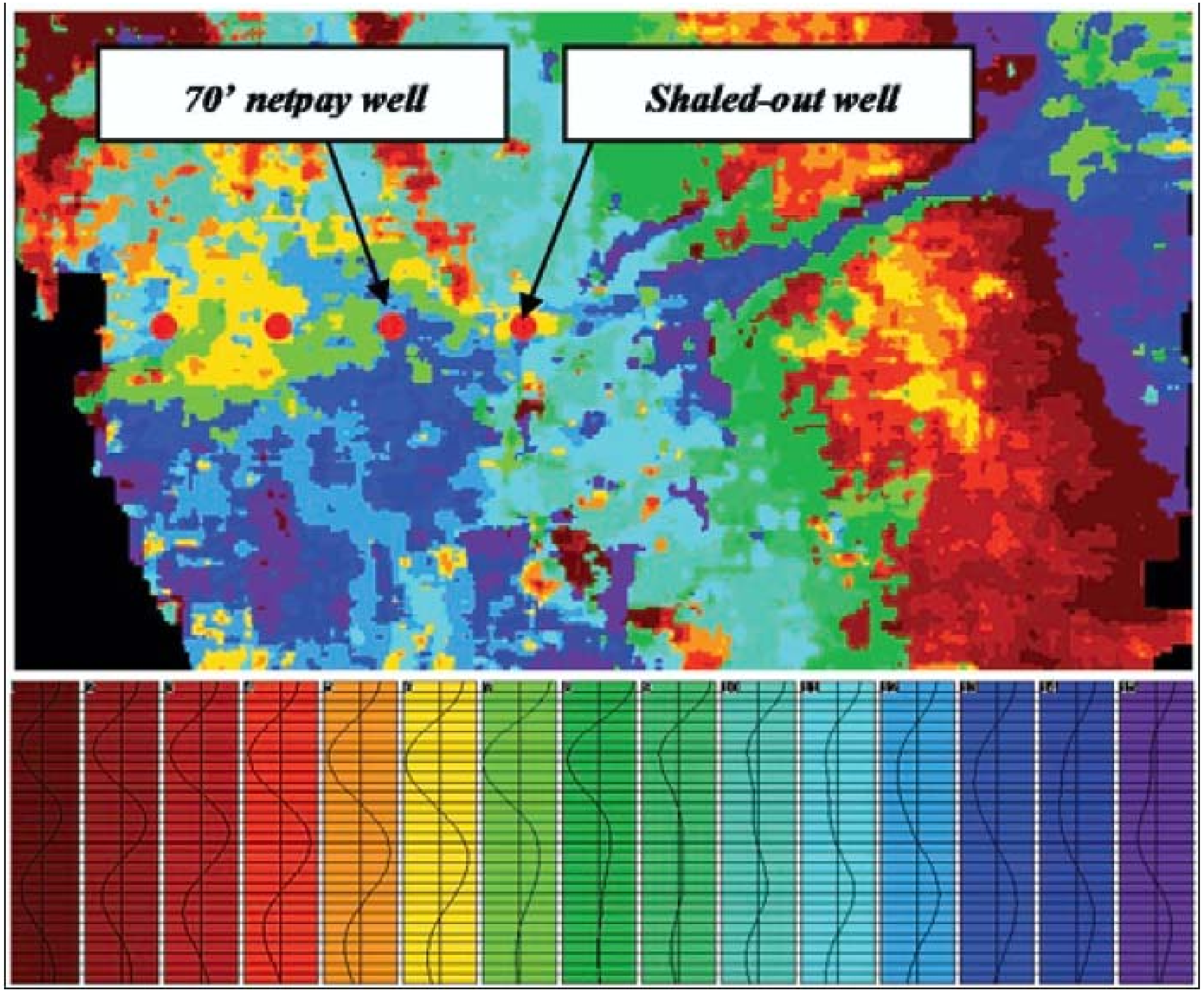
Left: Curvature attribute applications to 3D surface seismic data Chopra et al.Leading edge, april 2007

Right: Curvature-Based Transfer Functions for Direct Volume Rendering: Methods and Applications

Kindlmann et al. Vis 2003

Seismic derived attributes

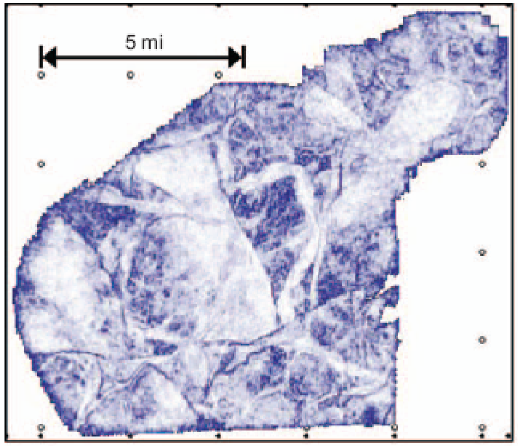
- Clustering of waveforms



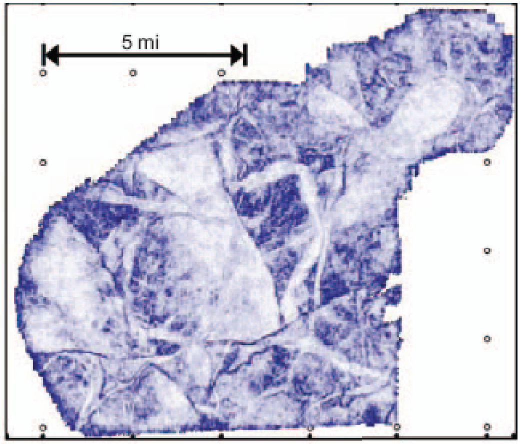
- Learning
- Statistics

Unsupervised seismic facies classification: A review and comparison of techniques and implementation COLÉOU et al. The Leading Edge, 2003

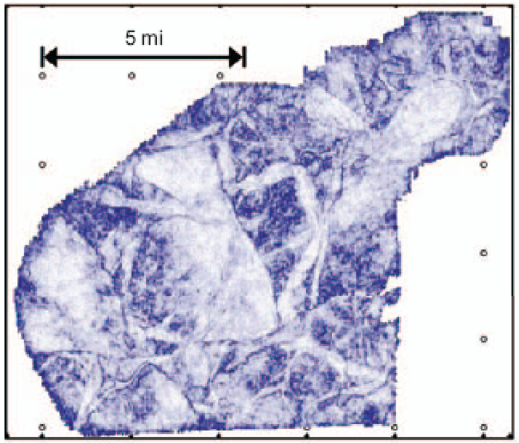
Redundant seismic attributes



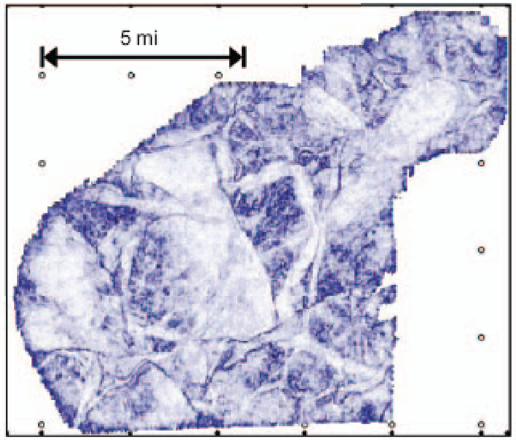
Correlation



Semblance



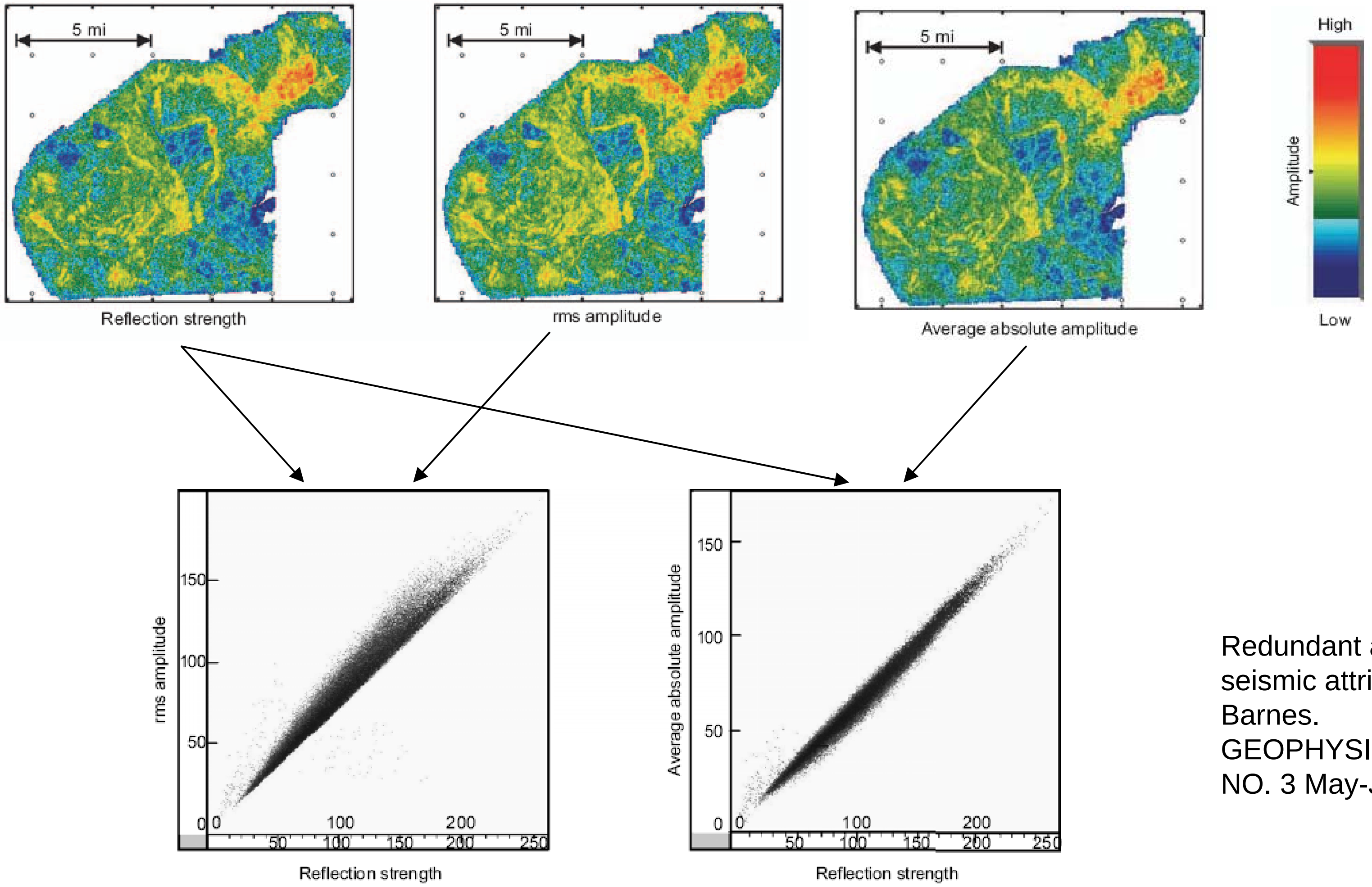
Covariance



Weighted correlation

Redundant and useless
seismic attributes
Barnes.
GEOPHYSICS,VOL. 72,
NO. 3 May-June 2007

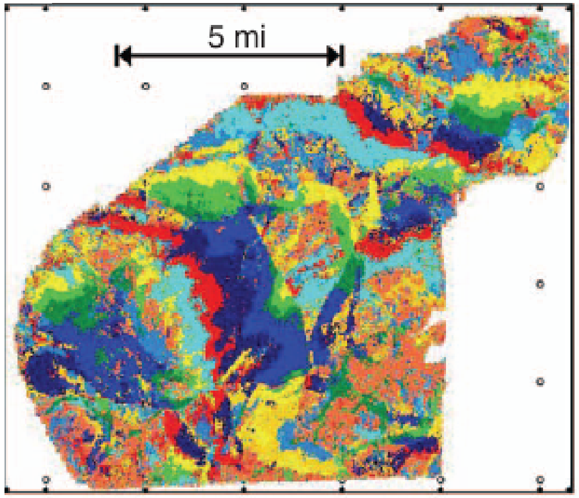
Redundant seismic attributes



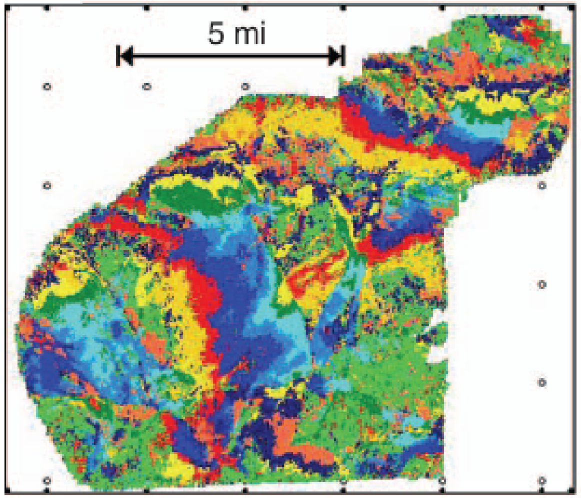
Redundant and useless seismic attributes
Barnes.
GEOPHYSICS,VOL. 72, NO. 3 May-June 2007

Redundant seismic attributes

- Kohonen Self Organising Feature Map (**KSOFM**)



- K-means clustering

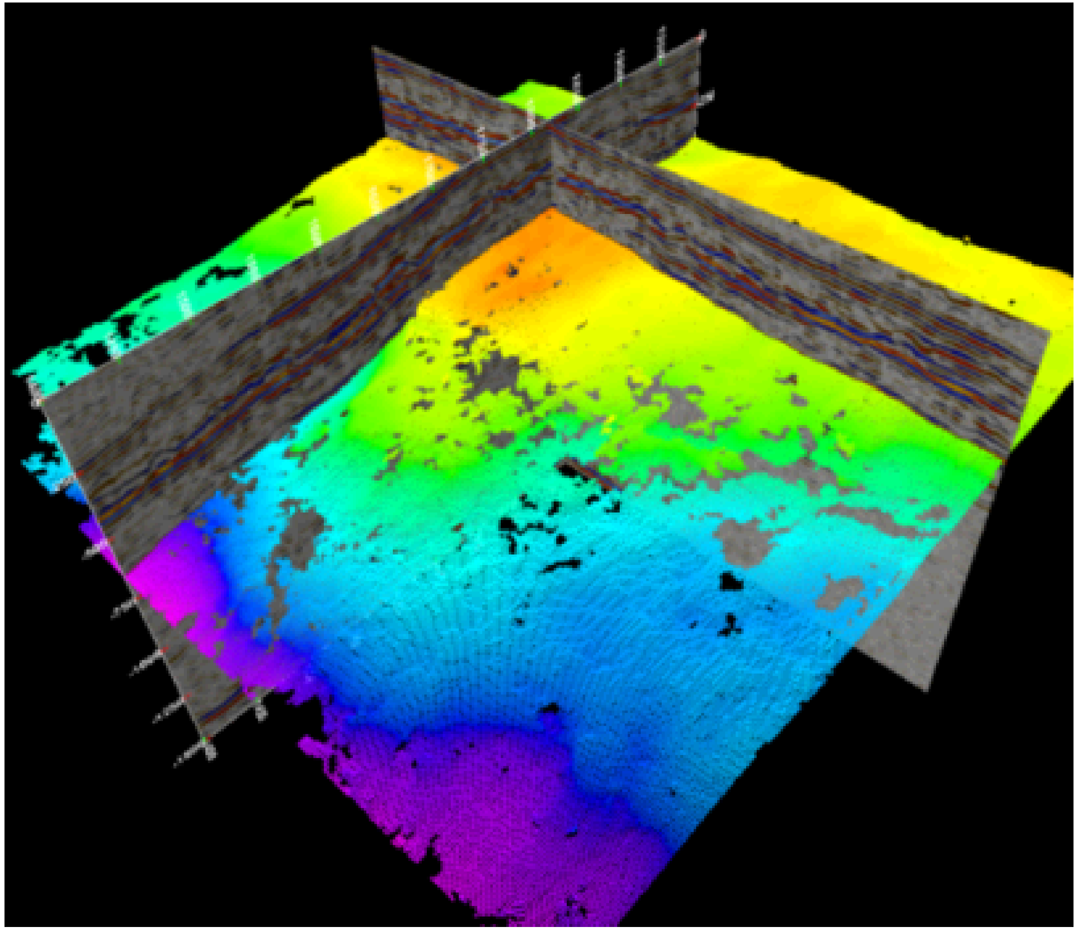


Tracing out horizons and faults

- Seed and grow
  - Select a point on what seems like a horizon/fault
  - Let an algorithm grow out other points with similar feature

Horizon interpretation

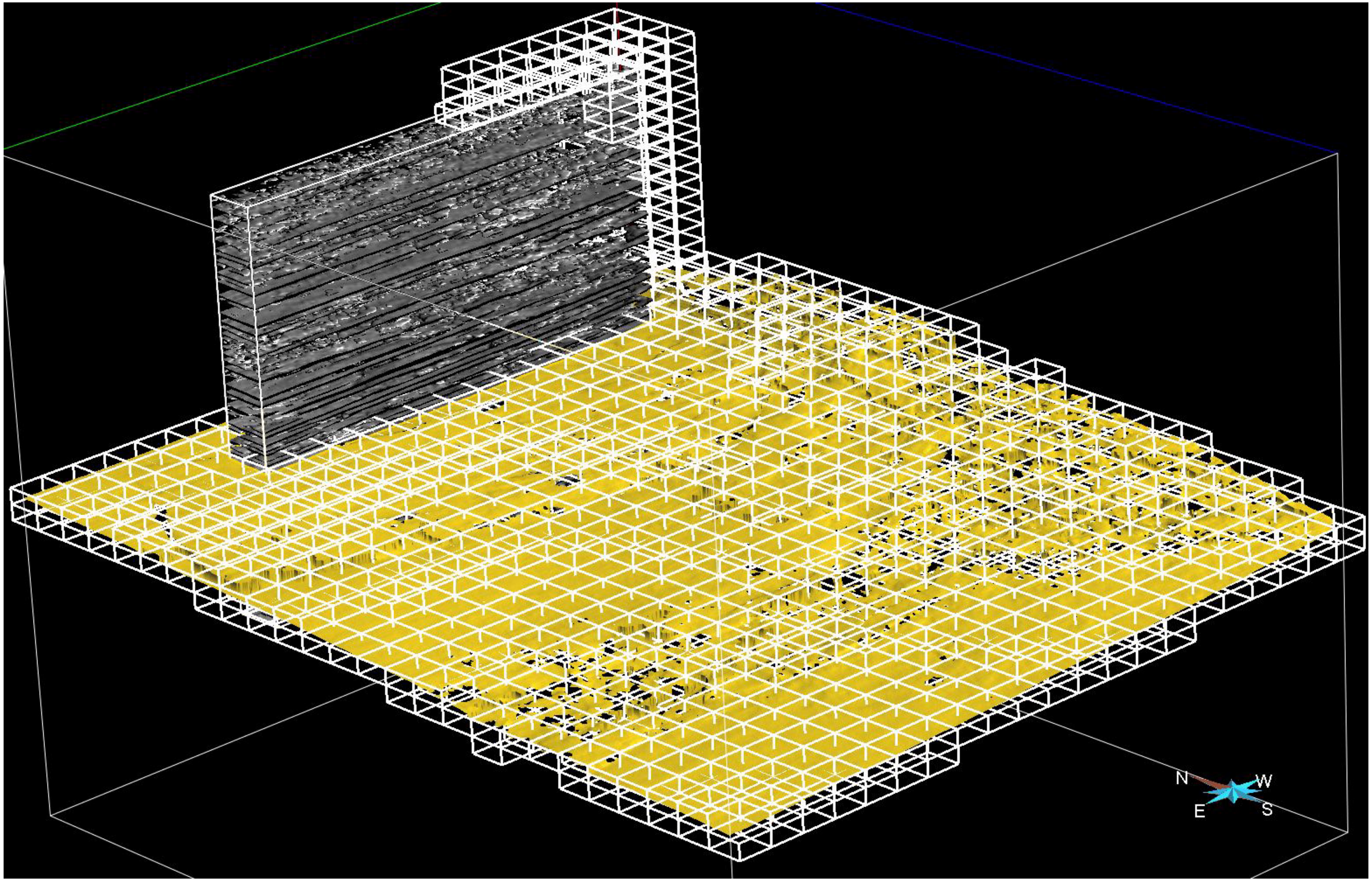
Figure 2. The figure shows a 3D Seeded Autotracking.



Schlumberger Petrel

VolumeExplorer paper

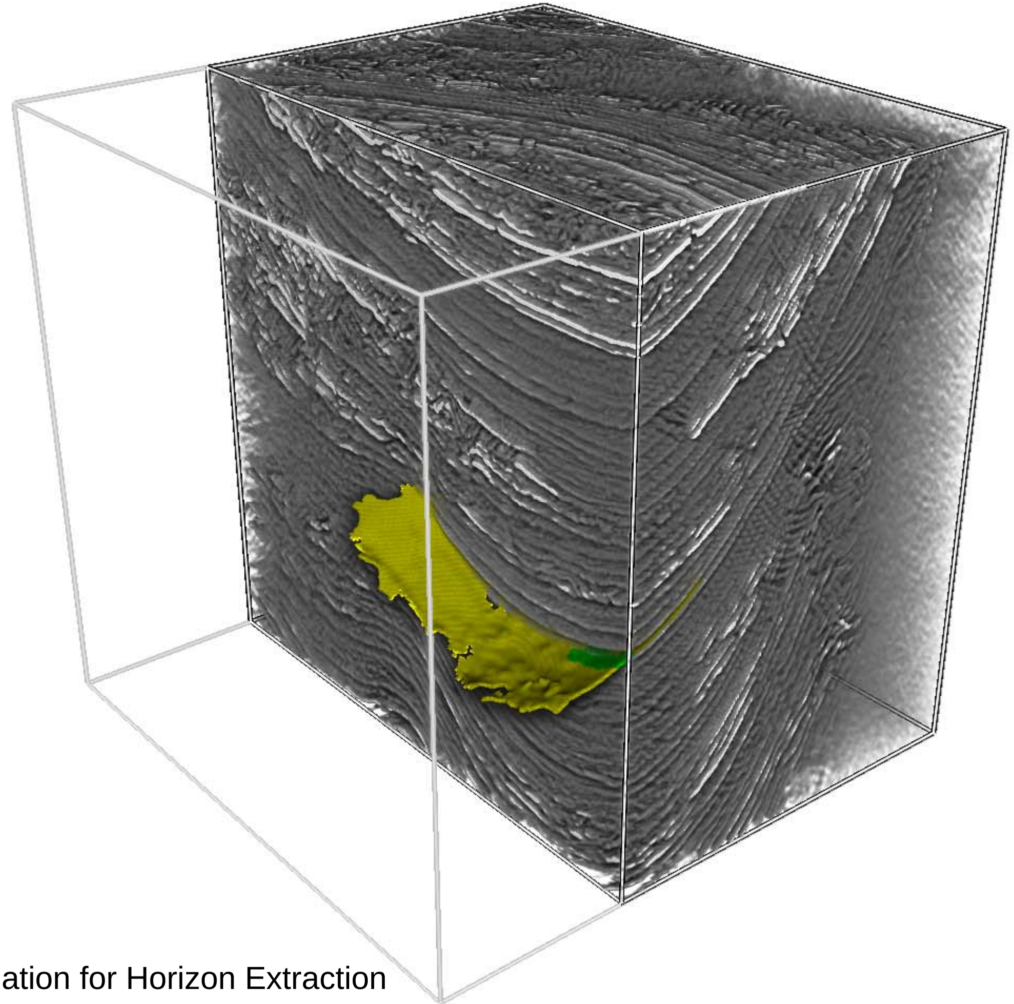
- Horizon growing based on waveform similarity



VolumeExplorer: Roaming Large Volumes to Couple Visualization and Data Processing for Oil and Gas Exploration. Laurent Castanie et al. Vis 2005

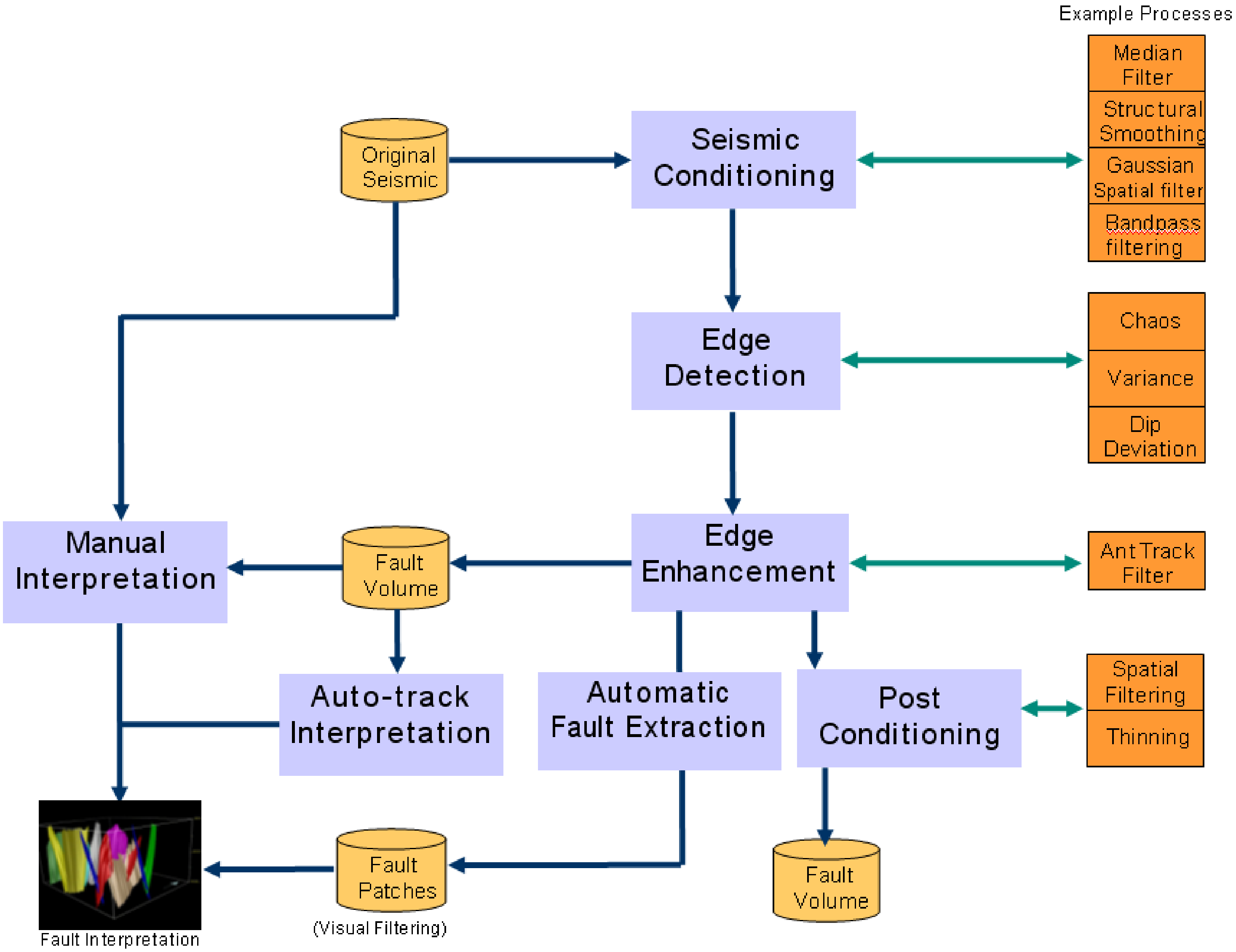
Horizon interpretation

- Quick 3D approach



Seismic Volume Visualization for Horizon Extraction
Patel et al. Proceedings of the IEEE Pacific Visualization Symposium. March 2010.

Fault interpretation



Example Processes

Original Seismic

Seismic Conditioning

Median Filter

Structural Smoothing

Gaussian Spatial filter

Bandpass filtering

Edge Detection

Chaos

Variance

Dip Deviation

Manual Interpretation

Fault Volume

Edge Enhancement

Ant Track Filter

Auto-track Interpretation

Automatic Fault Extraction

Post Conditioning

Spatial Filtering

Thinning

Fault Patches

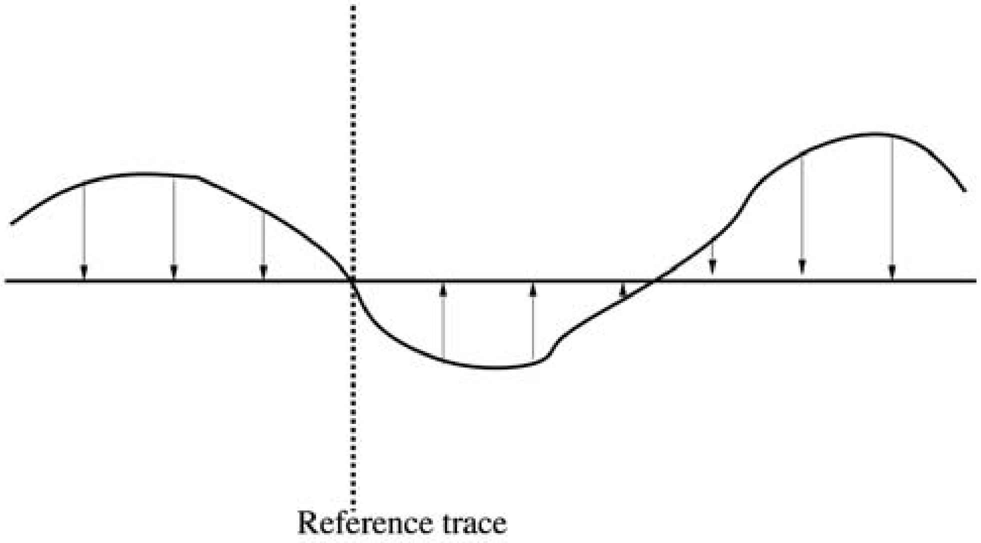
(Visual Filtering)

Fault Volume

Fault Interpretation

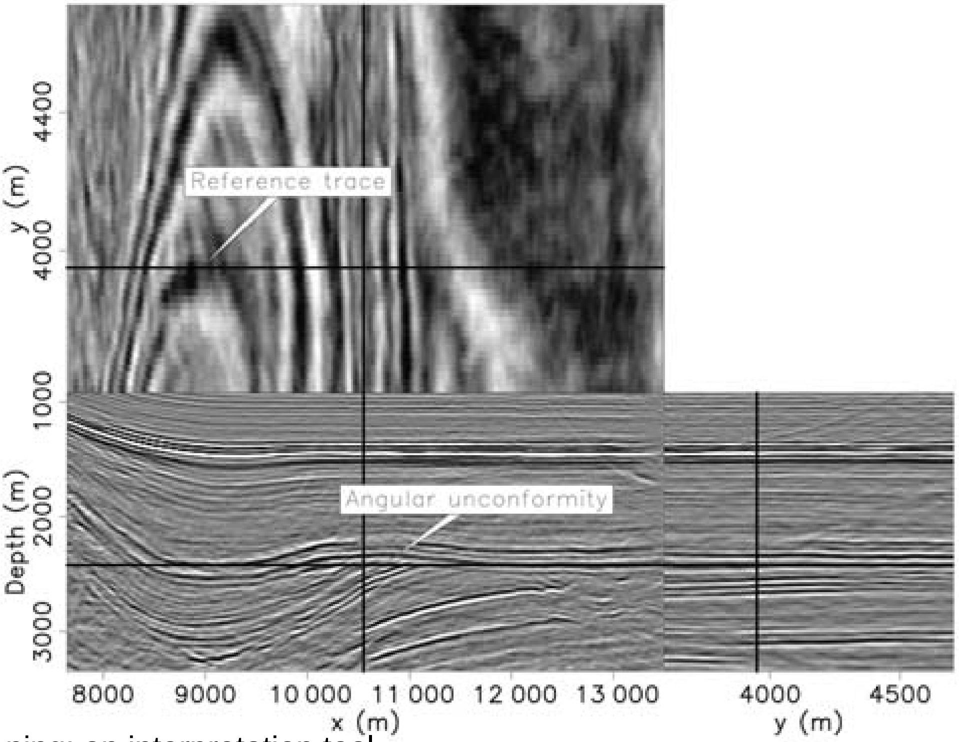
Schlumberger Petrel interpretation software

Volumetric horizon flattening



Volumetric flattening: an interpretation tool
Lomask et al., The Leading edge, 2007

Volumetric horizon flattening



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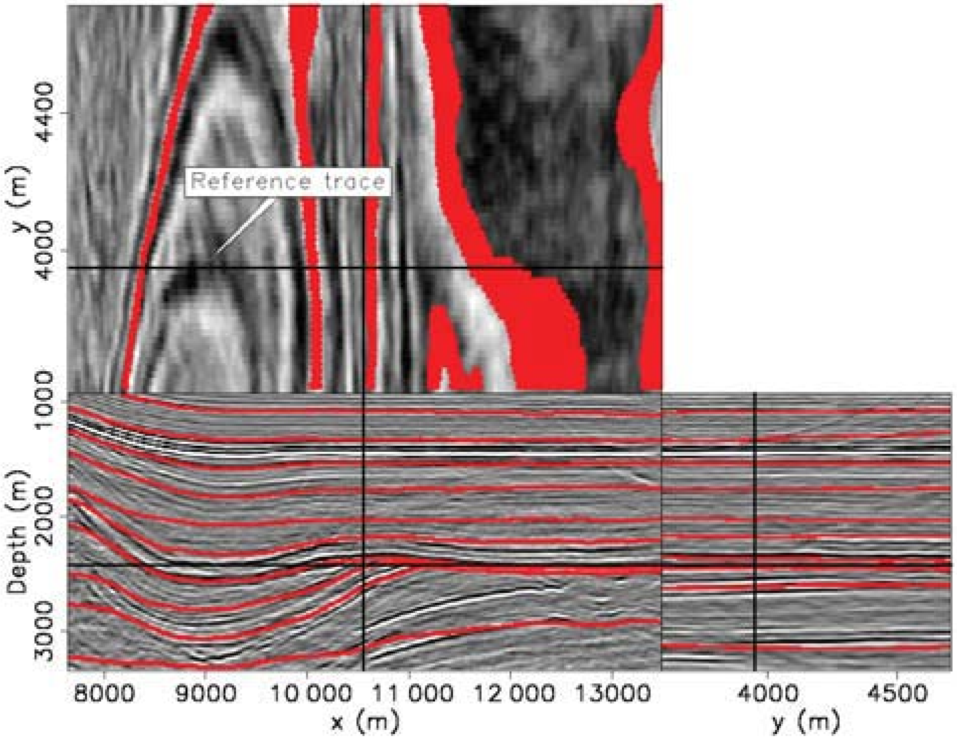

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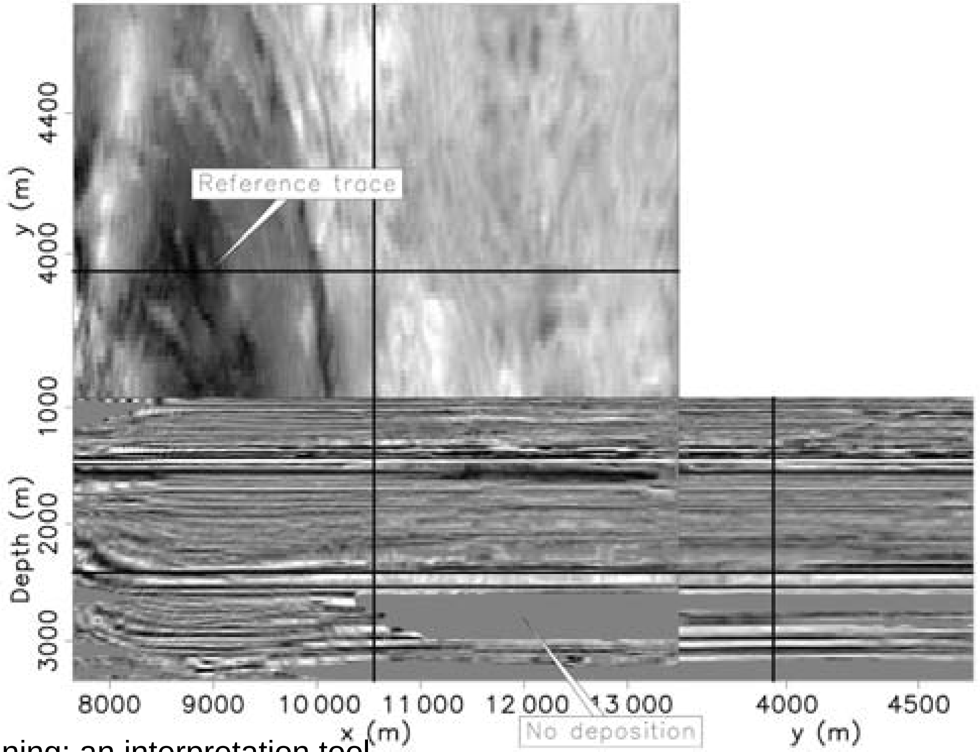

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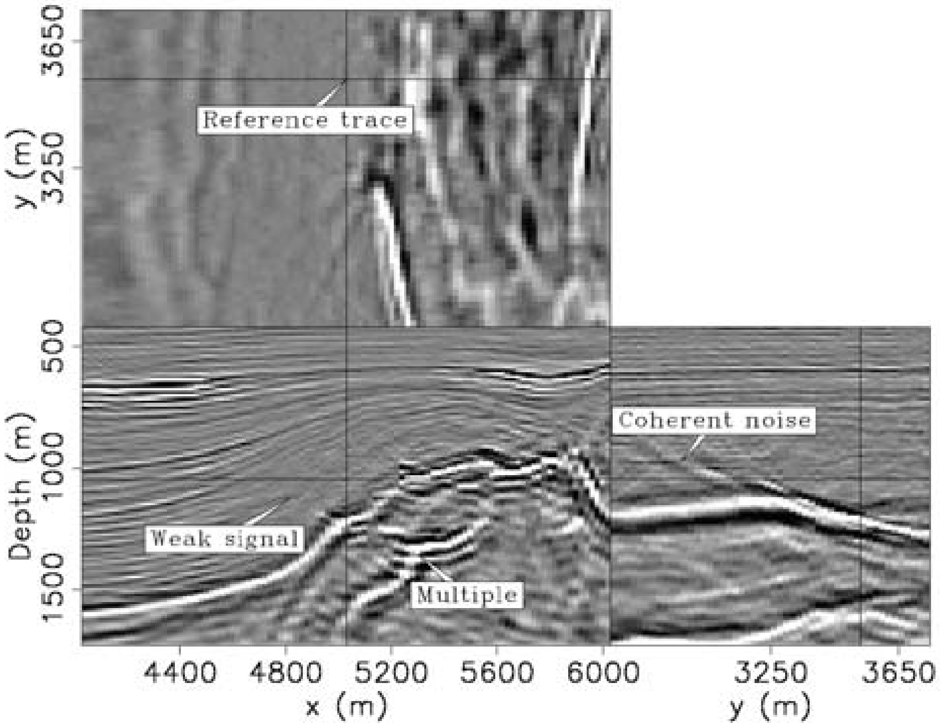

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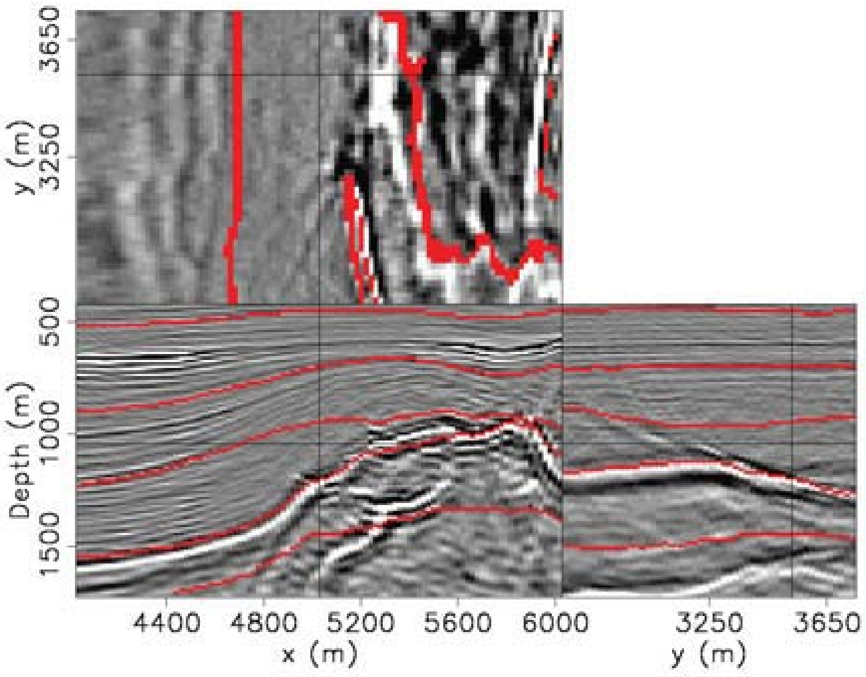

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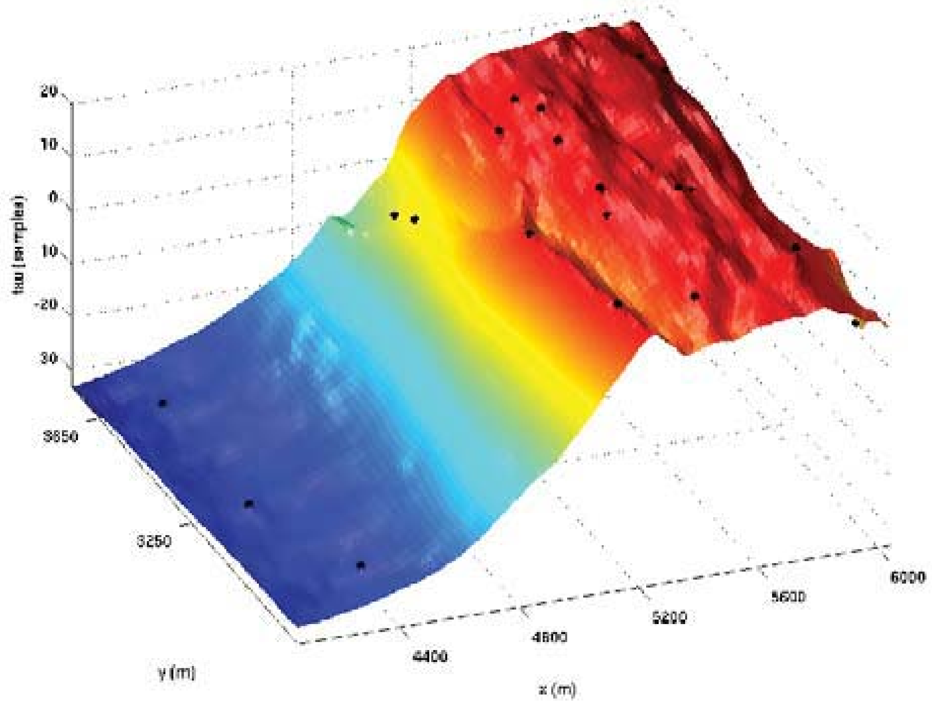
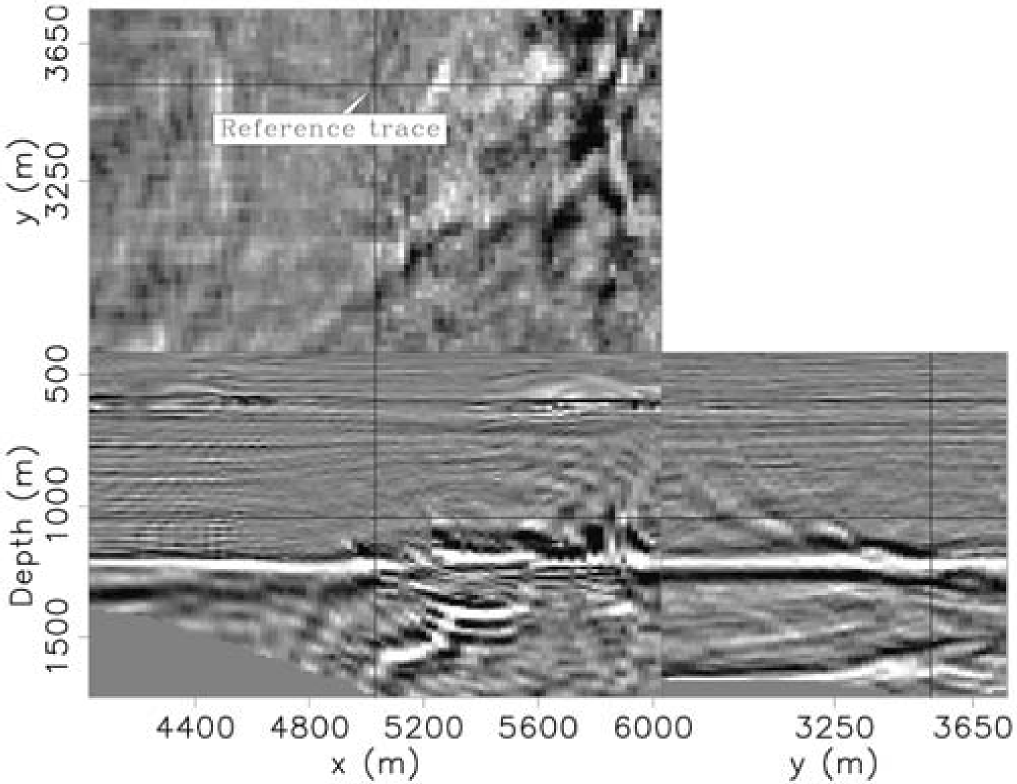
Volumetric horizon flattening



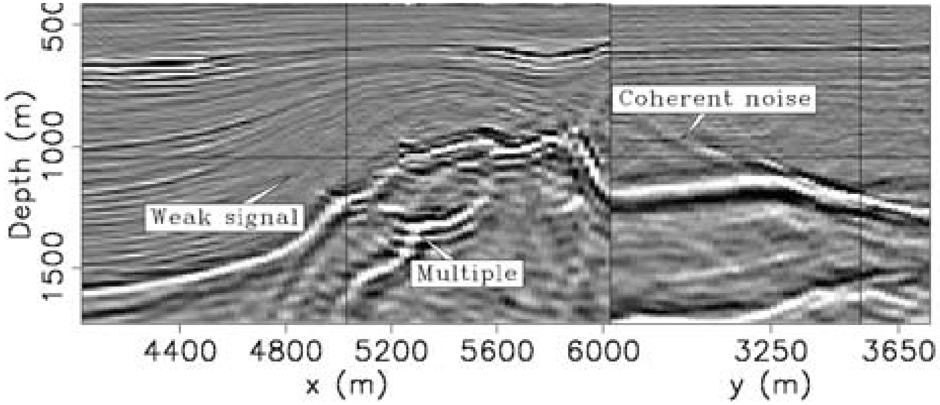
Volumetric flattening: an interpretation tool
Lomask et al., The Leading edge, 2007

Volumetric horizon flattening

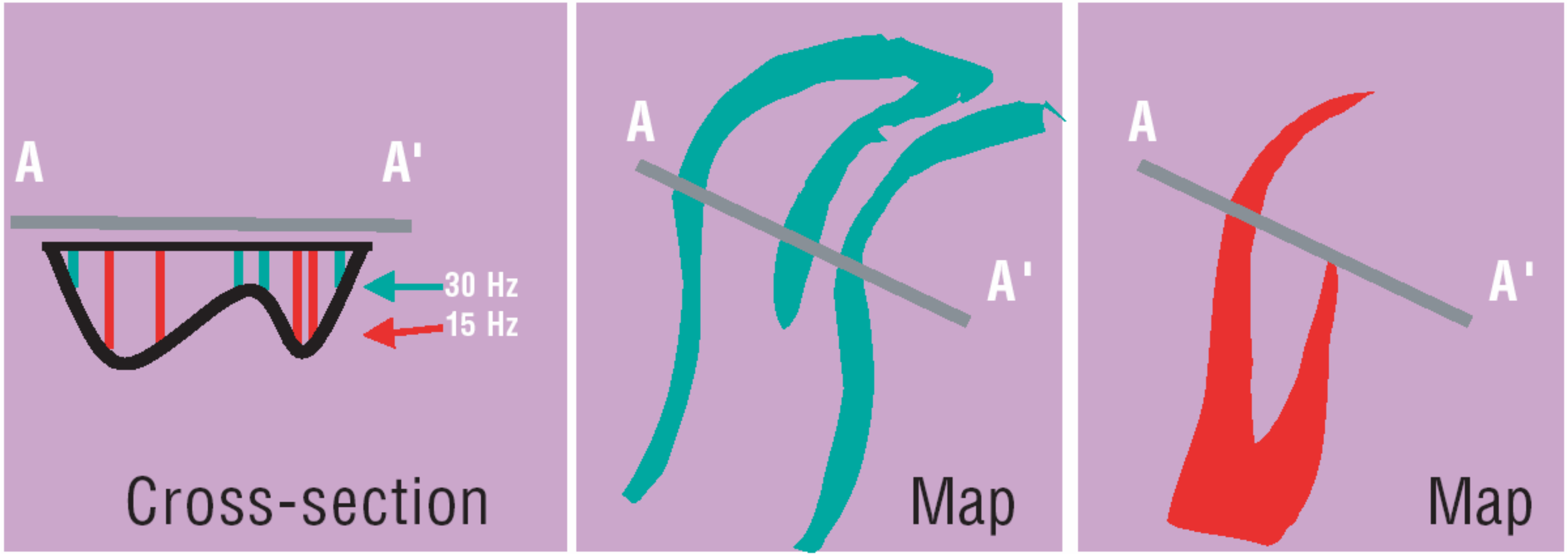
- Flattened:



- Original:



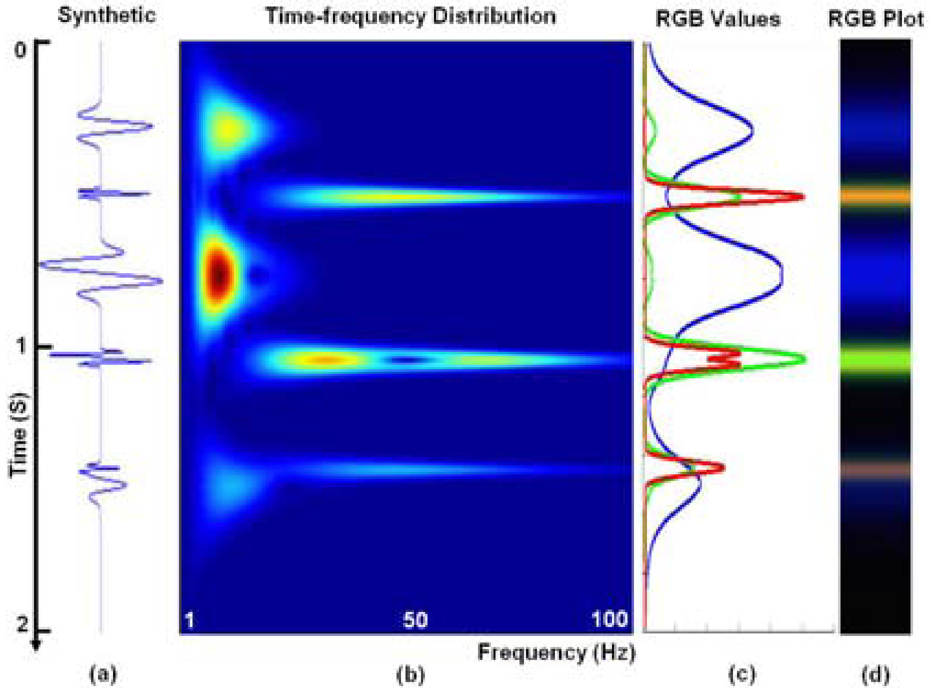
Spectral decomposition

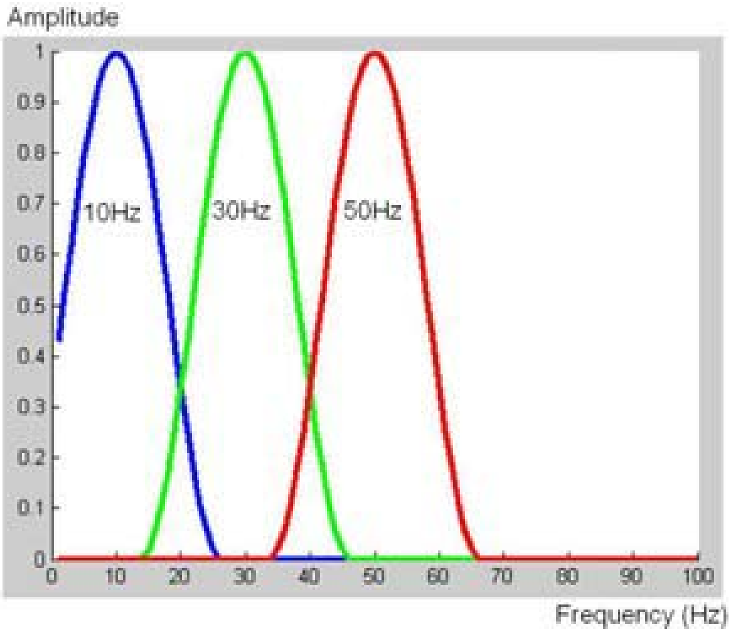


Spectral Decomposition for Seismic Stratigraphic Patterns
Laughlin et al.Search and Discovery Article #40096 (2003)

Spectral decomposition

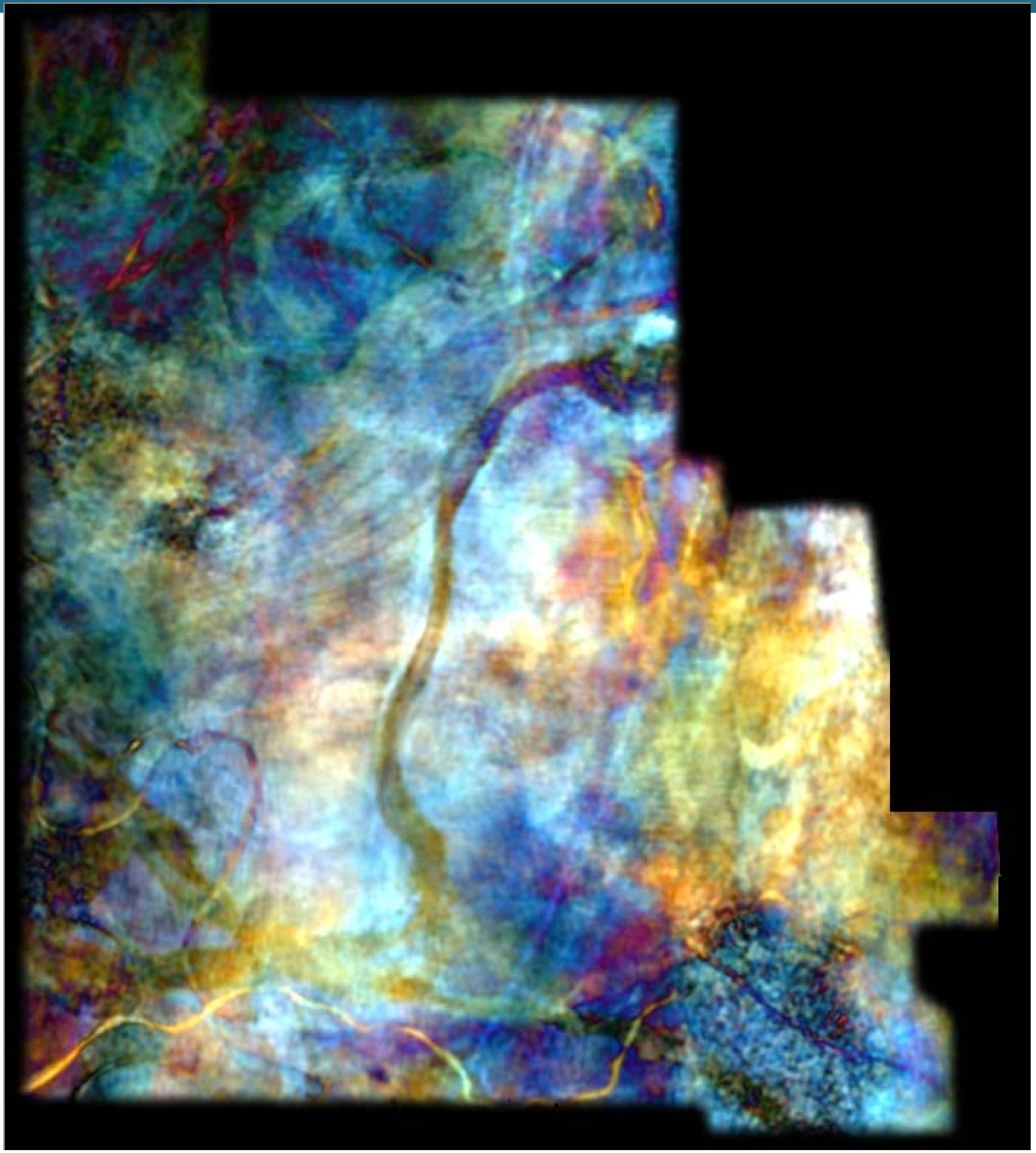
- Frequency transfer function





Multi-color display of spectral attributes

Liu et al.SEG New Orleans 2006

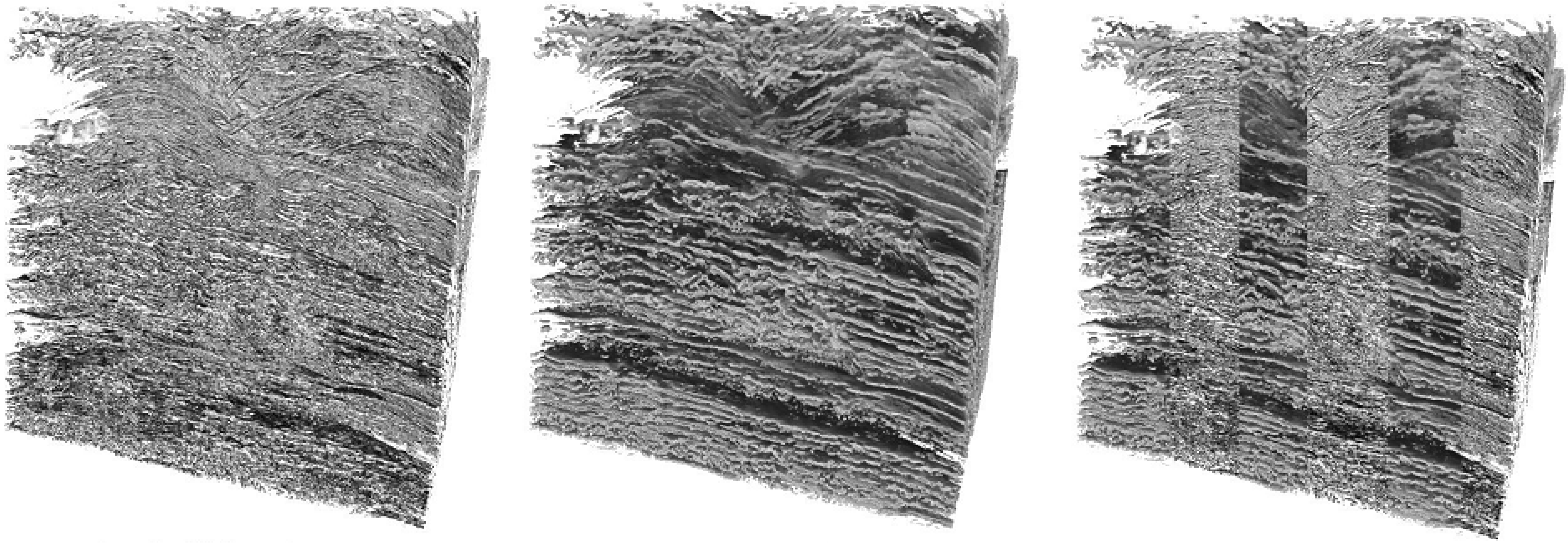


www.opengeosolutions.com/img/specdecomp1.gif

Perceptually aligned rendering of seismic data

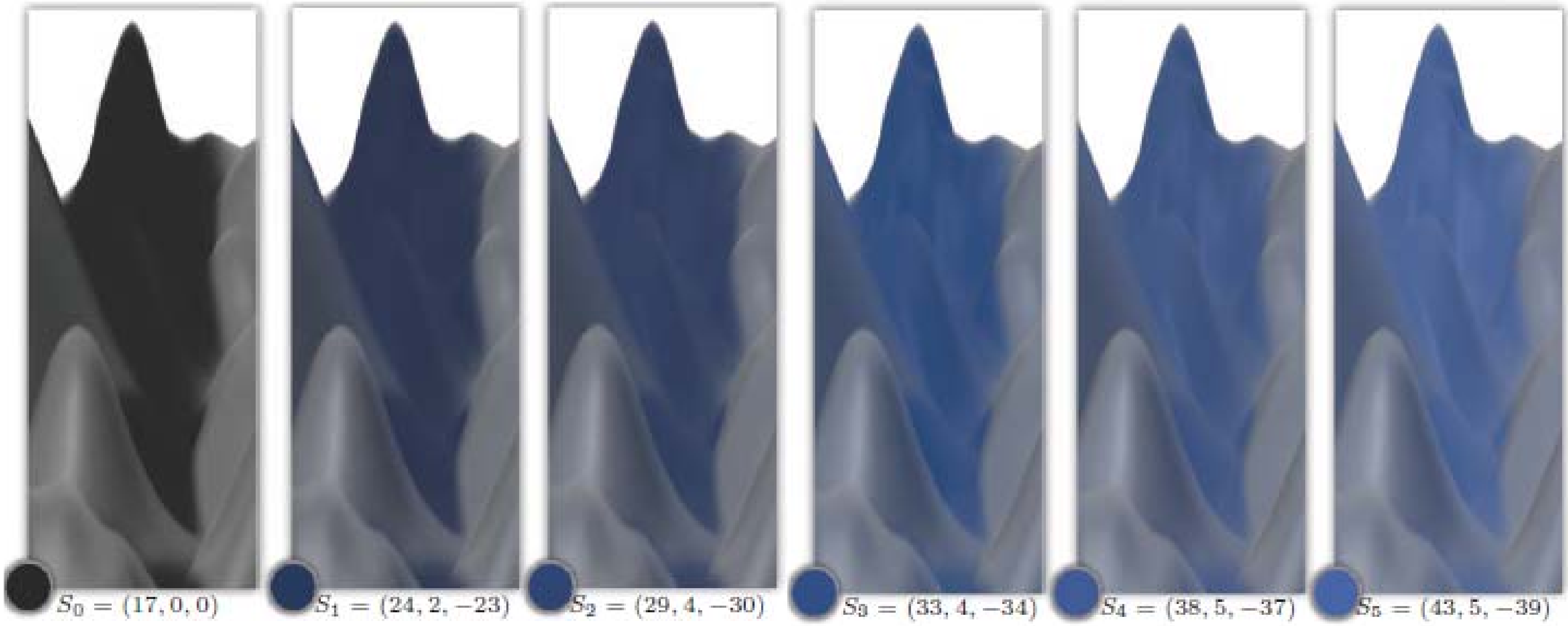
Light model for seismic data

- Film clip



Seismic Volume Visualization for Horizon Extraction
Patel et al. Proceedings of the IEEE Pacific Visualization Symposium. March 2010.

Blue shadows

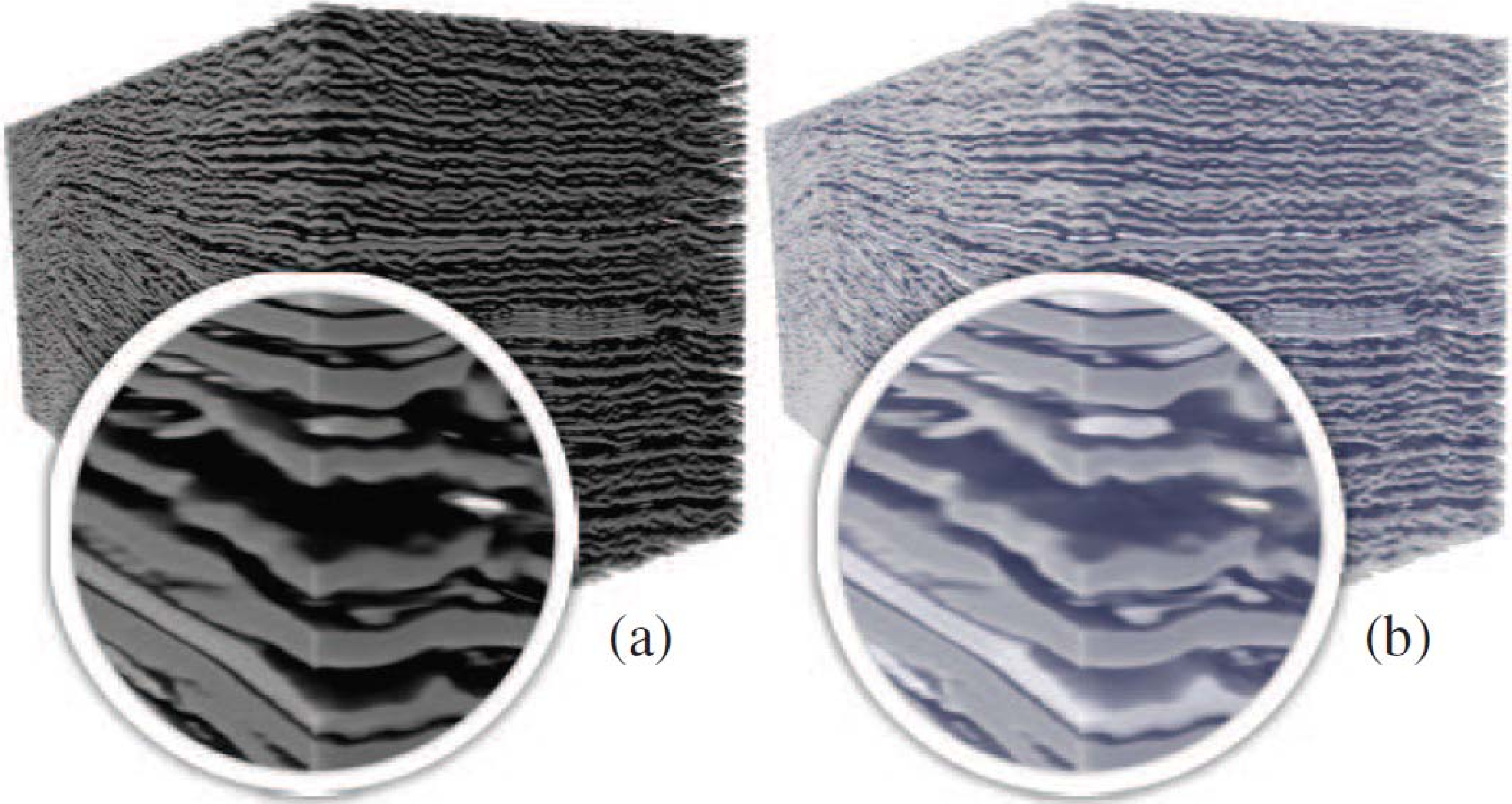


$S_0 = (17, 0, 0)$ $S_1 = (24, 2, -23)$ $S_2 = (29, 4, -30)$ $S_3 = (33, 4, -34)$ $S_4 = (38, 5, -37)$ $S_5 = (43, 5, -39)$

Chromatic Shadows for Improved Perception

Soltészová et al. Non-Photorealistic Animation and Rendering, NPAR 2011

Blue shadows

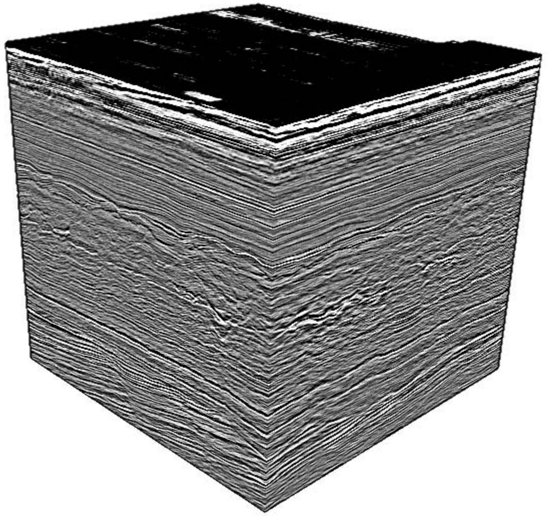


Chromatic Shadows for Improved Perception

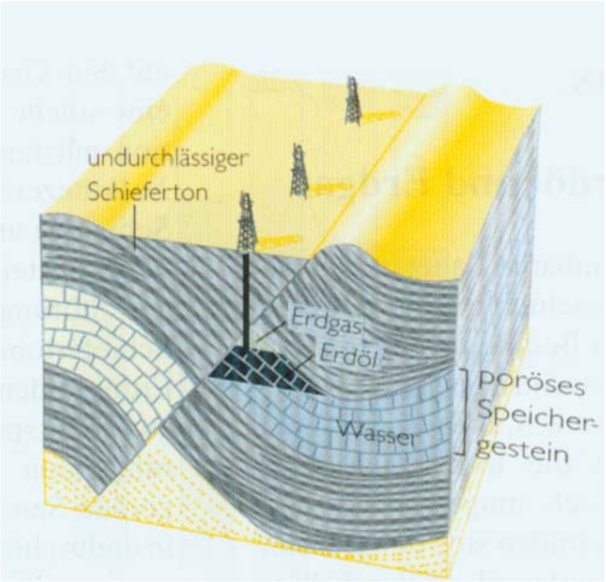
Soltészová et al. Non-Photorealistic Animation and Rendering, NPAR 2011

Scientific vs illustrative visualization

data



illustration



Understanding Earth, Grotzinger et. Al. NY Press

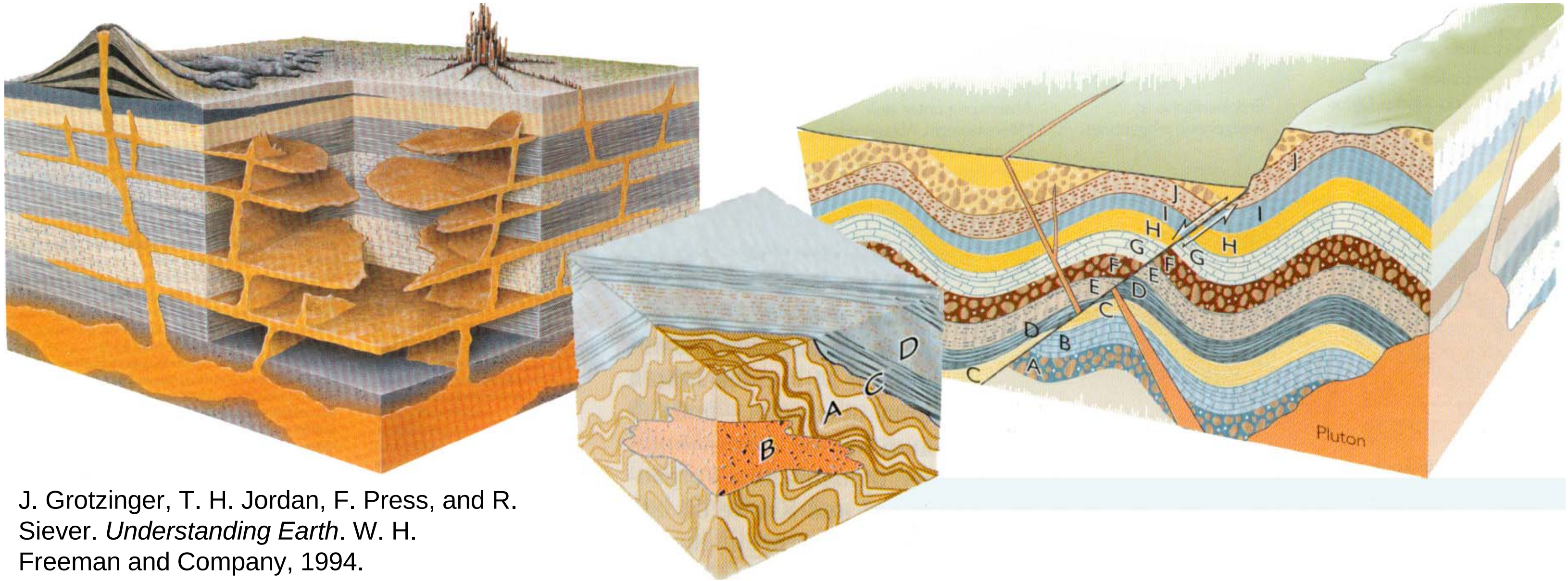
- Raw data
- Visual overload

- Abstracted data
- Shows essential aspects

Techniques in geoscientific illustrations

- Textures on planar surfaces to emphasize layers and faults
  - Textures bent along layers
  - Discontinuities over faults

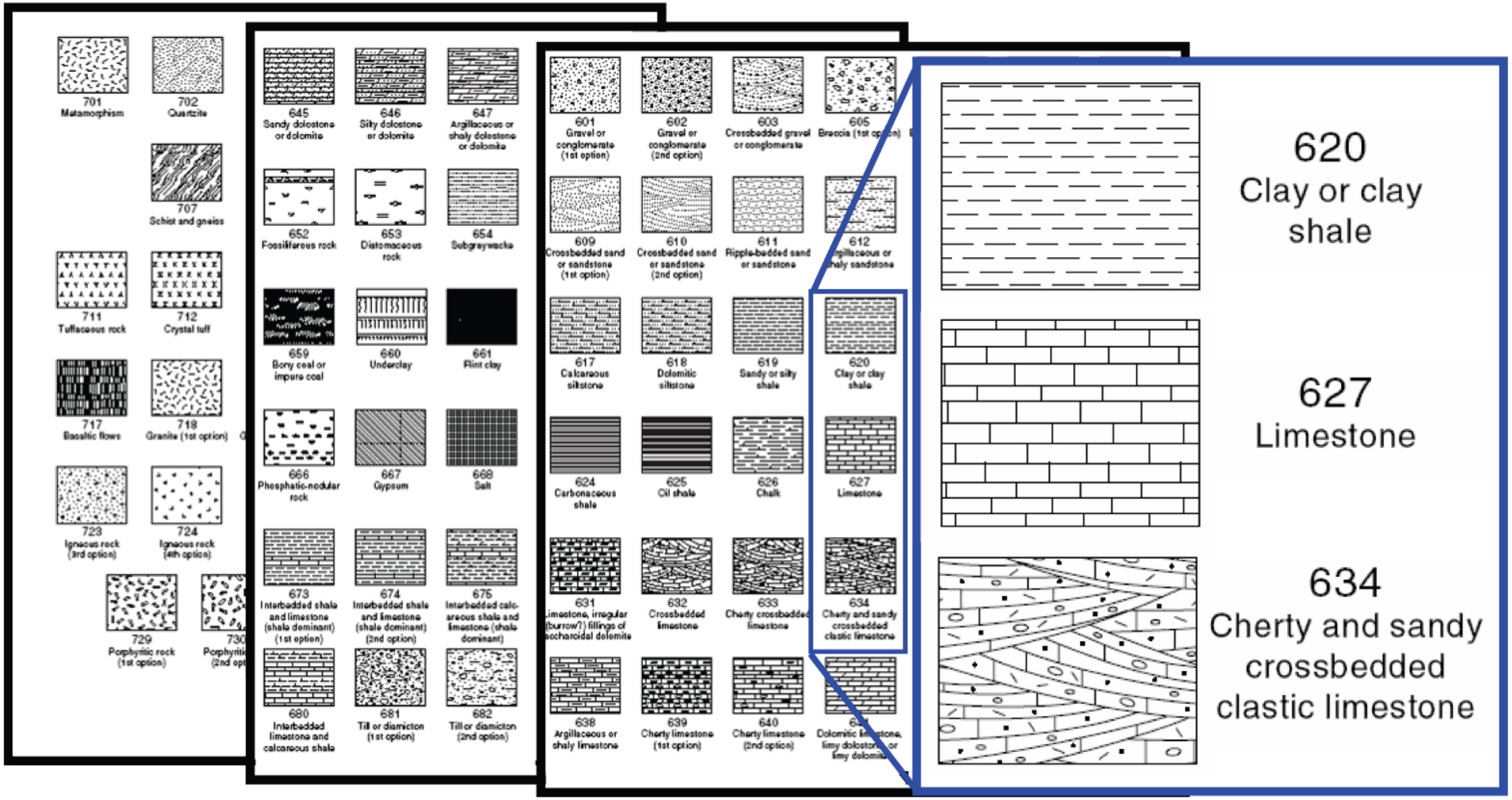
- Opaque cubes with textured surfaces for 3D context
  - Axis-aligned cut outs
  - Extruding features



J. Grotzinger, T. H. Jordan, F. Press, and R. Siever. *Understanding Earth*. W. H. Freeman and Company, 1994.

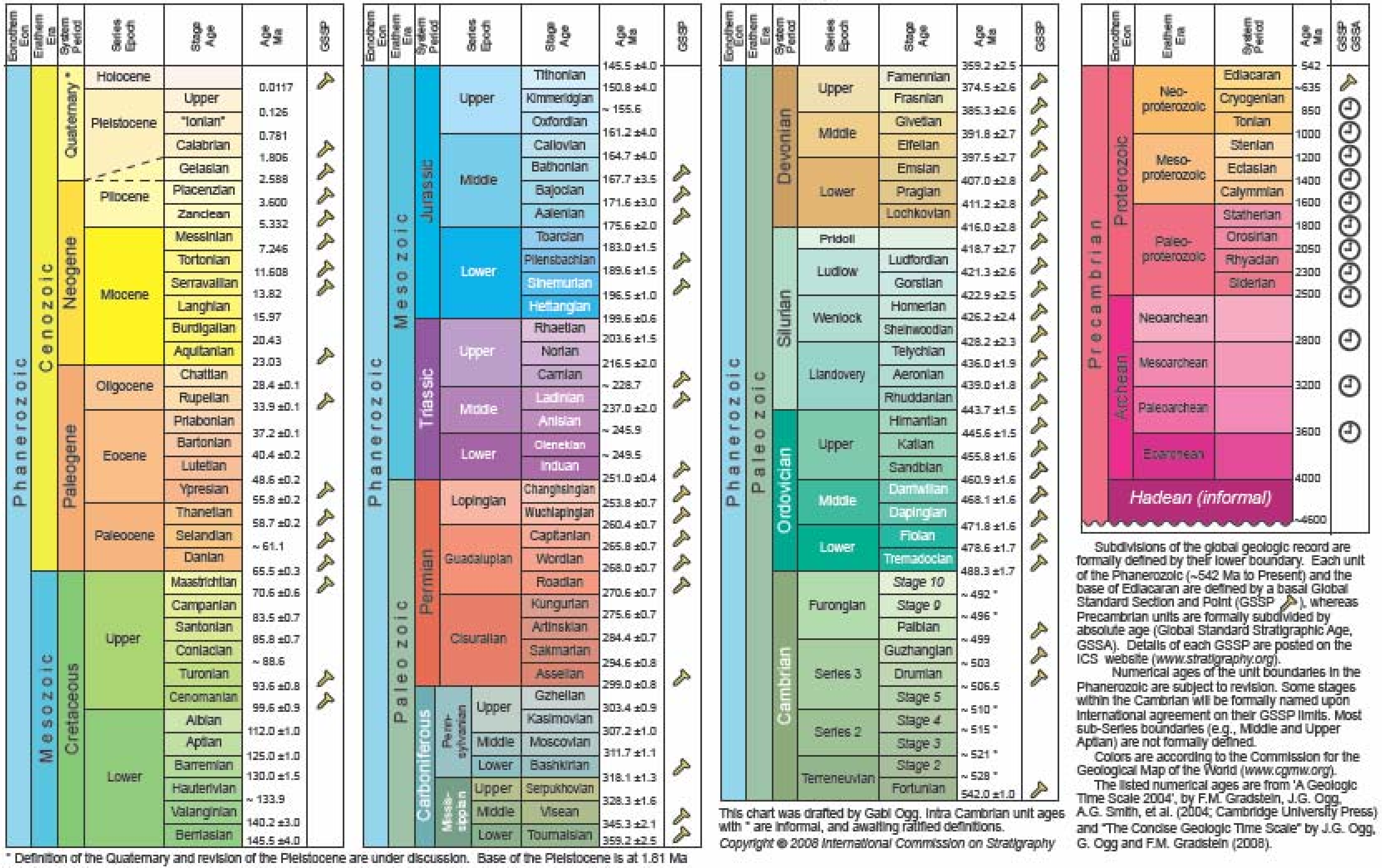
Symbols in geoscientific illustrations

US standard geological textures



INTERNATIONAL STRATIGRAPHIC CHART

International Commission on Stratigraphy



Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary *	Holocene		0.0117	✓
			Pleistocene	Upper	0.126	
				"Ionian"	0.781	
				Calabrian	1.806	✓
				Gelasian	2.588	✓
		Neogene	Pliocene	Piacenzian	3.600	✓
				Zanclean	5.332	✓
			Miocene	Messinian	7.246	✓
				Tortonian	11.608	✓
				Serravallian	13.82	✓
				Langhian	15.97	
				Burdigalian	20.43	
				Aquitanian	23.03	✓
		Paleogene	Oligocene	Chattian	28.4 ±0.1	
				Rupelian	33.9 ±0.1	✓
			Eocene	Priabonian	37.2 ±0.1	
				Bartonian	40.4 ±0.2	
				Lutetian	48.6 ±0.2	
				Ypresian	55.8 ±0.2	✓
			Paleocene	Thanetian	58.7 ±0.2	✓
				Selandian	~ 61.1	✓
				Danian	65.5 ±0.3	✓
	Mesozoic	Cretaceous	Upper	Maastrichtian	70.6 ±0.6	✓
				Campanian	83.5 ±0.7	
				Santonian	85.8 ±0.7	
				Coniacian	~ 88.6	
				Turonian	93.6 ±0.8	✓
				Cenomanian	99.6 ±0.9	✓
			Lower	Albian	112.0 ±1.0	
				Aptian	125.0 ±1.0	
				Barremian	130.0 ±1.5	
				Hauterivian	~ 133.9	
				Valanginian	140.2 ±3.0	
				Berriasian	145.5 ±4.0	

Eonothem Eon	Erathem Era	System Period		Series Epoch	Stage Age	Age Ma	GSSP
						145.5 ±4.0	
Phanerozoic	Mesozoic	Jurassic		Upper	Tithonian	150.8 ±4.0	
					Kimmeridgian	~ 155.6	
					Oxfordian	161.2 ±4.0	
				Middle	Callovian	164.7 ±4.0	
					Bathonian	167.7 ±3.5	✓
					Bajocian	171.6 ±3.0	✓
					Aalenian	175.6 ±2.0	✓
				Lower	Toarcian	183.0 ±1.5	
					Pliensbachian	189.6 ±1.5	✓
					Sinemurian	196.5 ±1.0	✓
					Hettangian	199.6 ±0.6	
		Triassic		Upper	Rhaetian	203.6 ±1.5	
					Norian	216.5 ±2.0	
					Carnian	~ 228.7	✓
				Middle	Ladinian	237.0 ±2.0	✓
					Anisian	~ 245.9	
				Lower	Olenekian	~ 249.5	
					Induan	251.0 ±0.4	✓
	Paleozoic	Permian		Lopingian	Changhsingian	253.8 ±0.7	✓
					Wuchiapingian	260.4 ±0.7	✓
				Guadalupian	Capitanian	265.8 ±0.7	✓
					Wordian	268.0 ±0.7	✓
					Roadian	270.6 ±0.7	✓
				Cisuralian	Kungurian	275.6 ±0.7	
					Artinskian	284.4 ±0.7	
					Sakmarian	294.6 ±0.8	
					Asselian	299.0 ±0.8	✓
		Carboniferous	Pennsylvanian	Upper	Gzhelian	303.4 ±0.9	
					Kasimovian	307.2 ±1.0	
				Middle	Moscovian	311.7 ±1.1	
				Lower	Bashkirian	318.1 ±1.3	✓
			Mississippian	Upper	Serpukhovian	328.3 ±1.6	
				Middle	Visean	345.3 ±2.1	✓
				Lower	Tournaisian	359.2 ±2.5	✓

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
					359.2 ±2.5	
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	374.5 ±2.6	✓
				Frasnian	385.3 ±2.6	✓
			Middle	Givetian	391.8 ±2.7	✓
				Eifelian	397.5 ±2.7	✓
			Lower	Emsian	407.0 ±2.8	✓
				Pragian	411.2 ±2.8	✓
				Lochkovian	416.0 ±2.8	✓
		Silurian	Pridoli		418.7 ±2.7	✓
			Ludlow	Ludfordian	421.3 ±2.6	✓
				Gorstian	422.9 ±2.5	✓
			Wenlock	Homerian	426.2 ±2.4	✓
				Sheinwoodian	428.2 ±2.3	✓
			Llandovery	Telychian	436.0 ±1.9	✓
				Aeronian	439.0 ±1.8	✓
				Rhuddanian	443.7 ±1.5	✓
		Ordovician	Upper	Hirnantian	445.6 ±1.5	✓
				Katian	455.8 ±1.6	✓
				Sandbian	460.9 ±1.6	✓
			Middle	Darriwilian	468.1 ±1.6	✓
				Dapingian	471.8 ±1.6	✓
			Lower	Floian	478.6 ±1.7	✓
				Tremadocian	488.3 ±1.7	✓
		Cambrian	Furongian	*Stage 10*	~ 492 *	
				Stage 9	~ 496 *	
				Paibian	~ 499	✓
			Series 3	Guzhangian	~ 503	✓
				Drumian	~ 506.5	✓
				Stage 5	~ 510 *	
			Series 2	*Stage 4*	~ 515 *	
				Stage 3	~ 521 *	
			Terreneuvian	*Stage 2*	~ 528 *	
				Fortunian	542.0 ±1.0	✓

	Eonothem Eon	Erathem Era	System Period	Age Ma	GSSP GSSA
				542	
Precambrian	Proterozoic	Neo-proterozoic	Ediacaran	~635	✓
			Cryogenian	850	◷
			Tonian	1000	◷
		Meso-proterozoic	Stenian	1200	◷
			Ectasian	1400	◷
			Calymmian	1600	◷
		Paleo-proterozoic	Statherian	1800	◷
			Orosirian	2050	◷
			Rhyacian	2300	◷
			Siderian	2500	◷
	Archean	Neoarchean		2800	◷
		Mesoarchean		3200	◷
		Paleoarchean		3600	◷
		Eoarchean		4000	
	Hadean (informal)			~4600	

* Definition of the Quaternary and revision of the Pleistocene are under discussion. Base of the Pleistocene is at 1.81 Ma (base of Calabrian), but may be extended to 2.59 Ma (base of Gelasian). The historic "Tertiary" comprises the Paleogene and Neogene, and has no official rank.

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Standard Section and Point (GSSP ✓), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (*www.stratigraphy.org*).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (*www.cgmw.org*).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

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