Q estimation by a match-filter method

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CREWES

outline

- Background
- Theory of math-filter method
- Numerical test
  synthetic 1D, 2D data and field data
- Conclusions

Background

- Knowledge of Q is very desirable
  - inverse Q filtering
  - amplitude analysis
  - lithology, porosity, fluid or gas saturation
- Measurement of Q
  - VSP data (limited availability and coverage)
  - reflection data (rarely attempted)
  - sensitive to SNR

Theory of spectral-ratio method

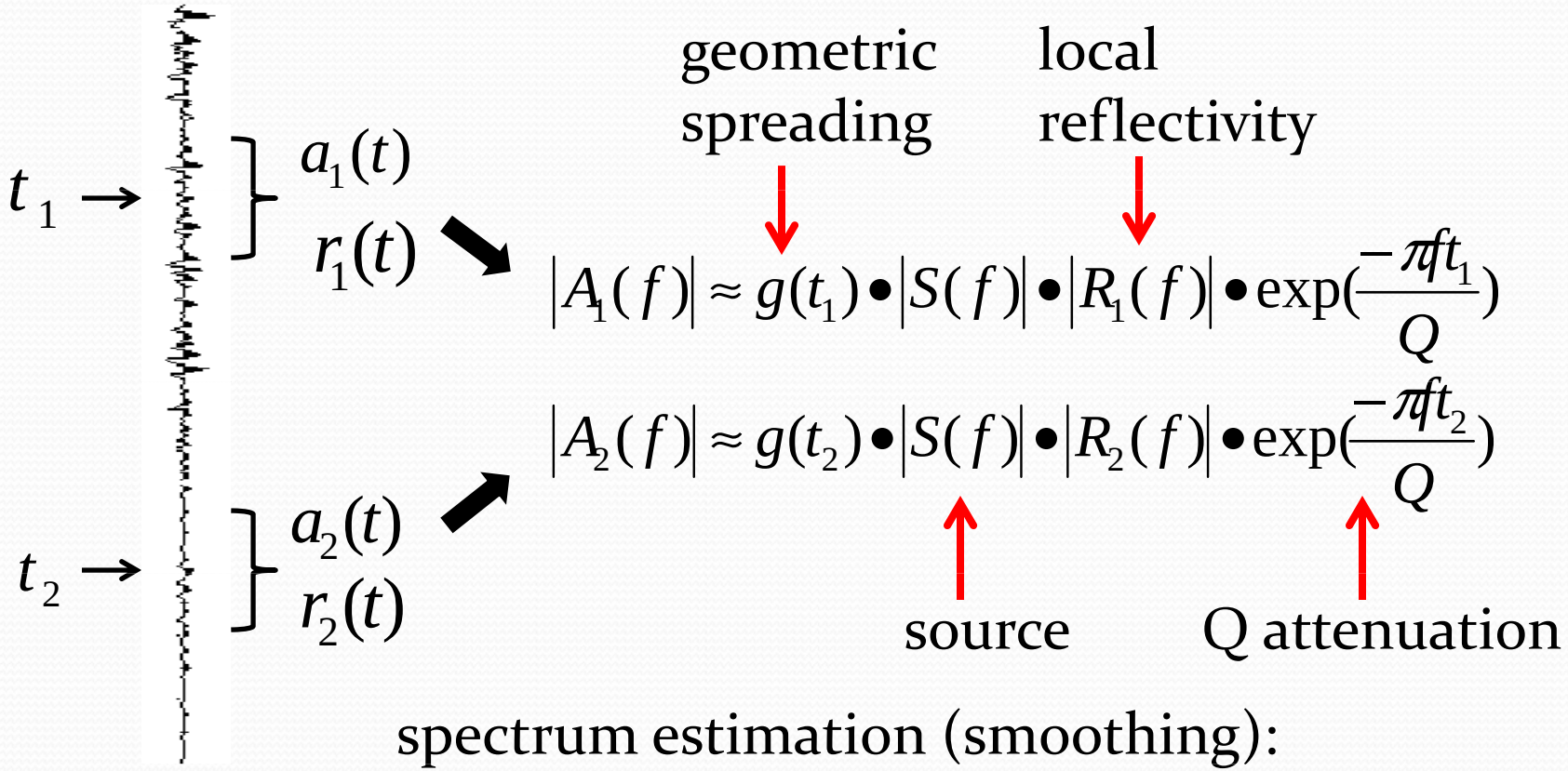
- classic spectral-ratio method (SR)

$$\ln\left(\frac{A_2(f)}{A_1(f)}\right) = \ln(G) - \frac{\pi f t}{Q}$$

$$Q = -\frac{\pi f t}{k}$$

k : the slope estimated from straight line fitting

Theory of match-filter method



spectrum estimation (smoothing):
multi-taper method (Thomson, 1982)

Theory of match-filter method

- match-filter method (MF)

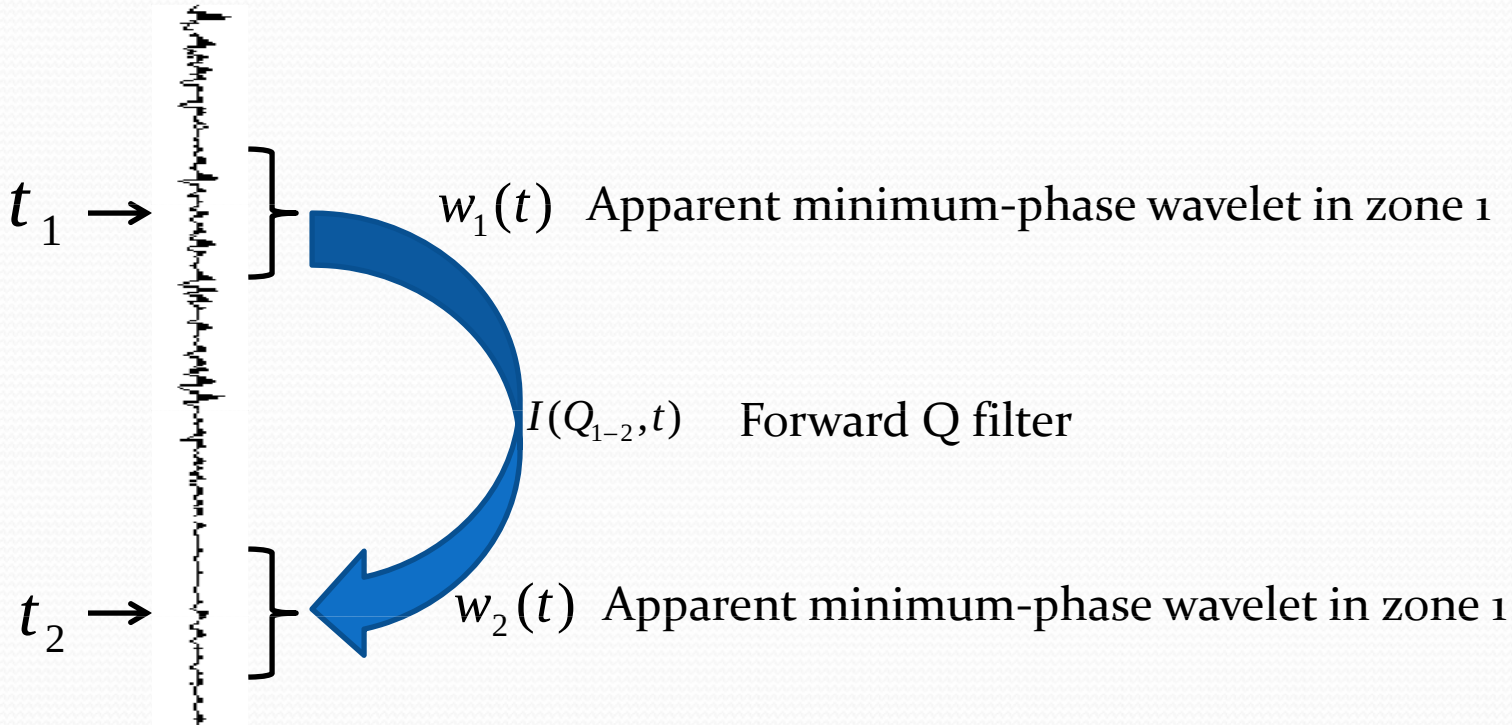
$$\overline{|A_1(f)|} \xleftrightarrow{Q?} \overline{|A_2(f)|}$$

attenuated embedded Wavelets (apparent wavelets)

$$\begin{cases} w_1(t) = F^{-1}\left(\overline{|A_1(f)|}\, e^{iH(\ln(\overline{|A_1(f)|}))}\right) \\ w_2(t) = F^{-1}\left(\overline{|A_2(f)|}\, e^{iH(\ln(\overline{|A_2(f)|}))}\right) \end{cases}$$

H: Hilbert transform

Theory of match-filter method



We seek the forward Q filter that best matches the apparent wavelet in zone 1 to that in zone 2

Theory of match-filter method

- match-filter method (MF)

$$Q_{est} = \min_{Q} \left\| w_1(t) * I(Q,t) - \mu w_2(t) \right\|^2$$

match filter: $$I(Q,t) = F^{-1}(\exp(\frac{-\pi f (t_2 - t_1)}{Q}) - iH(\frac{-\pi f (t_2 - t_1)}{Q}))$$

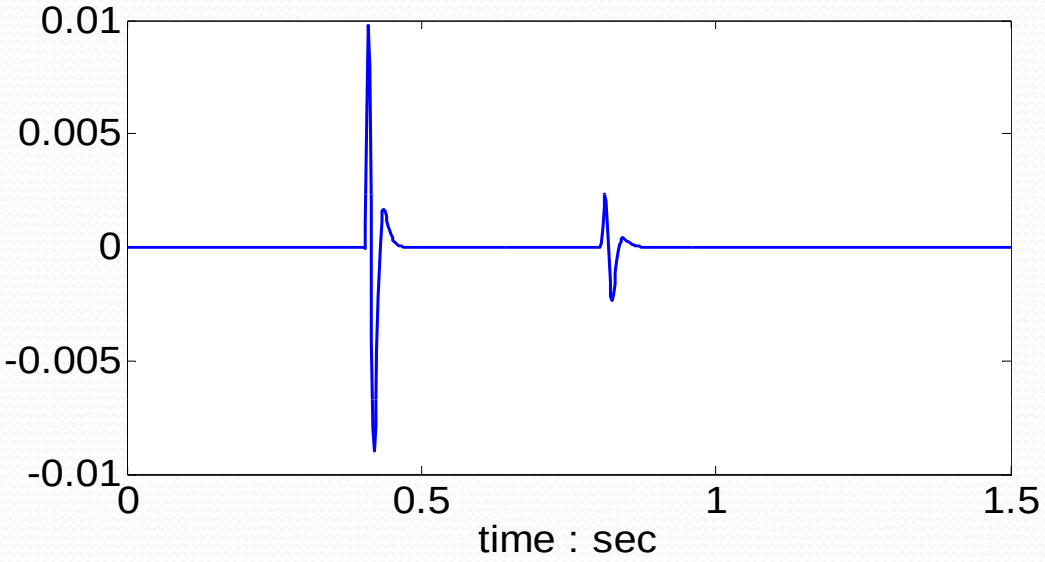
scaling factor: $$\mu = \frac{\int_{-\infty}^{\infty} (w_1(t) * I(Q,t)) \bullet w_2(t) dt}{\int_{-\infty}^{\infty} w_2{}^2(t) dt}$$

Numerical test

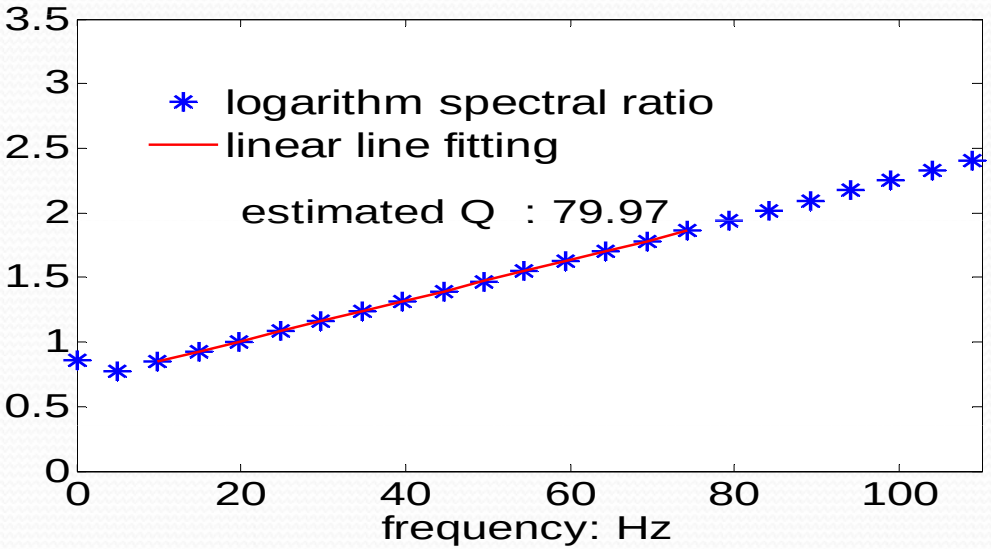
Case 1

- 1D Synthetic VSP data
- reflection data with isolated reflectors

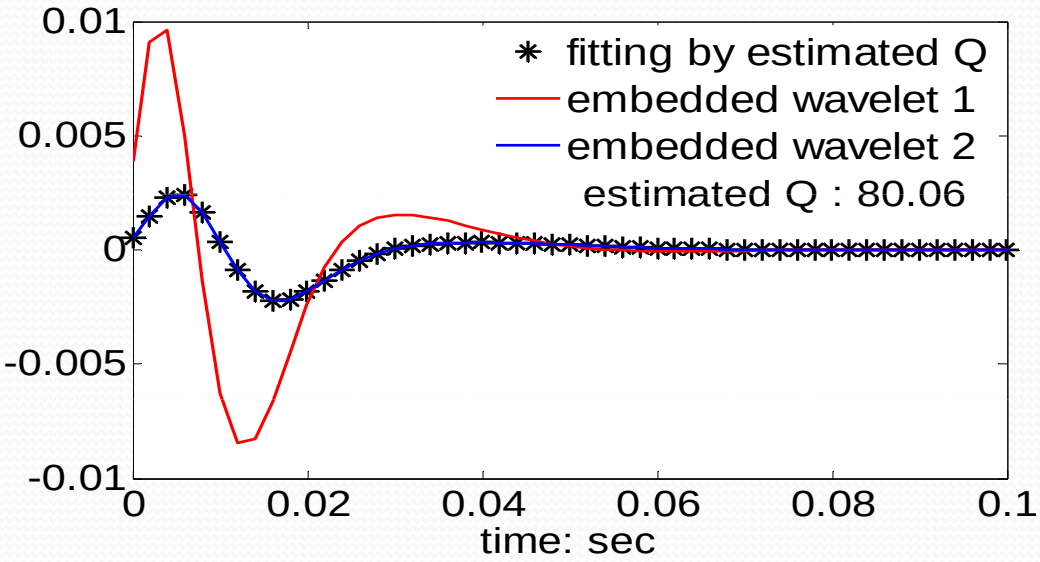
Attenuated seismic trace
Q = 80
(VSP data)



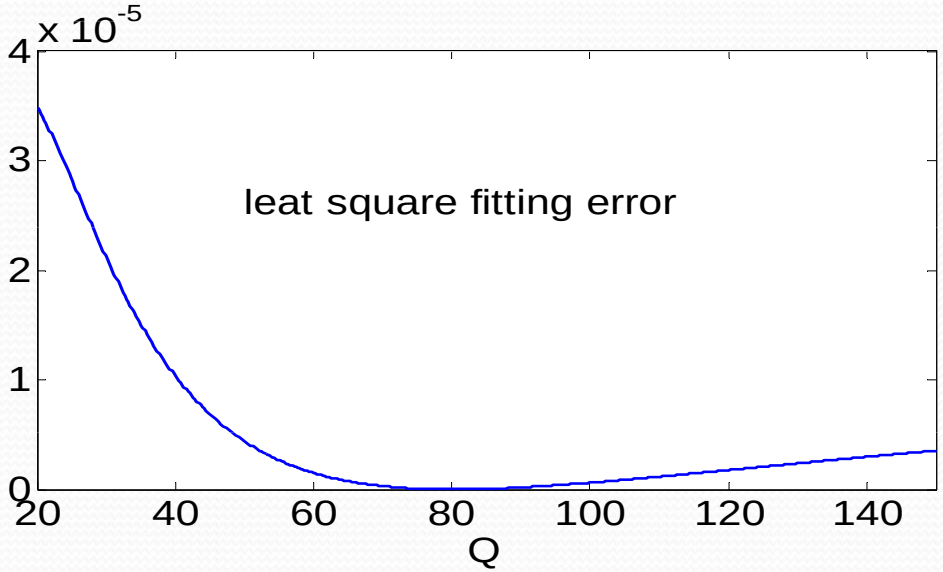
Q estimation
SR



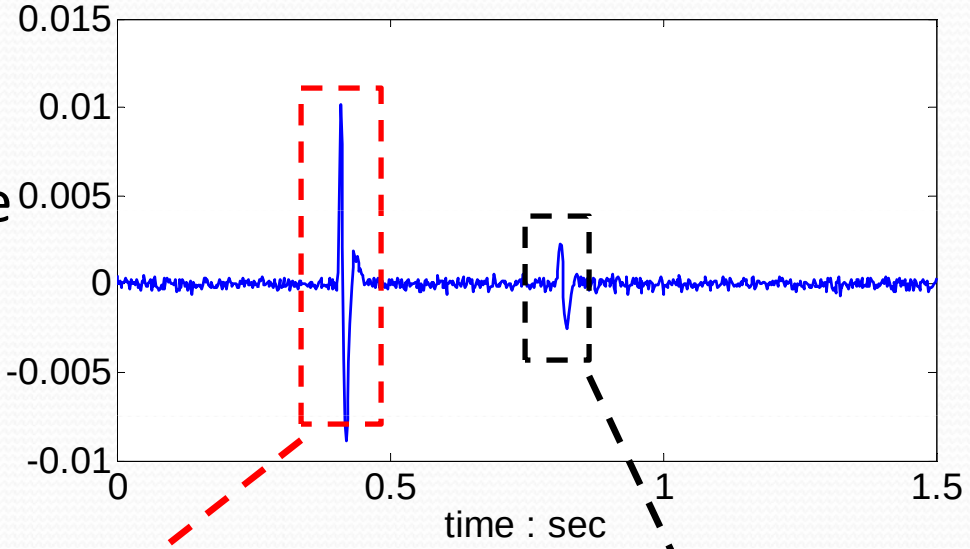
Q estimation
MF

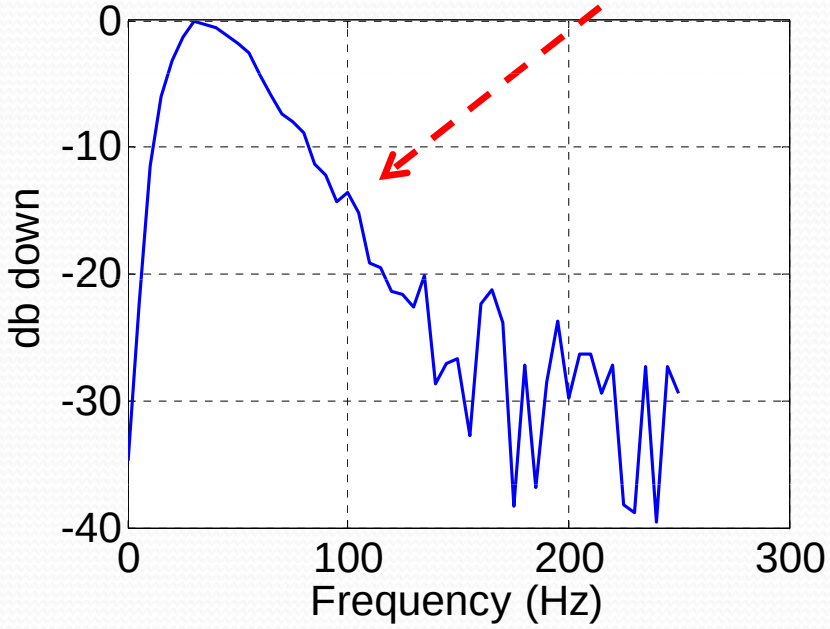


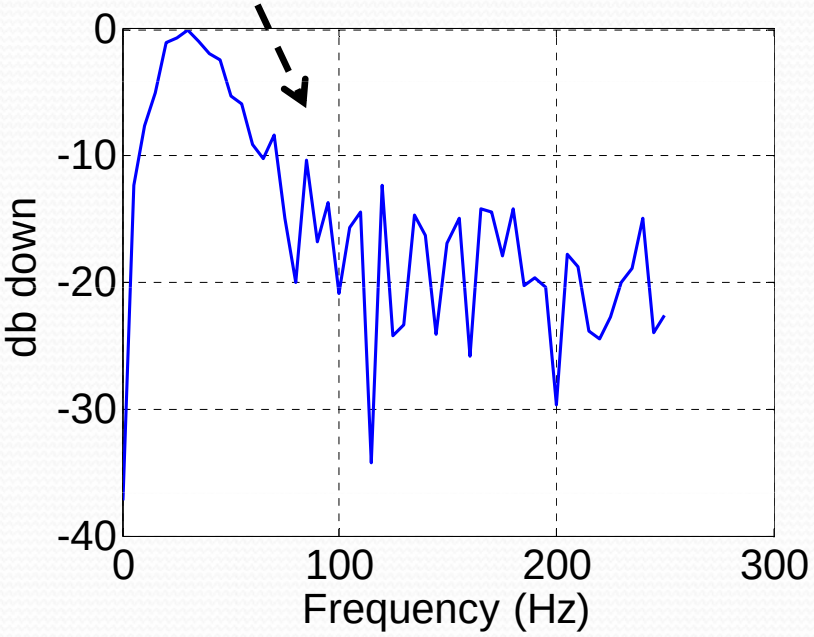
fitting error curve
for Q values



Noisy seismic trace
(VSP data)
Q = 80 SNR = 4







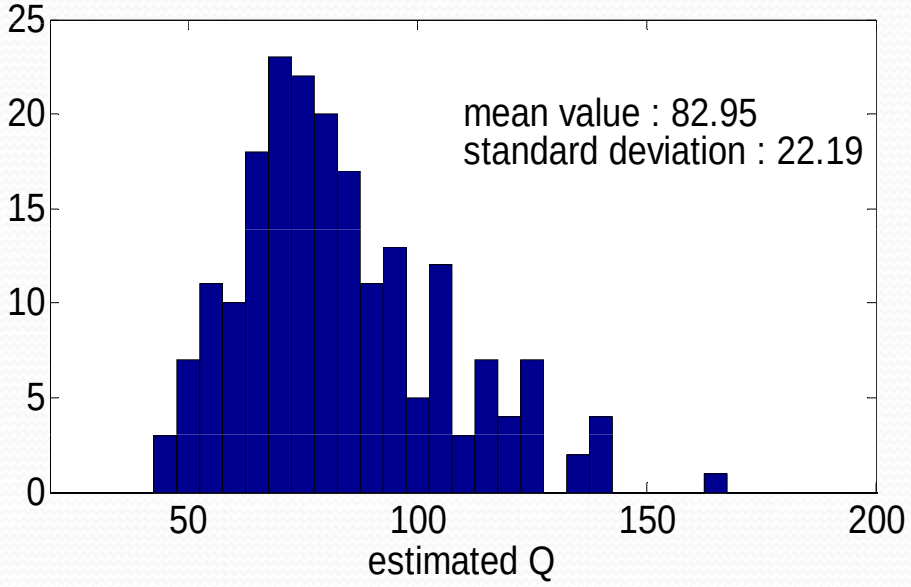
SR

VSP data

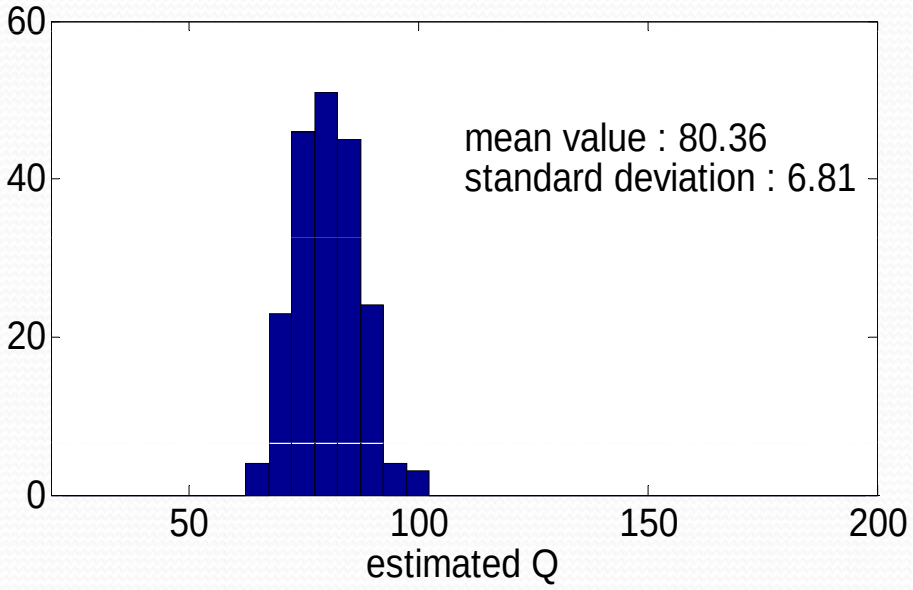
200 tests

Q = 80

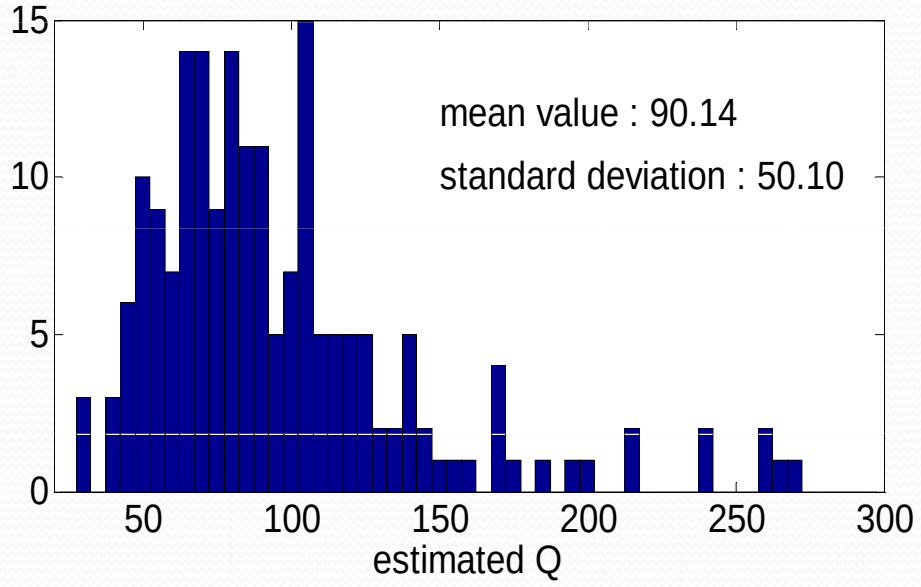
SNR = 4



MF



SR



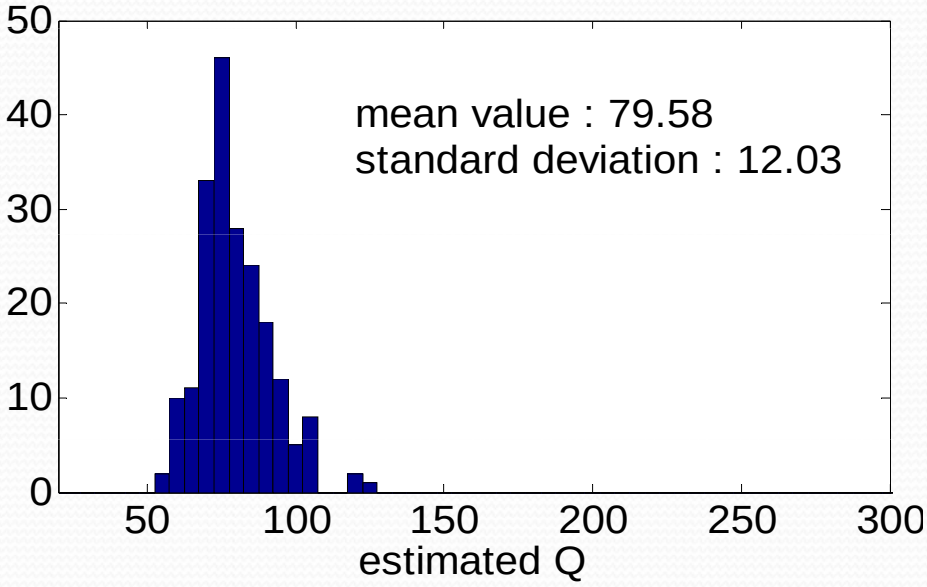
VSP data

200 tests

Q = 80

SNR = 2

MF

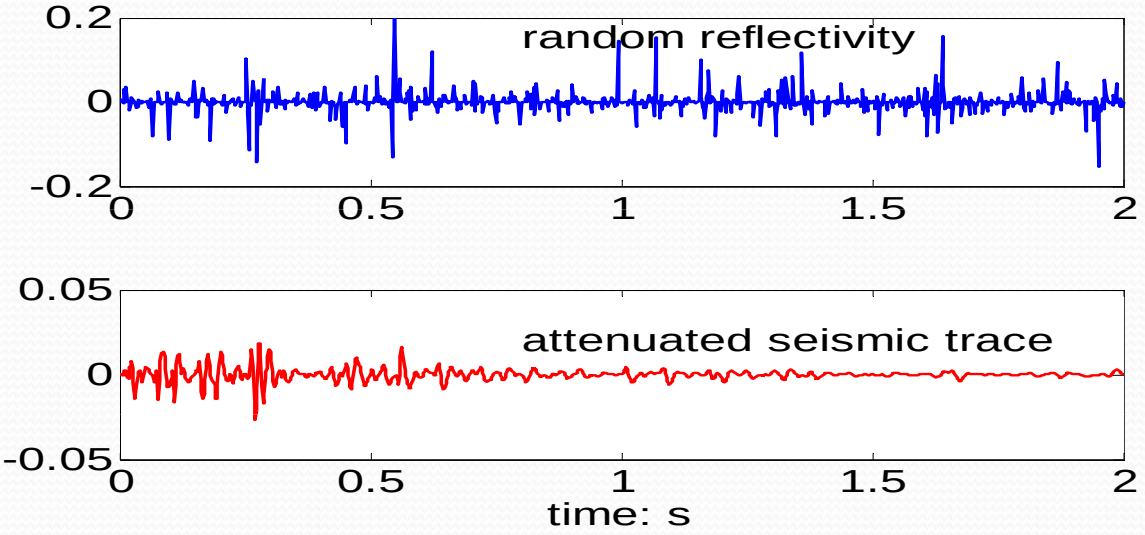


Numerical test

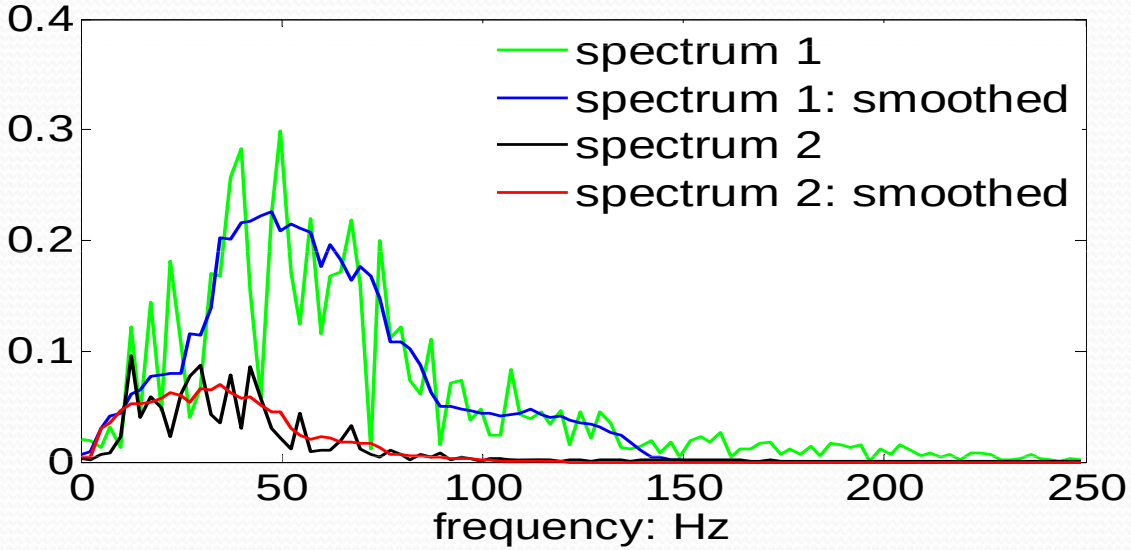
Case 2

- 1D synthetic reflection data

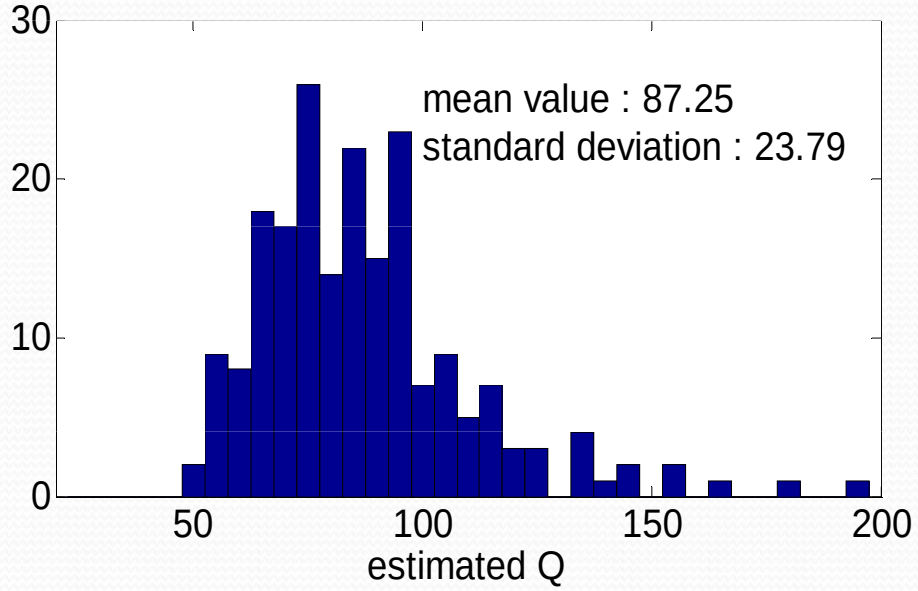
Attenuated seismic trace
Q = 80



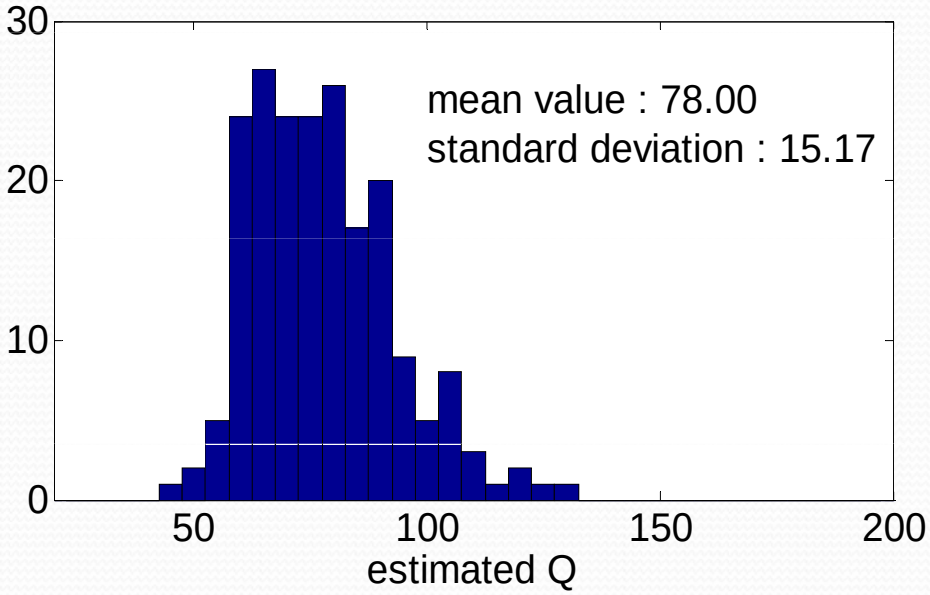
Spectra of local reflected waves
#1 100 - 500ms
#2 900 - 1300ms



200 seismic traces
Q = 80
Noise free
Local waves:
#1 100 - 500ms
#2 900 - 1300ms



SR



MF

200 seismic traces

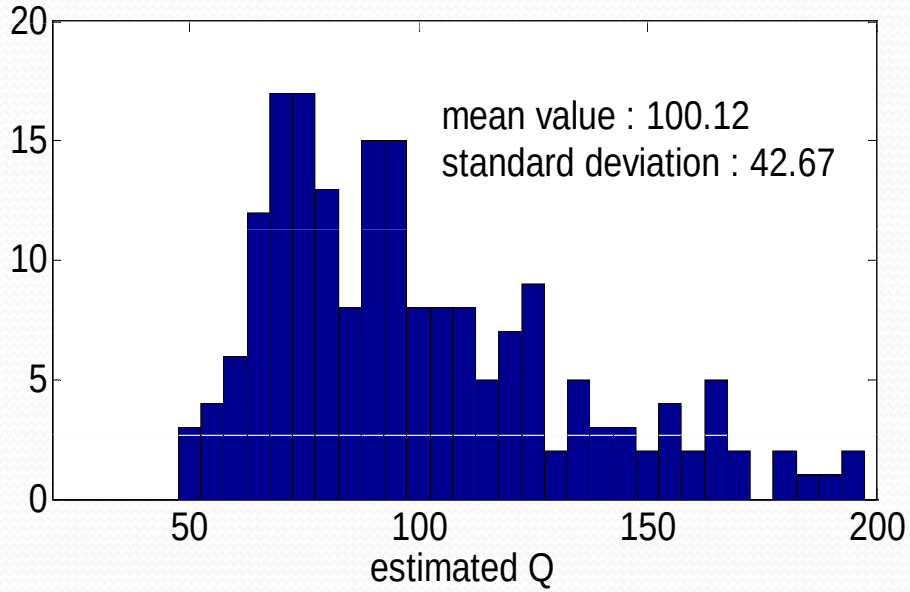
Q = 80

SNR = 4

Local waves:

#1 100 - 500ms

#2 900 - 1300ms



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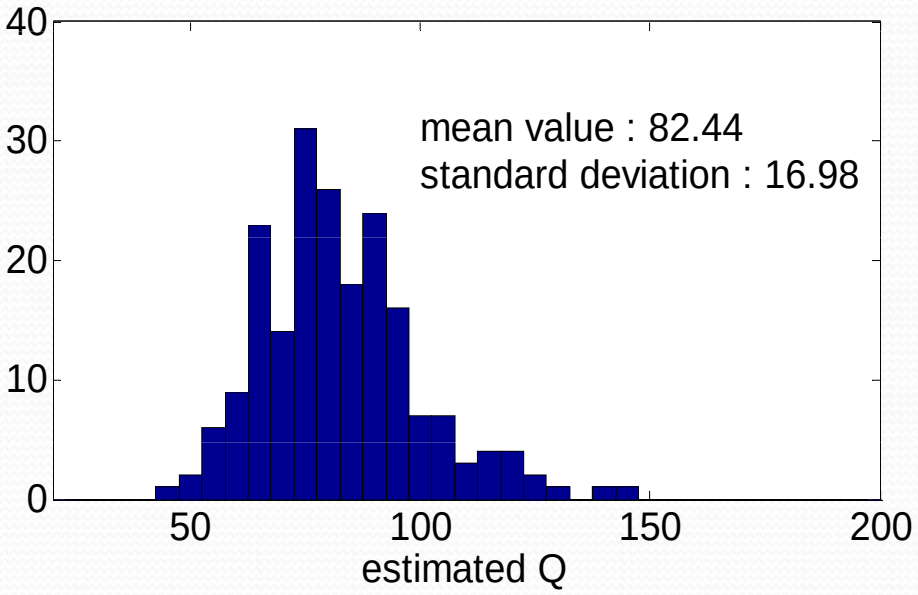


MF

200 seismic traces

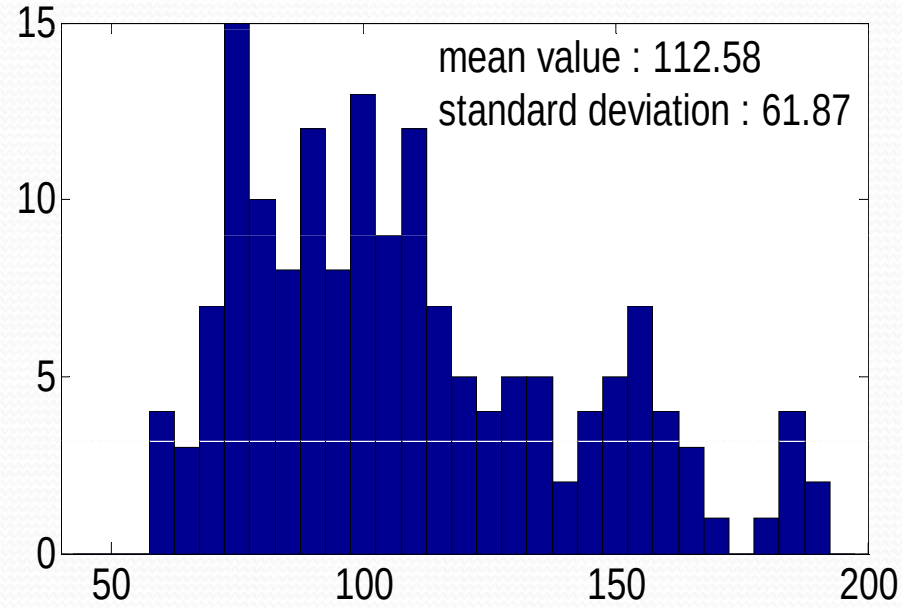
Q = 80

SNR = 2

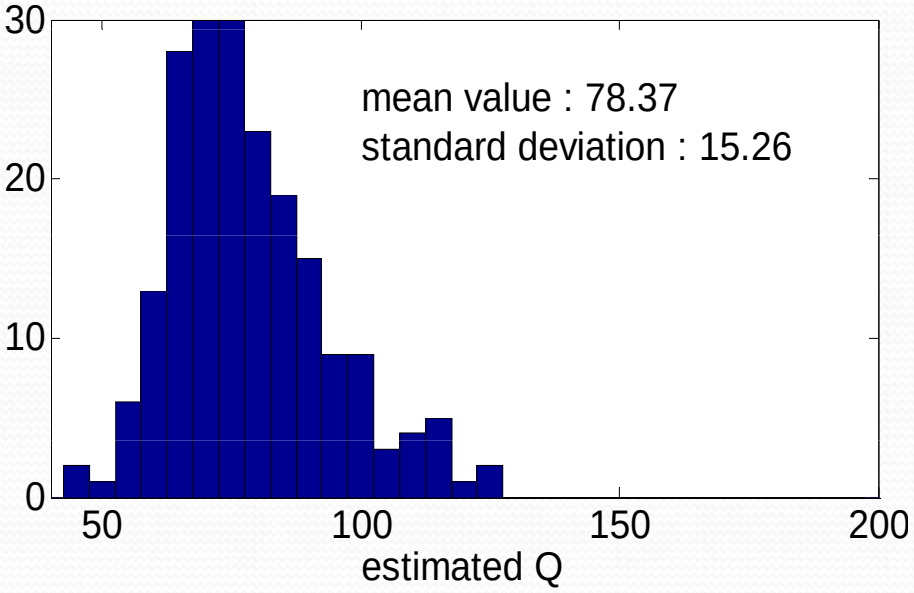
Local waves:

#1 100 - 500ms

#2 900 - 1300ms



SR



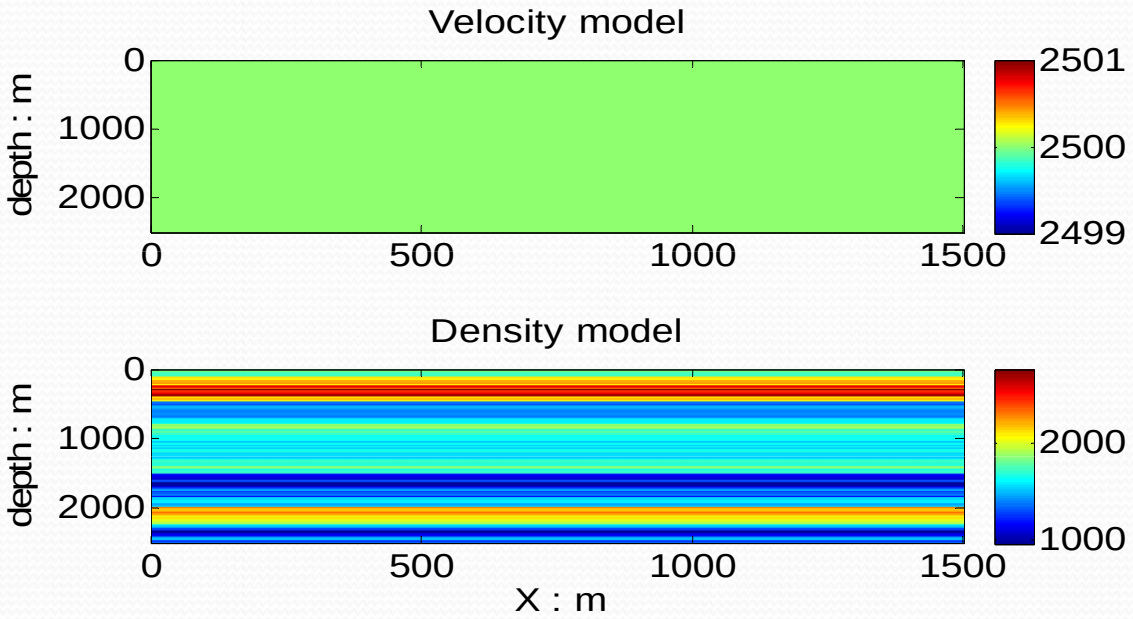
MF

Numerical test

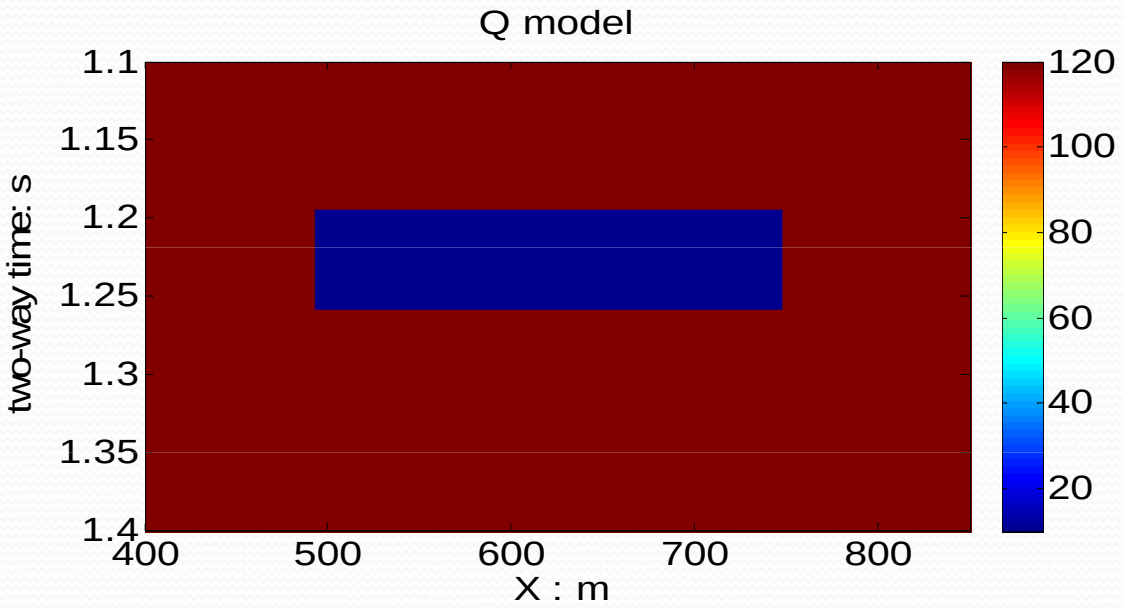
Case 3

- 2D synthetic reflection data

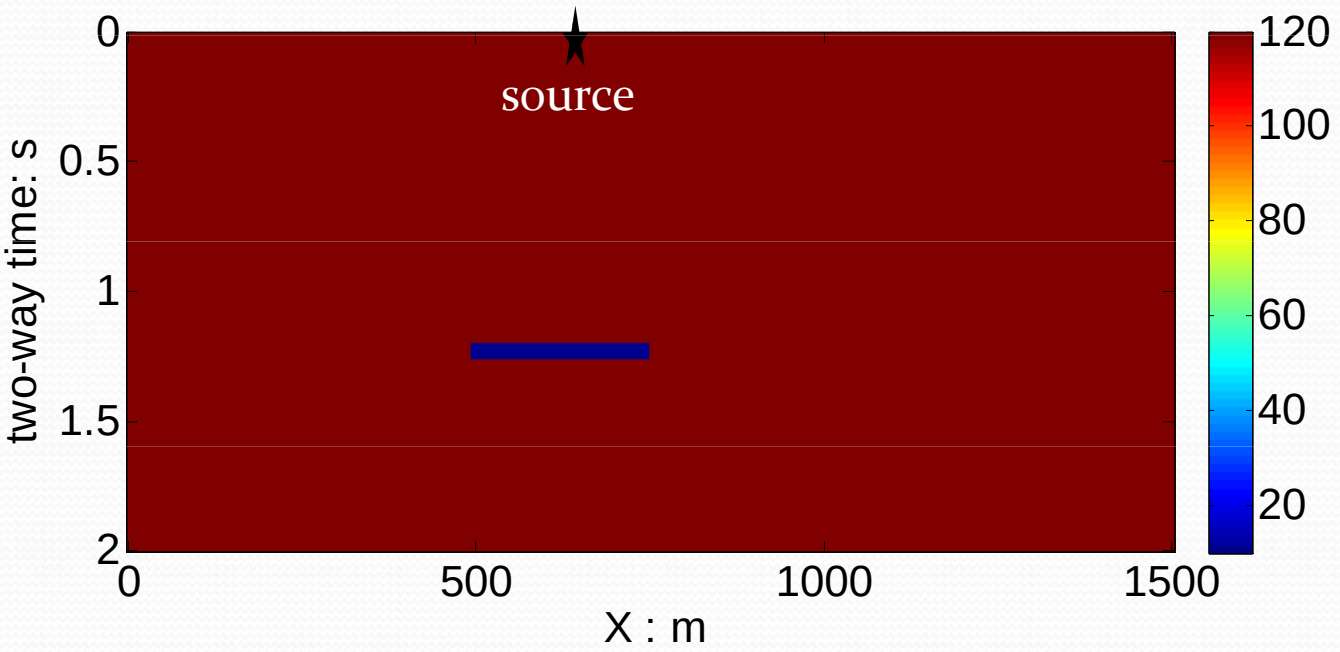
Layered earth model
X: 0 - 1500m
Z: 0 - 2500m

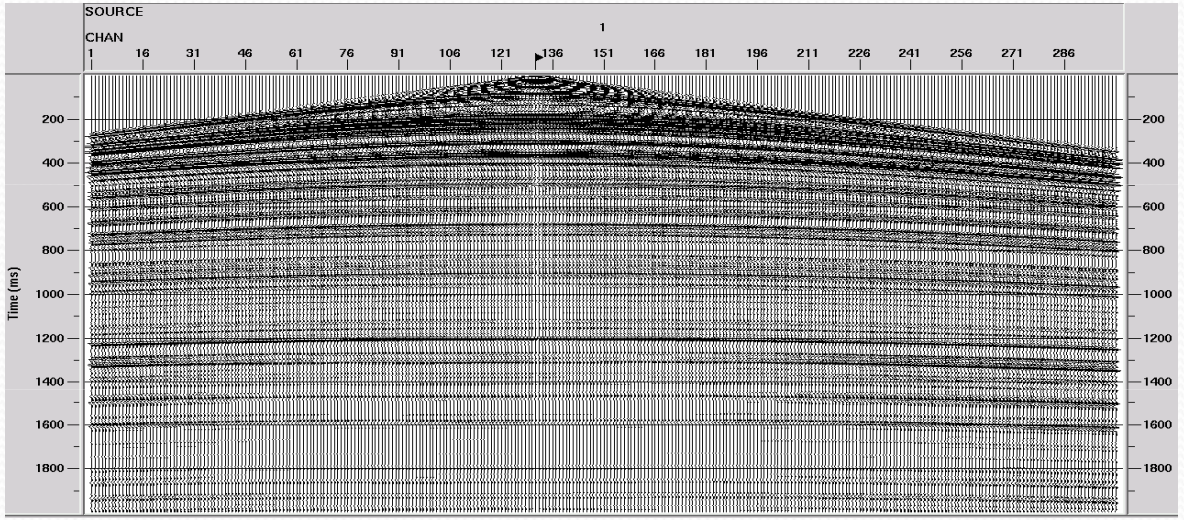


Low Q zone
X: 500 - 750m
t: 1.2 – 1.26s

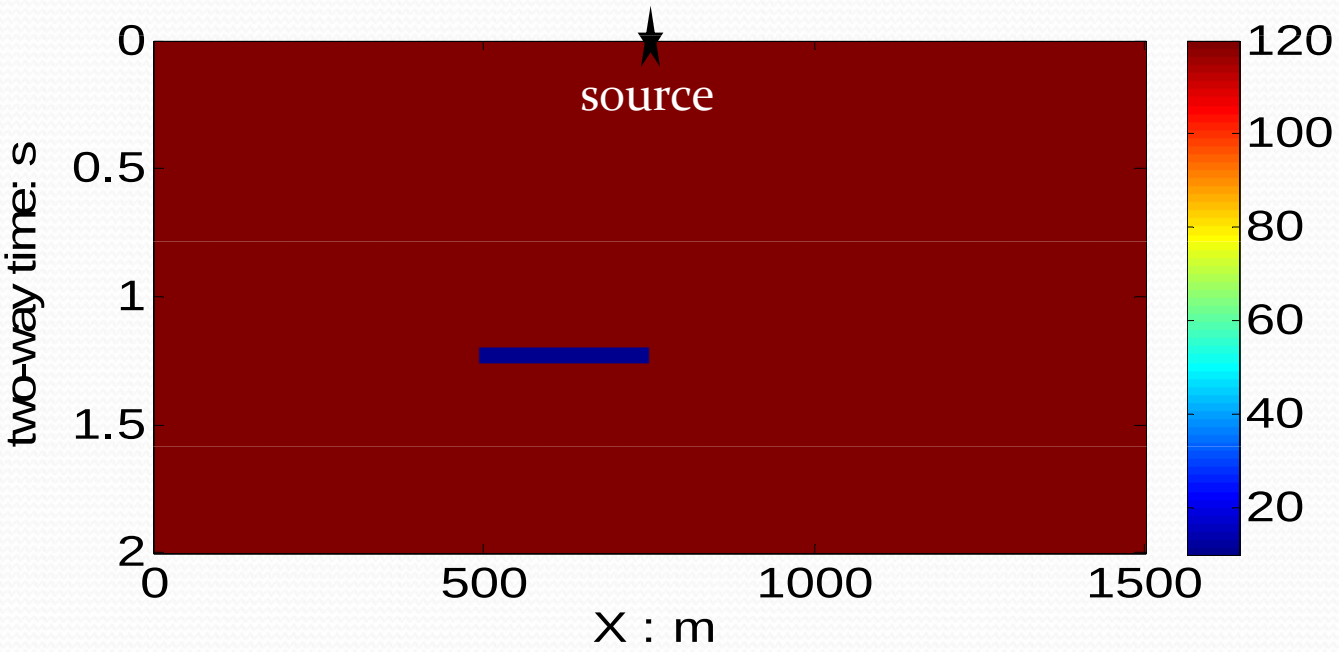


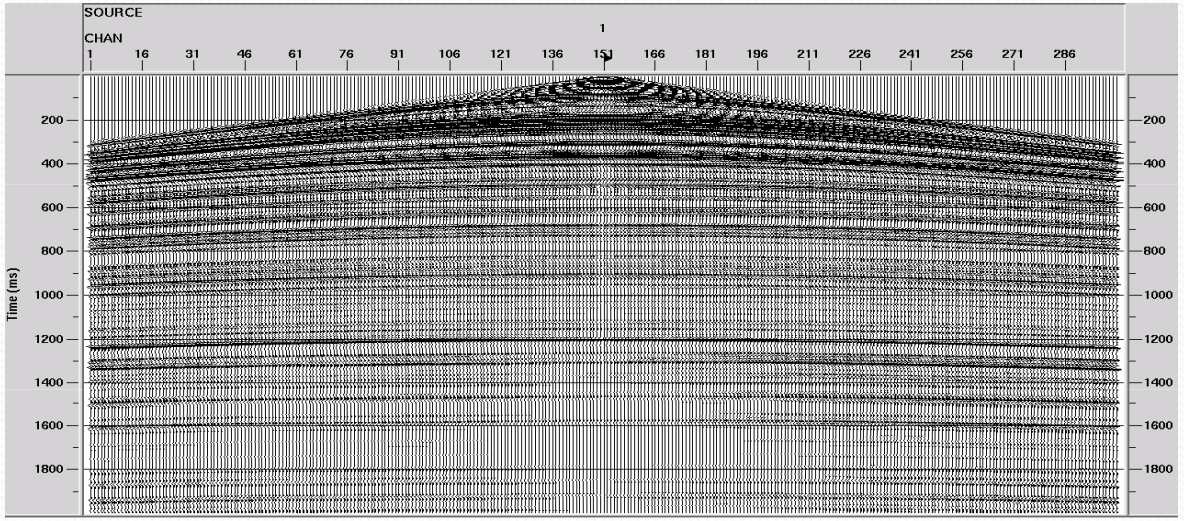
Shot record #1



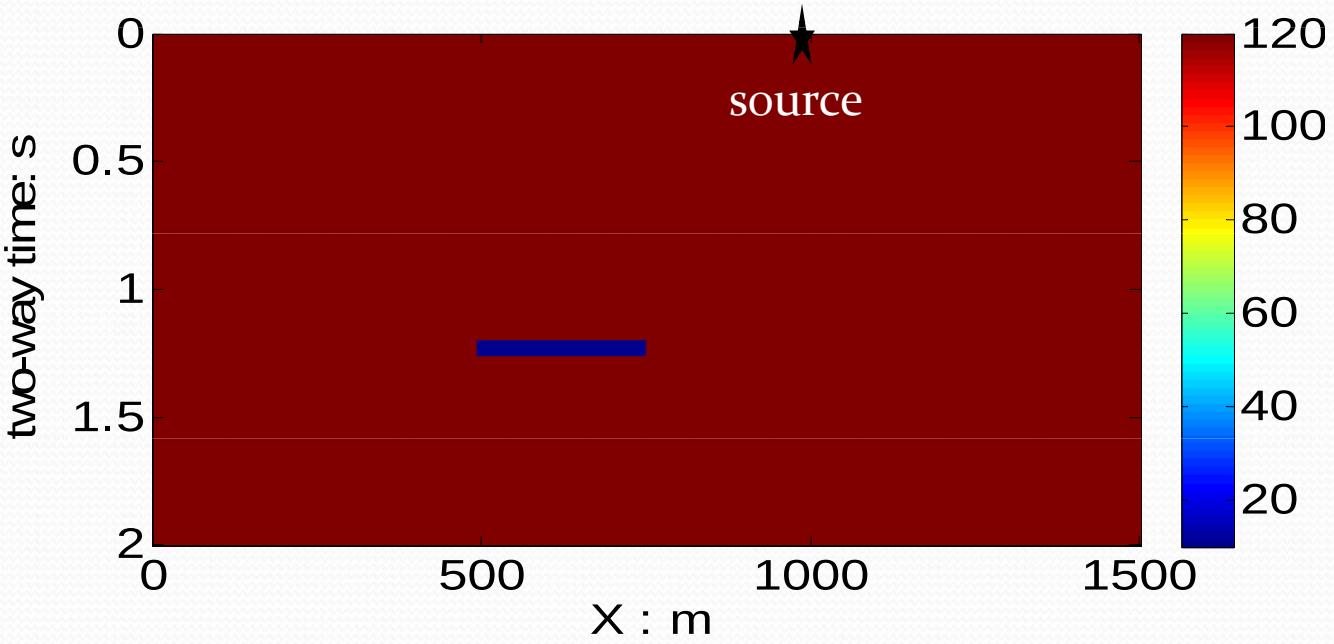


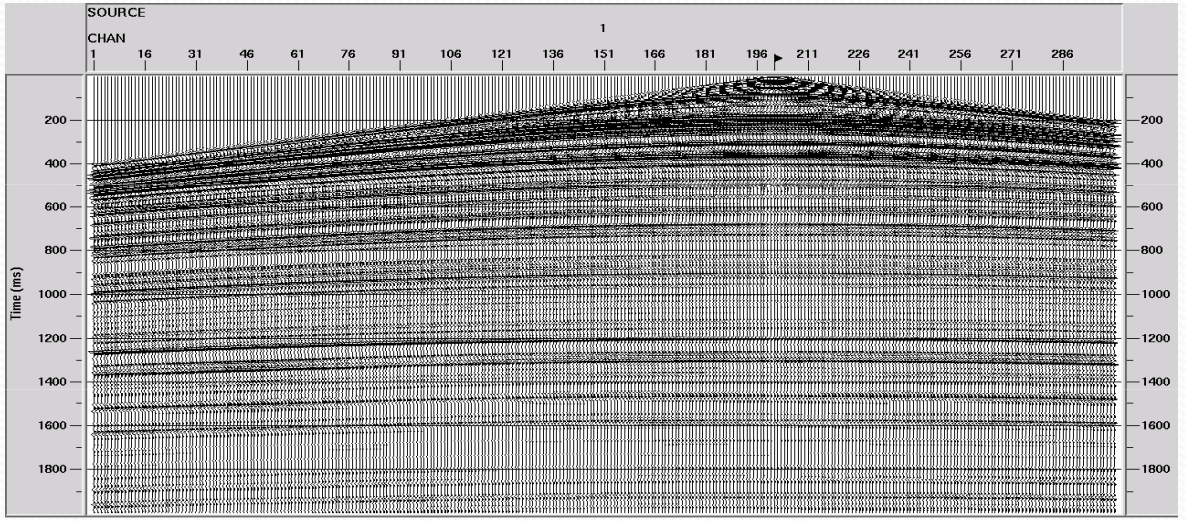
Shot record #2

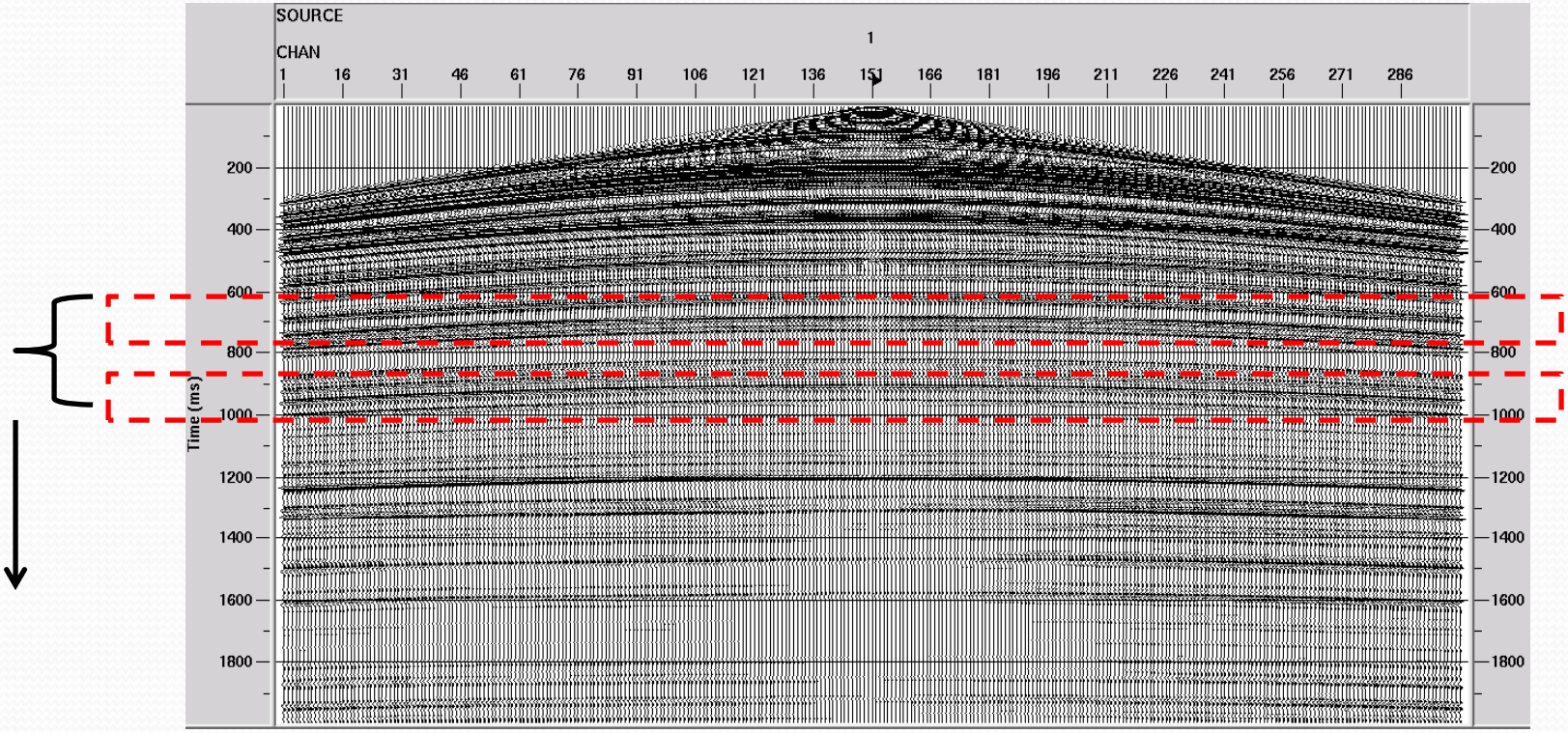




Shot record #3





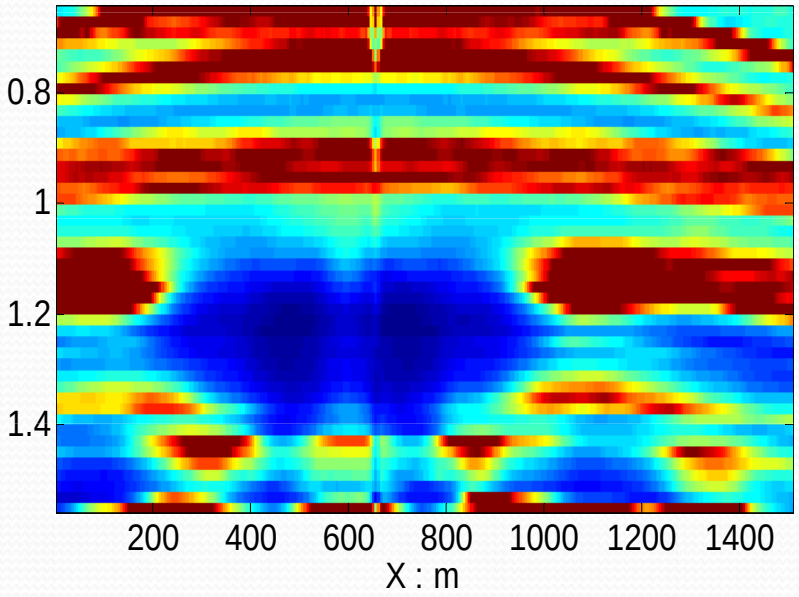


Q profile

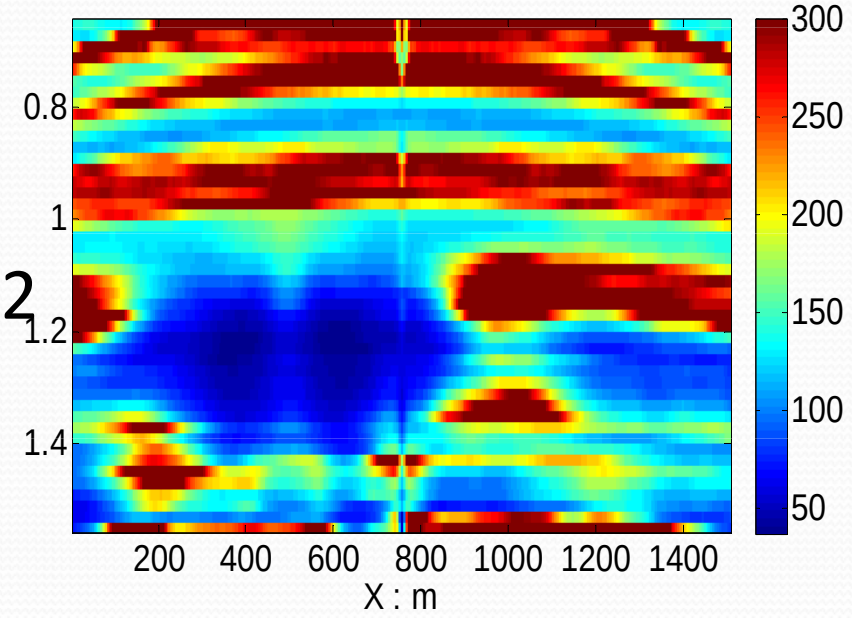
Window length : 200ms interval: 100ms

Increments: 10ms

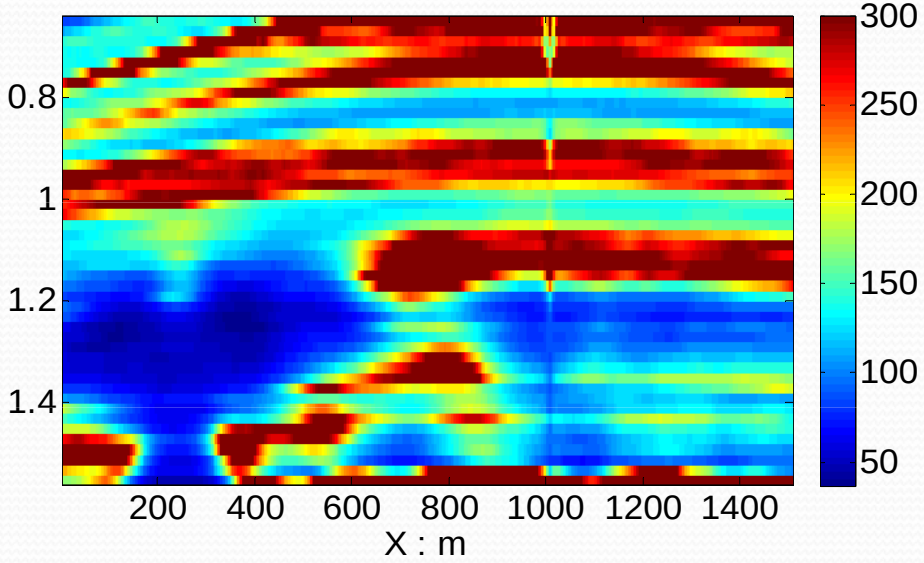
#1



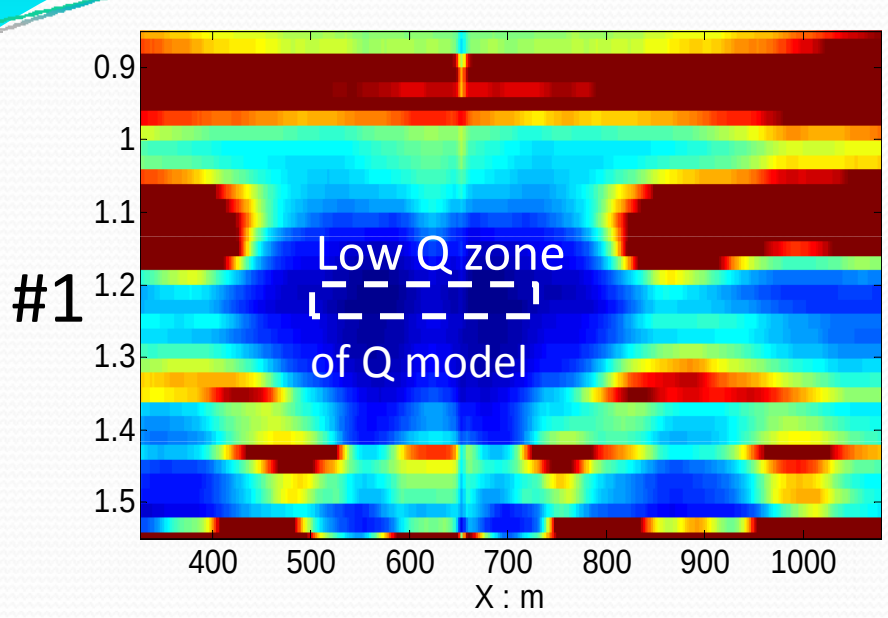
#2

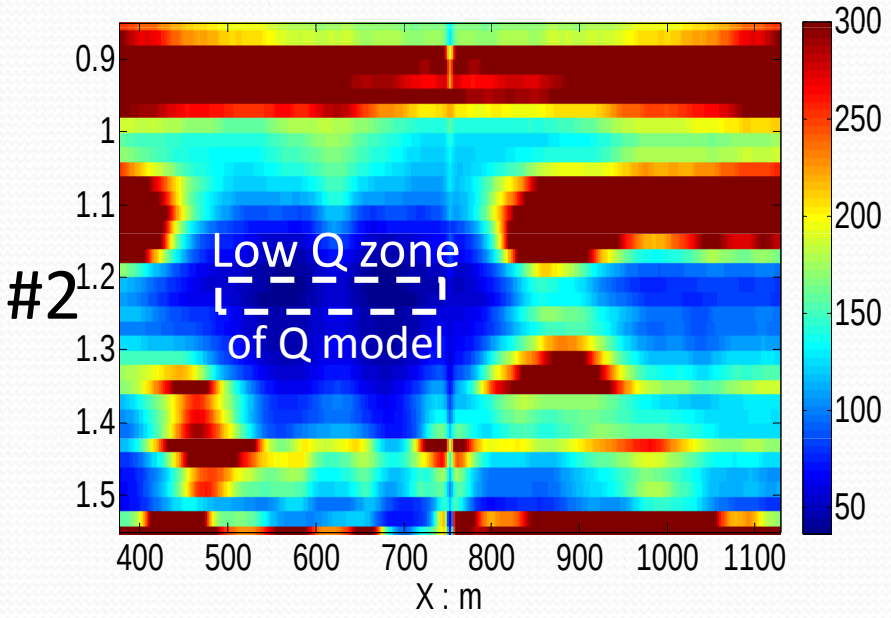


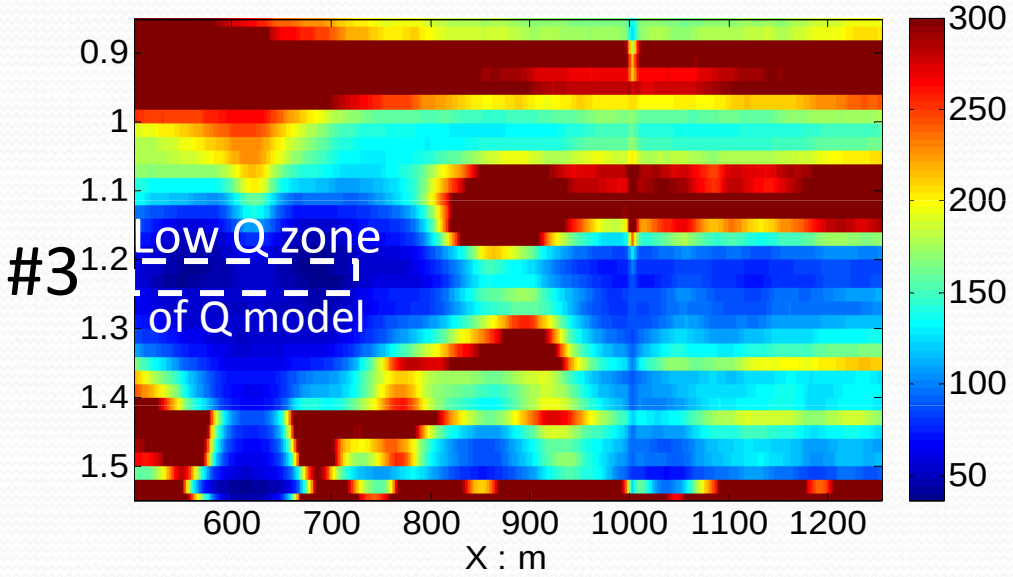
#3



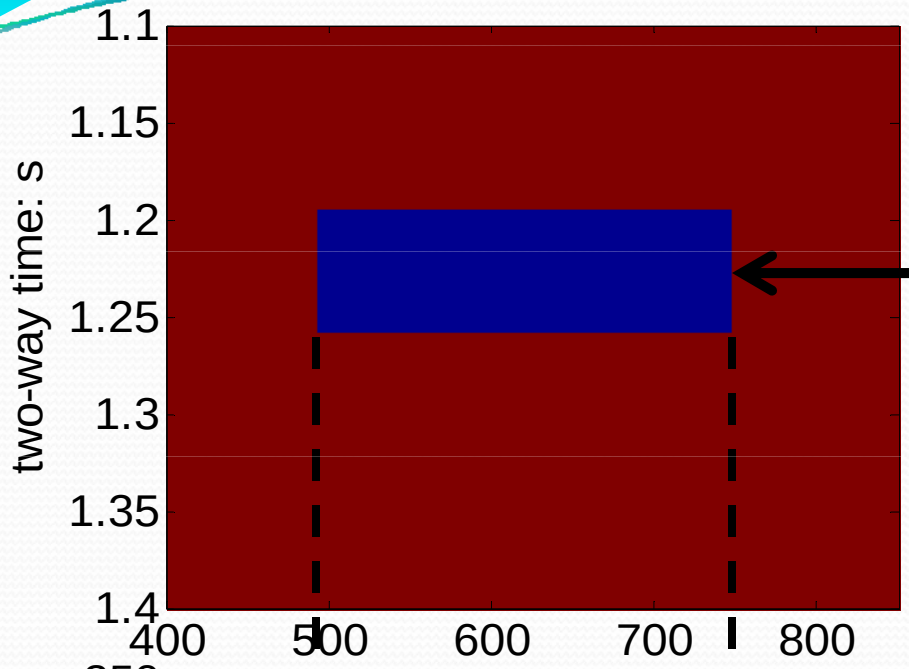
Q profiles for shot records

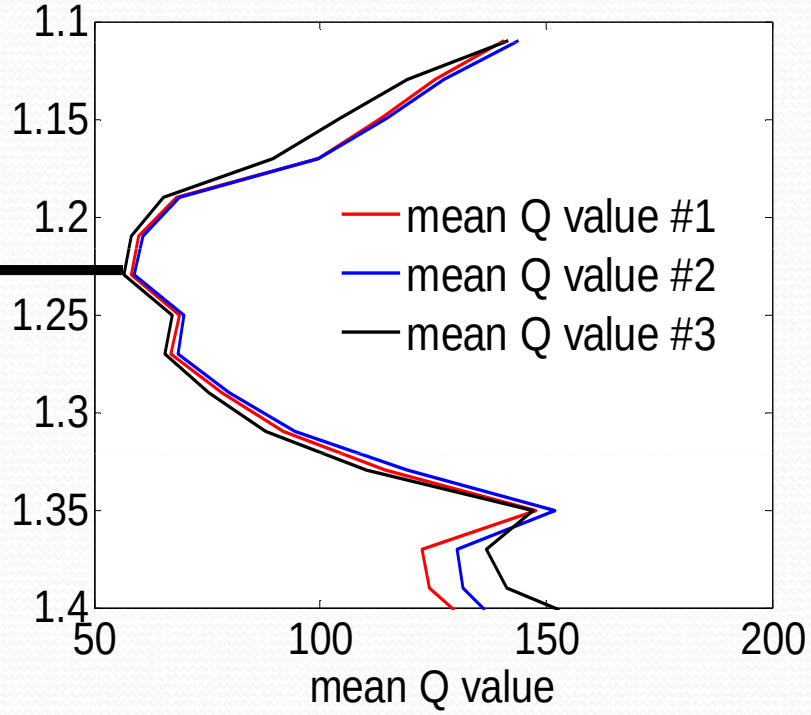


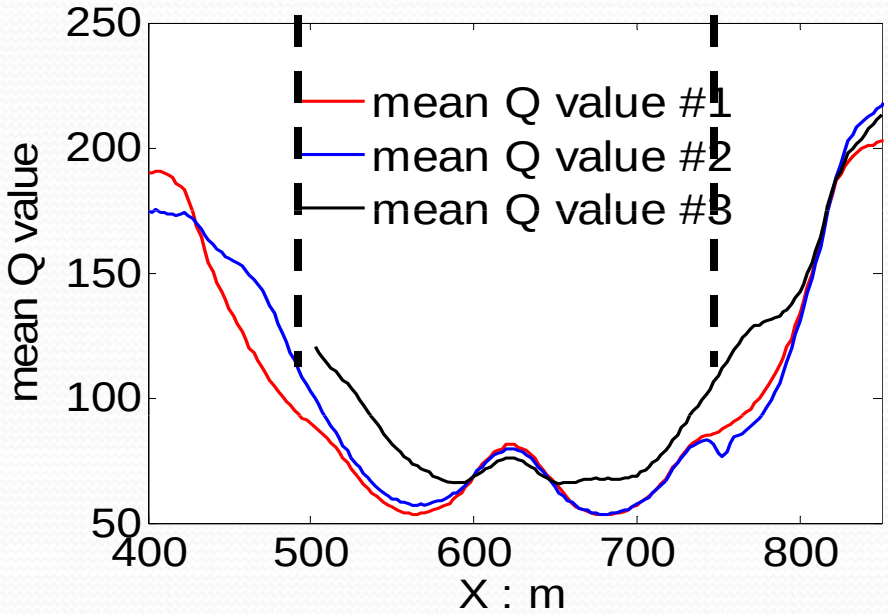




Q profiles for CDP gathers (NMO applied)





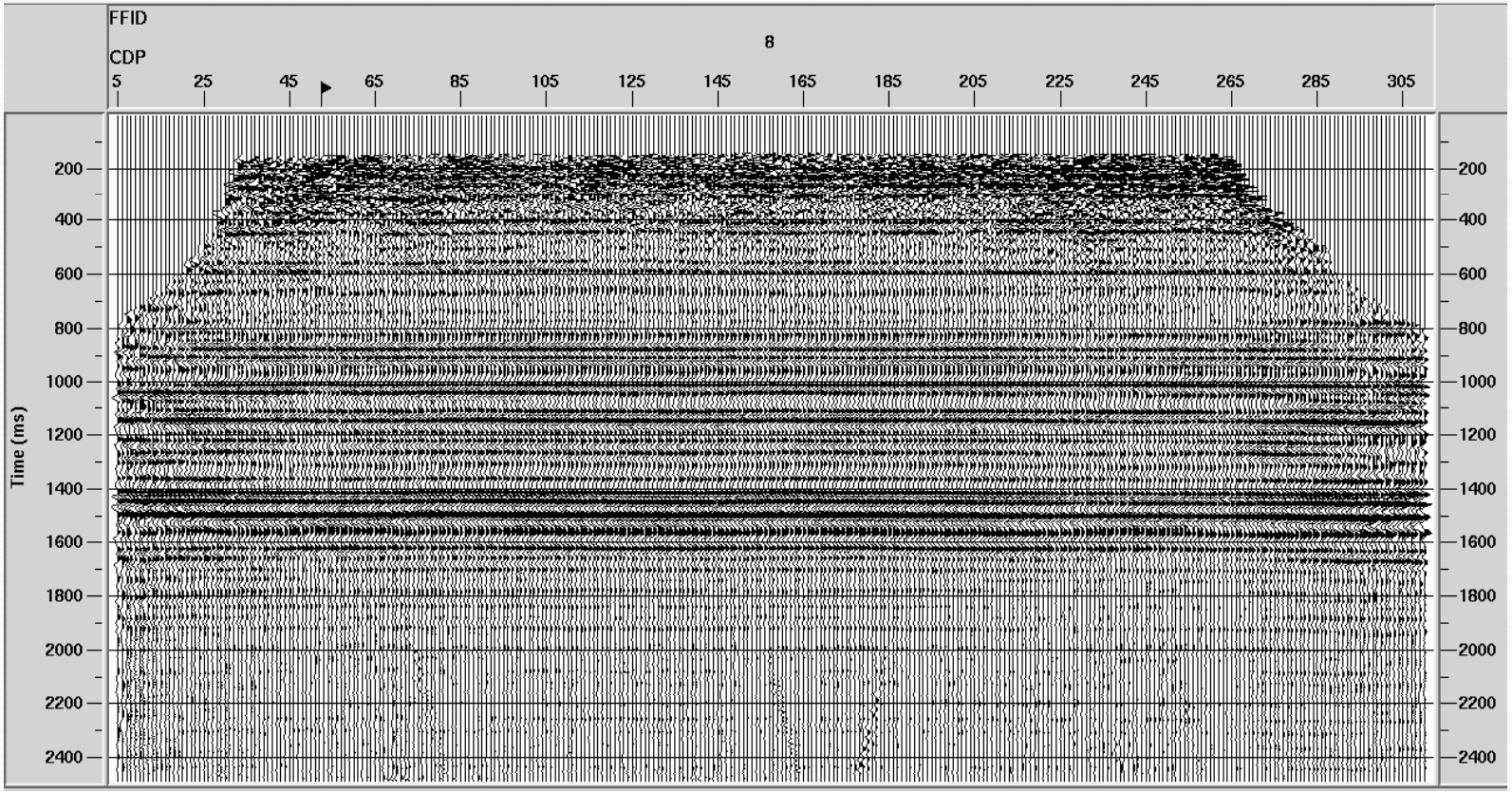


Refine the low Q zone

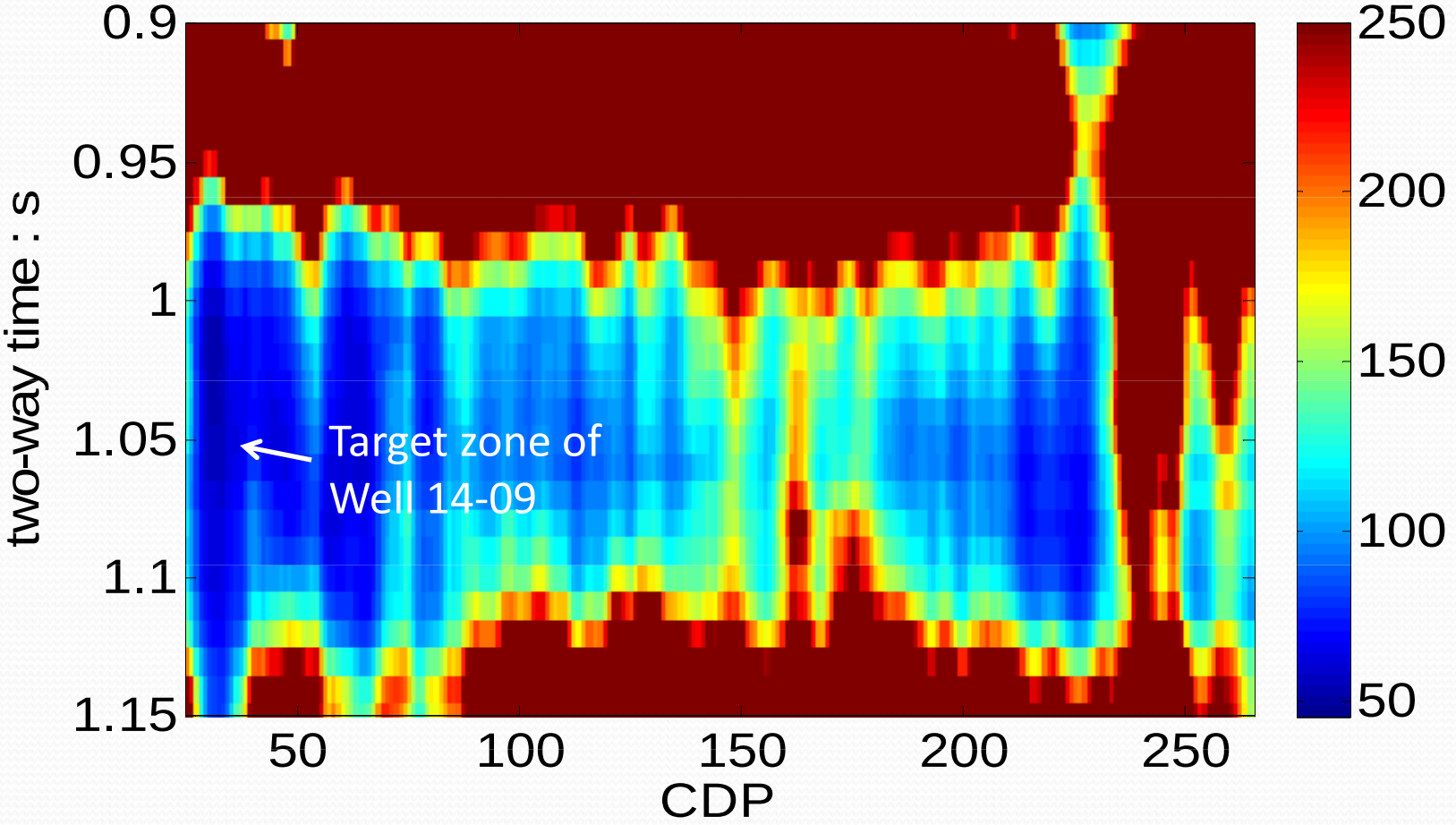
Numerical test

Case 4

- 2D field data



Blackfoot field data (stacked CDP gather)
target zone: 1050ms, well 14-09 : CDP 36



Q profile of stacked CDP gather

Conclusions

The match-filter method for Q estimation

- robust to noise.
- more suitable to be applied to reflection data.
- has the potential to identify localized low Q zone from seismic data.

Acknowledgment

- Sponsors of CEWEWS project
- CREWES faculty, staff, students

Thank you!