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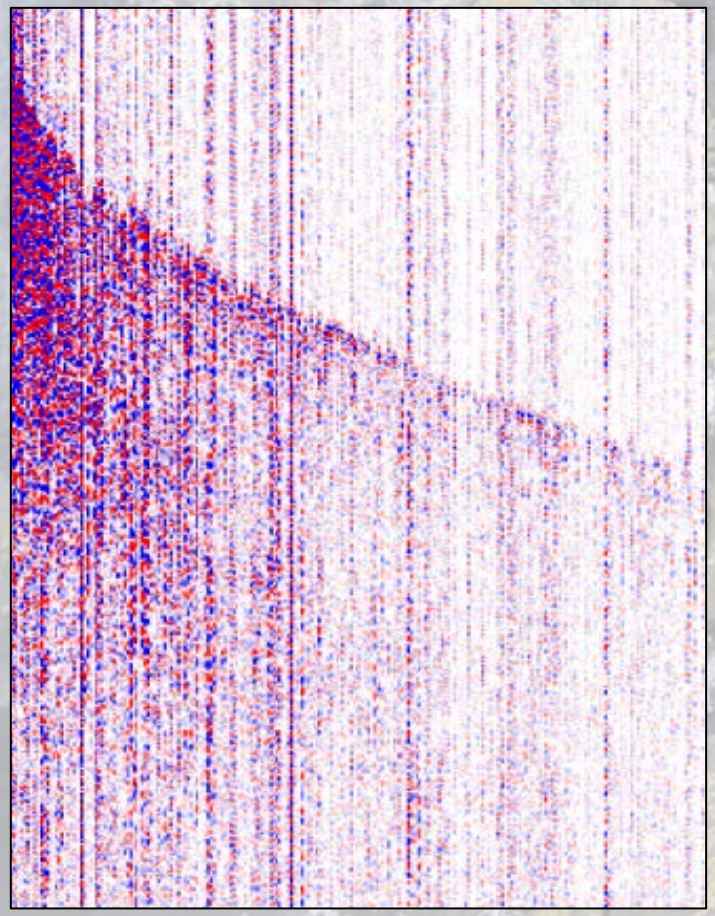

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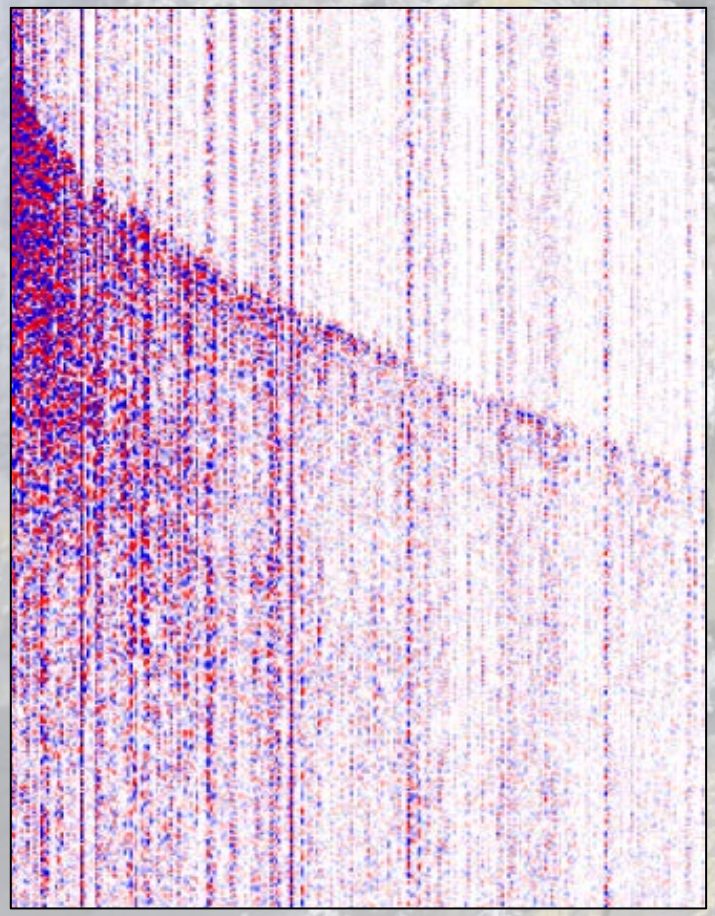

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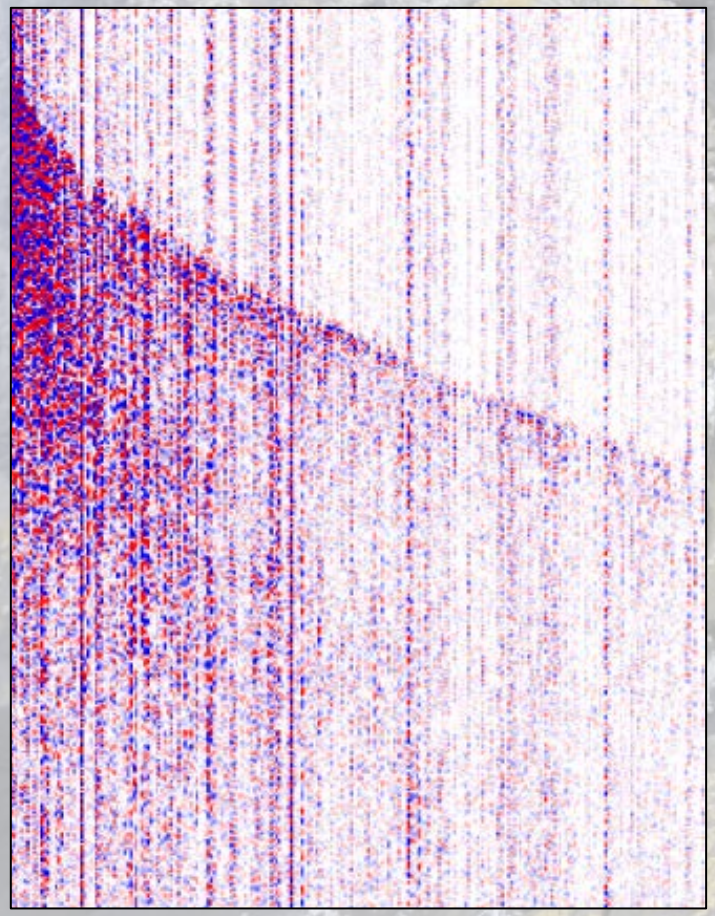

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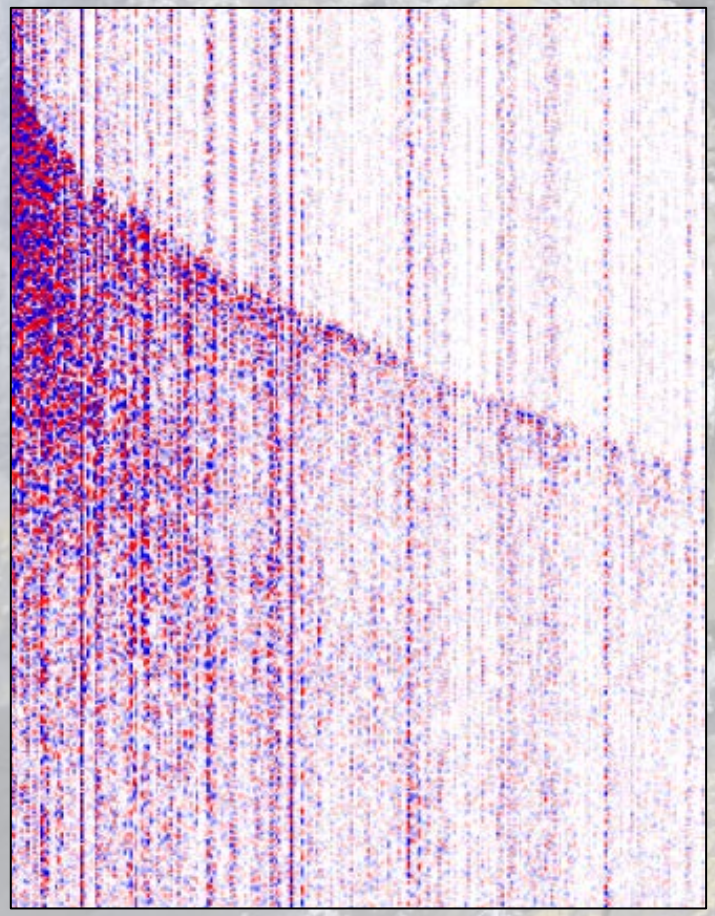

Let‘s give it a try…

(a) No idea

(b) Some old and low-quality seismic data

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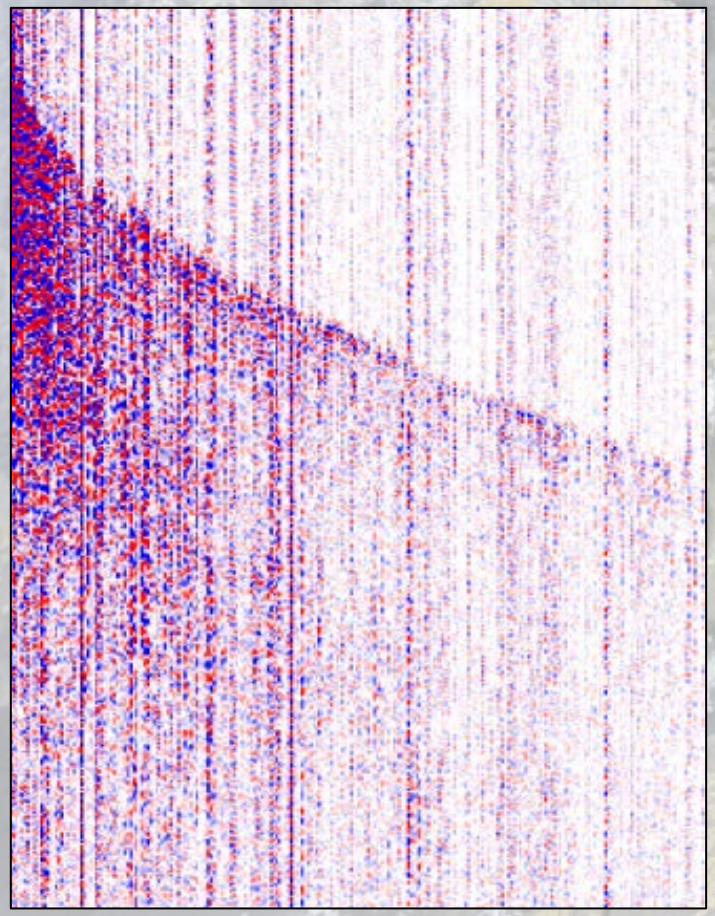

Let‘s give it a try…

(a) No idea

(b) Some old and low-quality seismic data

(c) A shot gather of industry-standard 3D land seismic data

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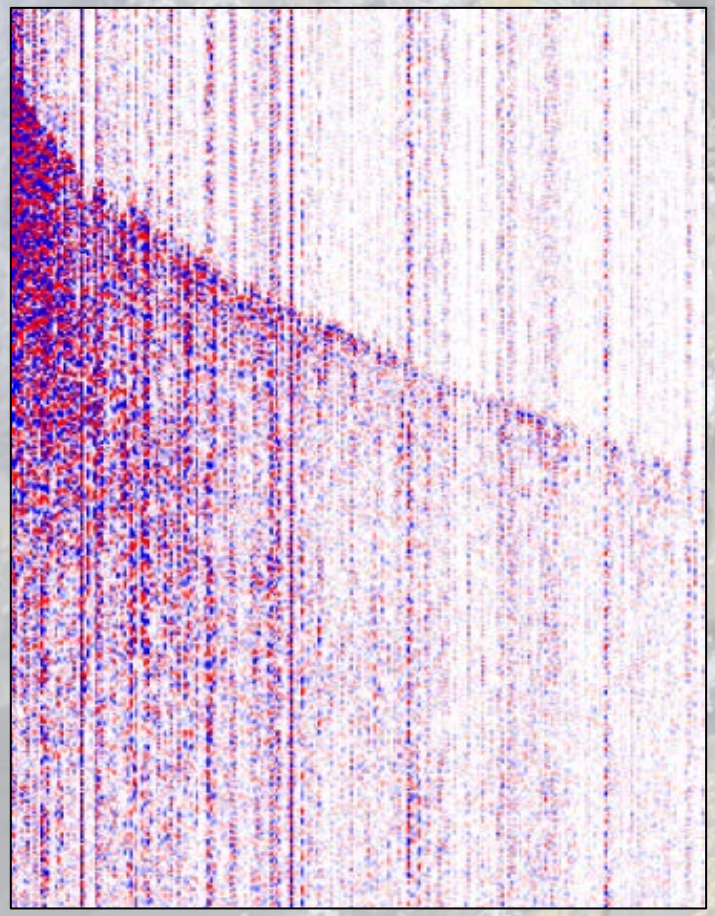

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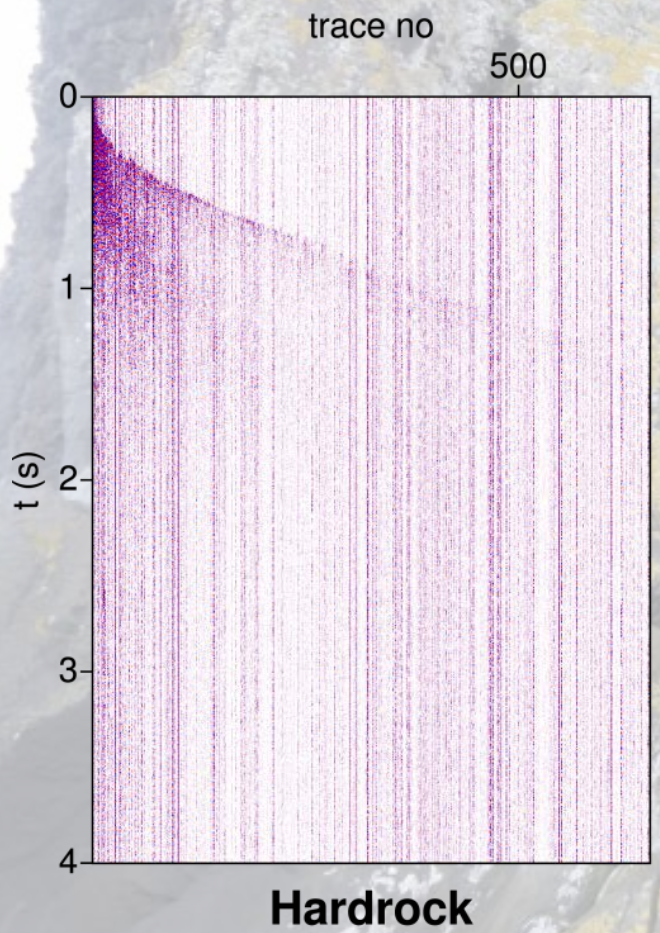

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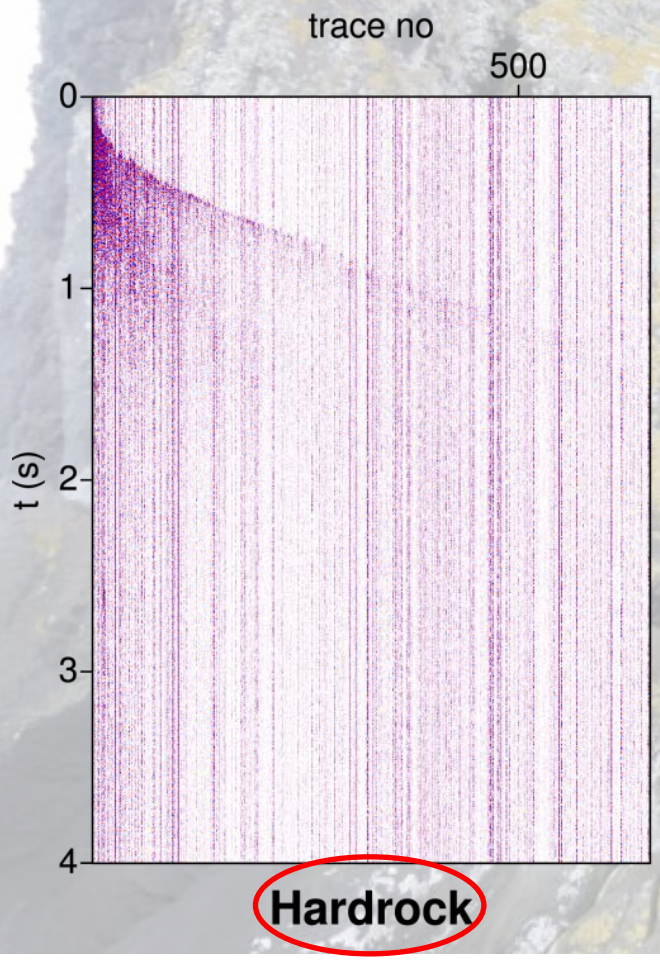

- Crystalline hard rock environment

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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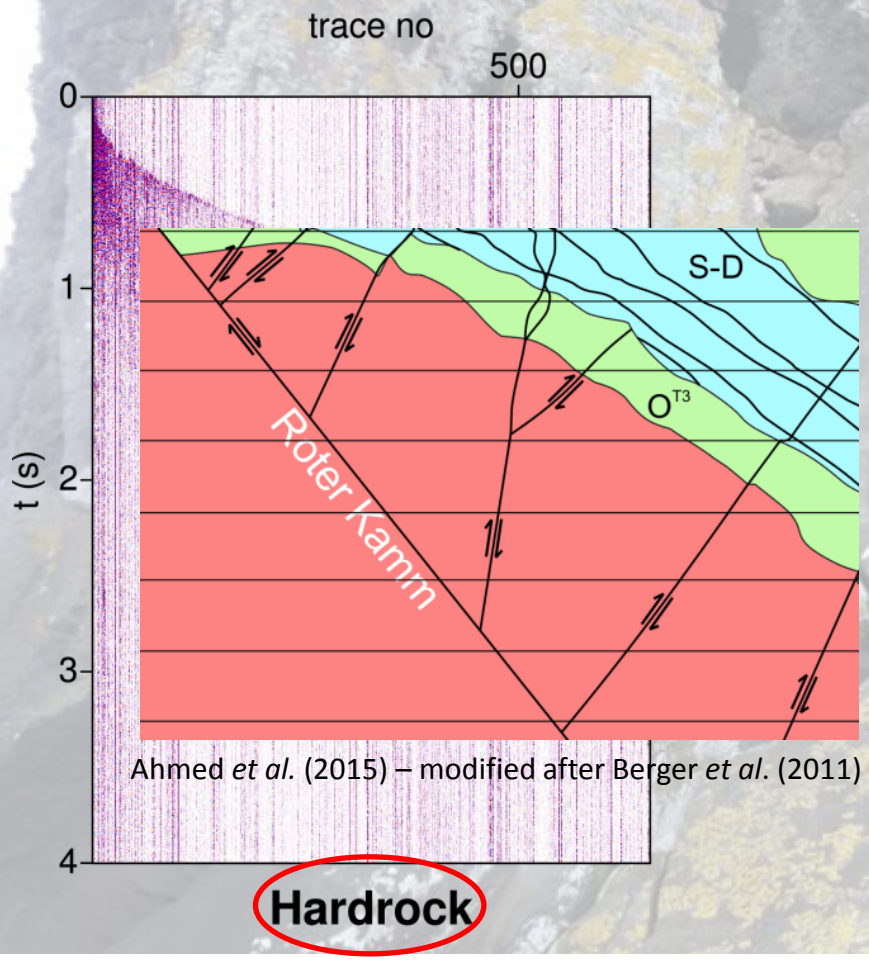

Ahmed *et al.* (2015) – modified after Berger *et al*. (2011)

- Crystalline hard rock environment
- Target: steep dipping faults

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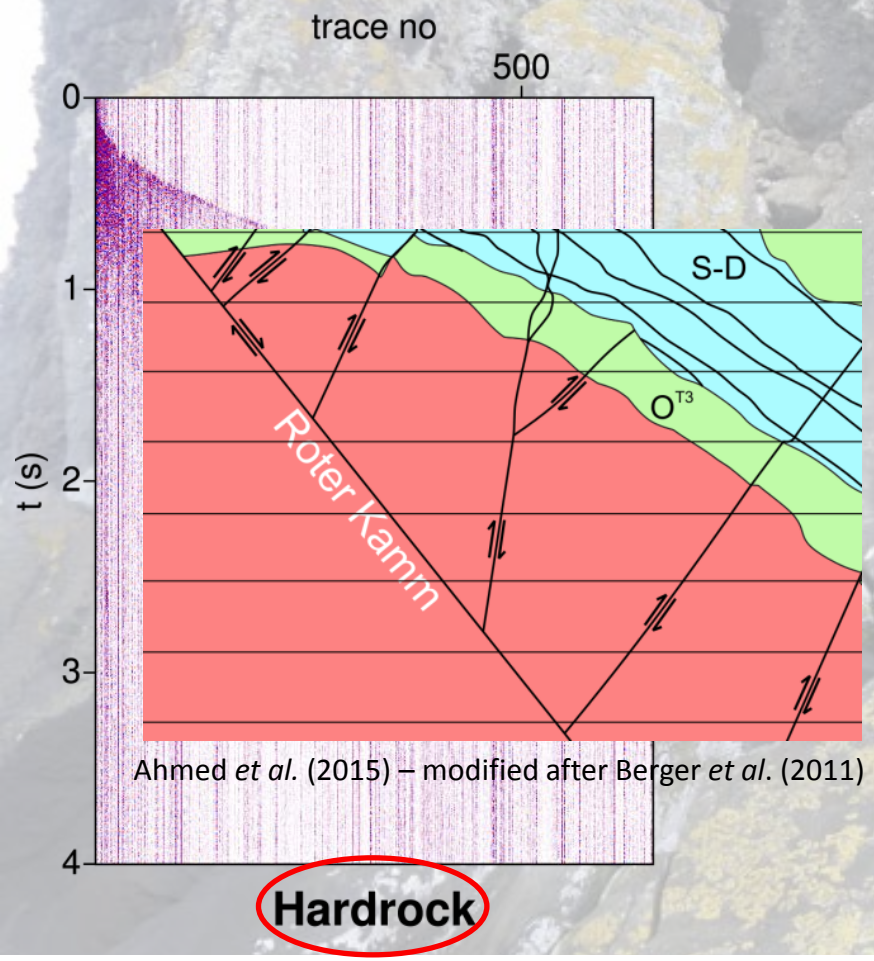

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- **Crystalline hard rock environment**
- **Target: steep dipping faults**

Need for special processing and 3D visualization techniques

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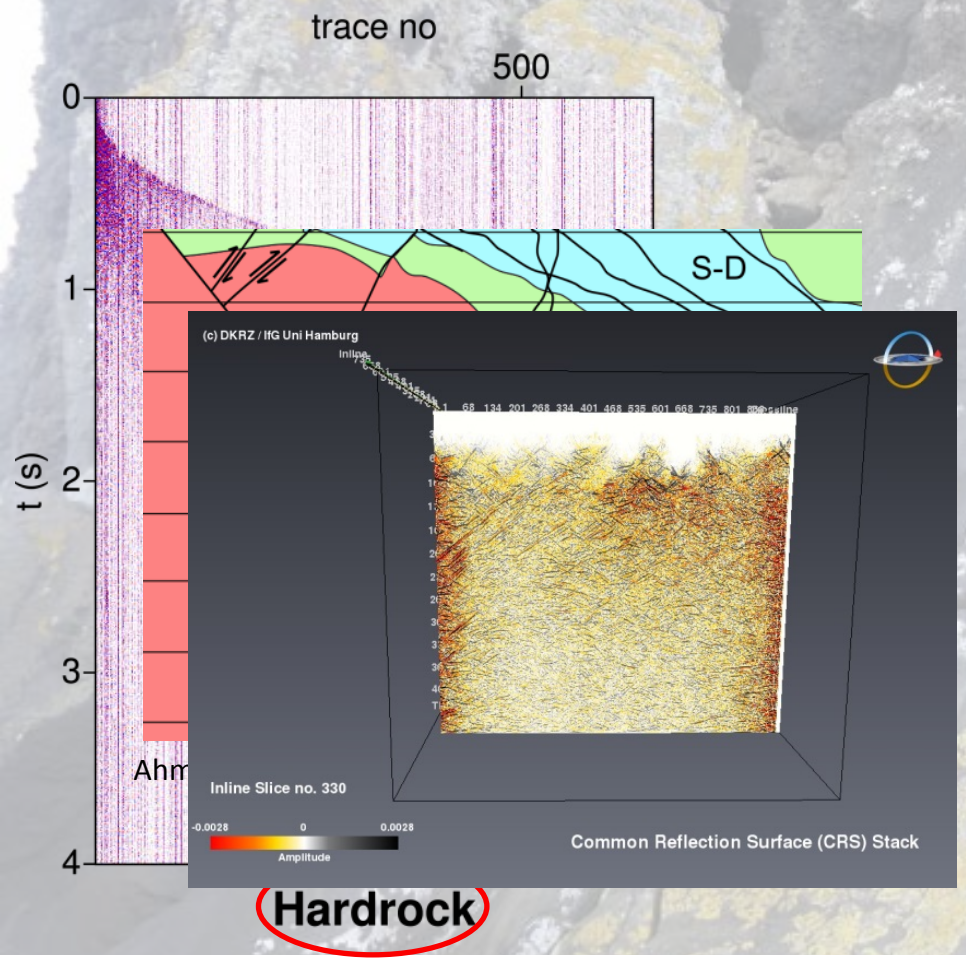

- Crystalline hard rock environment
- Target: steep dipping faults

Need for special processing and 3D visualization techniques

- 3D CRS Stack alone reveals little

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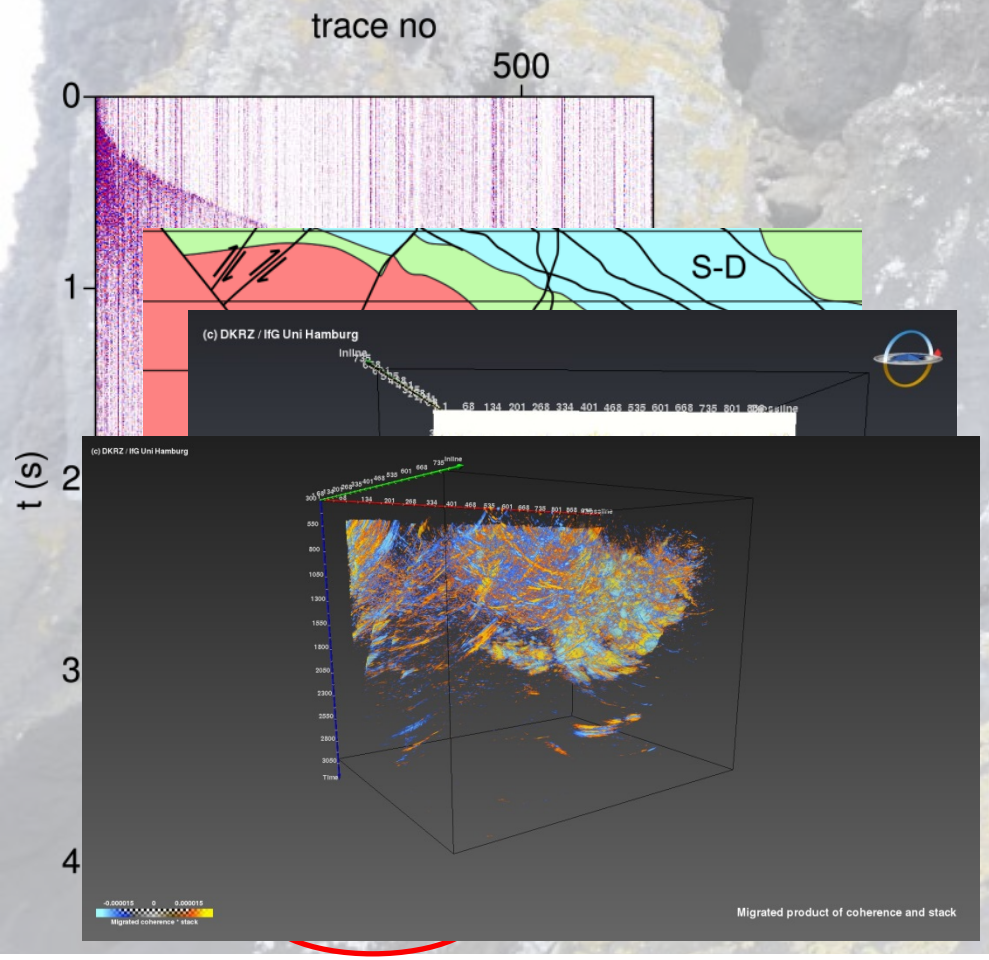

- Crystalline hard rock environment
- Target: steep dipping faults

Need for special processing and 3D visualization techniques

- 3D CRS Stack alone reveals little
- Migrated CWS and Avizo Earth reveal what is hidden in the data

Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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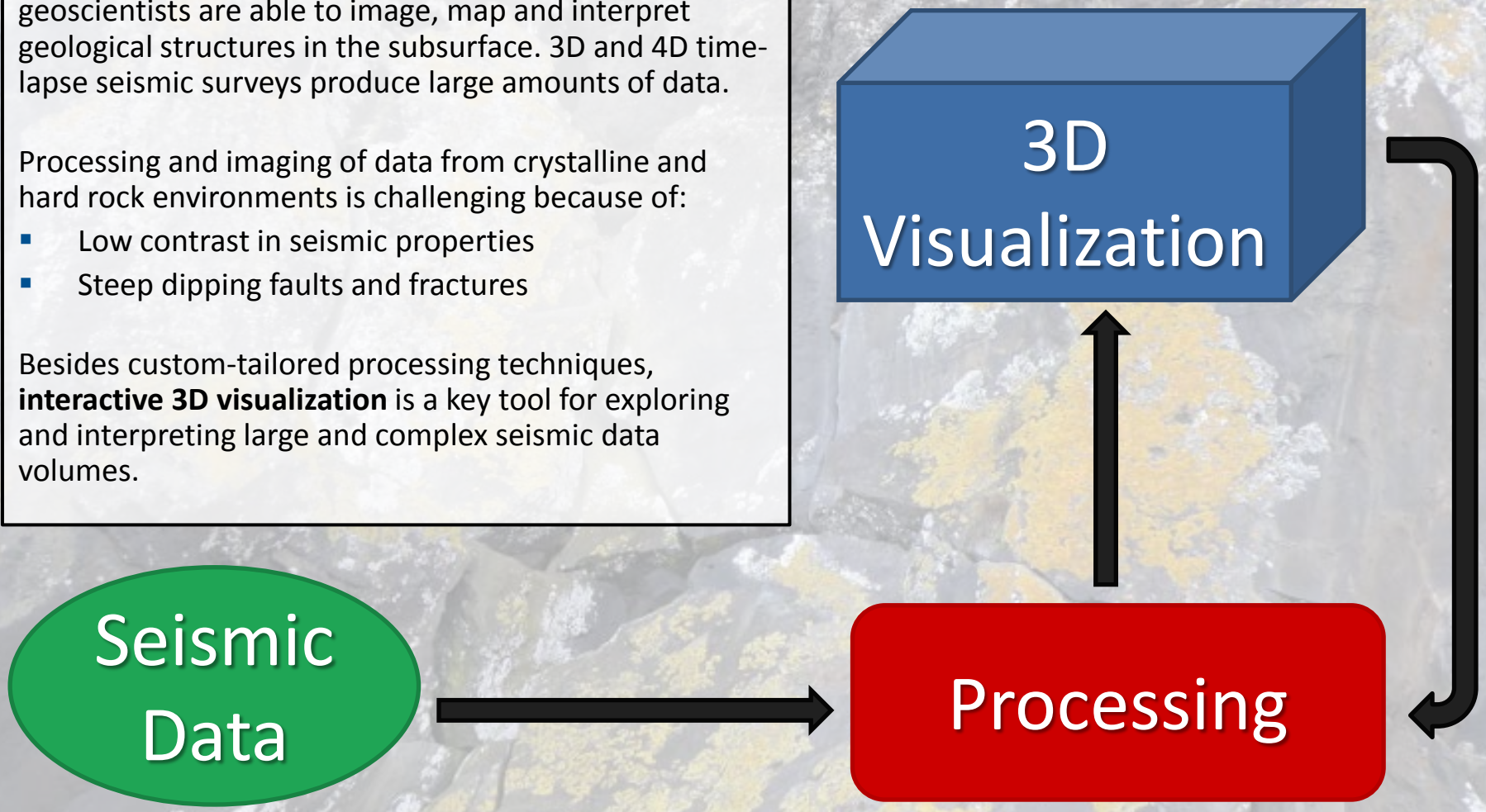
Using seismic data acquisition and imaging techniques, geoscientists are able to image, map and interpret geological structures in the subsurface. 3D and 4D time-lapse seismic surveys produce large amounts of data.

Processing and imaging of data from crystalline and hard rock environments is challenging because of:

- Low contrast in seismic properties
- Steep dipping faults and fractures

Besides custom-tailored processing techniques, **interactive 3D visualization** is a key tool for exploring and interpreting large and complex seismic data volumes.



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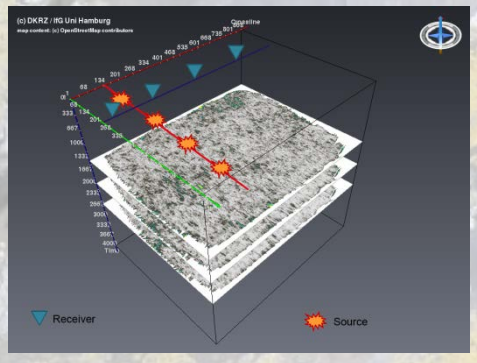
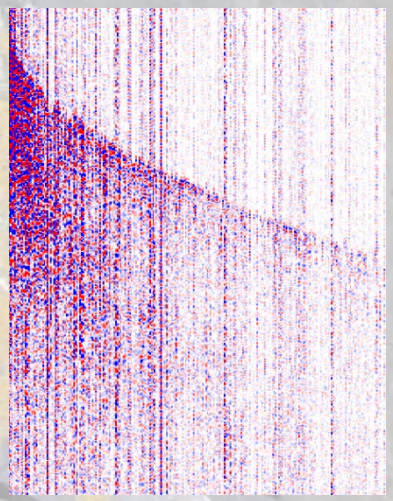
Seismic Data

Project, study area & geology

3D Data acquisition



Raw data



Project BMWi, Seismik im Kristallin
0325363C

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Project & study area

Schneeberg / Hartenstein, Saxony, Germany

Project BMWi, Seismik im Kristallin 0325363C

- Publicly-funded geophysical research project (Fed. Ministry of Economic Affairs and Energy)
- **Site:** Schneeberg / Hartenstein, Saxony, Germany
- **Objectives:** Exploration of a potential geothermal reservoir in a crystalline environment
  - Imaging of steep dipping faults with new techniques
  - Mapping of faults known from surface outcrops & mining (Roter Kamm, Dürre Henne etc.)
- Project partners: LIAG (Leibnitz Institute for Applied Geophysics), University of Hamburg, TU Bergakademie Freiberg & contractors
- Industry-standard 3D land seismic data
- Vibroseis & additional star-shaped explosion seismic experiment
  http://www.liag-hannover.de/fsp/ge/seismik-im-kristallin-sachsen-siks.html

Visualization of volumetric seismic data

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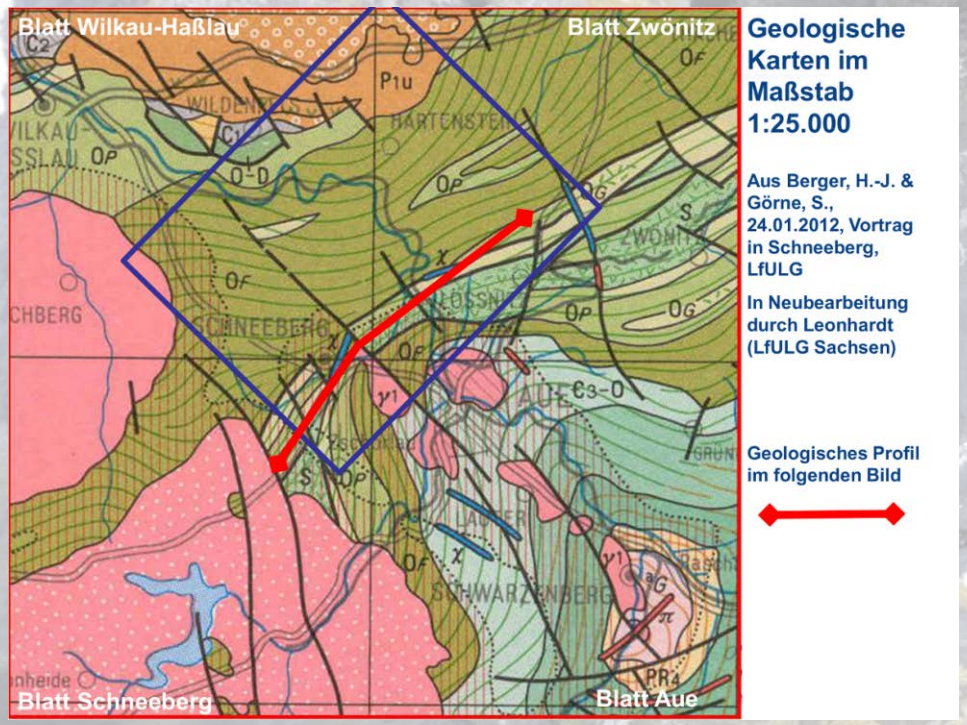
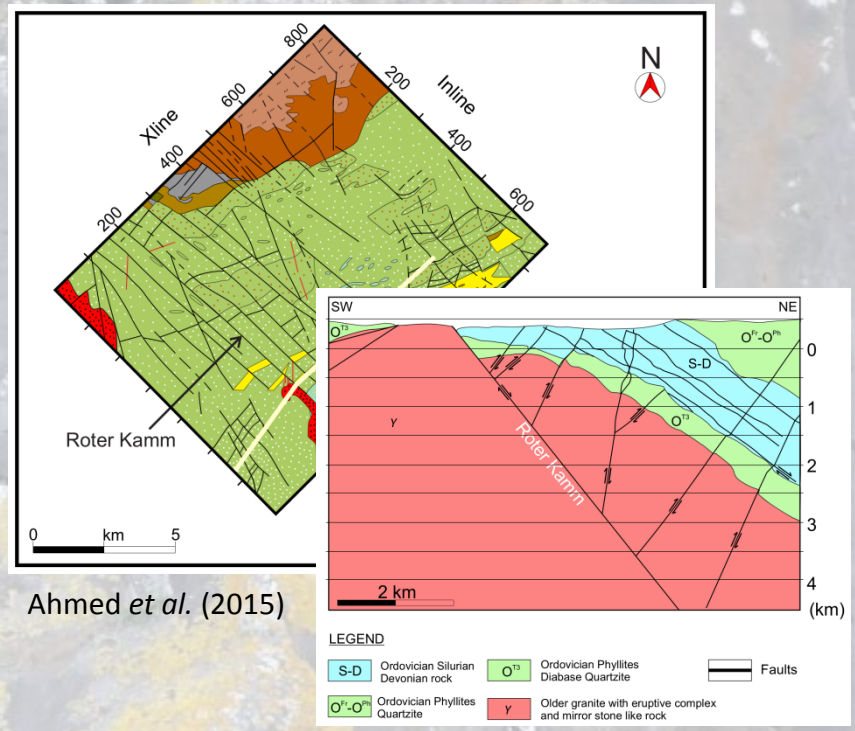
Geology of the study area



source:
http://www.liag-hannover.de/fileadmin/user_upload/dokumente/Geothermische_Energie/SIKS/Ergebnisse-Sachsen.pdf



Ahmed *et al.* (2015)

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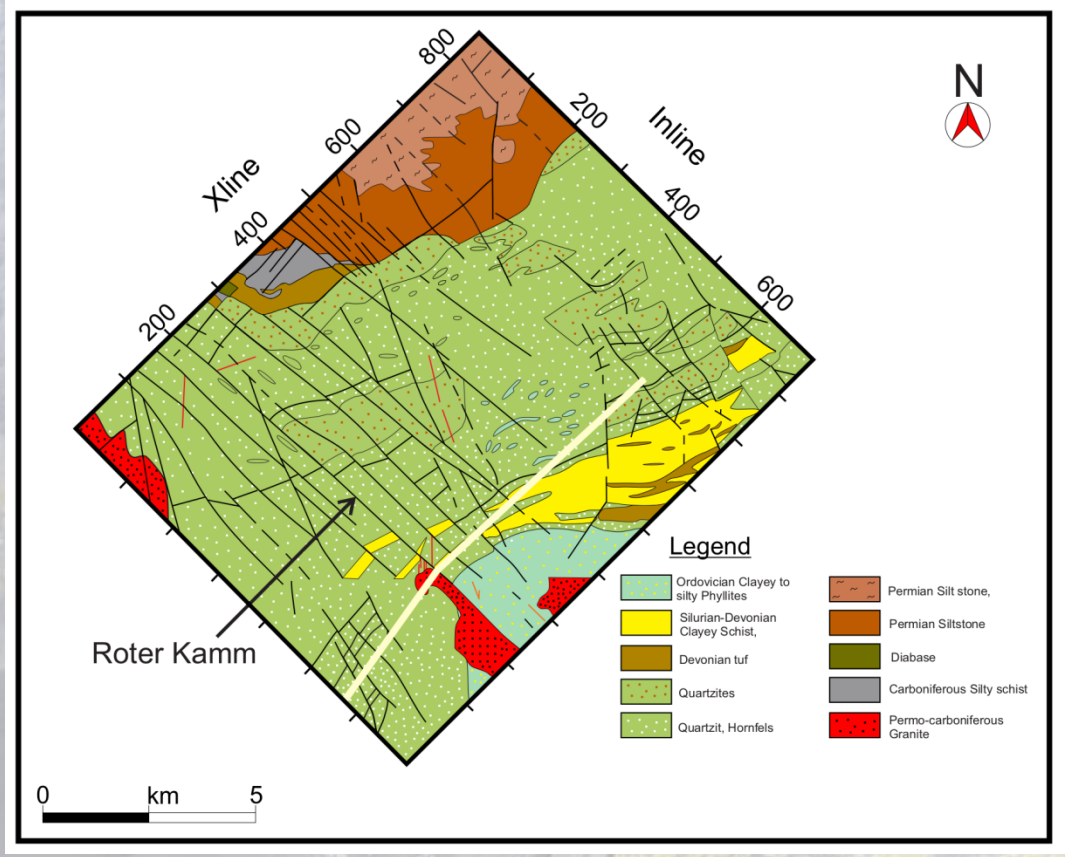
Geological map



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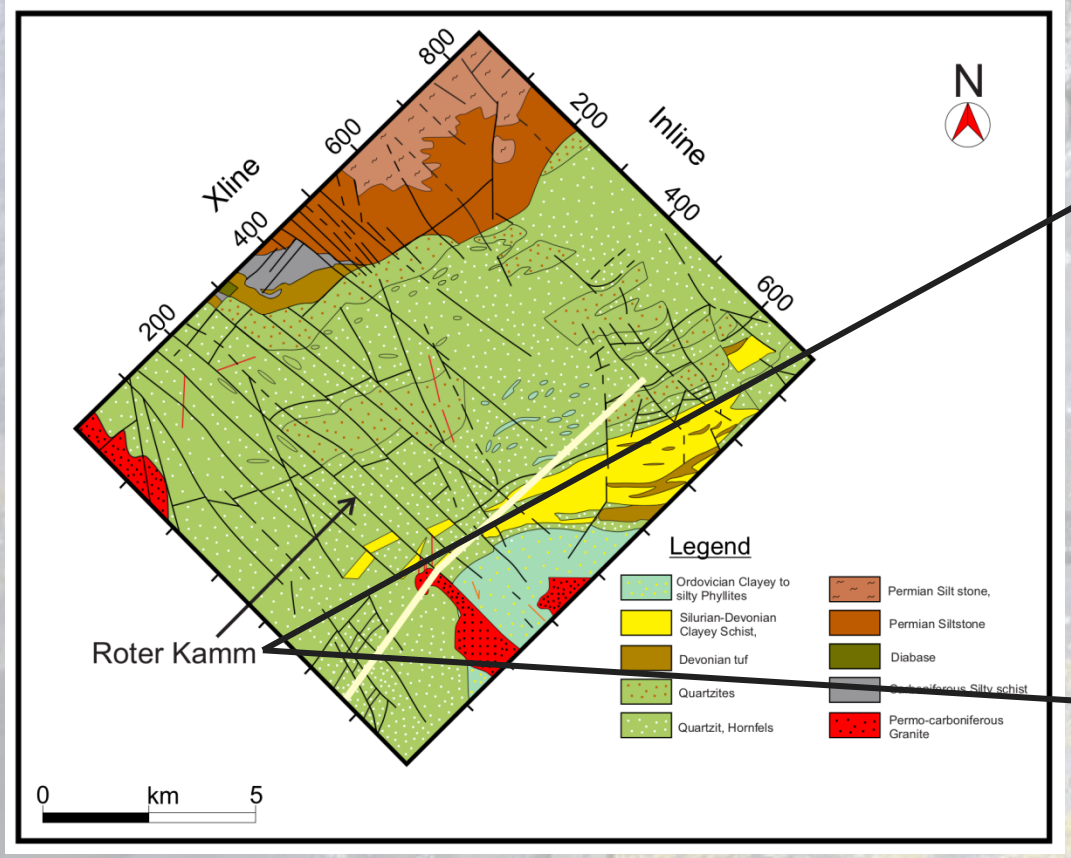

Ahmed *et al.* (2015)

Pfeifer (2014)

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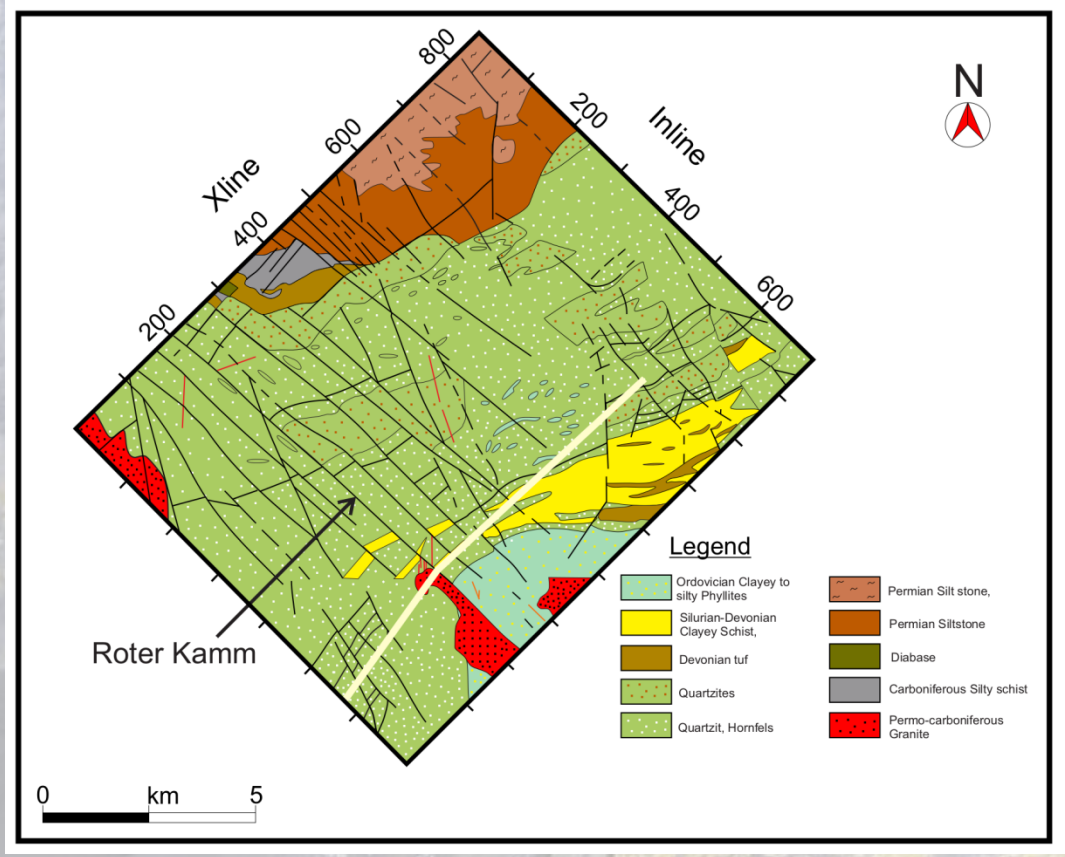

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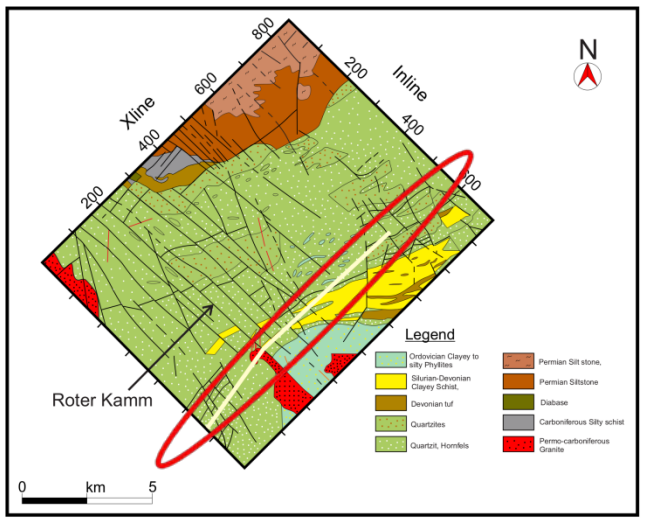
Geological cross section



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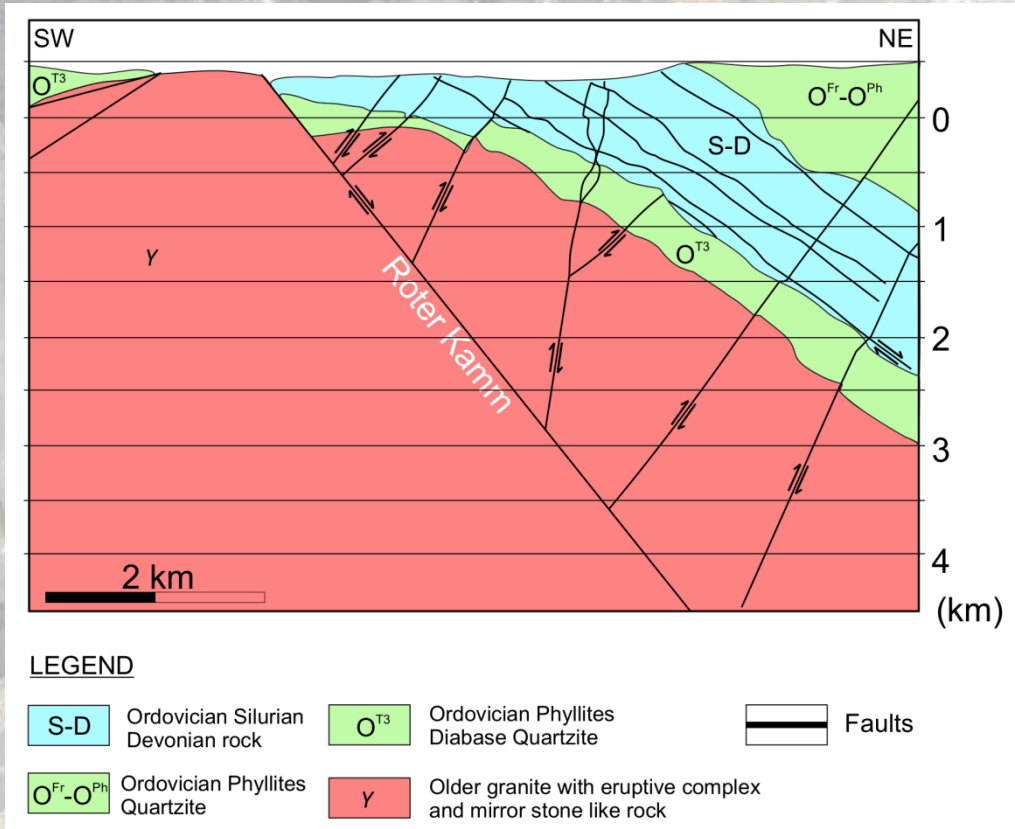

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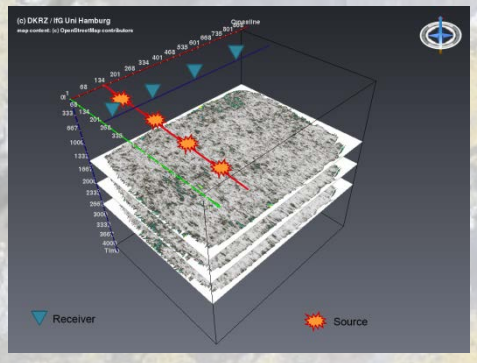
Seismic Data

Project, study area & geology

3D Data acquisition



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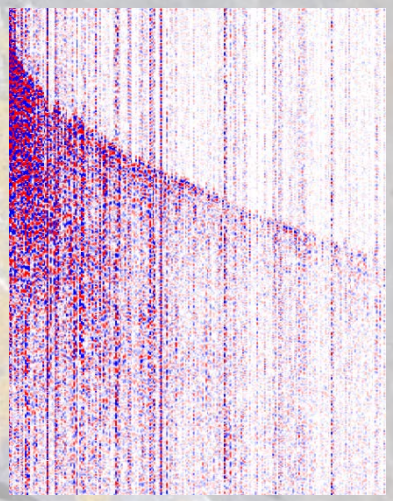

Project BMWi, Seismik im Kristallin
0325363C

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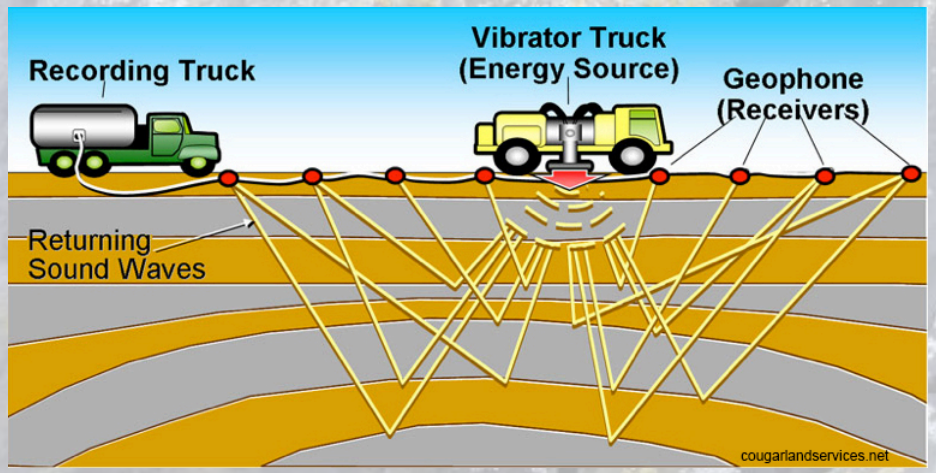
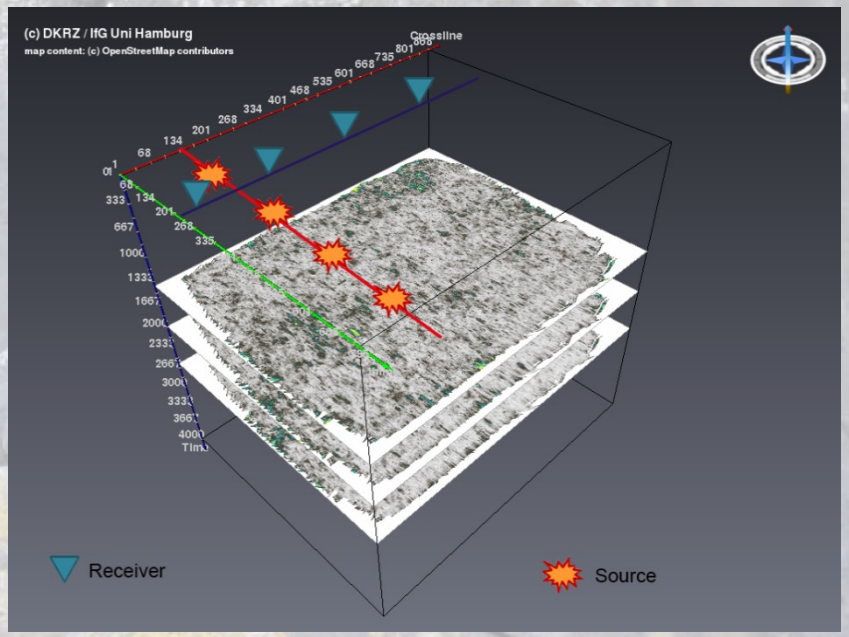


source:
http://www.utexas.edu/research/cem/Oil_gas_images/truck_wave.jpg



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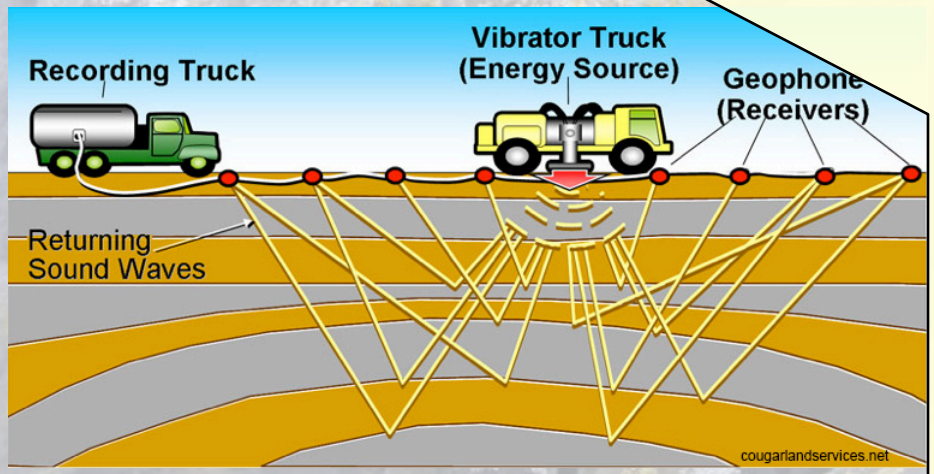

source:
http://www.utexas.edu/research/cem/Oil_gas_images/truck_wave.jpg

The vibroseis method

- A vibrator device (truck or pushcart) with vibrating baseplate as seismic source
- Vertical (p-waves) or horizontal (s-waves) excitation
- Signal is a frequency sweep ('upsweep' or 'downsweep') of several seconds
- The seismic waves are reflected and refracted at impedance contrasts (e.g. layer boundaries) in the subsurface
- Recording of reflected wave field with geophones at the surface
- Correlation of reflected wave field with input sweep to obtain shorter seismogram traces similar to those obtained with impulsive sources

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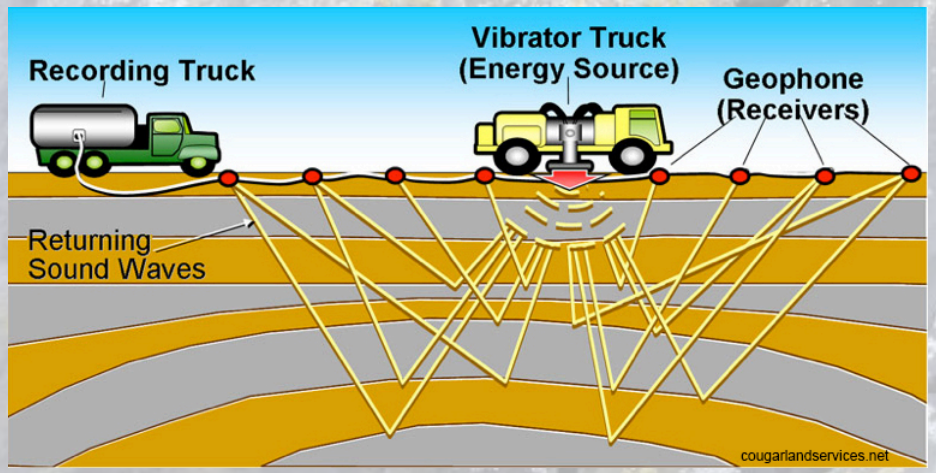

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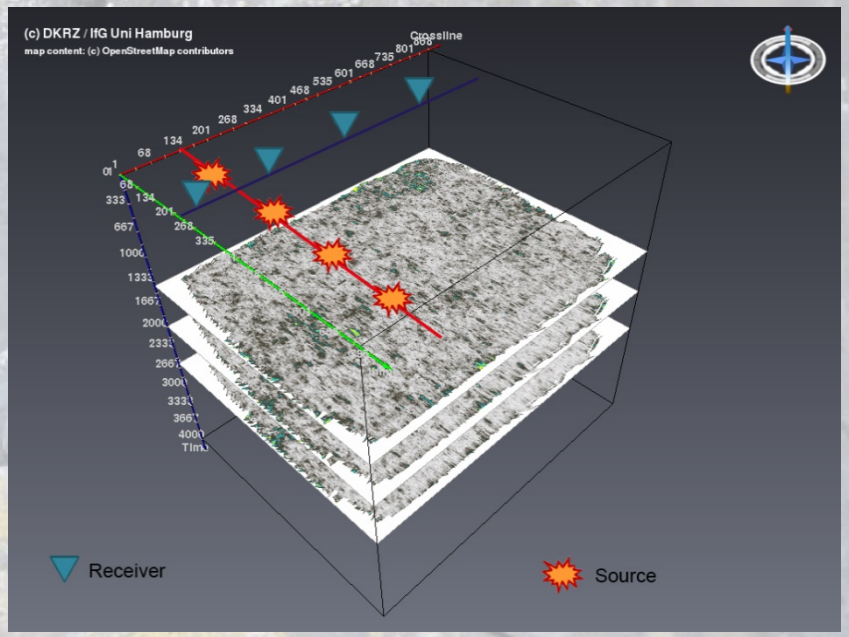

Visualization of volumetric seismic data

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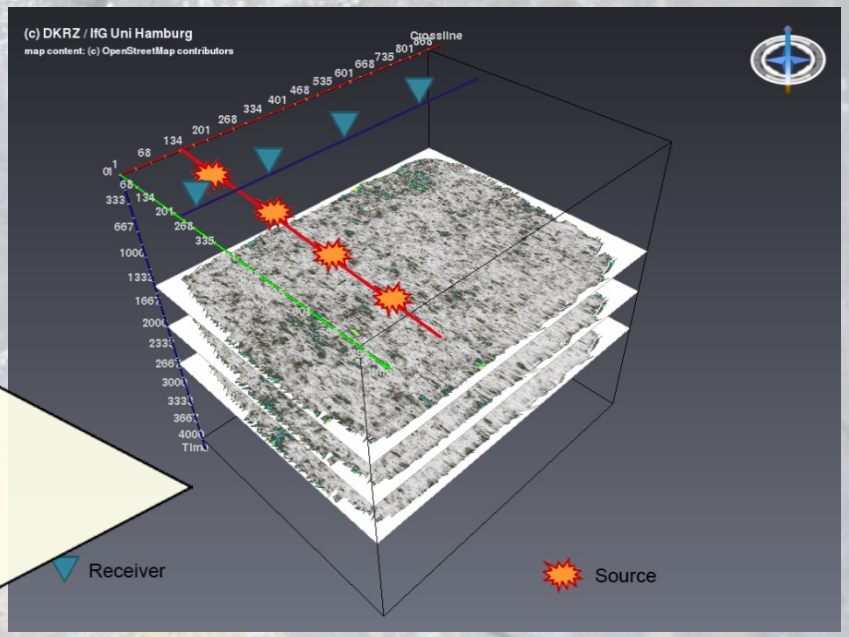
cquisition

Data acquisition for project BMWi 0325363C:

- Study area approx. 10 km x 12 km
- Seismic sources: 3 vibrator trucks INOVA AHV-IV, 27 tons
- Shot point spacing 30 m
- Source and receiver line spacing 400 m
- Seismic signal: 10 s sweep of 12-96 Hz, 8-fold stacking
- **Inline**: Direction of data recording with geophone bundles
- Seismic contractor: DMT GmbH & Co. KG, Essen
- **Crossline**: Perpendicular to **inline**; here: line of vibrator source points

This figure **exemplarily** indicates only one source- and receiver line.



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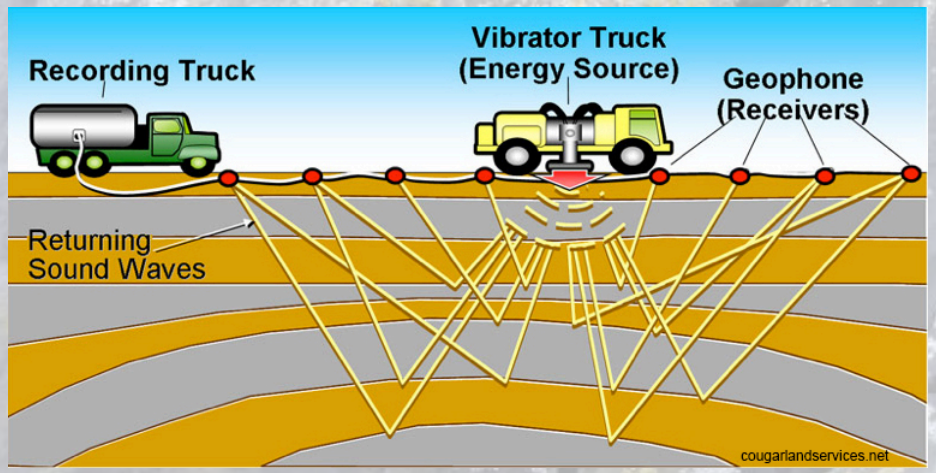

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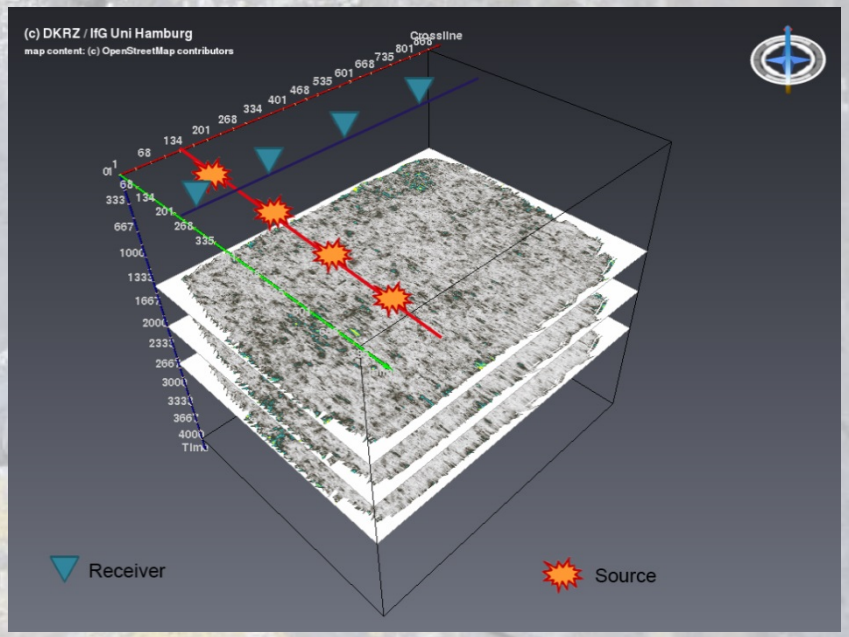

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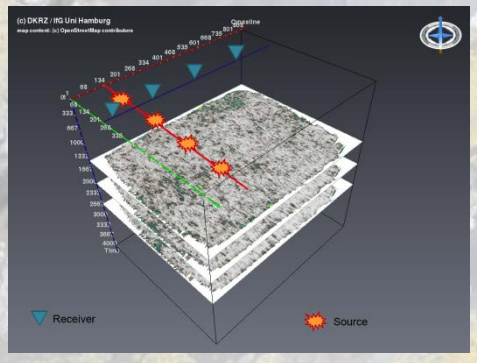
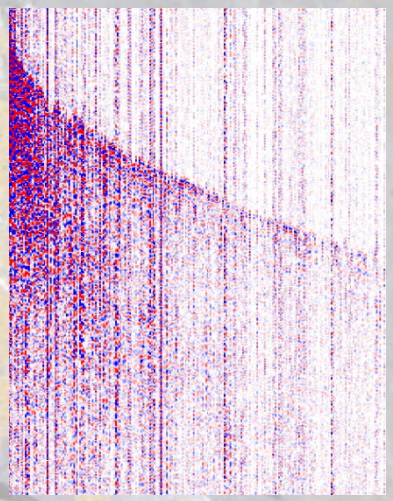


Raw data



Project BMWi, Seismik im Kristallin
0325363C

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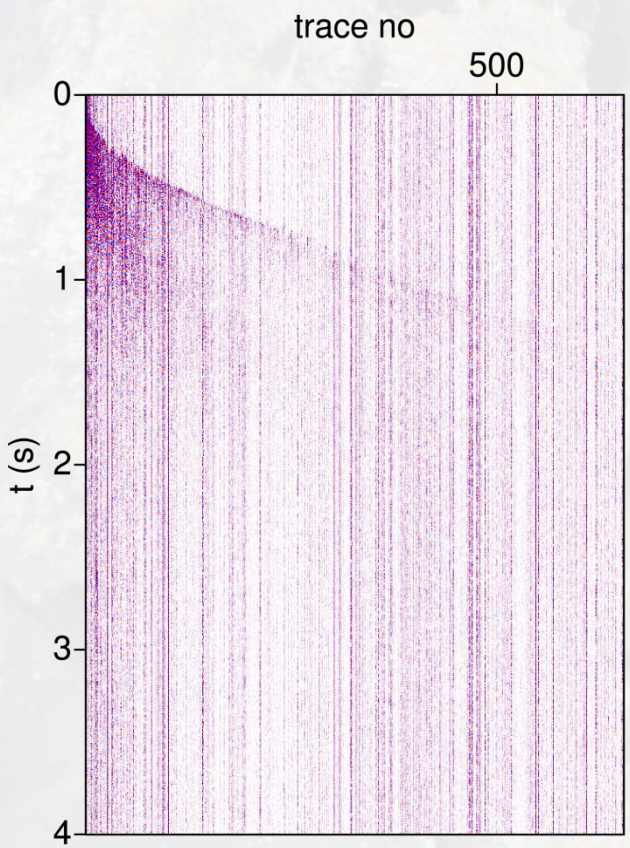
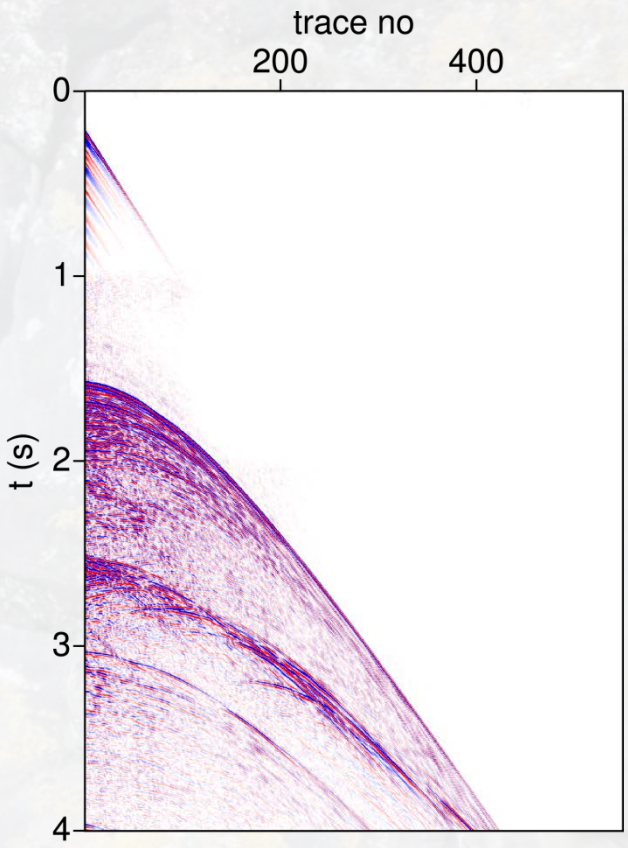


Hardrock



Sedimentary

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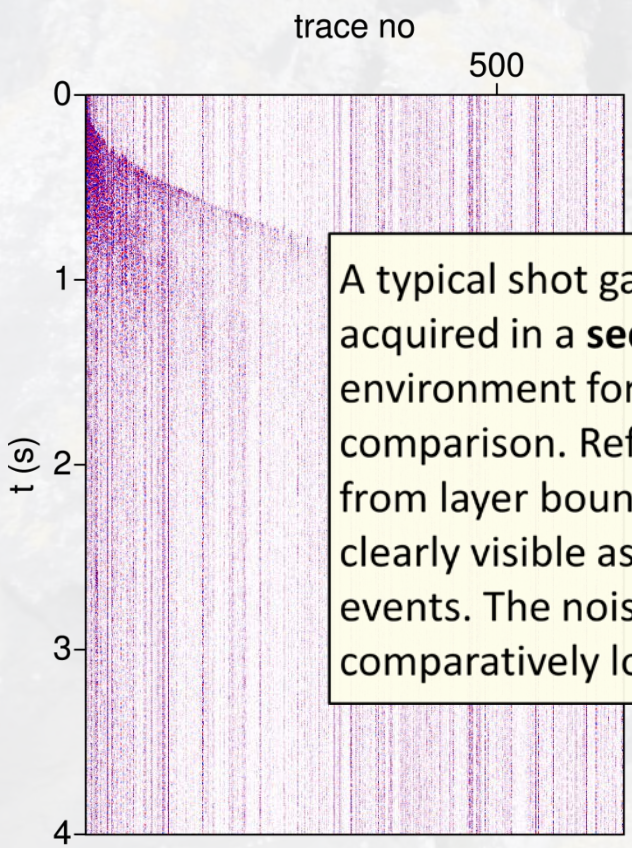
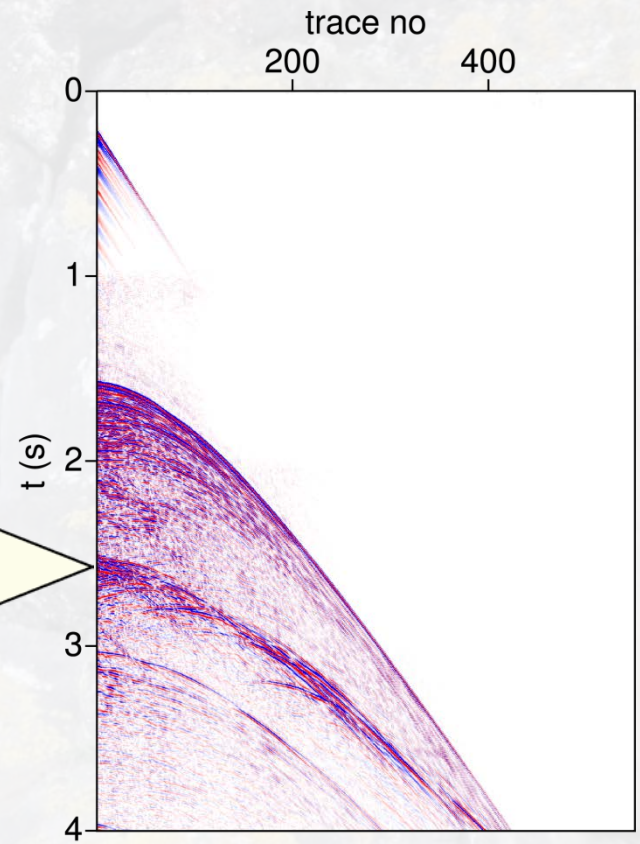


Hardrock

A typical shot gather acquired in a **sedimentary** environment for comparison. Reflections from layer boundaries are clearly visible as hyperbolic events. The noise level is comparatively low.



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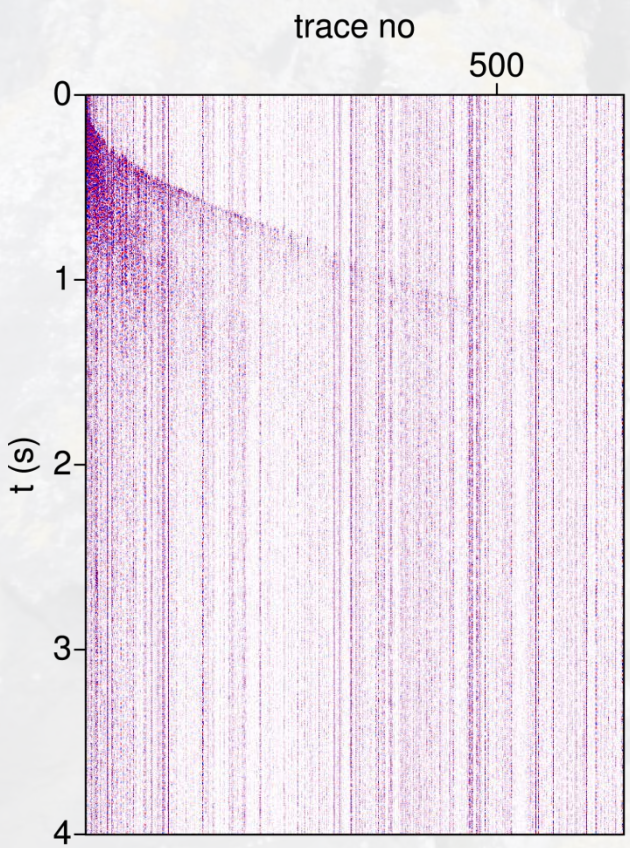
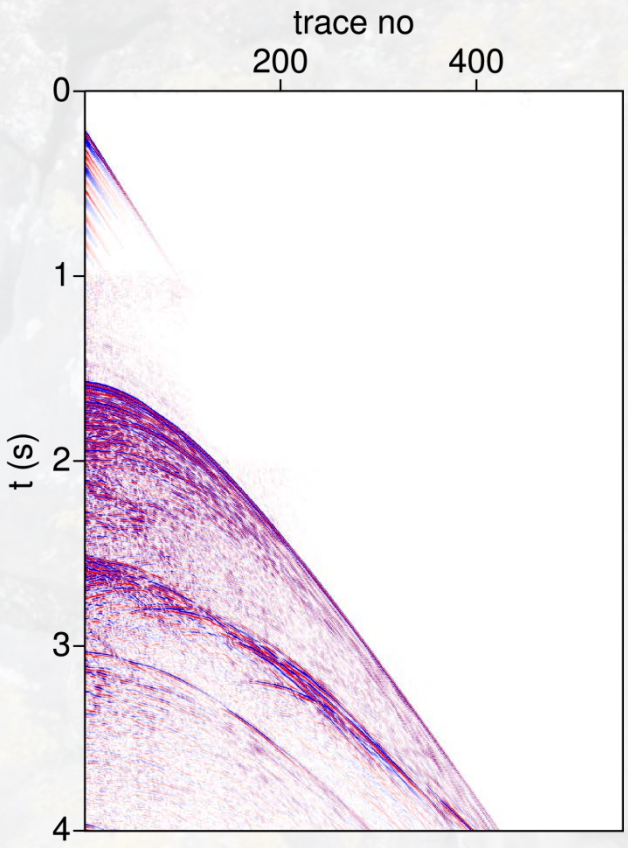
Raw data



Hardrock



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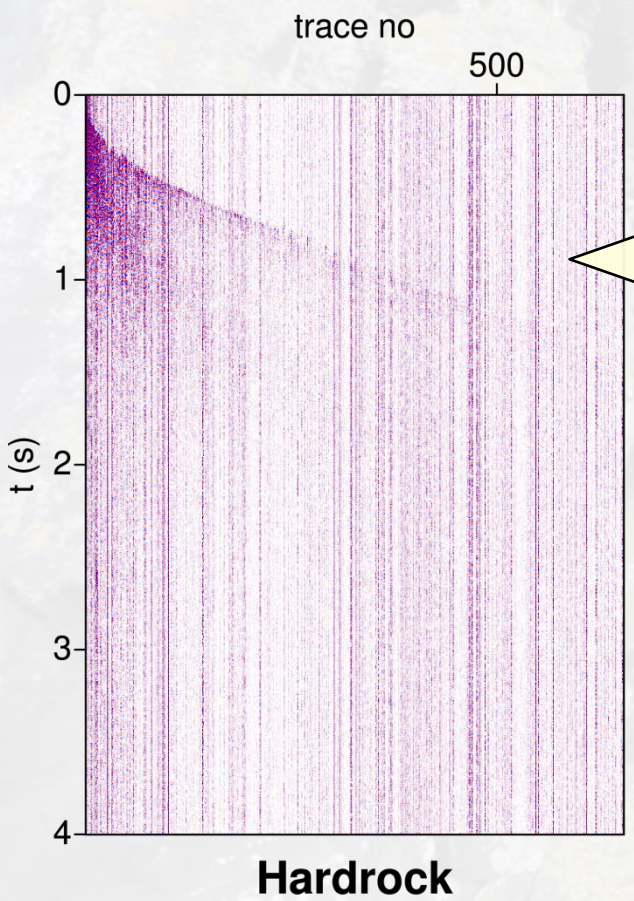

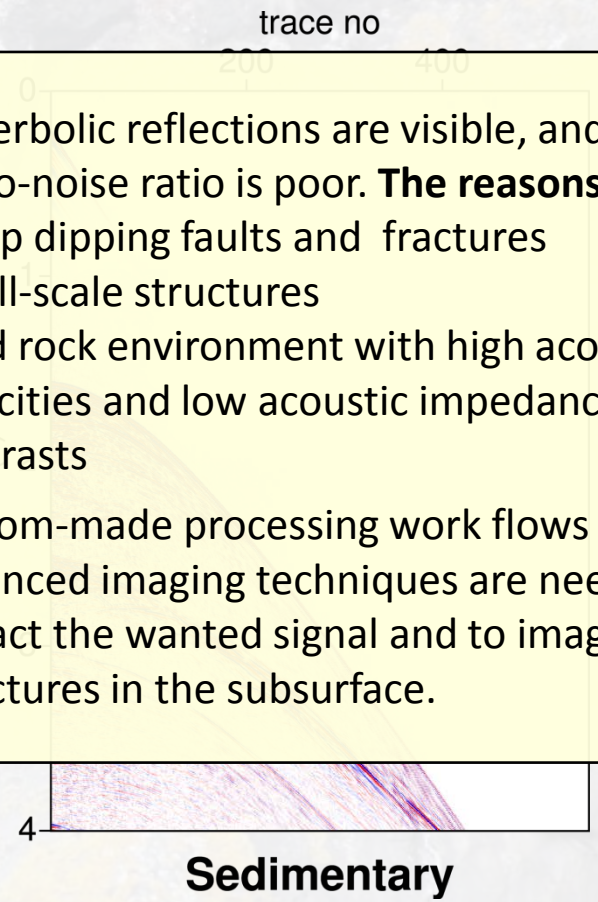

No hyperbolic reflections are visible, and the signal-to-noise ratio is poor. **The reasons:**

- Steep dipping faults and fractures
- Small-scale structures
- Hard rock environment with high acoustic velocities and low acoustic impedance contrasts

Custom-made processing work flows and advanced imaging techniques are needed to extract the wanted signal and to image structures in the subsurface.

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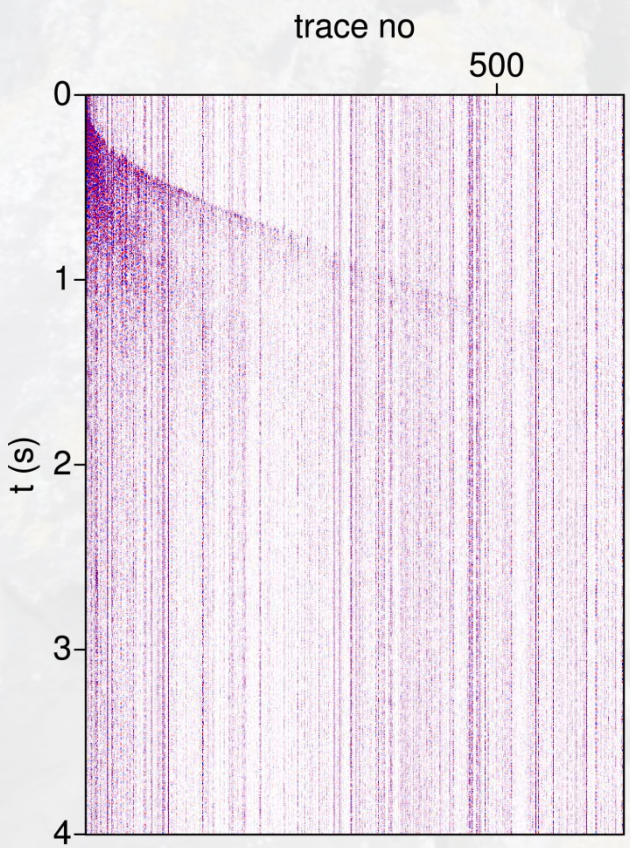
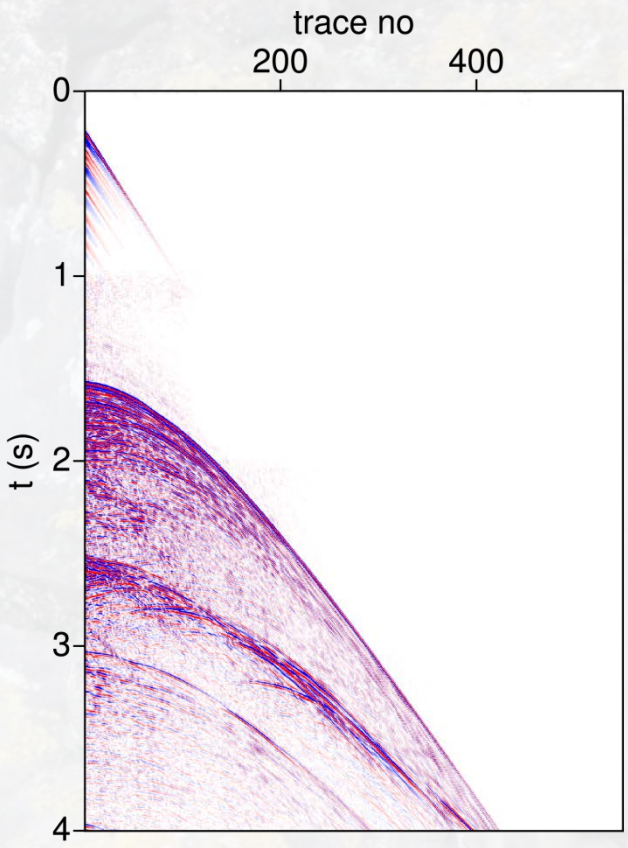


Hardrock



Sedimentary

Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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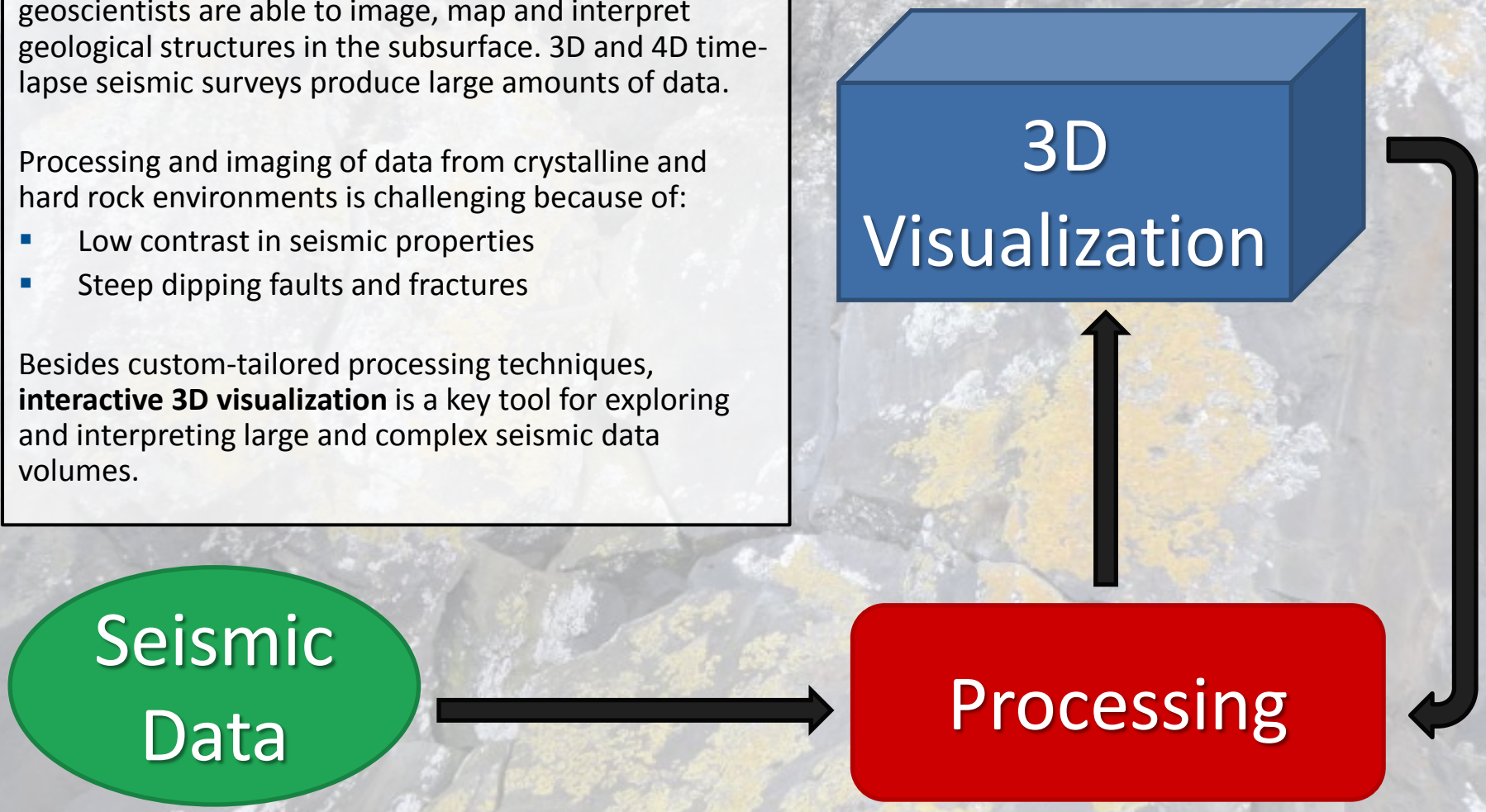
Processing and imaging of data from crystalline and hard rock environments is challenging because of:

- Low contrast in seismic properties
- Steep dipping faults and fractures

Besides custom-tailored processing techniques, **interactive 3D visualization** is a key tool for exploring and interpreting large and complex seismic data volumes.



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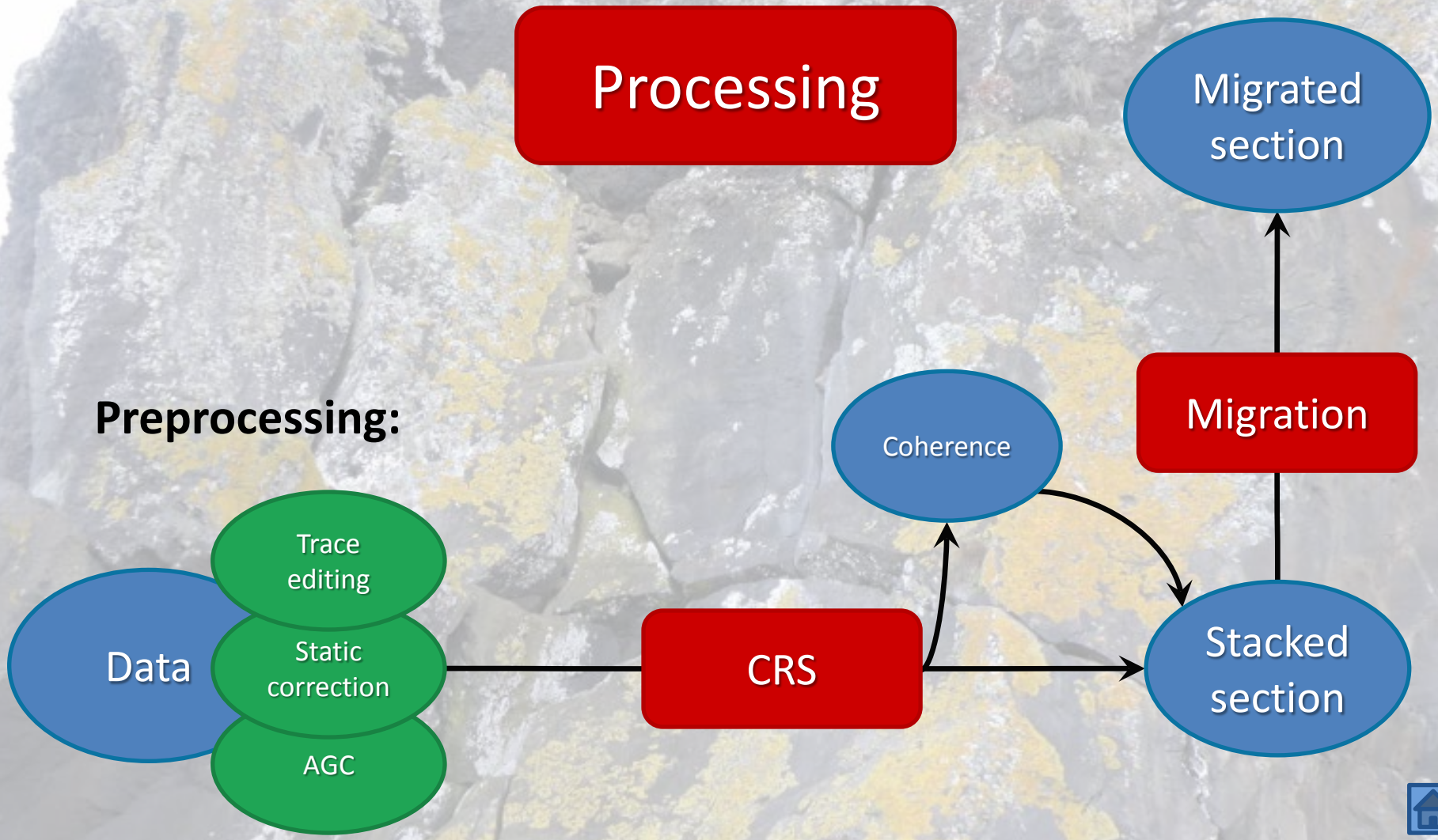

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Preprocessing steps

Trace editing	Static correction	AGC
• Removal of approx. 2 million dead and **defective** traces • **Defective** traces are affected by high noise levels over the whole recording time • **Objective:** Stack traces with coherent wanted signal	• Reduction of observed traveltimes for all receivers to a uniform reference level within the earth • **Objective:** Compensate for dissimilar receiver elevation and for effect of inhomogeneous and low-velocity weathering layer • Uses **additional information** such as velocity and layer thickness information from other measurements (e.g. uphole surveys or refraction seismics)	• **AGC: Automatic Gain Control** • **Scaling** of trace data within a certain time window to a uniform energy level • The time window is shifted along the time axis of the seismogram • Applied **trace-wise**, so that amplitudes of neighboring traces are no longer comparable • **Advantage:** Very weak events become visible

Visualization of volumetric seismic data

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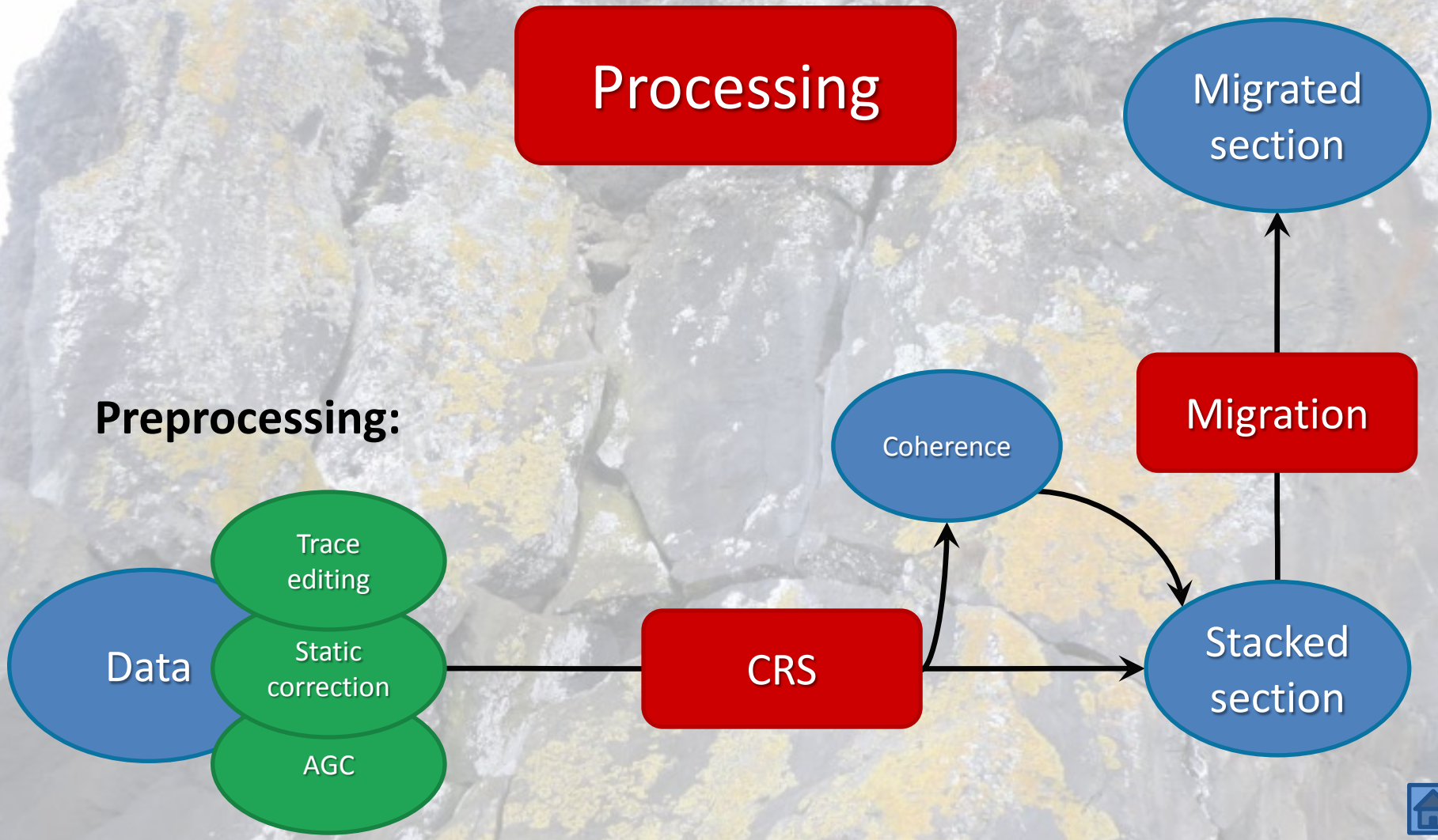

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Seismic data and CRS (Common-Reflection-Surface)

After recording, seismic data can be displayed as a **common shot gather**, which shows all recorded traces for a single shot. During the data acquisition, source position and receivers are shifted along the profile so that reflection points are repeatedly illuminated. The data are thus **multifold**. **Stacking methods** exploit this redundancy to obtain a time section (**zero-offset section**) of the data with improved signal-to-noise ratio.

In conventional seismic processing, source-receiver-pairs are sorted by common midpoints **(CMPs)** for stacking. The **CRS method**, in contrast, additionally stacks data along a second dimension and thus over a **travel time surface**, exploring the data redundancy even further.

The travel time surface for stacking **(CRS operator)** is a 2nd order hyperbolic approximation and a function of two coordinates and three (2D data) or eight (3D data) wave field attributes.

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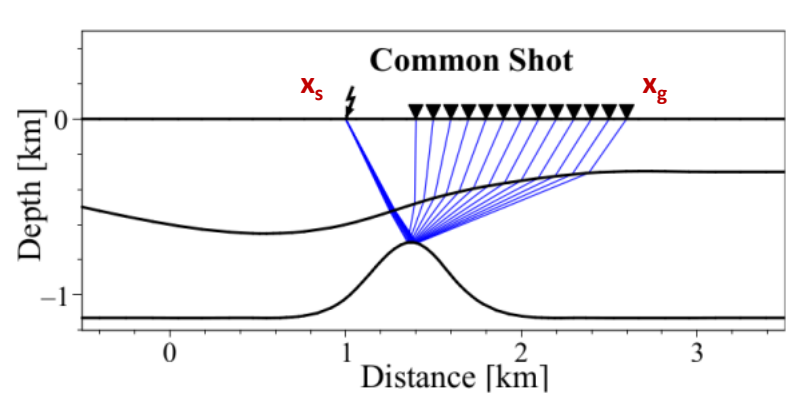
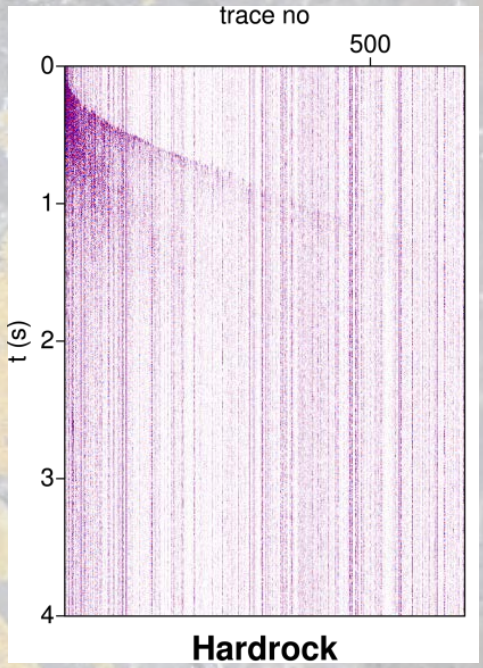
Common shot gather



Höcht (2002)

Data example



$\mathbf{x_s}$: source position (bolt of lightning)
$\mathbf{x_g}$: receiver positions (inverse triangles)

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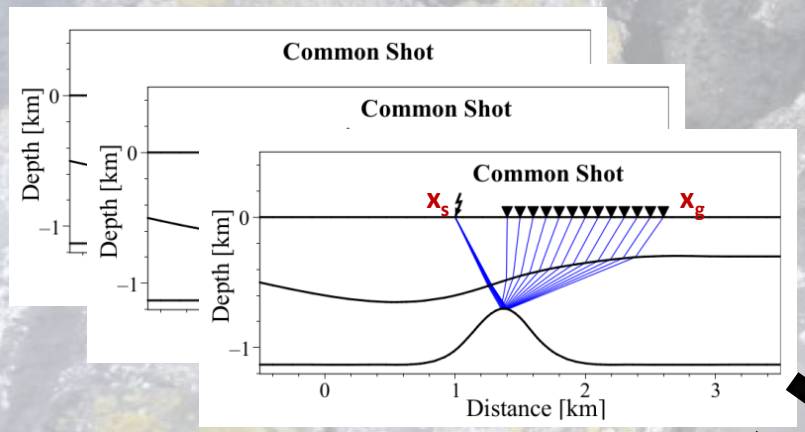
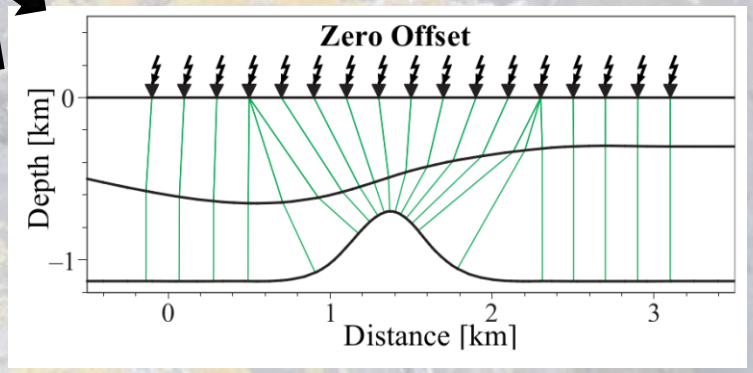
Zero-offset (ZO) section



Input

Desired simulated output



Höcht (2002)

The derived **zero-offset (ZO) section** suggests that it shows reflection events with the **shortest possible travel time t_0** between a source and receiver at the same surface position. For horizontal layering, this would be the **vertically down- and upgoing ray**. Otherwise, the reflection point is laterally shifted relative to the source and receiver position at the surface. The ZO section is then a **distorted** subsurface representation.

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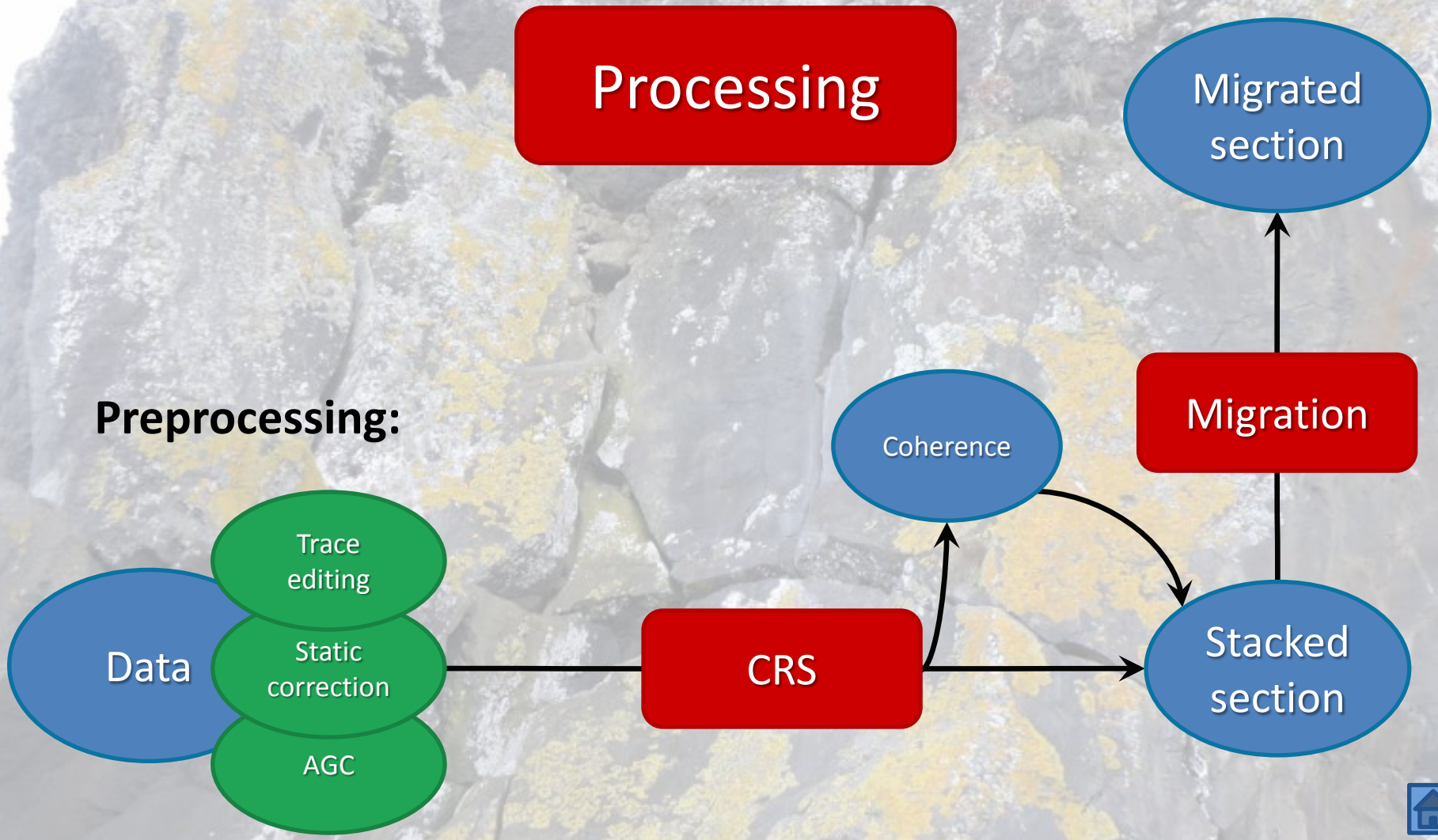

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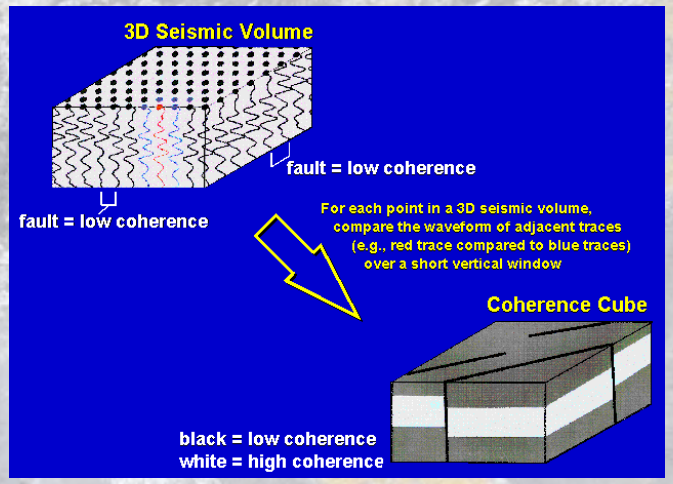
Coherence measure: Semblance

- Coherence measures the **similarity of wave forms** in adjacent traces within a certain time window.
- A common coherence measure for seismic data processing is **Semblance** (S).
- Semblance is **normalized** with values between 0 and 1.

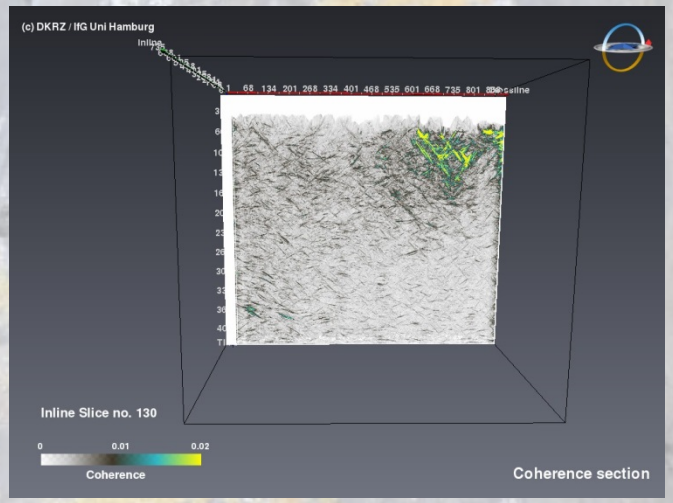
$$S = \frac{\sum_{j=-W/2}^{W/2} \left(\sum_{i=1}^{N} f_{i,j+k(i)} \right)^2}{N \sum_{j=-W/2}^{W/2} \sum_{i=1}^{N} f_{i,j+k(i)}^2}.$$

f: trace amplitude
i: trace index
j: time sample index
k: operator sample
N: no. of traces
W: time window width

Müller (2007) after Neidell and Taner (1971)



source: http://www.kgs.ku.edu/Workshops/IVF2000/nissan-ivf/R640/img006.gif



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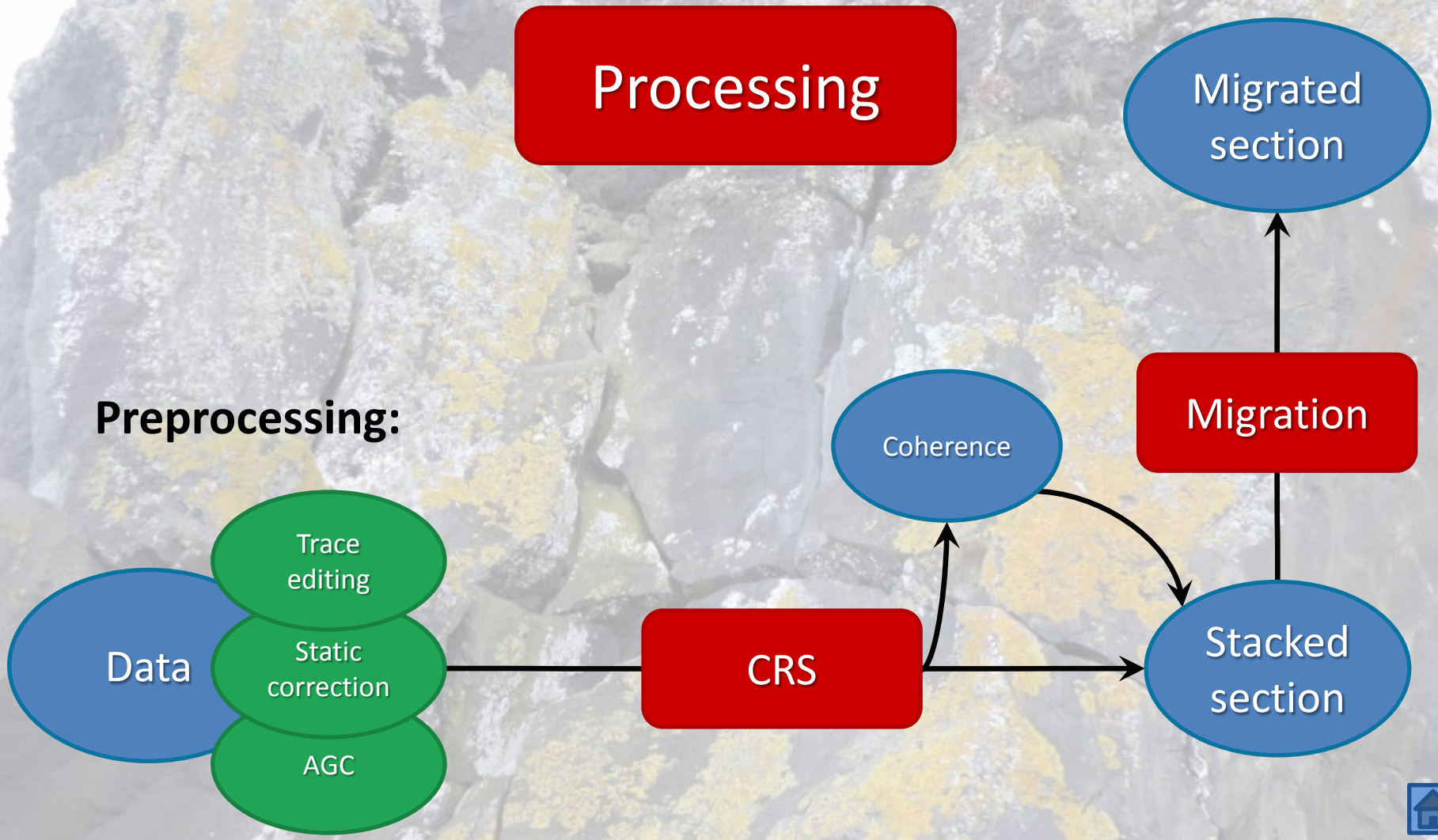

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Seismic migration

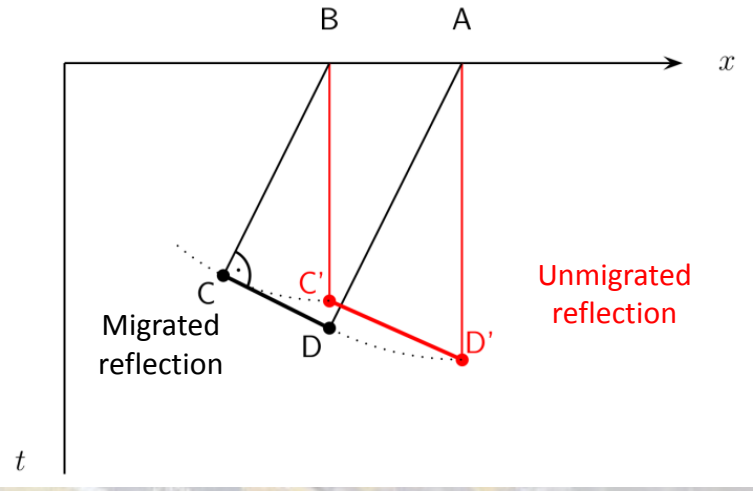
Objective: Obtain a geological representation of the subsurface from wave field observations at the surface

The figure on the right-hand side shows the migration principle, in this case in the **time domain** and on a stacked section (**post-stack**).

Migration:

- Shortens and steepens dipping reflections
- Moves reflections in 'updip' direction to their true subsurface position
- Collapses diffractions, visible as strongly curved events in unmigrated stacked sections
- Can be performed on **pre-stack** or **post-stack** data
- Unlike **time migration**, **depth migration** also considers lateral subsurface velocity variations and is more sensitive to velocity model errors. Its output is a **depth section**.

On the data of project BMWi 0325363C - Seismik im Kristallin **post-stack Kirchhoff time migration** was performed.



Gajewski (2013)

Types of migration:

Time u(x,t)	Depth u(x,z)
Pre-stack	Post-stack

Visualization of volumetric seismic data

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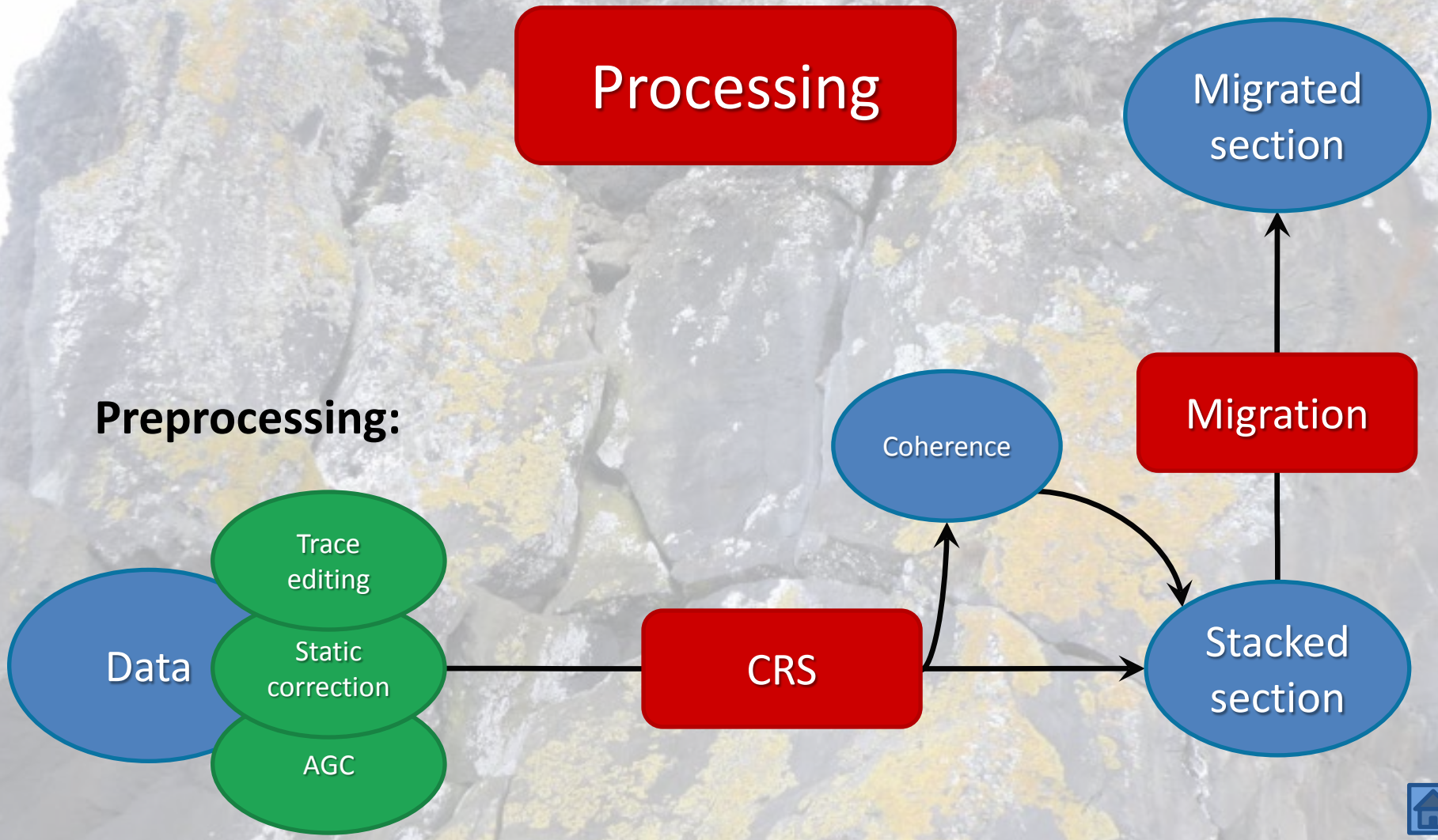

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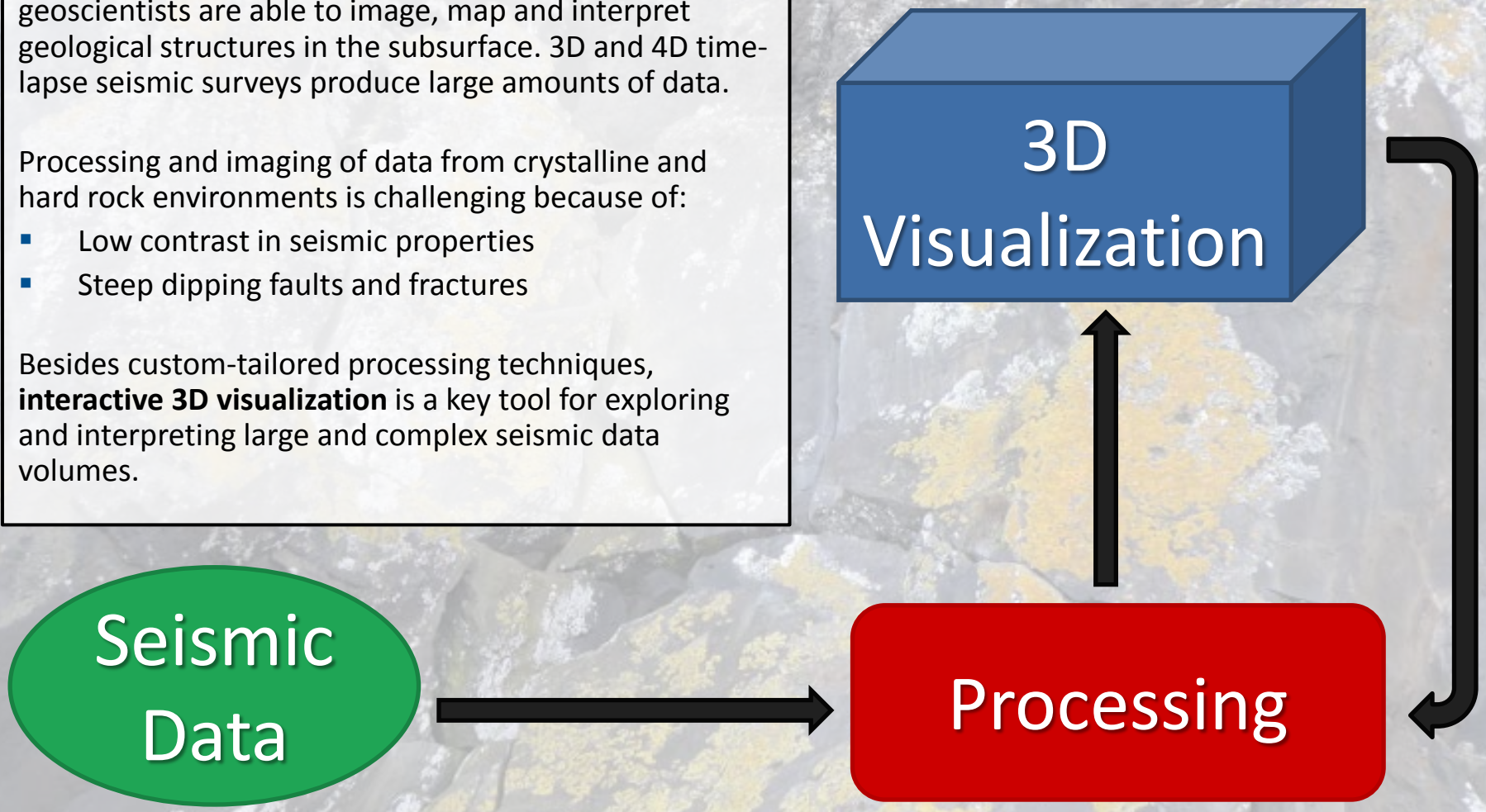

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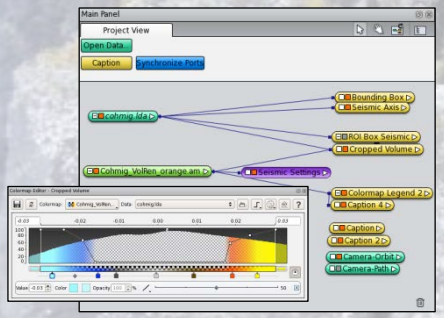
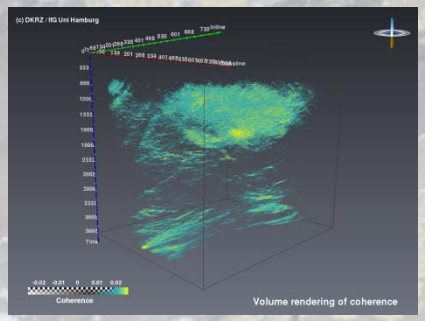
Avizo Earth



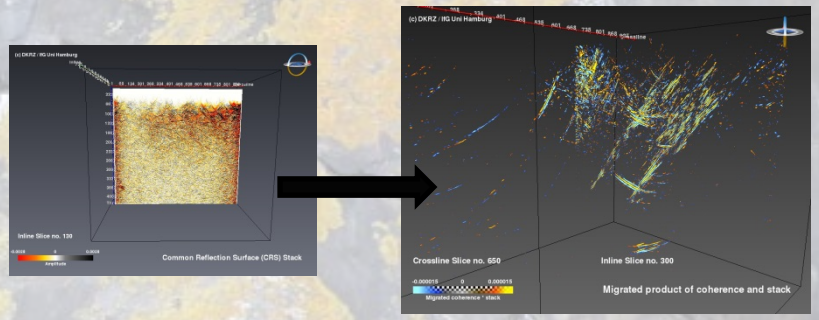
3D Visualization

DKRZ facilities

Visualization techniques



Results



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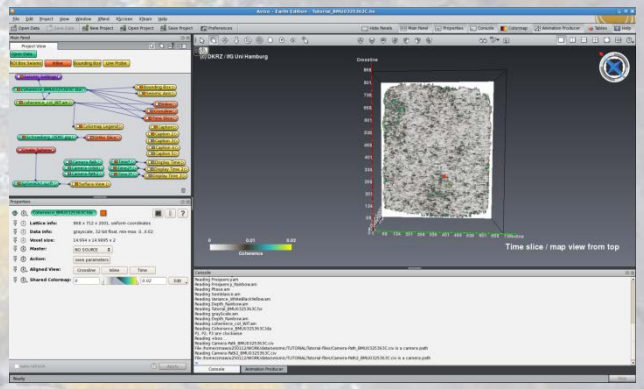
Avizo Earth: Interactive visualization of 3D geoscience data

Avizo Earth is a commercial 3D data visualization and analysis software for geosciences in the **Avizo** product series by the **FEI Visualization Sciences Group** (www.fei.com). It is especially suitable for volumetric seismic data visualization. Its key features include:

- Direct import of **SEGY data**
- Data storage in hierarchical multi-resolution **LDA** (**L**arge **D**ata **A**ccess) files allows for interactive visualization of data files exceeding the system memory
- **Script-based** using TCL language
- Intuitive **GUI**
- State-of-the-art **visualization techniques** for slices and volumes
- Expressive video clips using the **Animation Producer**



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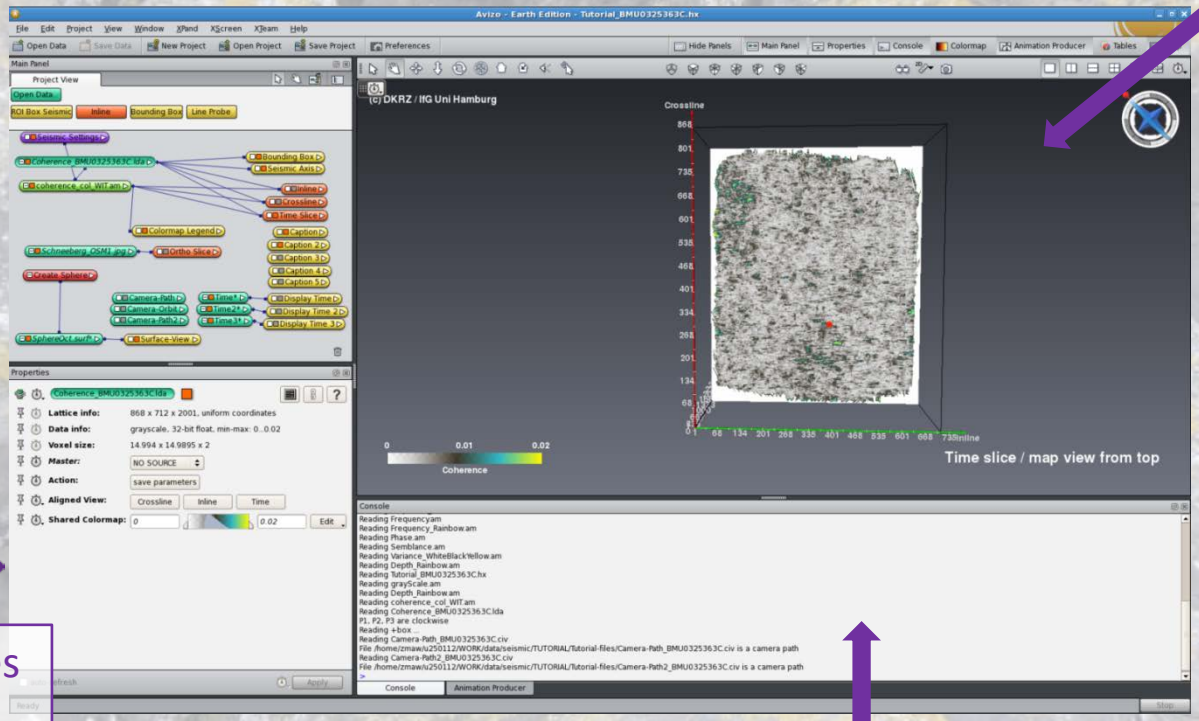
Avizo Earth GUI

3D Viewer

Visualization network editor



Module properties window

Console window for interactive scripting

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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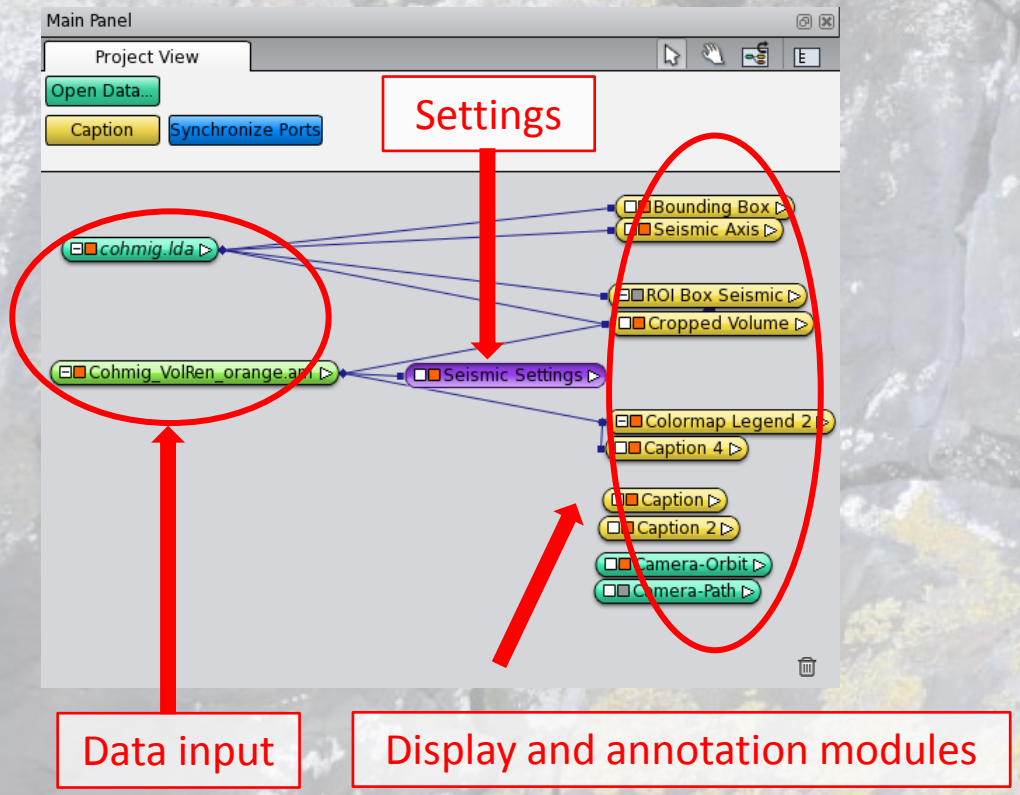
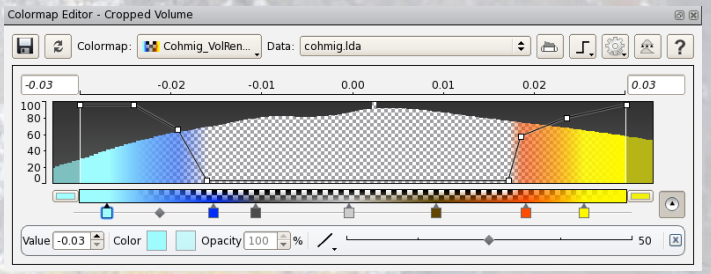
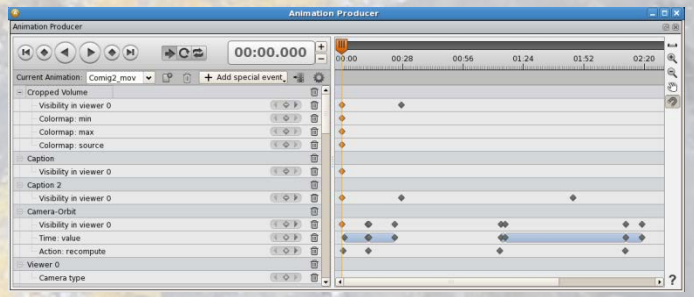
Avizo Earth key features



Colormap Editor



Animation Producer



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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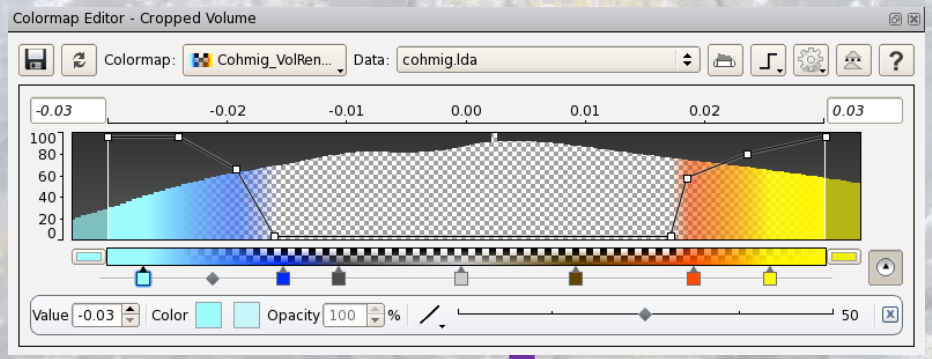
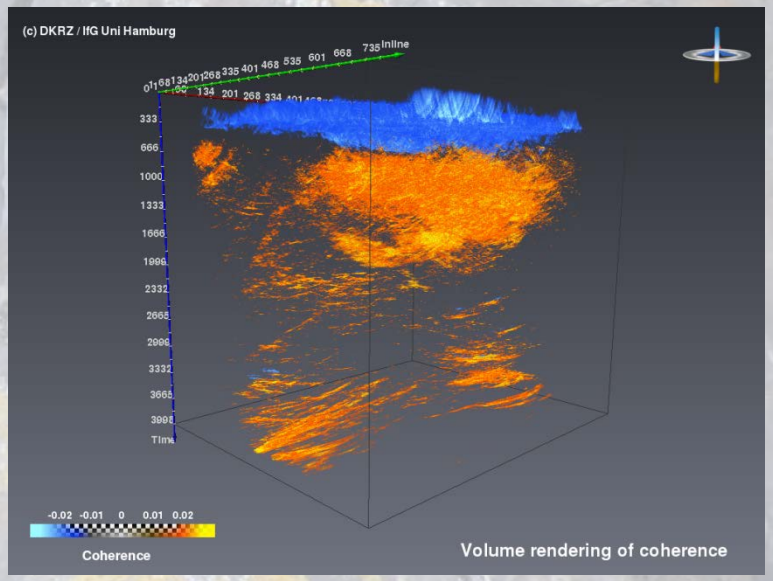
Colormap Editor

Mapping between amplitude values, color and transparency – interactively configurable



Colormap Editor

Rendered data



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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Animation Producer

Create powerful animations and export them as video files or image sequences

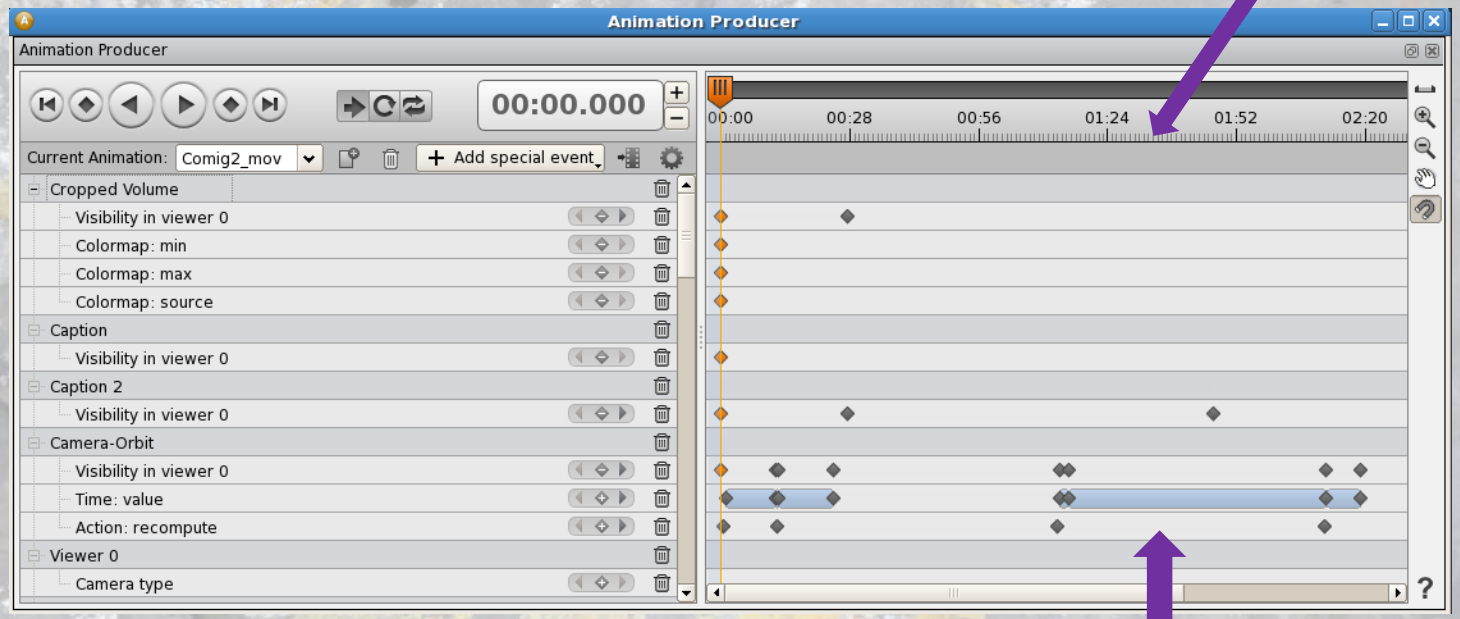
Steering buttons

Time axis

Objects and their channels

Object

Channels



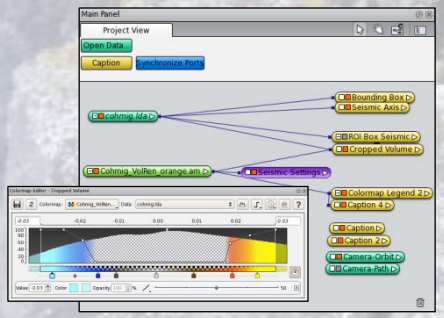
Keyframes and transitions

Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

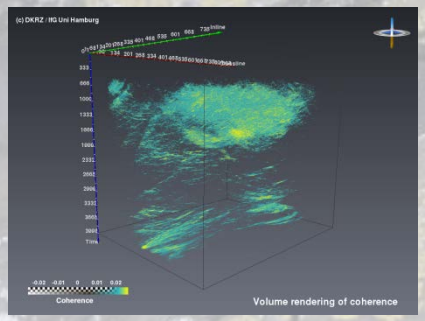
Avizo Earth



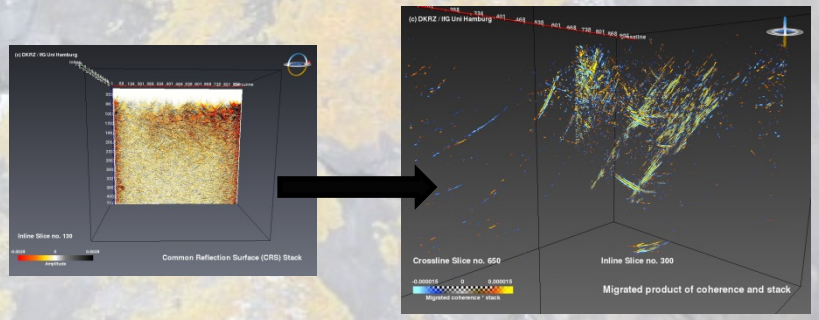
3D Visualization

DKRZ facilities

Visualization techniques



Results

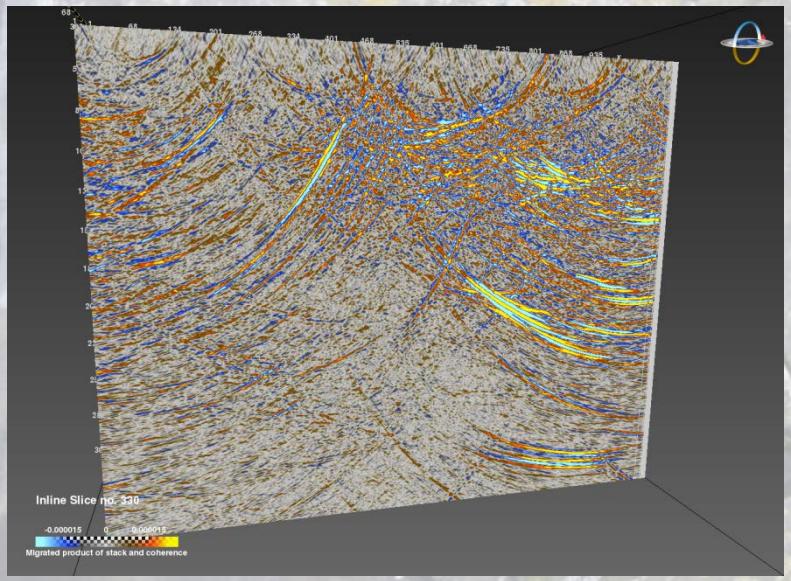


Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

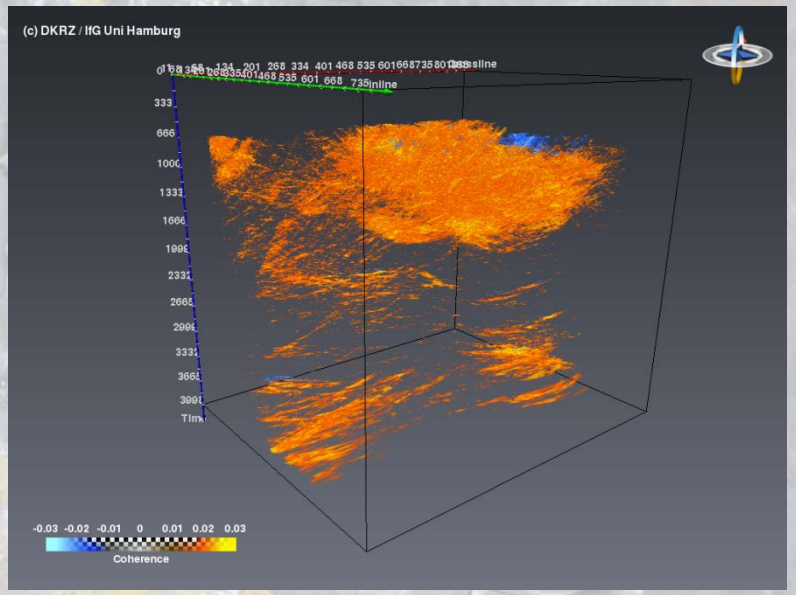
(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Visualization techniques

Slices



Volume rendering

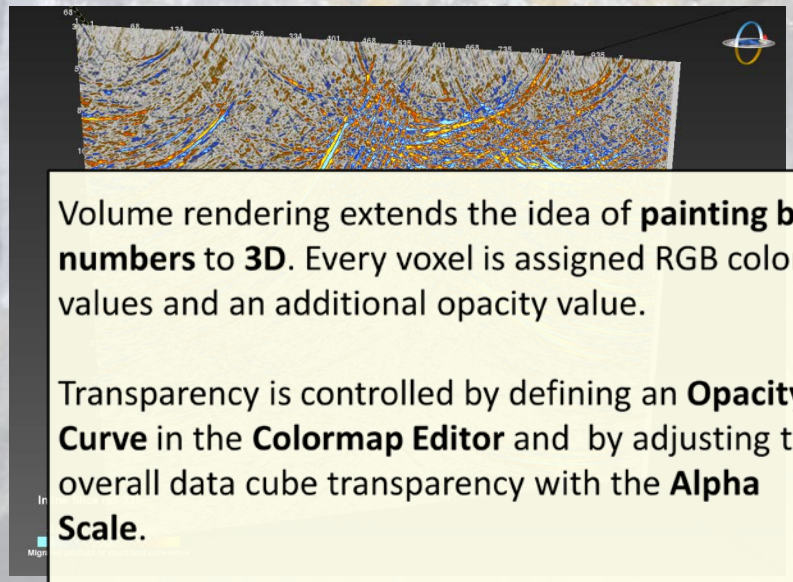


Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Visualization techniques

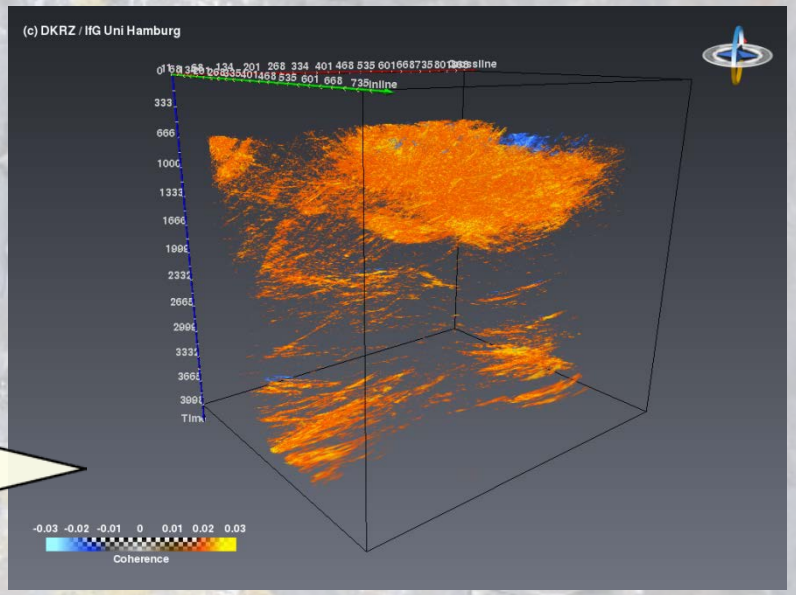
Slices



Volume rendering extends the idea of **painting by numbers** to **3D**. Every voxel is assigned RGB color values and an additional opacity value.

Transparency is controlled by defining an **Opacity Curve** in the **Colormap Editor** and by adjusting the overall data cube transparency with the **Alpha Scale**.

Volume rendering

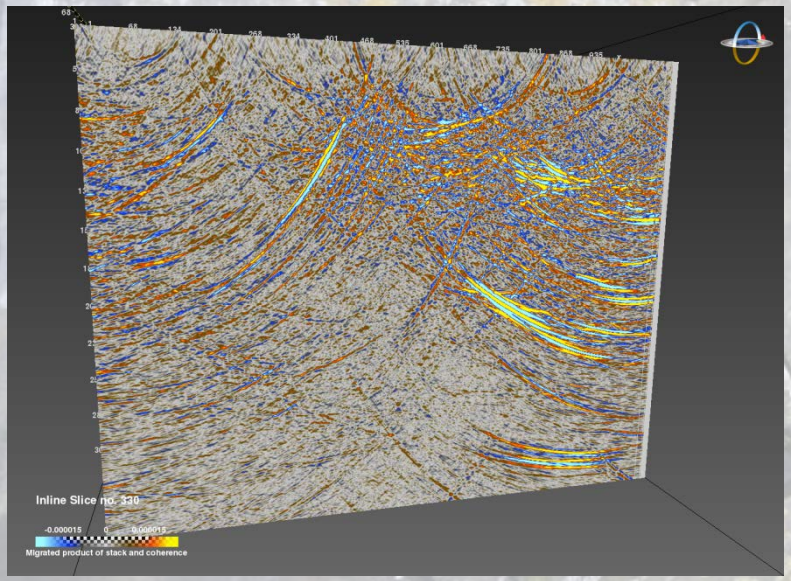


Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

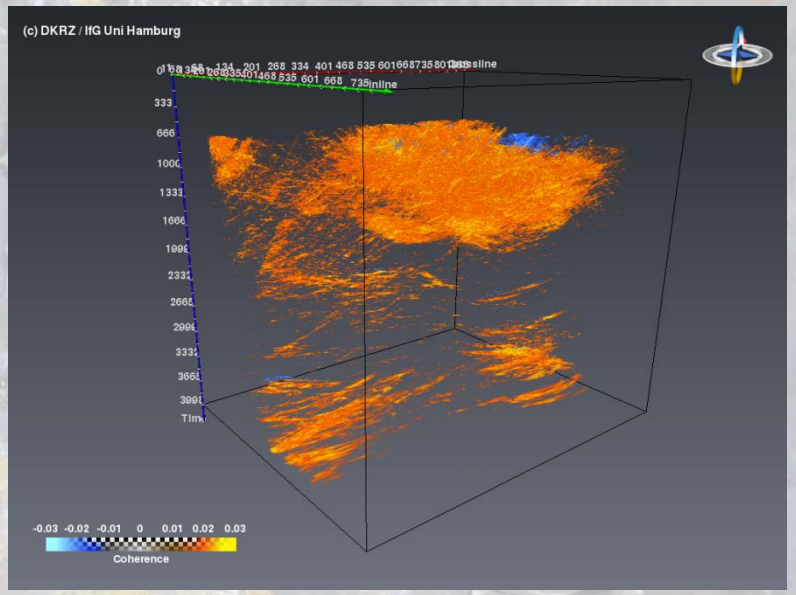
(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Visualization techniques

Slices



Volume rendering

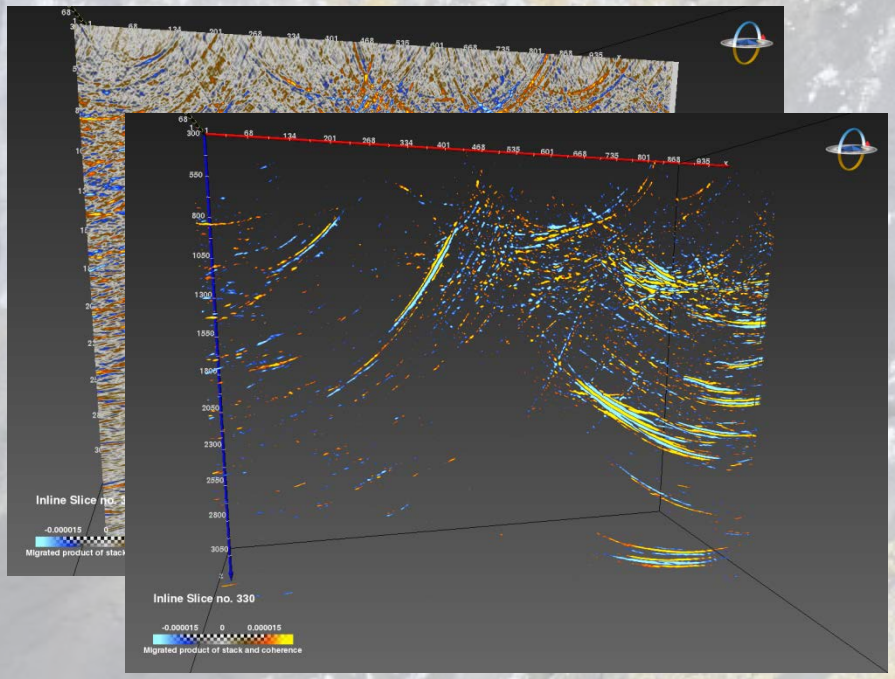


Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

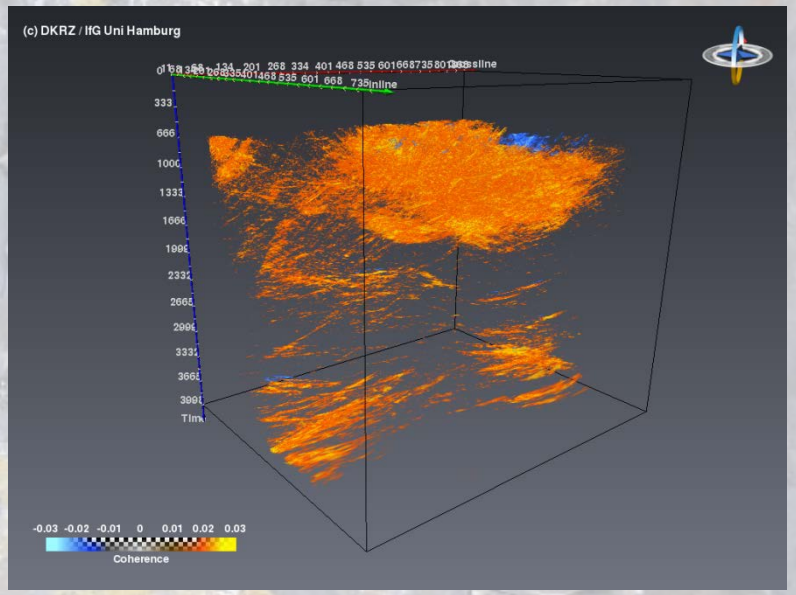
(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Visualization techniques

Slices



Volume rendering

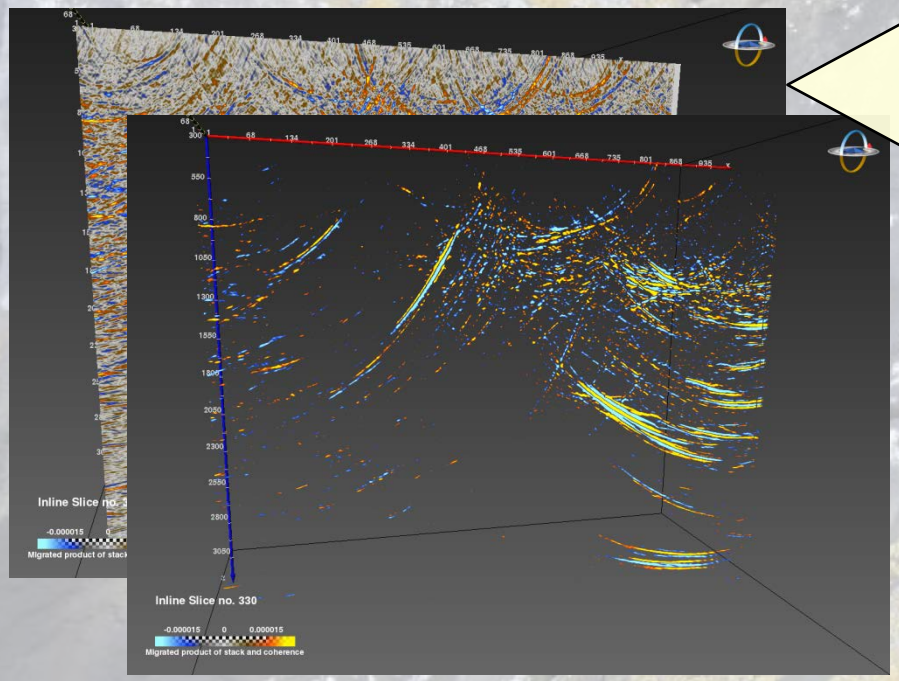


Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Visualization techniques

Slices



Slice through your 3D data volume to explore its internal structure. You may want to use:

- Slices along **inline**, **crossline** and **time axis** or at arbitrary orientation
- **Ortho slices** to include **images** (e.g. maps)
- **Transparency** to display certain amplitude ranges only
- **Multiple** transparent slices to achieve optical stacking
- An embossing effect to give slices a relief-like appearance
- **Animation of slices** in time to 'take a tour' through your data volume

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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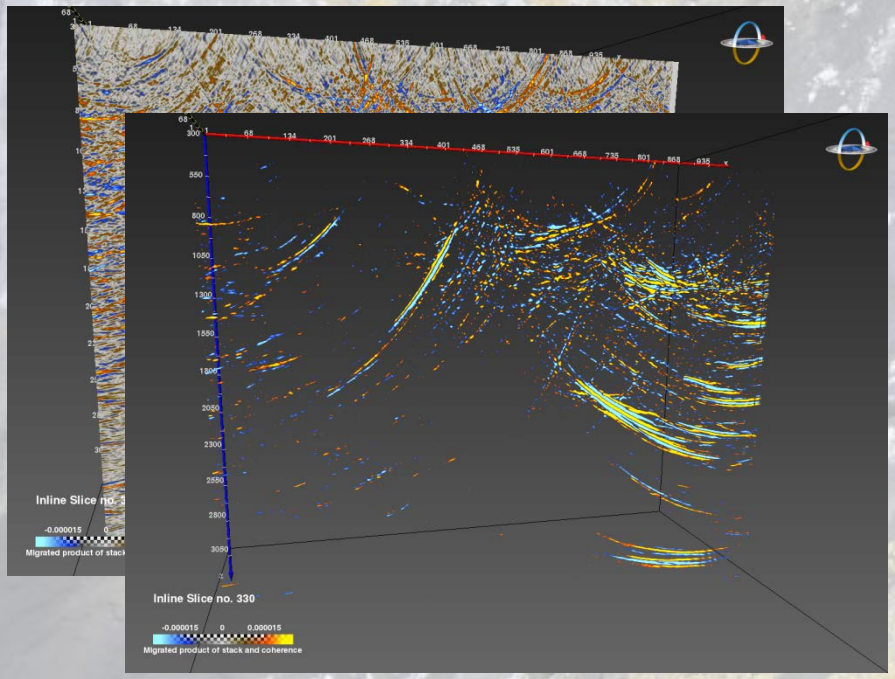
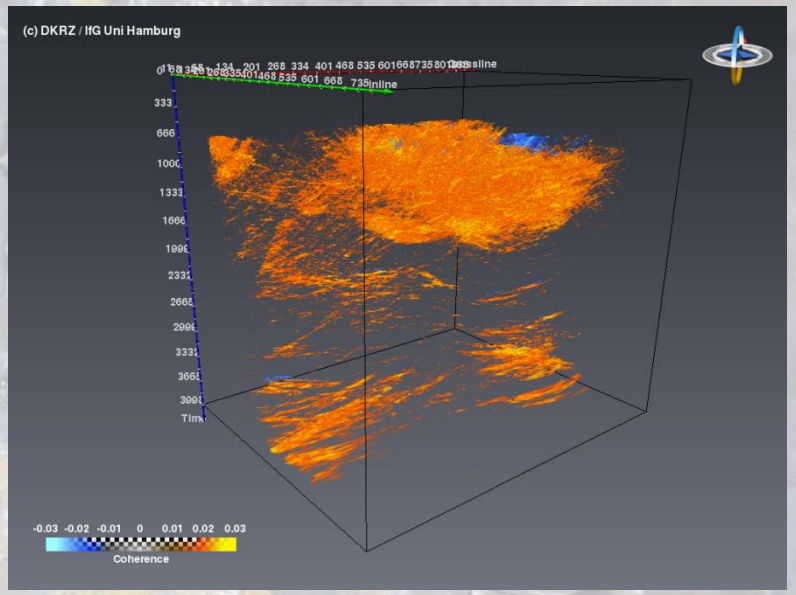
Visualization techniques

Slices



Volume rendering



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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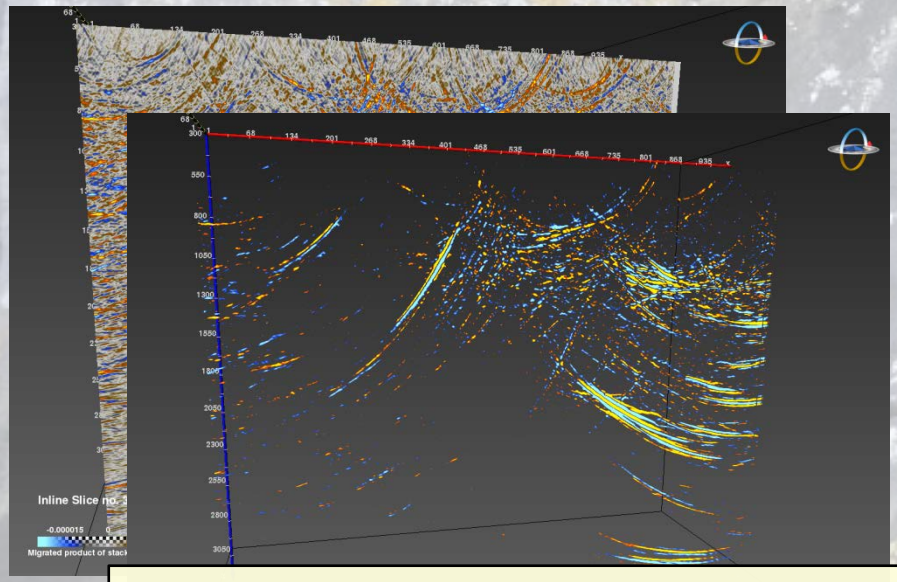
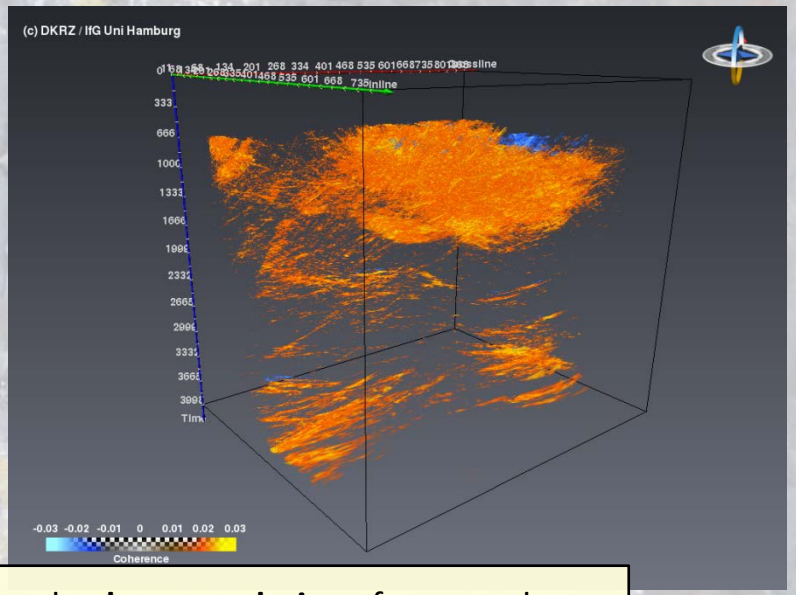
Visualization techniques

Slices



Volume rendering



Depending on your 3D data, a **combined** display of **slices** and **volume rendering** of, e.g. a sub-volume, may yield an even more expressive visualization. In this way, one or more data sets can be visually combined.

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

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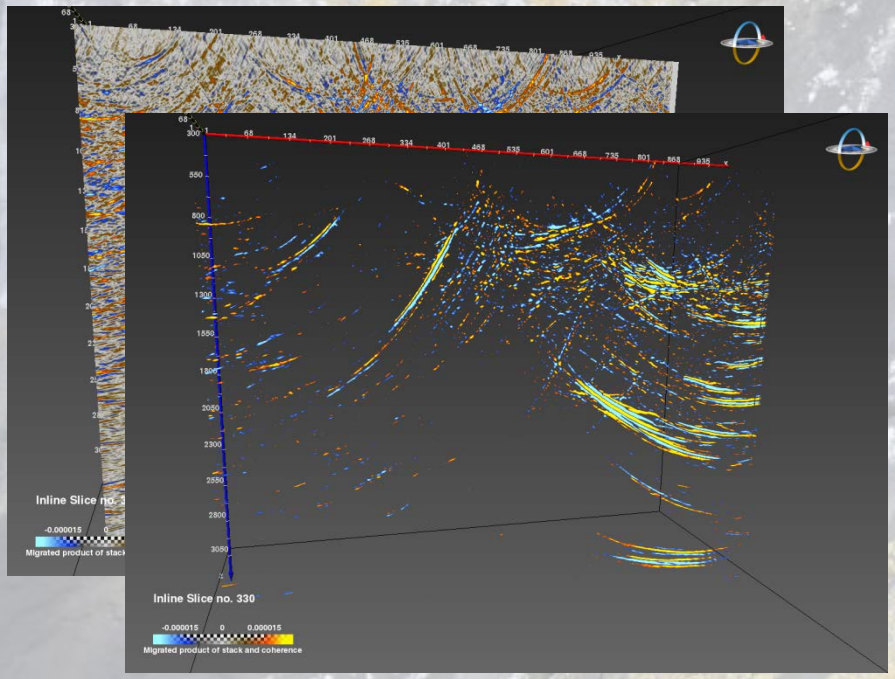
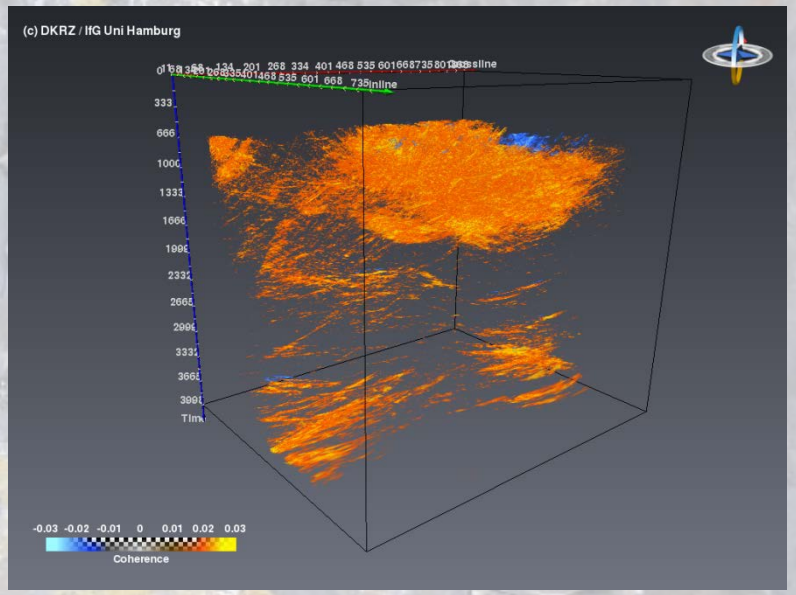
Visualization techniques

Slices



Volume rendering

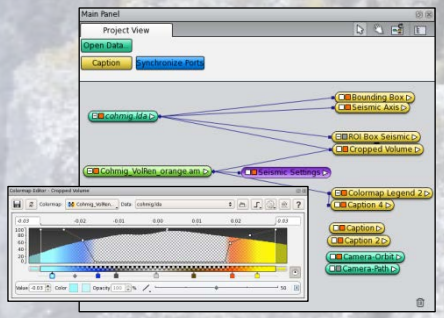


Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

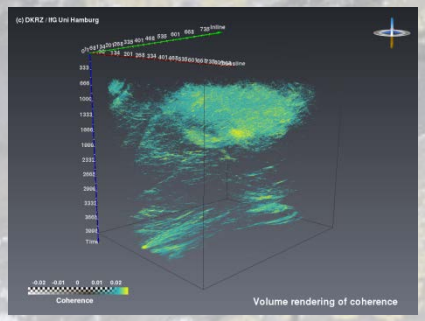
Avizo Earth



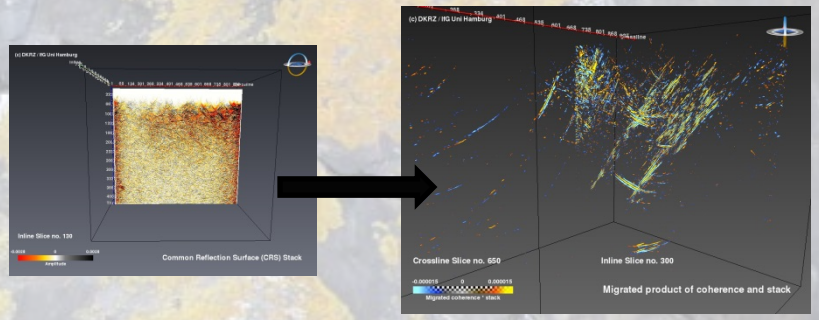
3D Visualization

DKRZ facilities

Visualization techniques



Results



Visualization of volumetric seismic data

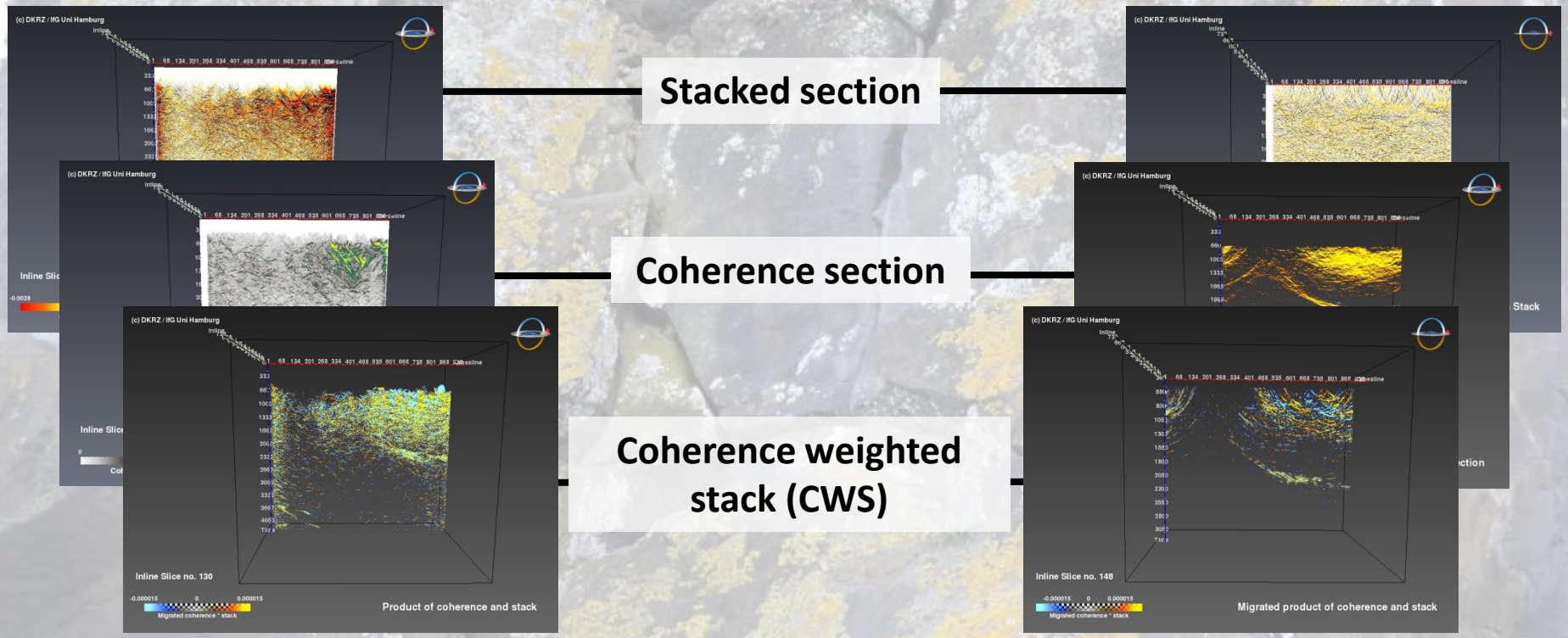
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Results

Unmigrated

Migrated



Stacked section

Coherence section

Coherence weighted stack (CWS)

Visualization of volumetric seismic data

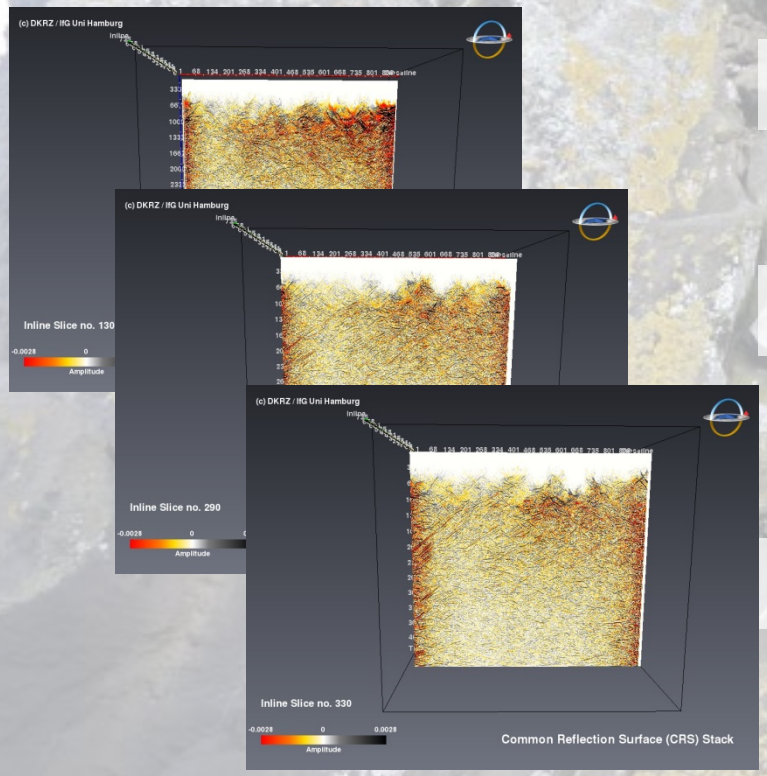
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Stacked section

Unmigrated

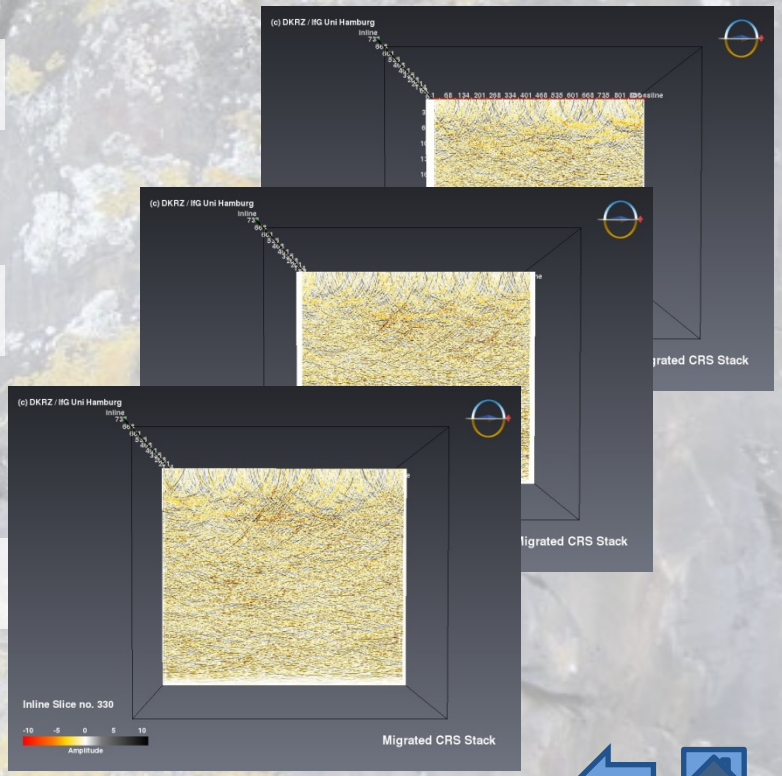
Migrated



Inline 130

Inline 290

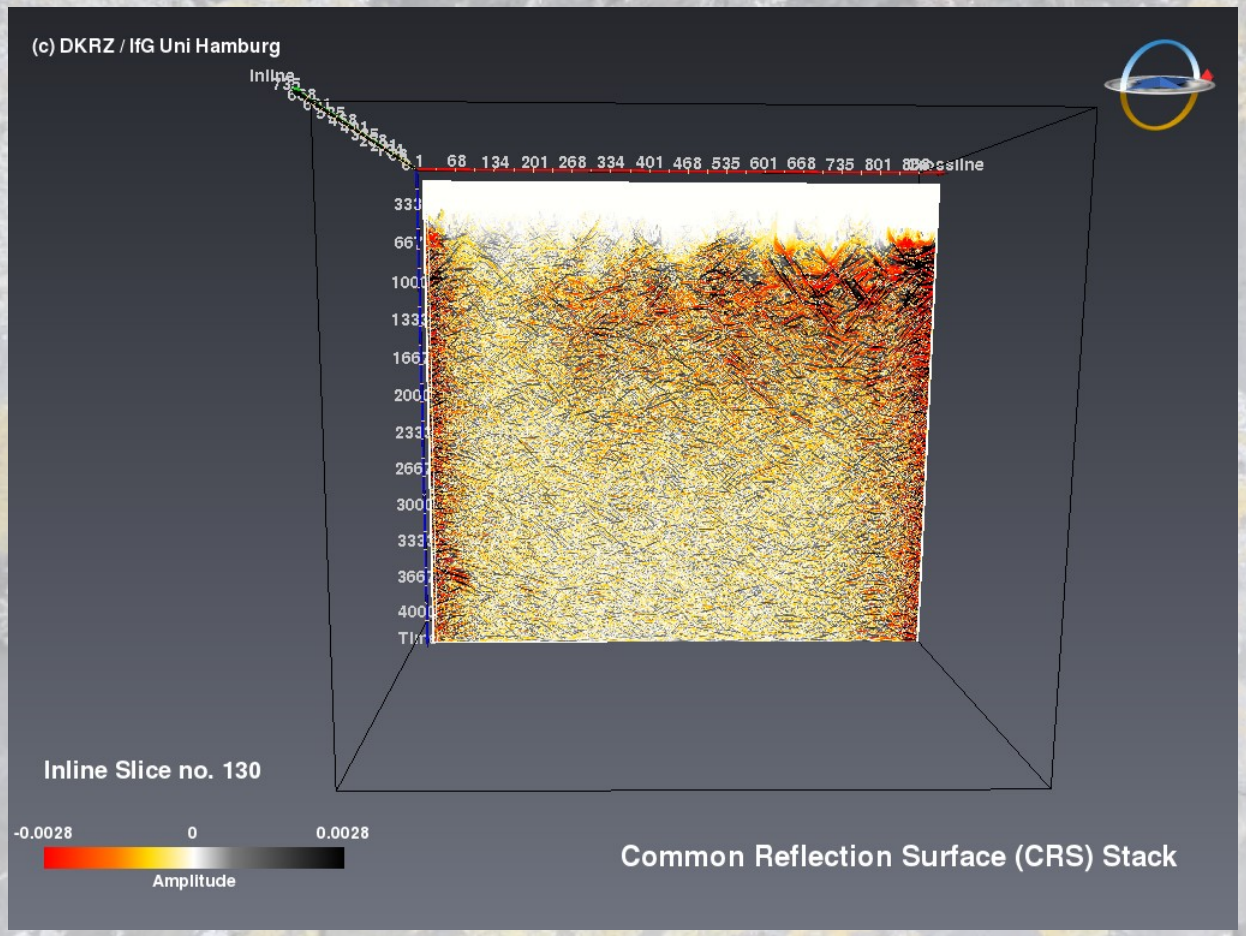
Inline 330



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

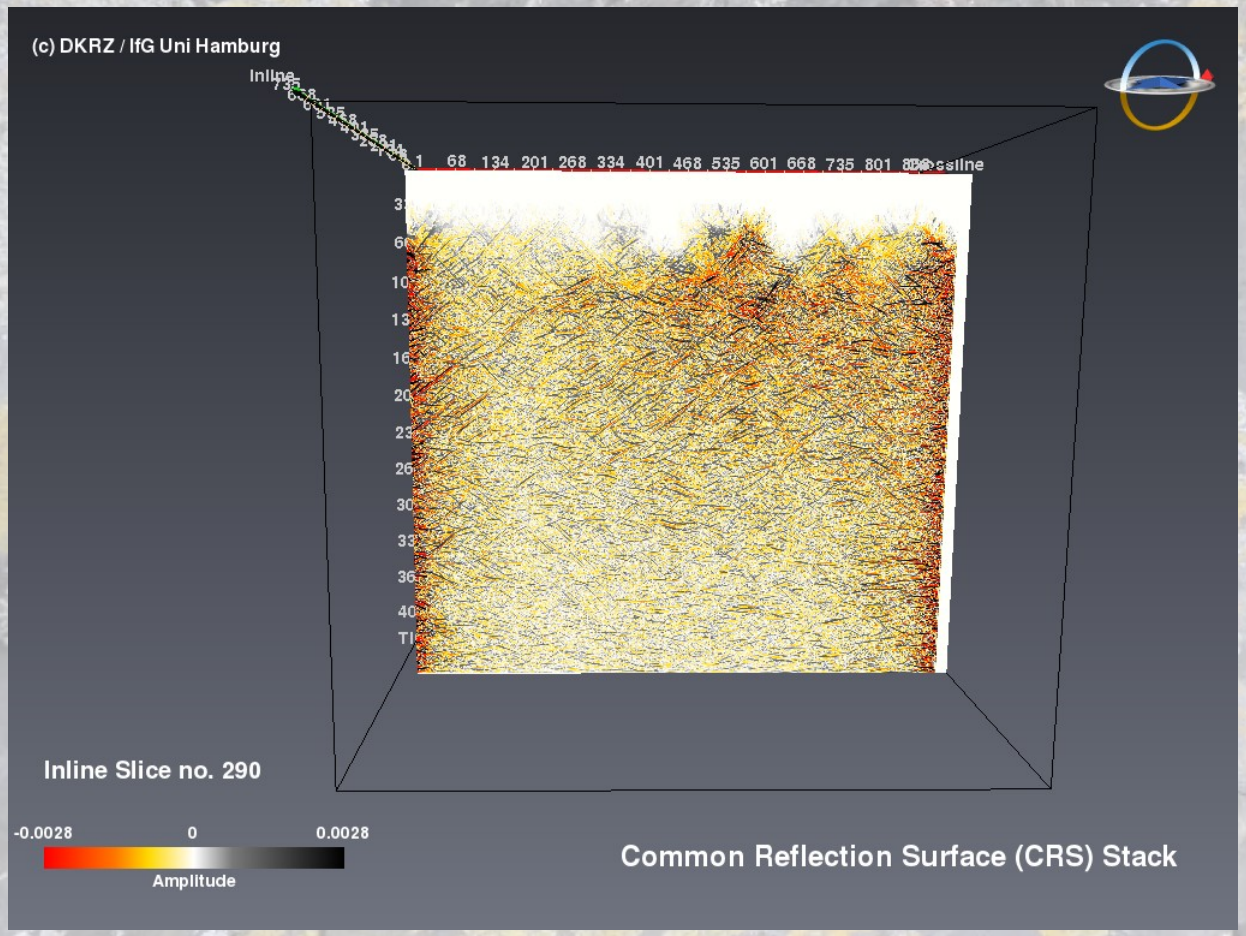
Stacked section – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

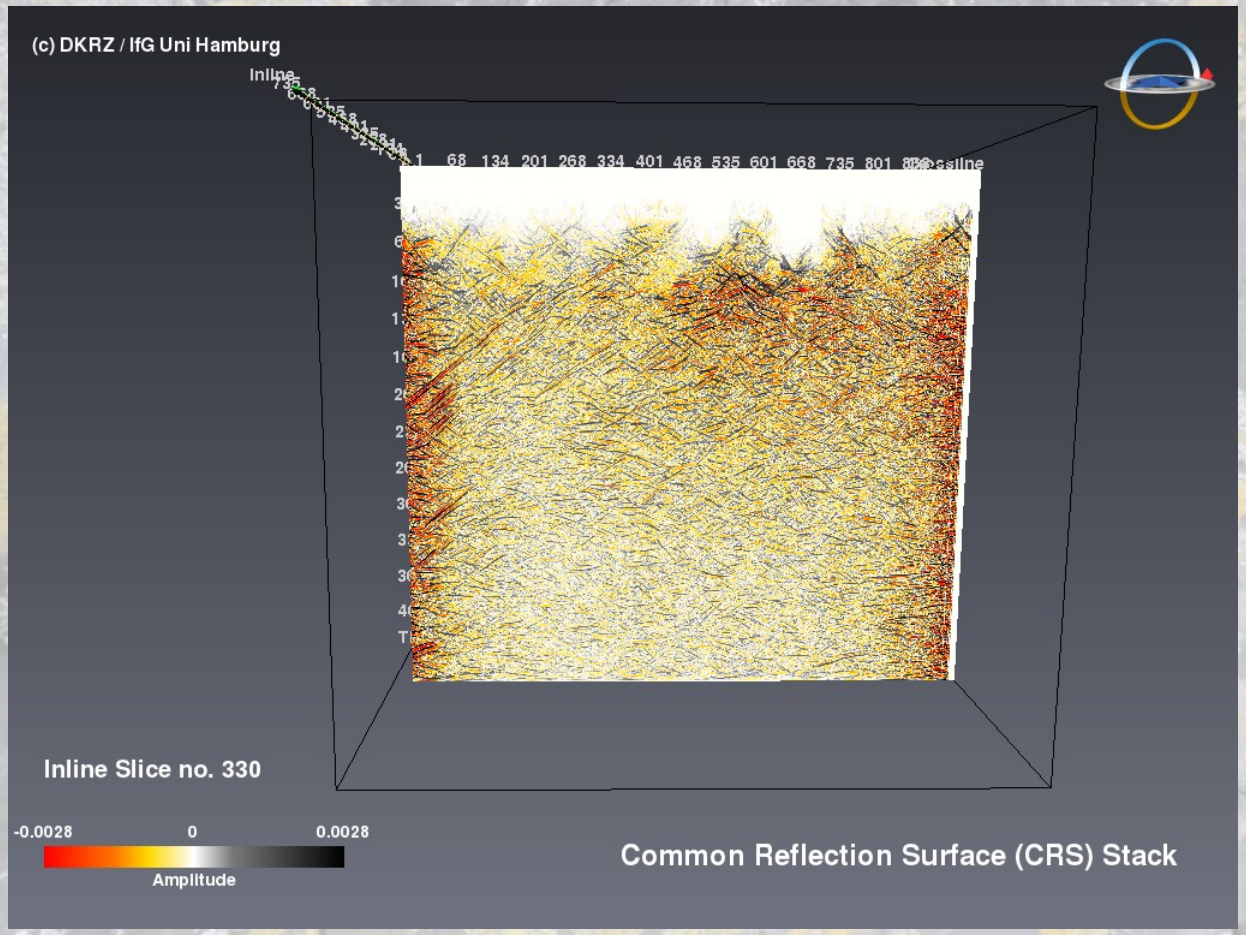
Stacked section – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Stacked section – Inline 330



Visualization of volumetric seismic data

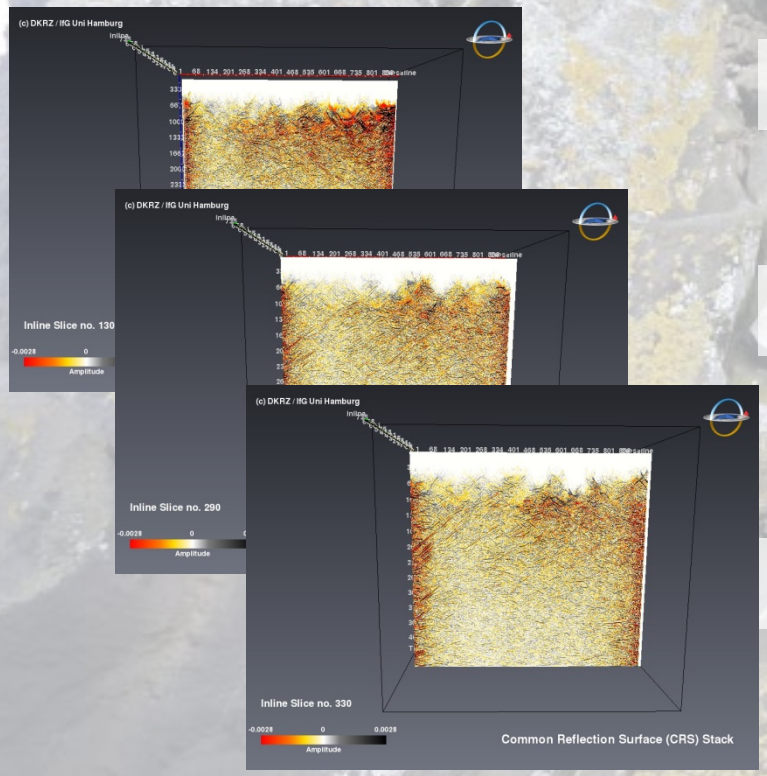
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Stacked section

Unmigrated

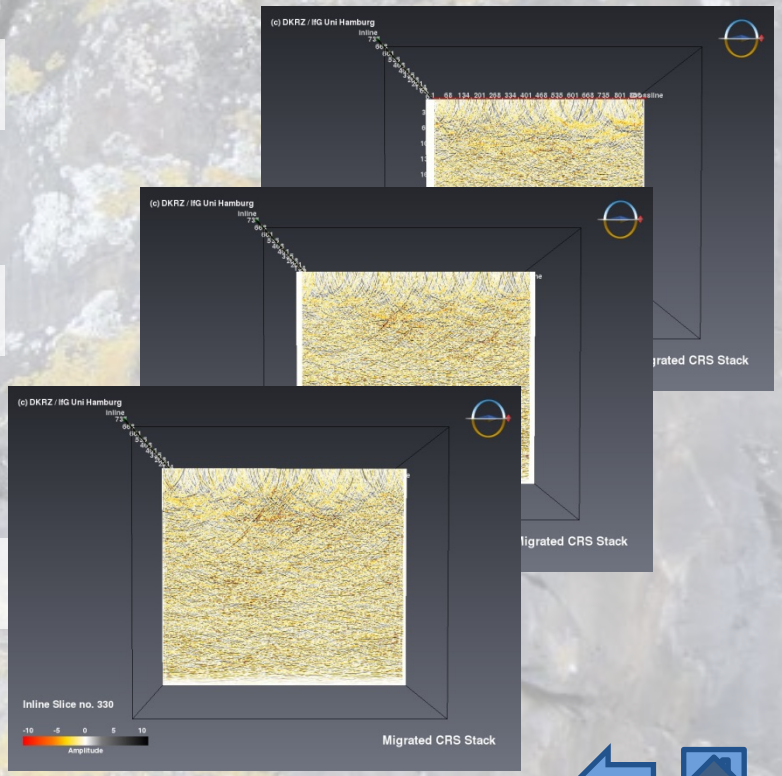
Migrated



Inline 130

Inline 290

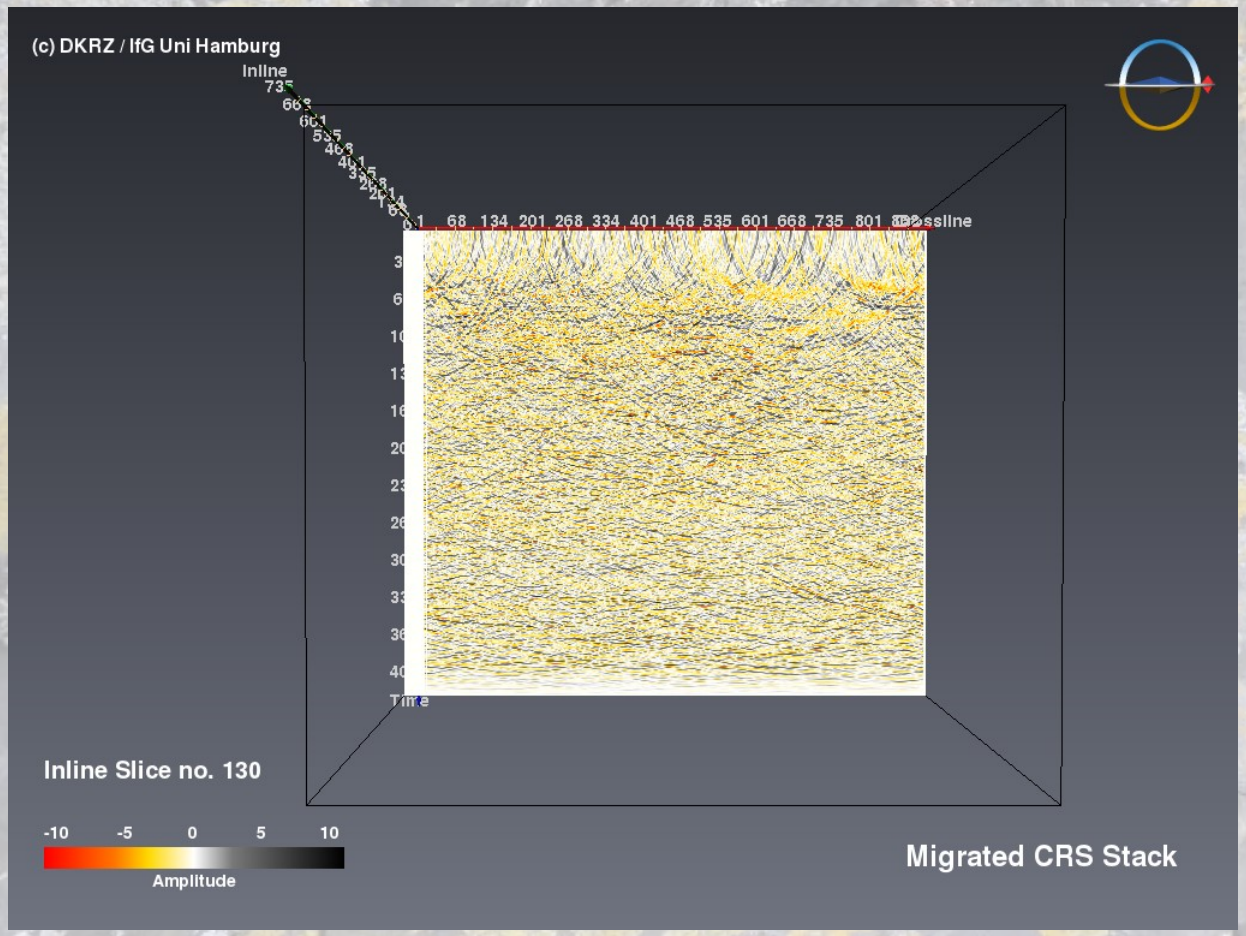
Inline 330



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

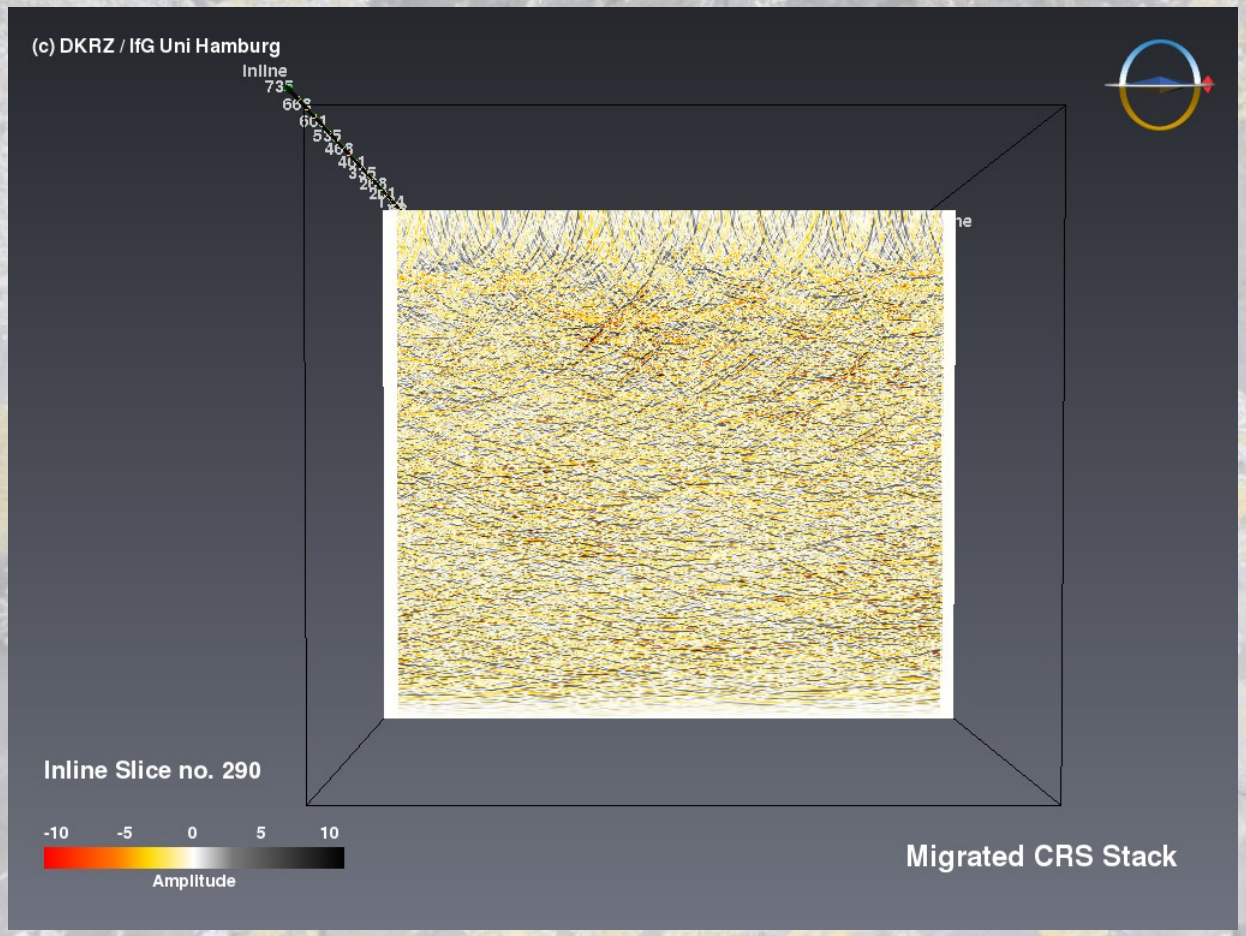
Migrated stacked section – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

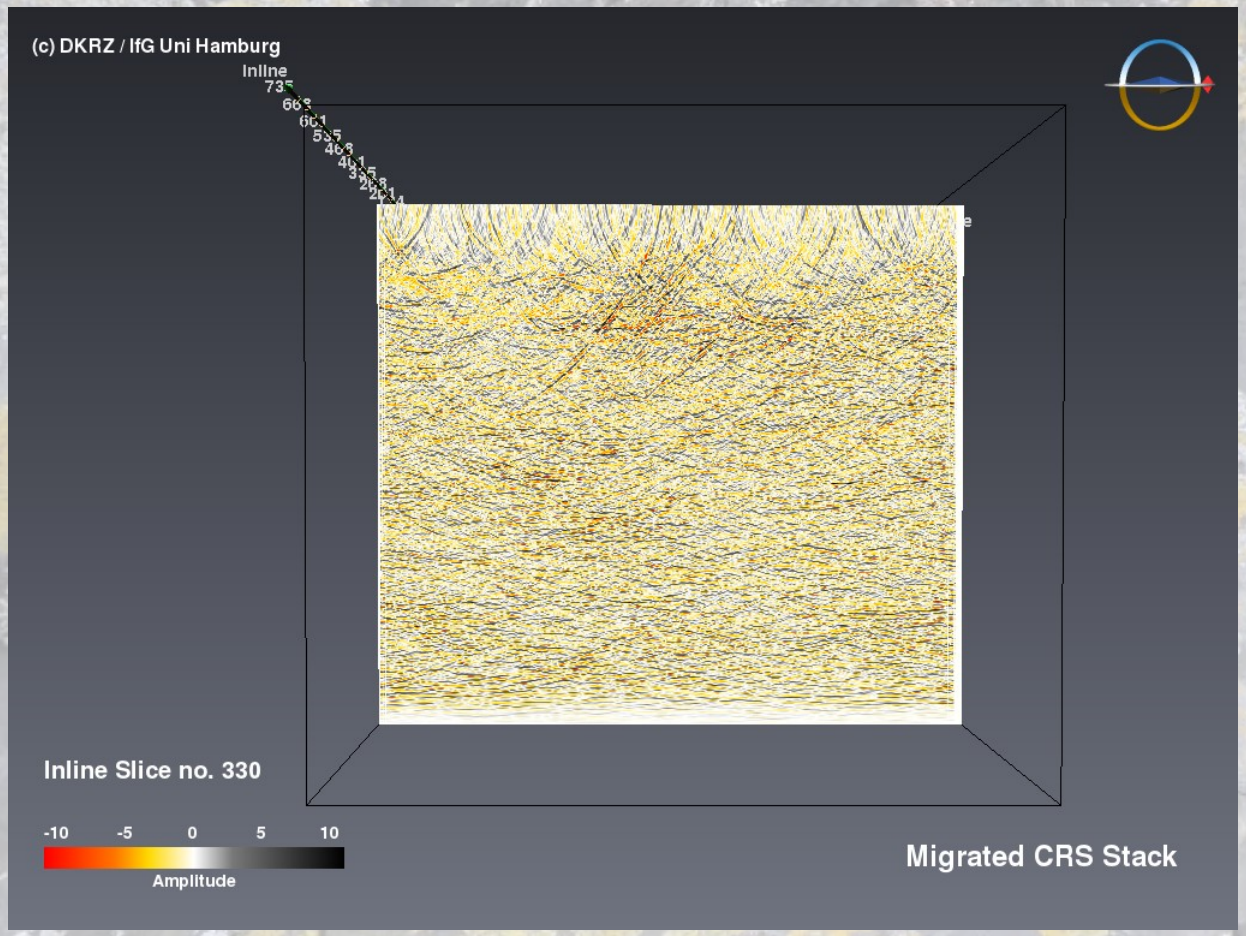
Migrated stacked section – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Migrated stacked section – Inline 330



Visualization of volumetric seismic data

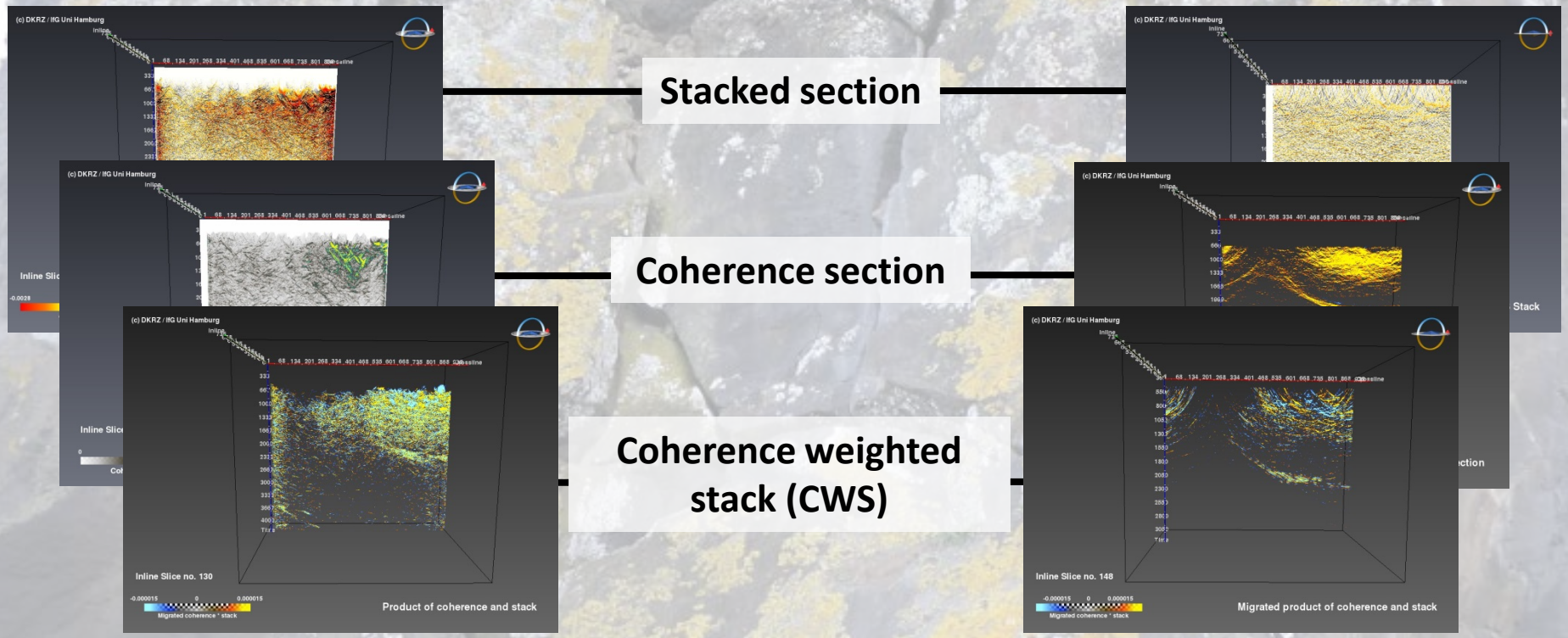
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Results

Unmigrated

Migrated



Stacked section

Coherence section

Coherence weighted stack (CWS)

Visualization of volumetric seismic data

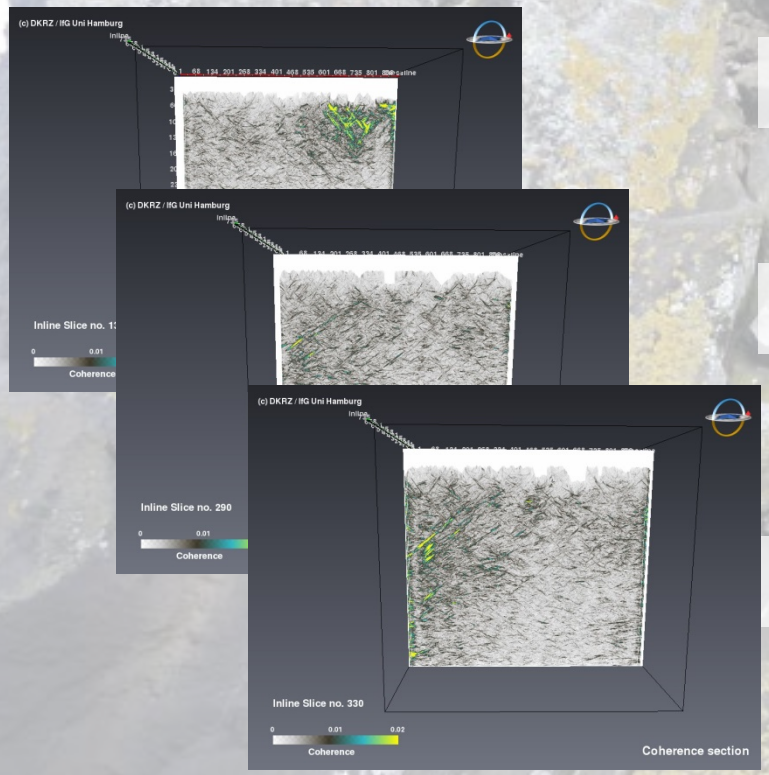
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence section

Unmigrated

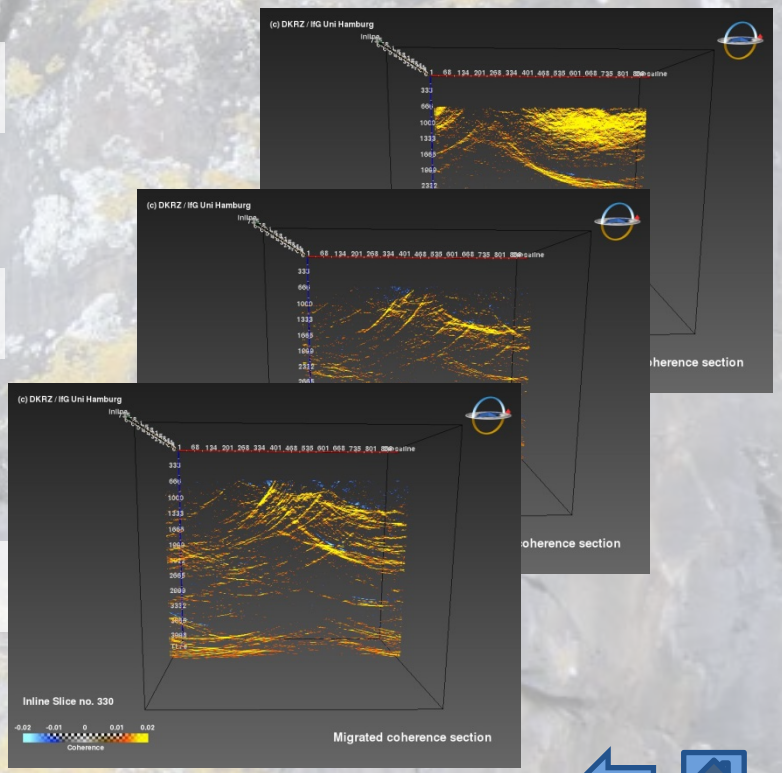
Migrated



Inline 130

Inline 290

Inline 330



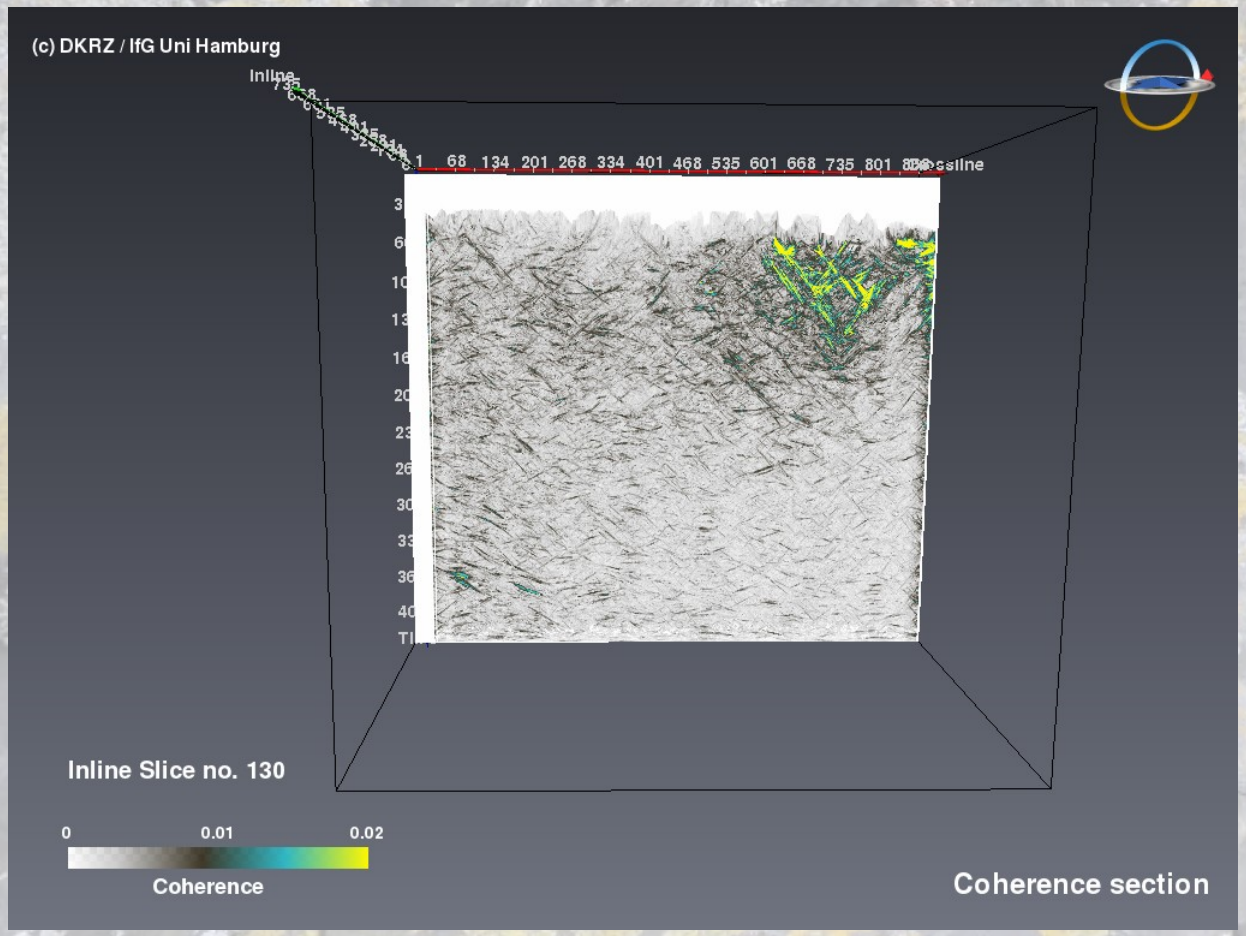
Video

Video

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

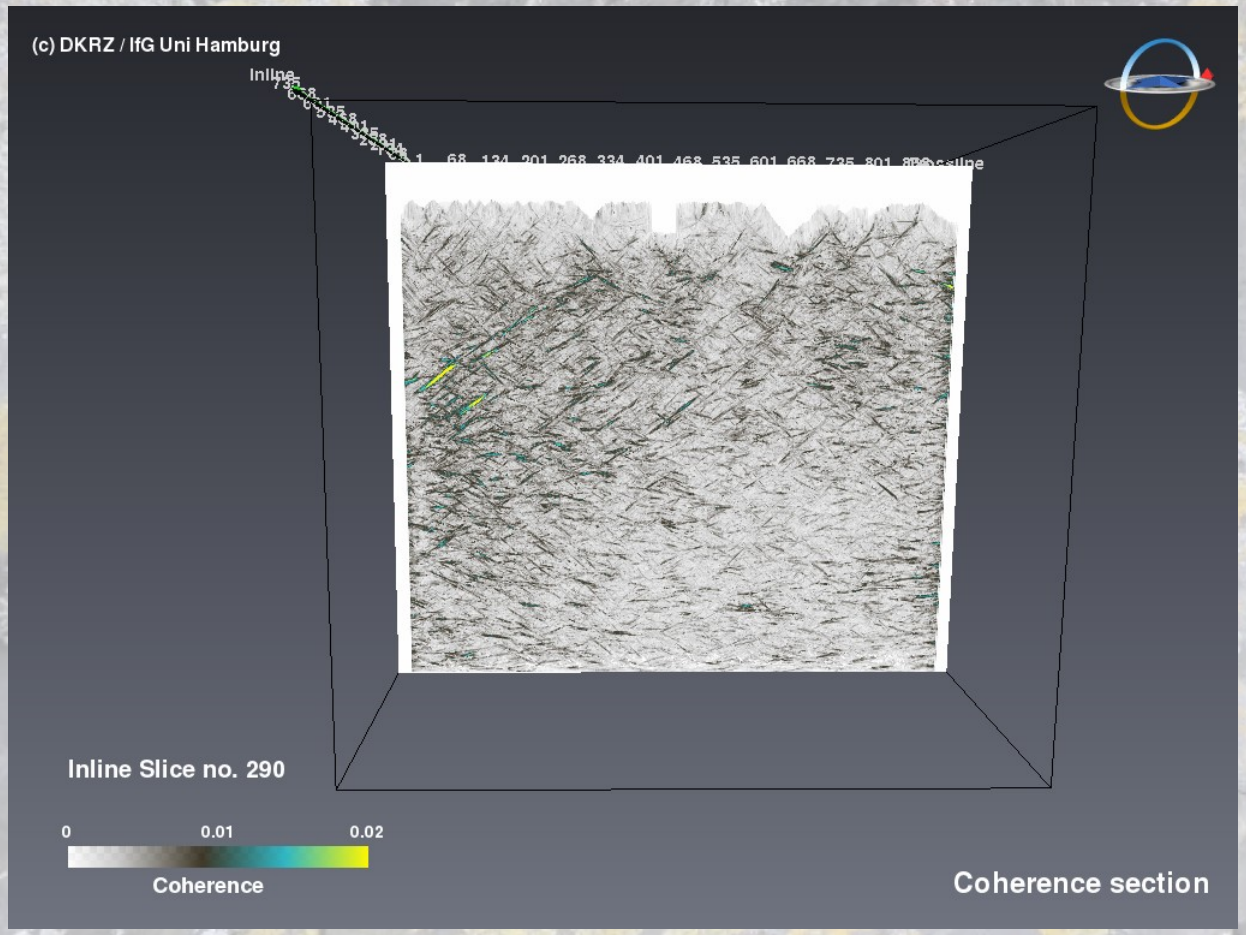
Coherence section – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

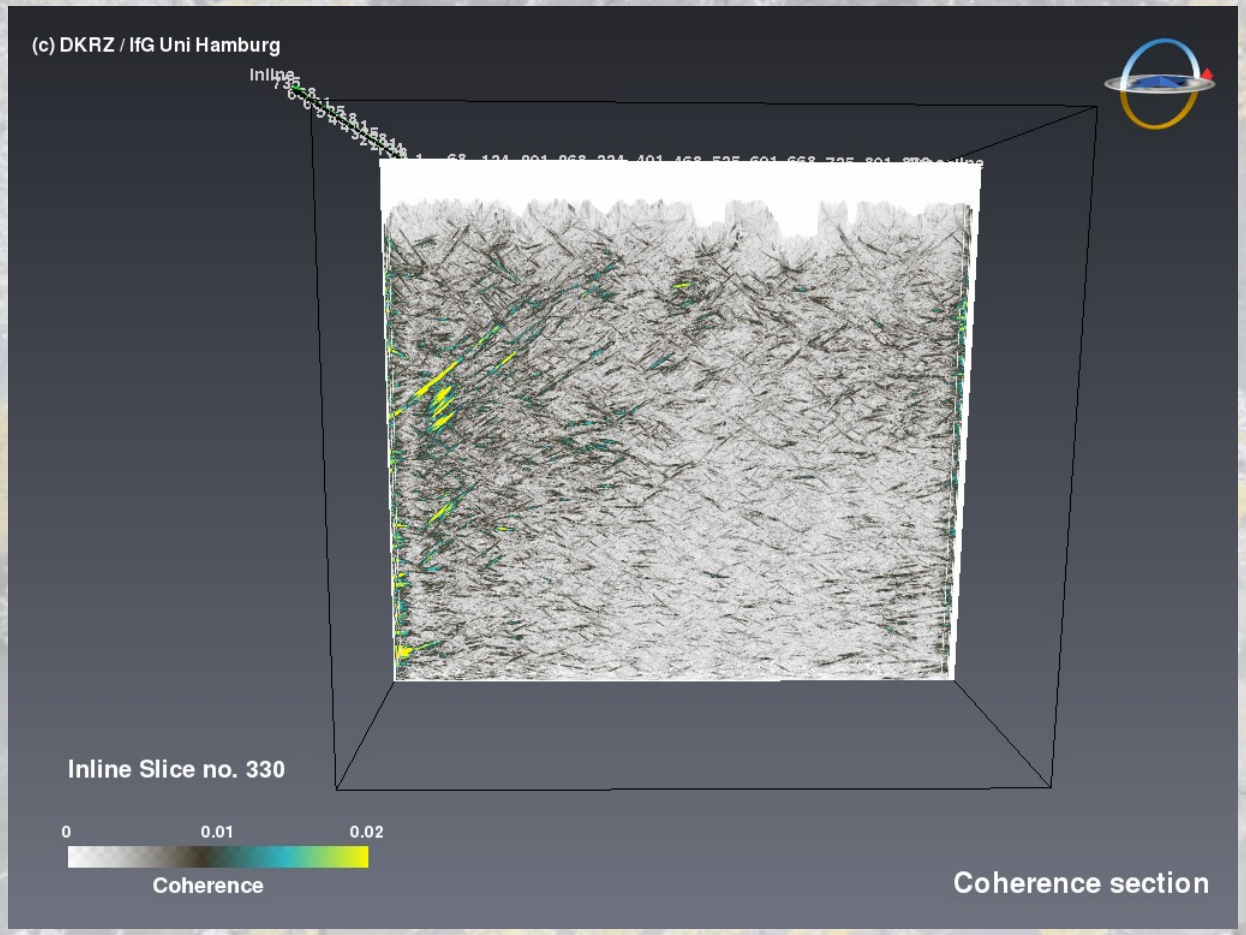
Coherence section – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

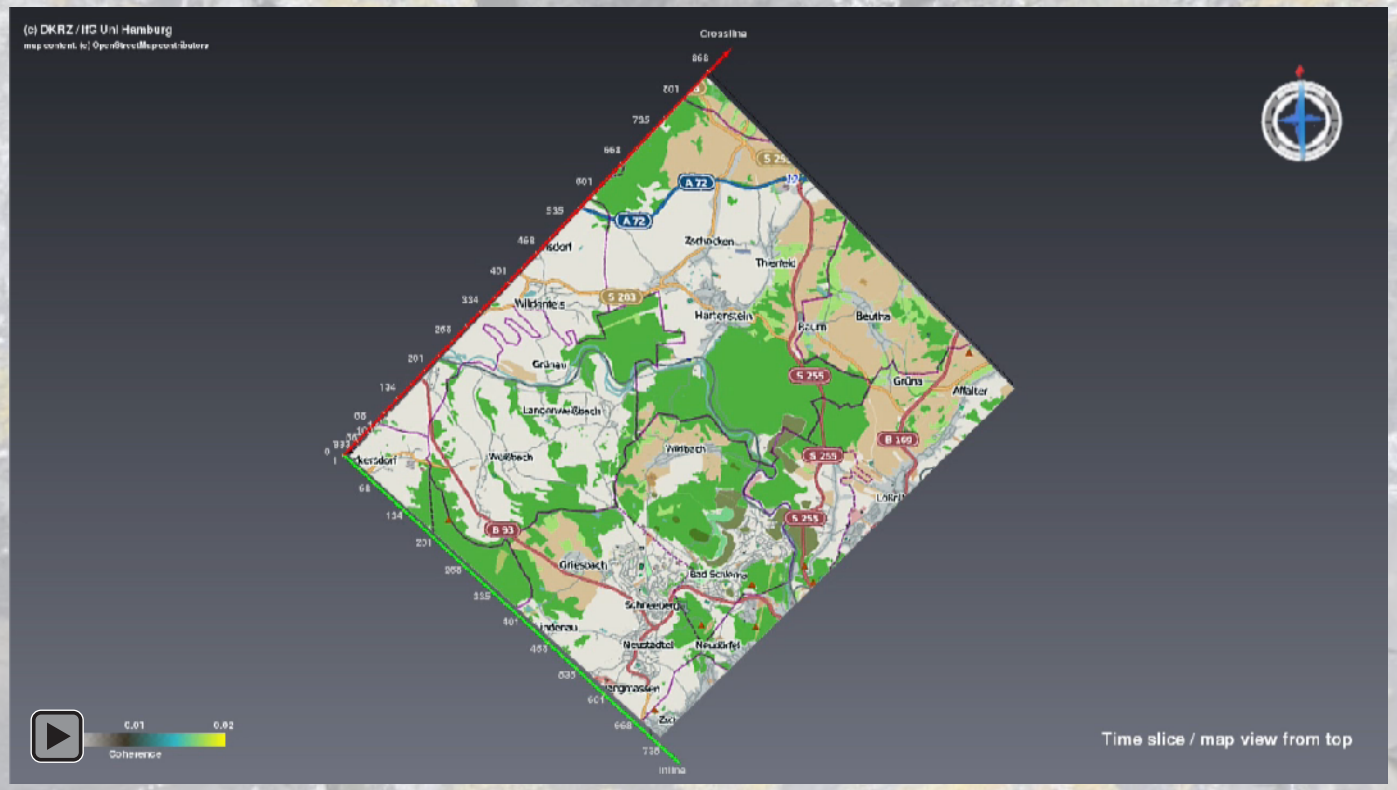
Coherence section – Inline 330



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence section with map and borehole position – Movie



Visualization of volumetric seismic data

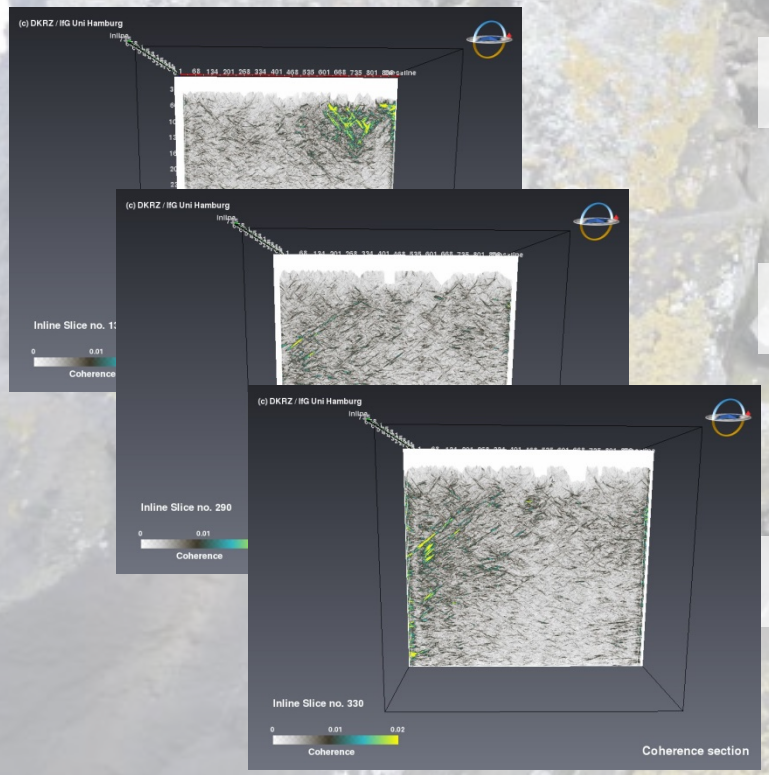
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence section

Unmigrated

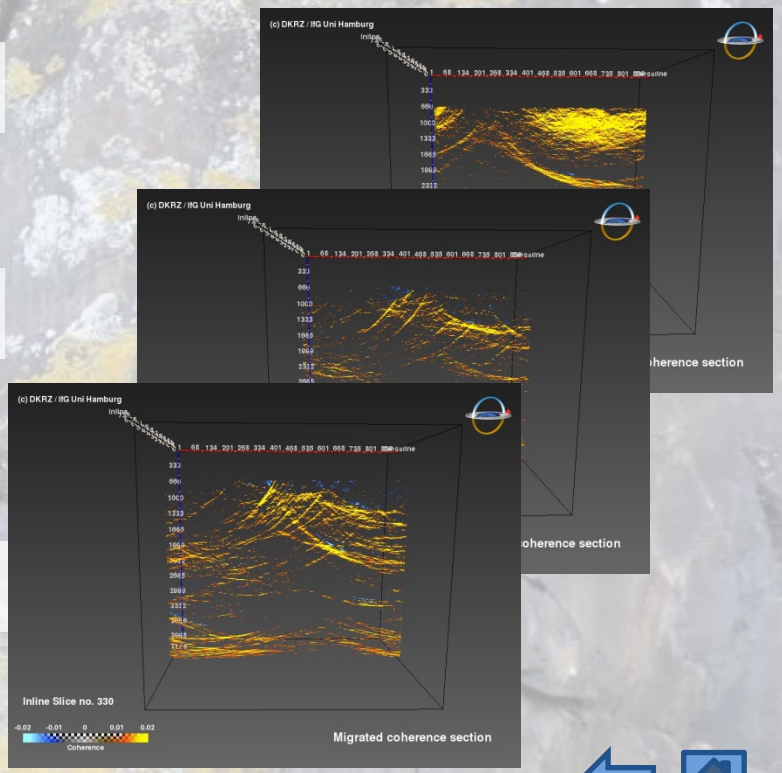
Migrated



Inline 130

Inline 290

Inline 330



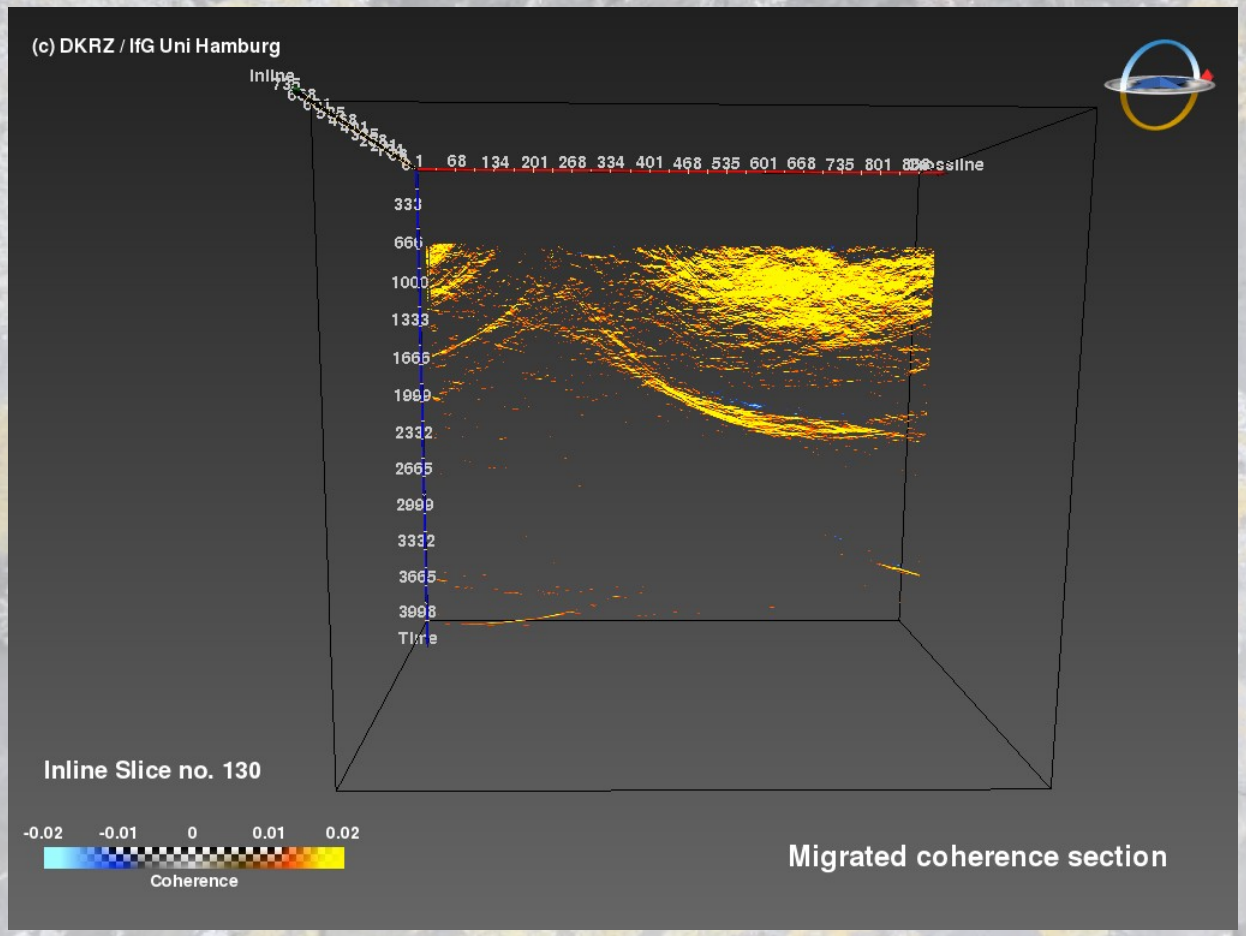
Video

Video

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

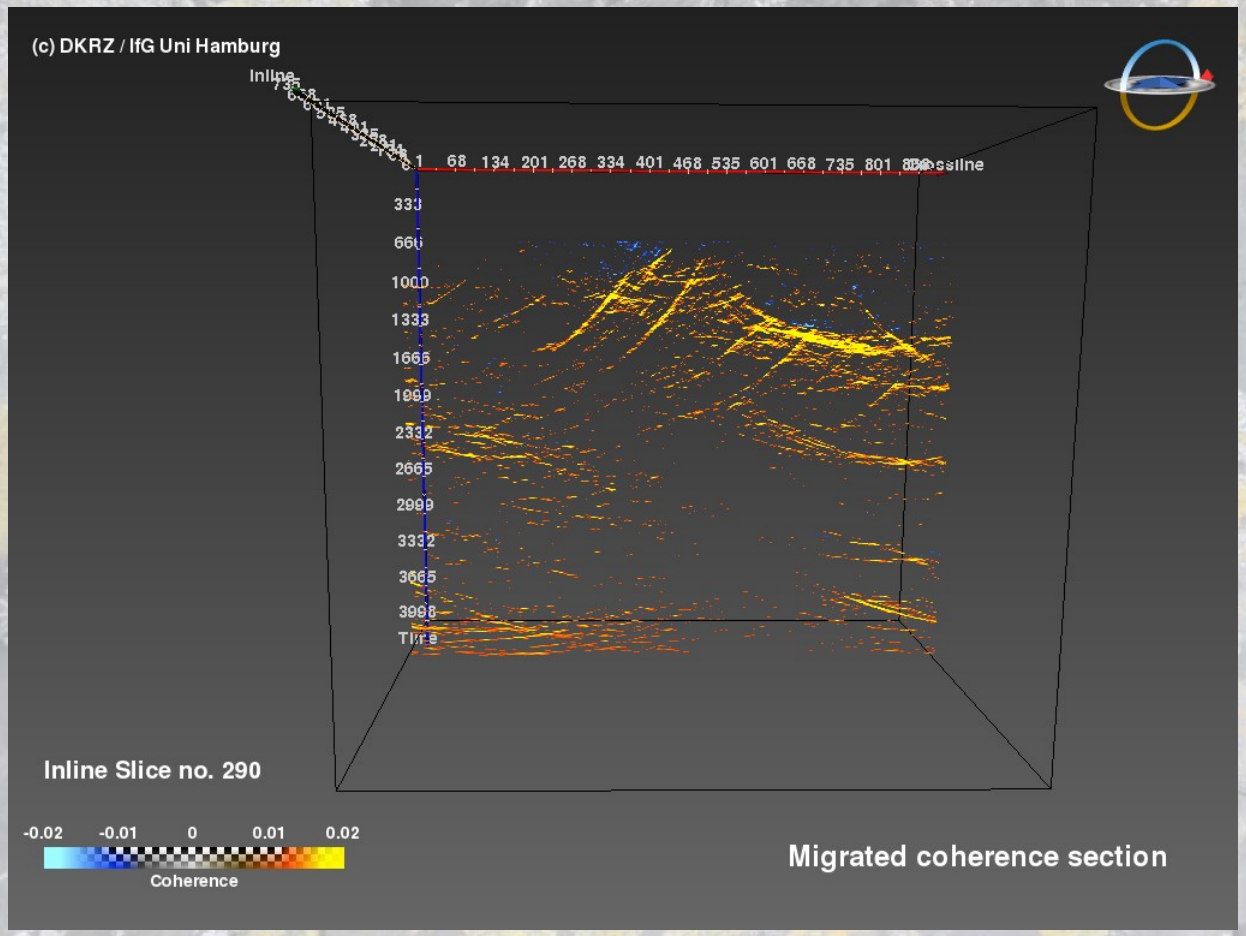
Migrated Coherence section – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

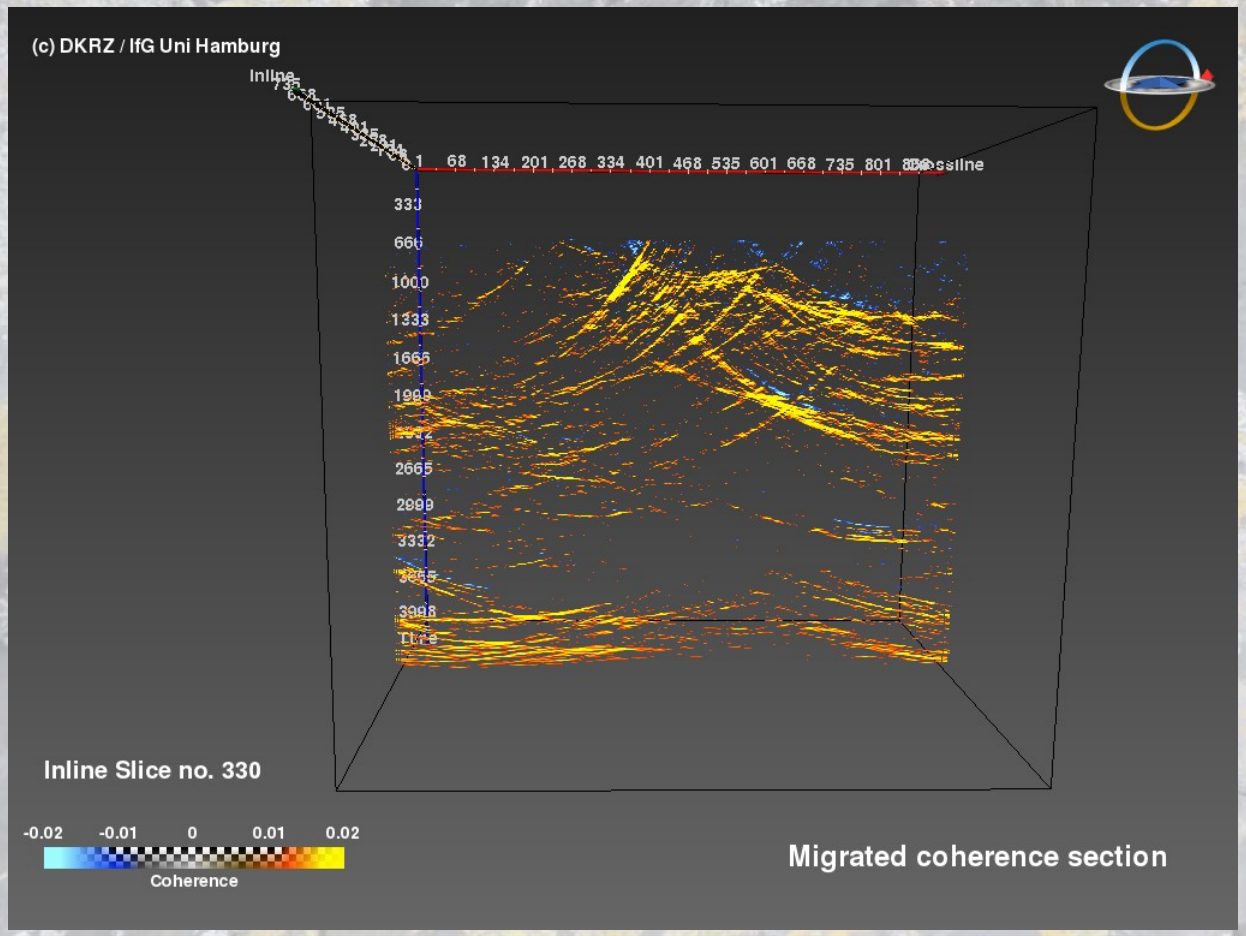
Migrated Coherence section – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

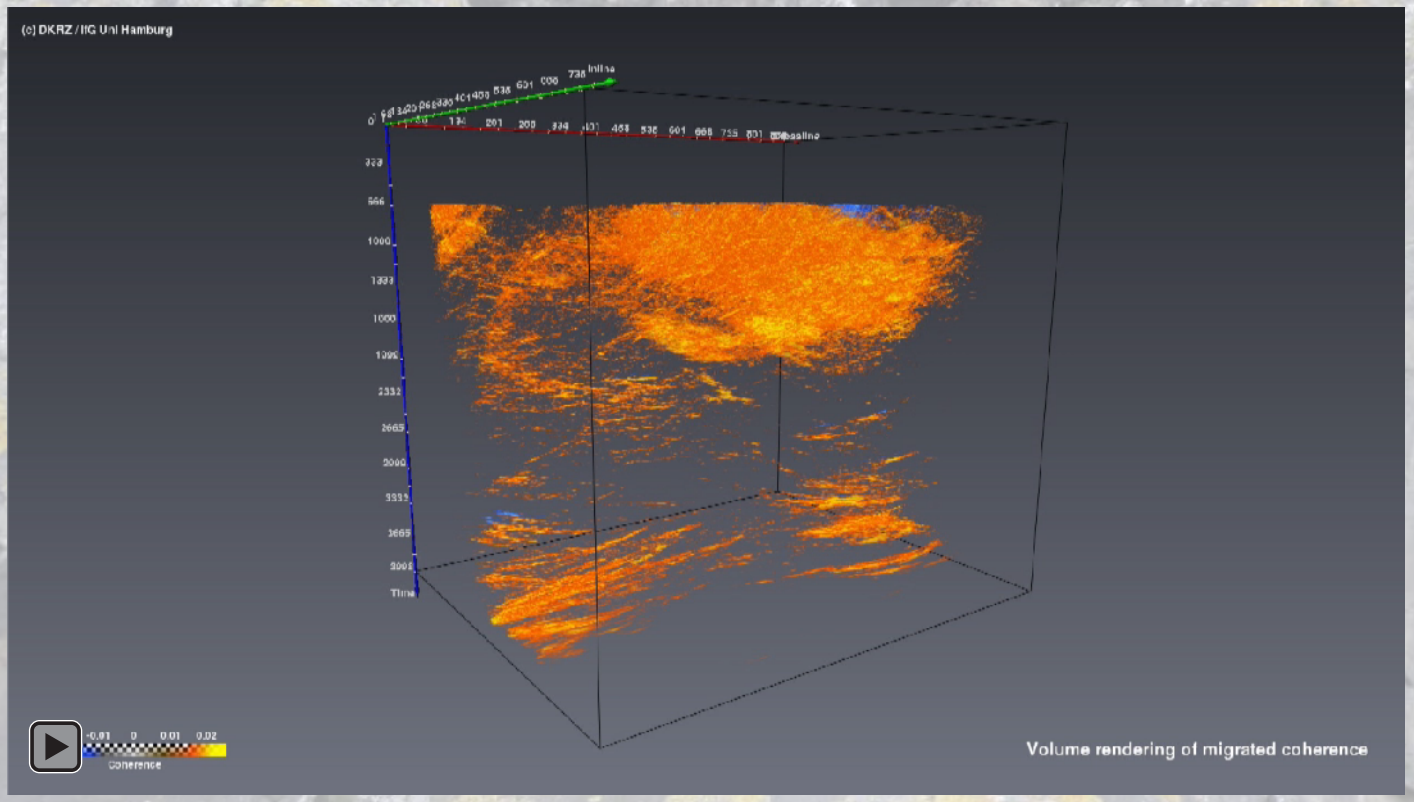
Migrated Coherence section – Inline 330



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Migrated Coherence section – Movie



Visualization of volumetric seismic data

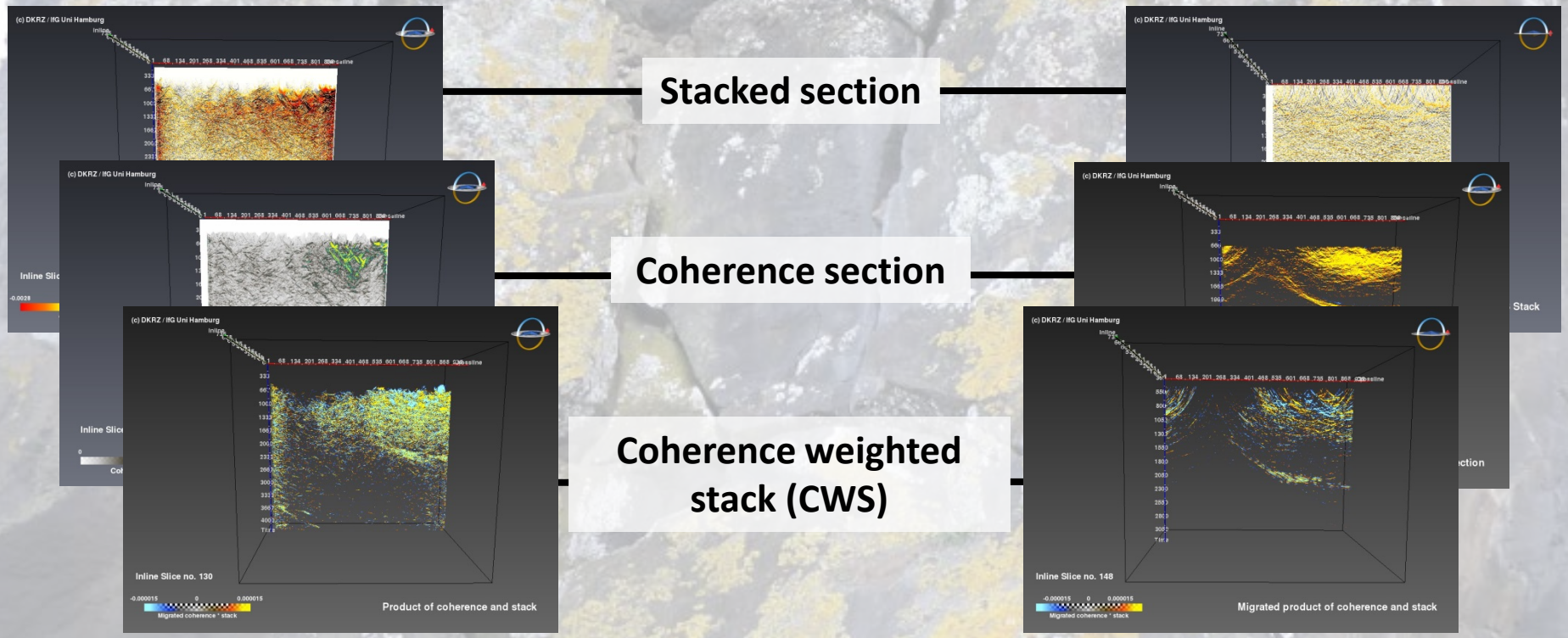
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Results

Unmigrated

Migrated



Stacked section

Coherence section

Coherence weighted stack (CWS)

Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence weighted stack (CWS)

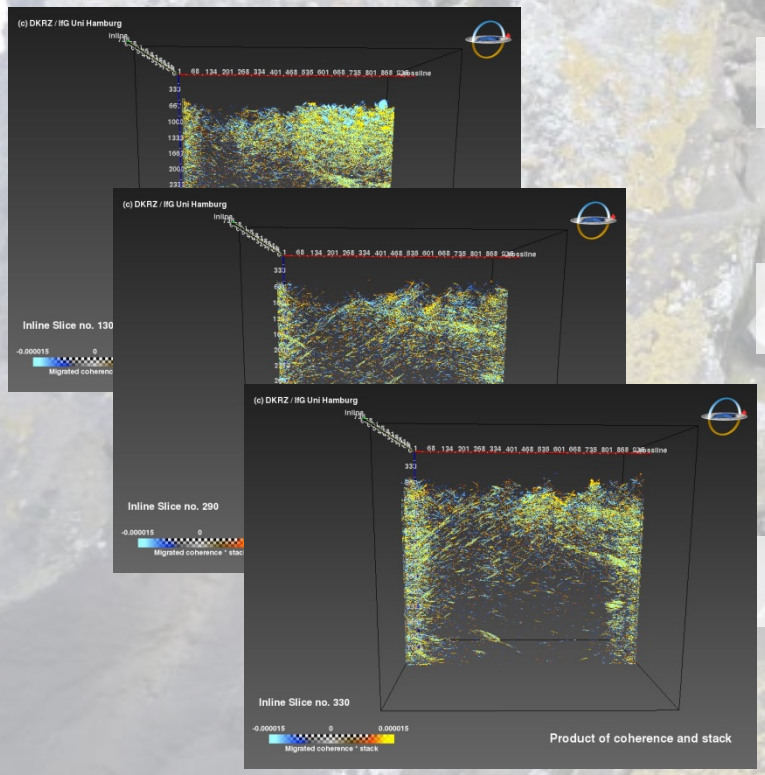
Unmigrated

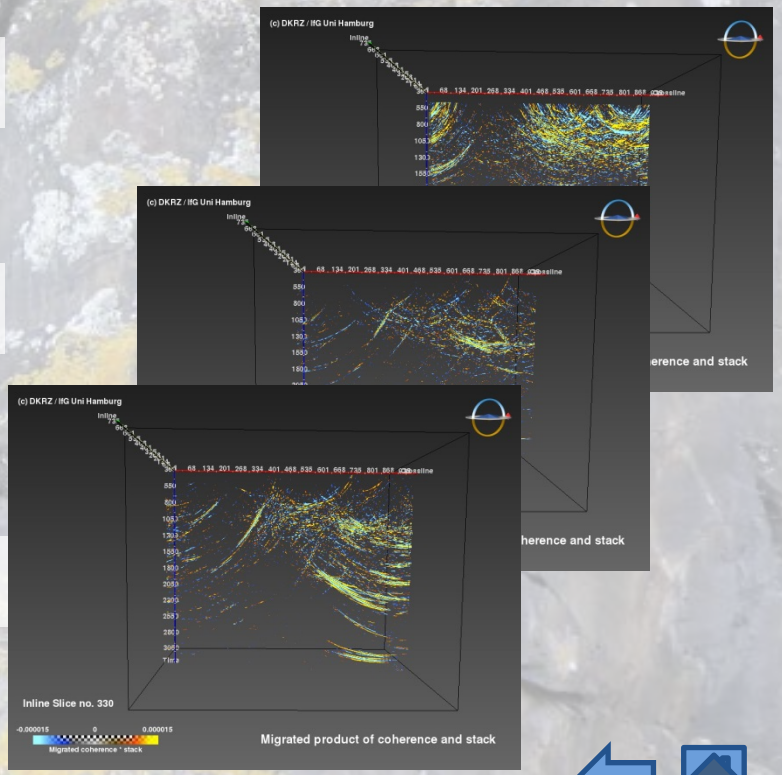
Migrated

Inline 130

Inline 290

Inline 330



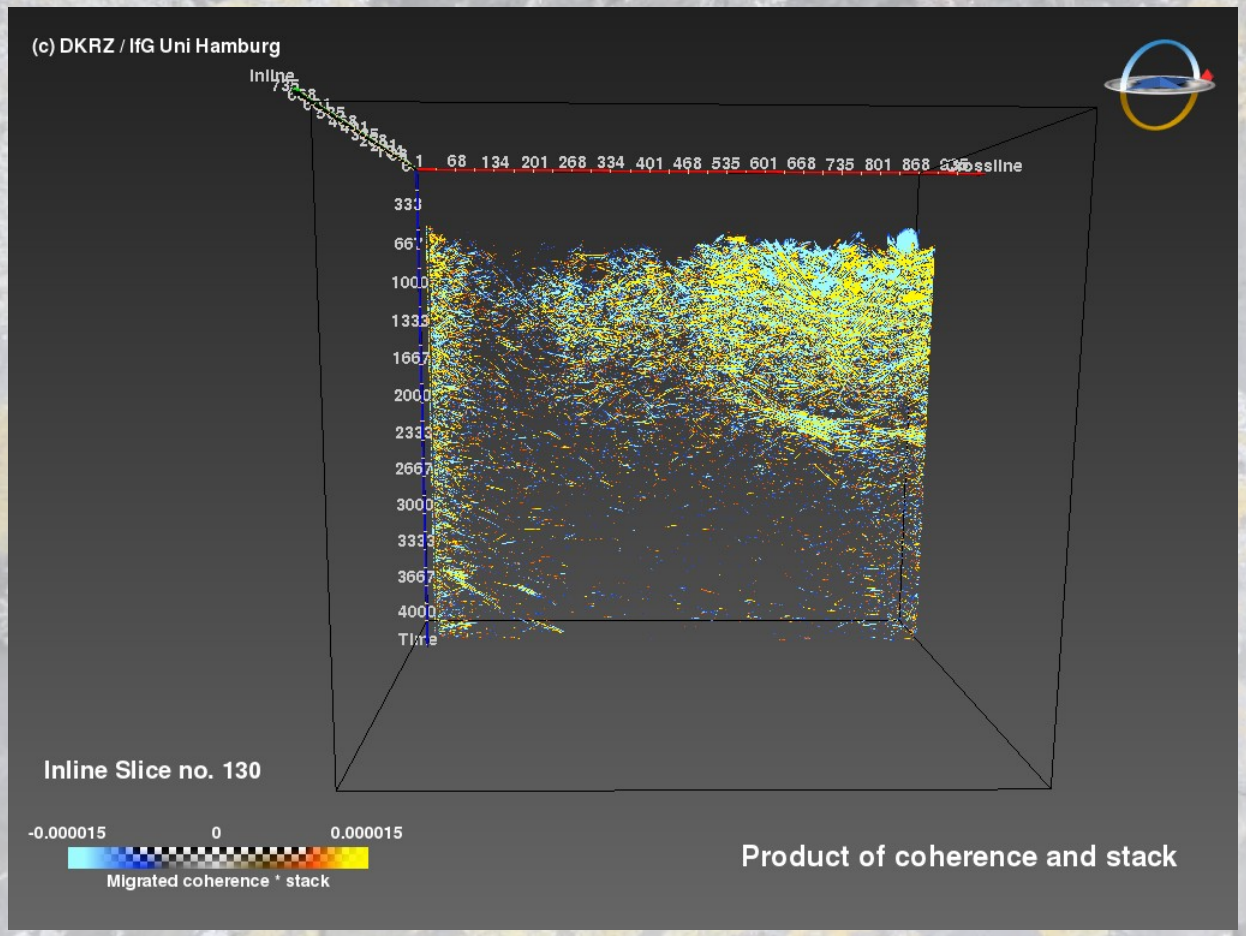


Video

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

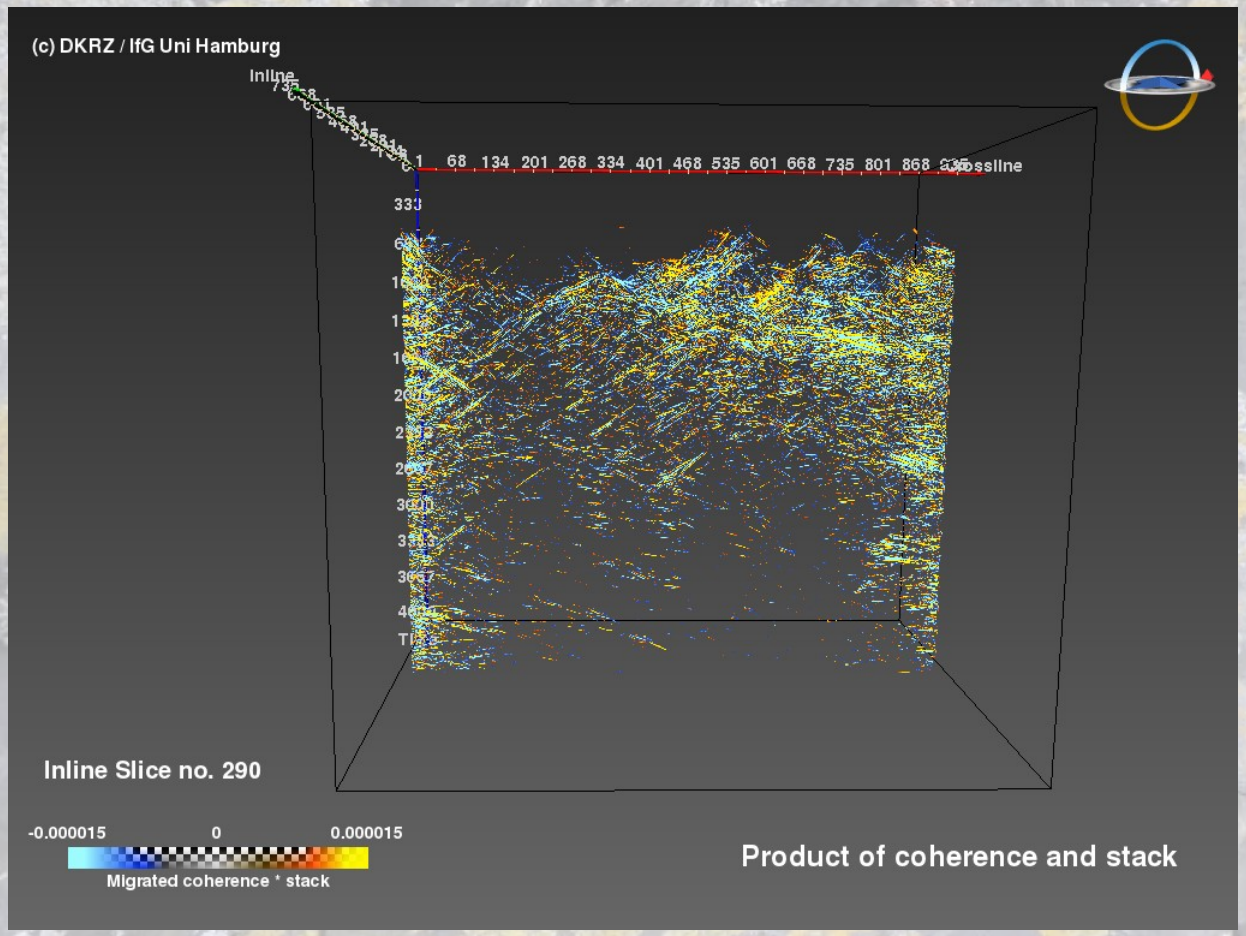
Coherence weighted stack – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

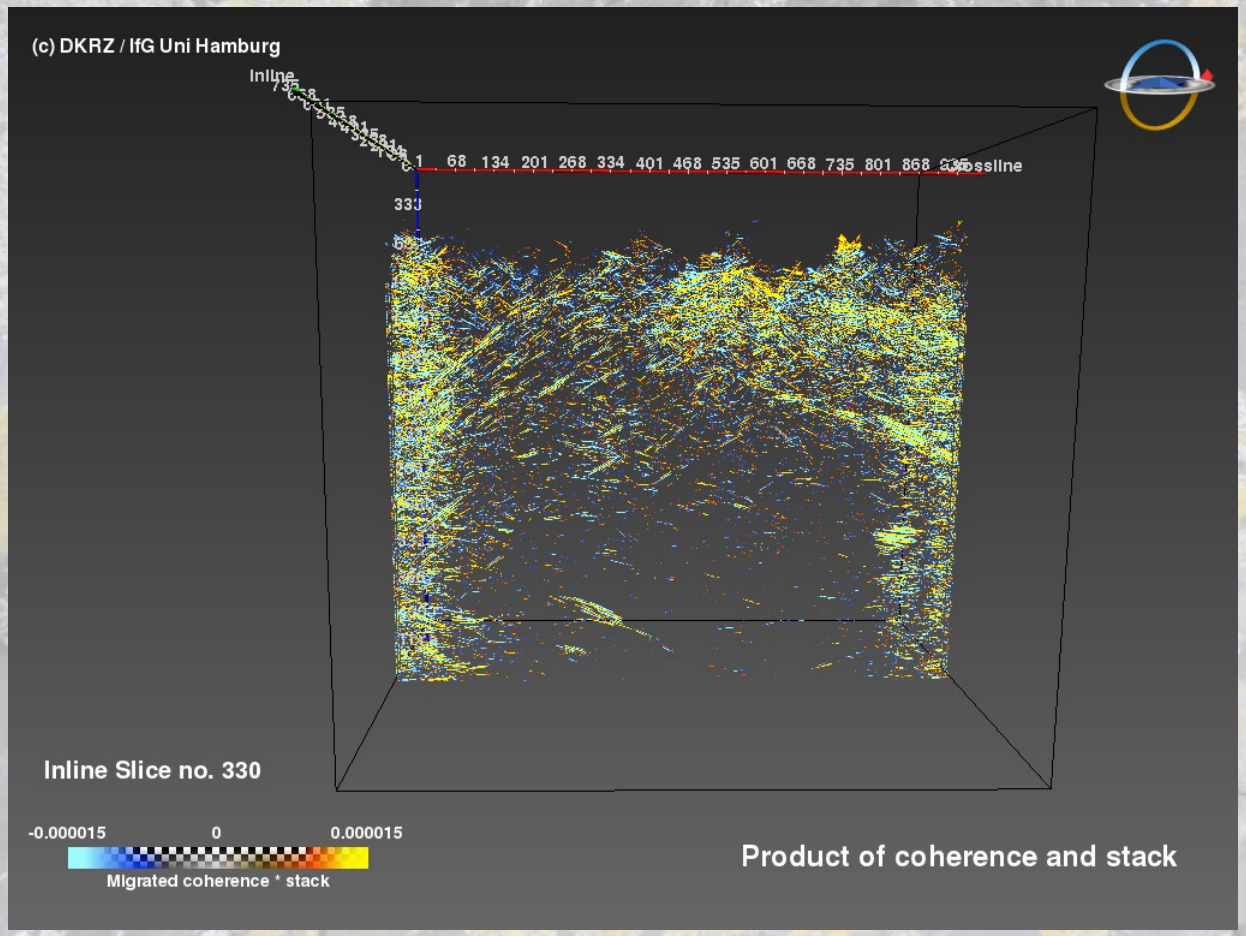
Coherence weighted stack – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence weighted stack – Inline 330



Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Coherence weighted stack (CWS)

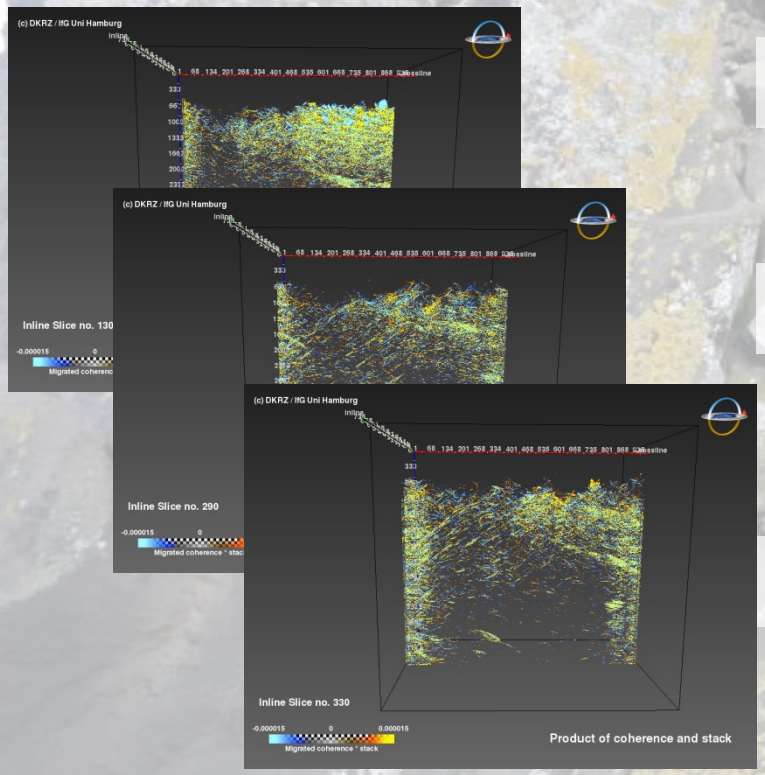
Unmigrated

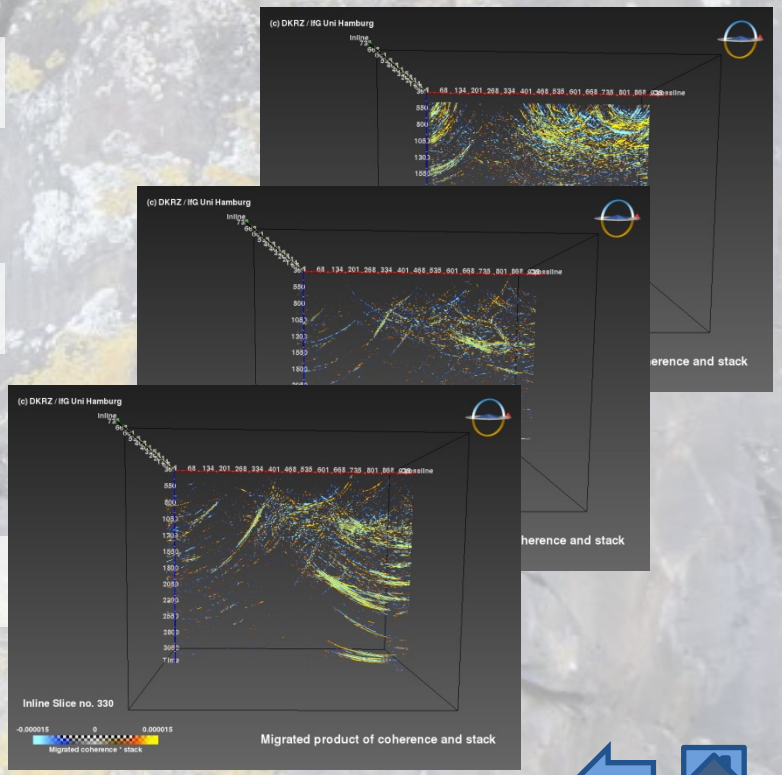
Migrated

Inline 130

Inline 290

Inline 330



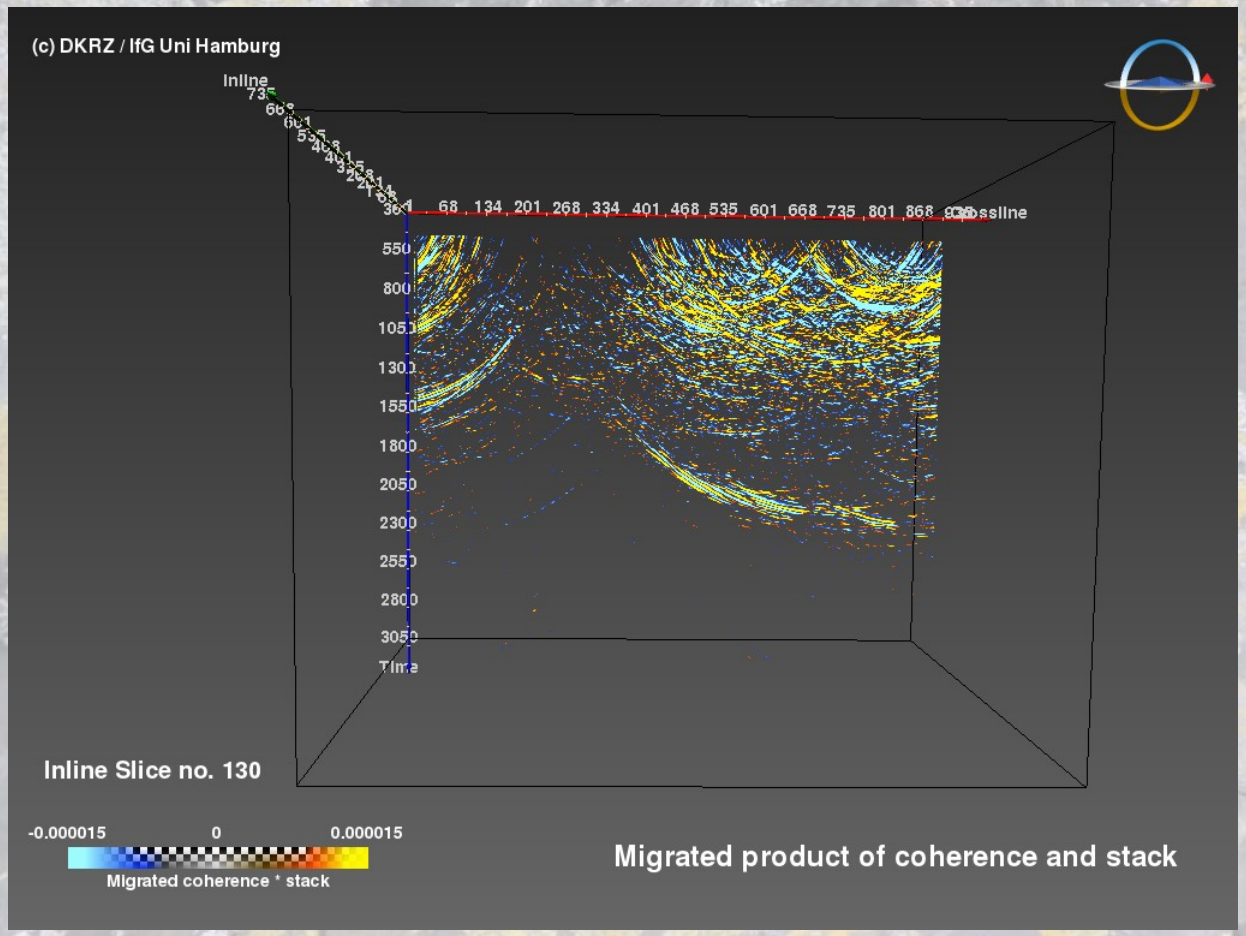


Video

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

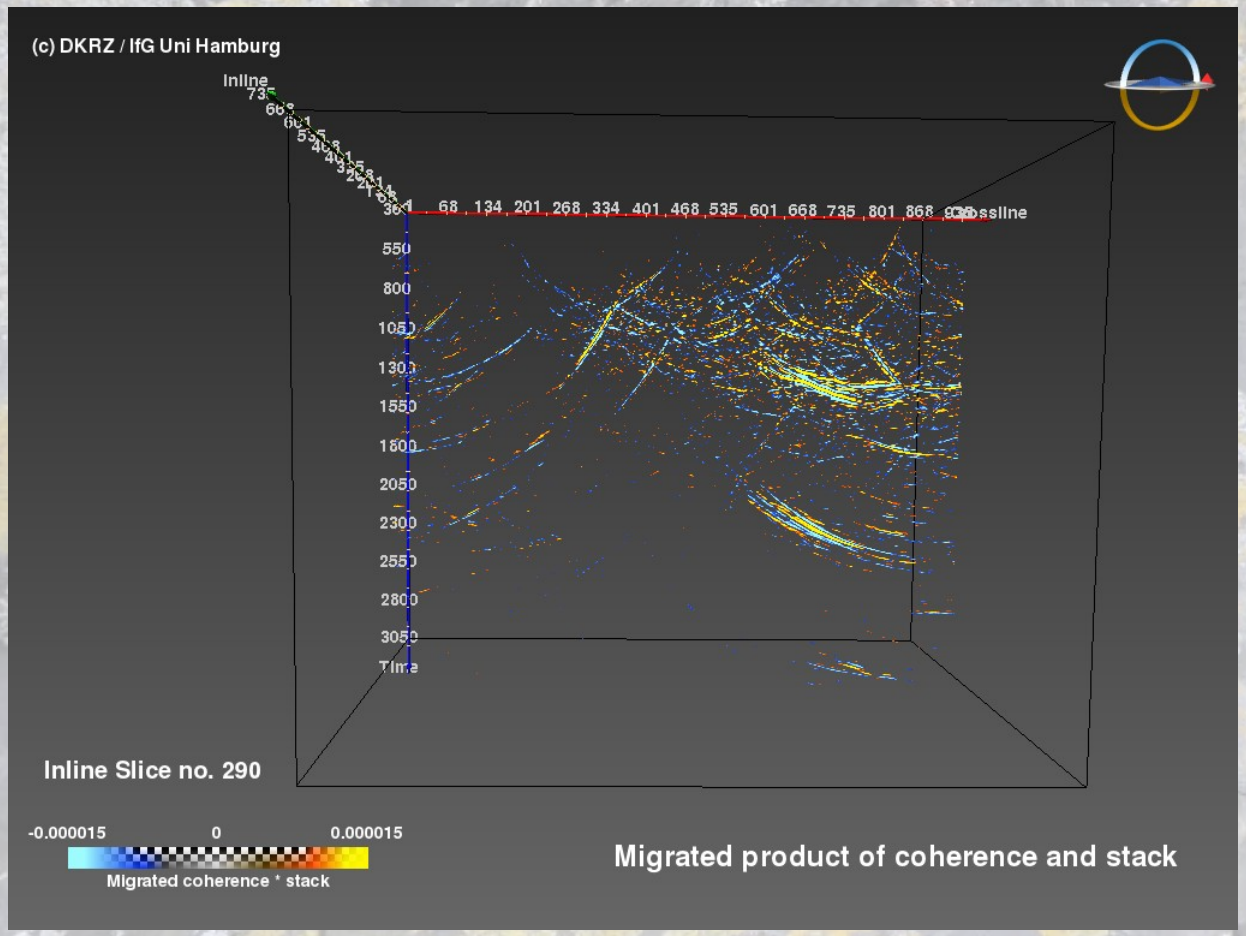
Migrated coherence weighted stack – Inline 130



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

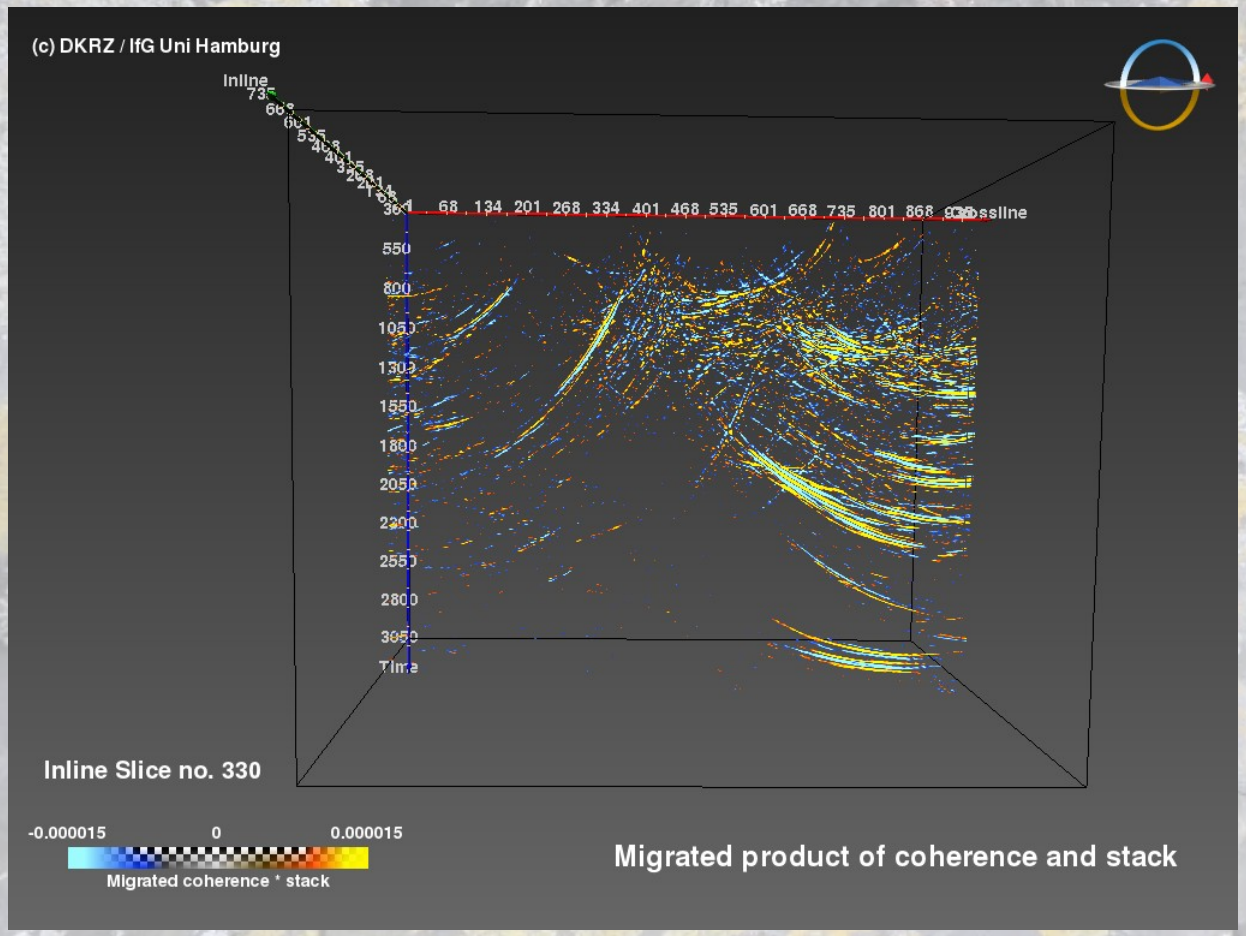
Migrated coherence weighted stack – Inline 290



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

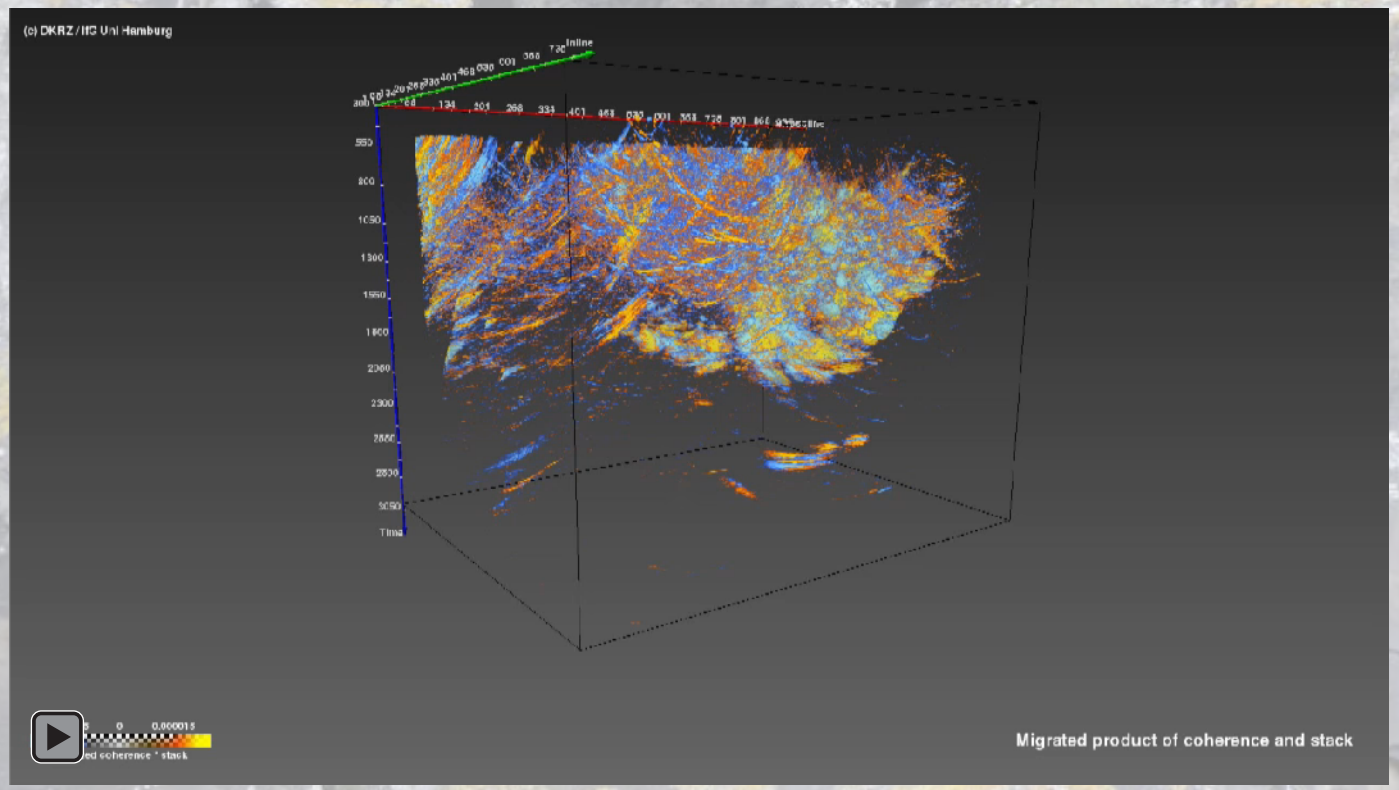
Migrated coherence weighted stack – Inline 330



Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Migrated coherence weighted stack – Movie

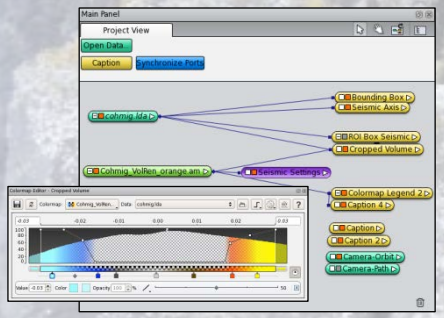


Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

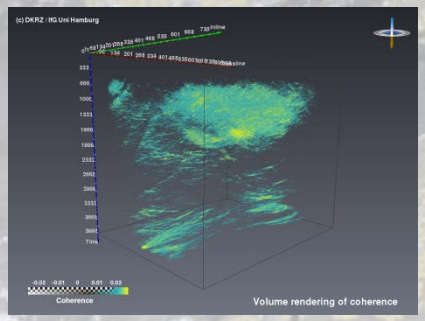
Avizo Earth



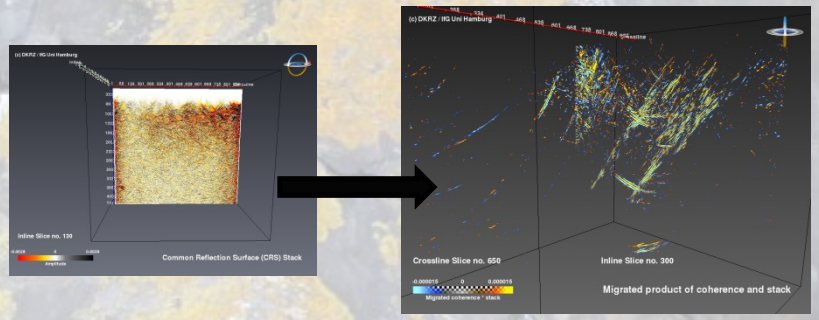
3D Visualization

DKRZ facilities

Visualization techniques



Results

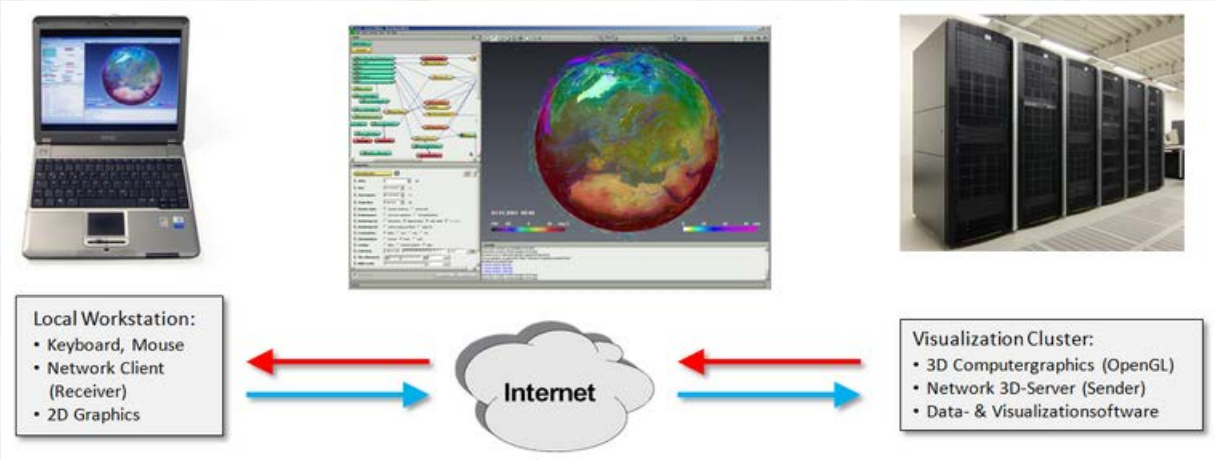


Visualization of volumetric seismic data

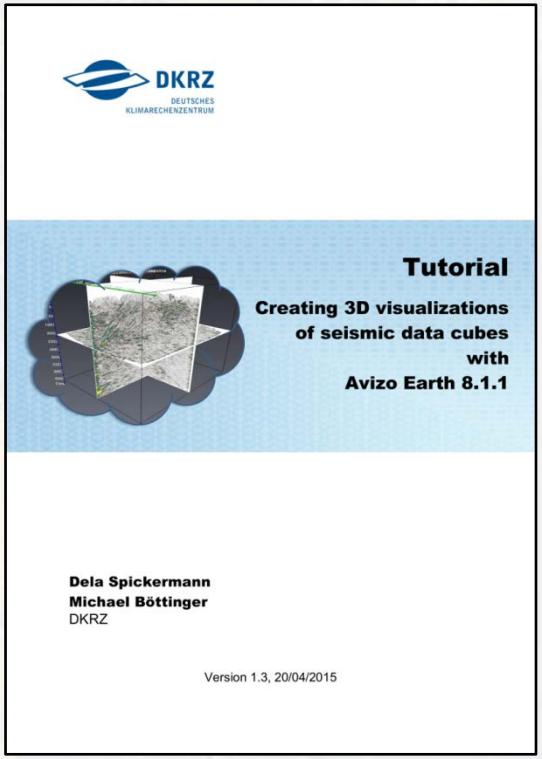
Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

Earth science data visualization at DKRZ



http://www.dkrz.de/Nutzerportal-en/doku/vis



http://www.dkrz.de/Nutzerportal-en/doku/vis/sw/avizo-earth

Visualization of volumetric seismic data

Dela Spickermann (1,2), Michael Böttinger (2), Khawar Ashfaq Ahmed (1), and Dirk Gajewski (1)

(1) University of Hamburg, (2) DKRZ, German Climate Computing Center

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