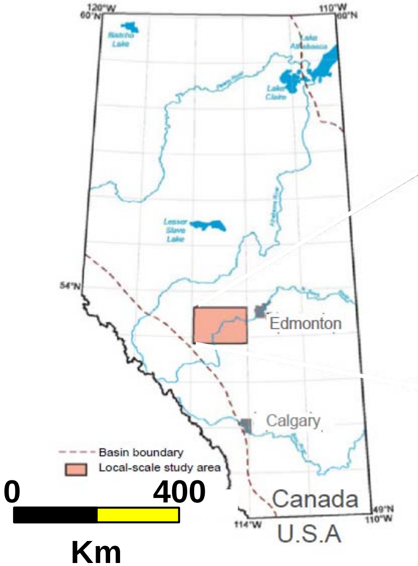
Violet Grove time-lapse revisited: an application of surface-consistent matching filters

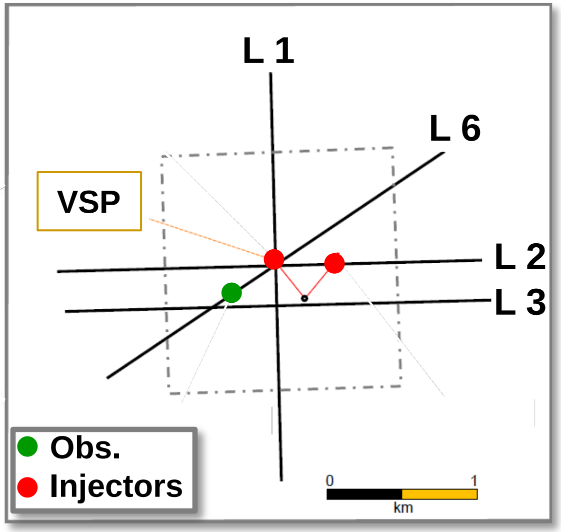
Mahdi Almutlaq
Dr. Gary Margrave

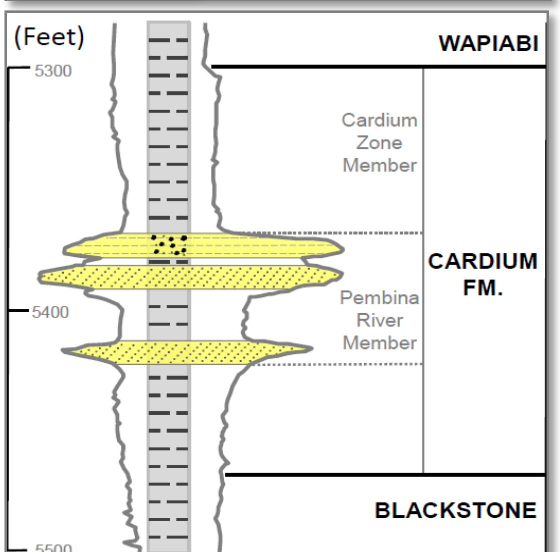
Outline

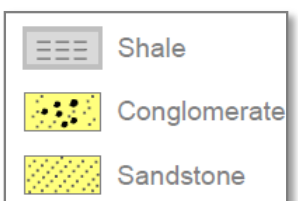
- Violet Grove data
- What are the objectives?
- Review the "**S**urface-**c**onsistent **m**atching **f**ilters" or **SCMF**
- Examples
- Conclusions

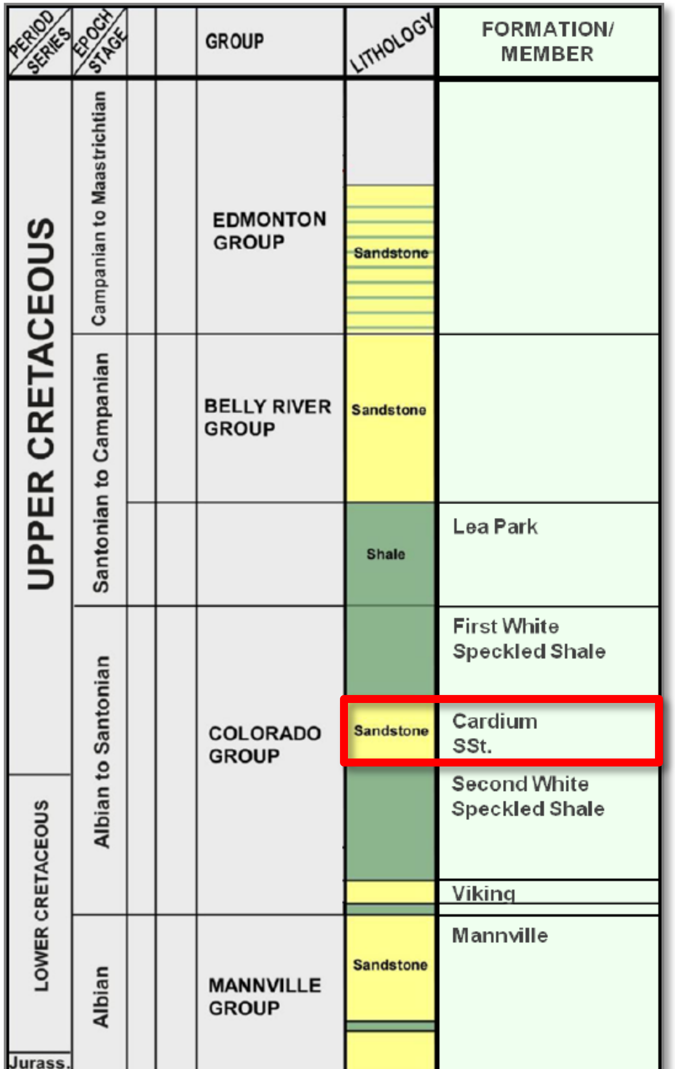
Violet Grove









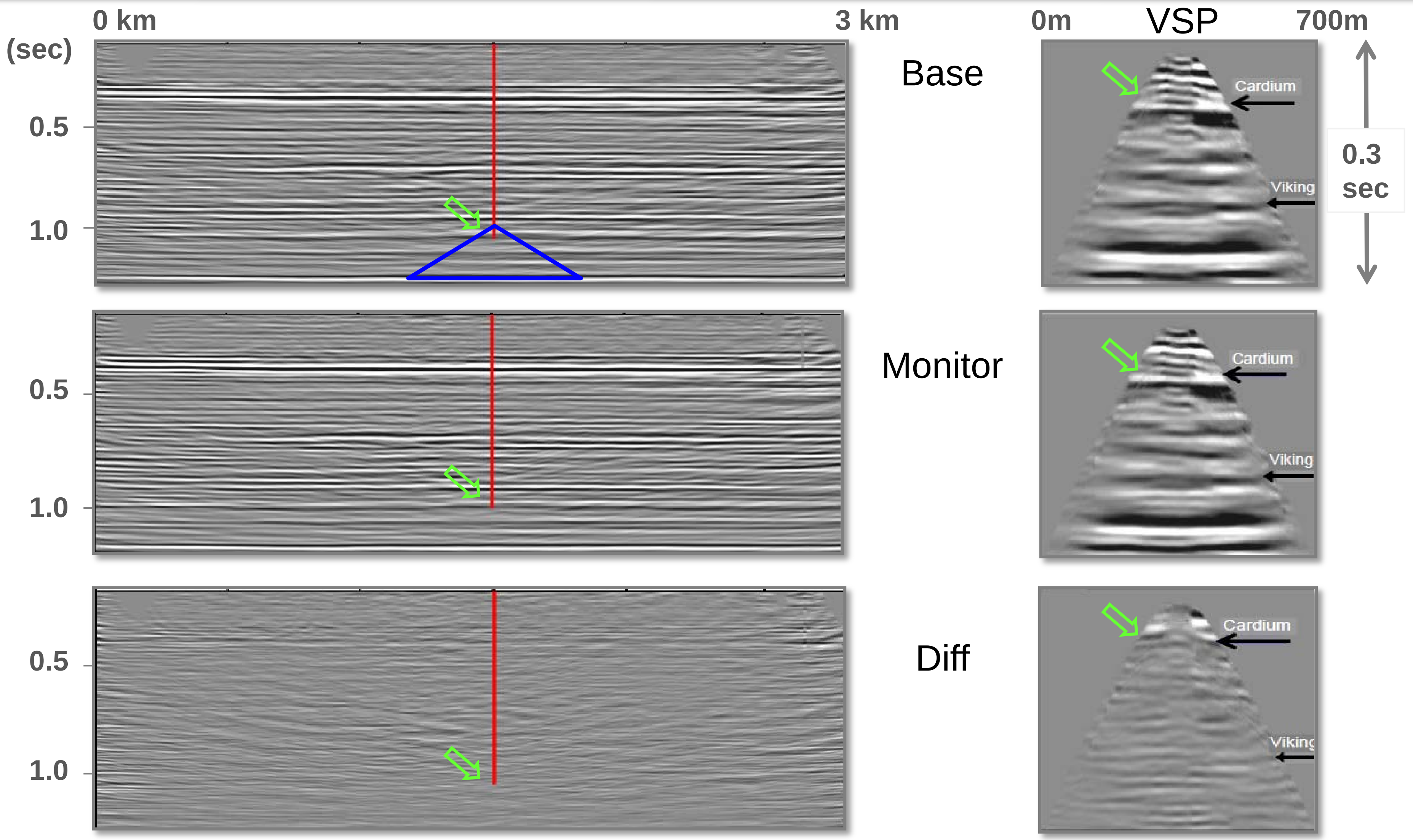


Alshuhail et al., 2008, CREWES rep.

Data acquisition

Phase	Seismic Data	Date	Injected CO_2 (tonnes)
I (baseline)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones)	March 2005	0
II (1^{st} monitor)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones)	December 2005	$15,000$
III (2^{nd} monitor)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones) vi. Addition of - (a) 16-level VSP (b)southwest-northeast 2D line (line 6).	March 2007	$60,000$

Violet Grove: seismic



Alshuhail et al., 2008, CREWES rep.

Objectives

- When to perform surface-consistent matching filters (SCMF) in prestack processing?
- Compute the 4-components SCMF.
- Apply the SCMF.

Match filters ↔ Spectral Ratios

To match two traces

$$m(t) * d_2(t) = d_1(t) \quad \Rightarrow \quad \sum_t \left(m(t) * d_2(t) - d_1(t) \right)^2 = \min$$

In freq. domain:

$$\hat{m}(\omega) = \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)}$$

$$\text{match filters in time domain} \Leftrightarrow \text{spectral ratio in freq. domain}$$

A stable trace-by-trace match filter:

Time-domain least squares → fft → Spectral ratios

Surface-consistent equations

Baseline survey, any trace

$$d_1(t) = s_1(t) * r_1(t) * h_1(t) * y_1(t)$$

Monitor survey, corresponding trace

$$d_2(t) = s_2(t) * r_2(t) * h_2(t) * y_2(t)$$

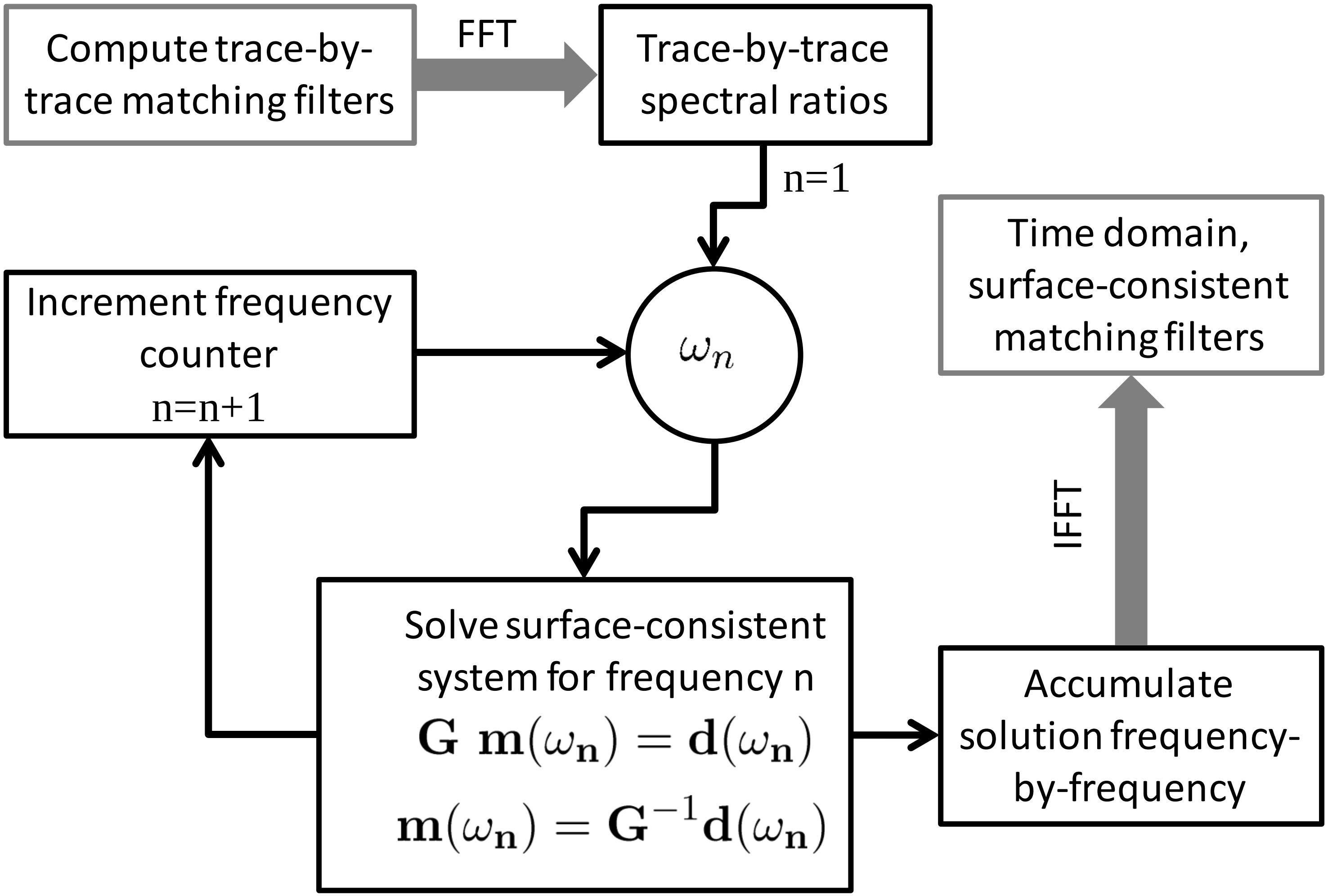
In the log-frequency domain

$$\underbrace{\log \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)}}_{\text{Data log-spectral ratio}} = \underbrace{\log \frac{\hat{s}_1}{\hat{s}_2}(\omega) + \log \frac{\hat{r}_1}{\hat{r}_2}(\omega) + \log \frac{\hat{h}_1}{\hat{h}_2}(\omega) + \log \frac{\hat{y}_1}{\hat{y}_2}(\omega)}_{\text{Sum of surface-consistent terms, one equation per frequency per trace}}$$

Data log-spectral ratio

Sum of surface-consistent terms, one equation per frequency per trace

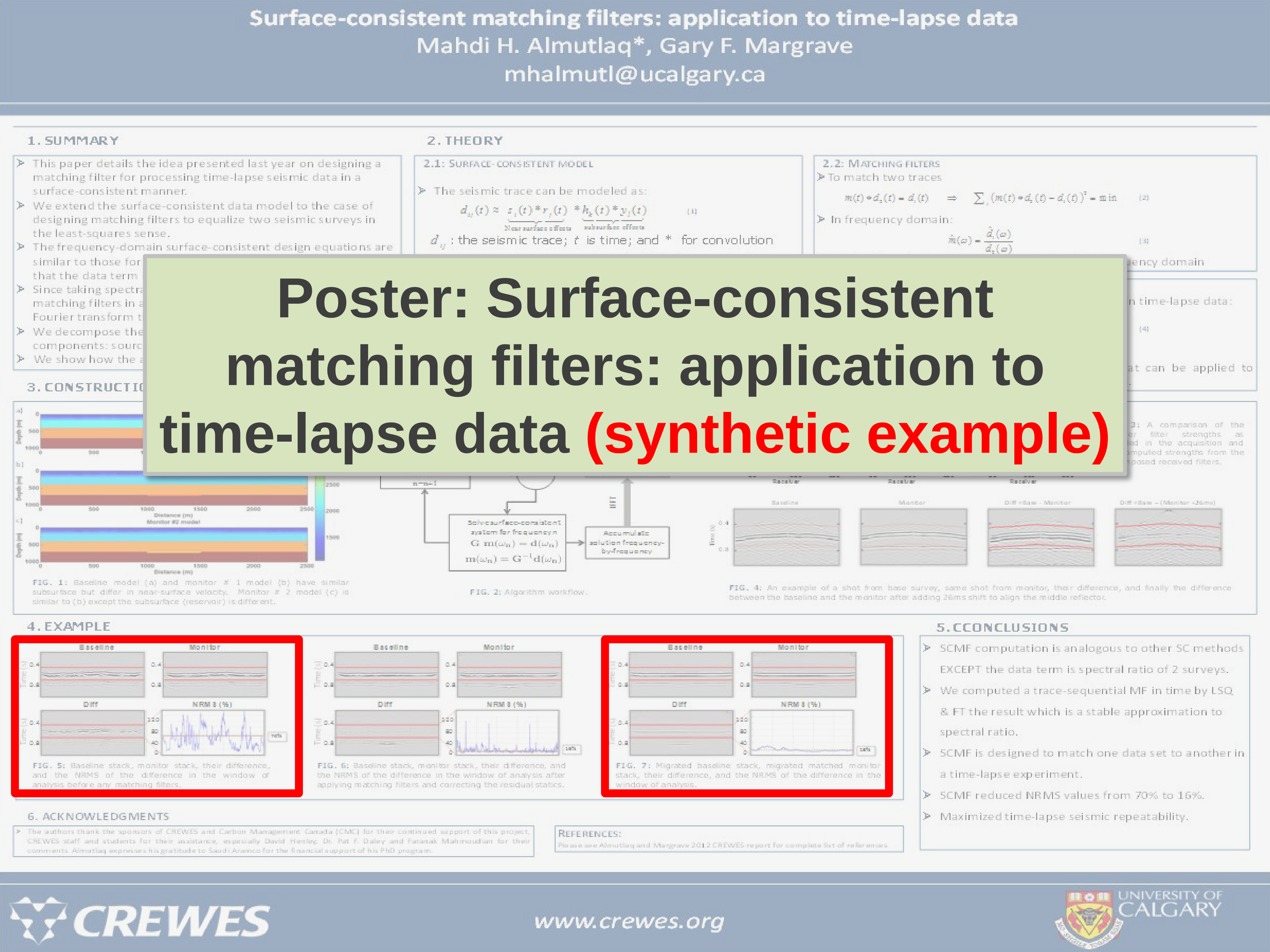
Algorithm workflow



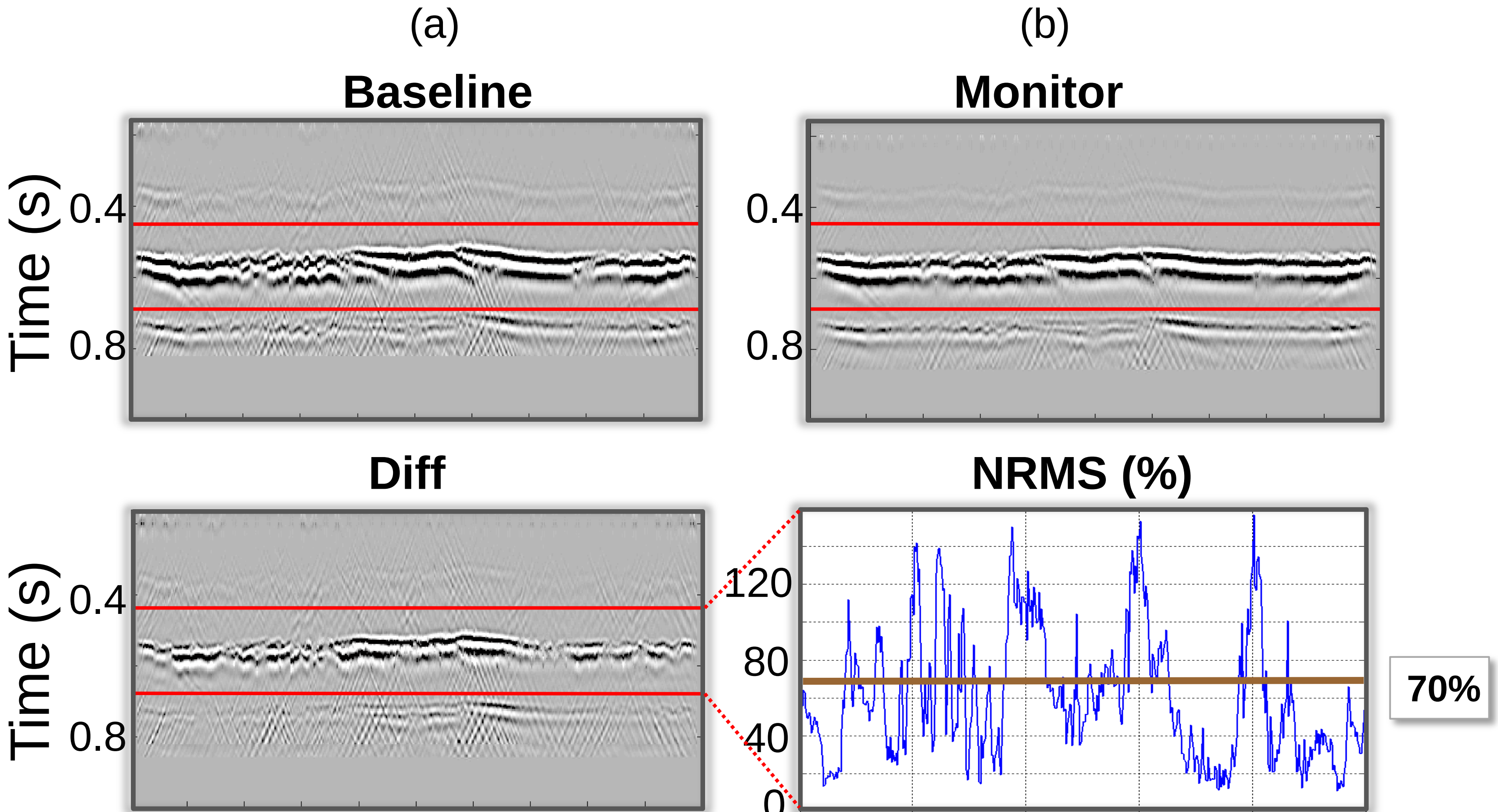
Outline

- Violet Grove data
- What are the objectives?
- Review the "**S**urface-**c**onsistent **m**atching **f**ilters" or **SCMF**
- **Examples**
- Conclusions

Poster: Surface-consistent matching filters: application to time-lapse data (synthetic example)

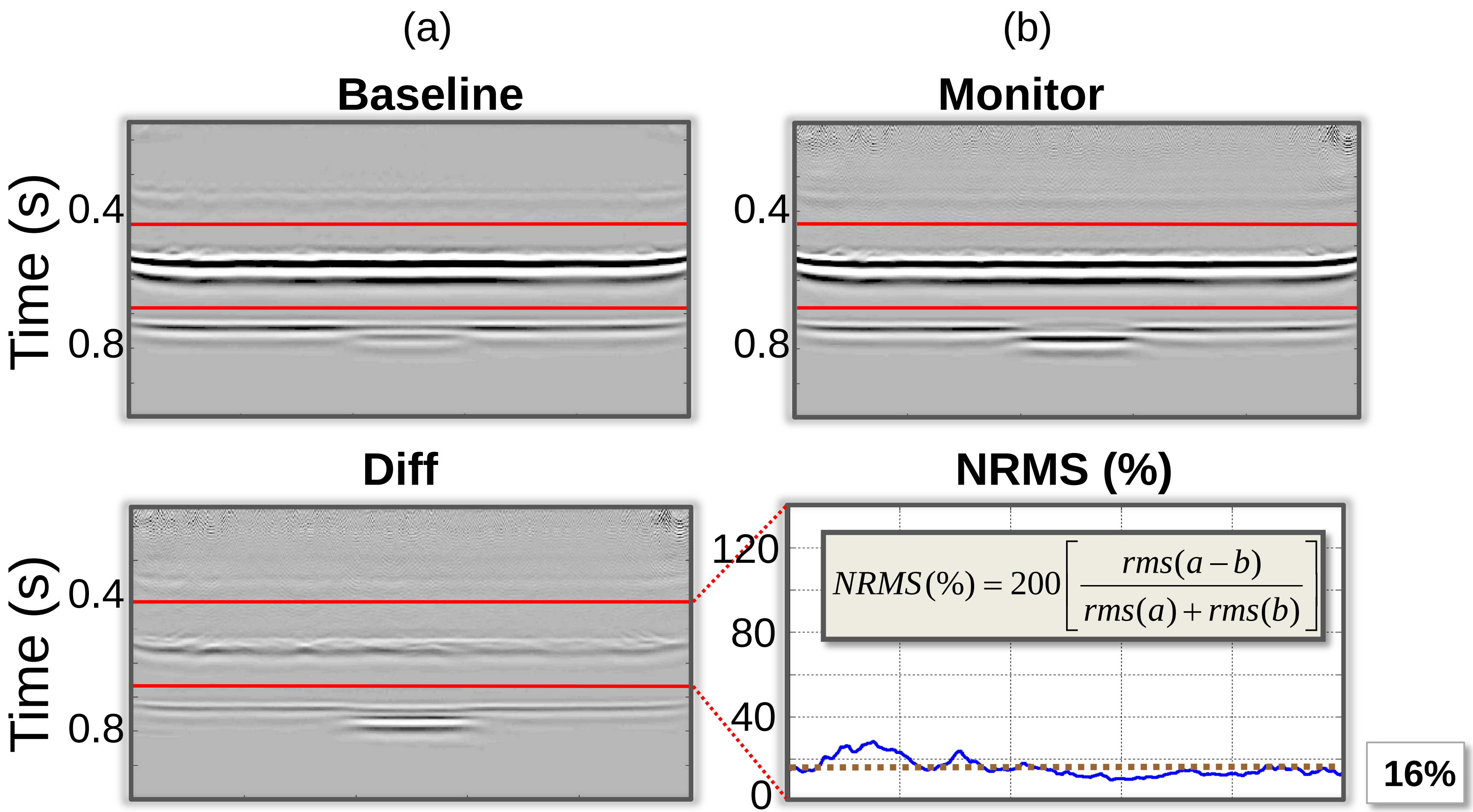


Before SCMF



$$NRMS(\%) = 200\left[\frac{rms(a-b)}{rms(a)+rms(b)}\right]$$

After SCMF


(a)
(b)
Baseline
Monitor
Time (s)
0.4
0.8
Diff
NRMS (%)
120
80
40
0
$NRMS(\%) = 200\left[\frac{rms(a-b)}{rms(a)+rms(b)}\right]$
16%

Processing steps

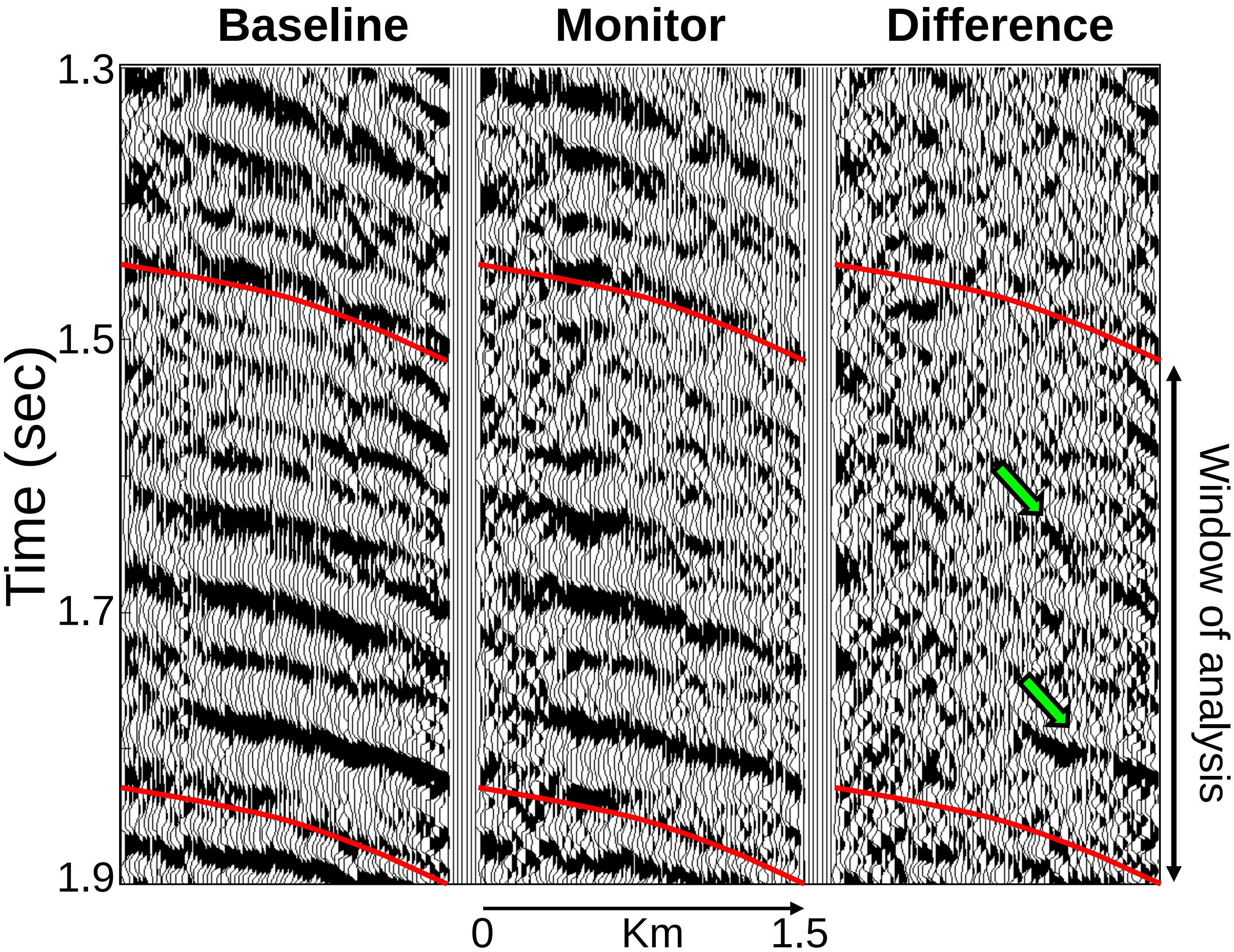
Baseline

- Geometry assignment
- Ground roll attenuation
- Trace edits + mute
- Amplitude recovery
- Surf.-consis. Amp. Corr.
- Surf.-consis. spiking decon.
- **-**
- **Velocity analysis**
- Surf.-consis. residual statics
- CDP stacking
- Post stack kirk. migration

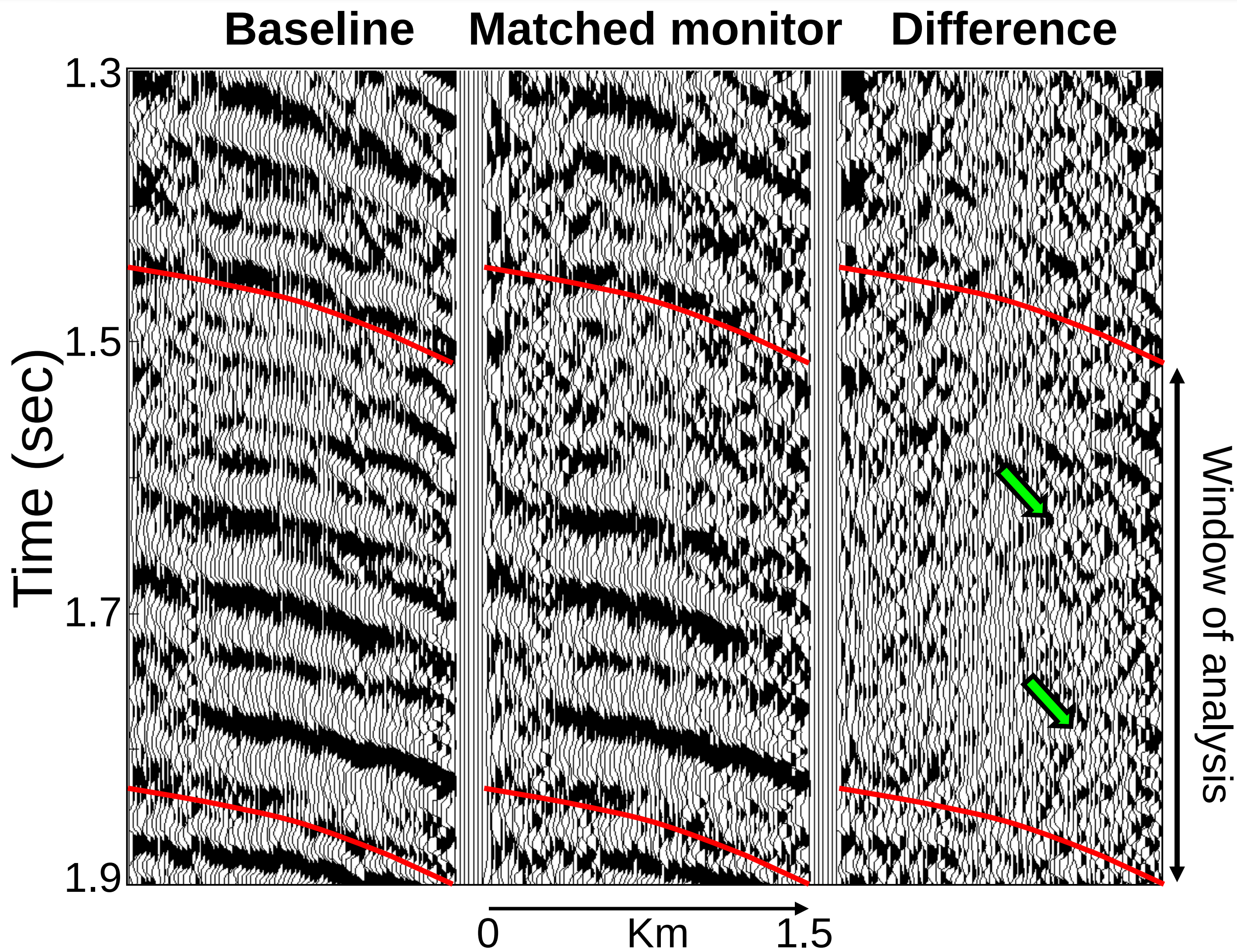
Monitor

- Geometry assignment
- Ground roll attenuation
- Trace edits+ mute
- Amplitude recovery
- Surf.-consis. Amp. Corr.
- Surf.-consis. spiking decon.
- **Surf.- consis. matching filters**
- **-**
- Surf.- consis. residual statics
- CDP stacking
- Post stack kirk. migration

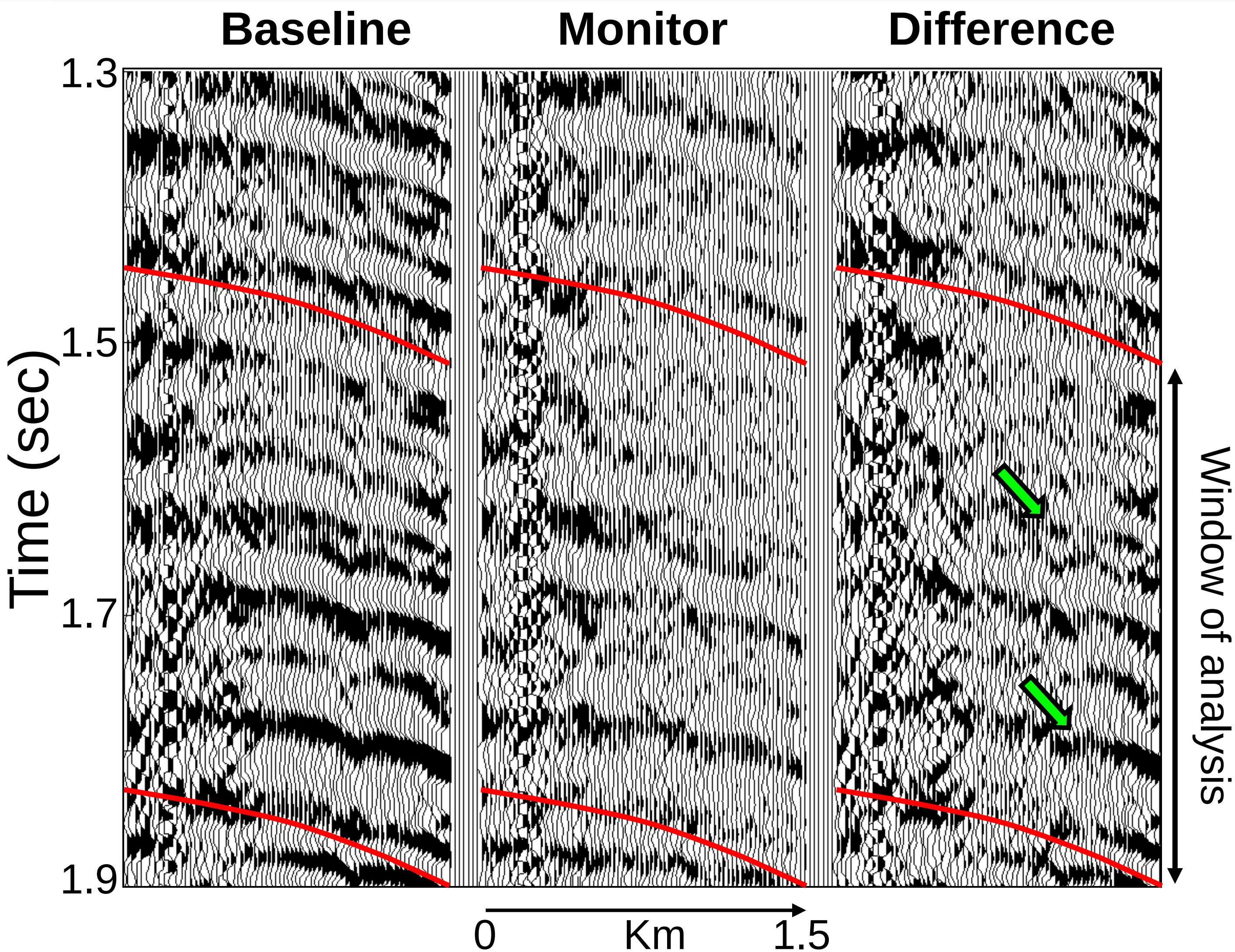
Prestack: before SCMF



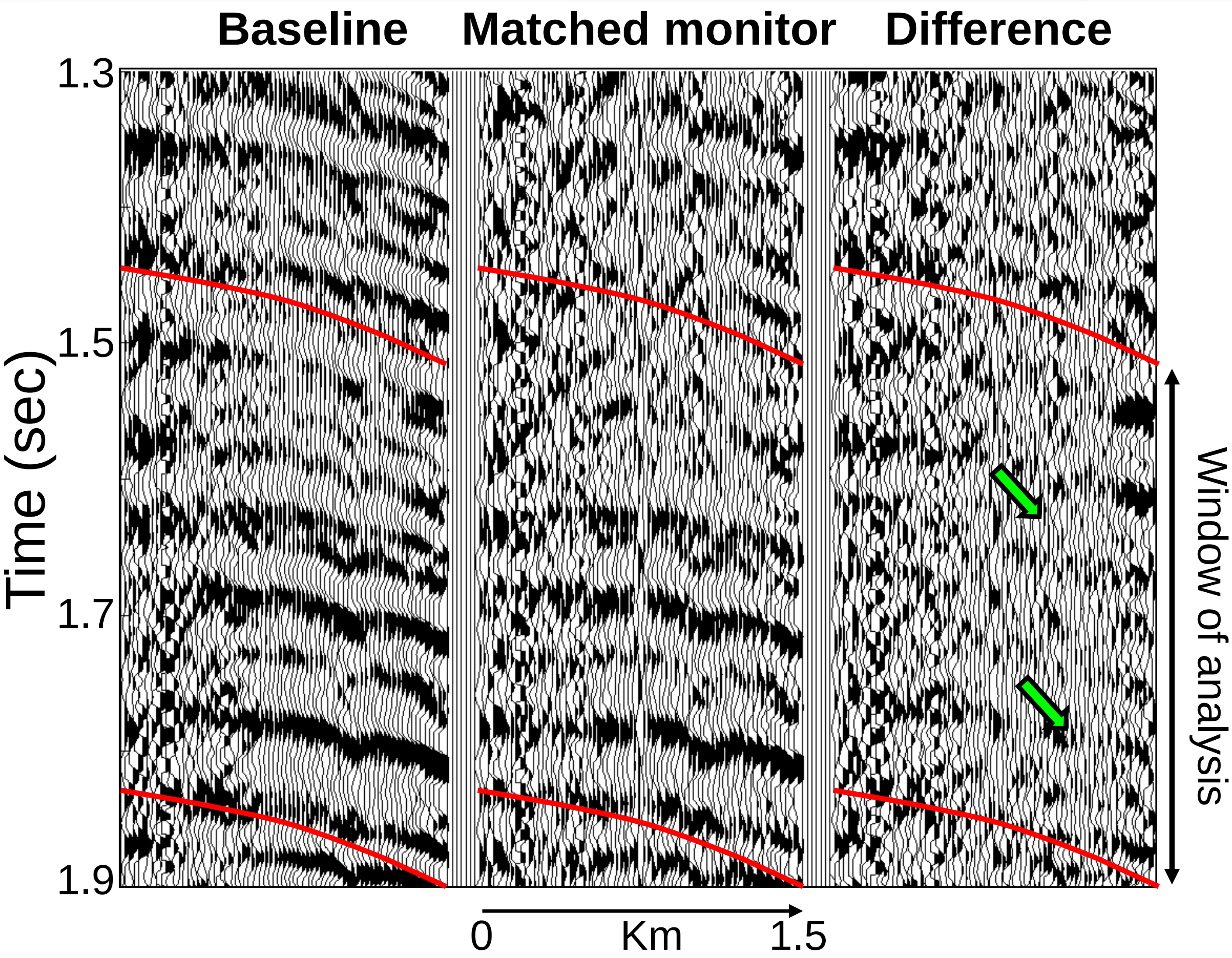
Prestack: after SCMF



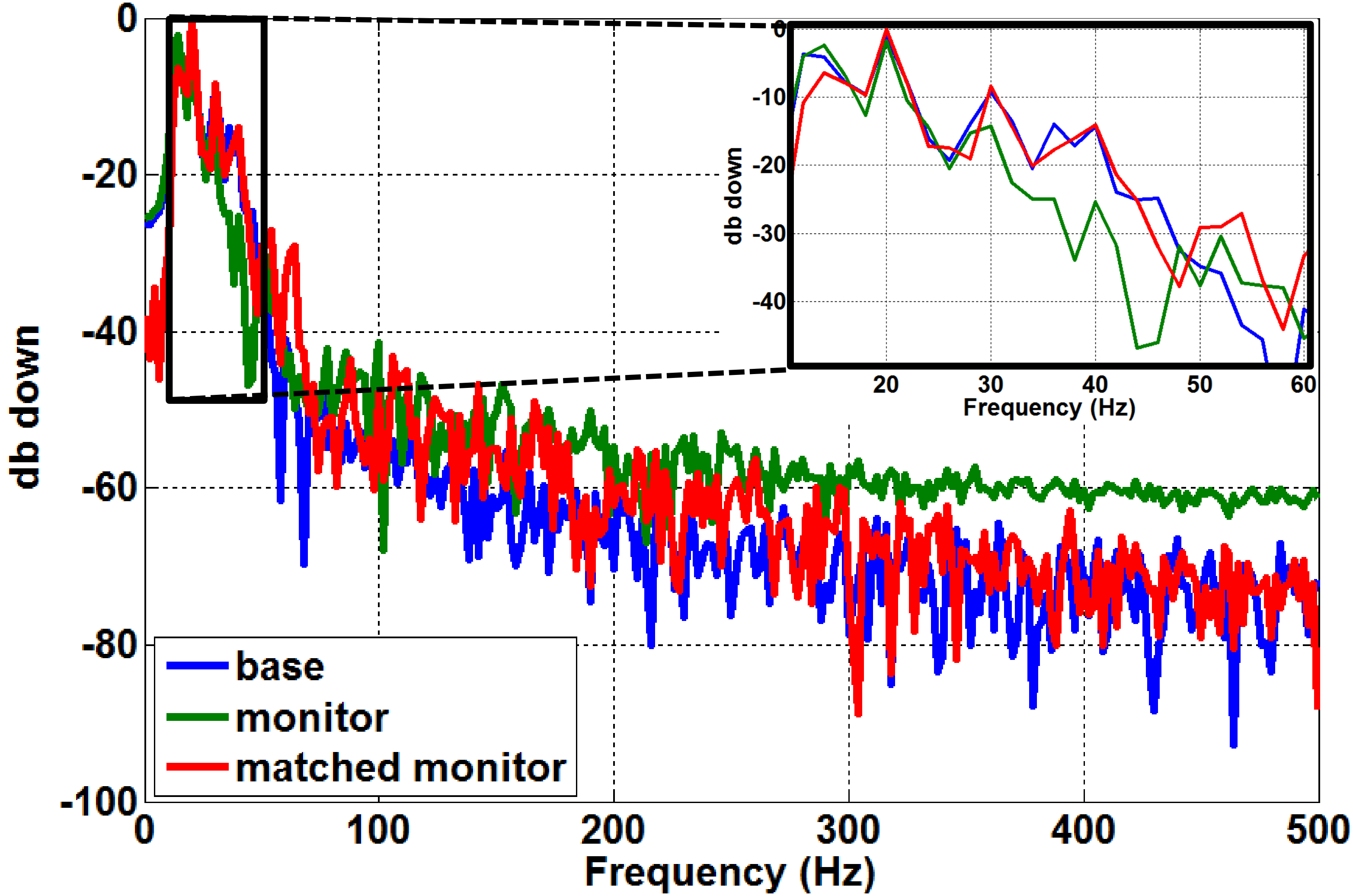
Prestack: before SCMF



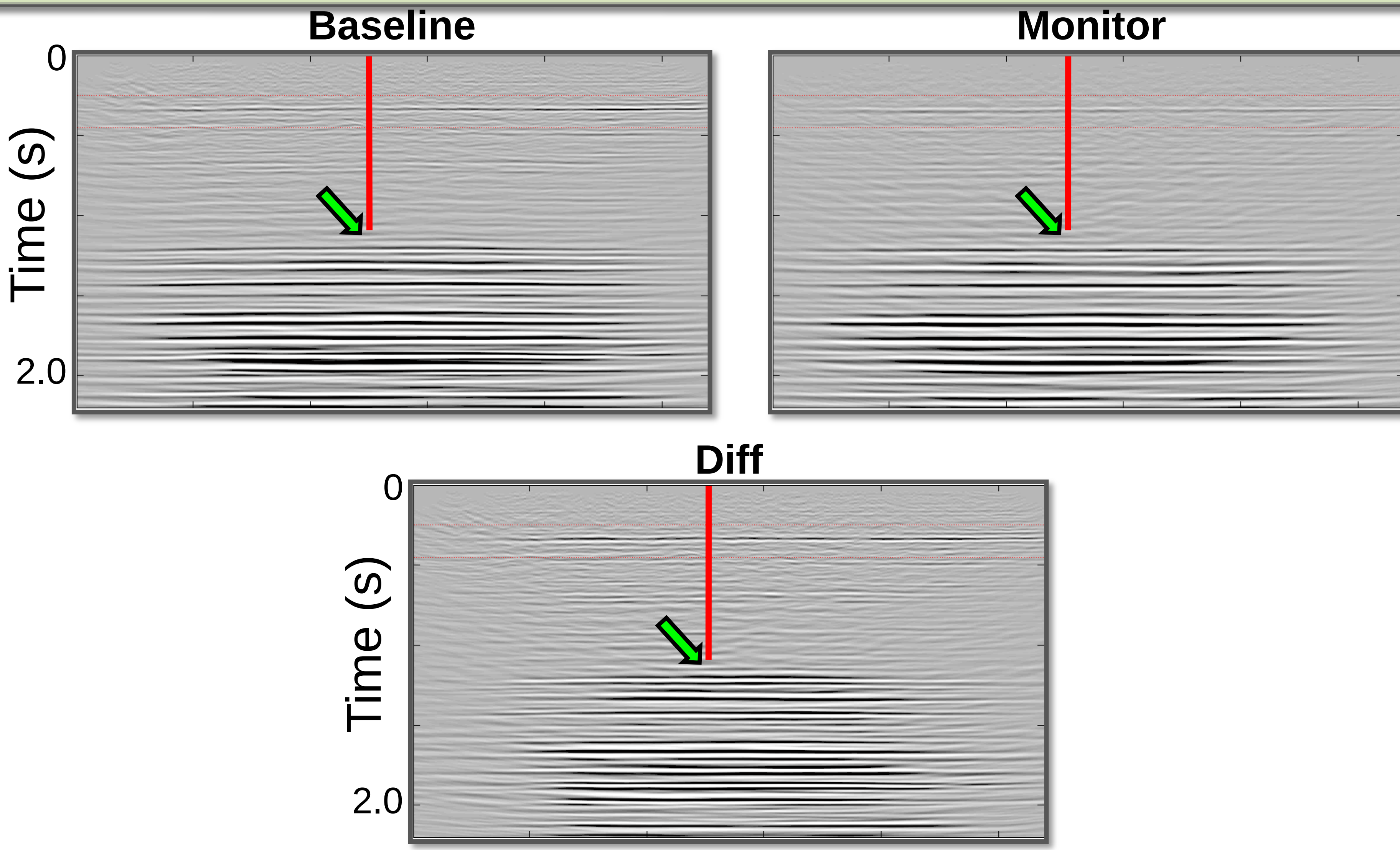
Prestack: after SCMF



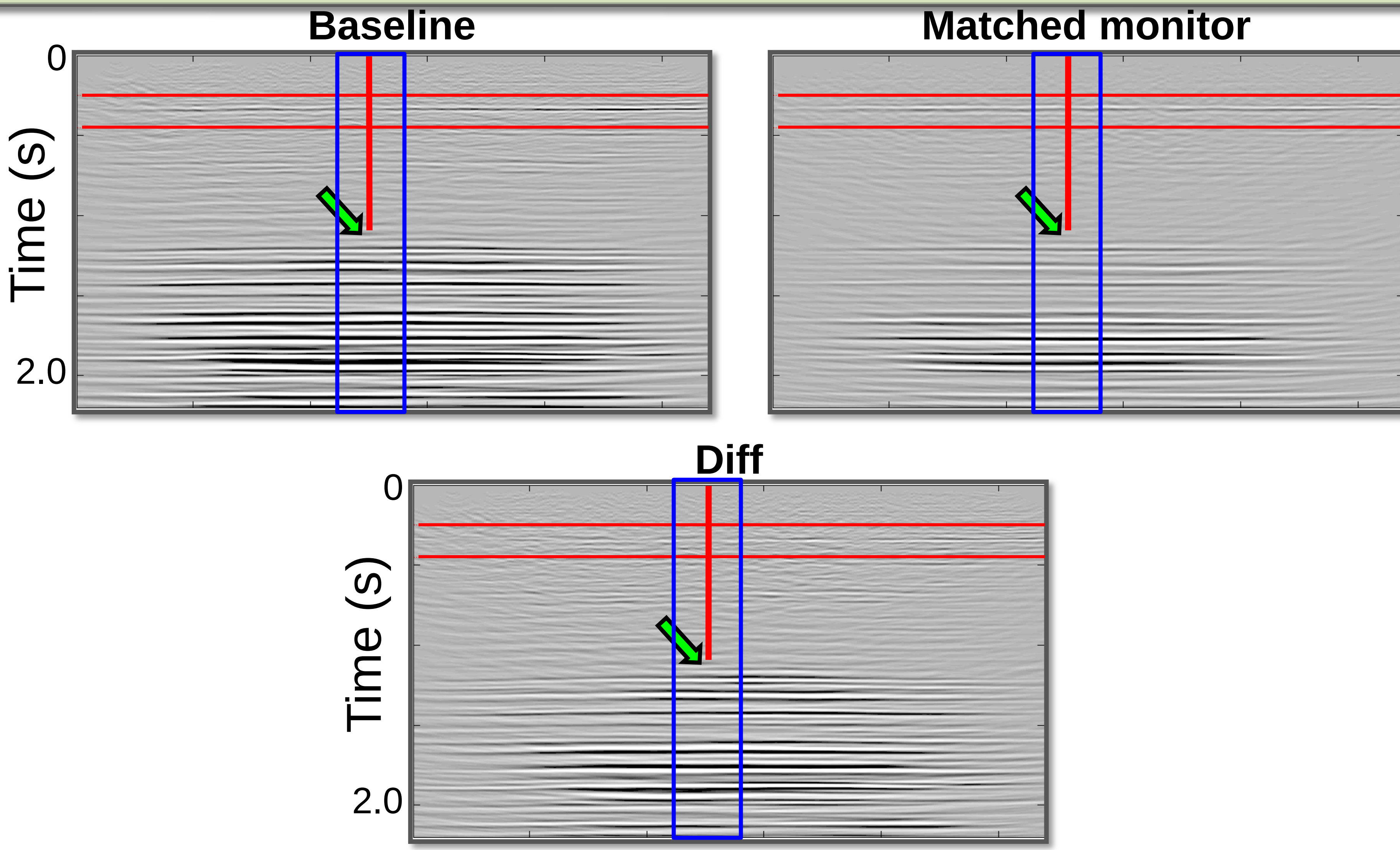
Amplitude spectrum



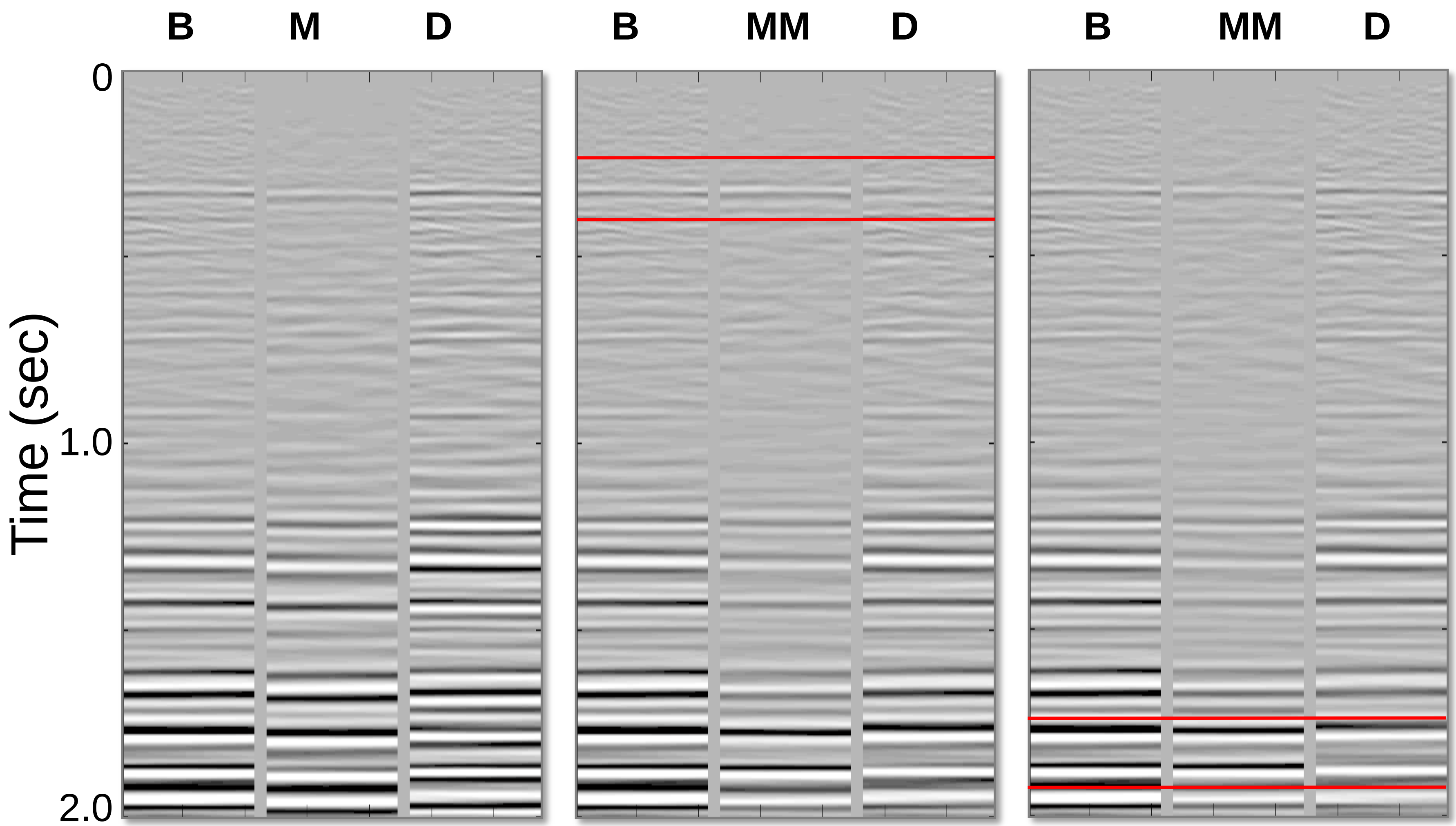
Before SCMF



After SCMF



More comparisons



Conclusions

- SCMF computation is analogous to other SC methods EXCEPT the data term is spectral ratio of 2 surveys.
- SCMF is designed to match one data set to another in a time-lapse experiment.
- SCMF reduced NRMS values from 70% to 16% in synthetic data set.
- Successfully reduced most of the observed difference inside the window of SCMF in Violet Grove data set.
- Maximized time-lapse seismic repeatability.

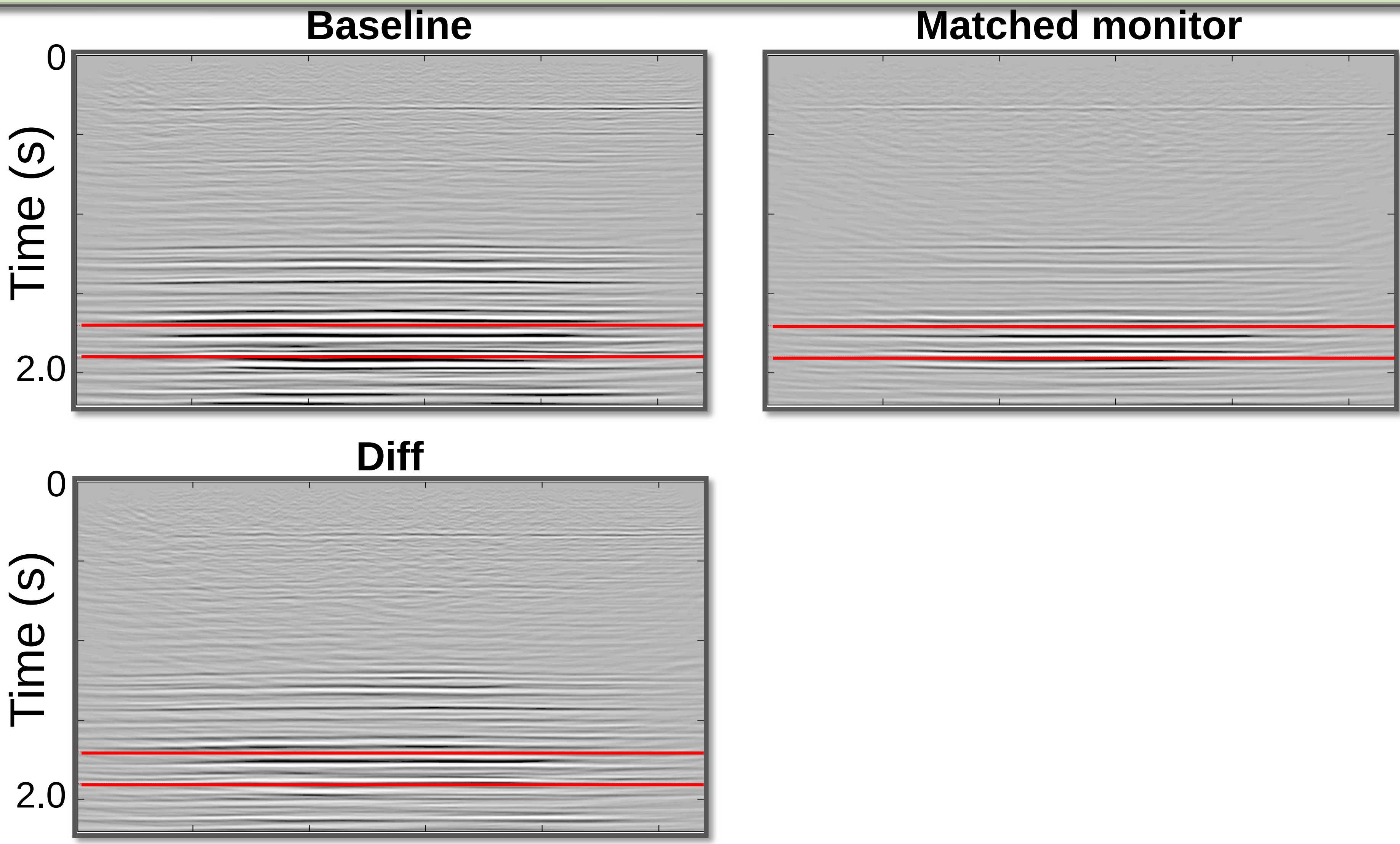
Acknowledgements

- CREWES & all the sponsors.
- A special thanks to Saudi Aramco for generously sponsoring Almutlaq's PhD program.
- Thanks to Dave Henley, Kevin Hall, Helen Isaac and Faranak Mahmoudian for their help.

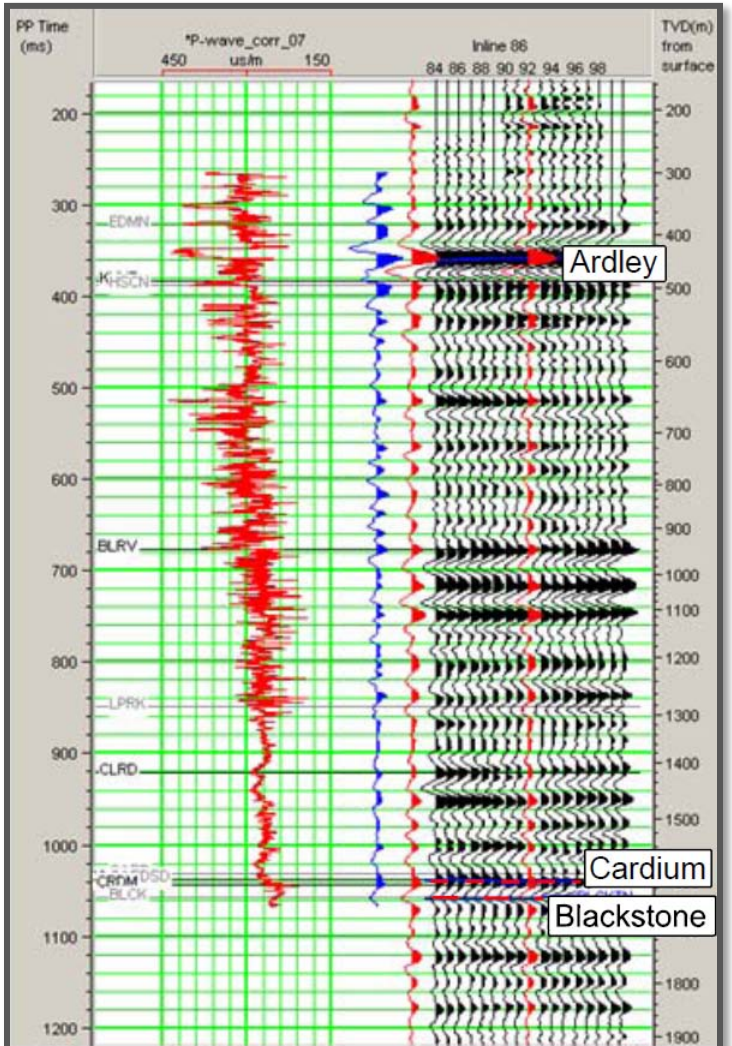
UNIVERSITY OF CALGARY

CREWES

After SCMF



Well-tie


PP Time (ms)
*P-wave_corr_07
450 us/m 150
Inline 86
84 86 88 90 92 94 96 98
TVD(m) from surface
200
300
400
500
600
700
800
900
1000
1100
1200
EDMN
HSCN
BLRV
LPRK
CLRD
BLCK
Ardley
Cardium
Blackstone
1300
1400
1500
1800
1900

2006 vs 2012 processing

→ Done

→ Not done

Table 3: The standard processing work flow of the surface seismic data set (Lu et al., 2006).

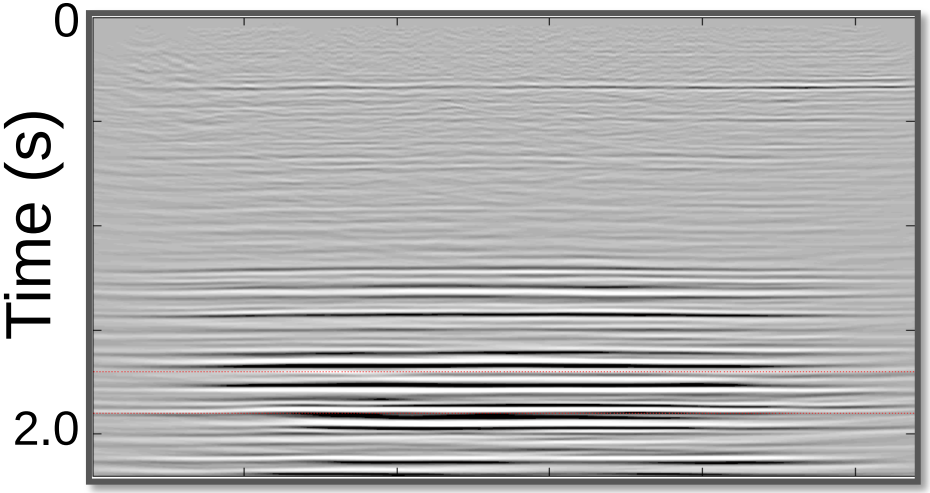
Processing work flow for the PP data
→ Geometry assignment
→ Ground roll attenuation
→ Trace edits
→ Amplitude recovery
→ Minimum phase deconvolution
→ Tomographic structure statics
→ Velocity analysis
→ Surface-consistent residual statics
→ Spectral whitening
→ Mute and ~~trim statics~~ →
→ Surface-consistent scaling
→ CDP stack
→ F-X noise attenuation
→ Poststack kirchhoff migration
→ Bandpass filter

Table 4: Processing work flow of Line 1.

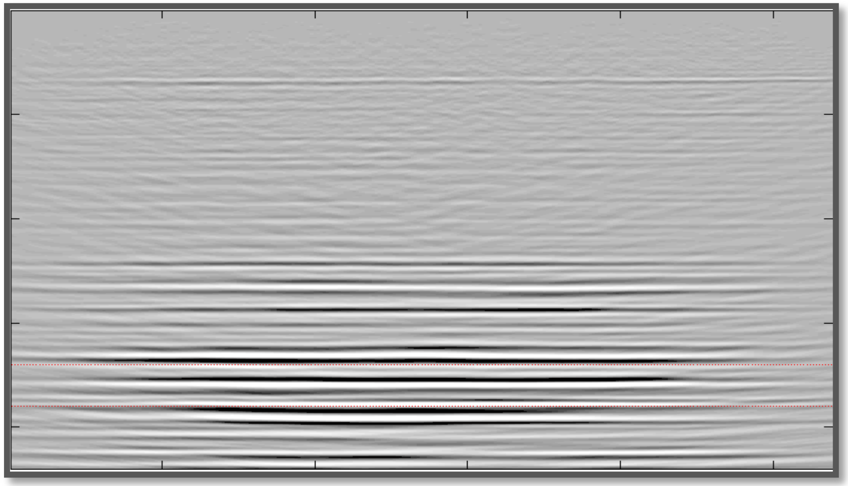
Baseline	**Monitor**
Geometry assignment	Geometry assignment
Ground roll attenuation	Ground roll attenuation
Trace edits	Trace edits
Amplitude recovery	Amplitude recovery
Surface consistent Amplitudes correction	Surface consistent Amplitudes correction
Surface consistent Spiking deconvolution	Surface consistent Spiking deconvolution
-	**Surface consistent matching filters**
Velocity analysis	-
Surface-consistent residual statics	Surface-consistent residual statics
CDP stack	CDP stack

Before SCMF

Baseline



Monitor



Diff