Attenuating the ice flexural wave on arctic seismic data

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Summary

- Introduction—What is the ice flexural wave, how is it excited?
- Characteristics of the flexural wave
- Noise attenuation methods
- R-T domain techniques—spectral clipping, Gabor deconvolution
- Example—Hansen Harbour
- Conclusions

What is the ice flexural wave?

- Flexural wave is often observed on floating ice in the Arctic
- Flexural wave motion is similar to that of a drum membrane
- Flexural wave can be described as P-SV internally reflected modes (Ewing et al)
- Flexural wave is excited by surface vertical source or internal compressional source in a hard layer bounded by fluids

Characteristics of the flexural wave

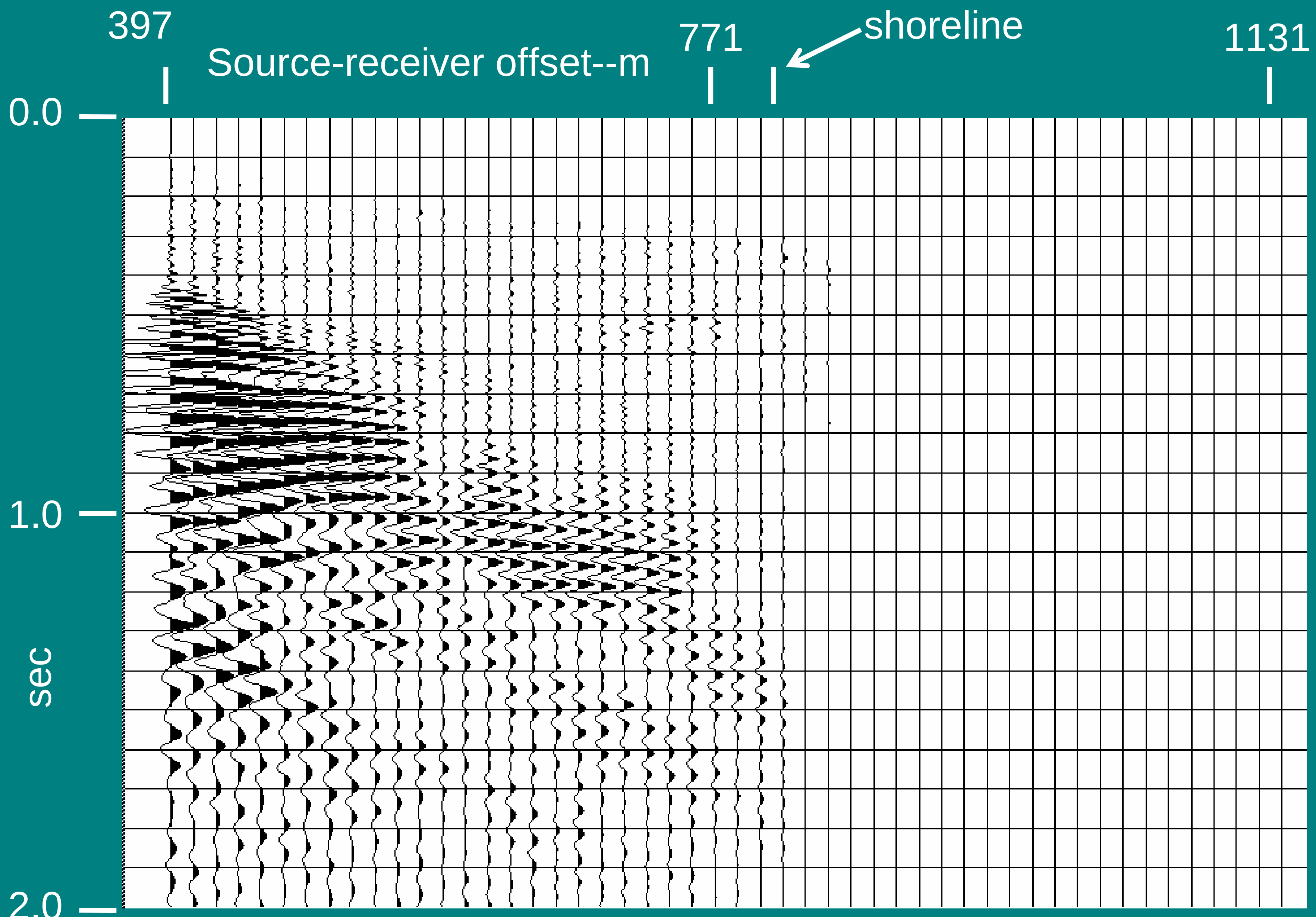
- Very powerful—usually the strongest wavefield on a shot record ***by orders of magnitude***
- 2-D wave—attenuates as ***1/r***, *not* ***1/r²***
- Highly dispersed—***high*** frequencies can move at ice P-wave velocity; ***low*** frequencies slower than air velocity
- Confined to the ice—wave does not propagate past edge of floating ice, but reflects efficiently from shore

Noise attenuation methods

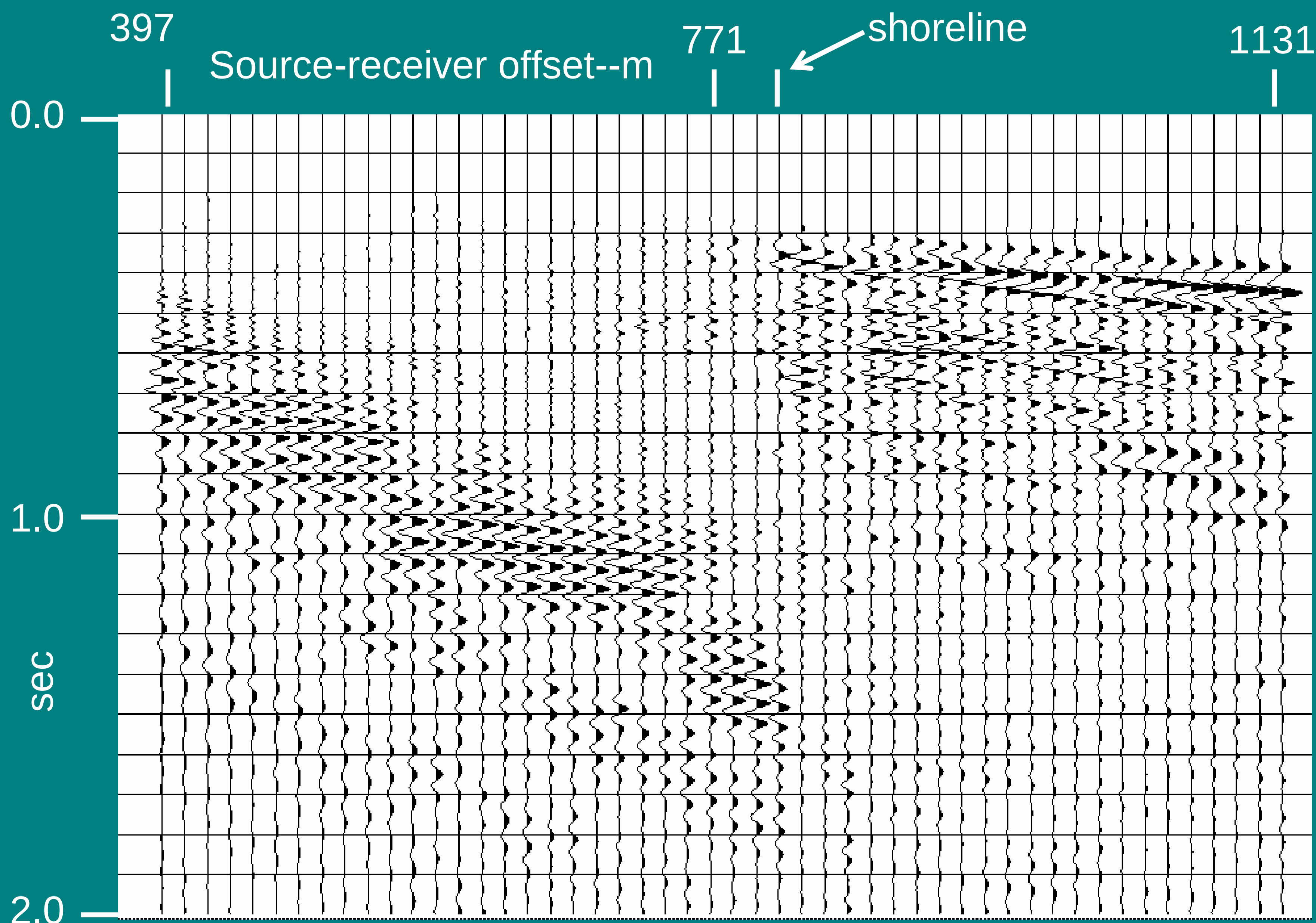
- Model noise in R-T domain and subtract in X-T domain—***linear***
- Attenuate noise directly in R-T domain using spectral whitening—***linear,*** or spectral clipping—***nonlinear***

Hansen Harbour CREWES 3-C

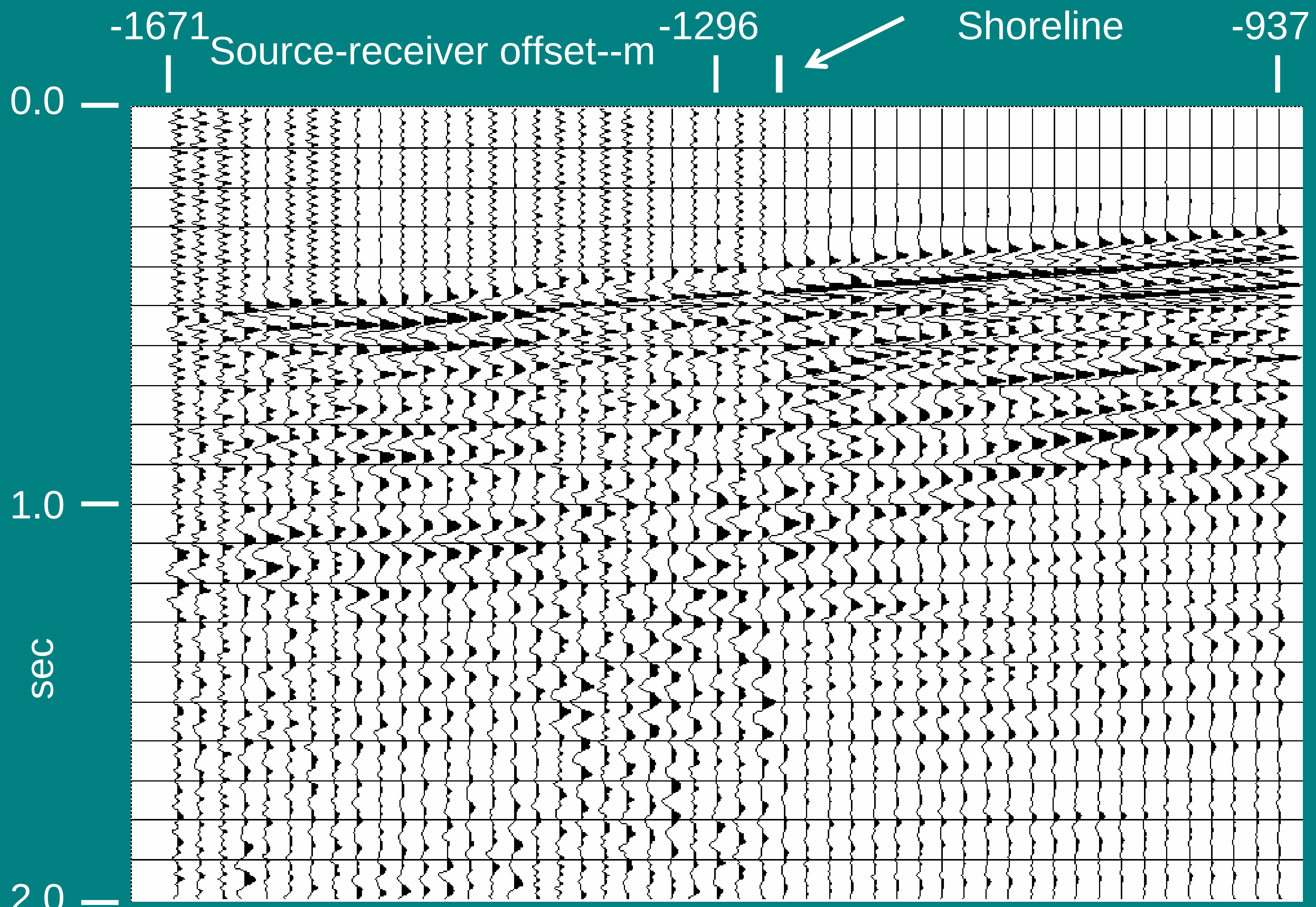
- Receiver spread—50 3-C single phones 15 metres apart
- Colinear shot line centred on receiver spread—203 shots 30 metres apart
- Dynamite and Vibroseis used as sources to record separate profiles
- Vertical component Vibroseis data used for ice wave attenuation study



Unscaled raw shot gather: source point on floating ice



Scaled raw shot gather: source point on floating ice

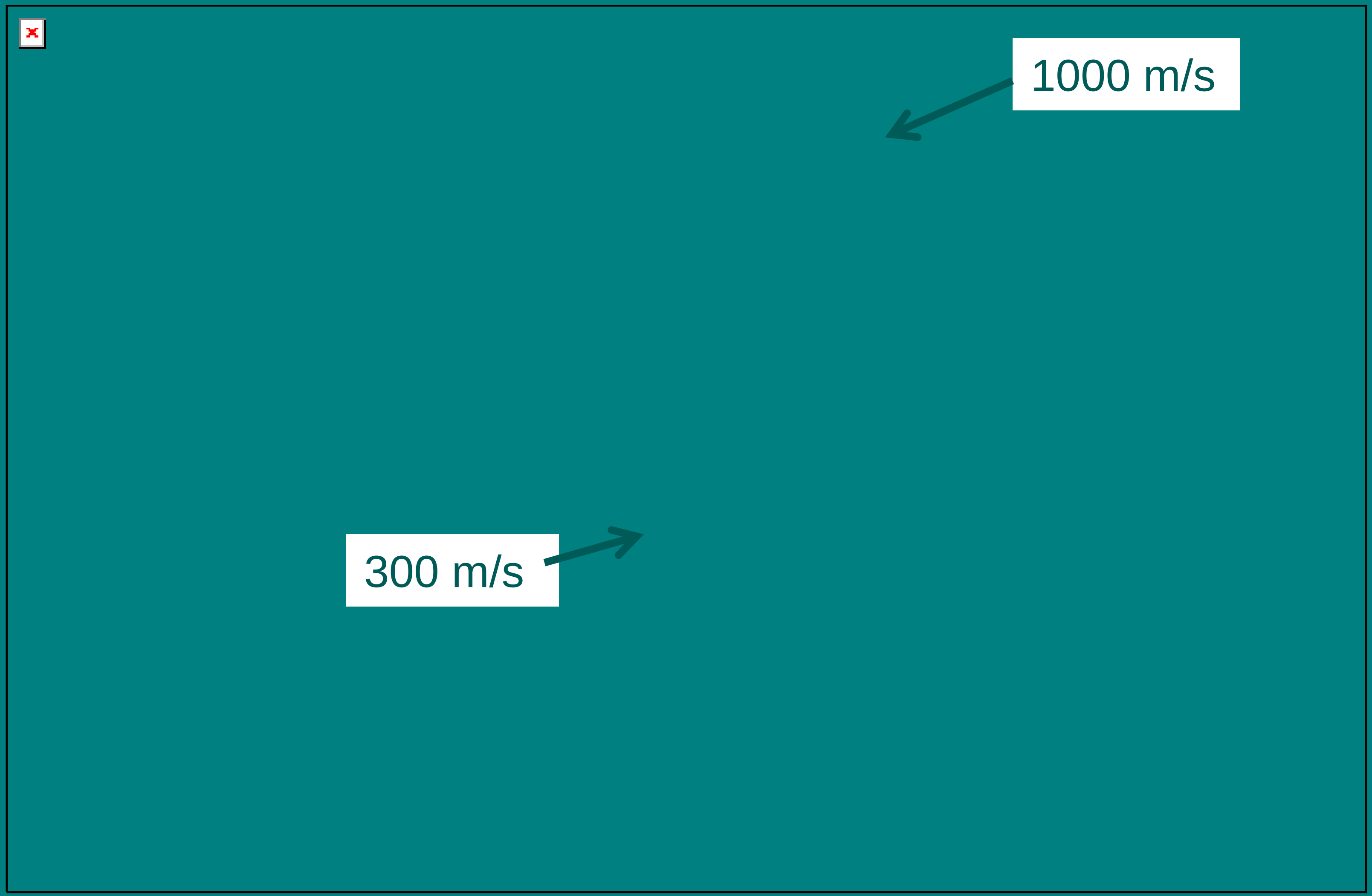


Scaled raw shot gather: source point on land

Dispersion and aliasing

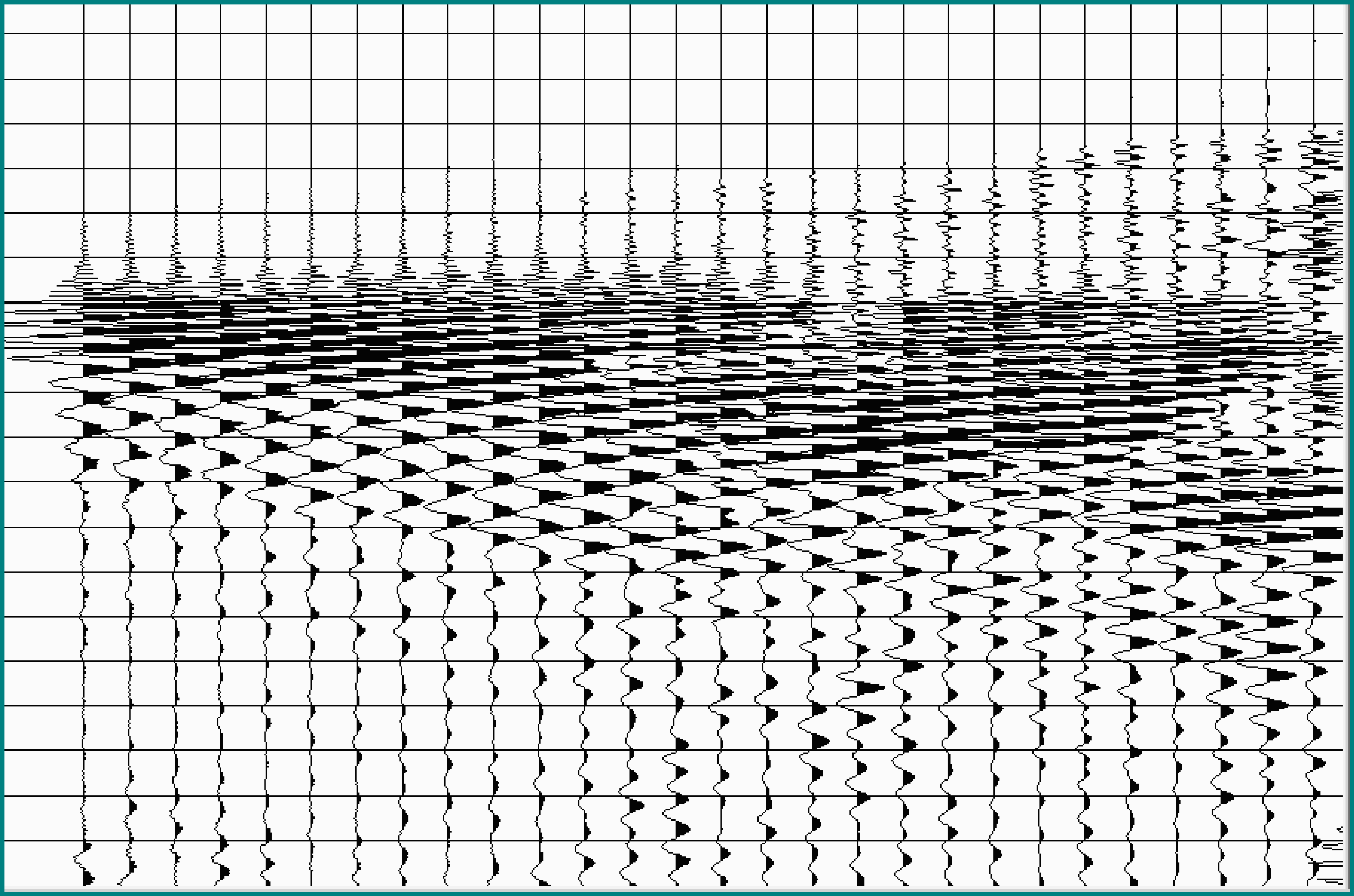
- Dispersion provides unique separation of ice wave frequency components in R-T domain
- Spatial aliasing compromises effectiveness of frequency separation by moving components up into seismic band
- Ideal acquisition would sample ice wave with no aliasing at any frequency

Aliasing of the ice flexural wave



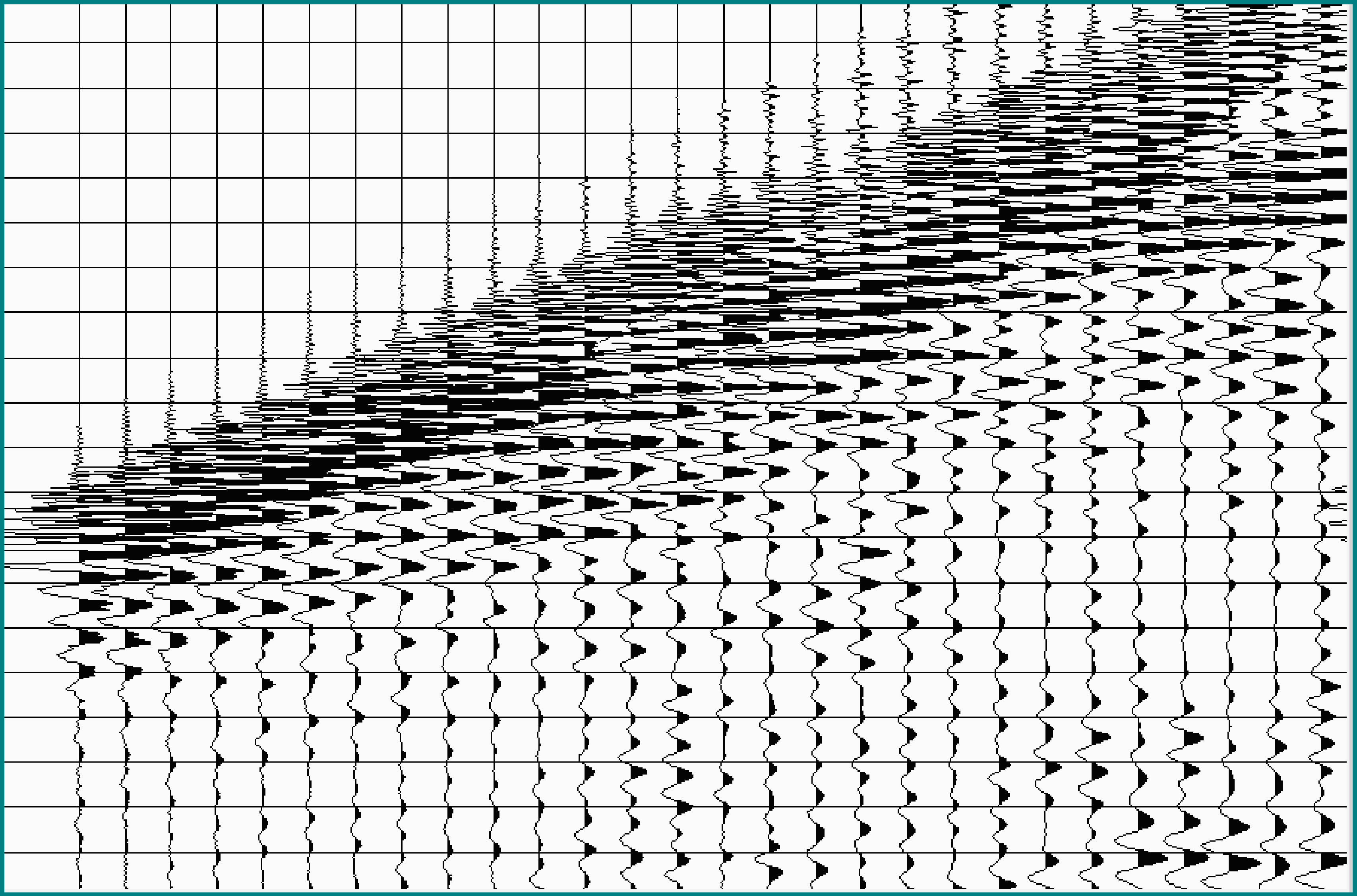
No NMO—Ice wave aliased at all frequencies

Aliasing of the ice flexural wave

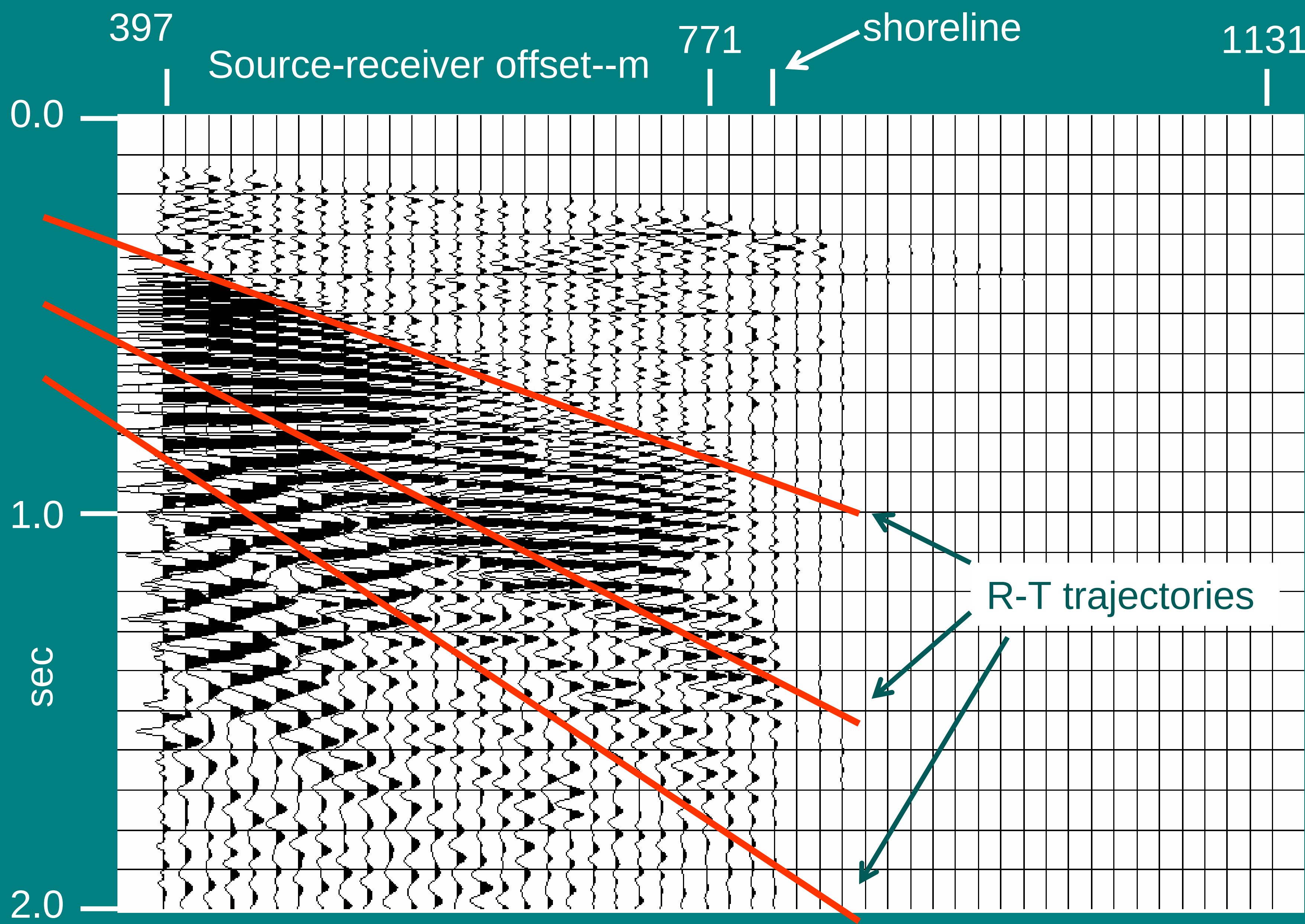


1000 m/s linear NMO—lower frequencies still aliased

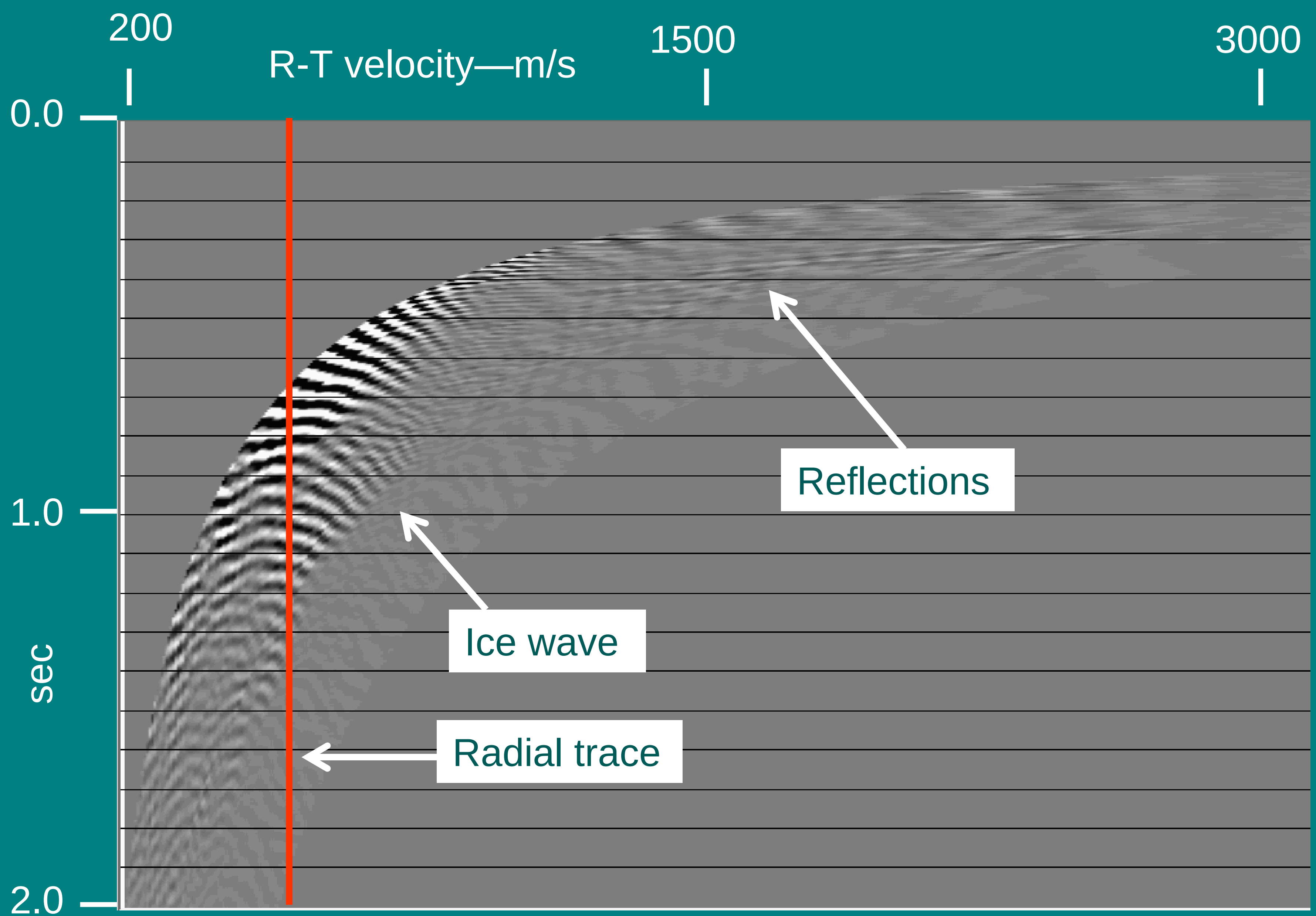
Aliasing of the ice flexural wave



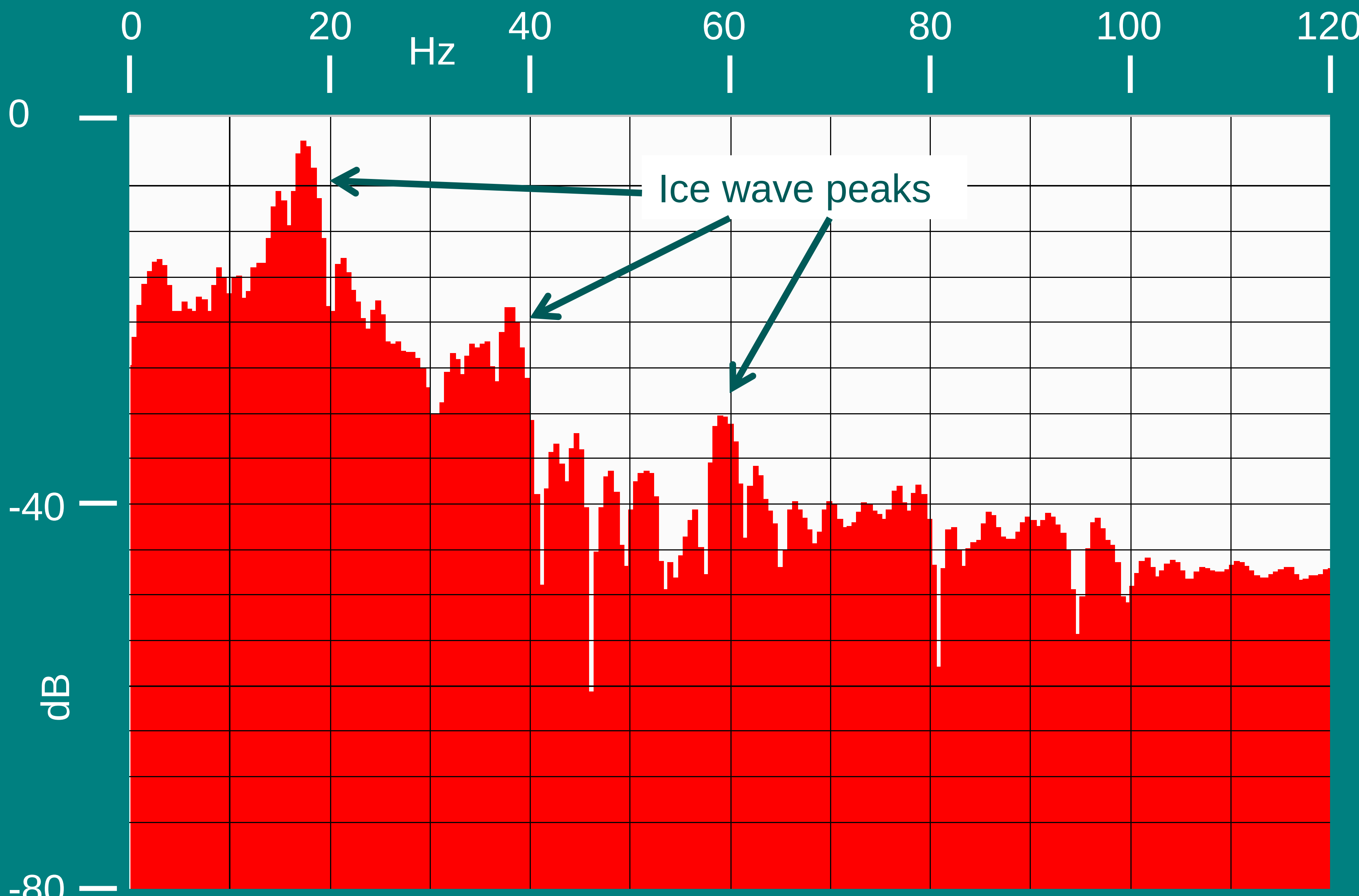
250 m/s linear NMO—higher frequencies aliased



Unscaled raw shot gather: source point on floating ice. R-T trajectories encounter monochromatic noise, due to dispersion of ice wave



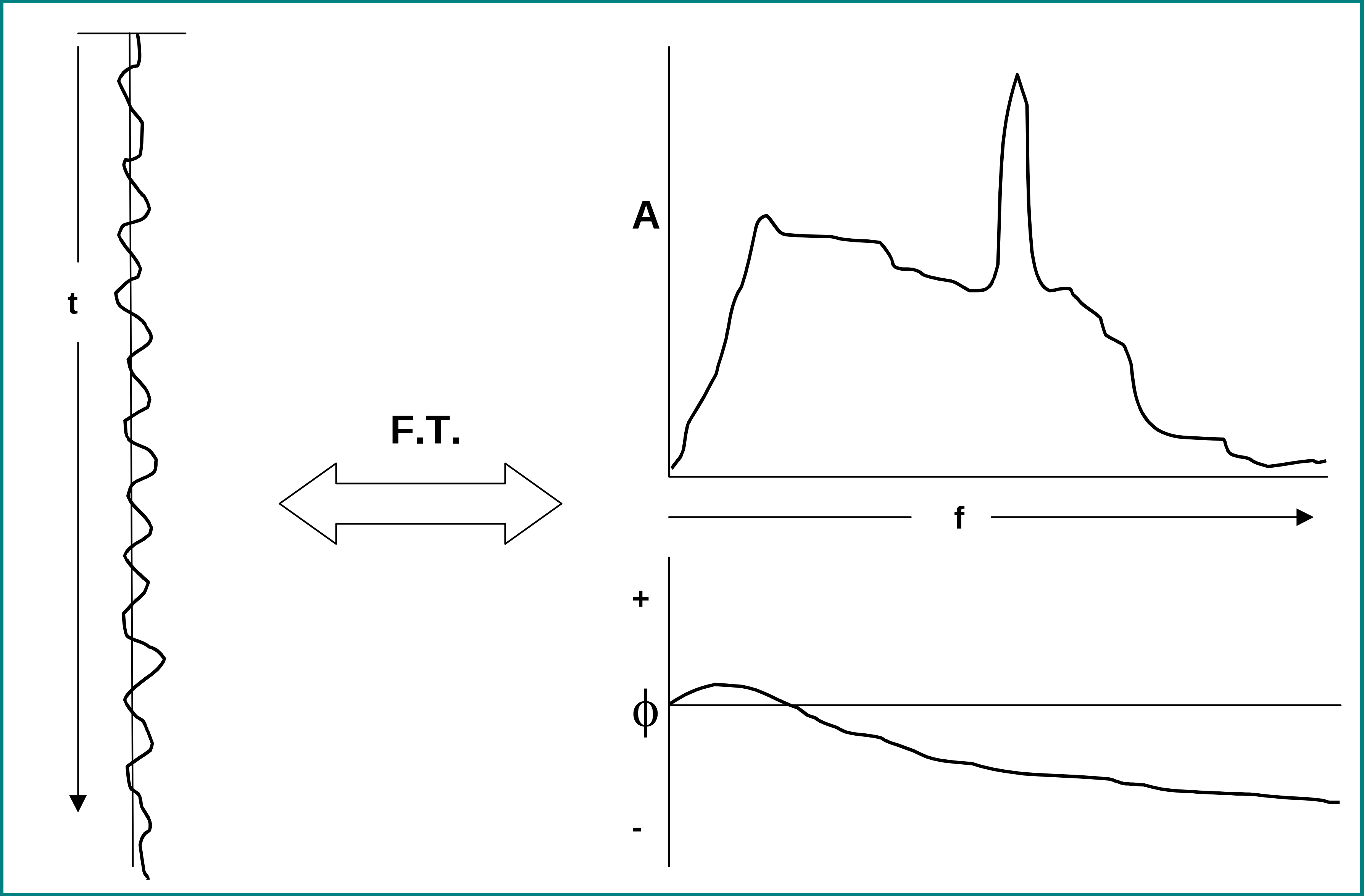
R-T fan transform of raw shot gather—ice wave on radial trace is monochromatic



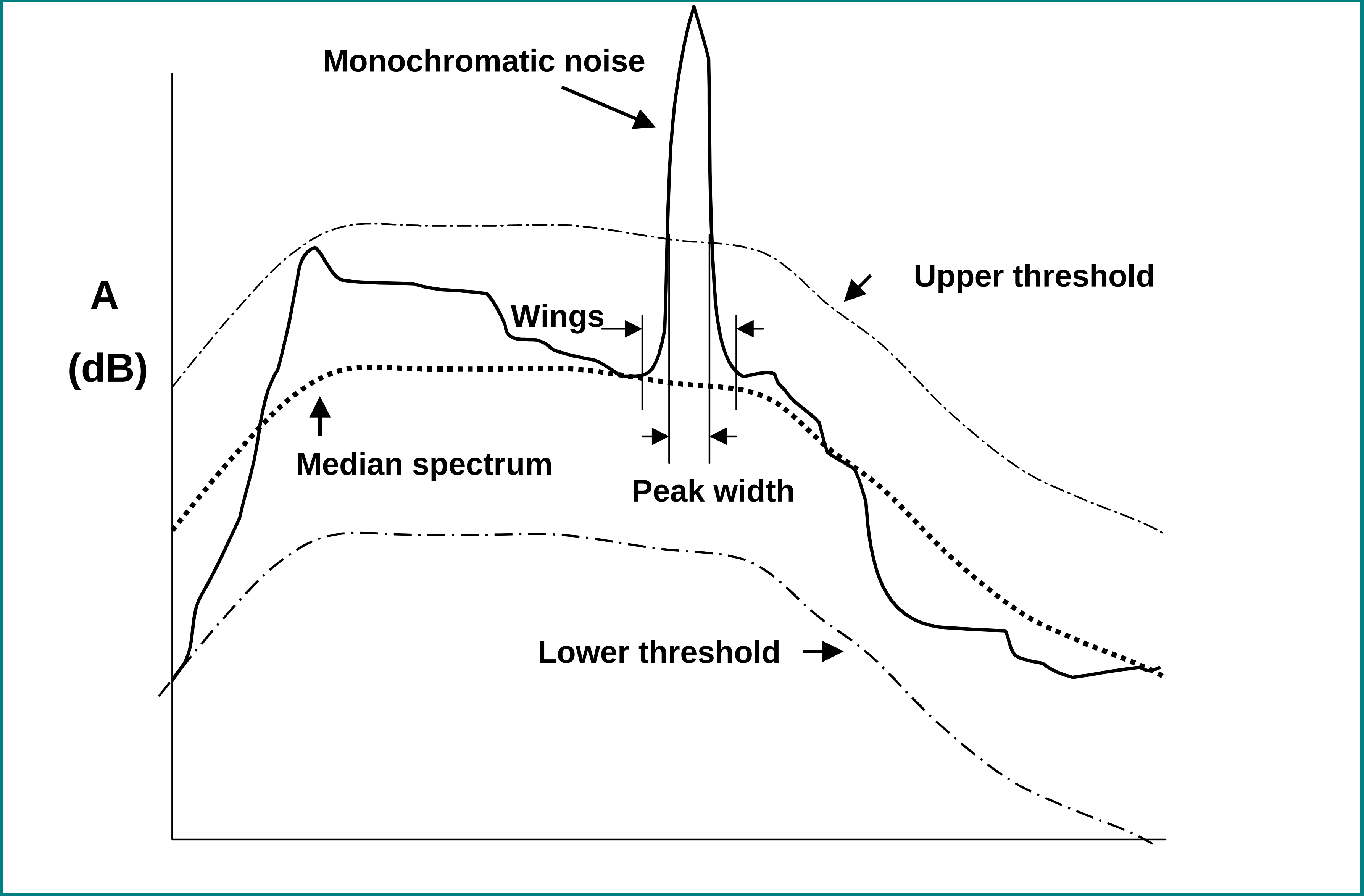
Spectrum of radial trace with ice wave noise

Editing the spectrum

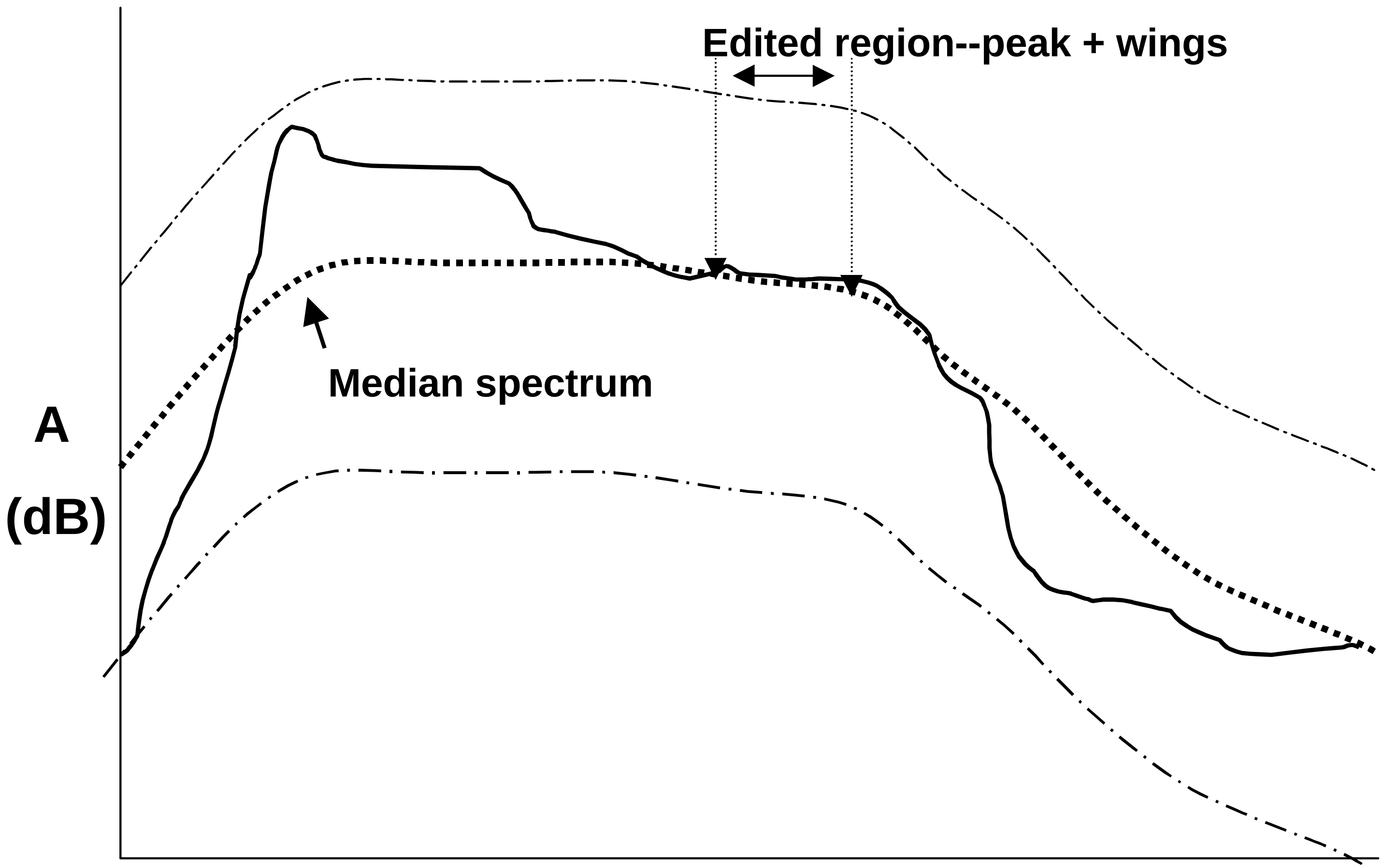
- Gabor deconvolution—***linear***, more effective on weaker, less monochromatic noise
- Spectral clipping—***nonlinear***, most effective on the strongest, most monochromatic noise



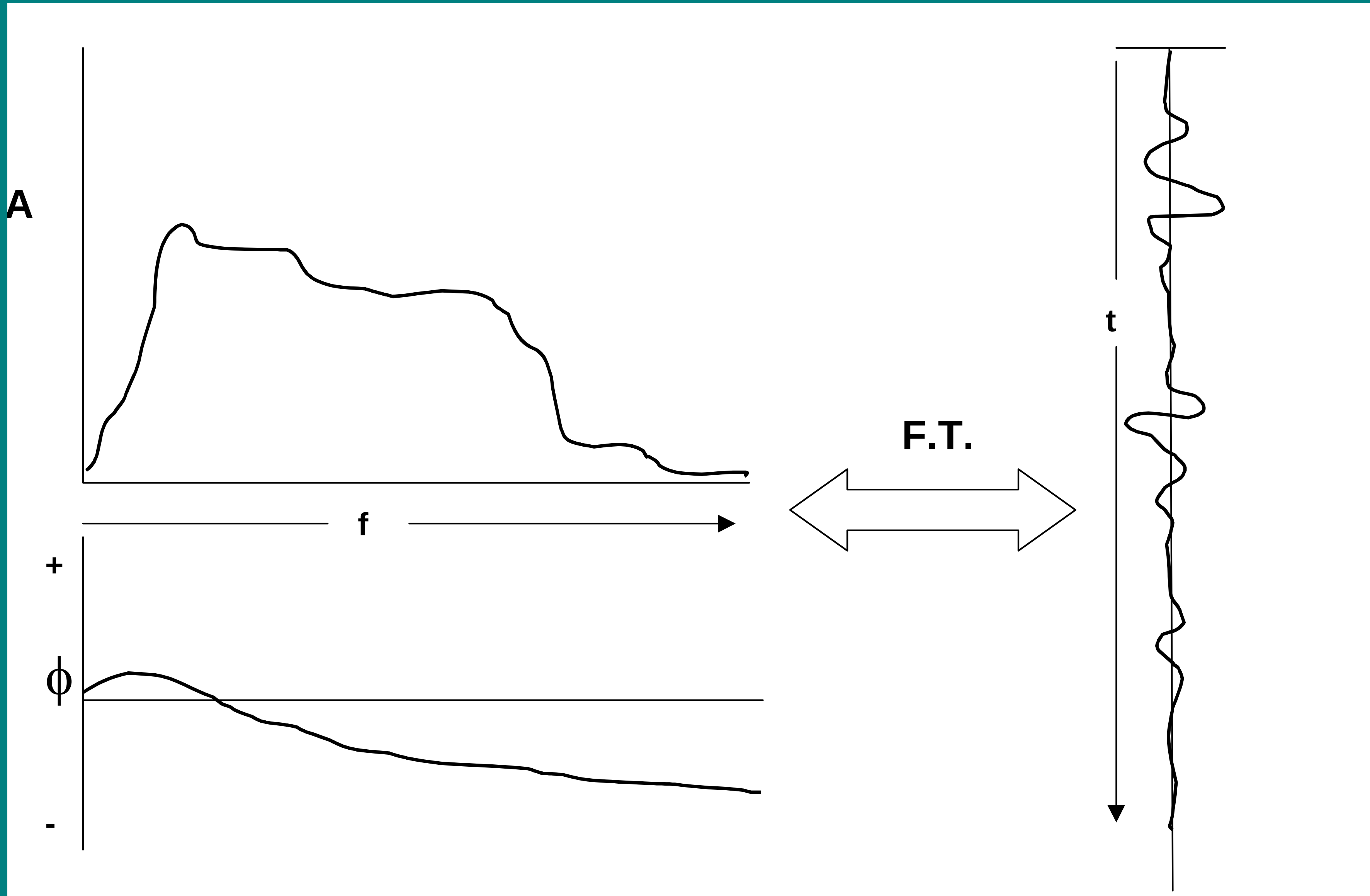
Seismic trace contaminated with monochromatic noise is transformed to frequency domain



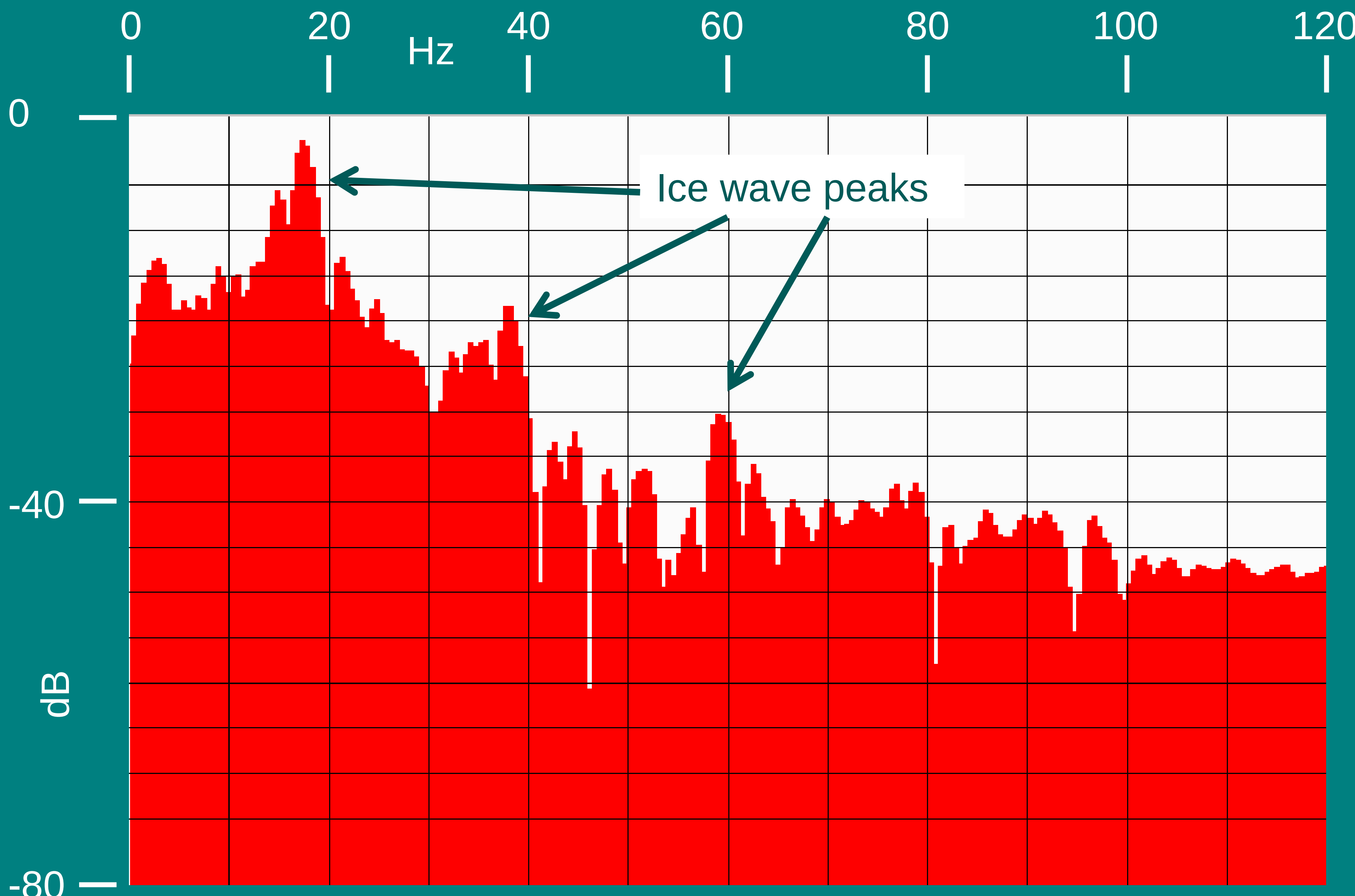
Median spectrum computed from raw spectrum; threshold curves placed parallel to median; peaks in raw spectrum exceeding threshold are flagged



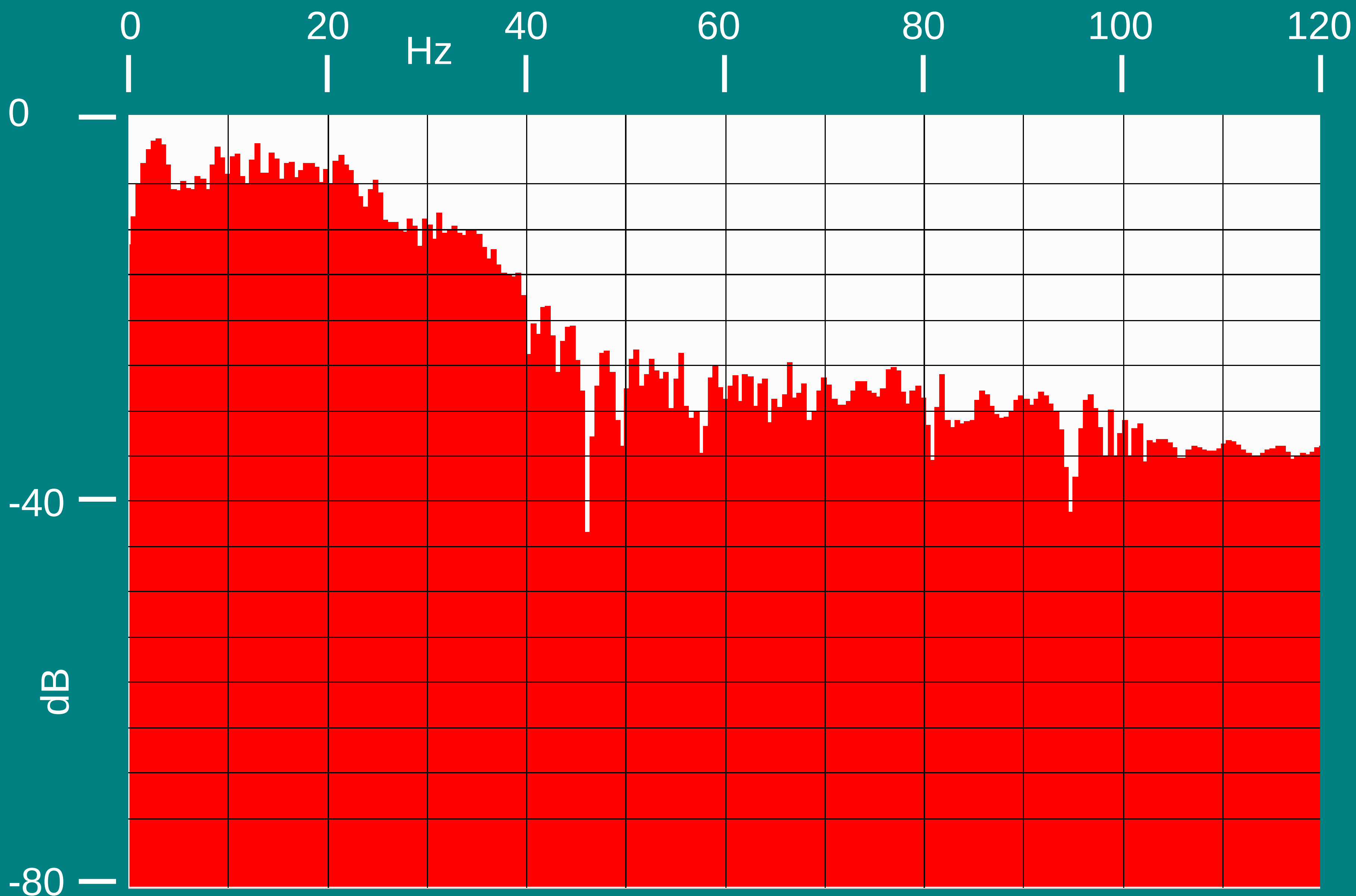
Flagged raw spectral amplitudes are replaced with median values, phase is unaltered



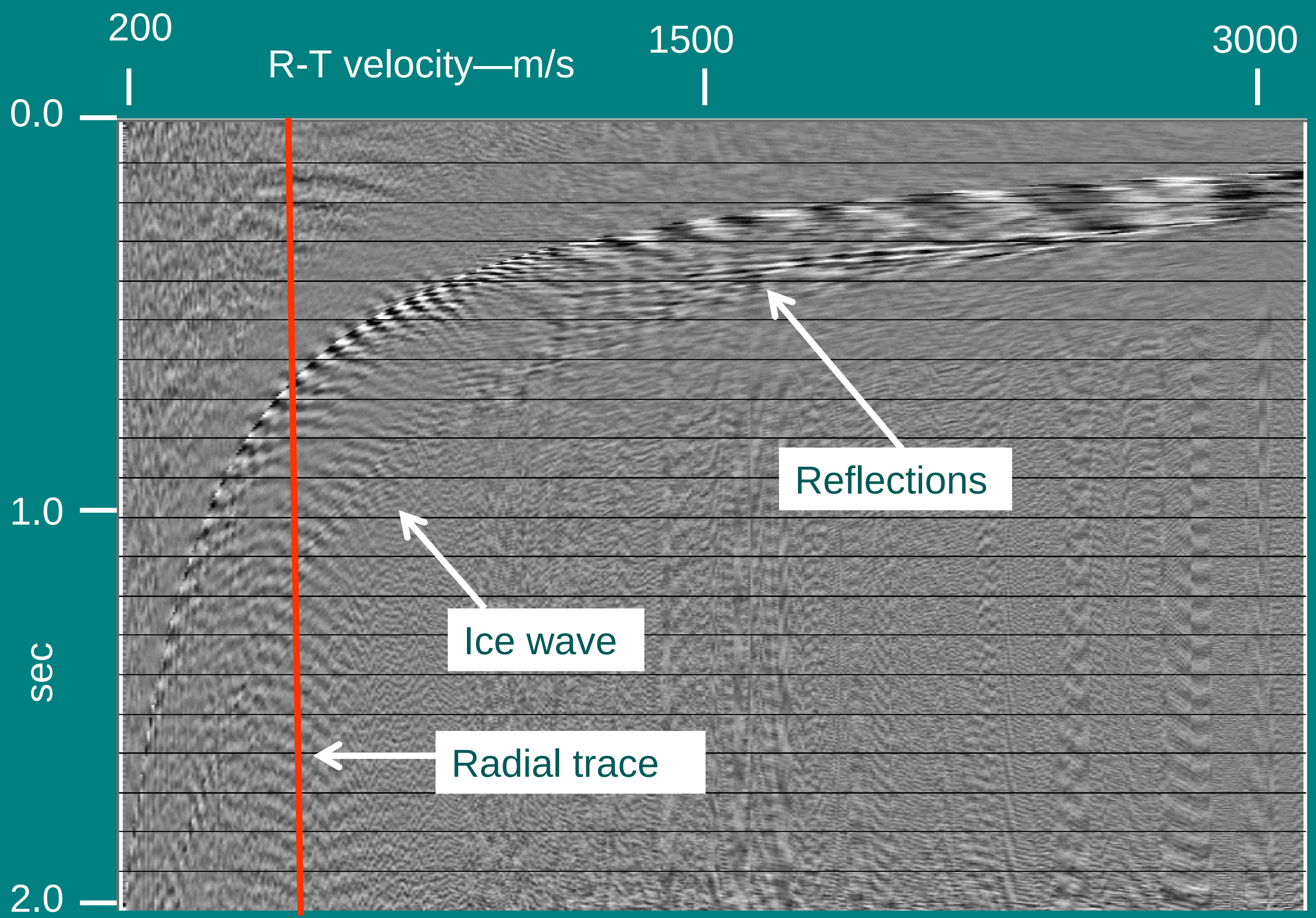
Edited spectrum is transformed back to seismic trace, sans monochromatic noise



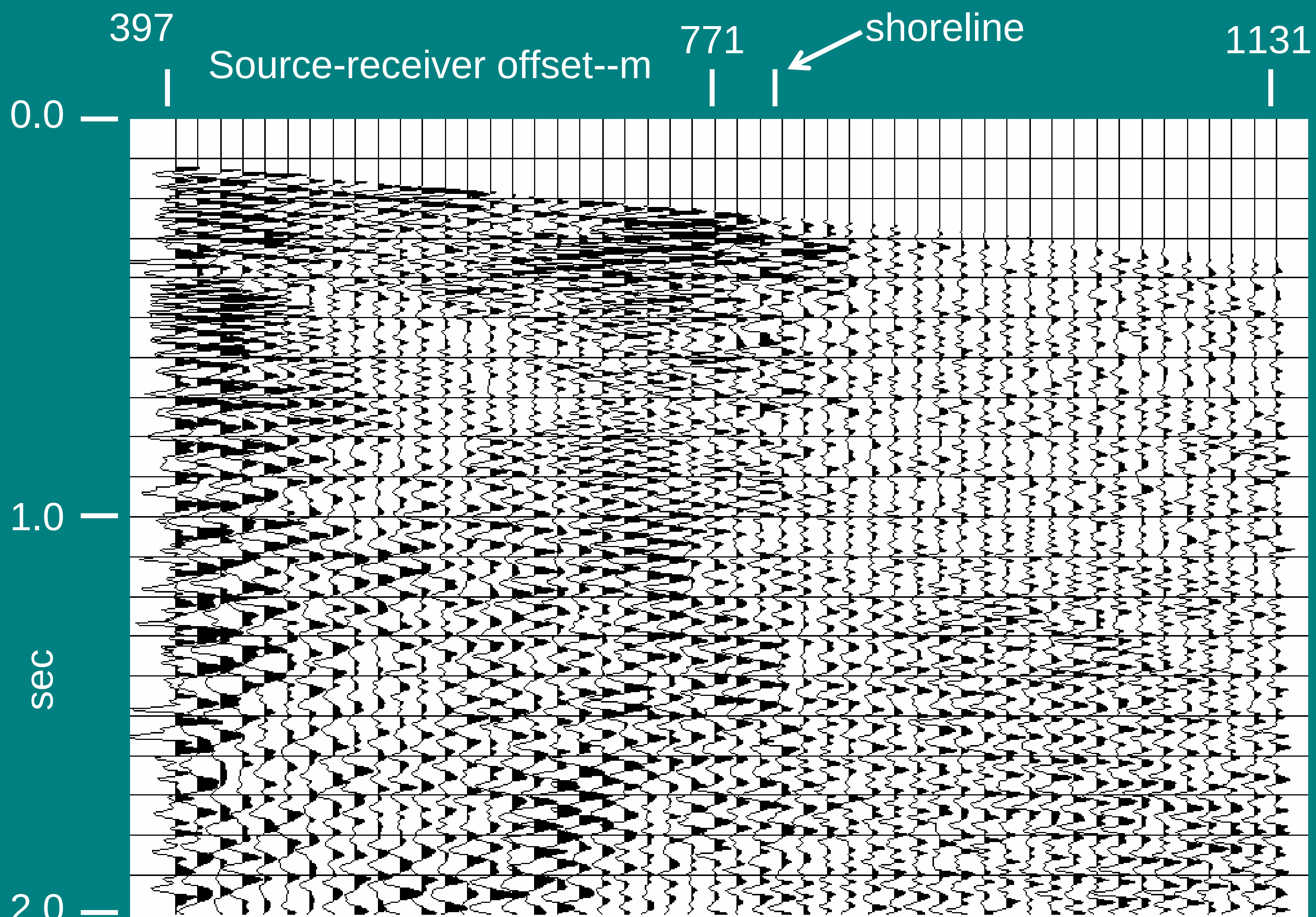
Spectrum of radial trace with ice wave noise



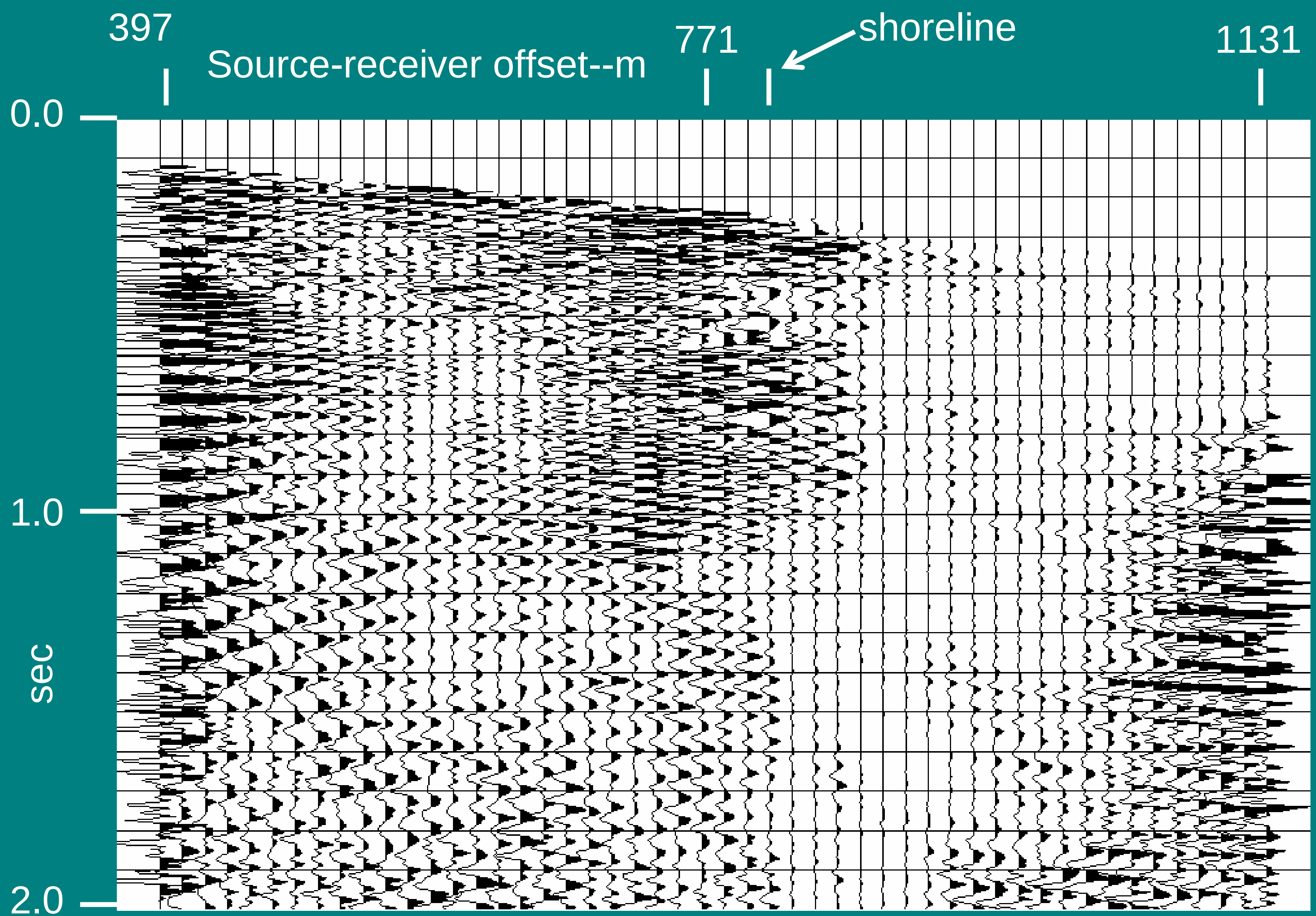
Spectrum of radial trace with ice wave noise after spectral clipping



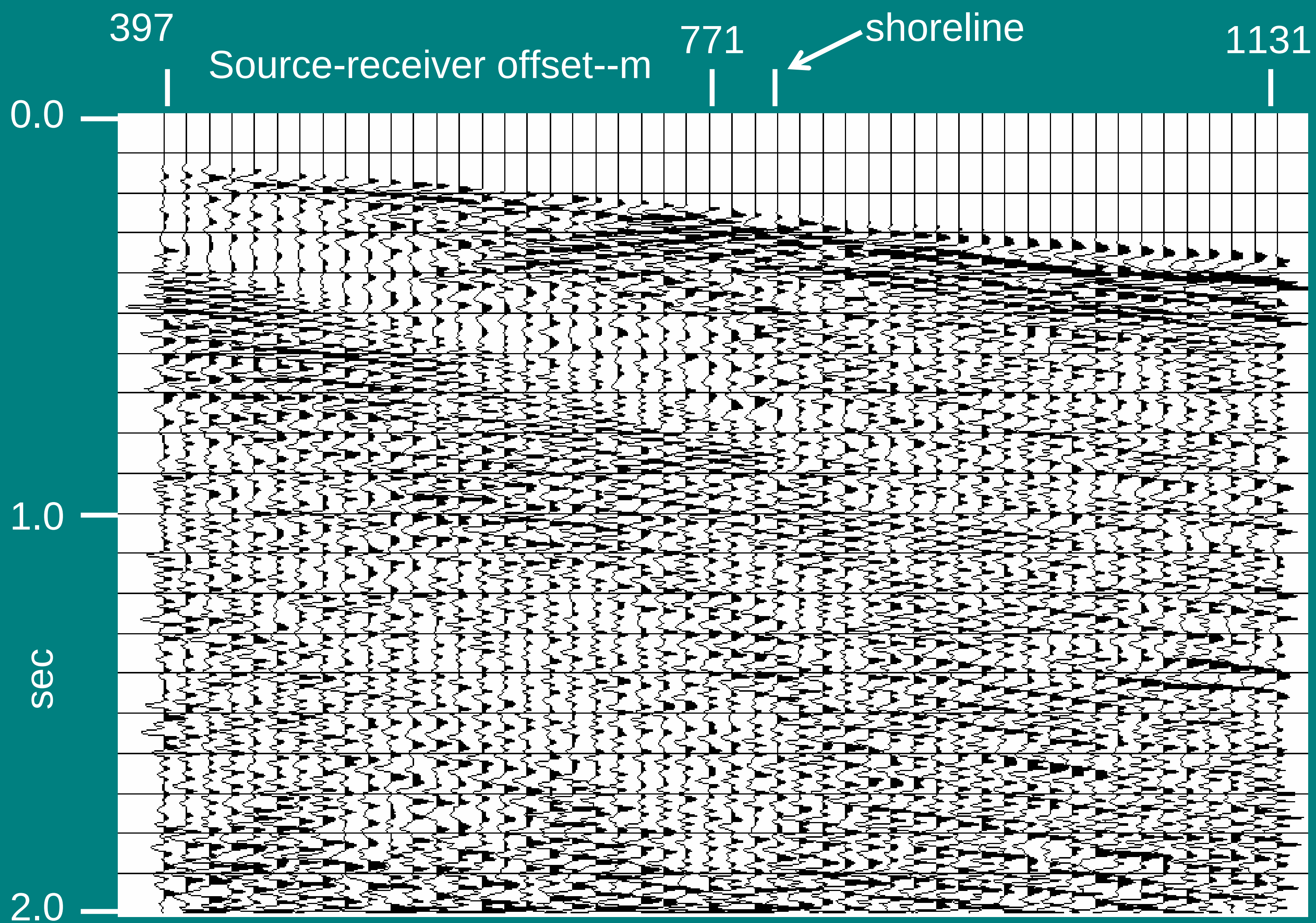
R-T fan transform of raw shot gather after spectral clipping—monochromatic noise greatly attenuated



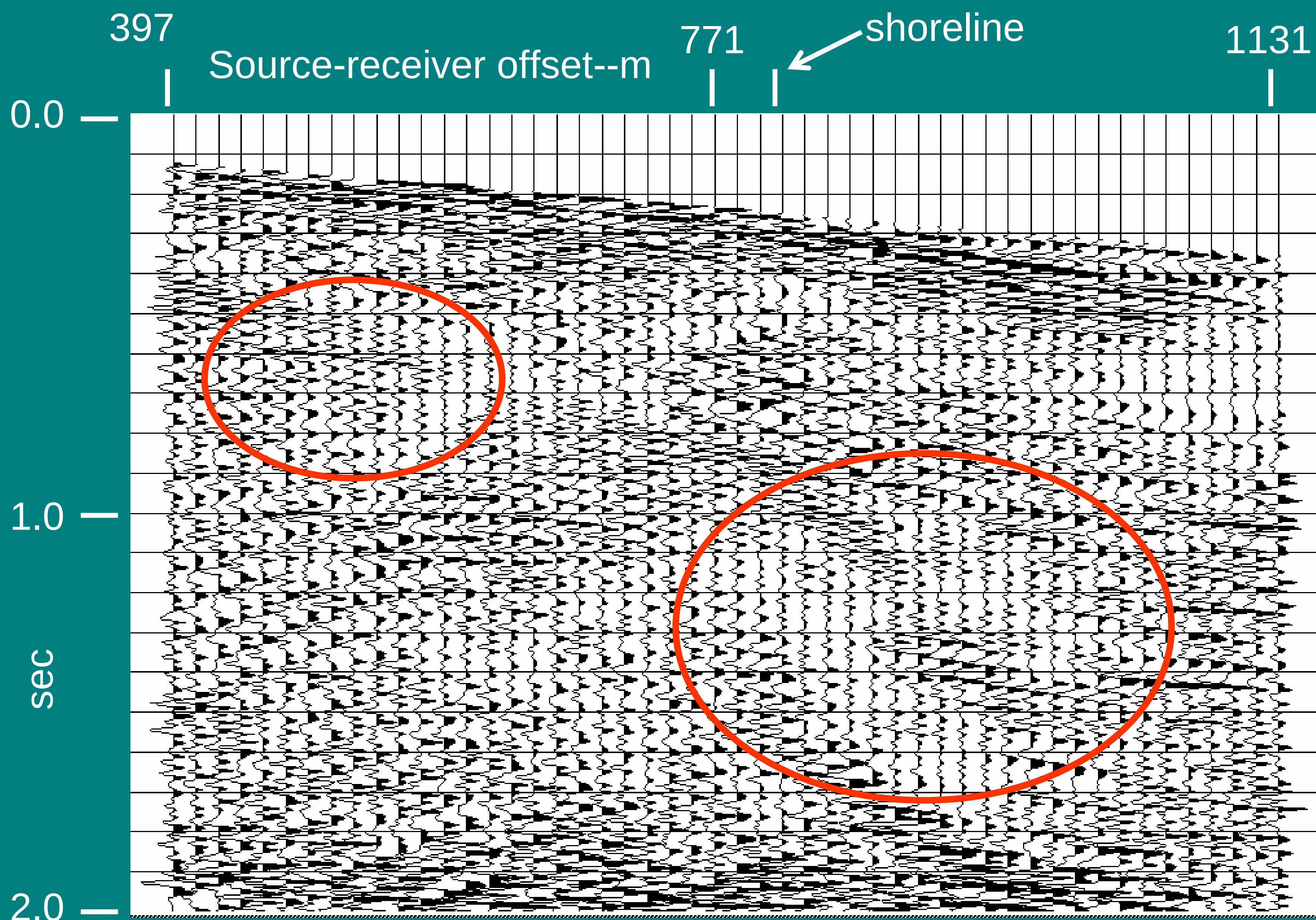
Spectral clipping applied in R-T domain



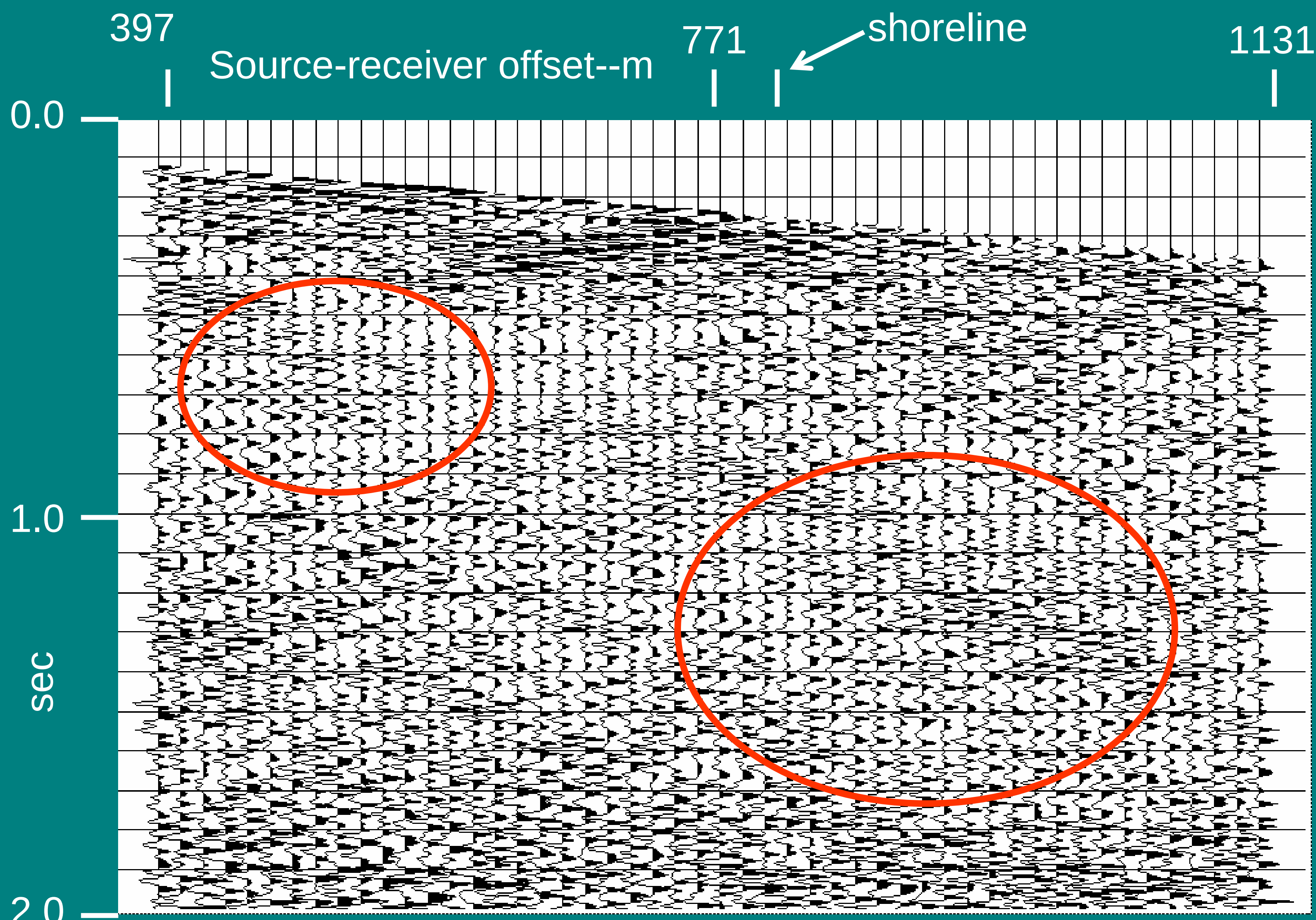
Gabor deconvolution applied in R-T domain



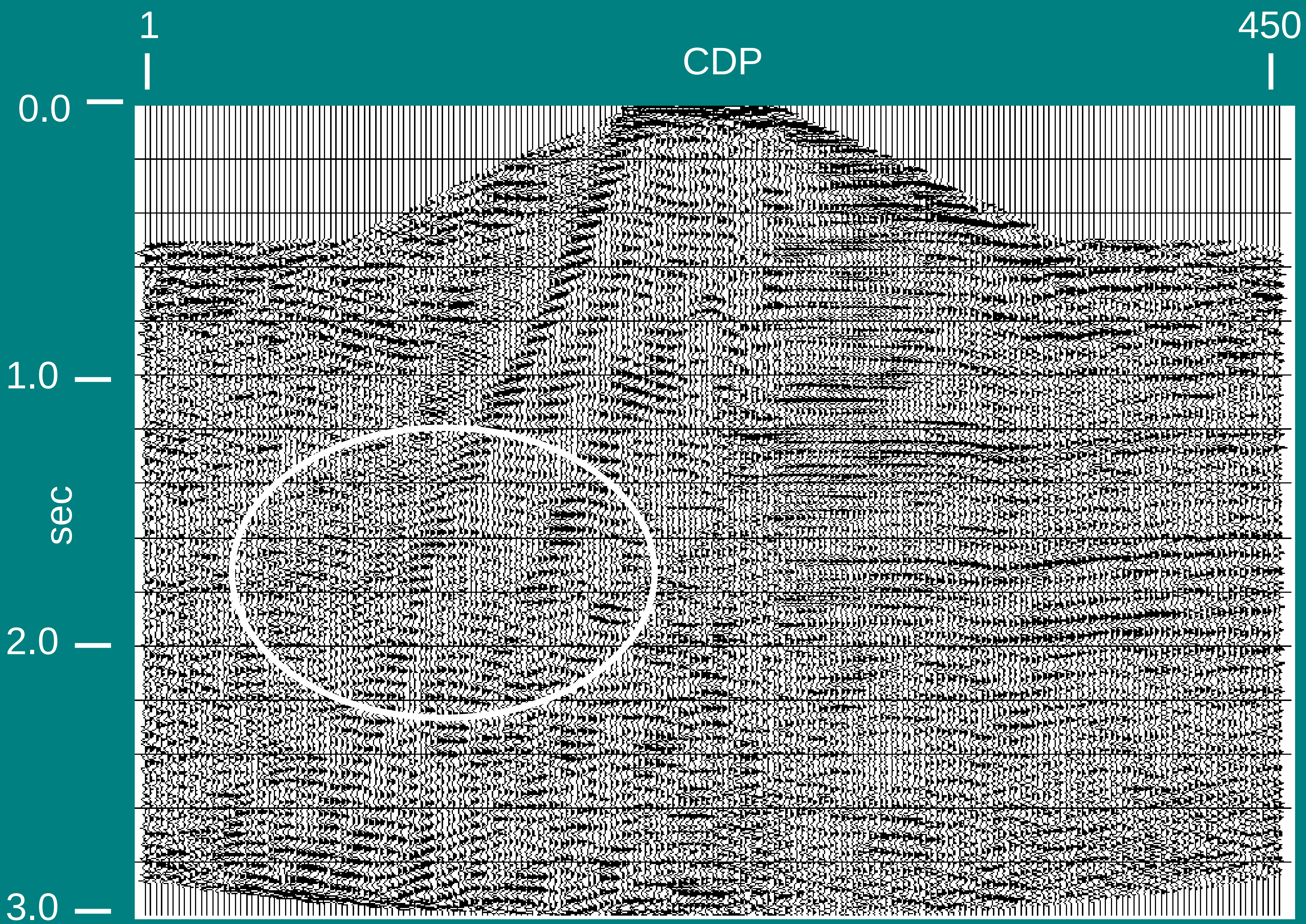
Gabor deconvolution applied in X-T domain—no R-T processing



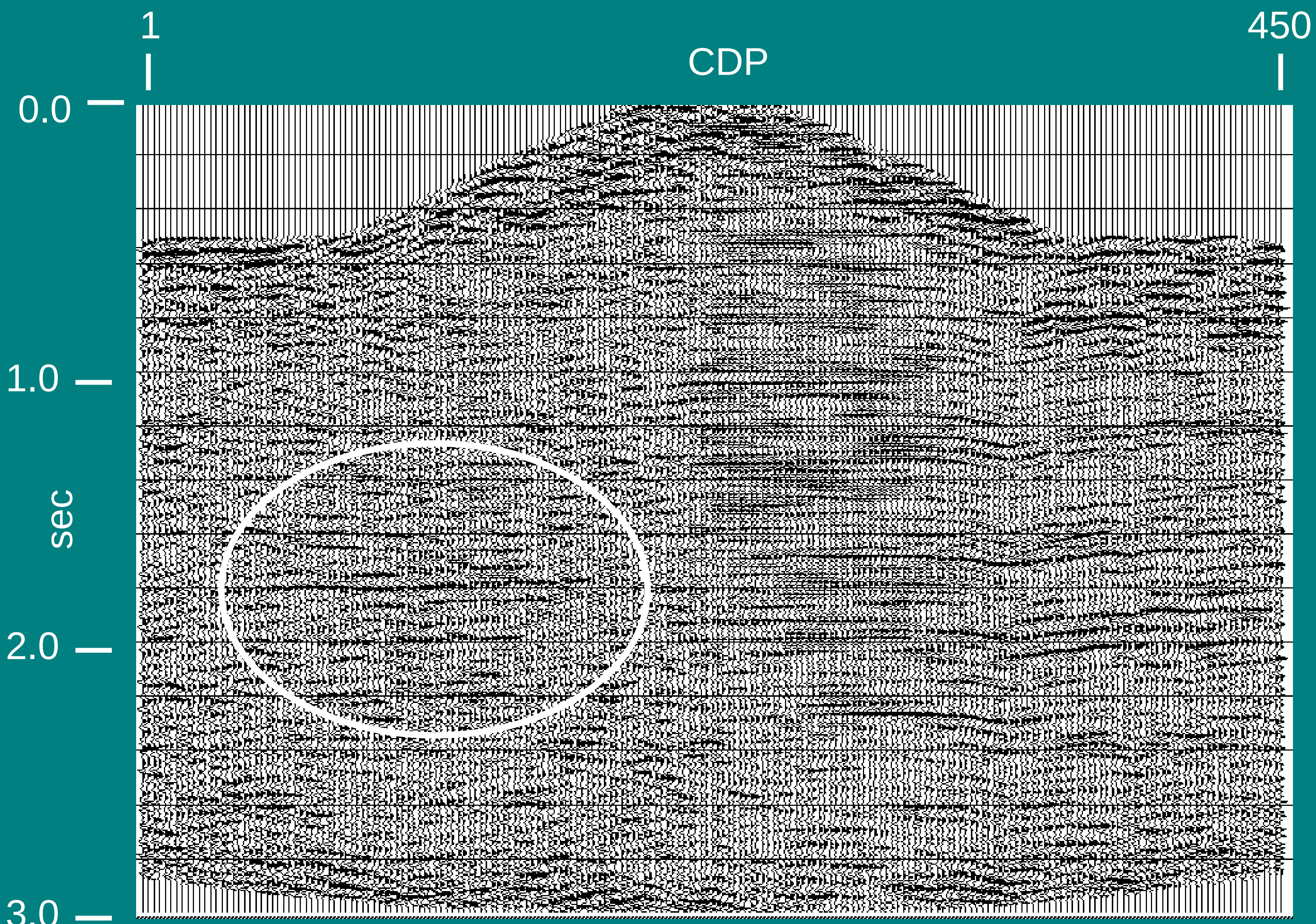
Gabor deconvolution applied in X-T domain—R-T domain Gabor deconvolution



Gabor deconvolution applied in X-T domain—R-T domain spectral clipping



Brute stack of Hansen Harbour line with no ice wave filtering



Brute stack of Hansen Harbour line after ice wave filtering

Conclusions

- Stacking alone is not sufficient to attenuate ice wave noise
- ***Ice wave should be properly spatially sampled during acquisition***
- R-T domain more effective than X-T domain for ice wave attenuation
- Spectral clipping marginally more effective than Gabor decon for strong ice wave

Acknowledgements

- Thanks to Sponsors and staff of CREWES for support and assistance
- Thanks also to Natalia Soubotcheva for focussing my attention on Hansen Harbour and the ice wave problem