QQI – a quality indicator for Q estimation from VSP using spectral ratio method

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Outline

- Introduction
- Methodology
- Qp estimation
- Qp, Vp/Vs and logs
- Discussion
- Conclusion
- Acknowledgements

Introduction

- Definition
  - As an intrinsic property of rock, Q is a ratio of stored energy to dissipated energy

$$Q = \frac{2\pi W}{\Delta W}$$

- Rock physics: about fluids and cracks
- Geophysicist: effective Q of a system
- Intrinsic – a matter of scale

- **Spectral ratio method**

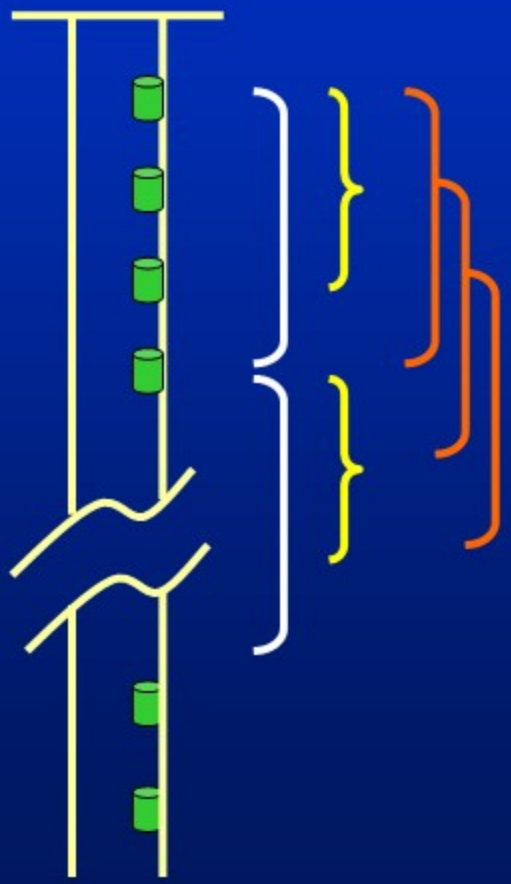
Depth:

$$\ln\left(\frac{|A(\omega)_{d2}|}{|A(\omega)_{d1}|}\right) = -\frac{|\omega|}{2Q}\left(\frac{d_2}{v_2} - \frac{d_1}{v_1}\right)$$

Time:

$$\ln\left(\frac{|A(\omega)_{d2}|}{|A(\omega)_{d1}|}\right) = -\frac{|\omega|}{2Q}\left(t_2 - t_1\right)$$

- **Normal ways to calculate Q**



1. Choose any two levels – choose which 2?
2. Choose two groups of geophone
3. Sliding-window-average

Need to be apart with certain distance (NOT using adjacent geophone level) to get smoothed value – how far to be apart?

Methodology

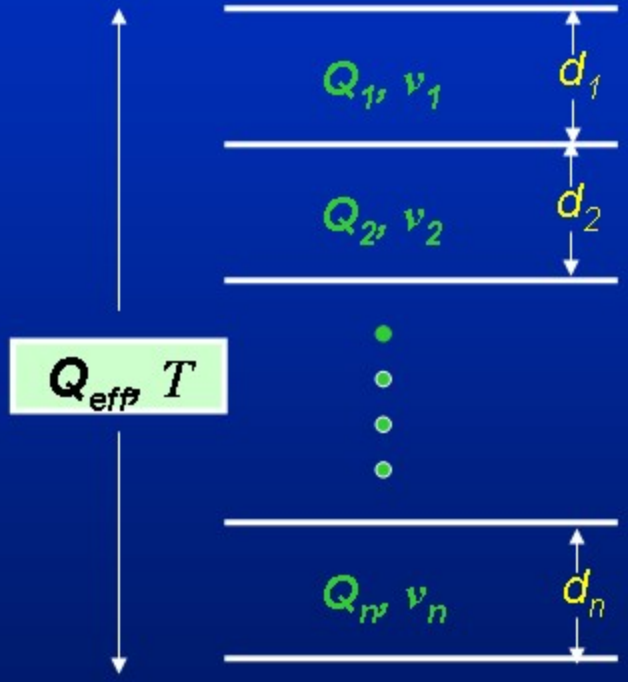
A different approach:

Set surface as the reference, calculate average Q first

Assumptions:

1. VSP source is relatively constant for all geophone levels
2. The source has flat spectrum

- Layered model:



$$\frac{T}{Q_{eff}} \equiv \sum_{n=1}^{N} \frac{d_n}{Q_n v_n}$$

(Bale et al., 2002)

$Q_{eff} \rightarrow Q_{ave}$, recursive format:

$$\frac{T(n+1)}{Q_{ave}(n+1)} = \frac{T(n)}{Q_{ave}(n)} + \frac{T(n+1)-T(n)}{Q_{\text{int}}(n+1)}$$

n = 1, 2, 3, …, N-1, and $Q_{int}(1) = Q_{ave}(1)$

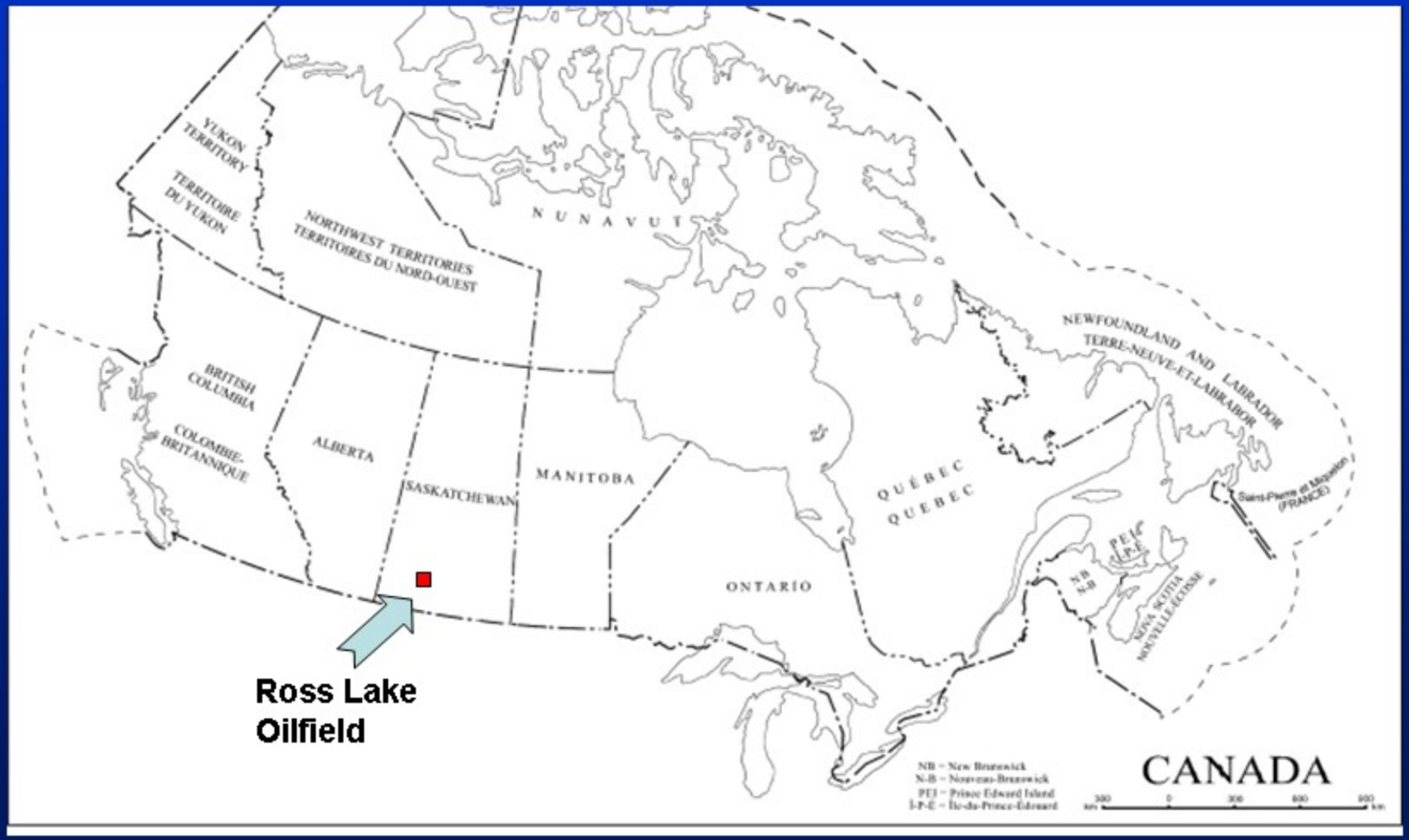
Qp estimation

- Ross Lake walkaway VSP

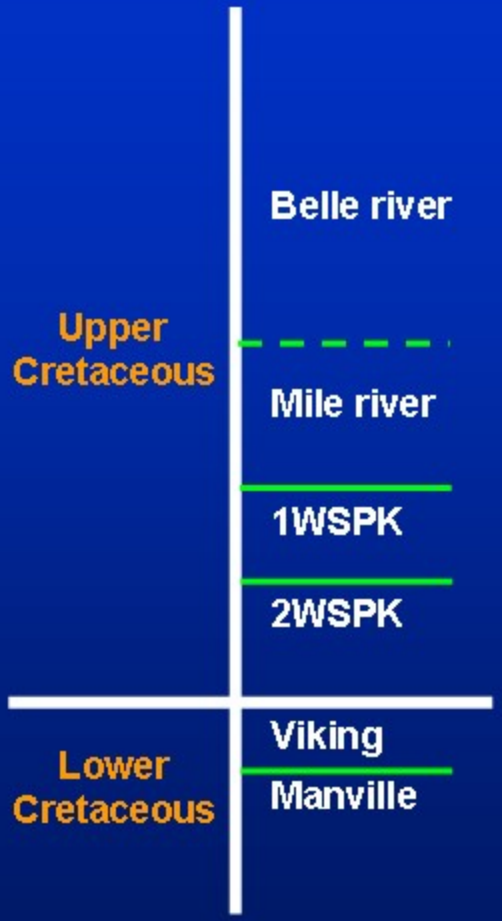
- Zero-offset vertical mini-vibrator
  - 12 seconds 8-180 Hz linear sweep
- Zero-offset horizontal mini-vibrator
  - 12 seconds 5-100 Hz linear sweep

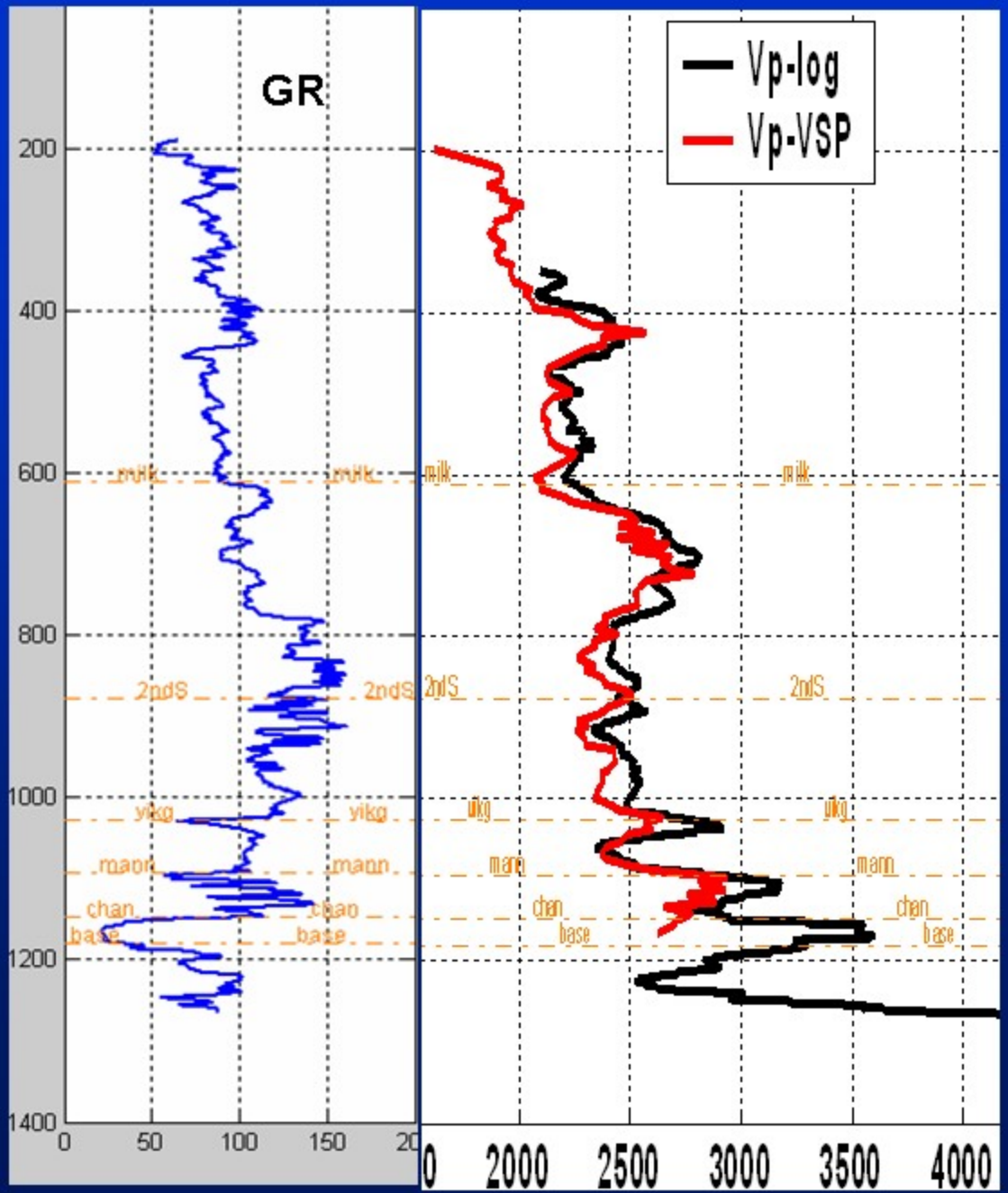
- 198m – 1165m @ 7.5m interval
- 130 geophone levels

Location of Ross Lake – Southwestern Saskatchewan

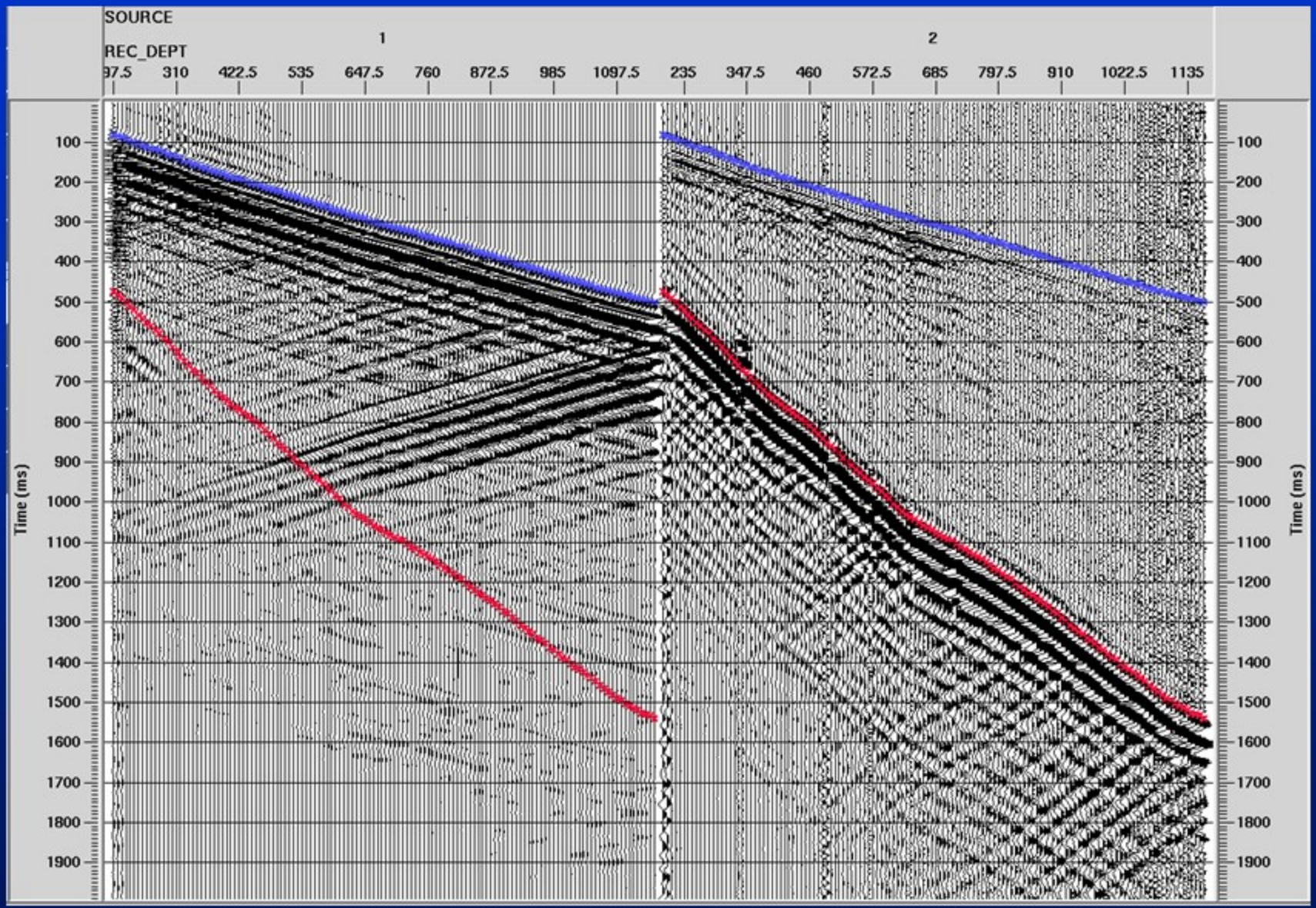


Well 11-25-13-17w3



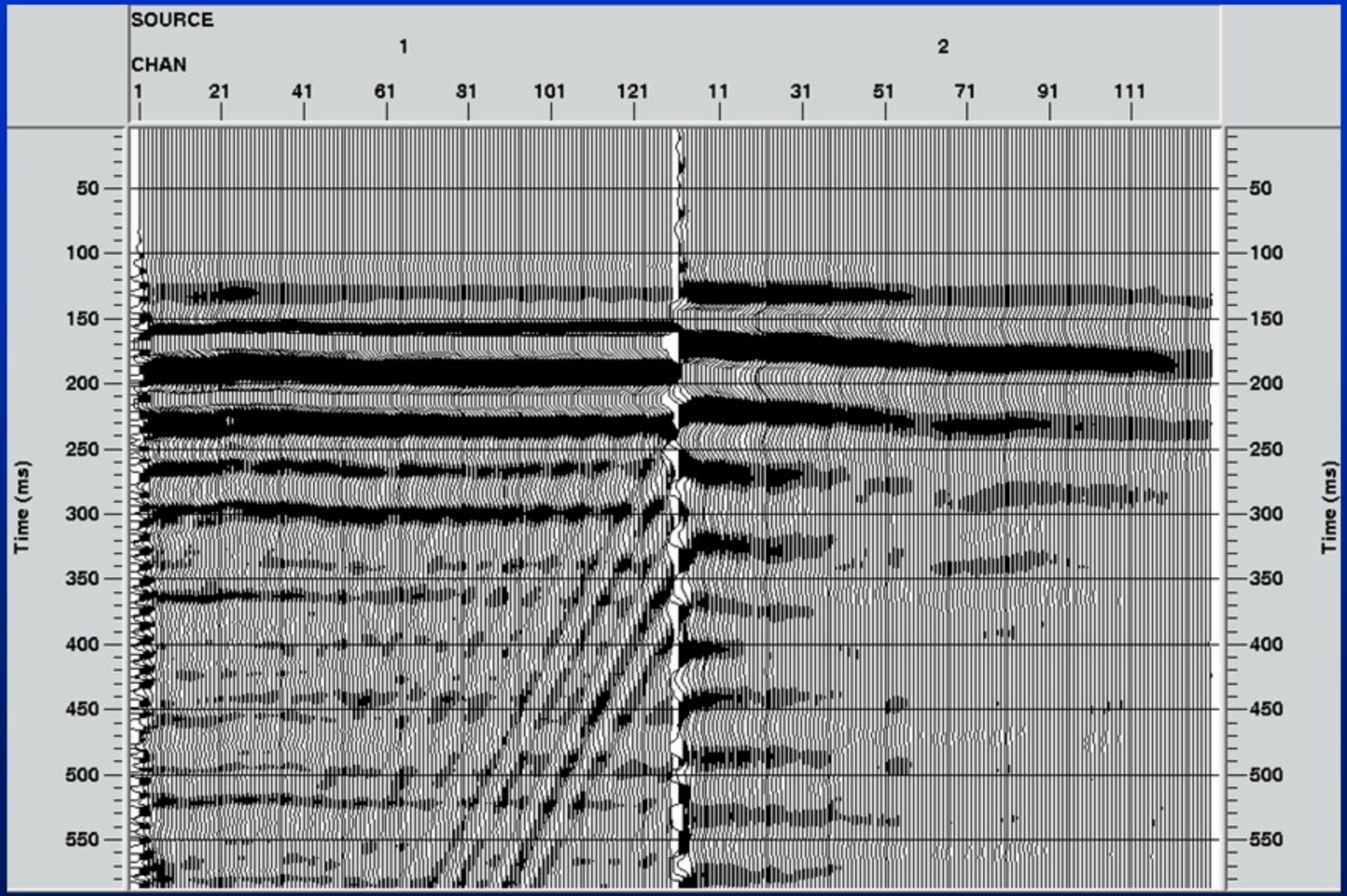


VSP traces P-P S-S

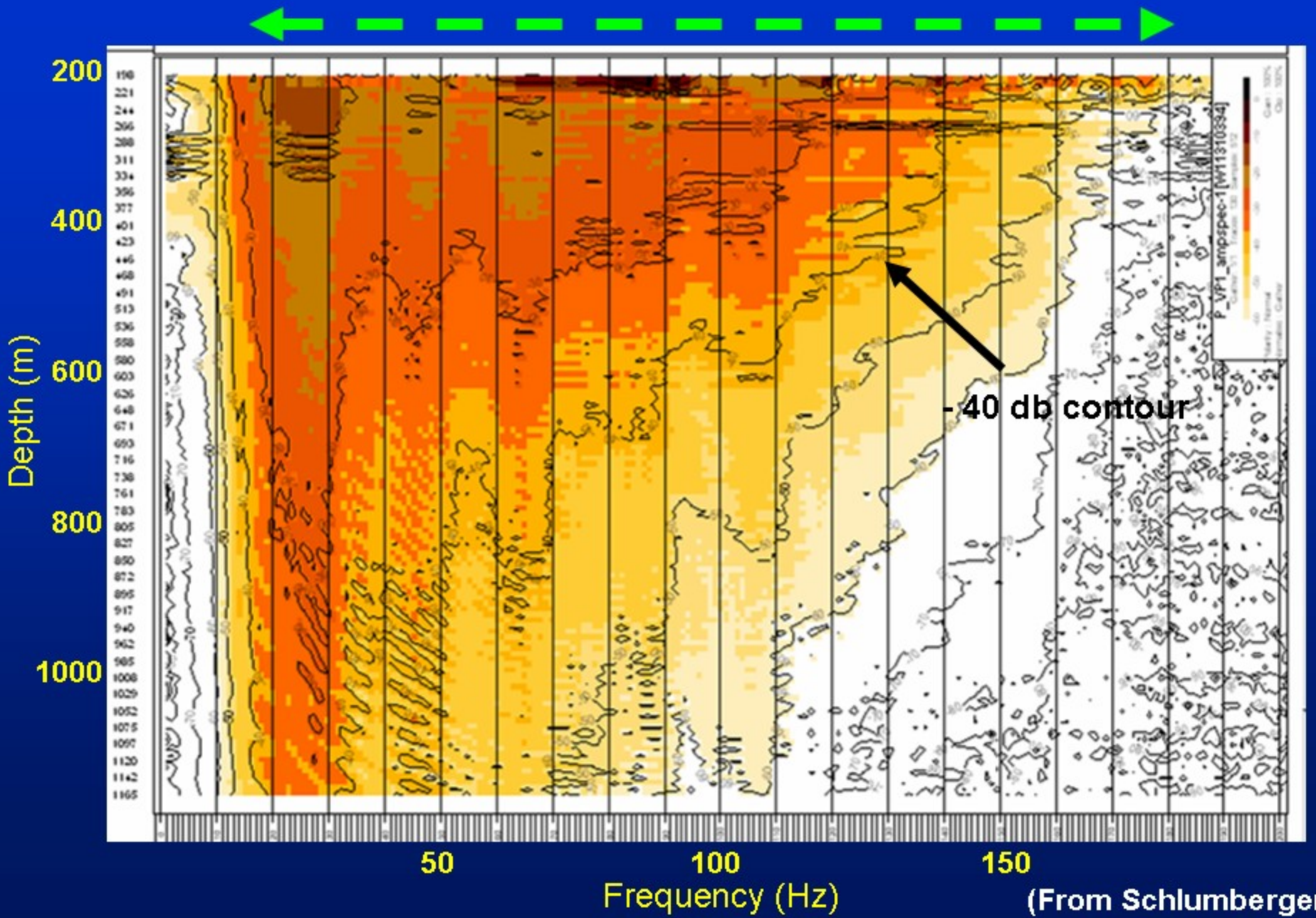


Downgoing P

Downgoing S

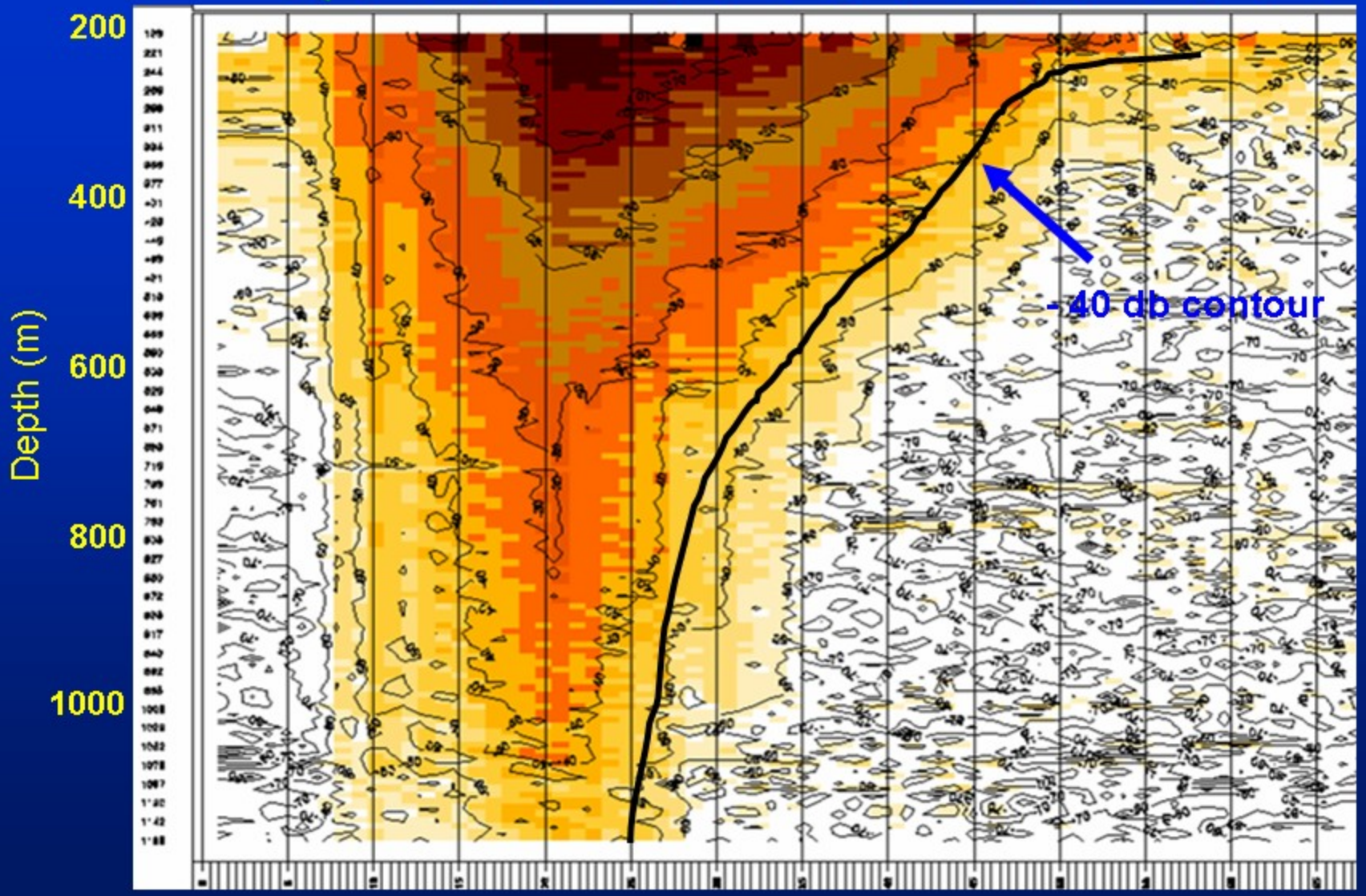


Amplitude spectrum of raw PP data



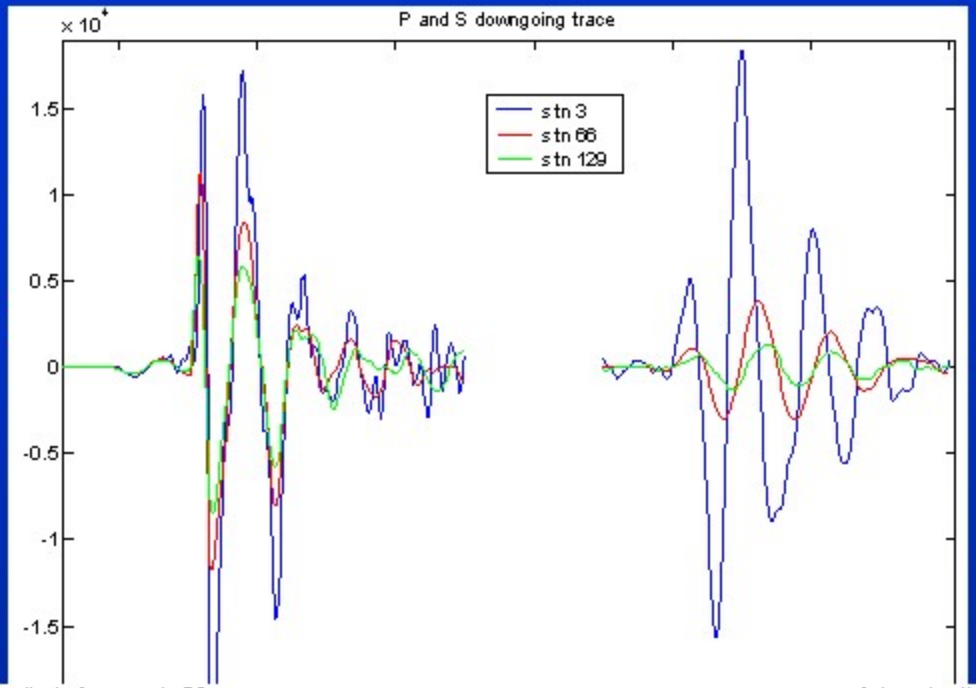
(From Schlumberger)

Amplitude spectrum of raw SS data



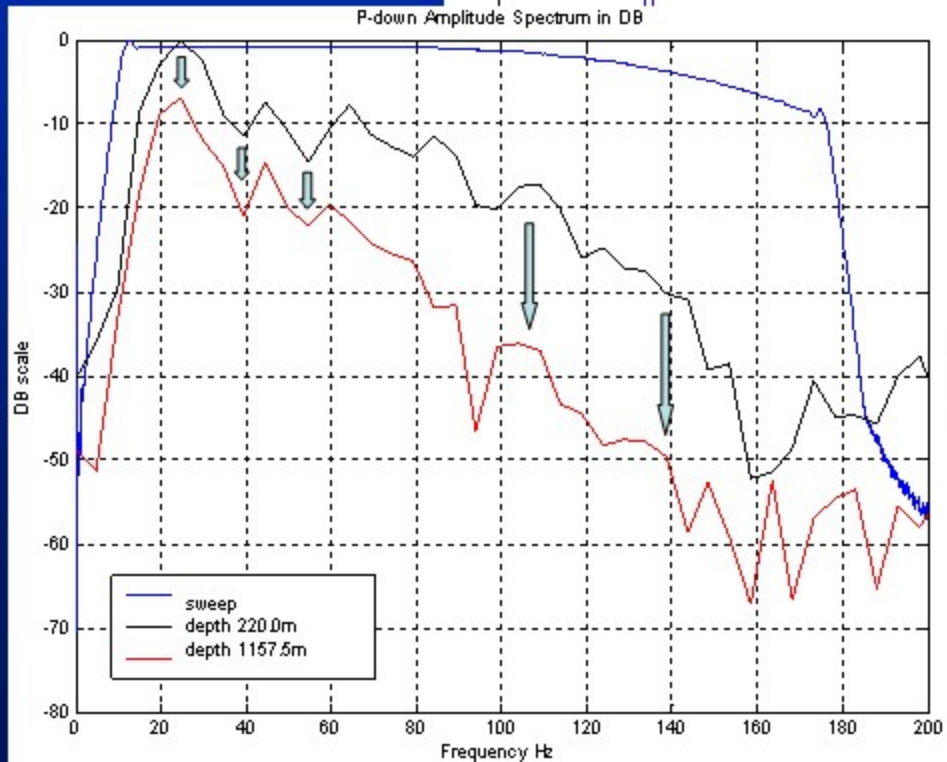
(From Schlumberger)

P-down traces

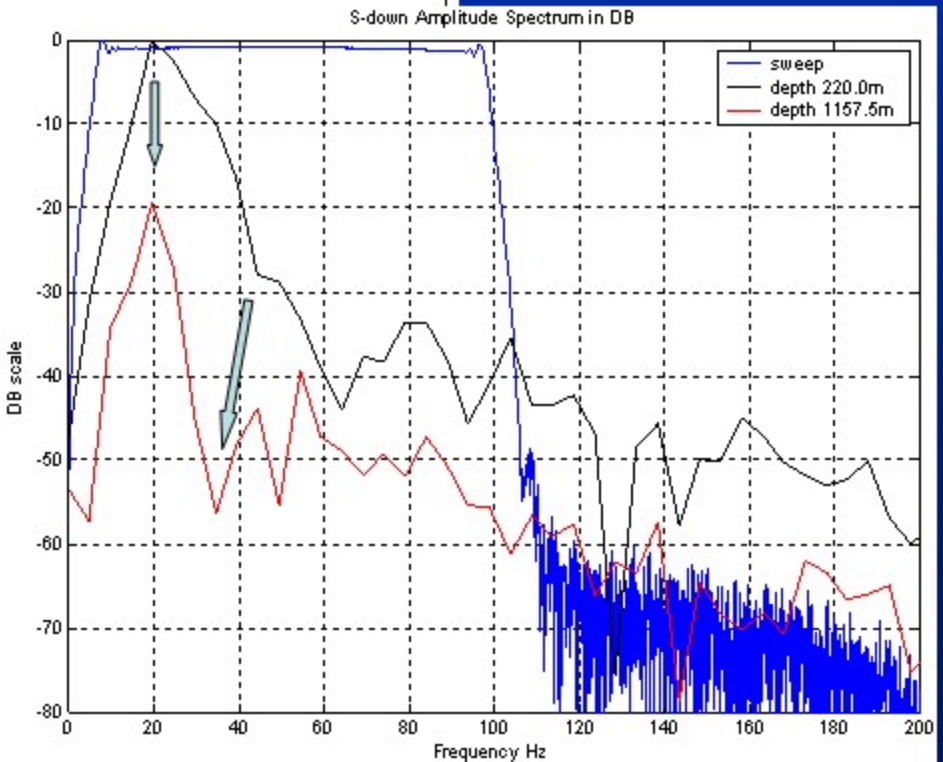


S-down traces

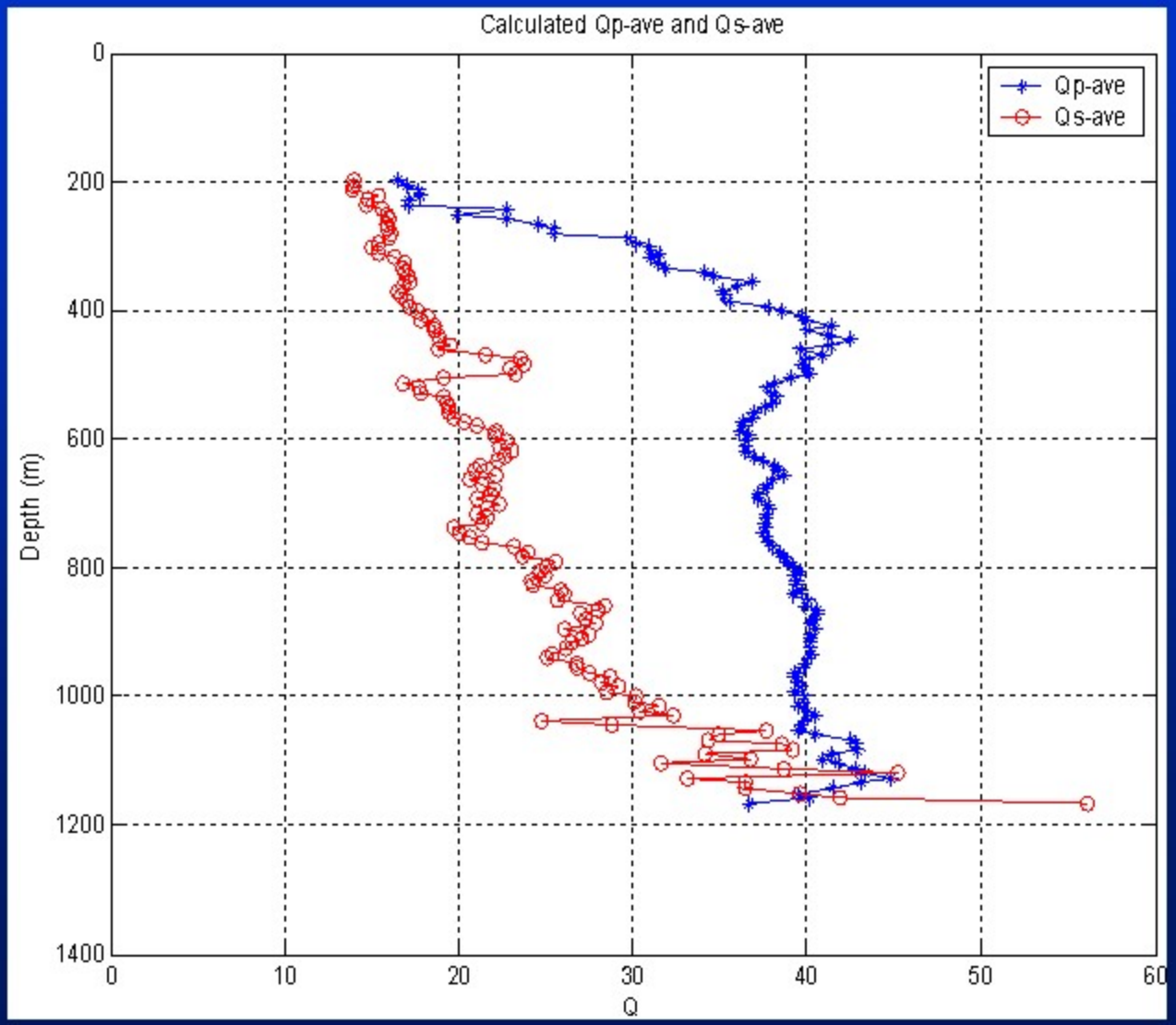
P-down spectrum



S-down spectrum



- Spectral ratio to calculate Qp-ave



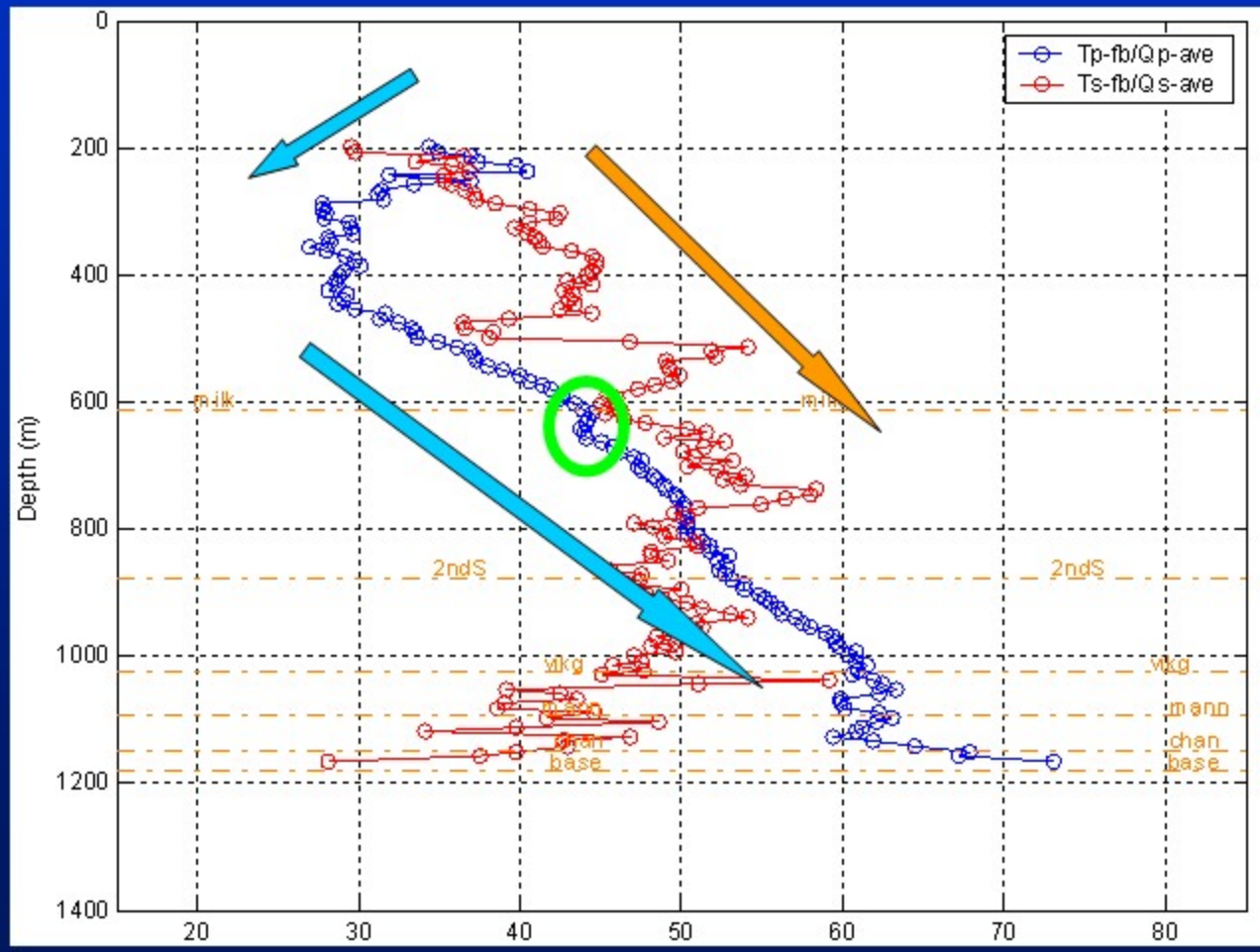
$$\frac{T(n+1)}{Q_{ave}(n+1)} = \frac{T(n)}{Q_{ave}(n)} + \frac{T(n+1)-T(n)}{Q_{int}(n+1)}$$

Plot curve $\frac{T}{Q_{ave}}$

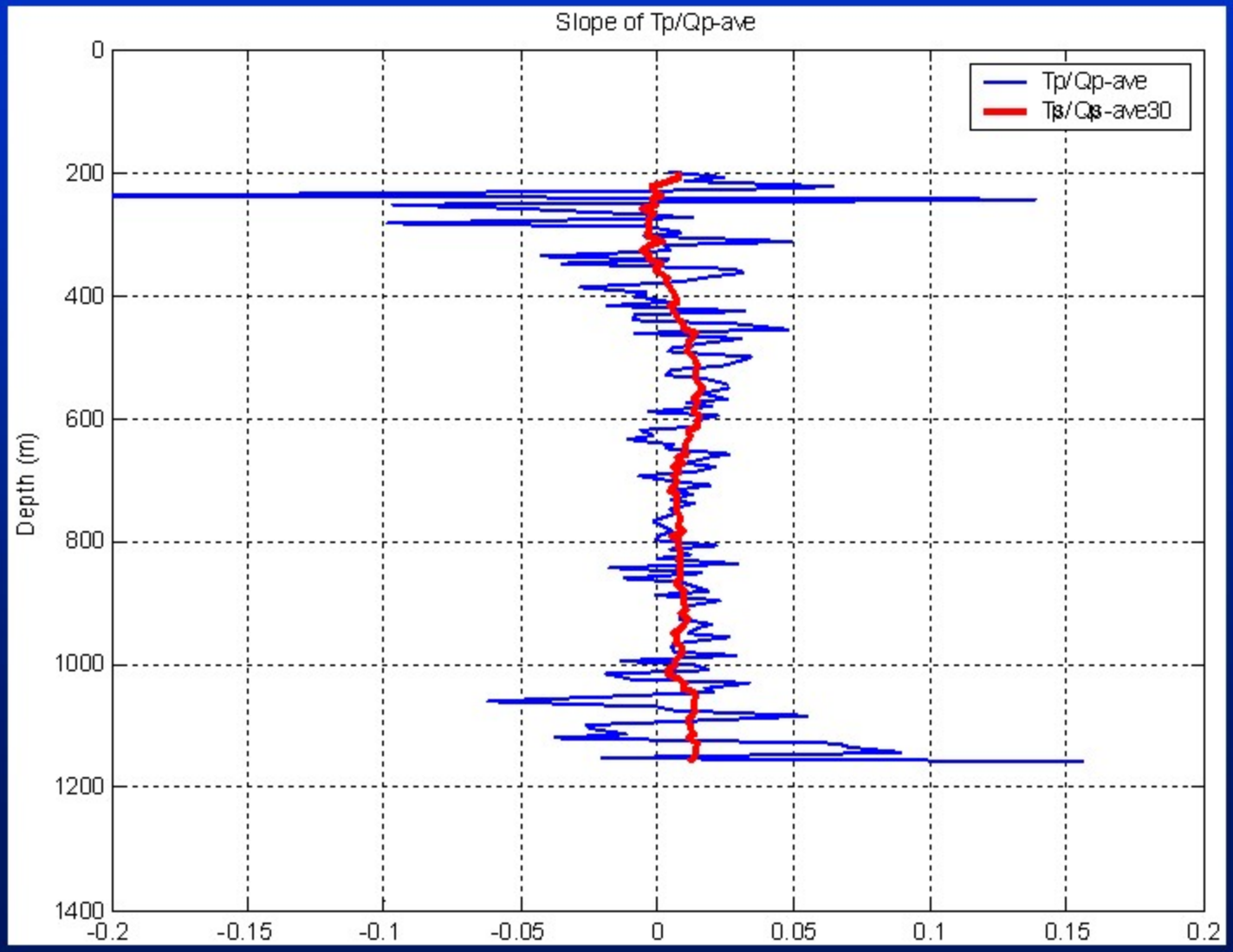
1. + slope → Q>0
2. - slope → Q<0
3. Near vertical → large Q
4. Smoothing will keep the trend.

It could indicate whether and where we'll get a reasonable Q.

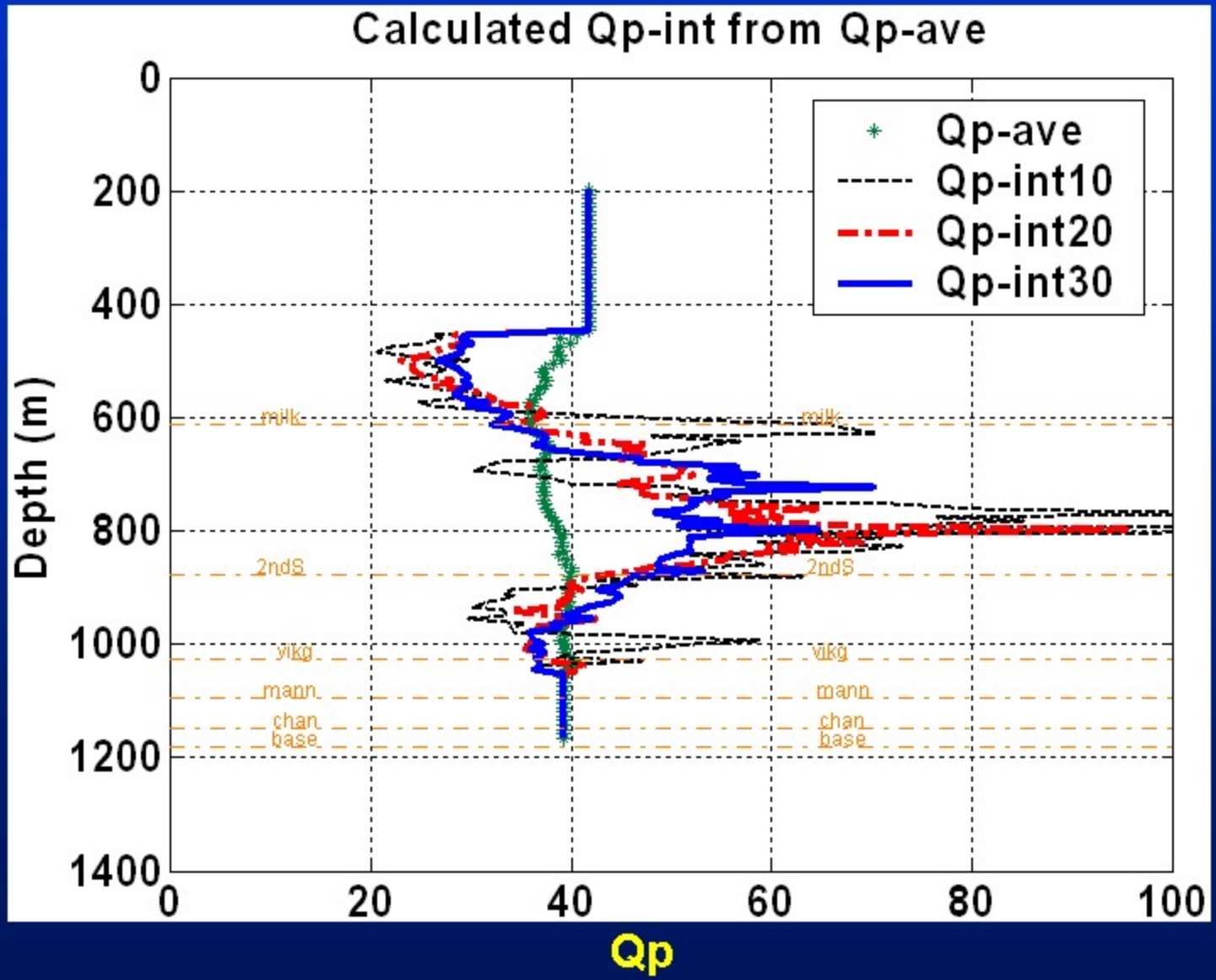
So, call it **QQI – quality indicator** of Q estimation



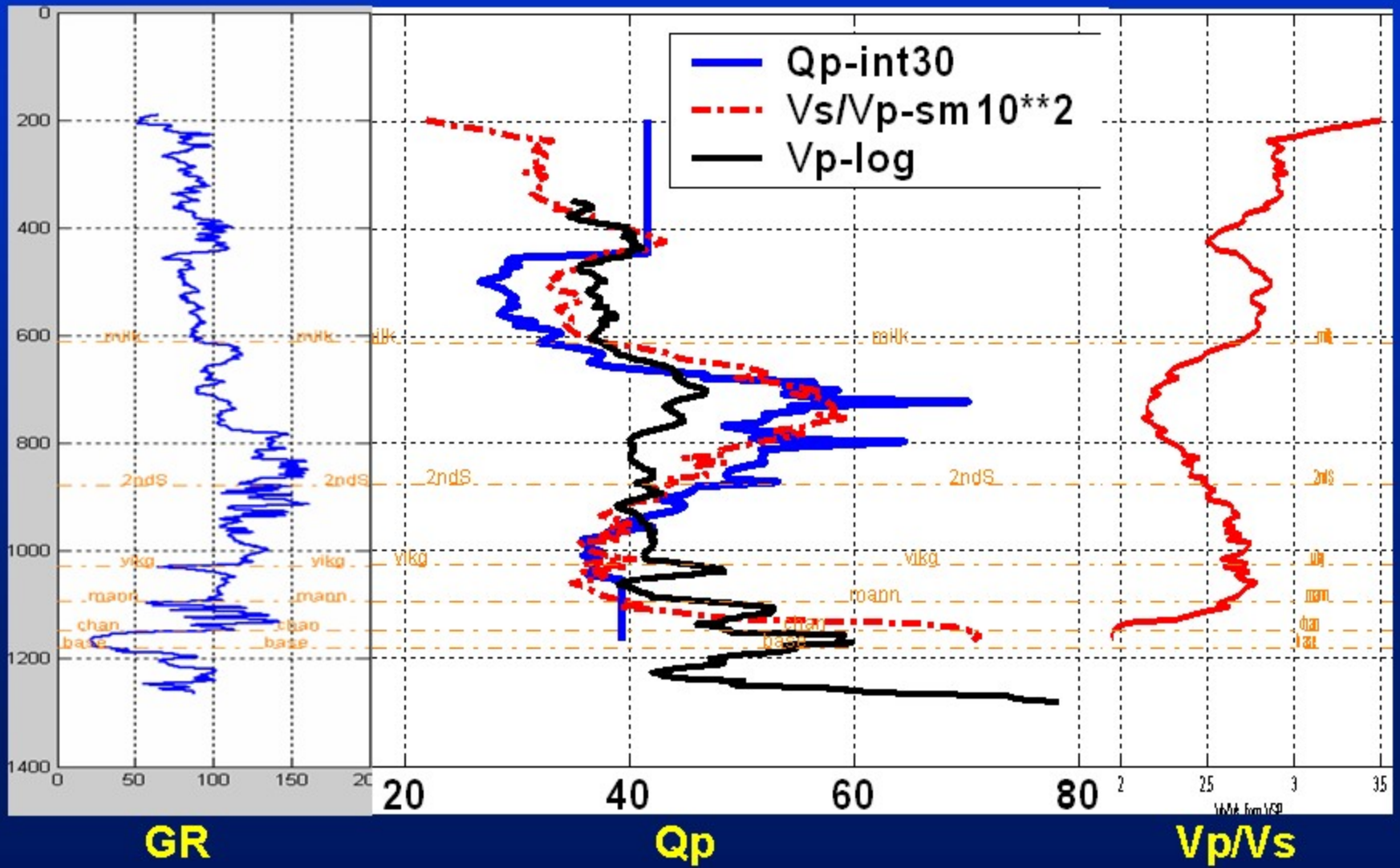
$d(T/Q_{ave})/dz$


Slope of Tp/Qp-ave
Tp/Qp-ave
Ts/Qs-ave30
Depth (m)
0
200
400
600
800
1000
1200
1400
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2

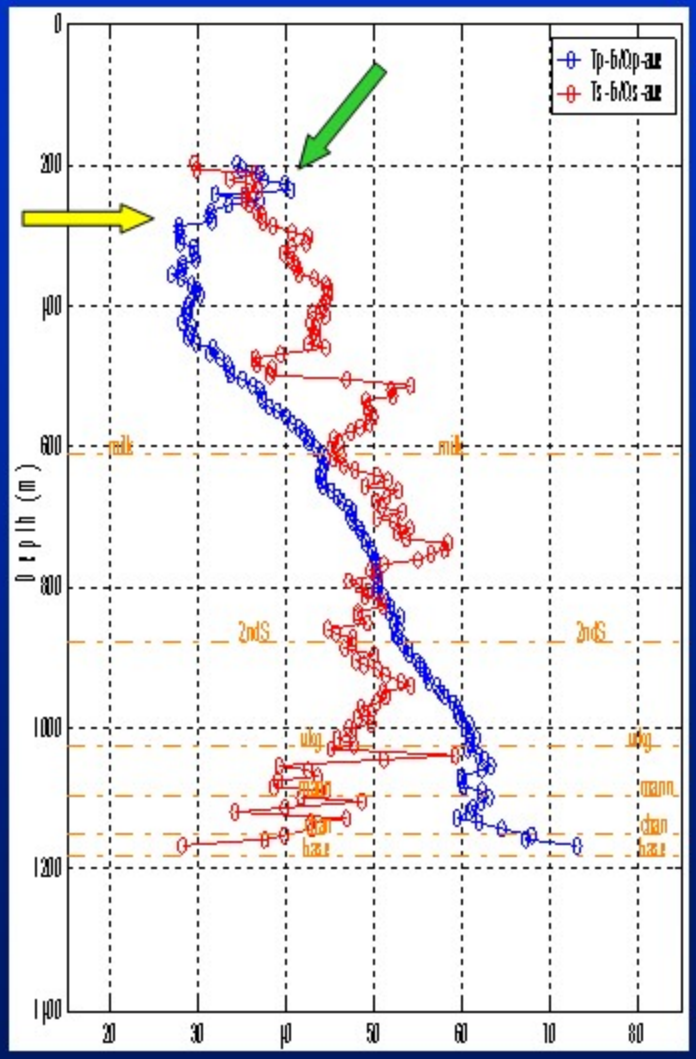
Qp-ave and Qp-int with different smoothers



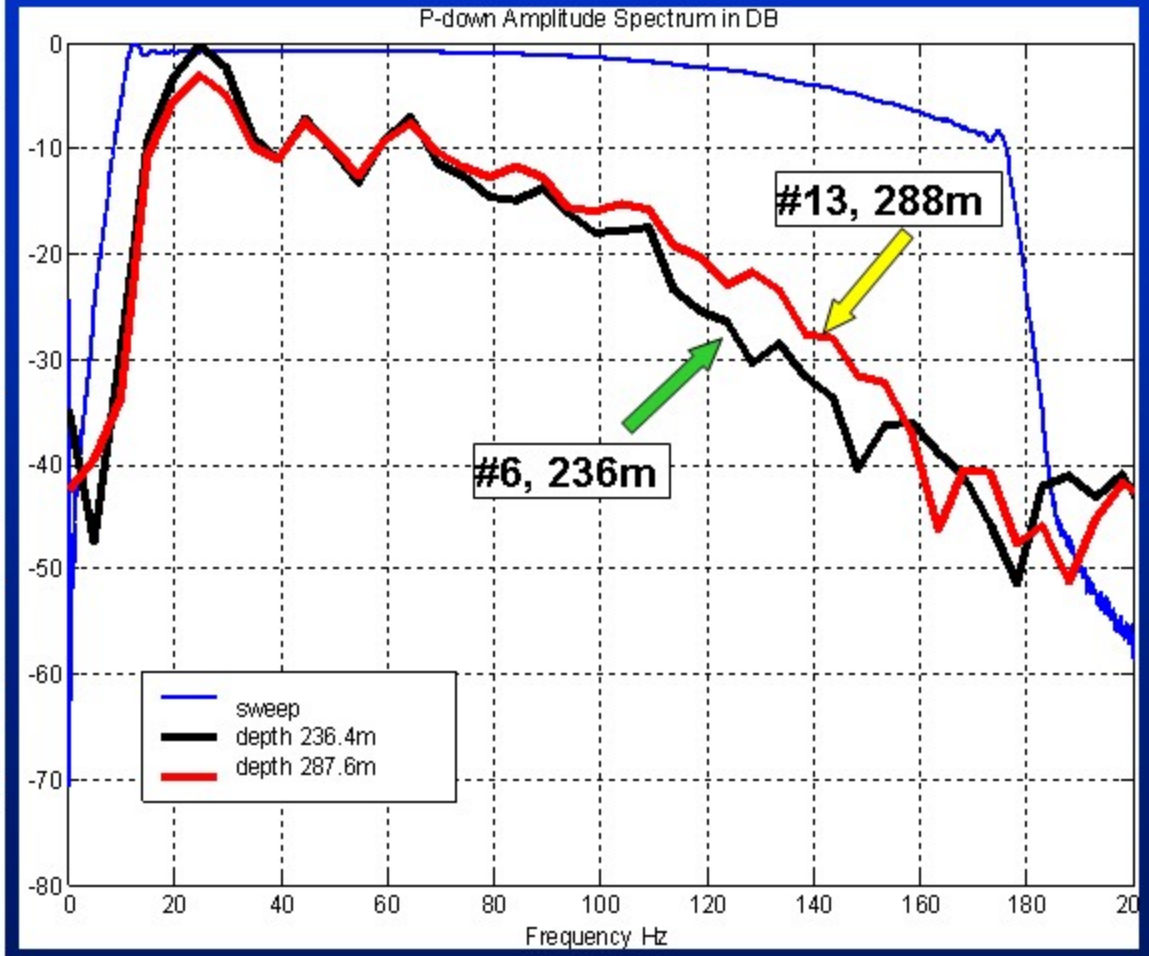
Qp, Vp/Vs versus logs

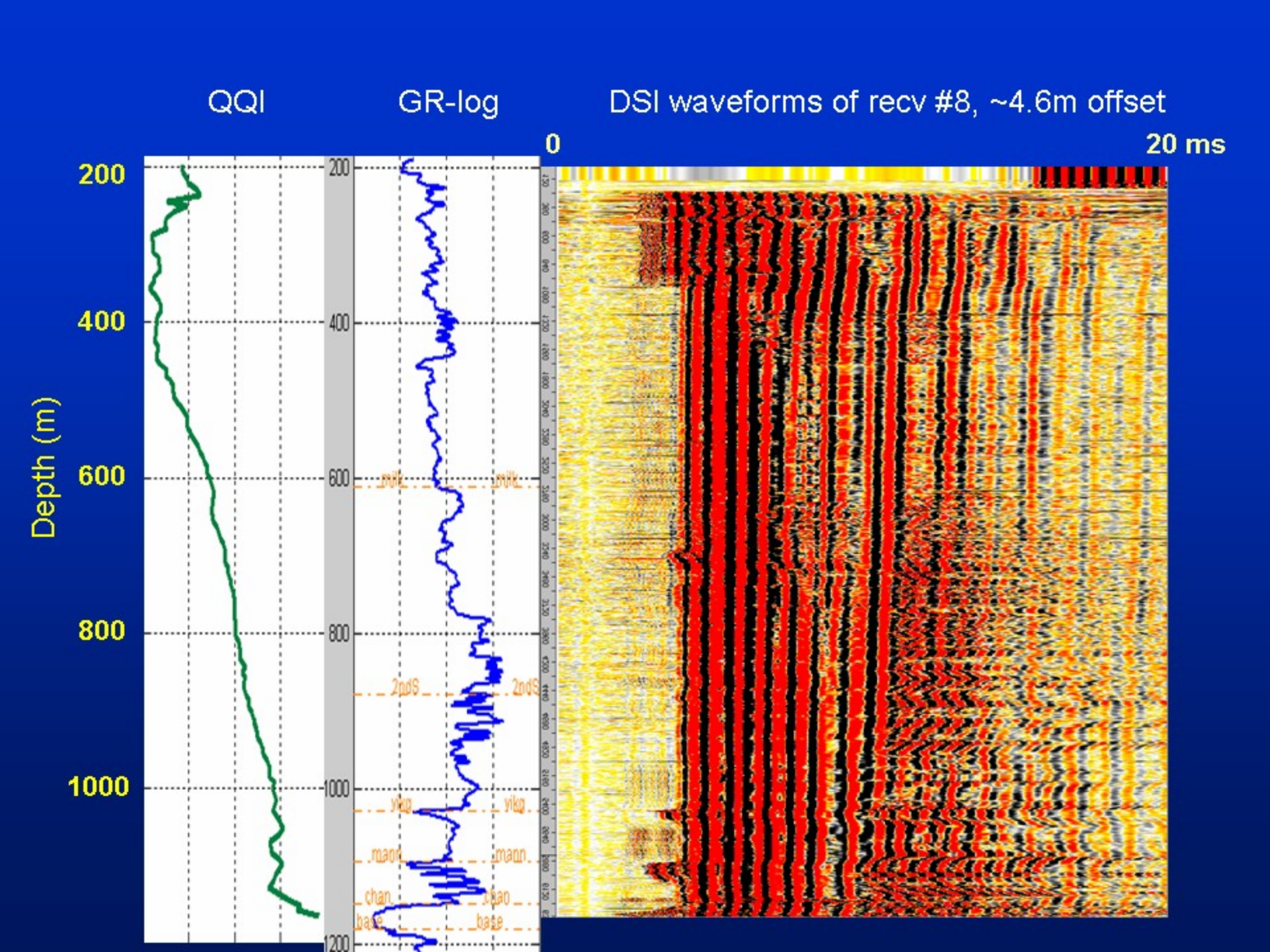


Discussion



T/Q$_{ave}$




QQI
GR-log
DSI waveforms of recv #8, ~4.6m offset
0
20 ms
Depth (m)
200
400
600
800
1000
1200
2ndS
yikp
maqn
chan
base

Discussion

- In cased well, the cement bond condition could affect Q estimation.
  - Partial cement bond
  - Double casing
  - 1st interface: casing with cement
  - 2nd interface: cement with formation

- Difference between logging and VSP
  - Size of wavelength – different size of cracks
  - Position of source and receivers – different effect from same crack (for cased hole)

Conclusions

- An alternative approach of spectral ratio method to calculate the interval Q from VSP data.
- The quality indicator for Q (T/Q_{ave}) indicates whether and where to get a reasonable Q.
- A continuous interval Qp is estimated from a zero-offset P-source VSP, and shows good correlation with VSP derived $(Vs/Vp)^2$ and logs.
- Check casing program and cement bond log before calculate Q.

Future work

- Investigate Qp around reservoir
- Get Qs by other methods
- Relation of Q and V, in particular, Qp/Qs vs Vp/Vs from VSP data

Acknowledgements

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