Seismic Oil of Olay: removing wrinkles from 3D source ensembles

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- CREWES annual meeting

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Outline

- Introduction—near-surface effects
- Raypath interferometry—more general than statics
- 2D raypath interferometry—example
- Full 3D raypath interferometry—*full 3D survey*
- Limited 3D interferometry—*single source—receiver effects only*
    - 2D interferometry—X/T domain
    - 3D interferometry—X/T domain
    - 3D interferometry—raypath domain
- Summary

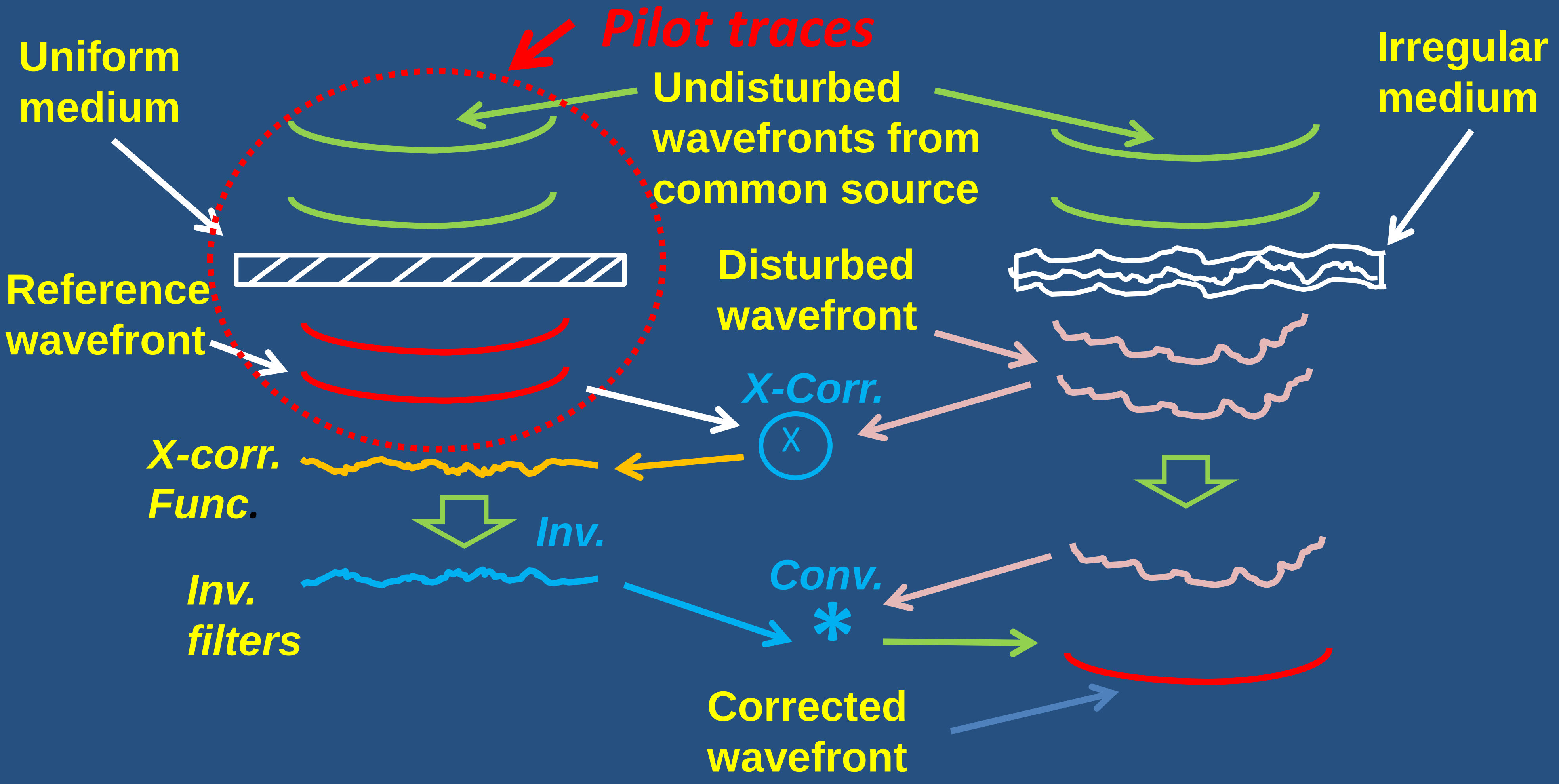
Near-surface correction

- Reflection wavefronts are distorted by near-surface irregularities
- Corrections required before imaging reflections
- Conventionally, time shifts align reflection events on traces
- A more general interferometric method can be more effective, *especially for converted wave data*

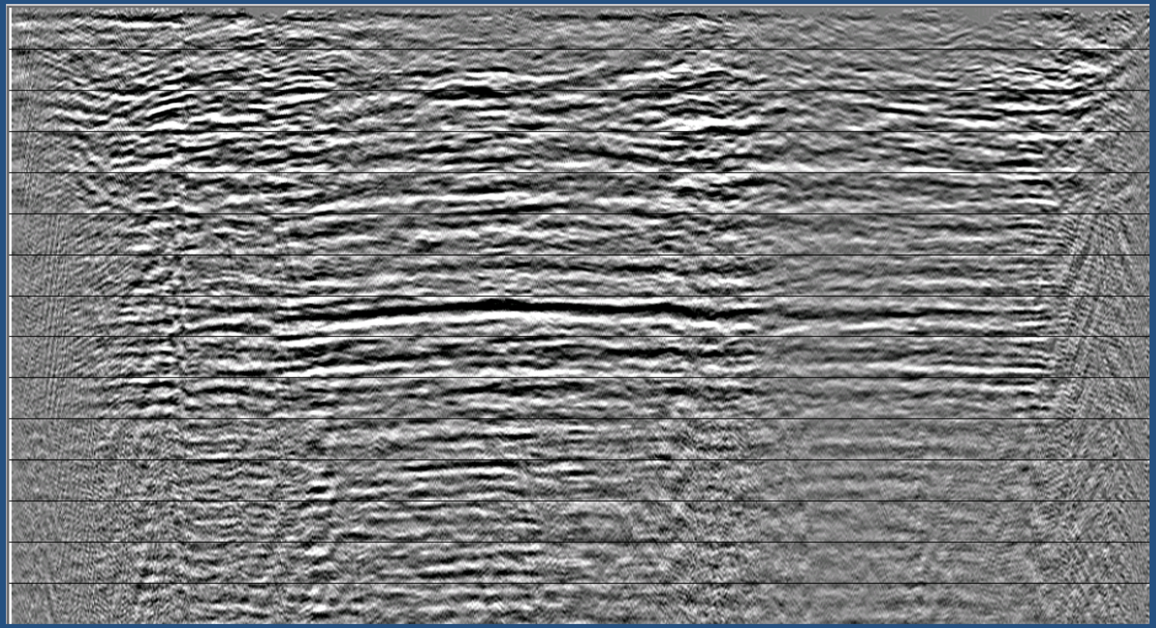
Raypath interferometry

- Surface-consistency replaced by raypath-consistency
- Single reflection arrival replaced by arrival distribution wavelet (surface function)
- X/T data transformed to ray-parameter domain
- Optical interferometry analog used to find and deconvolve surface functions

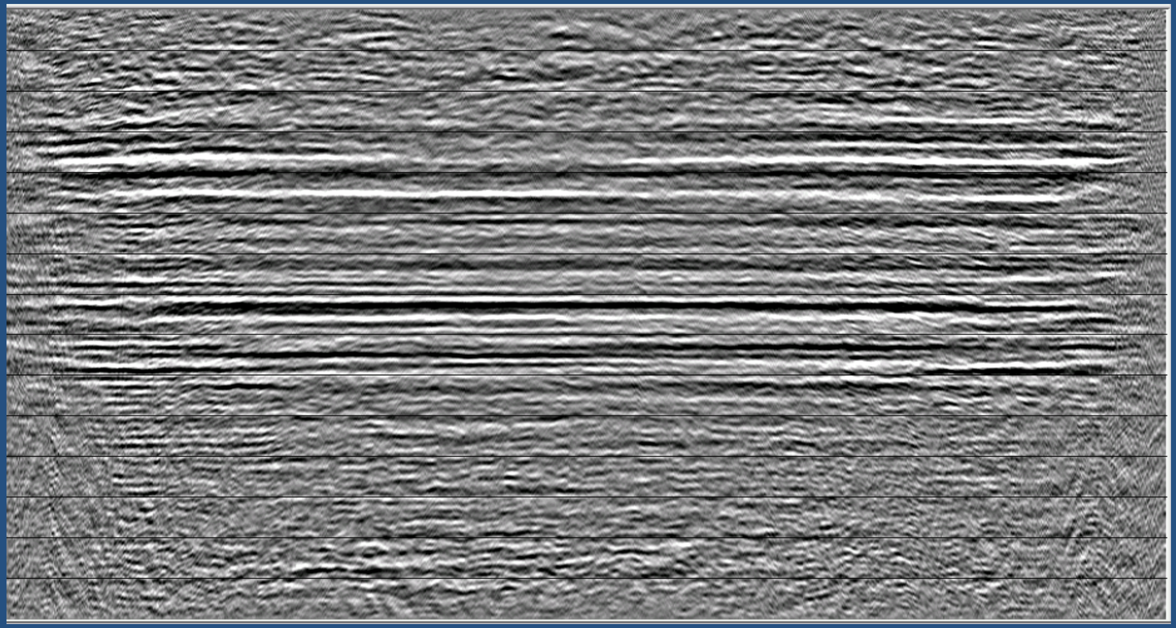
Interferometry concept



Hussar PS

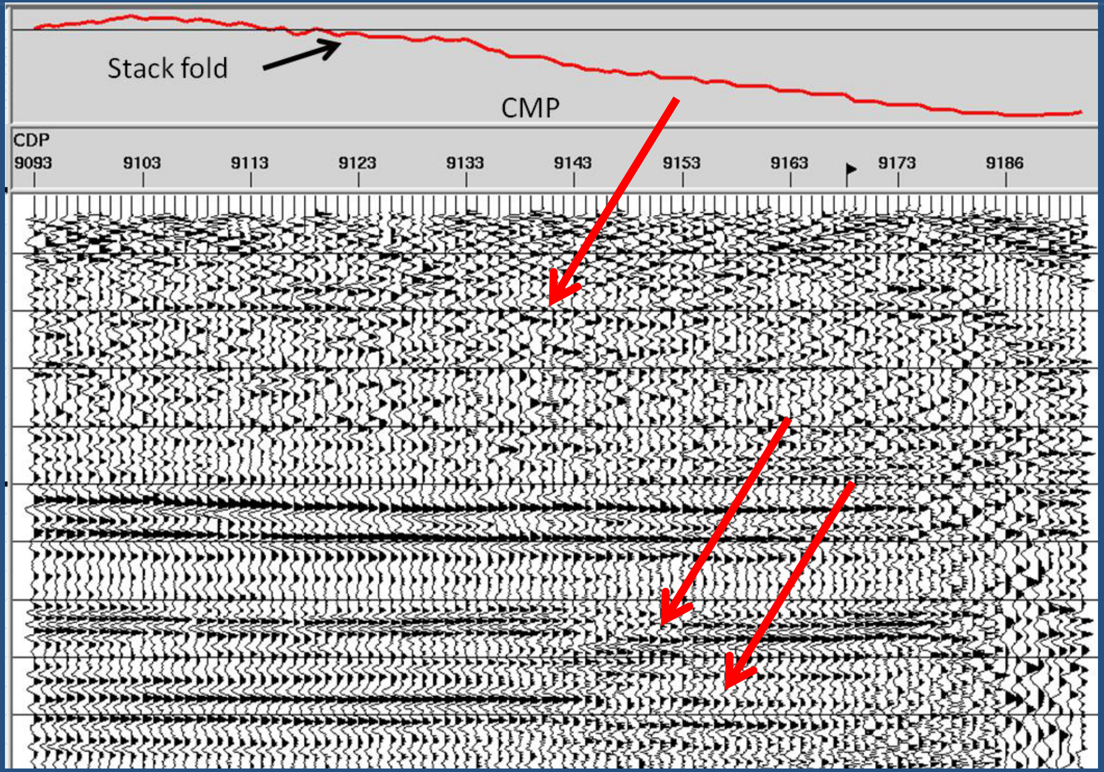


Brute CCP stack—*no statics*

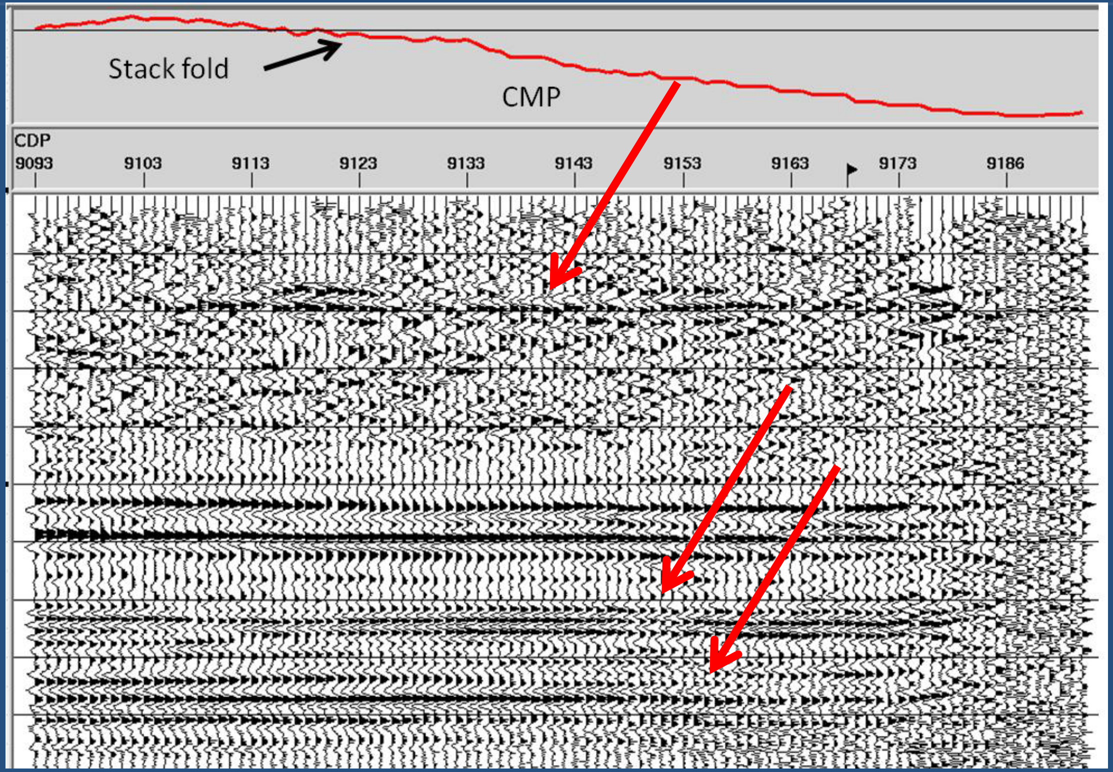


CCP stack—*raypath interferometry*

Blackfoot 3D 3C



CMP swath line—PP—*no statics*



CMP swath line—PP—*interferometry*

3D raypath interferometry difficulties

- Cartesian *survey* coordinates must reconcile with polar *surface function* coordinates
  - Bins difficult to populate uniformly
  - Bin spatial ordering difficult (source index problematic)
- Transform to/from raypath domain has complications
  - RT transform inverse not properly implemented (now repaired)
  - Tau-P transform requires massive storage

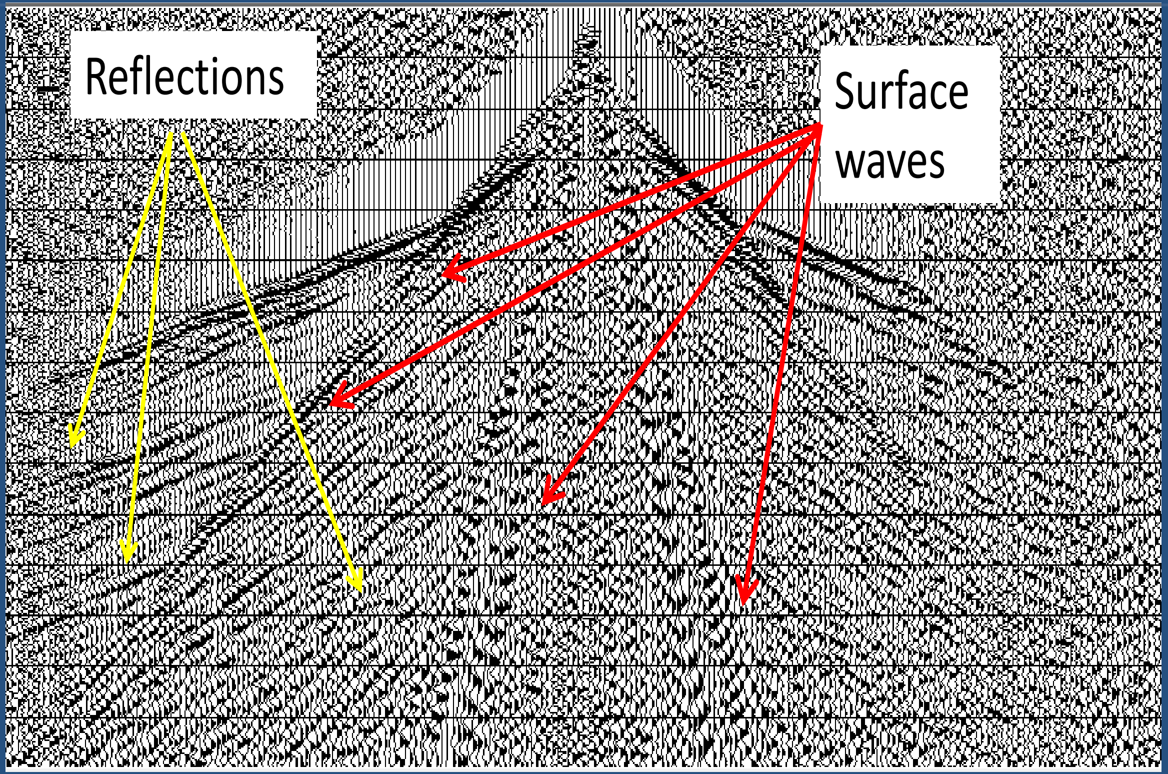
Limited 3D interferometry

- Apply interferometry within source gathers to remove receiver-oriented near-surface 'wrinkles'
  - 2D mode—receiver line gathers; X/T domain
  - 3D mode—azimuth/receiver line gathers; X/T domain
  - 3D mode—azimuth/offset Tau-P gathers; raypath domain
- Devise a scheme to reconcile 'de-wrinkled' source gathers for imaging

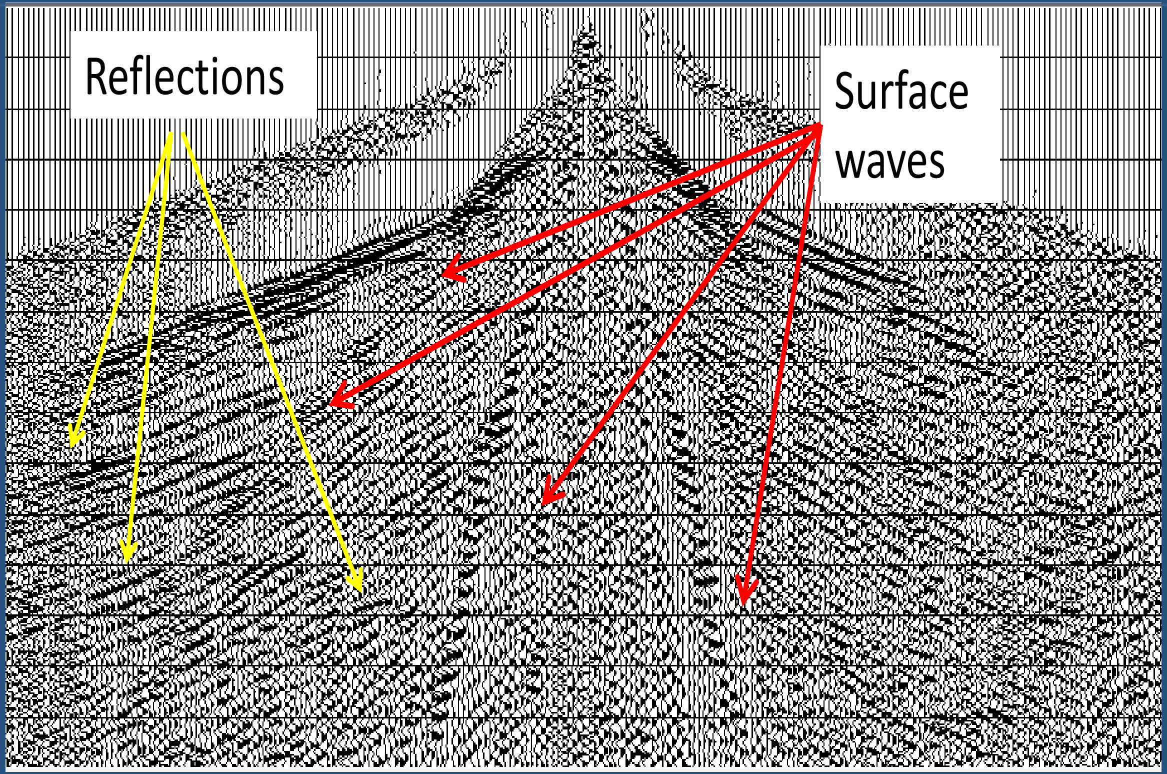
2D interferometry on receiver lines

- Reflections are best sampled by receiver line gathers *in a single 3D source ensemble* (but not in a full 3D survey, where CMP gathers are best)
- Coherent surface wave noise (including near-surface refractions) is also best sampled in receiver line gathers
  - Coherent noise adversely affects interferometry, so:
  - Coherent noise attenuation applied to all receiver line gathers before any interferometry
- *All interferometry results compared by receiver lines*

Coherent noise attenuation

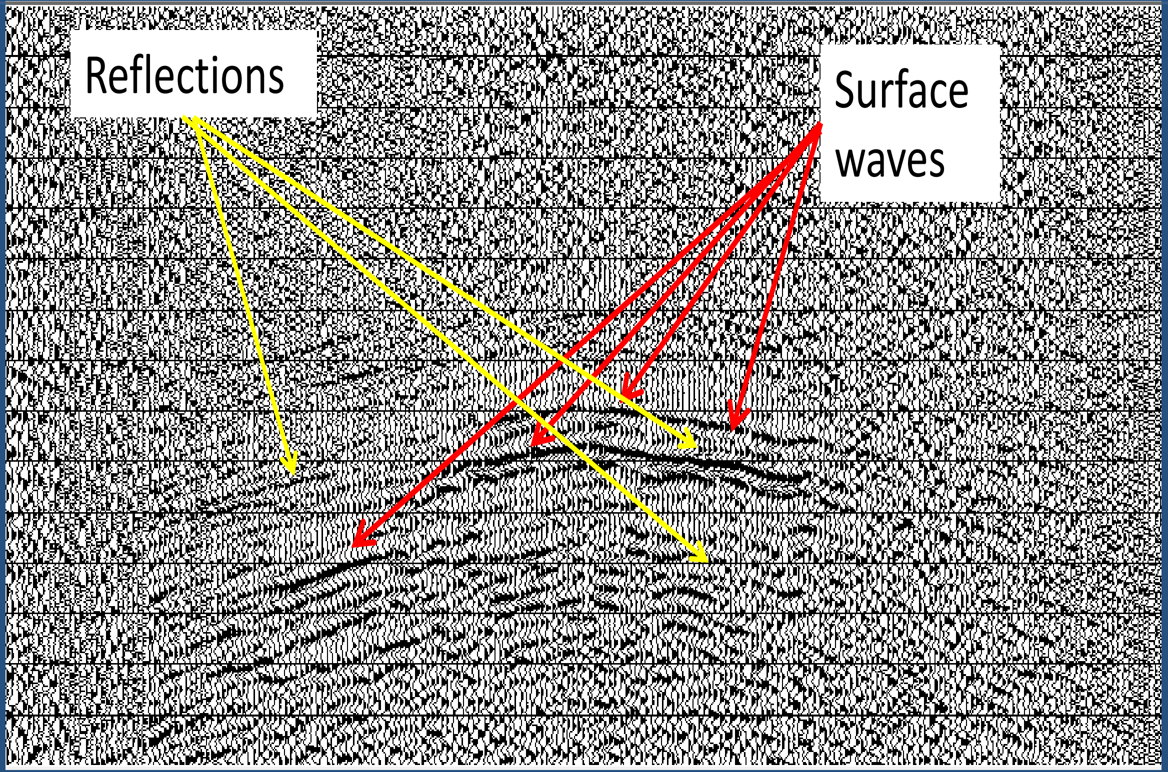


Receiver line 17—no filter

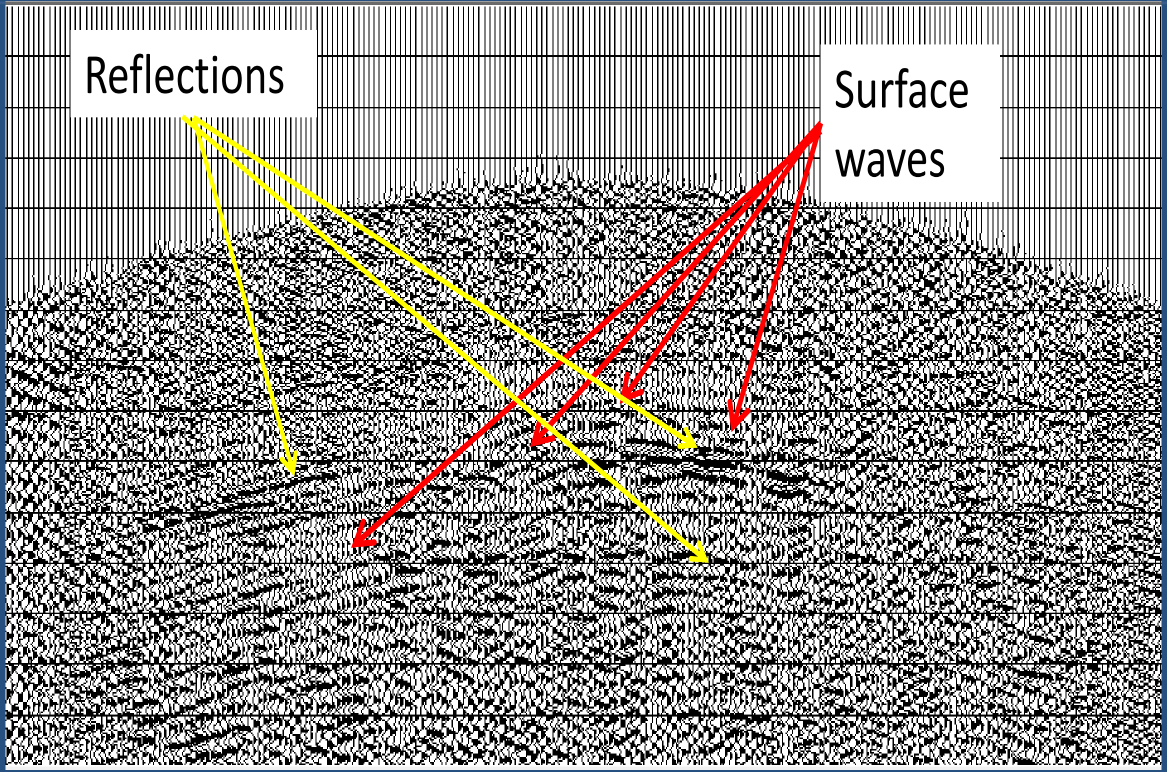


Receiver line 17 after RT fan filter

Coherent noise attenuation

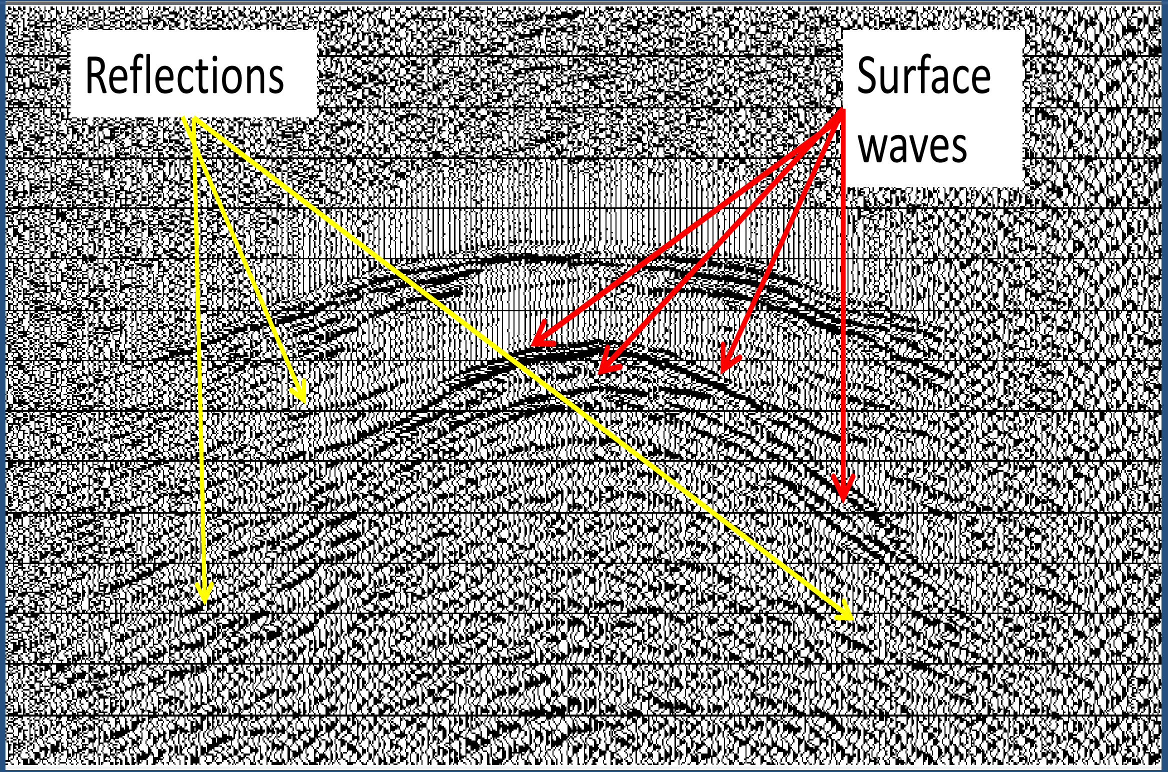


Receiver line 3—no filter

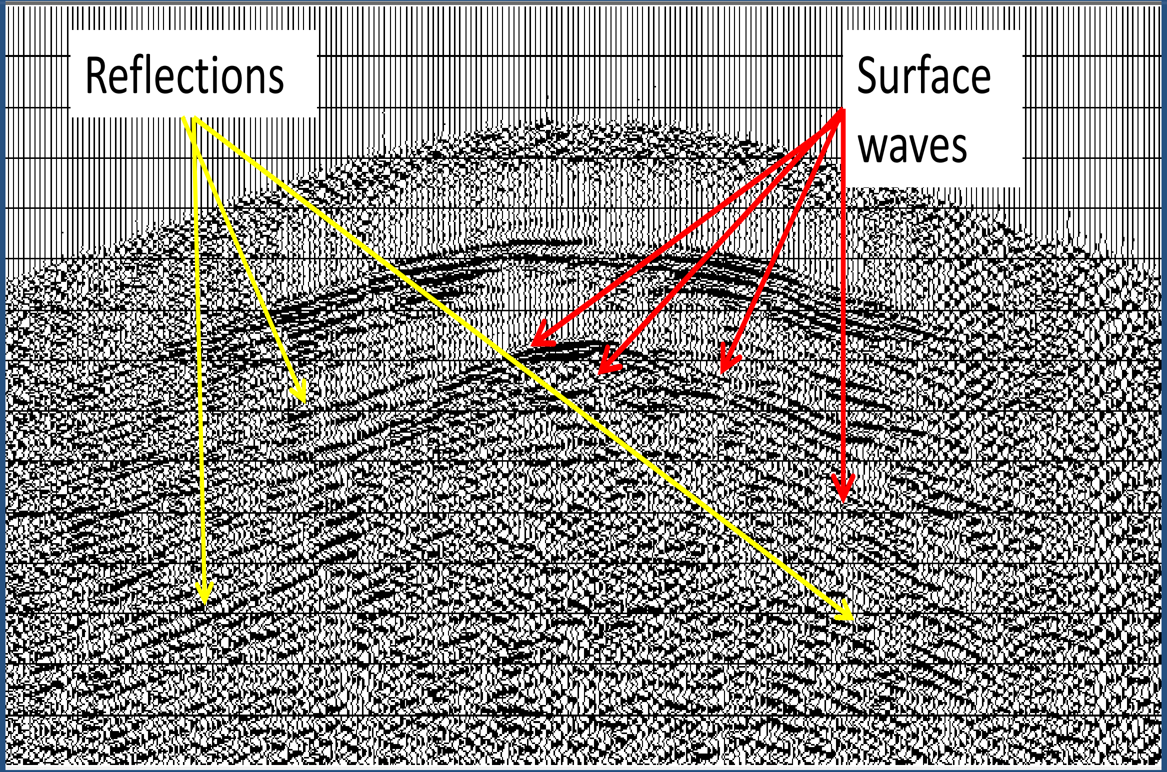


Receiver line 3 after RT fan filter

Coherent noise attenuation



Receiver line 8—no filter

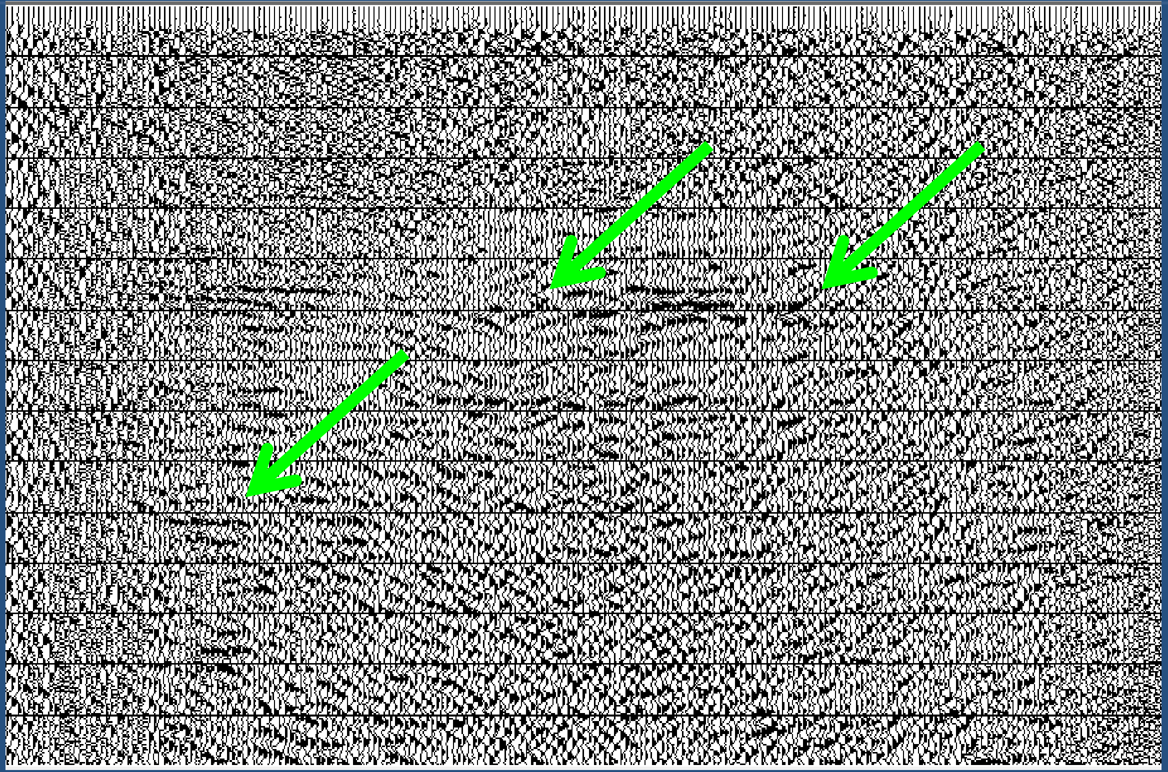


Receiver line 8 after RT fan filter

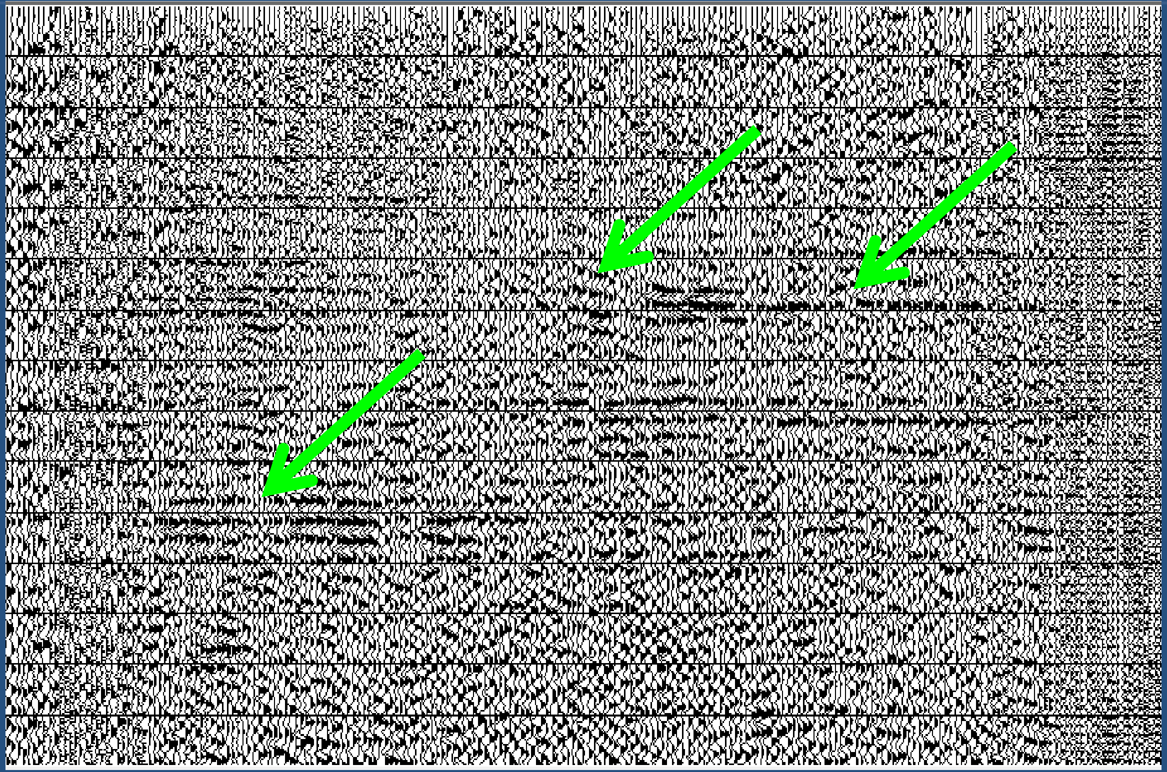
2D X/T interferometry on receiver lines

- Linear moveout applied—no stretch
- 2D estimated wavefield created by smoothing receiver line gathers
- Corresponding traces on raw receiver lines and estimated wavefield cross-correlated
- Cross-correlations used as match filters to correct raw receiver line traces

2D X/T interferometry

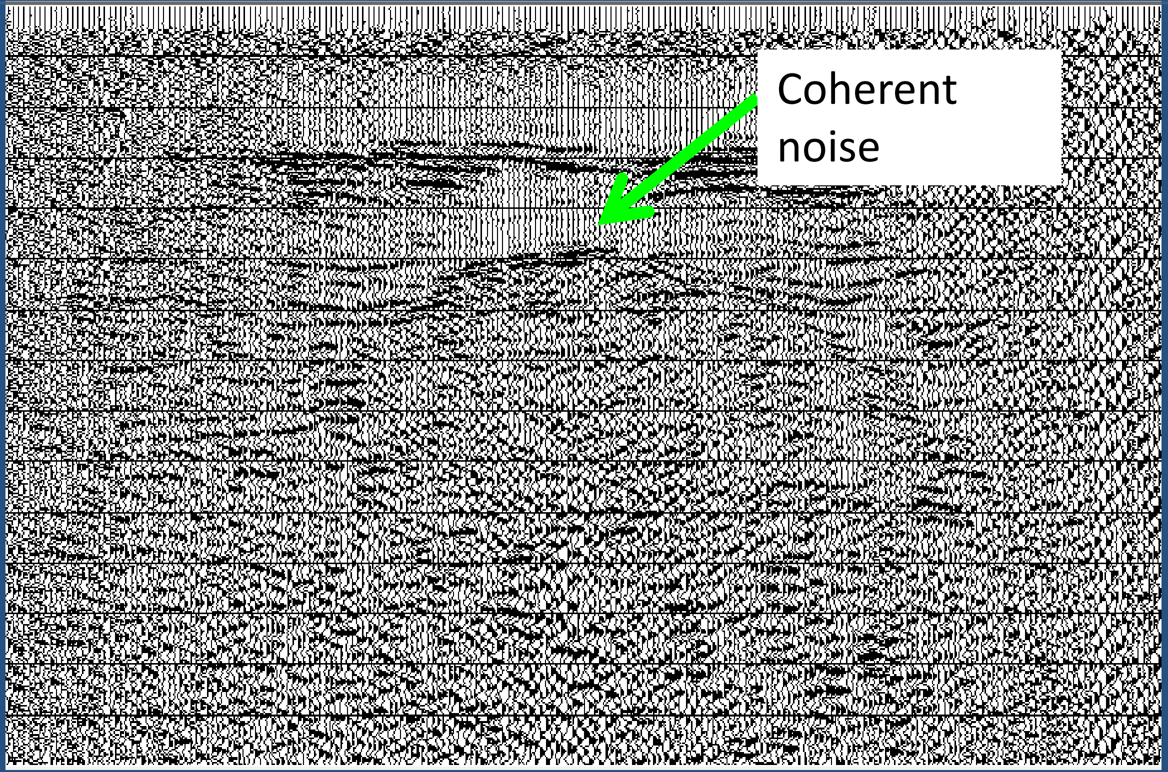


Receiver line 3—RT filtered

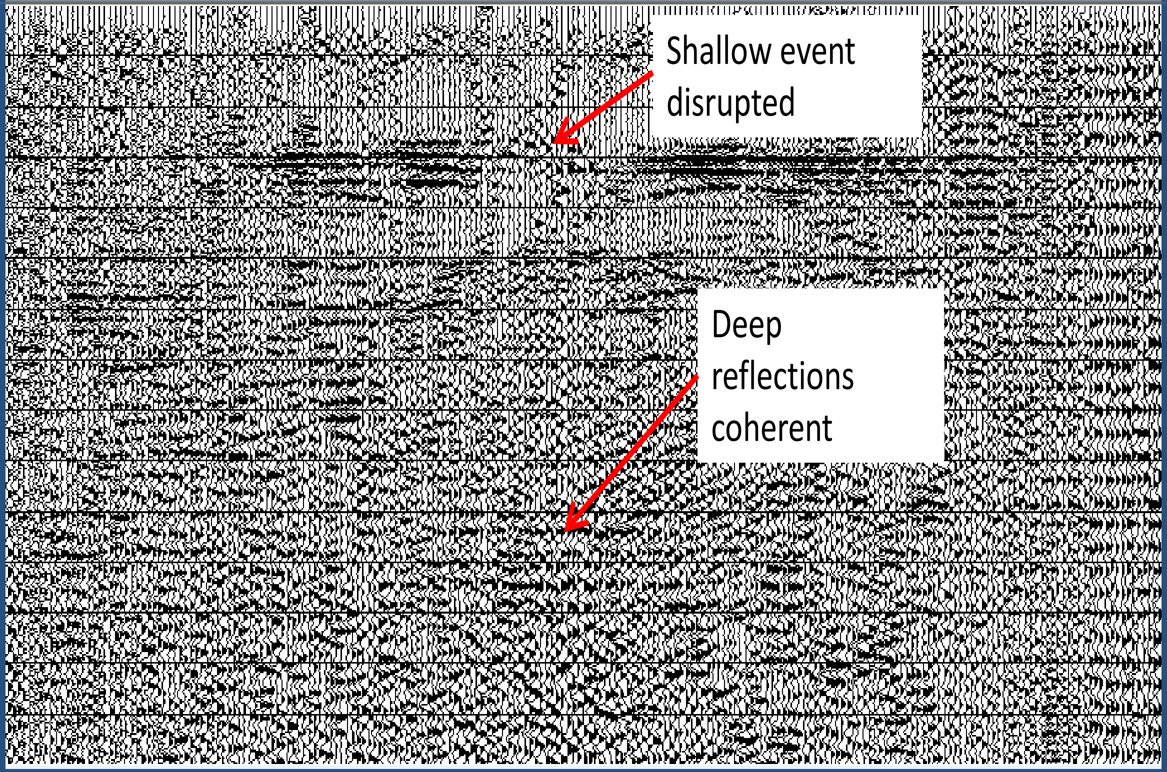


Receiver line 3 after 2D interferometry

2D X/T interferometry

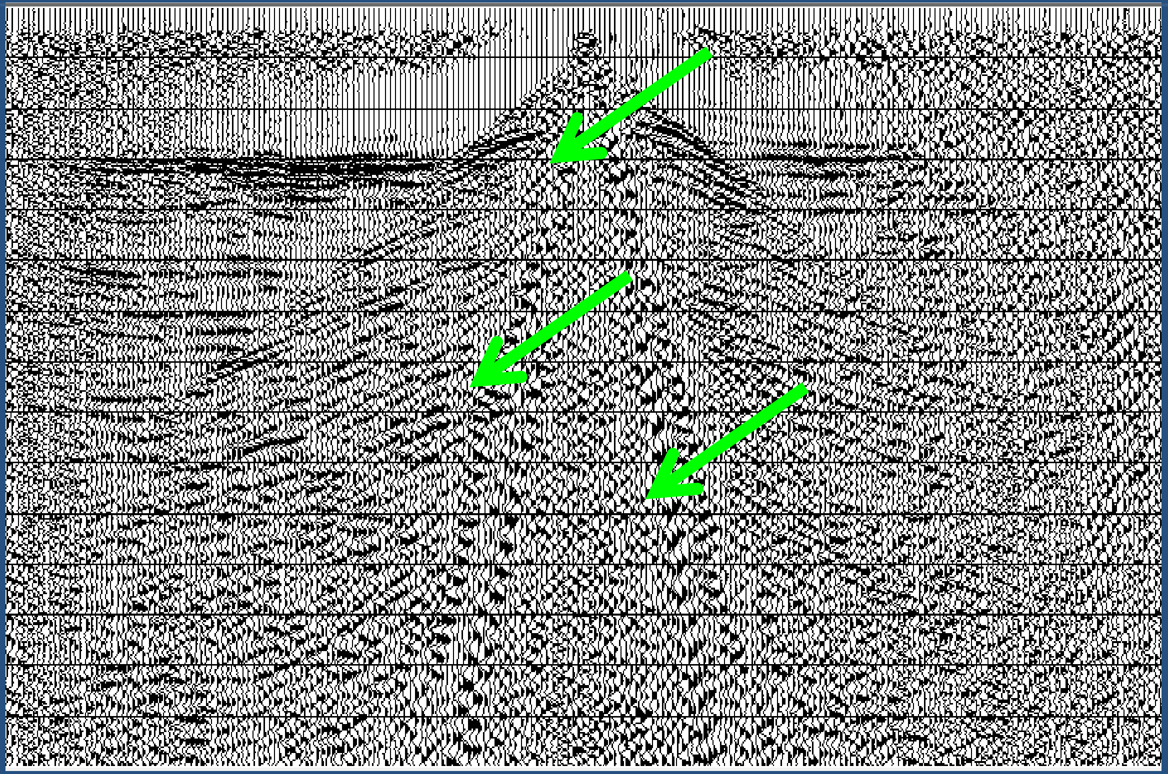


Receiver line 8—RT filtered

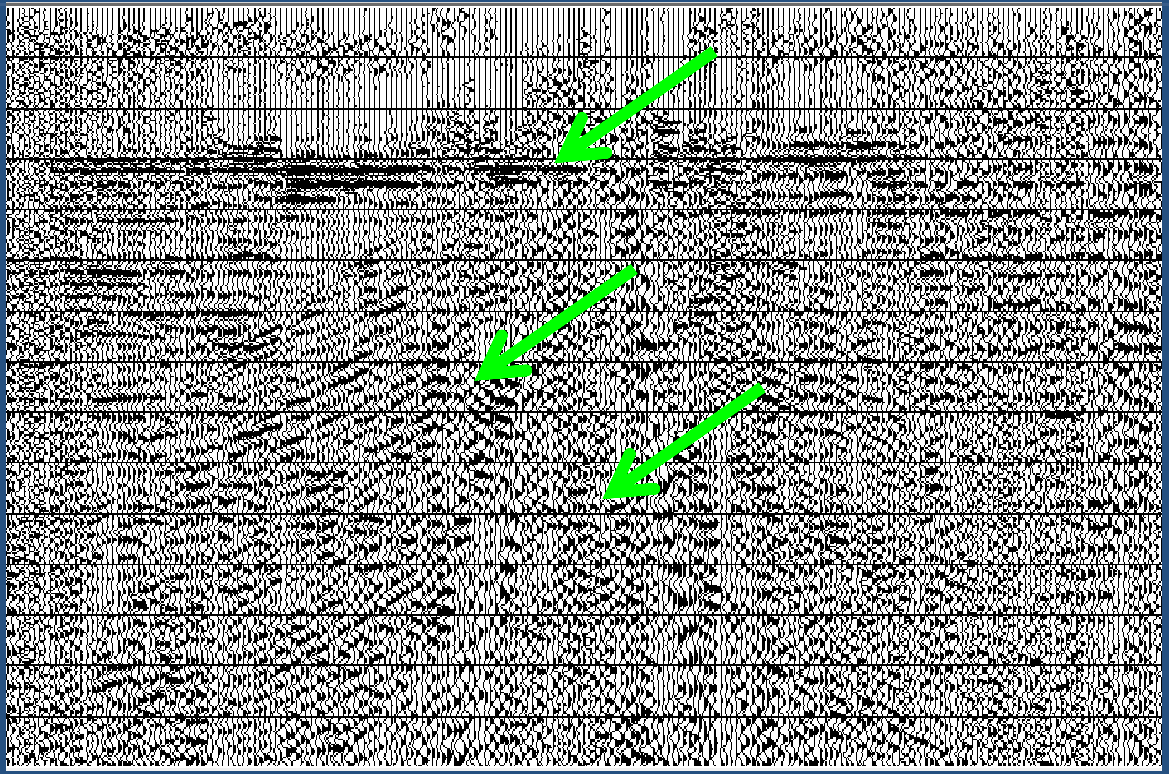


Receiver line 8 after 2D interferometry

2D X/T interferometry



Receiver line 17—RT filtered

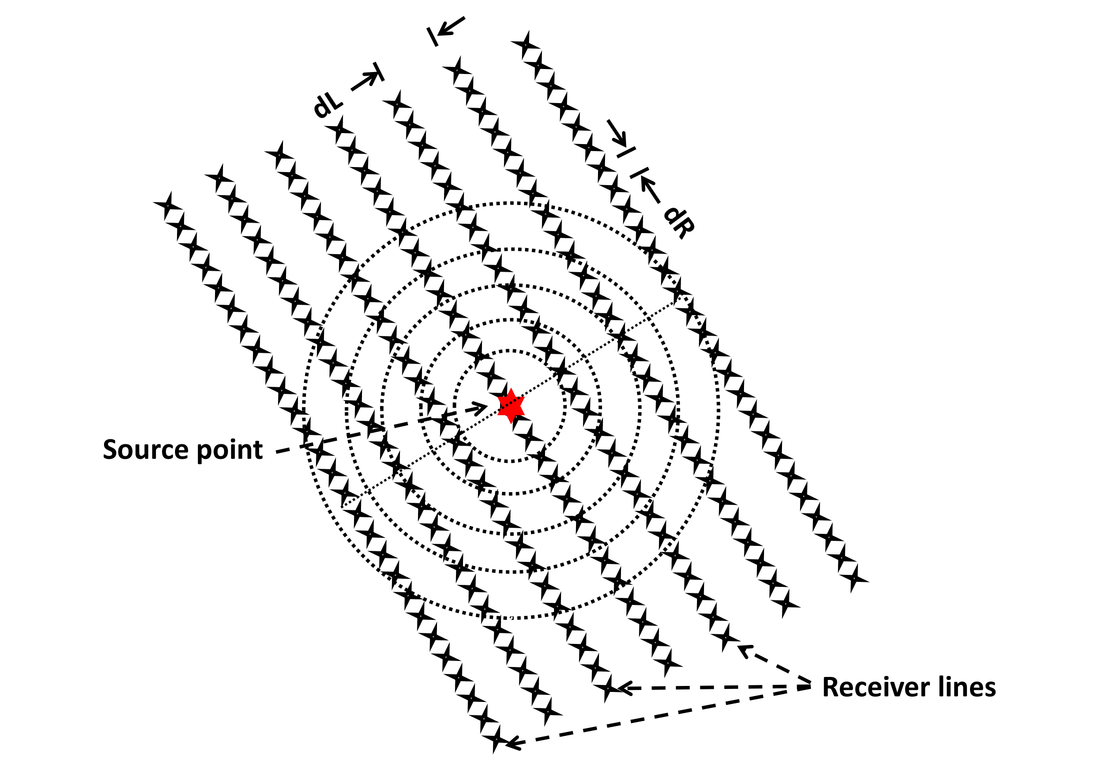


Receiver line 17 after 2D interferometry

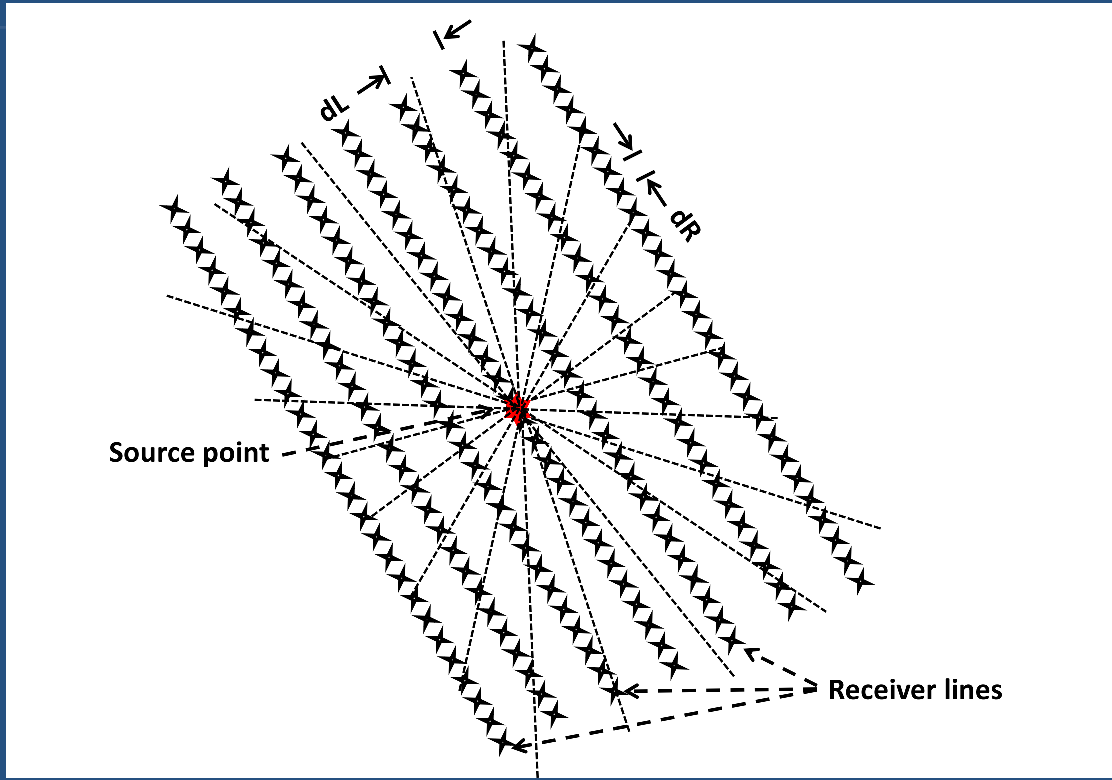
3D interferometry geometry

- Areal binning required—must reconcile with surface geometry
- Estimated wavefield smoothed in two directions
- Corresponding traces from raw trace bins and estimated wavefield bins are cross-correlated
- Cross-correlations used as match filters to correct raw traces in bins

3D bin geometry



Common-offset bins are rings

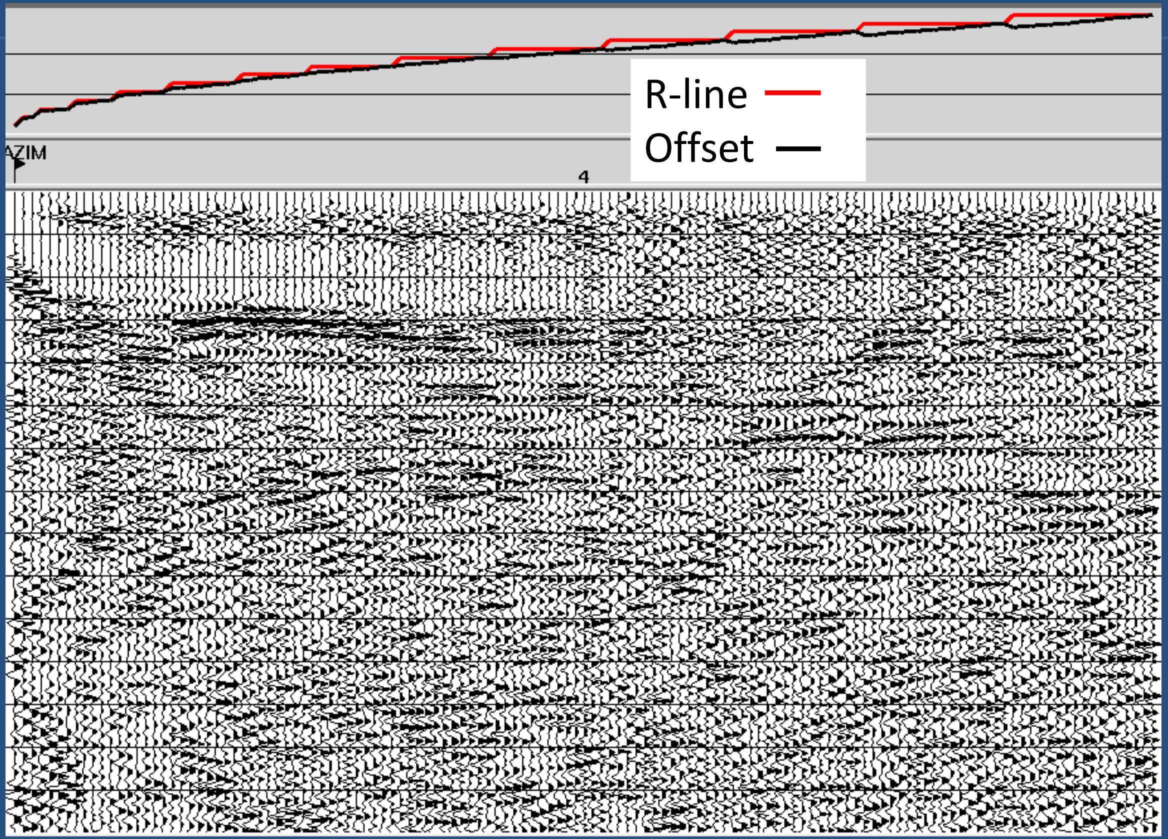


Common-azimuth bins are segments

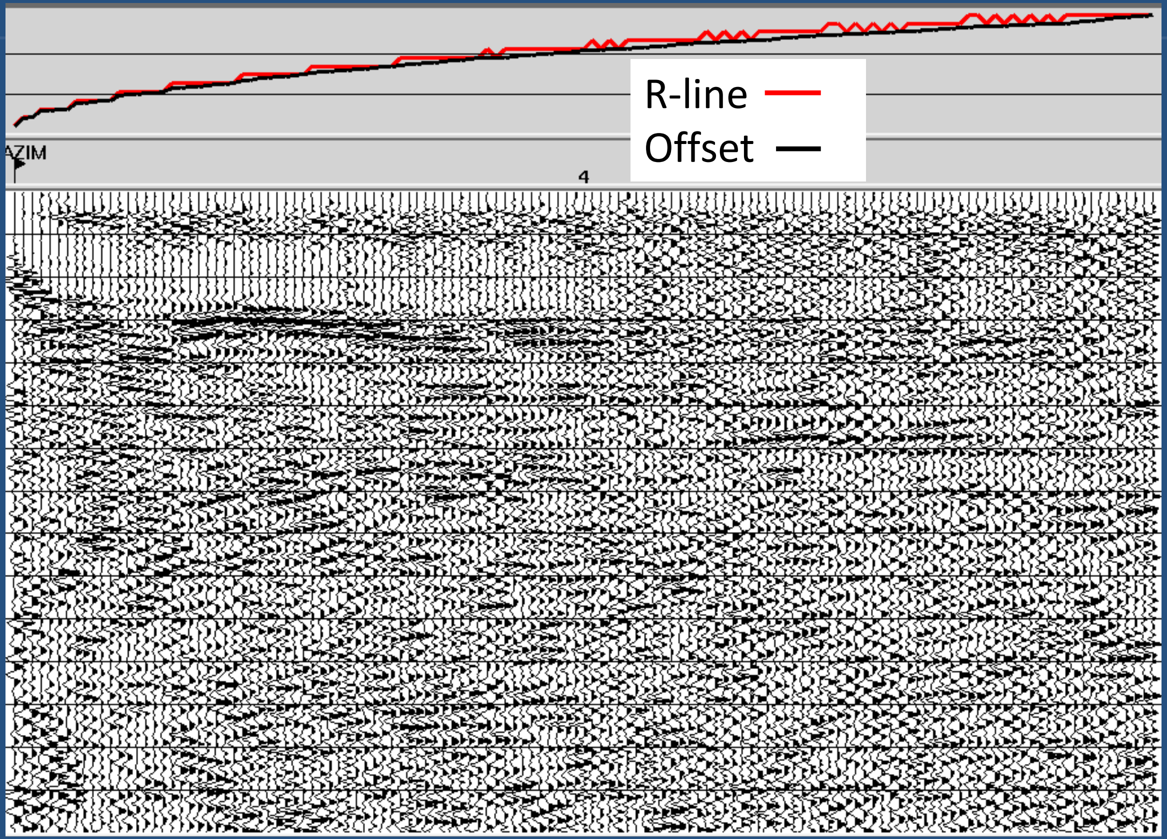
3D bin sorting

- Common-azimuth bins make the most intuitive sense
- Bins must be large enough that trace distributions are reasonably uniform
- Secondary sort within azimuth can be either receiver line or source-receiver offset

3D bin sorting—azimuth bin 4

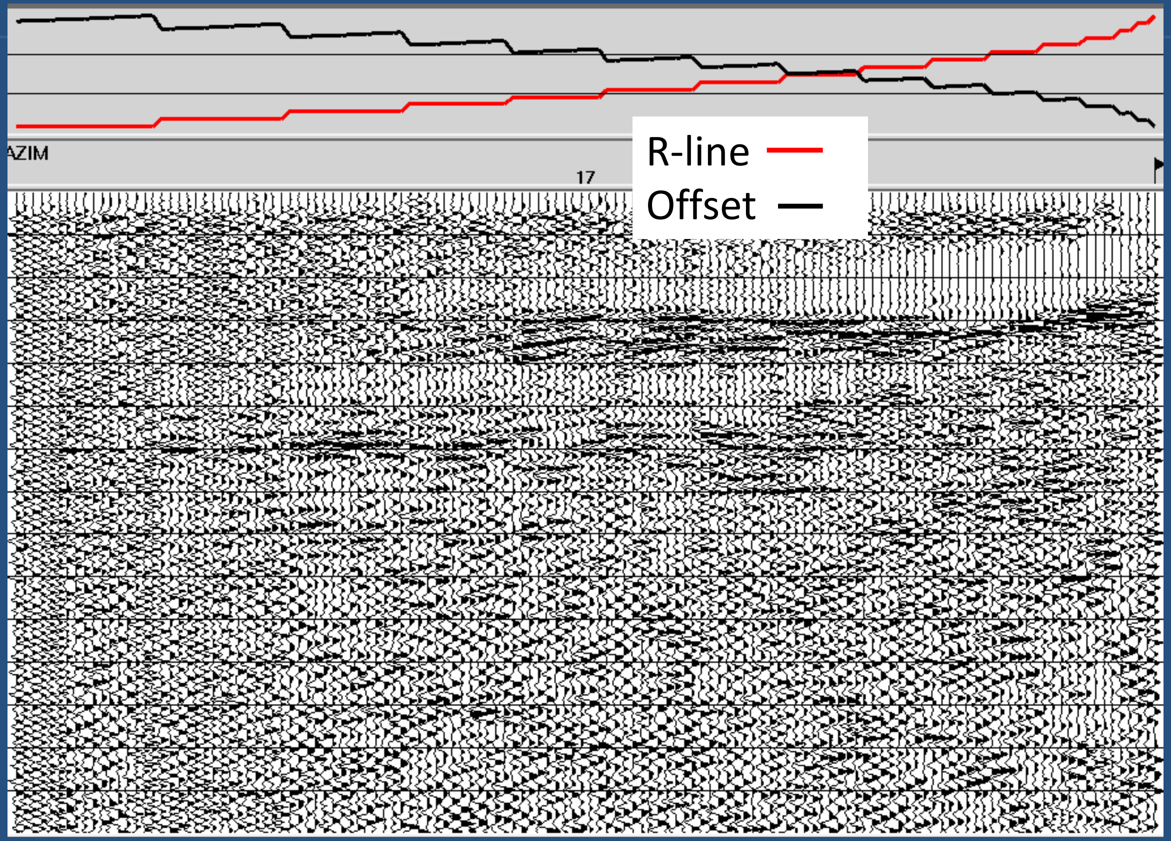


Sorted by receiver line

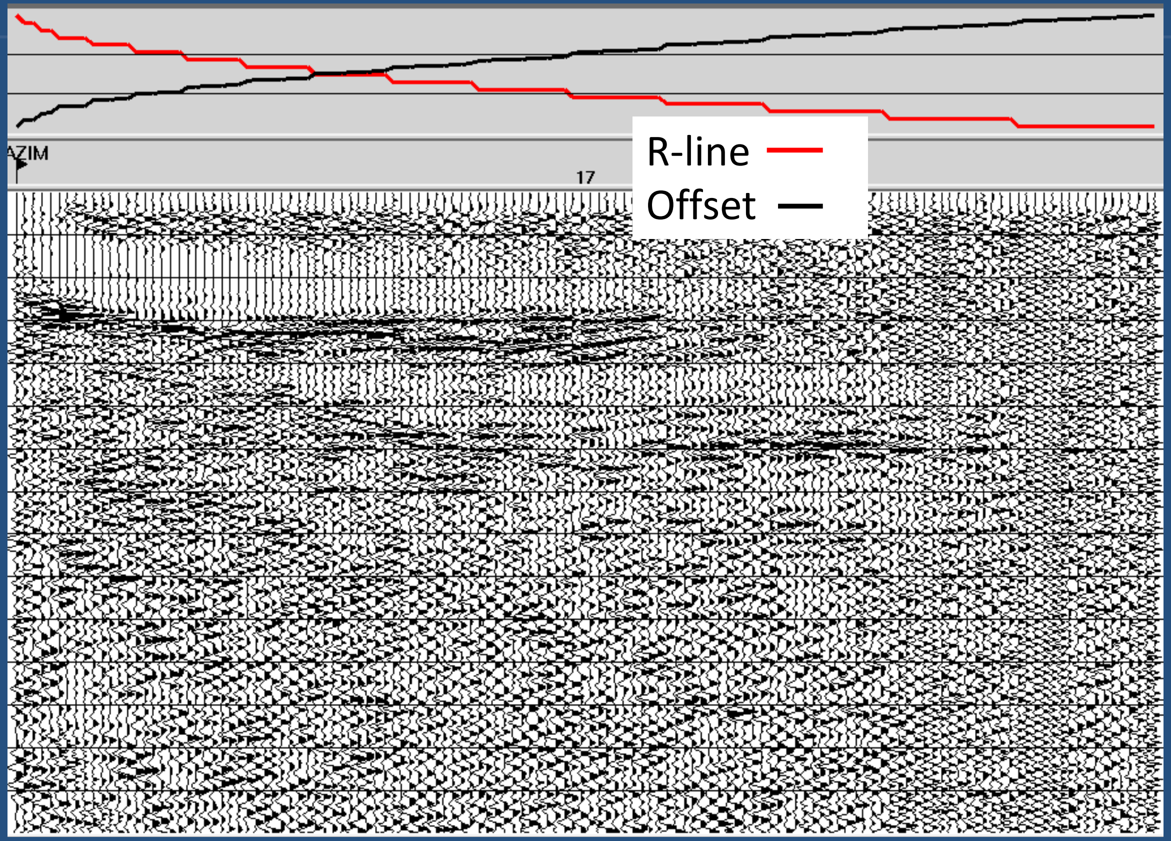


Sorted by offset

3D bin sorting—azimuth bin 17

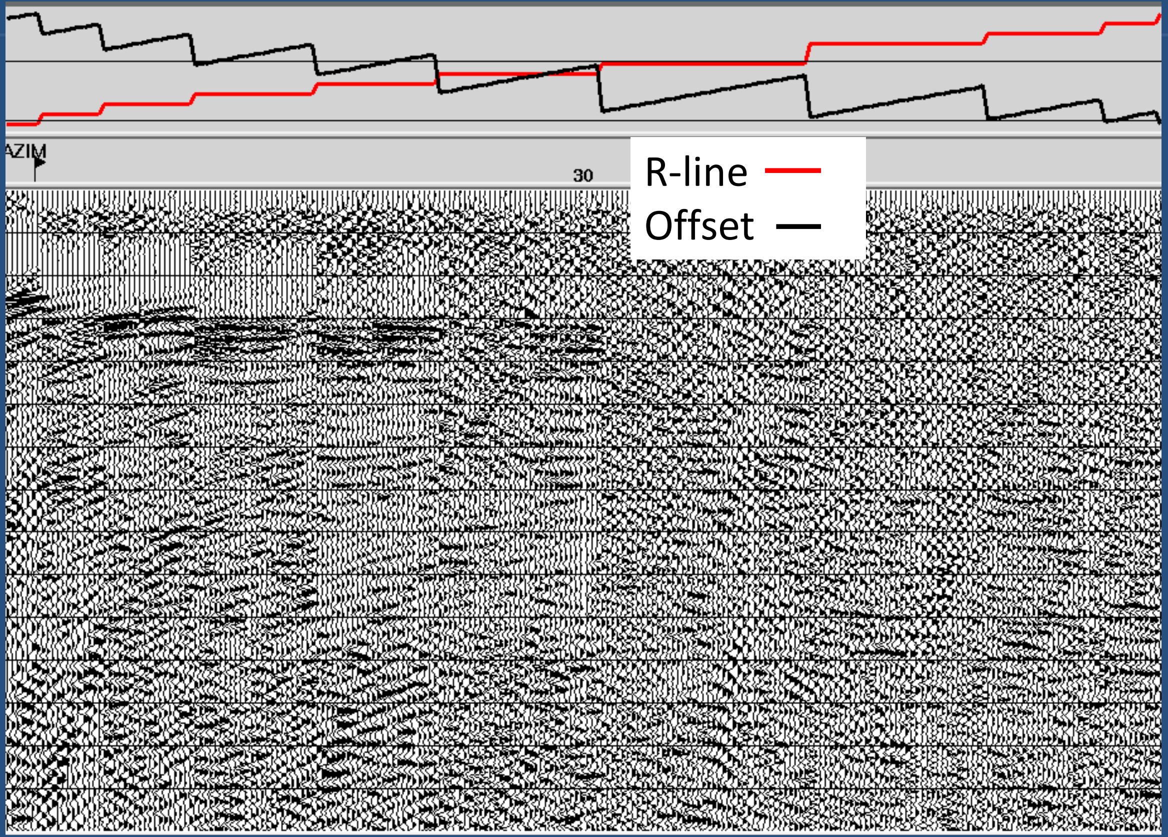


Sorted by receiver line

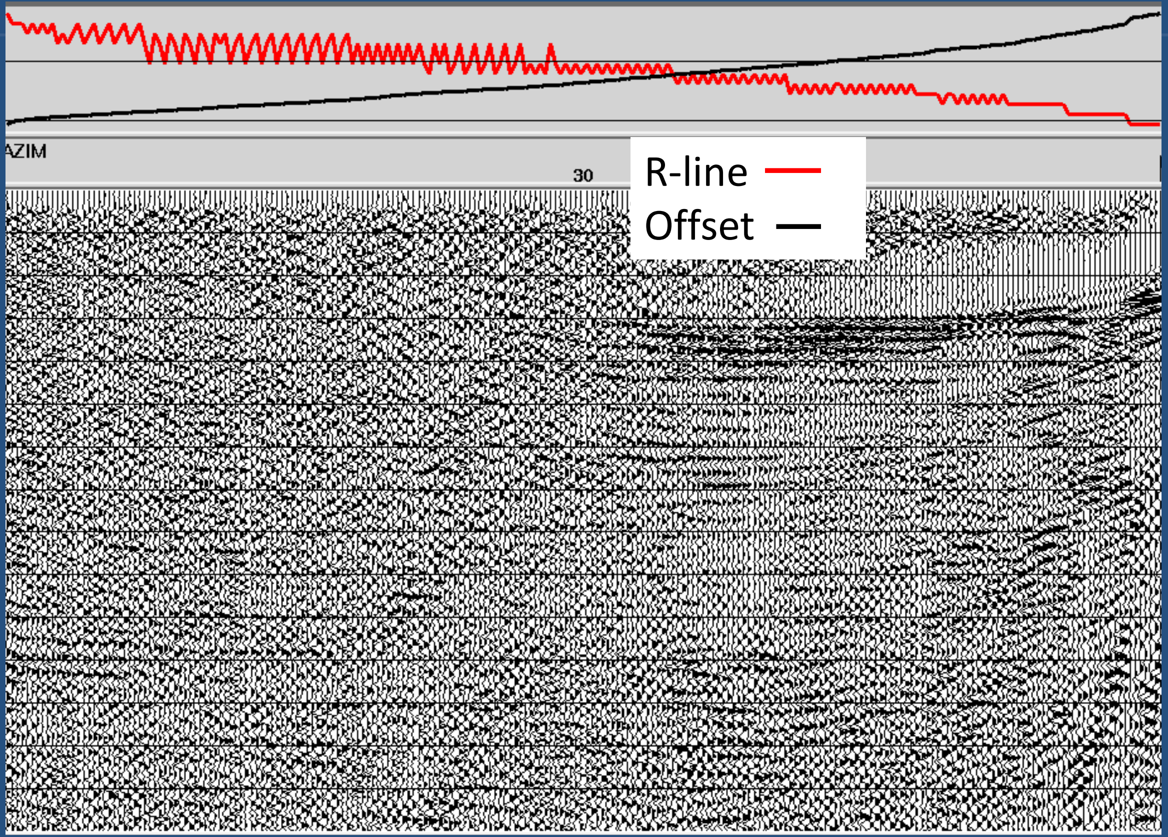


Sorted by offset

3D bin sorting—azimuth bin 30



Sorted by receiver line

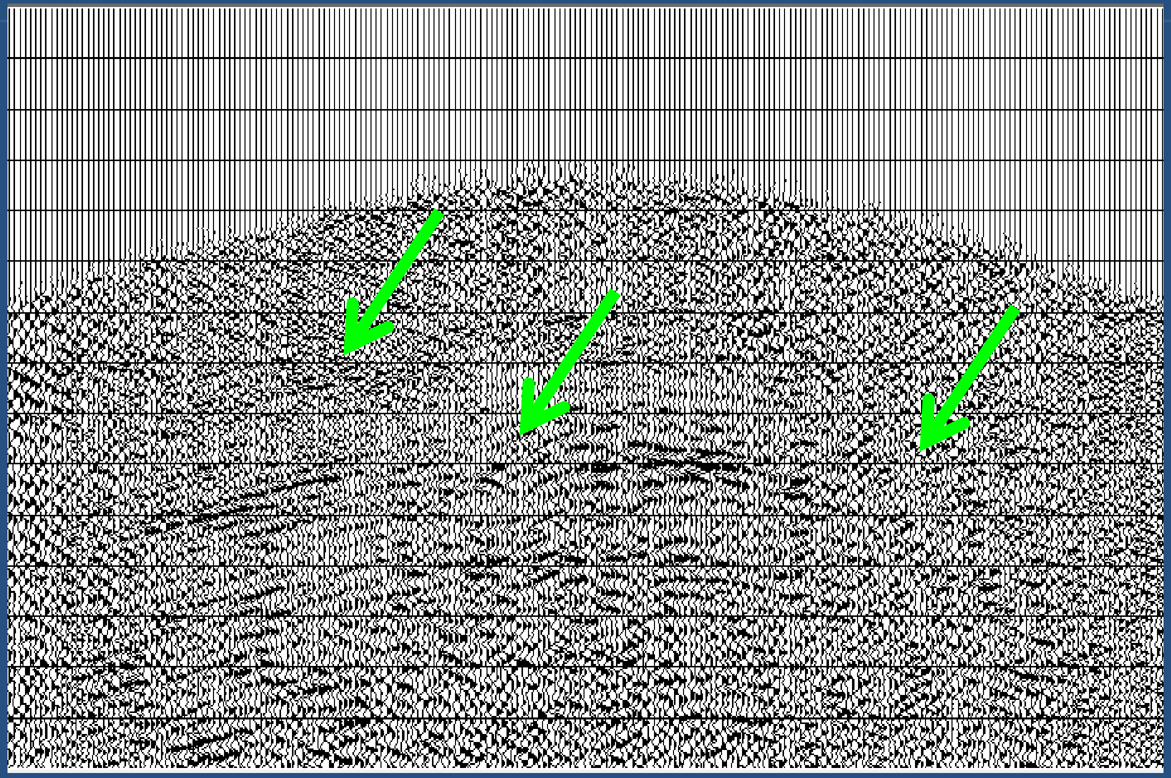


Sorted by offset

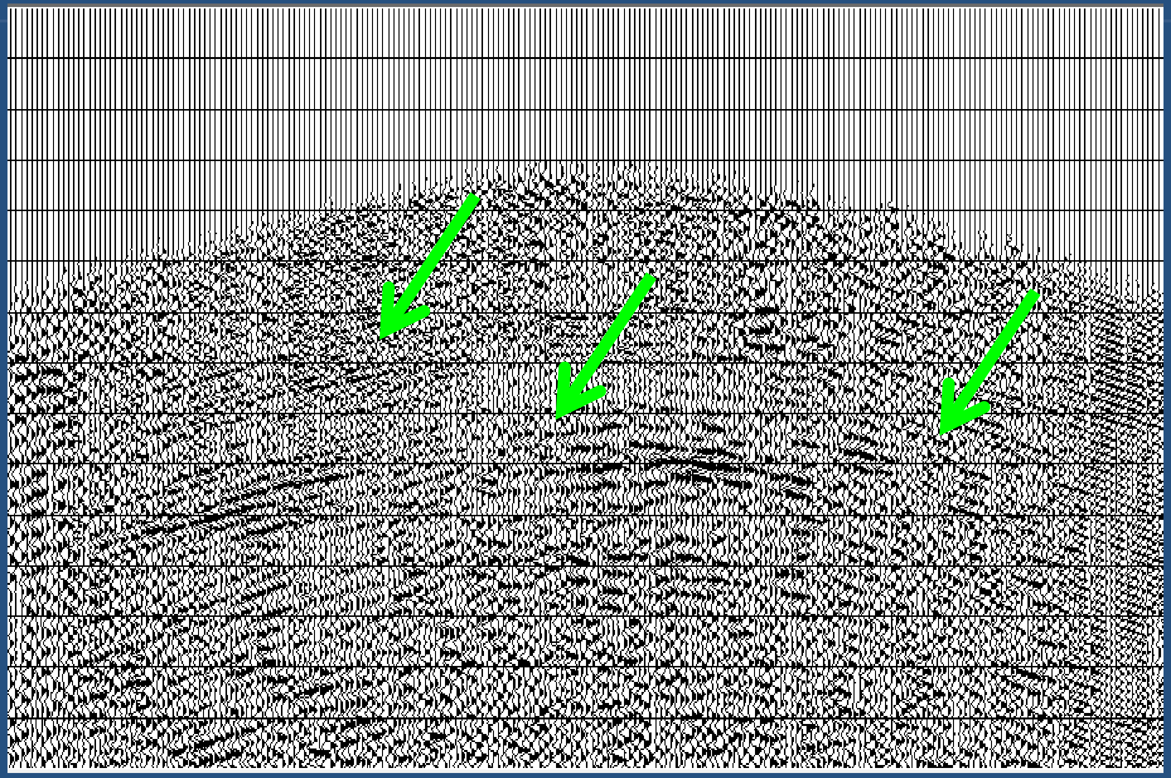
3D X/T interferometry

- Apply Linear moveout
- Bin traces by azimuth/receiver line: smooth over receiver line
- Re-sort traces by receiver line/azimuth: smooth over azimuth—this is estimated wavefield
- Cross-correlate corresponding traces in common-azimuth bins and estimated wavefield bins
- Apply cross-correlations as match filters to raw common-azimuth traces

3D X/T interferometry

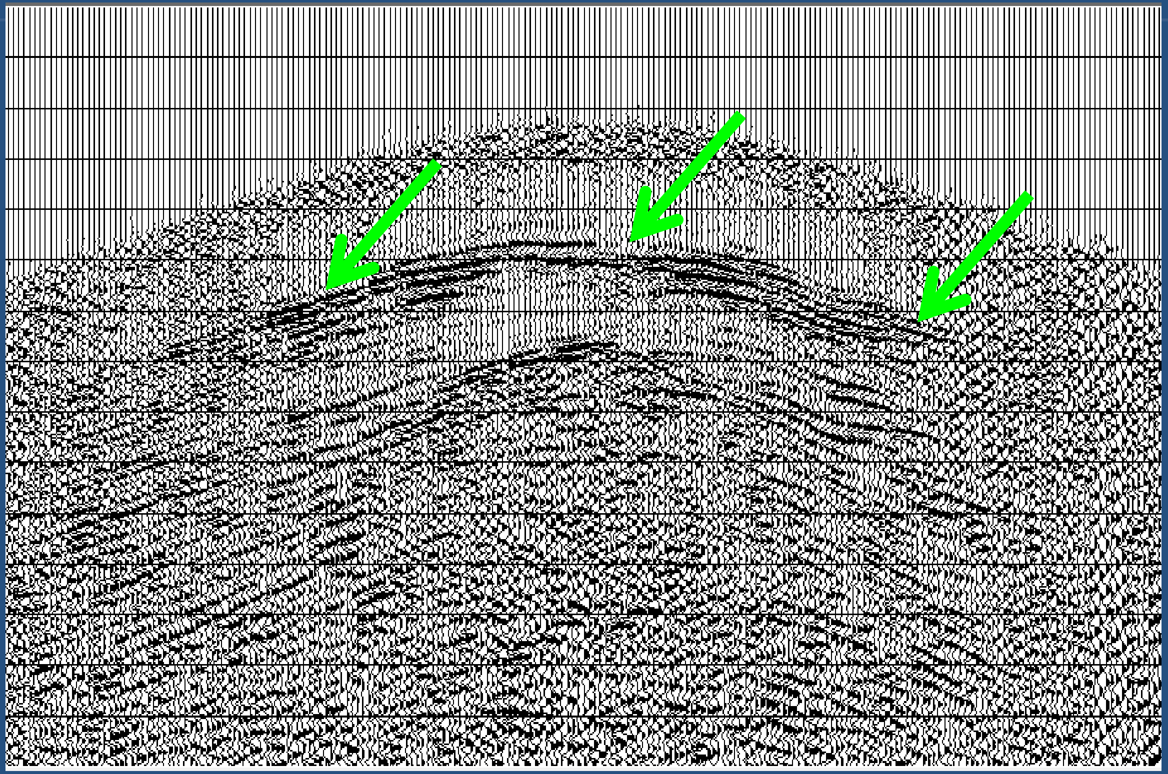


Receiver line 3—RT filtered

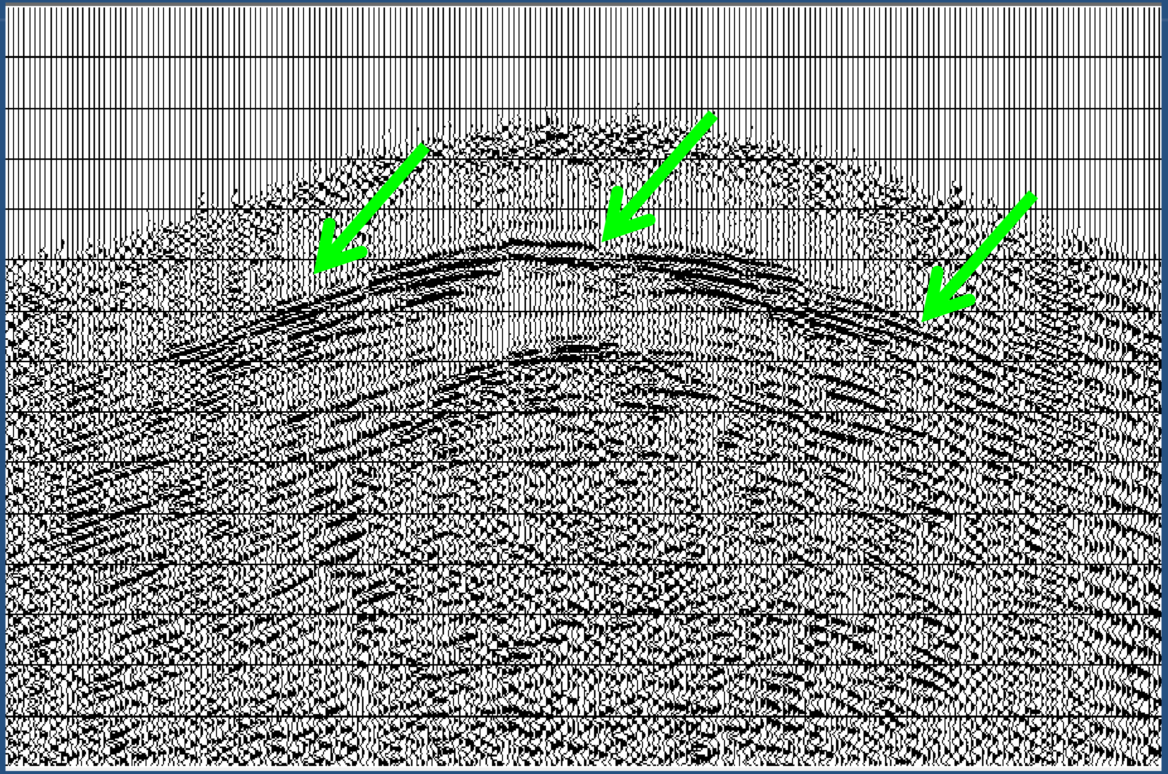


Receiver line 3 after 3D interferometry

3D X/T interferometry

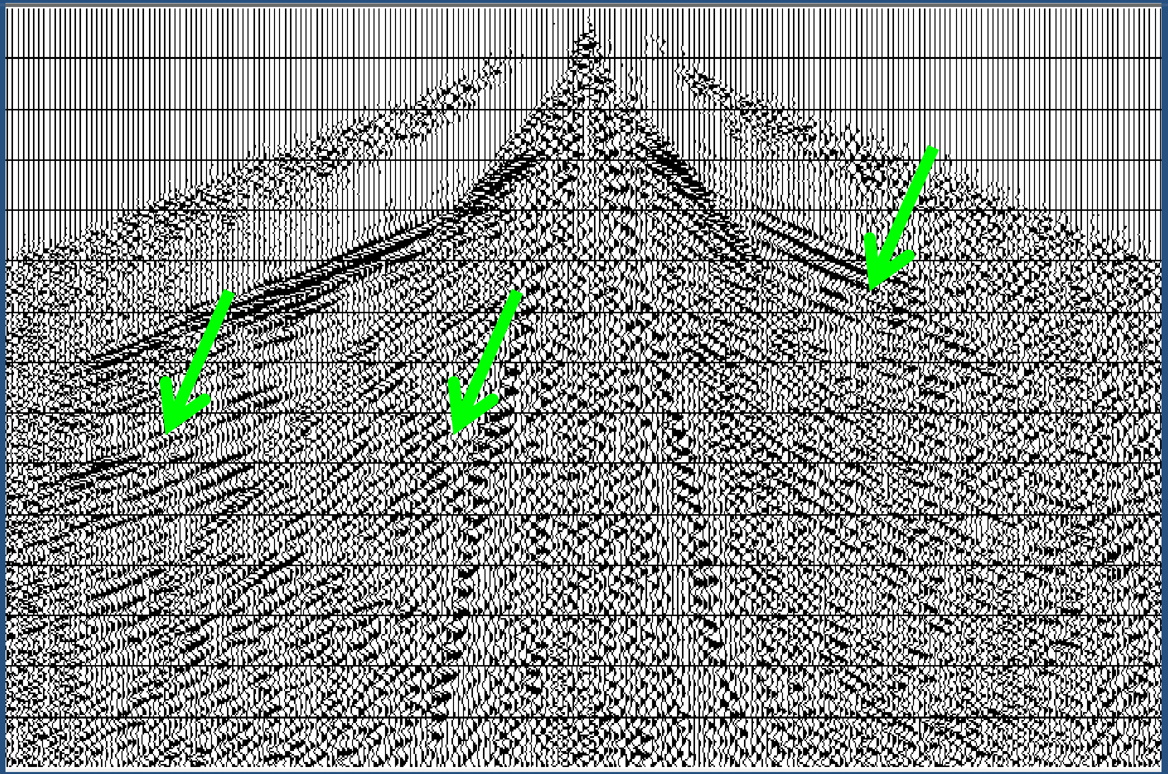


Receiver line 8—RT filtered

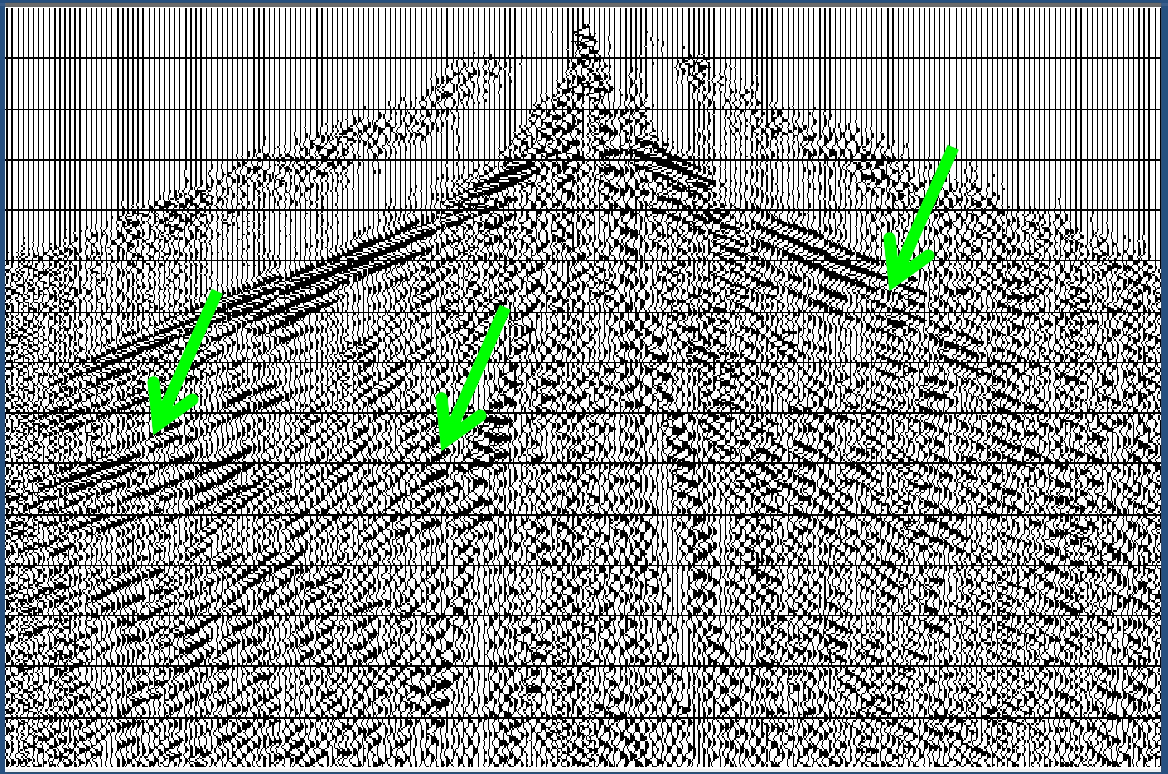


Receiver line 8 after 3D interferometry

3D X/T interferometry



Receiver line 17—RT filtered

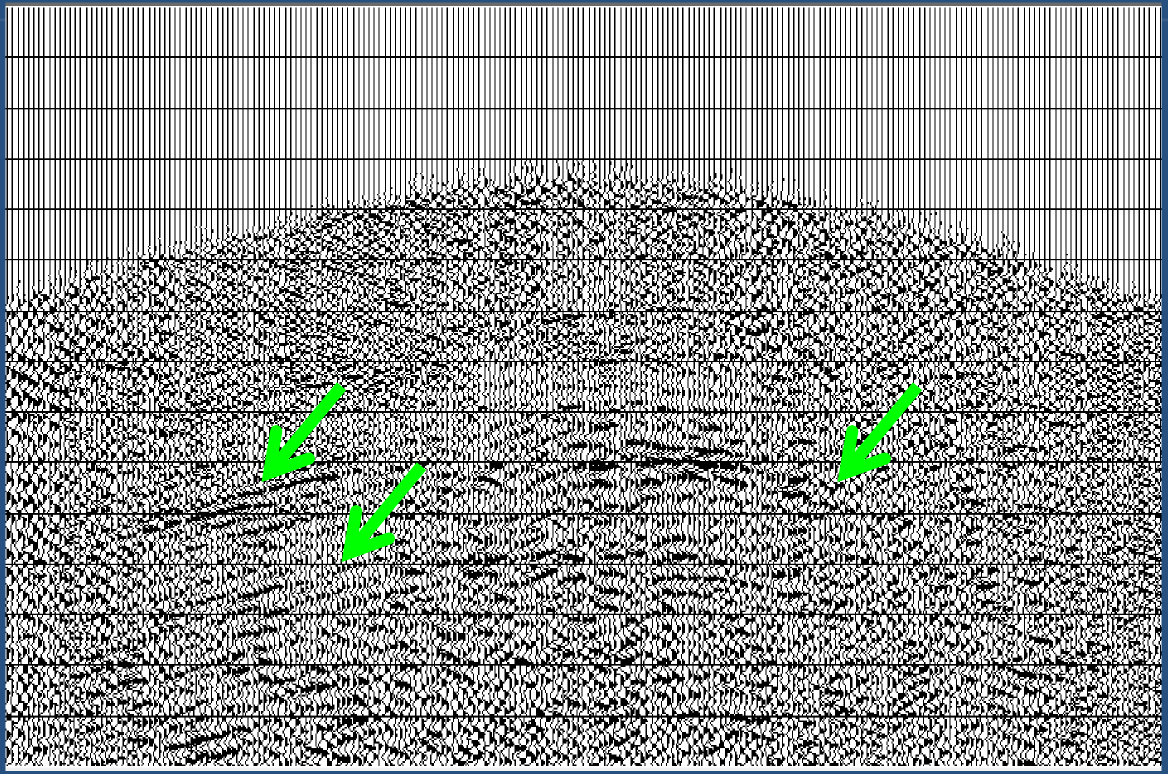


Receiver line 17 after 3D interferometry

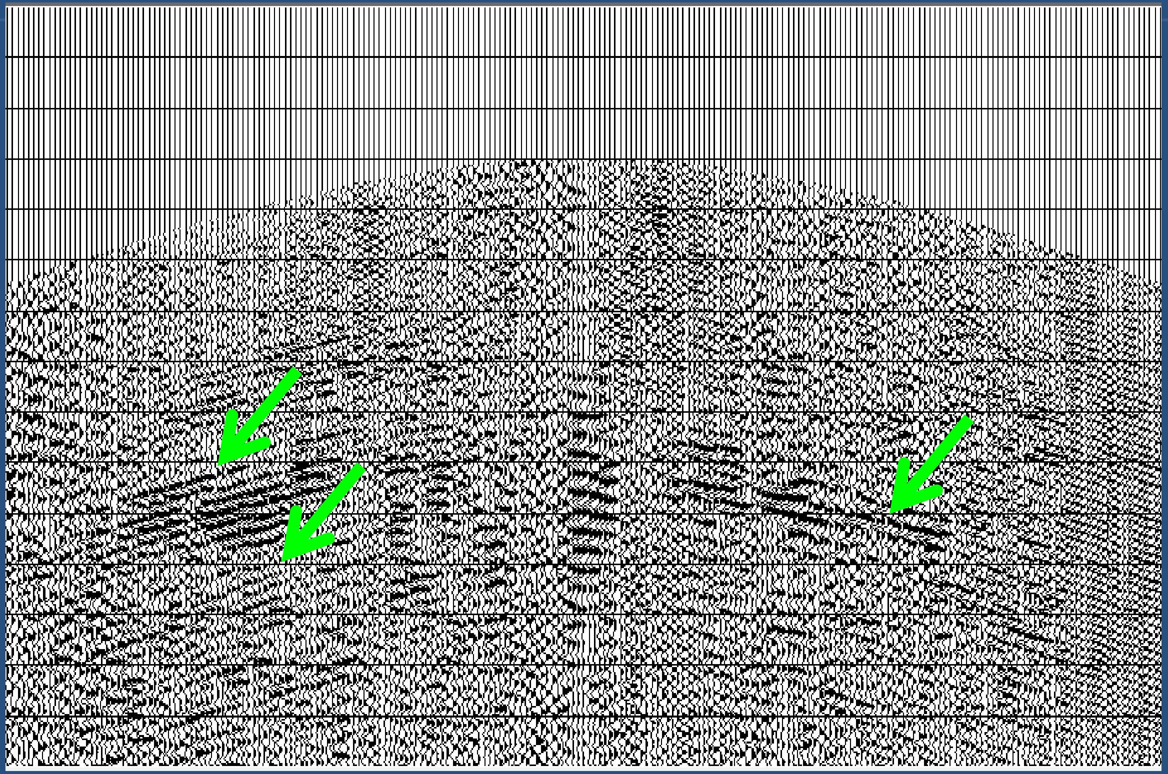
3D raypath interferometry

- Bin traces by azimuth/offset: smooth over offset
- Re-sort traces by offset/azimuth: smooth over azimuth—this is estimated wavefield
- Apply Tau-P transform to azimuth/offset gathers
- Apply Tau-P transform to azimuth/offset estimated wavefield gathers
- Cross-correlate corresponding Tau-P traces in wavefield bins and input bins
- Apply cross-correlations as match filters to the Tau-P traces of the input azimuth/offset gathers
- Inverse Tau-P transform to get corrected X/T azimuth/offset traces

3D raypath interferometry

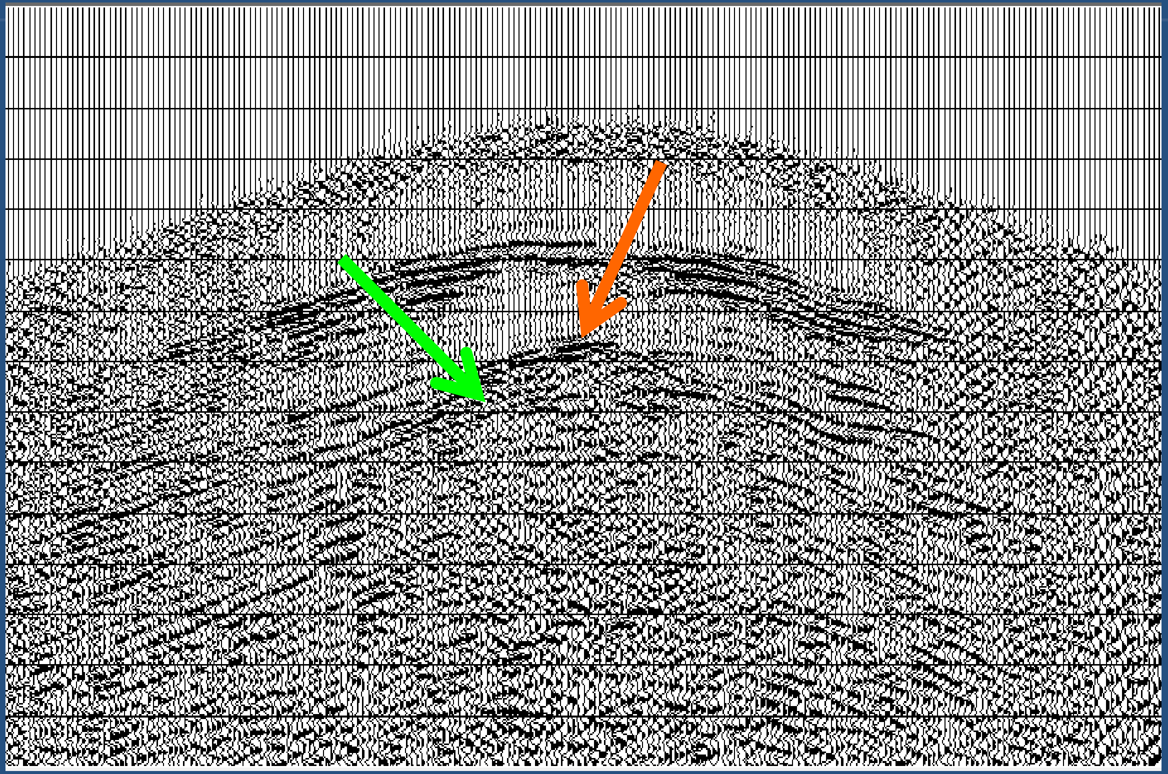


Receiver line 3—RT filtered

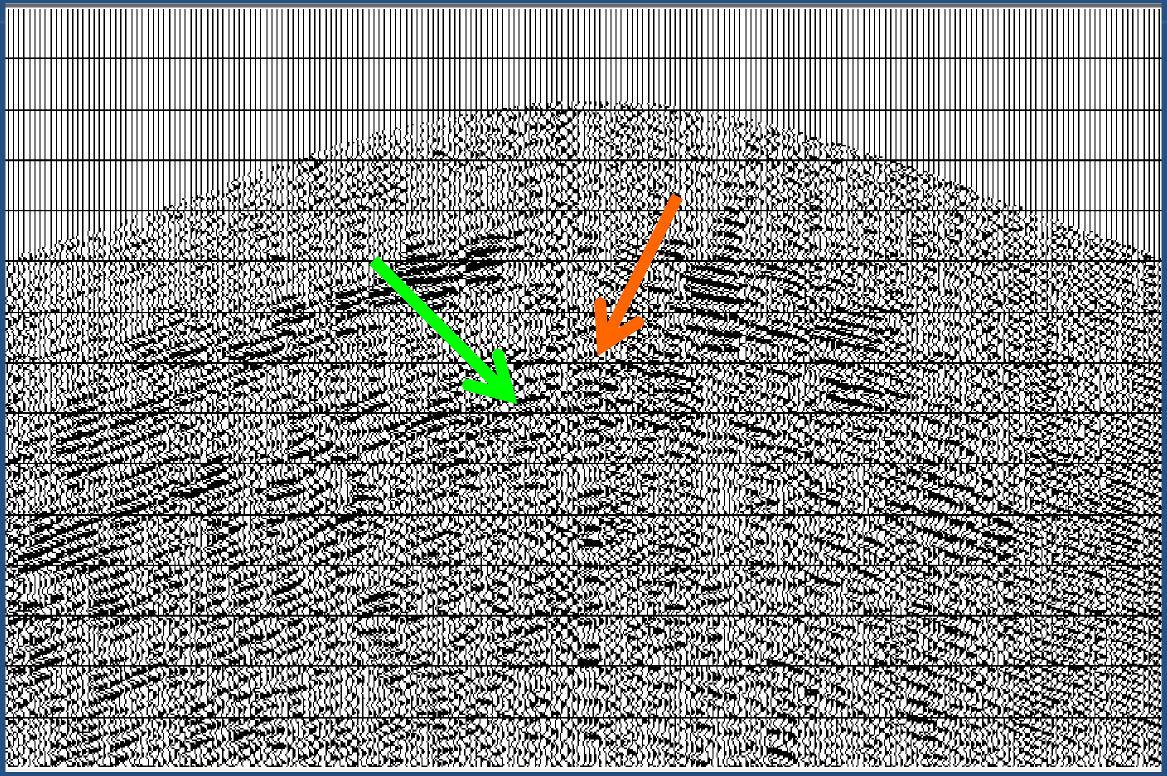


Receiver line 3 after raypath interferometry

3D raypath interferometry

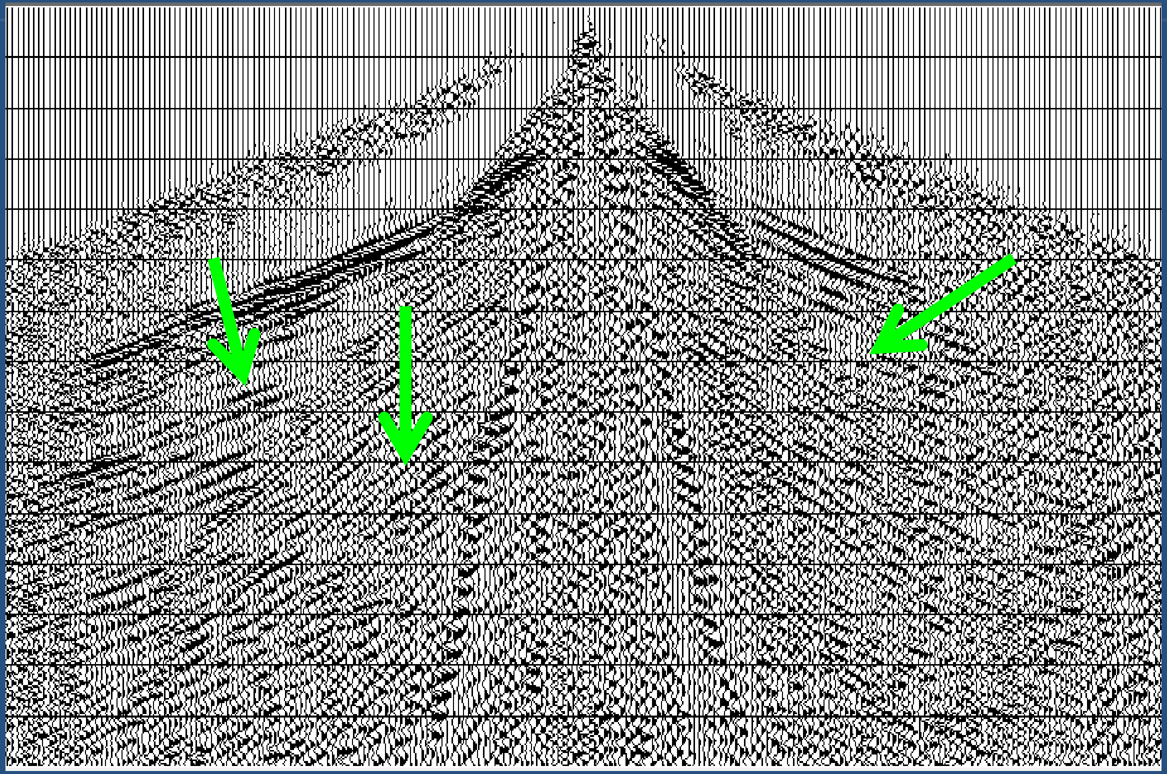


Receiver line 8—RT filtered

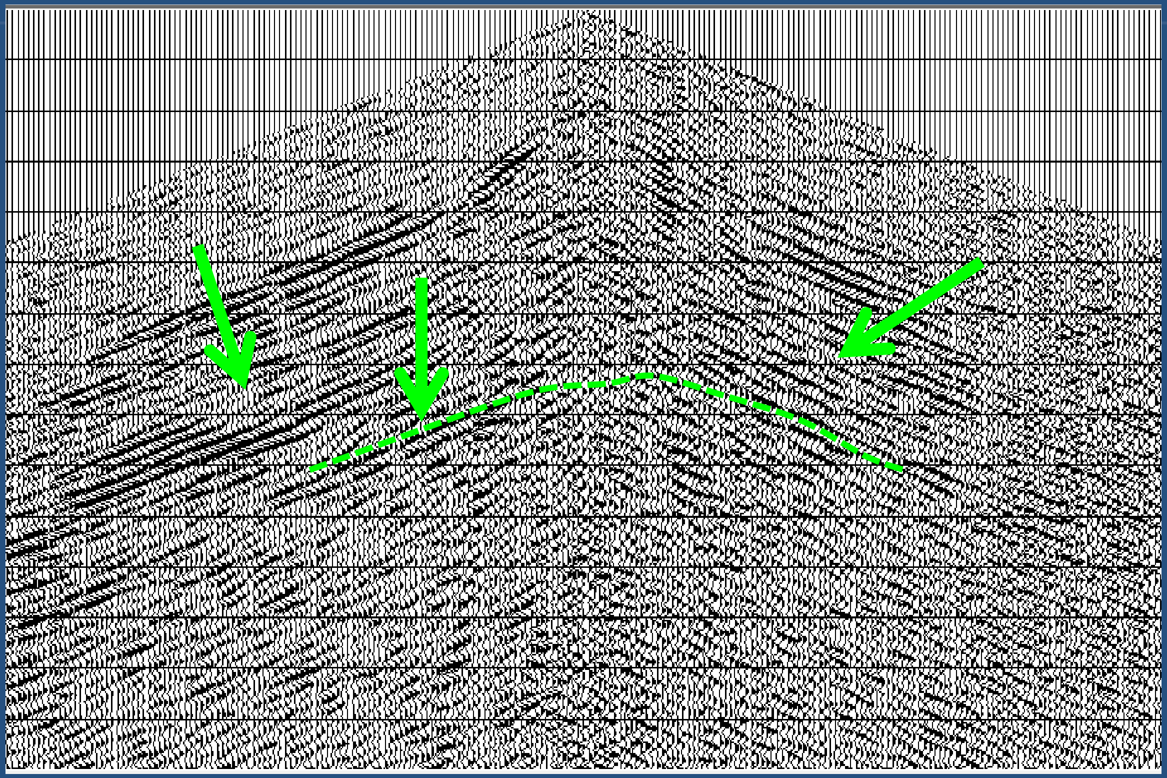


Receiver line 8 after raypath interferometry

3D raypath interferometry



Receiver line 17—RT filtered



Receiver line 17 after raypath interferometry

Summary

- 2D interferometry effectively corrects receiver line gathers, but:
  - Individual receiver lines not correlated—2D correction only
  - Residual noise is coherent and interferes
- 3D X/T (azimuth/receiver line) interferometry improves receiver line coherence, but:
  - Corrections less effective than in 2D, but correlated between receiver lines
  - Residual noise not coherent in this domain, interferes less
- 3D raypath (azimuth/offset Tau_P) interferometry improves receiver line coherence, and:
  - Is more effective at longer offsets and greater travel times
  - Appears to bandlimit the data slightly
  - Residual noise further attenuated

Conclusions

- Interferometric techniques can be used to reduce or remove receiver-side time ‘wrinkles’ due to near-surface effects within 3D source ensembles
- 3D interferometry better than 2D
- Raypath interferometry may be better than X/T
- Effective strategy needed to reconcile individual source ensembles for complete 3D survey

Acknowledgements

- CREWES sponsors and NSERC for funding
- Marianne Rauch-Davies and Nexen for data