Seismic Reflection Imaging – from Time to Depth

Jürgen Mann

Wave Inversion Technology (WIT) Consortium
Geophysical Institute, University of Karlsruhe (TH)

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Overview

The task of reflection seismics

Data acquisition

Time domain imaging

Macrovelocity model determination

Time-depth transformation

Conclusions & outlook

Acknowledgments

Announcement

The task of reflection seismics

- explore subsurface with elastic waves
  - controlled source at known position and source time
  - many receivers at known positions
  - perform many experiments to obtain highly redundant data
- generate image of subsurface

acquired data in time domain

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structural image in depth domain

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Seismic sources

- land seismics
  - explosives
  - vibrators
  - (accelerated) drop weights
- marine seismics

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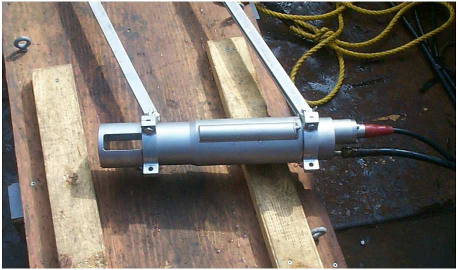

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Seismic receivers

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  - geophone
  - measured quantity:
    one or more components of particle velocity (or acceleration) vector
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- final result: multicoverage data in time domain, discrete time series for discrete source and receiver locations

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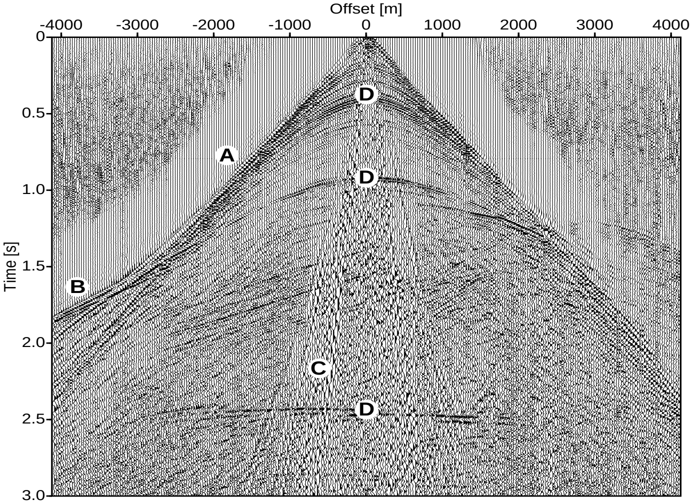
A field data record



A: direct wave B: refracted waves
C: ground roll D: reflected waves

Assumptions

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  - isotropic, laterally inhomogeneous model
  - no a priori information about velocity model
  - ray theory is applicable
  - only primary reflection events
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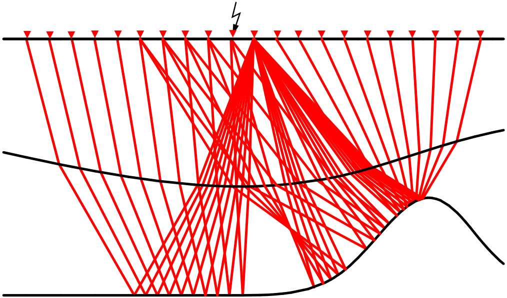

- common-shot configuration (as acquired)
- observations:
  - various points on reflector illuminated
  - rays pass through different parts of overburden

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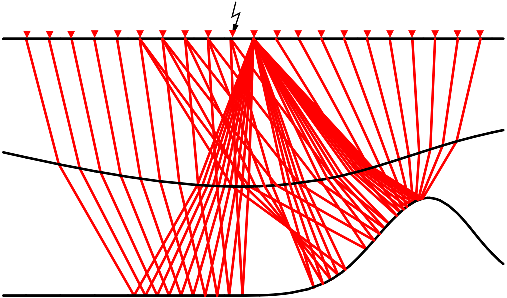

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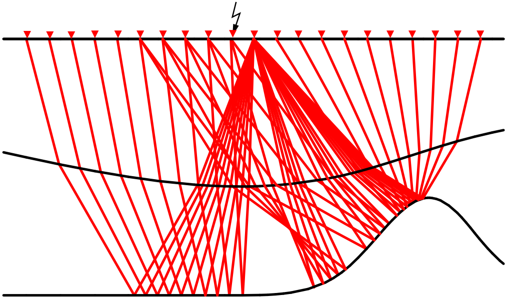

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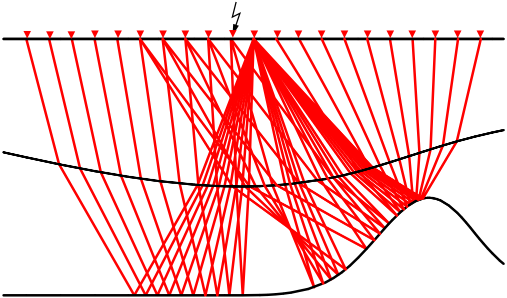

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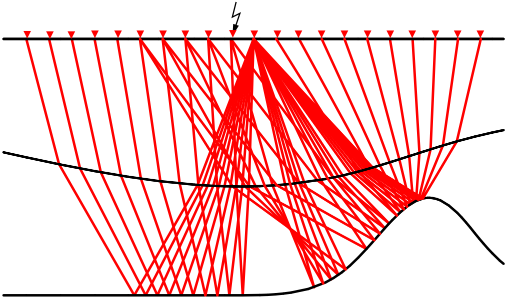

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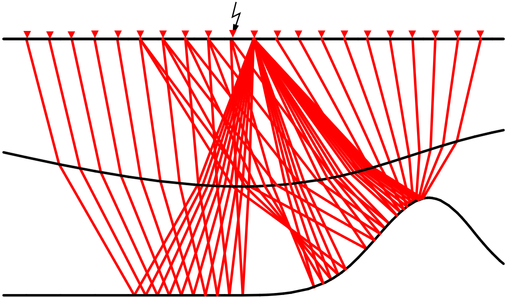

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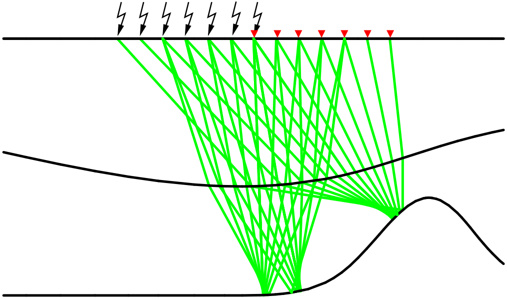

- common-midpoint configuration
- observations:
  - reflection points more or less focused
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  - second-order approximation of traveltime available
  - allows stacking velocity analysis (1 parameter)

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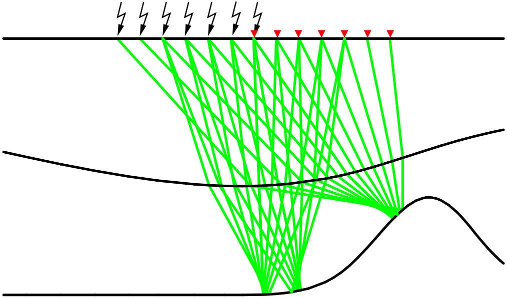

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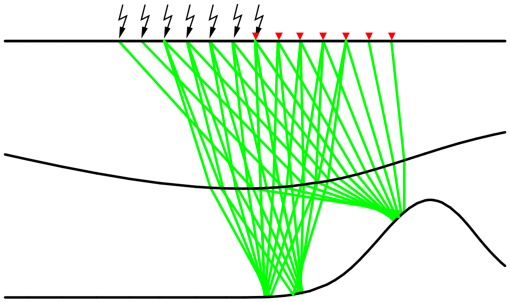

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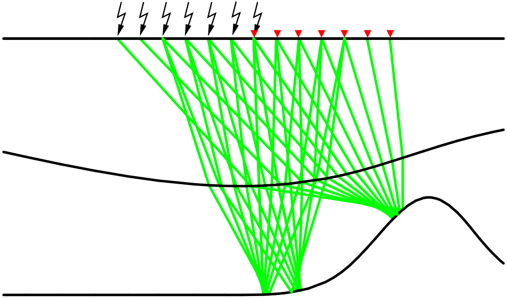

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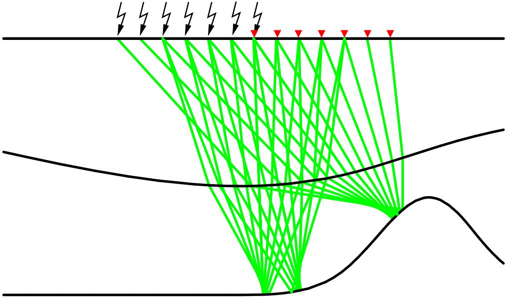

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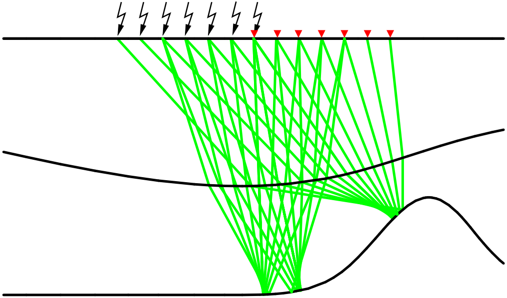

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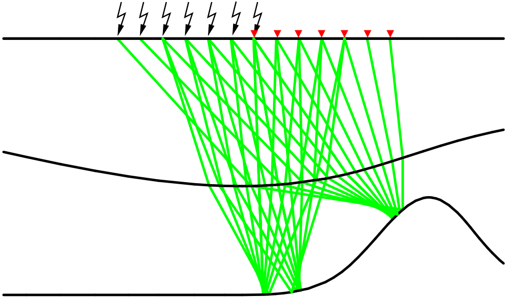

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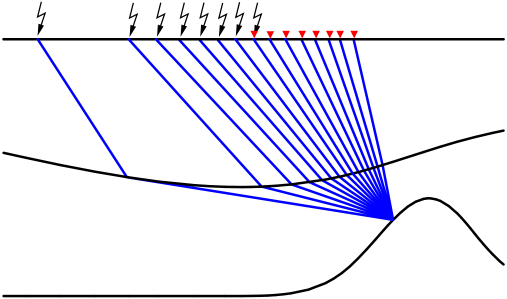

- common-reflection-point (CRP) configuration
- observations:
  - focuses in exactly one reflection point
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  - allows (in principle) generalized stacking velocity analysis (2 parameters)

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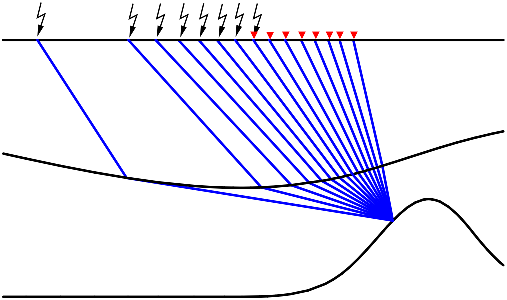

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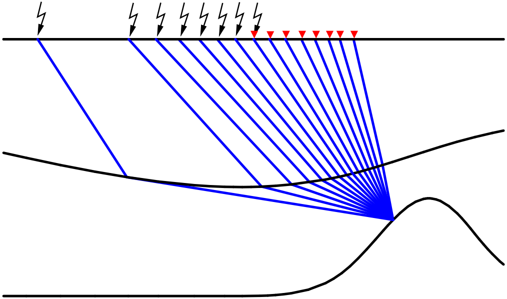

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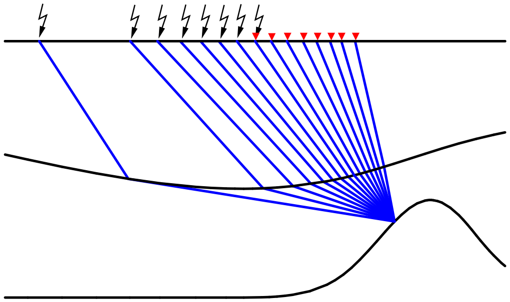

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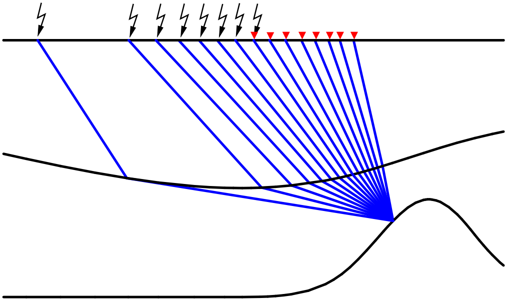

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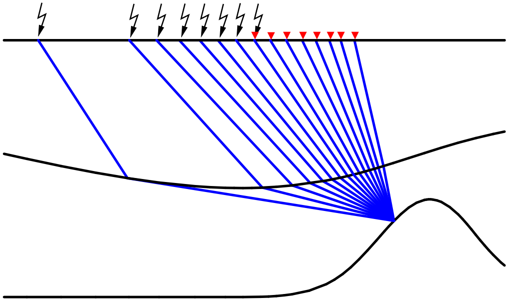

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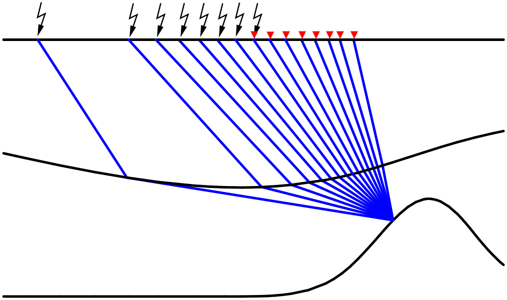

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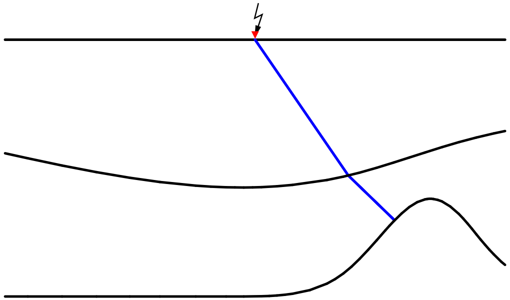

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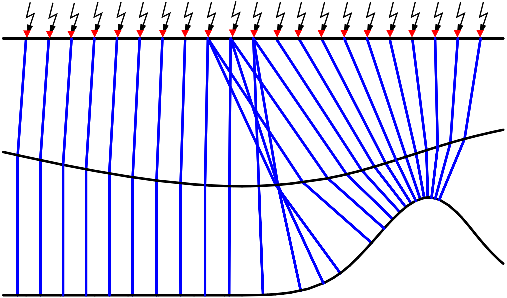

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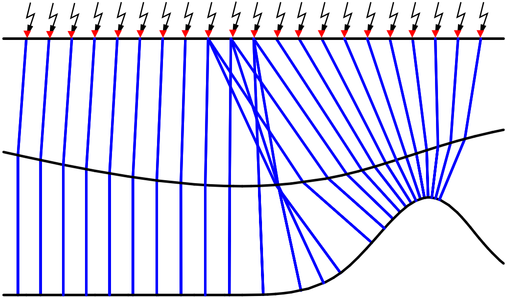

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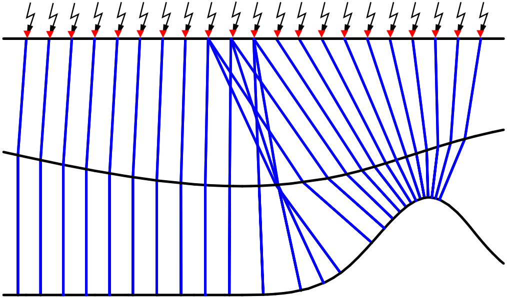

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Common-Reflection-Surface stack

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  - search for stacking operator fitting best actual reflection event
  - based on coherence analysis
- data-driven stacking with CRP trajectories
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  - consider entire reflector segments
    i. e., consider neighboring CRPs
    i. e., consider local curvature of reflector
    ➥ fitting *spatial* operator to traveltime *surface*
    ➥ three stacking parameters

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- data-driven stacking with CRP trajectories
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    ➥ highly ambiguous, hardly applicable
- solution:
  - consider entire reflector segments
  - i. e., consider neighboring CRPs
  - i. e., consider local curvature of reflector
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☞ Common-Reflection-Surface stack

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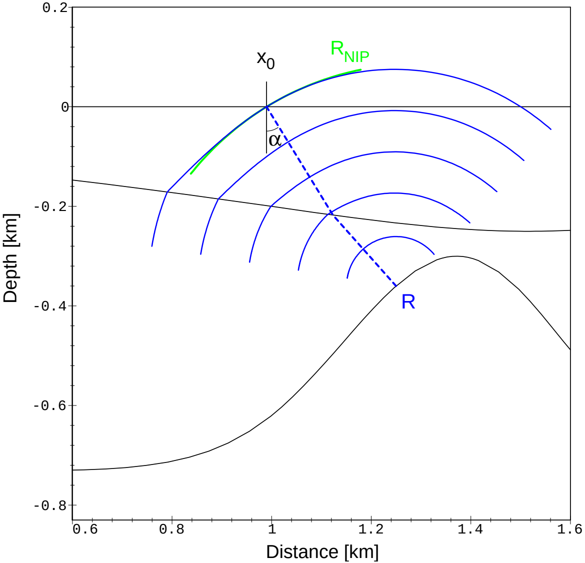
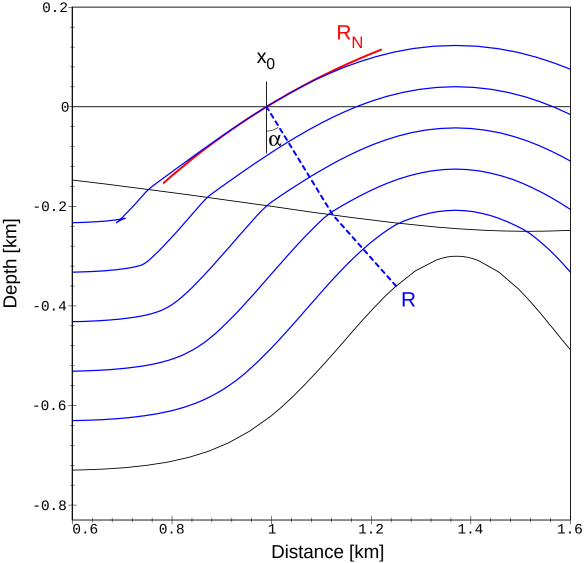
Interpretation of stacking parameters



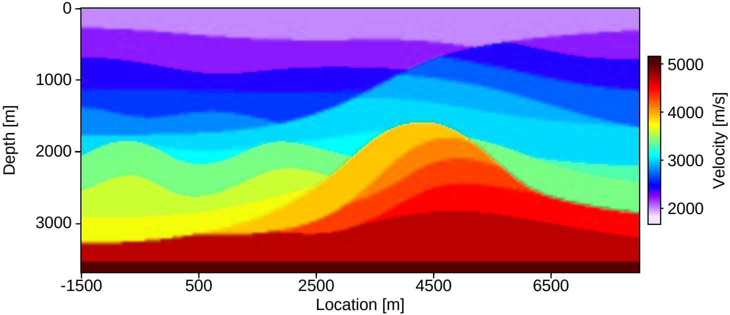
Normal-incidence-point (NIP) wave experiment

Interpretation of stacking parameters



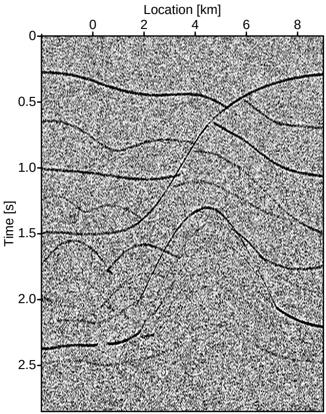
Normal wave experiment

Synthetic data example

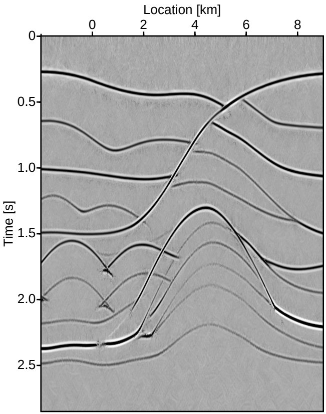


Velocity model for synthetic data

Synthetic data example

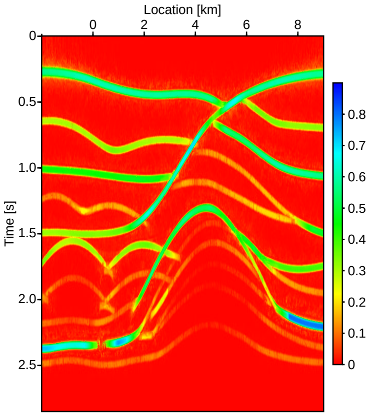


Near-offset section

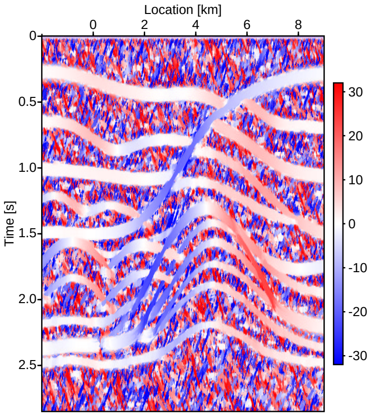


CRS stacked section

Synthetic data example

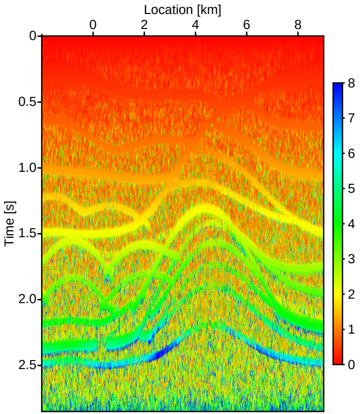


Coherence section

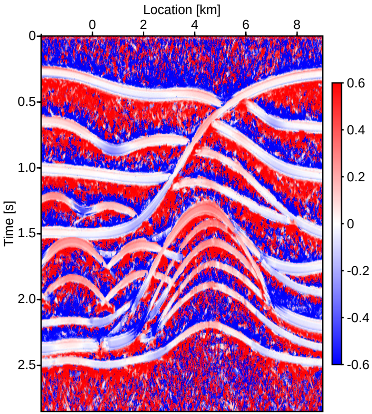


Emergence angle section [°]

Synthetic data example

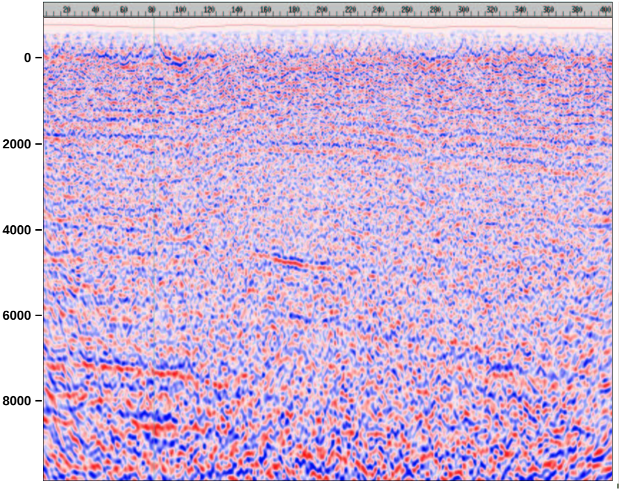


1/Knip section [km]



Kn section [1/km]

Real data example



Conventional 3D prestack depth migration
Data and image courtesy of ENI E&P division

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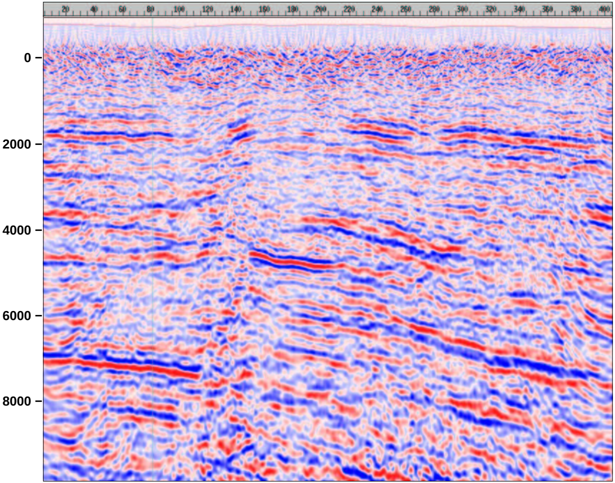

3D poststack depth migration of CRS stack
Data and image courtesy of ENI E&P division

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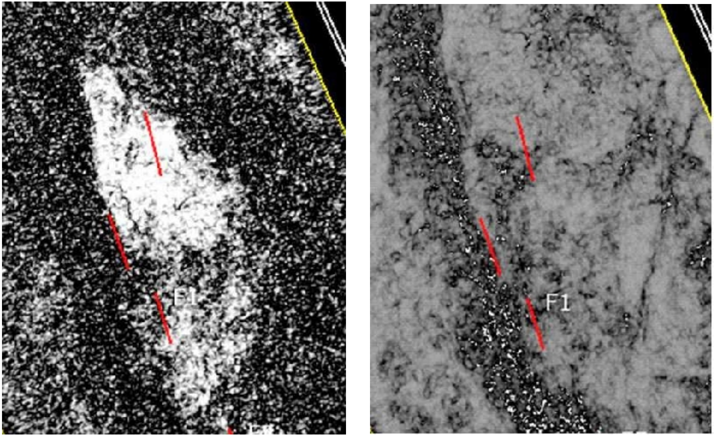

Depth slices of coherence cubes, conventional vs. CRS
Data and image courtesy of ENI E&P division

Further real data examples:

- *Seismic imaging practice with CRS stack*
  Trappe et al., session S5B
- *Anwendung des Common-Reflection-Surface Stack auf reflexionsseismische Daten*
  Chávez Zander et al., session S5C
- *A seismic reflection imaging workflow based on the CRS stack: a data example from the Oberrheingraben*
  Hertweck et al., session S5D
- *Salt tectonics in the Southern Levantine Basis (GEMME I)*
  Netzeband et al., session SMP11
- *CRS imaging of salt tectonic structures in the Southeastern Mediterranean Sea (GEMME I)*
  Gradmann et al., session SMP12

Results so far

- simulated zero-offset section with high signal/noise ratio
- 3 stacking parameters or *kinematic wavefield attributes* related to
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  - alternative interpretation: propagation direction and curvatures of wavefronts due to hypothetical experiments
- remaining tasks:

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Macrovelocity model determination

- pick local reflection events in simulated zero-offset section
- extract associated wavefield attributes
- define (simple) initial model of velocity distribution and reflector segments
- forward-modeling of traveltimes and wavefield attributes by dynamic ray tracing
- iterative minimization of misfit between forward-modeled and picked traveltimes and attributes

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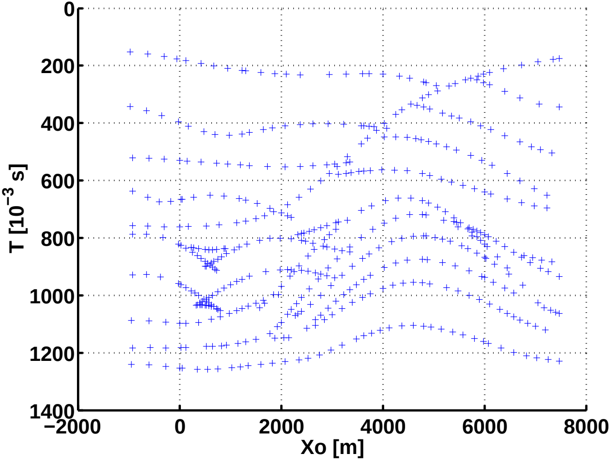

Picked zero-offset samples

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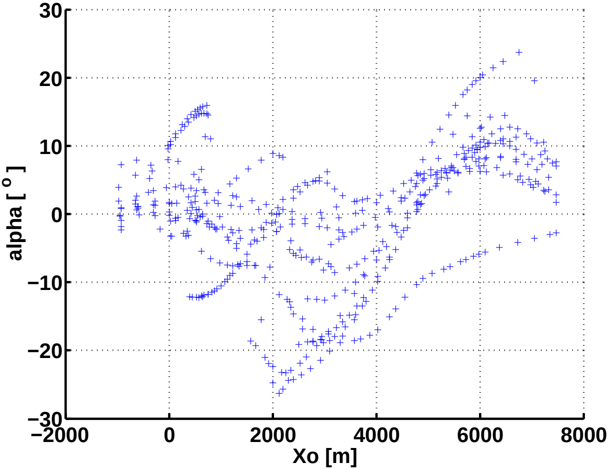

Extracted wavefield attributes (first order)

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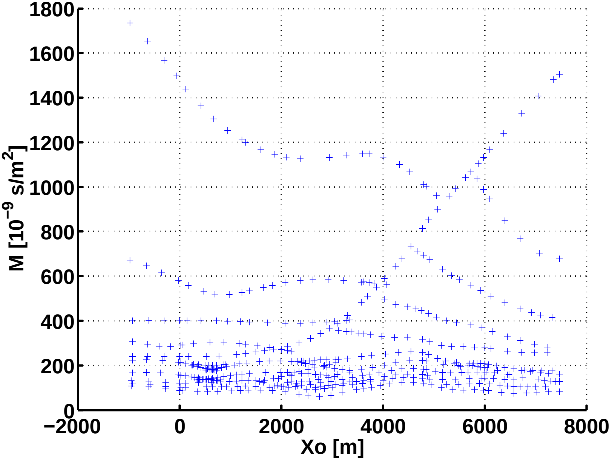

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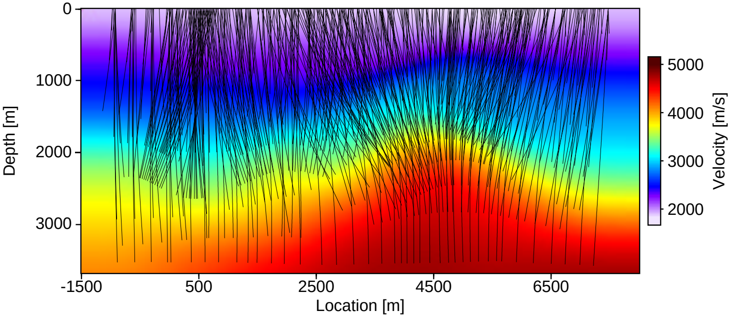
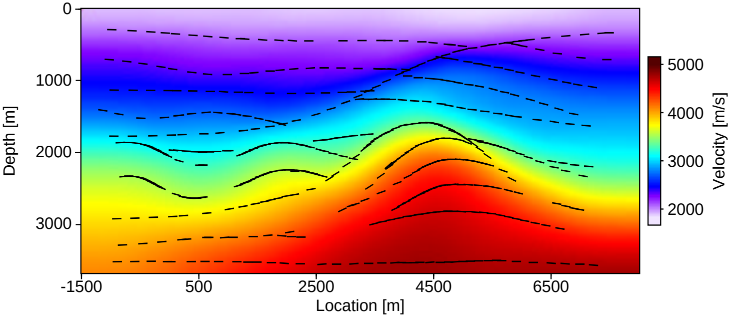


Reconstructed velocity model and normal rays

Synthetic data example



Reconstructed velocity model and reflector segments

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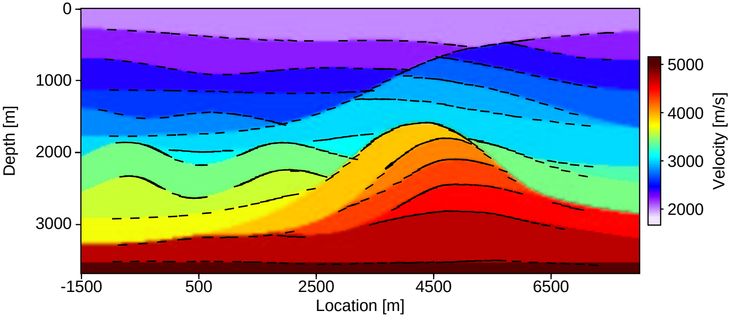

Original velocity model overlain with reconstructed reflector segments

Time-depth transformation

- macrovelocity model allows time-depth transformation:
  - poststack depth migration of CRS stack result and/or
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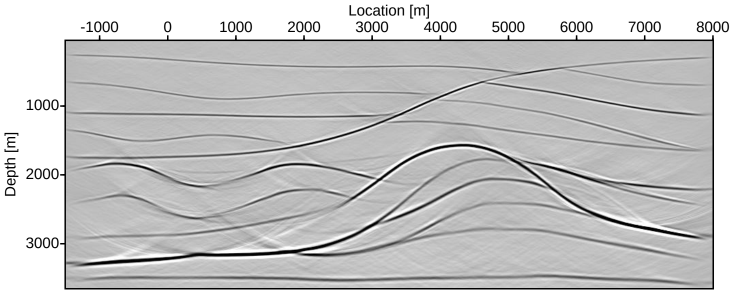

Poststack migration of CRS stack section

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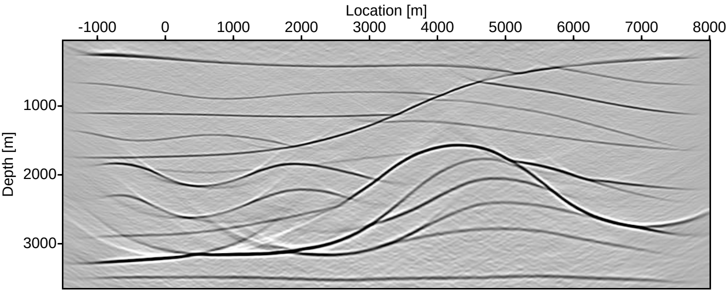
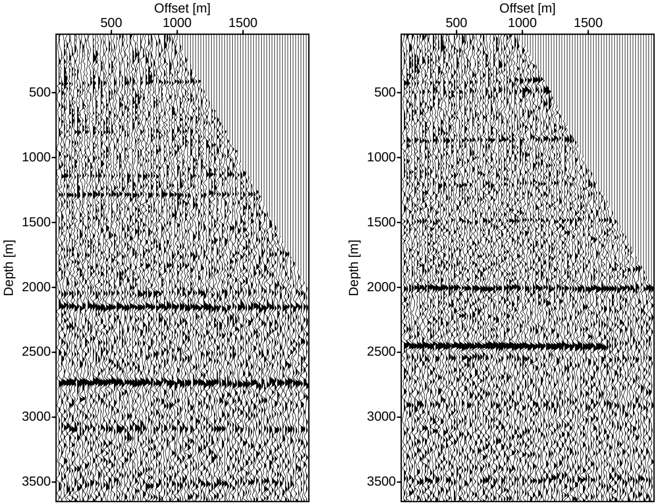


Stack of migration results for different offsets

Synthetic data example



Common-image gather x=3000 m **Common-image gather x=6000 m**

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Acknowledgments

I would like to thank

- my colleagues in Karlsruhe, especially
  - Steffen Bergler (CRS stack, forward-modeling)
  - Eric Duveneck (tomographic inversion)
  - Thomas Hertweck (migration)
- ENI E&P Division, Milano, Italy, for their data examples
- the sponsors of the Wave Inversion Technology (WIT) Consortium, Karlsruhe, Germany, for their support
- Till Tantau for his LaTeX beamer class

More about imaging: