Applications of Broadband Land Seismology*

Ruijie Zhang[1]

Search and Discovery Article #70253 (2017)**
Posted April 10, 2017

*Adapted from oral presentation given at AAPG Middle East Geosciences Technology Workshop, Advances in Subsurface Imaging and Mapping, Muscat, Oman, October 26-27, 2016

[1]BGP, CNPC, Beijing, China (zhangrujie@bgp.com.cn)

Abstract

The reef-flat facies reservoirs in carbonate are dominantly developed along the Eastern Edge of the Pre-Caspian Basin. Due to the influences of salt domes and strong heterogeneity, the pre-salt stratigraphy-controlled traps cannot be well imaged with the conventional source, geometry, and processing methods. The narrow-azimuth and low-fold geometry cannot provide high S/N data and image salt domes and pre-salt reef-flat bodies distinctively; the lack of low frequencies and the loss of high frequencies severely affect the resolution of seismic data and inversion quality. The broadband vibrator, LFV3 that enhances low frequency energy from 3Hz, has been developed and was deployed in AMG 3D project, Kazakhstan in 2013. A Wide-azimuth, Broadband, and High-density (WBH) data volume was acquired. Following the acquisition, a WBH processing and inversion flow was set up, and the imaging accuracy of the salt dome boundaries and pre-salt reflections and resolution were greatly improved.

Reference Cited

Goodway, B., and S. Ronen, 2013, Introduction to this special section: Offshore and onshore broadband seismology: The Leading Edge, v. 32/11, p. 1354-1355.

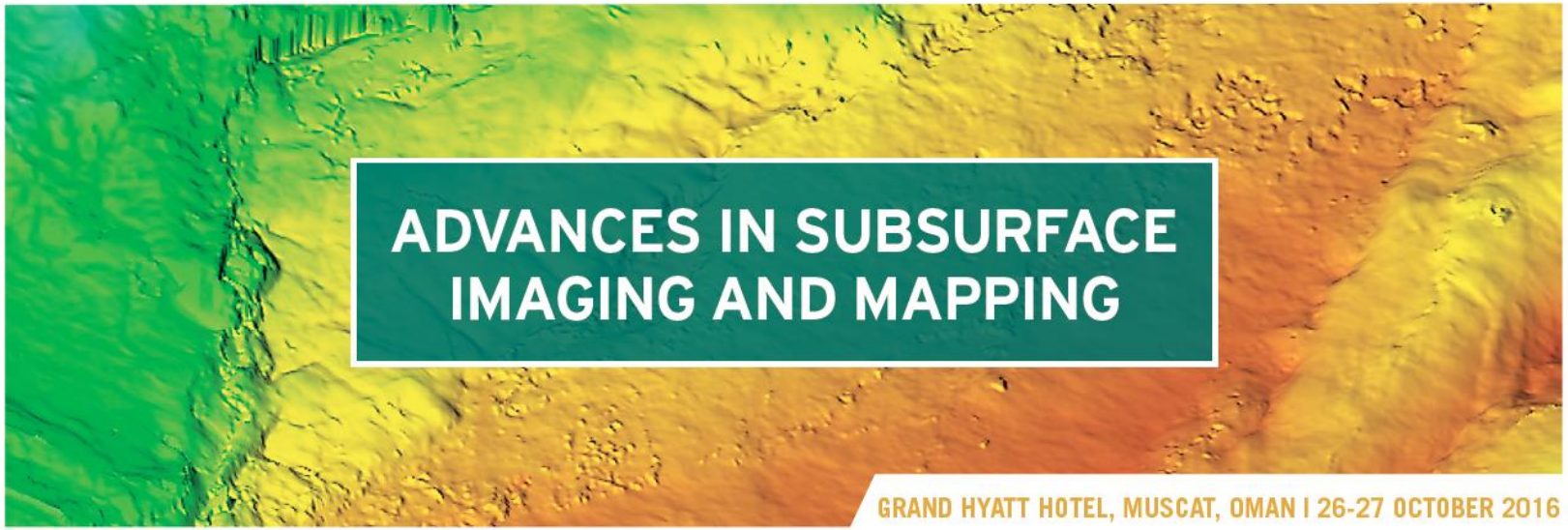
Applications of Broadband Land Seismology

Zhang, Rujie

26-27, October, 2016. Muscat, Oman

Contents

Motif of this workshop



Keywords:

ACQ: WAZ, ***Low-frequency, Broadband***, High-density, Long-offset High-productivity, Nodal system, Point source/sensor;

PROC: Statics, De-noise, De-multiples, *Low-frequency recovery*, Q-compensation, Accurate velocity, Anisotropy, PSTM/PSDM.

Low frequency technology

SEG/EAGE 2010
SUMMER RESEARCH
WORKSHOP
SNOWBIRD, UTAH

15-20 August 2010

Review the value and challenges of frequencies below what is normally captured in seismic operations. In particular, we will focus on the following:

- *Sourcing Low Frequencies both actively and passively*
- *Capturing Low Frequencies in acquisition*
- *Preserving signal and suppressing noise in processing*
- Complementing Low Frequency content with other geophysical measurements
- Utilizing Low Frequencies in imaging and inversion
- Applying Low Frequencies and making a difference
- Looking at the Road Ahead in Low Frequencies

Broadband Seismic Technology

Vol.32No.11，Leading Edge:

Introduction to this special section: Offshore and onshore broadband seismology , *BILL GOODWAY,SHUKI RONEN*

……Despite a proliferation of broadband solutions employing combinations of equipment, acquisition techniques, and processing, the full potential of broadband has not been achieved in the authors' opinion. They go on to describe and conclude that the best broadband results come from the solutions which have tackled both the receiver and source ghost notches to extend the seismic bandwidth to "over six octaves".,……

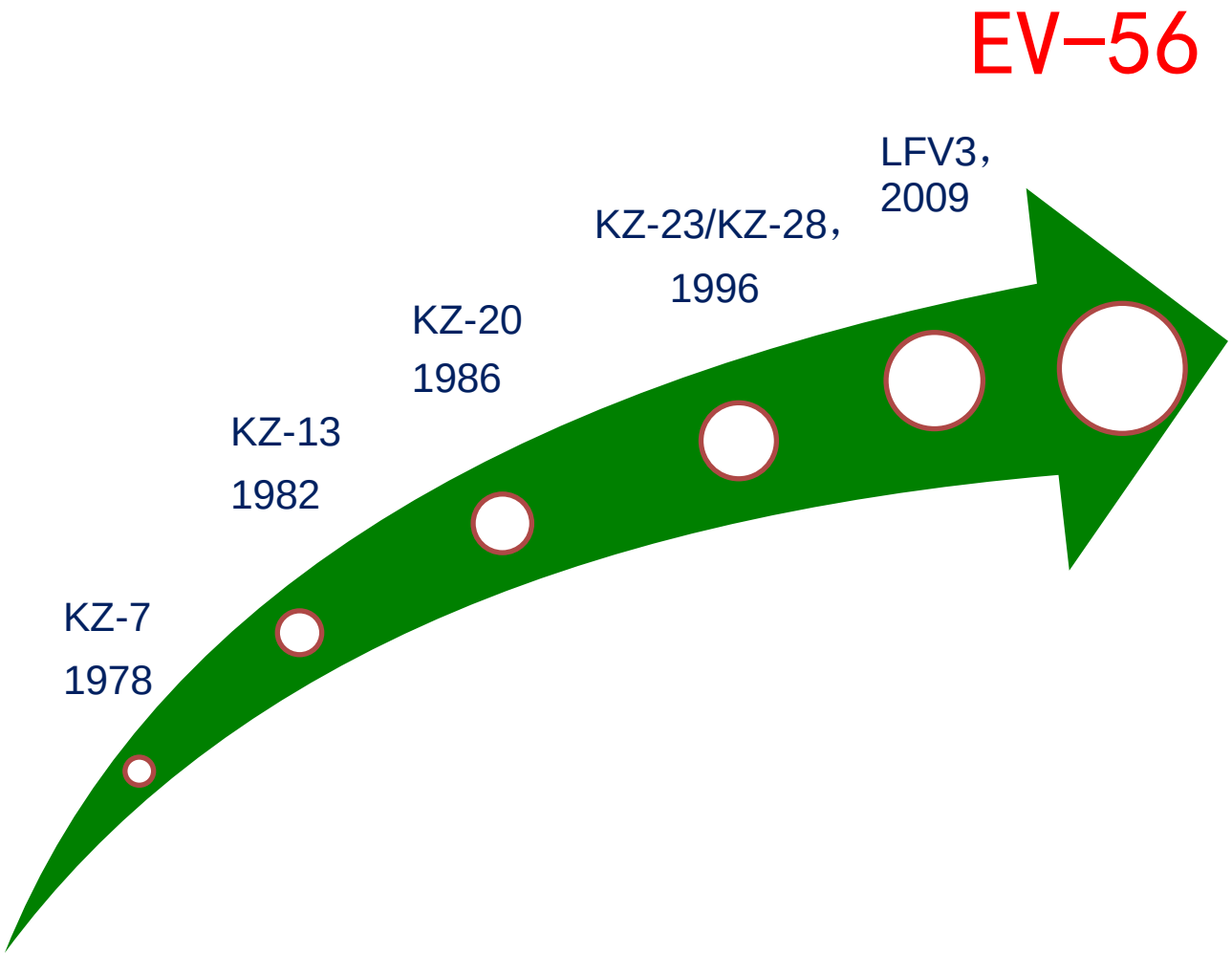
There are no quantitative definitions to many ACQ terms mentioned above.

Contents

Road map of BGP vibrator

Vibrator manufacturing started in 1978 :

- KZ-7, peak force 16,000lbs
- KZ-13, peak force 28,000lbs
- KZ-20, peak force 42,000lbs
- KZ-23/2000, peak force 51,000lbs
- KZ-28, peak force 62,000lbs
- LFV3, peak force 62,000lbs
- EV-56, peak force 56,000lbs



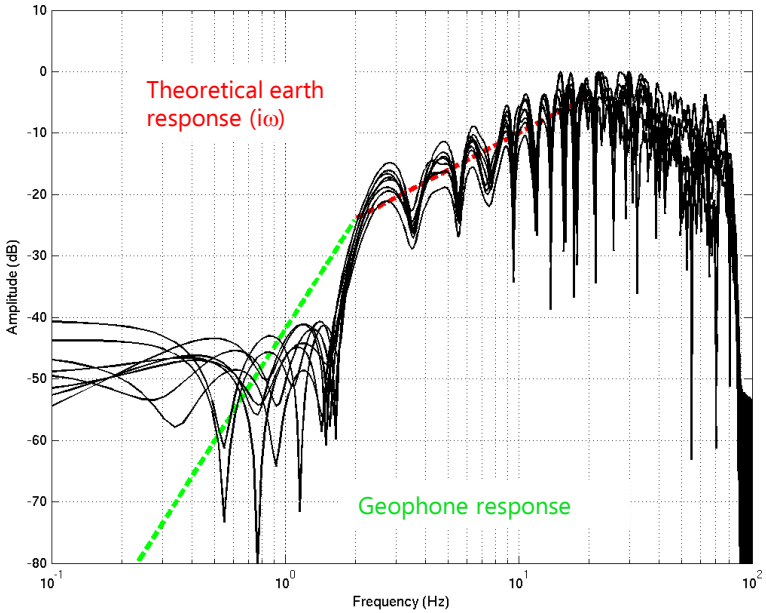
What is low frequency vibrator?

The "low frequency vibrator" refers to the vibrator that can start shooting at a frequency less than 5Hz with full-drive-force.

Model	Peak Force(N)	RM Weight (kg)	Usable stroke (m)	Piston Area (m^2)	Pump flow_ rating m^3/s	lowest limited freq. (Hz)
KZ28	282000	4600	0.076	0.01378	0.00680	**6.4**
KZ34	390000	6800	0.076	0.0168	0.0078	**6.2**
Vibrator A	266900	5696	0.102	0.01329	0.01009	**5.3**
Vibrator B	278000	4082	0.076	0.01334	0.00763	**6.7**
Vibrator C	400300	7000	0.102	0.0157		5.0

KZ28LF vibrator (Prototype)

1.5Hz signal was recorded by conventional geophones(10Hz) in both downhole and the surface (long-offset (30km) 2D acquisition trials).



Ground forces & downhole signals

(in 2009)

Low frequency vibrator LFV3

High lights：

- Linear sweep starting from 1.5Hz with only 0.5s taper;
- Symmetrical wave field reducing source anisotropy;
- Computer-aided hydraulic flow summing technique.

Based on KZ 28 vibrator chassis.

EV 56 broad band^{++} vibrator

Broad band $^{++}$: More accurate modeling w/vibrator, less perturbation of mass, and low distortion force output

EV-56

- Eastern Vibrator
  - 56,000 Lbs

EV-56

- ✓ EV-56 is a broad band vibrator with the peak force 251KN（or 56,000lbs）from 3Hz to 160Hz. Its fundamental force is comparable with regular 276KN（62,000lbs）vibrator !
- ✓ The state-of-art chassis structure supports its reliability in low frequency emitting and accurate control based on John Sallas's modeling, which improves the output-force distortion in both low and high frequencies.

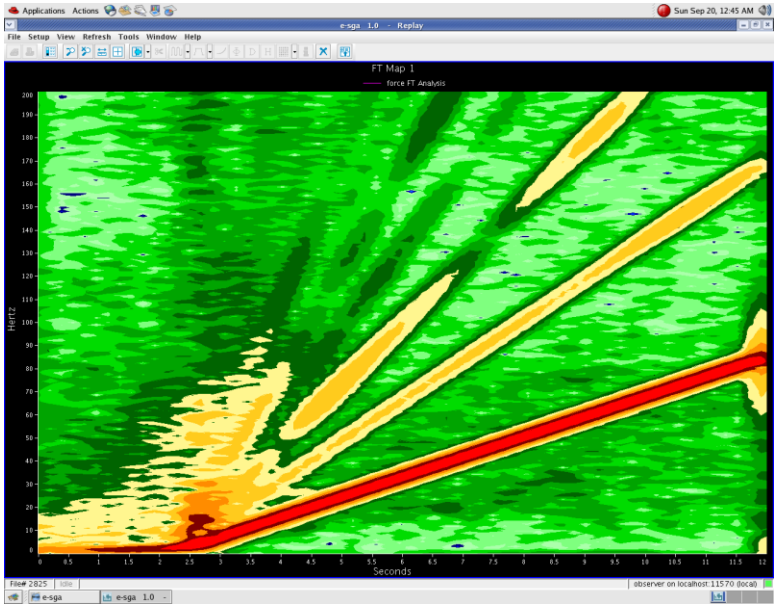
Specs of EV56

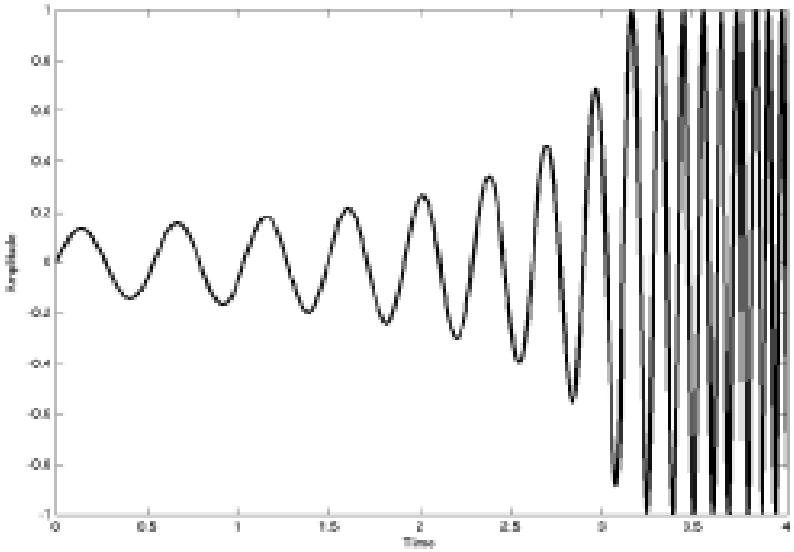
Index	LFV3	EV 56
MAX. HD，kN	281	310
Peak Force，kN	276	251
Limited LF，Hz	3	3
Max. Stroke，mm	178	210
Areas of BP，m^2	3.35	3.35
Mass Weights，kg	5250	5900
BP Weights，kg	1920	2032
MASS/BP Ratio	2.66	2.9
MAX frequency, Hz	100	160
Vibration HP，Mpa	21	21

Highlights of broadband source

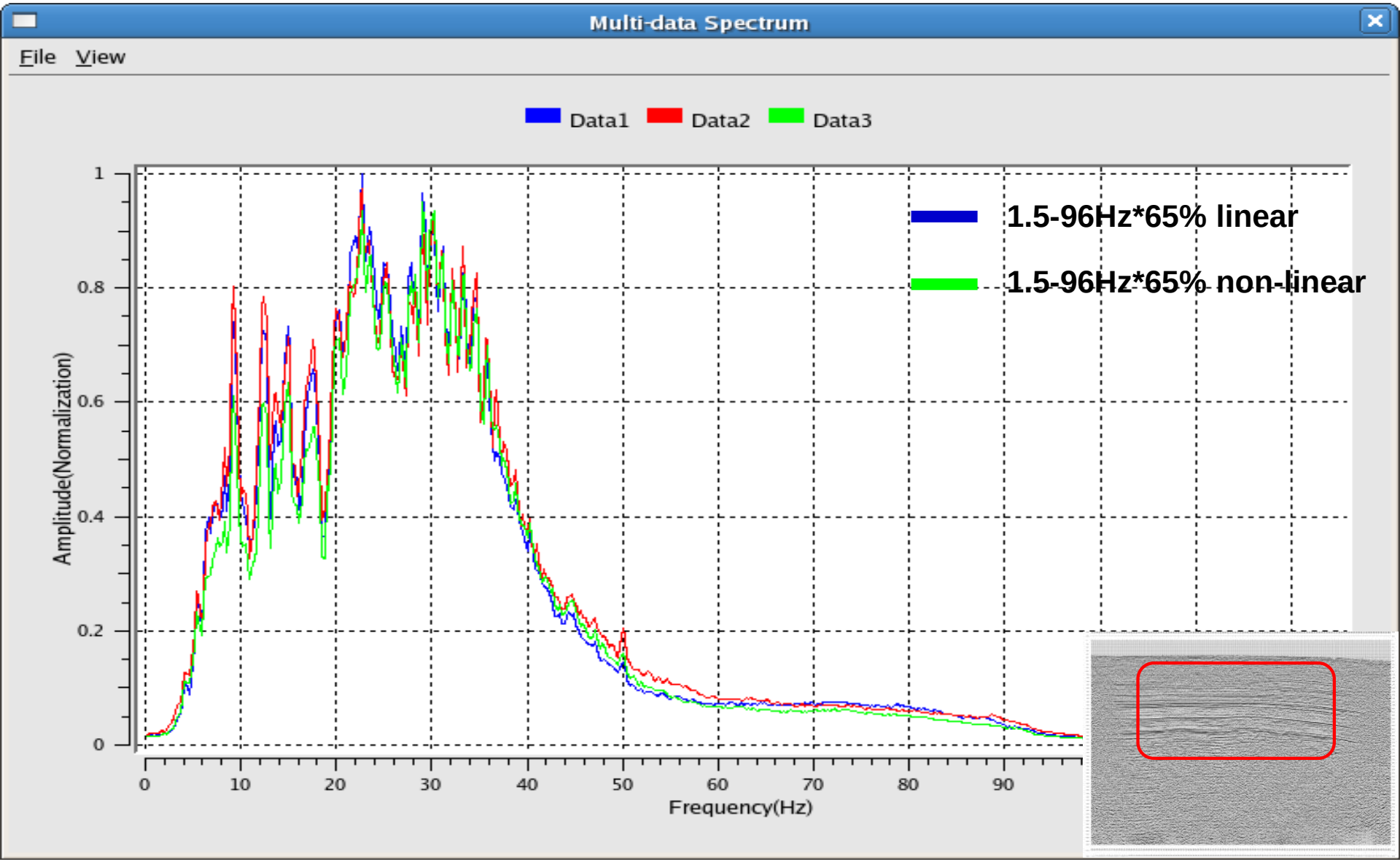
1. A linear sweep starts at 3 Hz with full-drive force.
2. A linear sweep can start at 1.5Hz with full-drive force using only a 0.5 second taper.
3. Broadband sweep is from 1.5-160Hz.

Notice: Strong harmonic distortion appears at the transition point from non-linear to linear sweep, referencing to the paper by Claudio Bagaini.



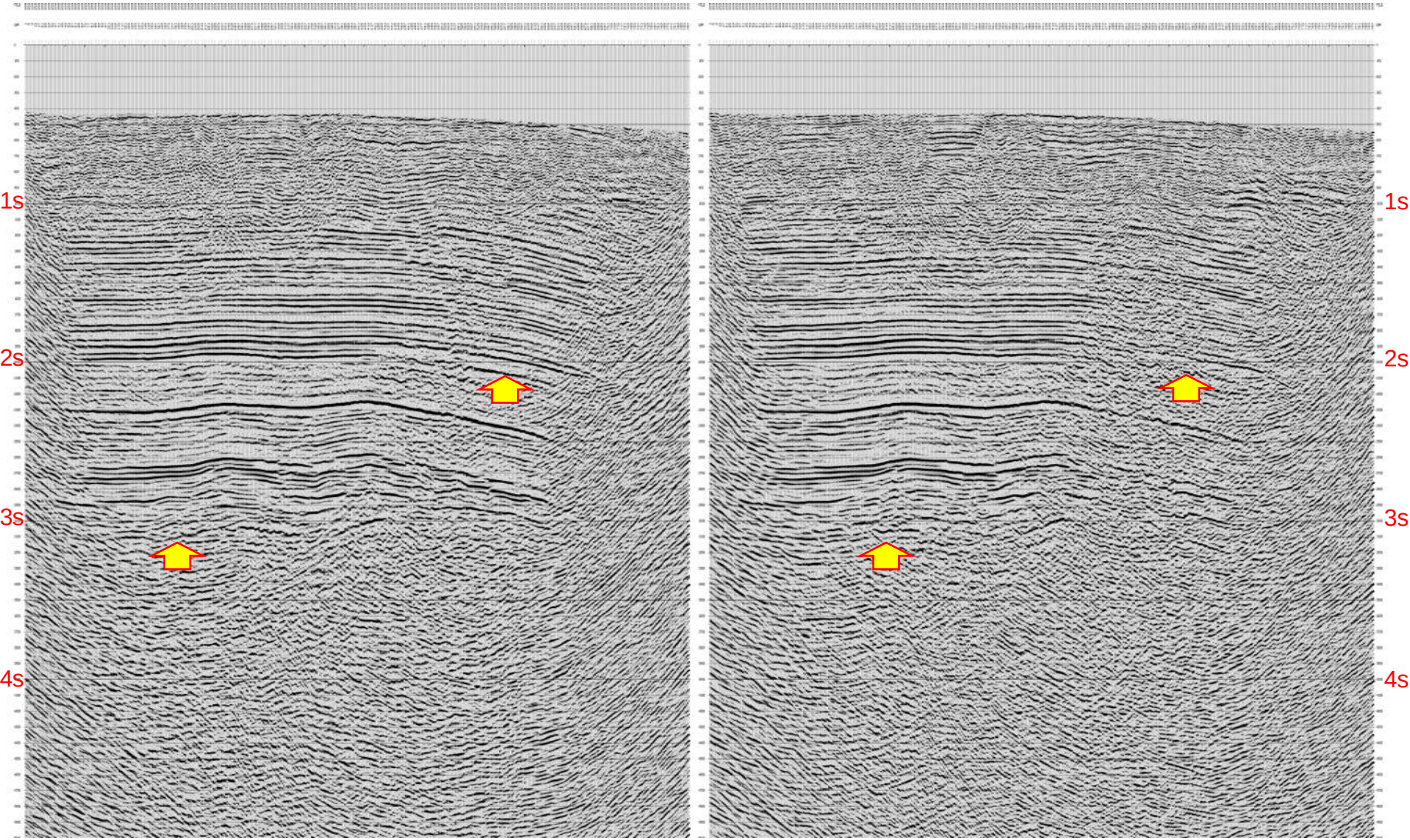


Sweep type comparison



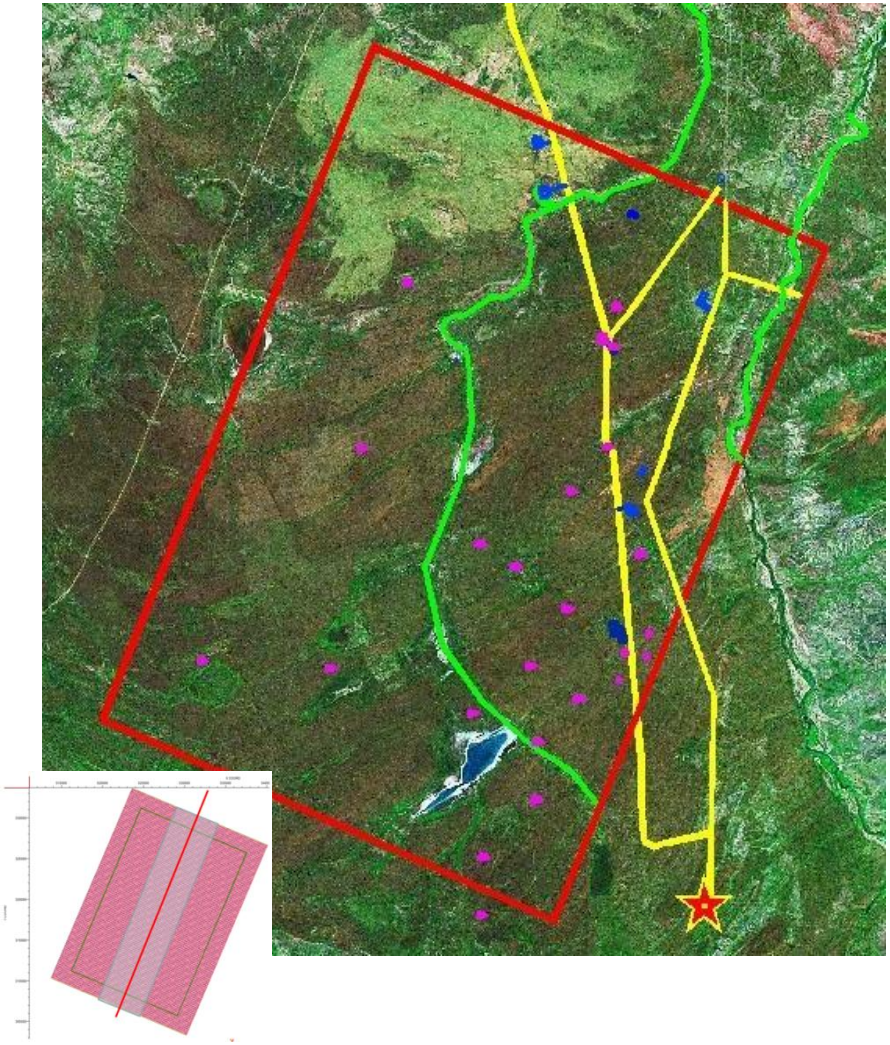
Comparison with different sweep types

Linear 1.5-96Hz*65% PSTM **Non-linear 1.5-96Hz*65%**



Contents

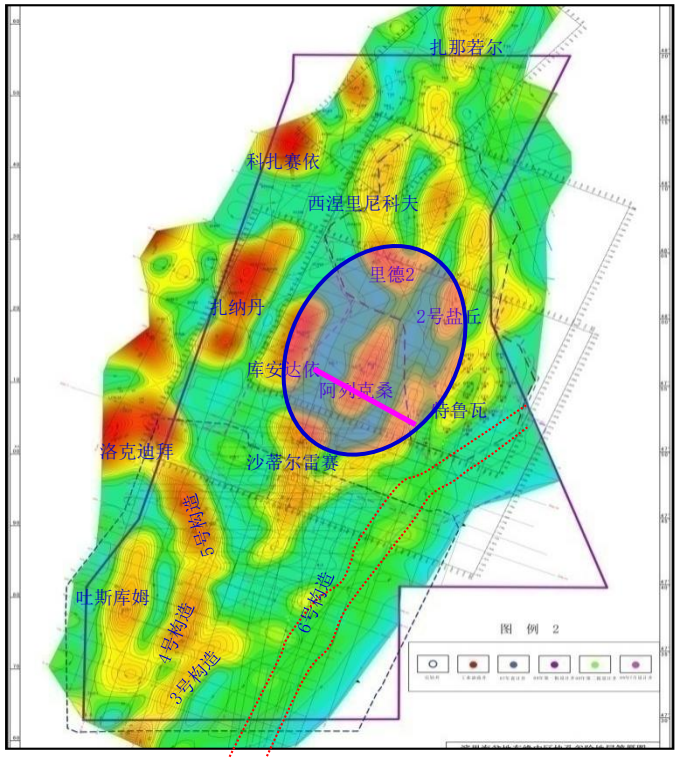
3D Seismic Survey in Kazakhstan

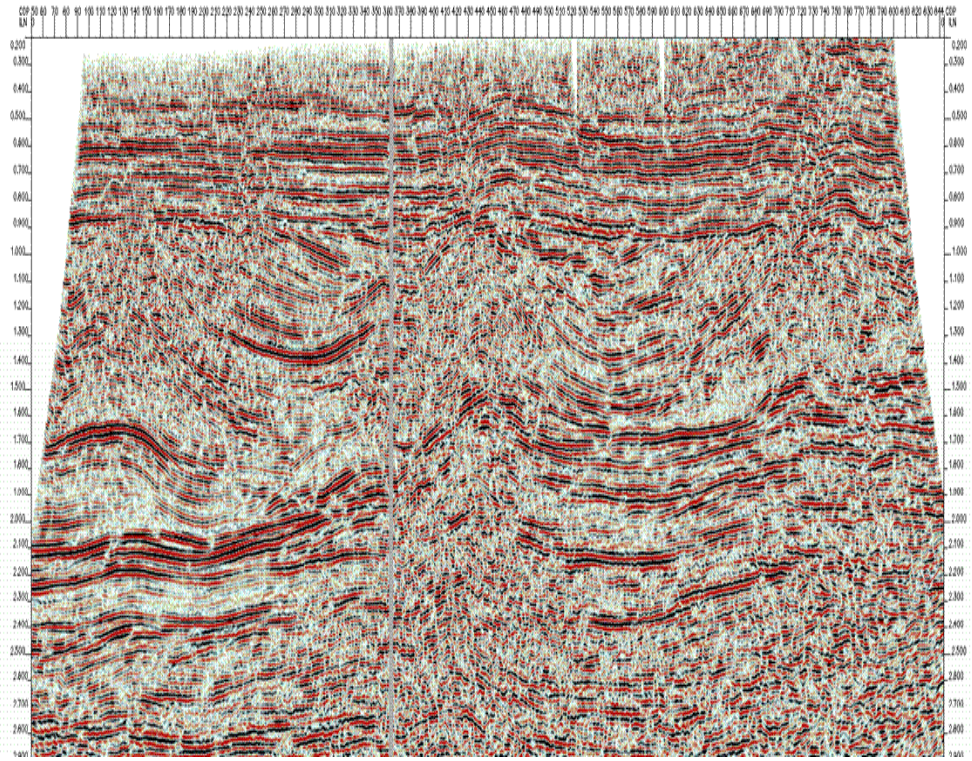


Item	Pre-planned	Acquired	Overlapped
Num. of SPs	182,880	233,549	5,0669
Num. of RPs	9,0216	109,872	1,9656
Survey area	454km^2		

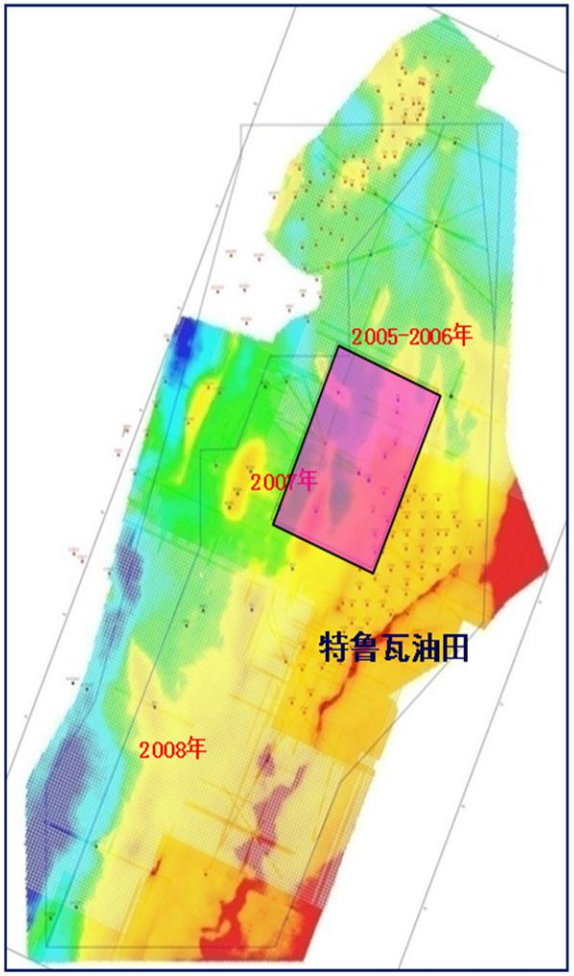
Challenges

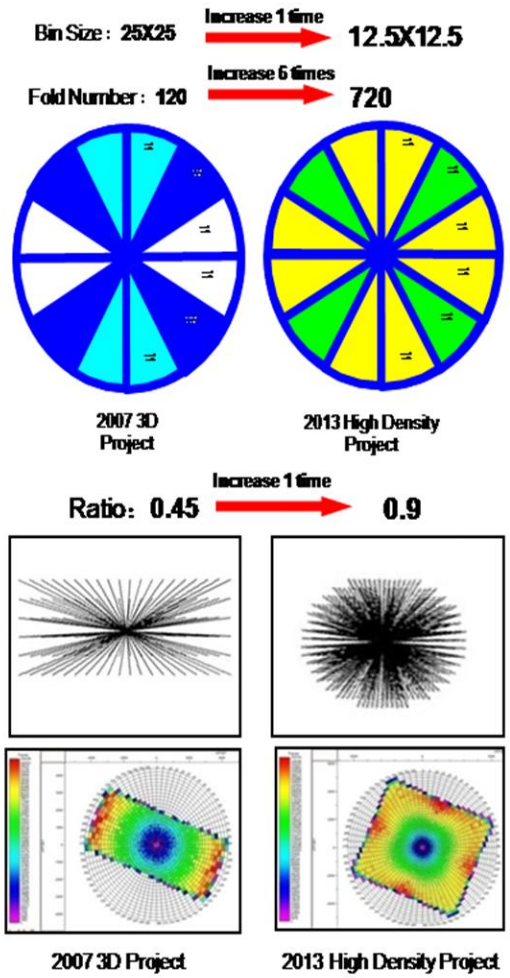
- Large salt domes in this area
- Low resolution of conventional seismic data
- Poor image of pre-salt strata with conventional seismic acquisition
- Unclear boundary of reef-shoal
- Thin carbonate reservoirs with strong heterogeneity





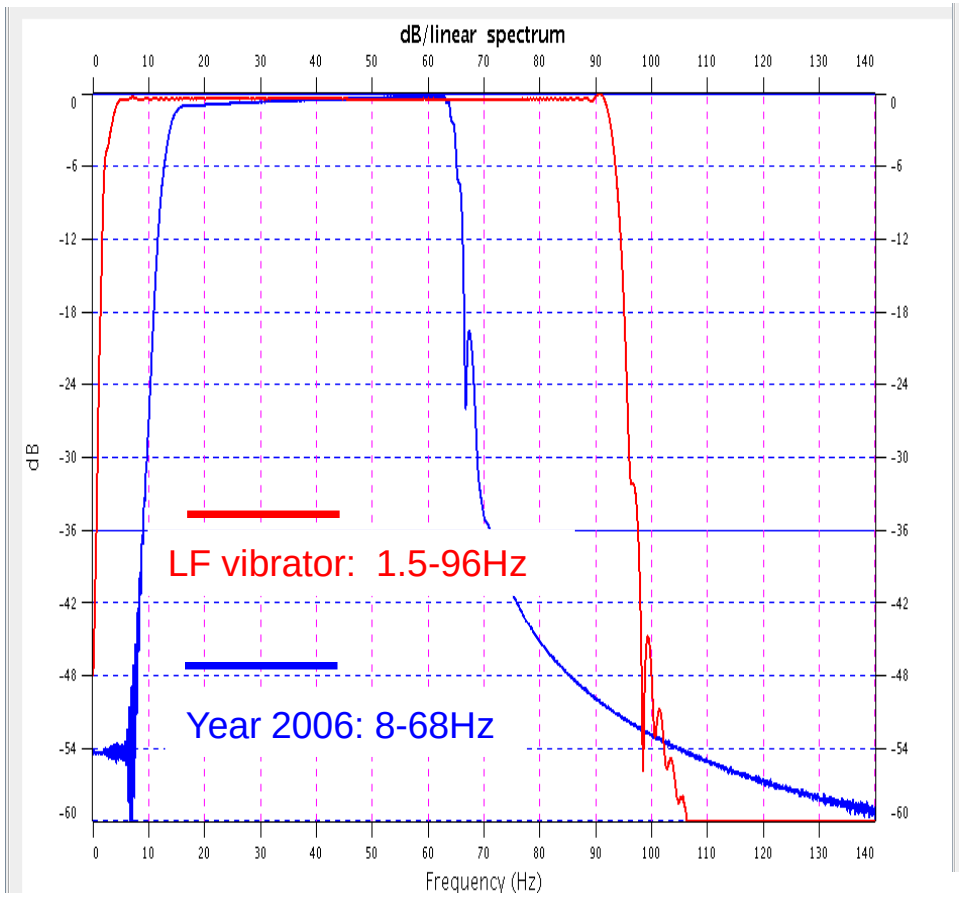
3D seismic survey

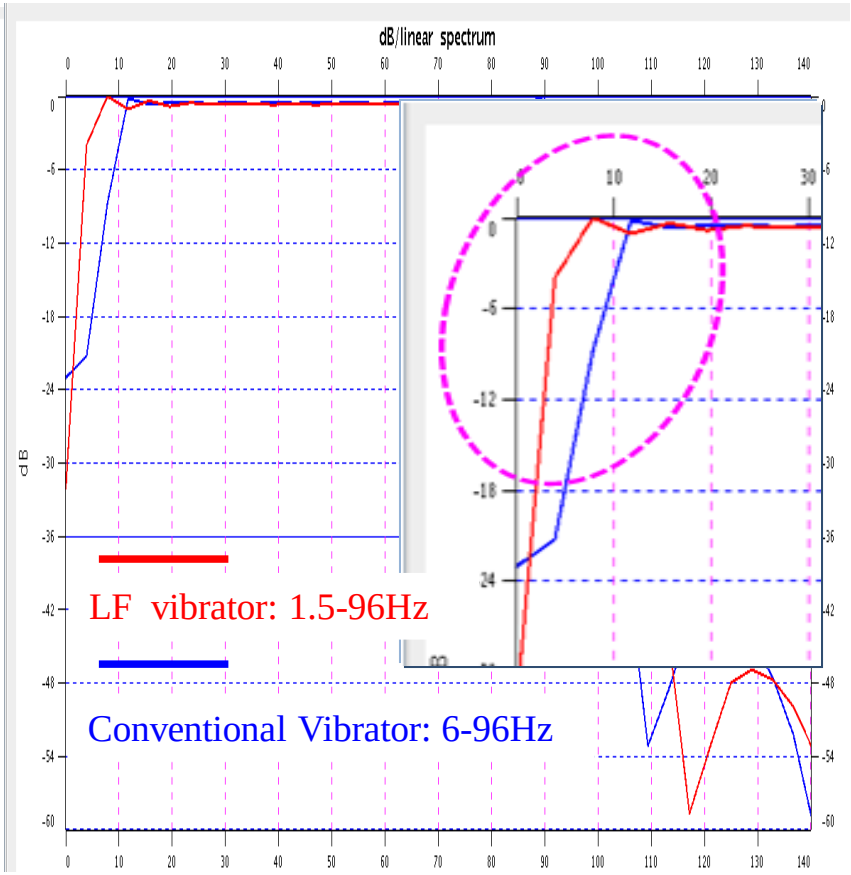




	Parameters
Bandwidth	1.5-96Hz（8-68Hz）
Sweep type	Single Sweep
Geometry	36L×8S×320P
Bin Size	12.5m×12.5m
Total Fold	18*40=720
Total Channels	36×320=11520
Receiver line interval	200m
Source line interval	100m
In-line offset to far trace	3587.5
Cross-line offset to far trace	3987.5
The farthest offset	5363
Ratio	0.90

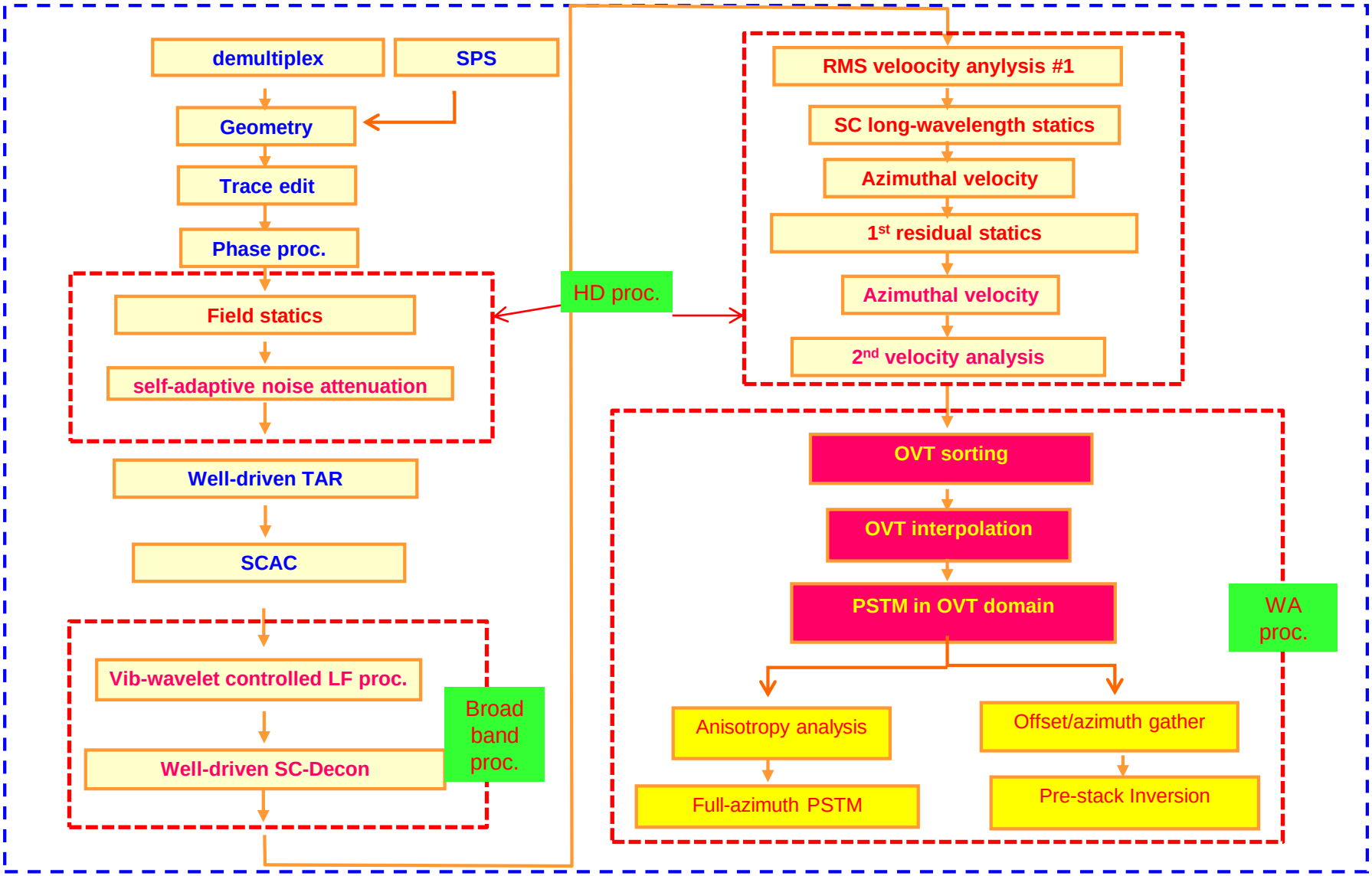
Broadband shooting: Six Octaves



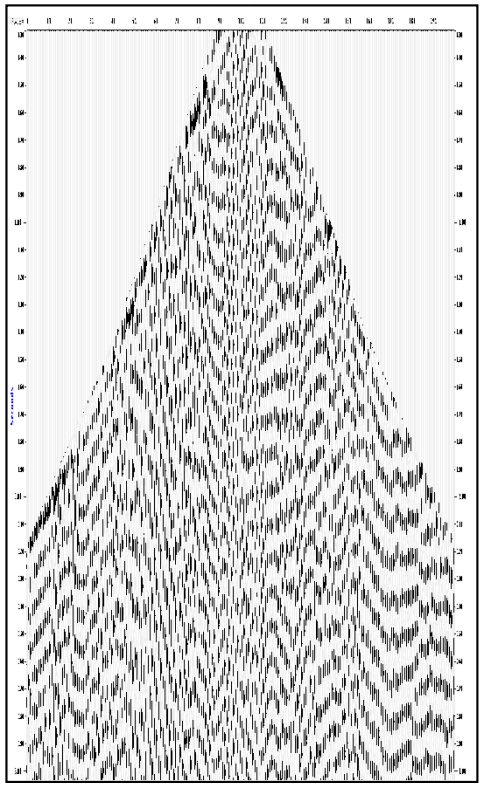


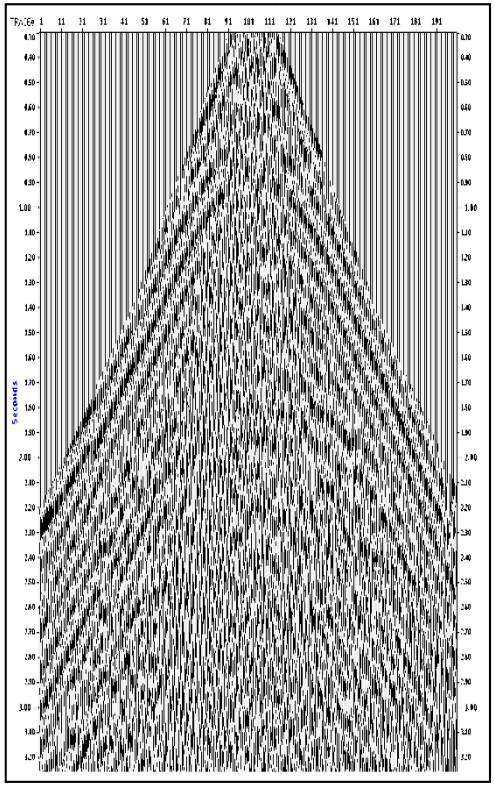
Spectrum of sweep signals

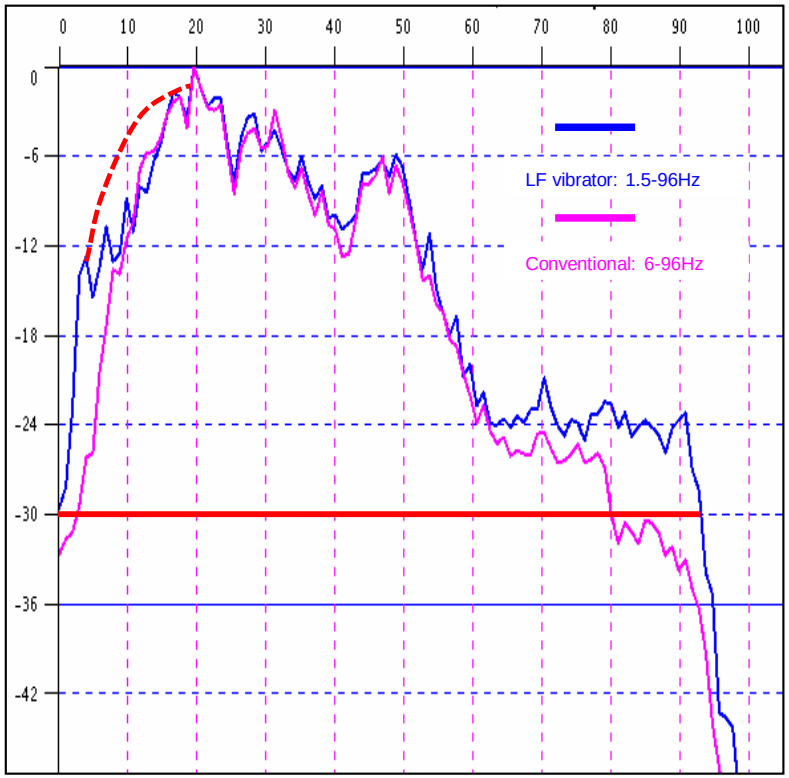
WA, Broadband, and HD Vibroseis data processing flow



“Source-wavelet controlled” LF recovery

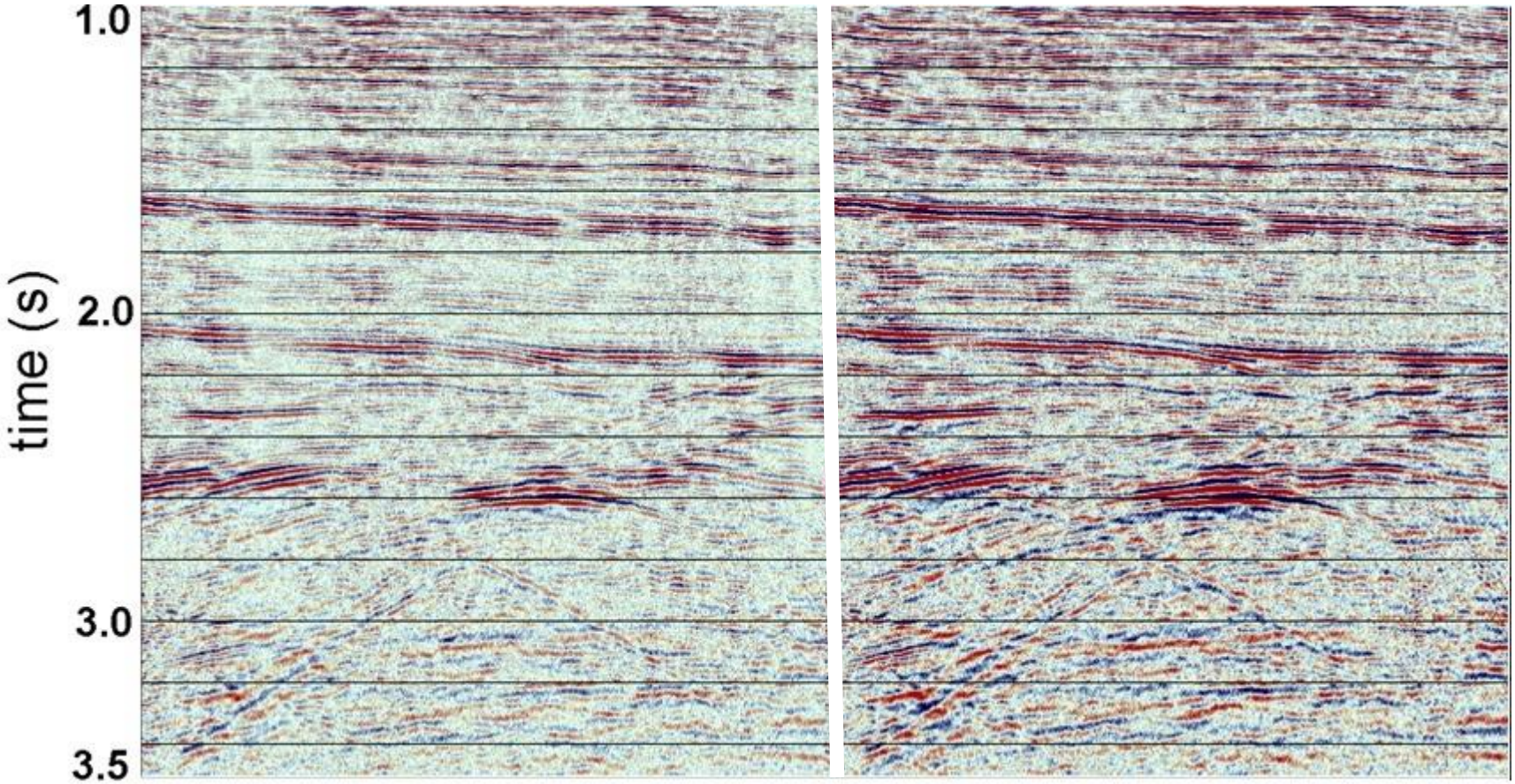






Conventional **Low pass< 9Hz** **LF vibrator**

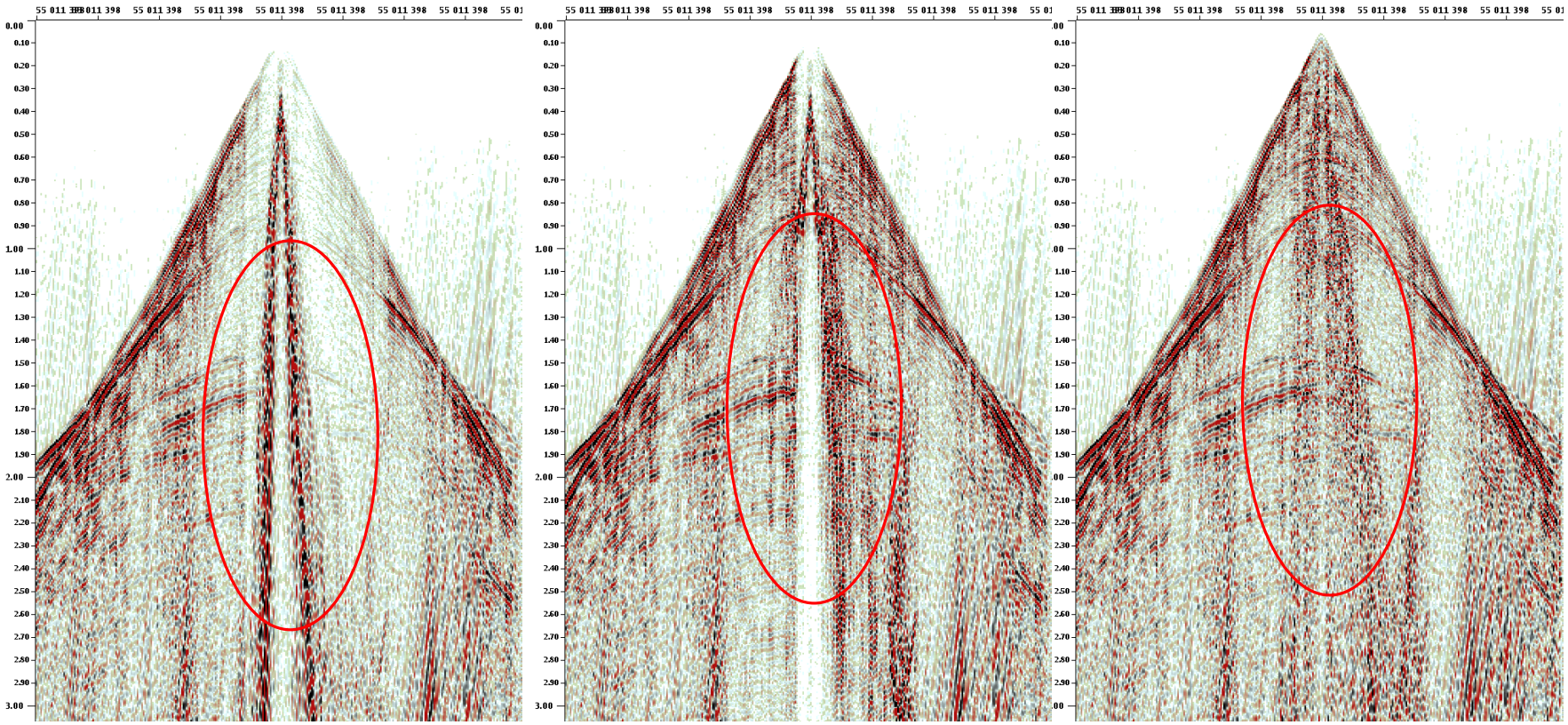
Stacked data comparison (No filtering)



raw data

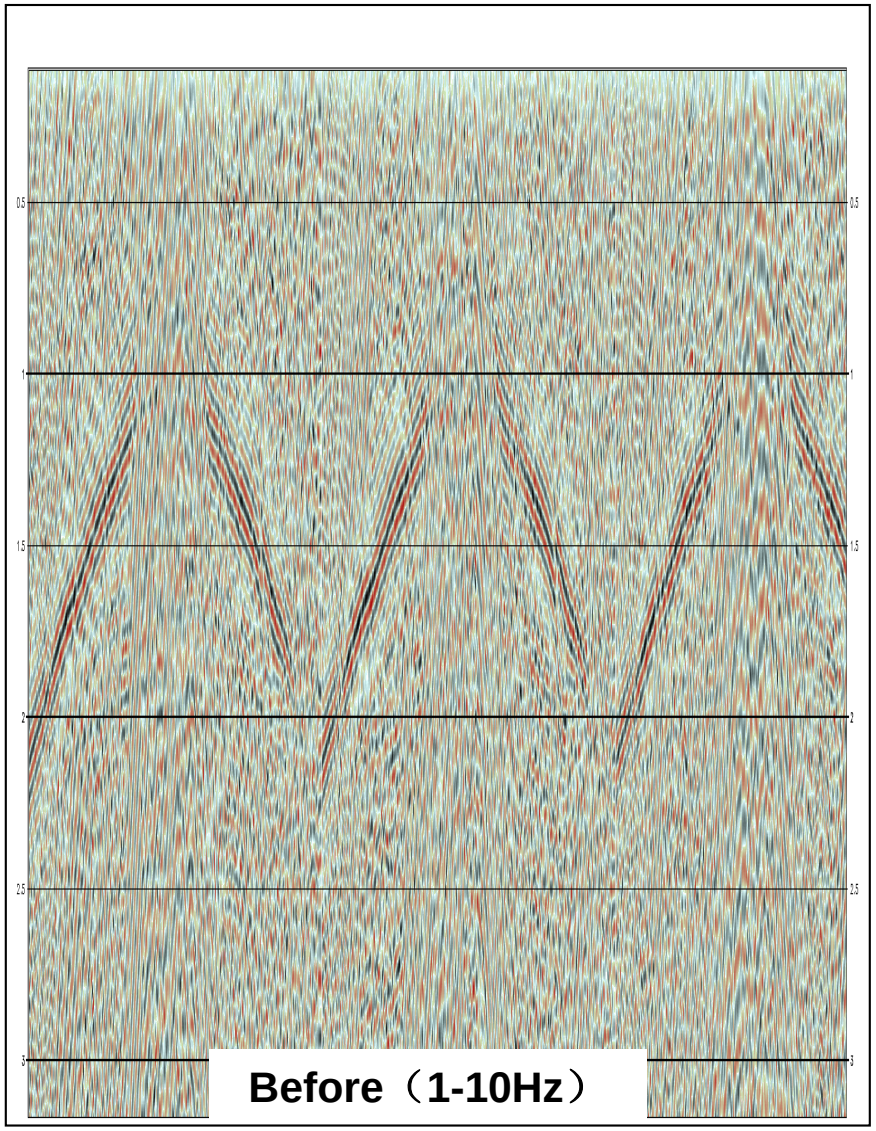
recovered data

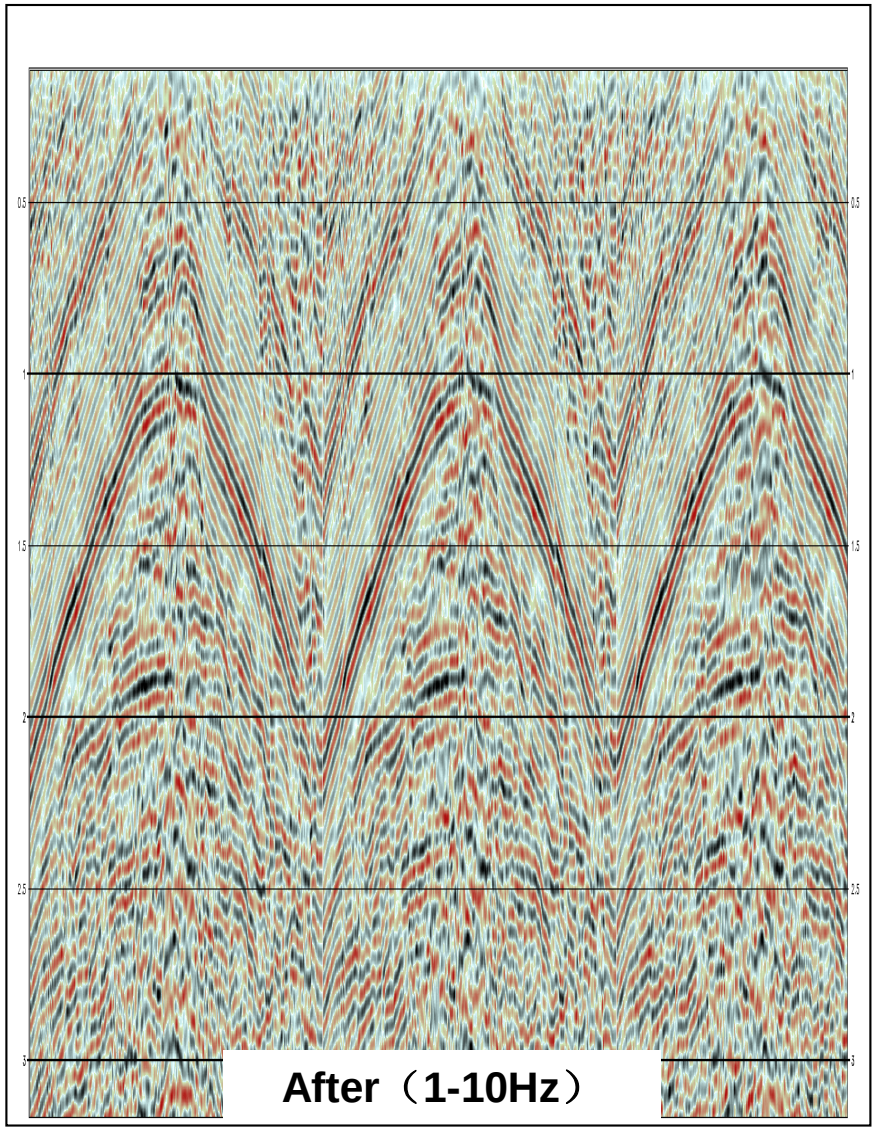
Data-driven self-adaptive ground roll attenuation



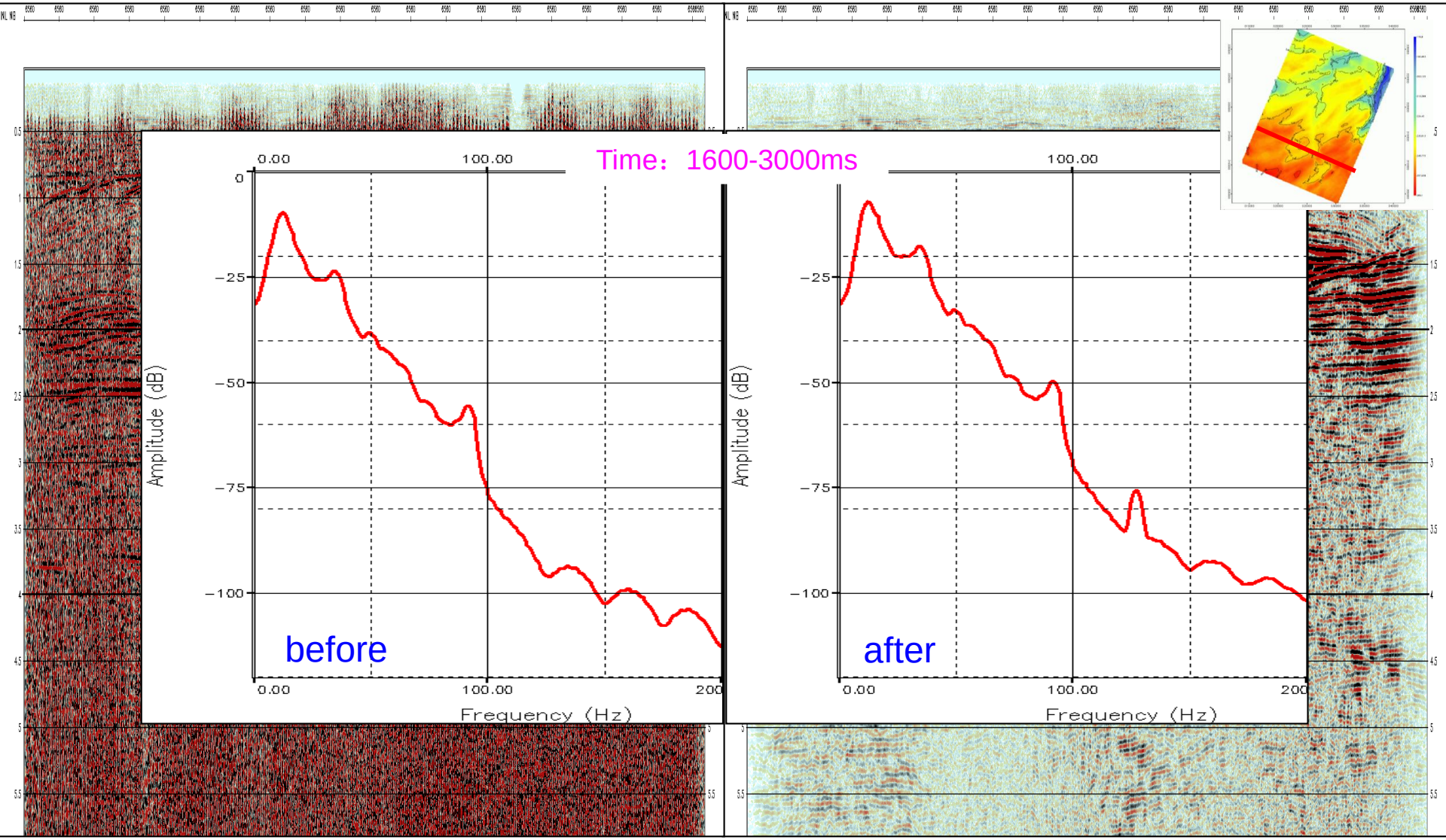
Raw data Conventional Adaptive

Data-driven self-adaptive ground roll attenuation

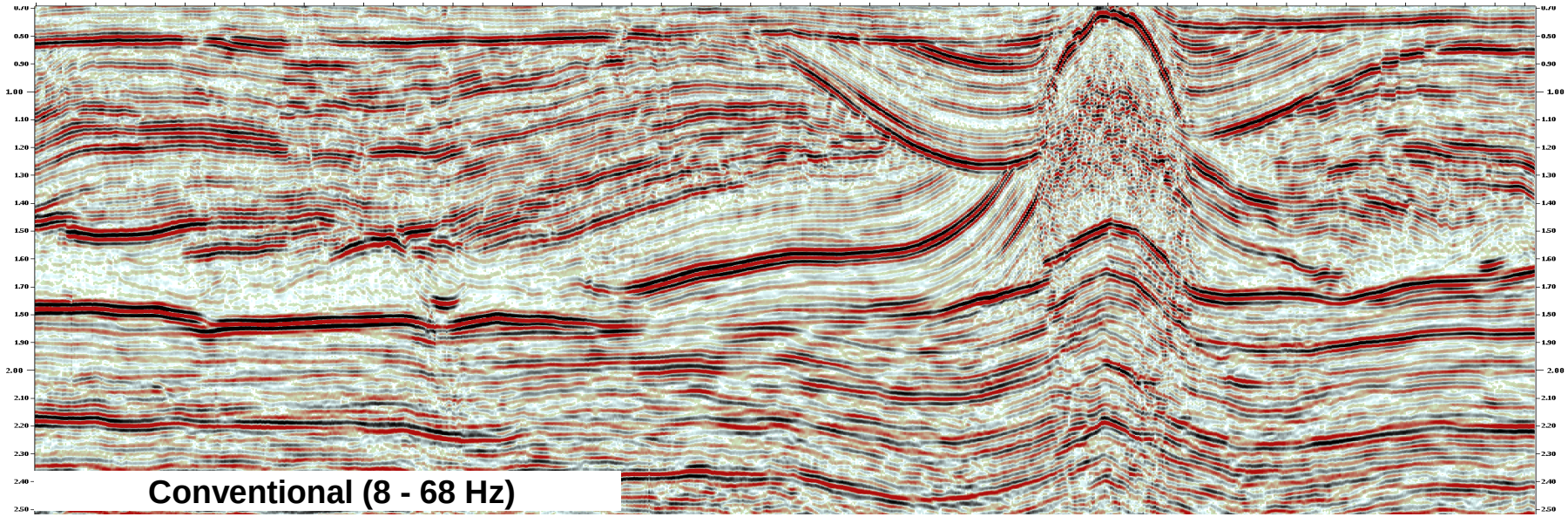




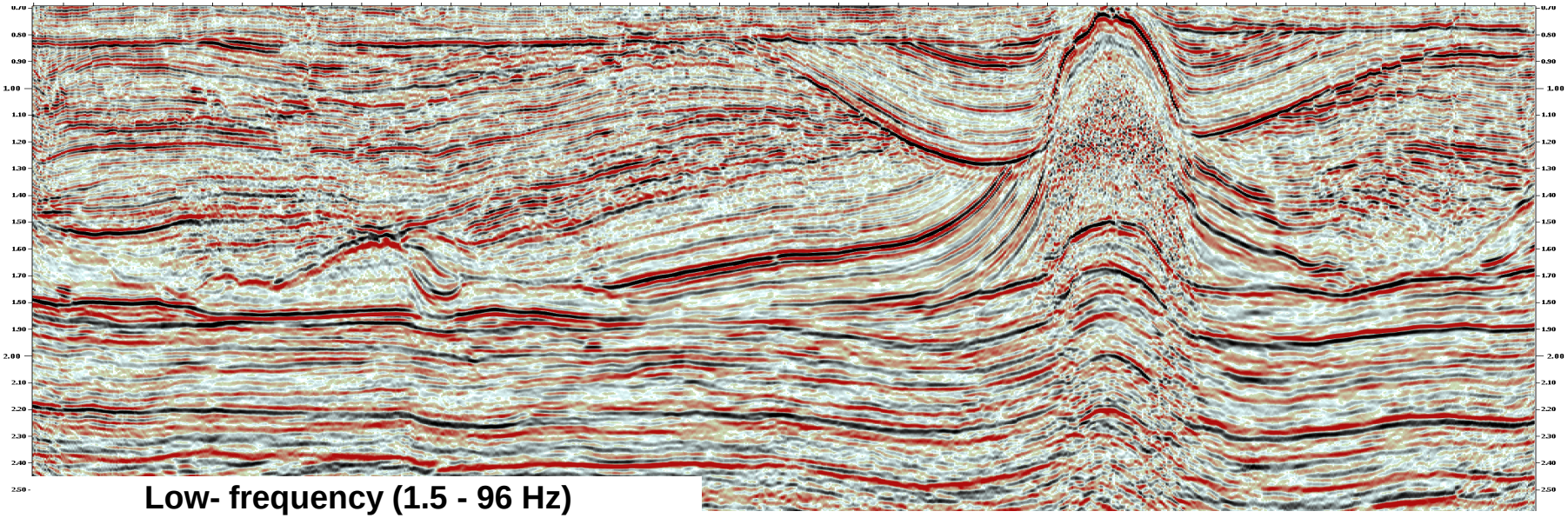
Data-driven self-adaptive ground roll attenuation



Comparison of conventional and WHB data

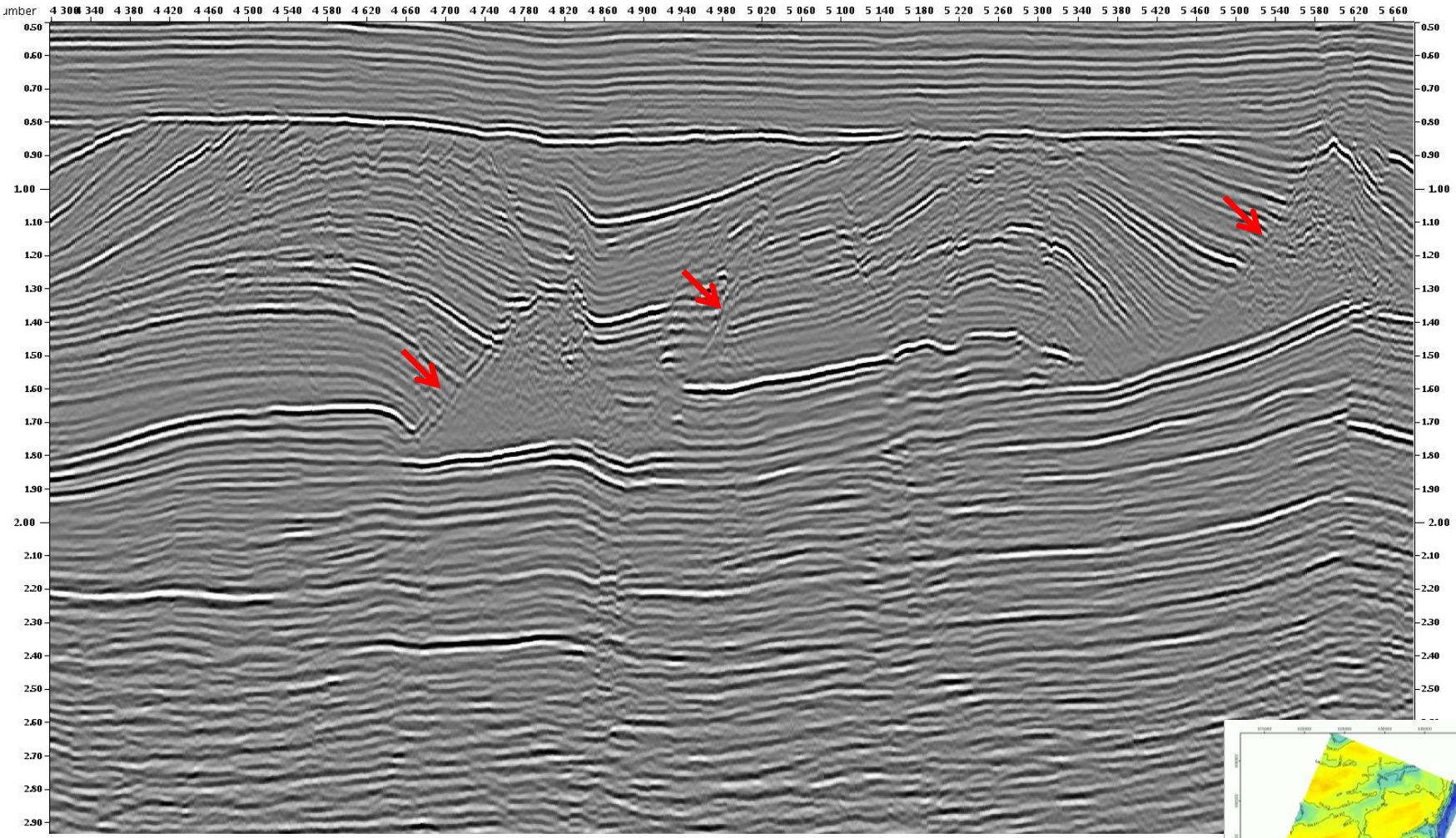


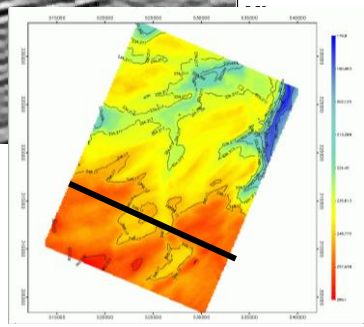
Conventional (8 - 68 Hz)



Low- frequency (1.5 - 96 Hz)

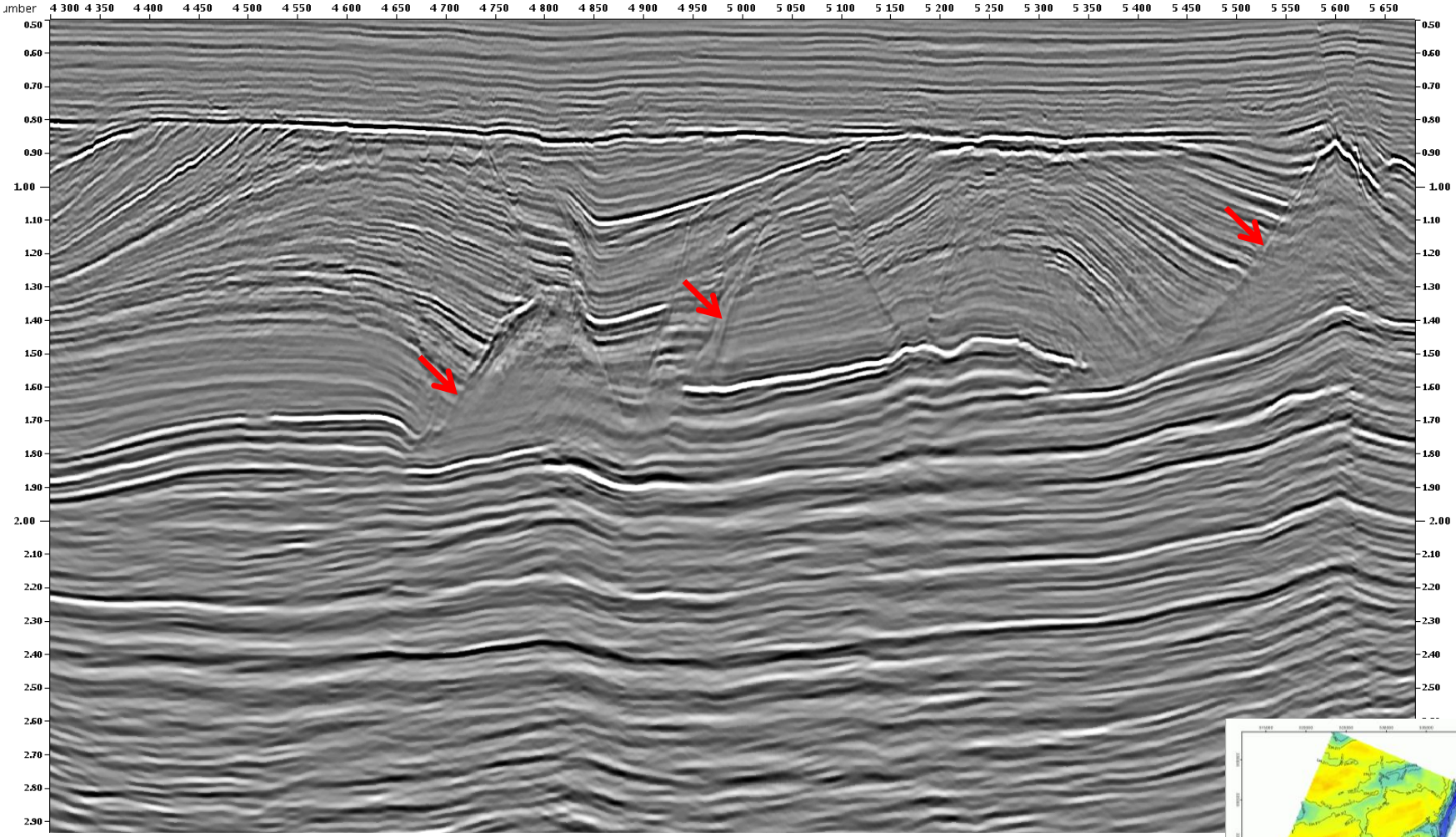
Comparison of legacy and WHB data

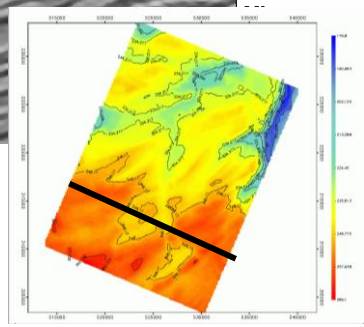




Legacy 3D_PSTM（INL7040）

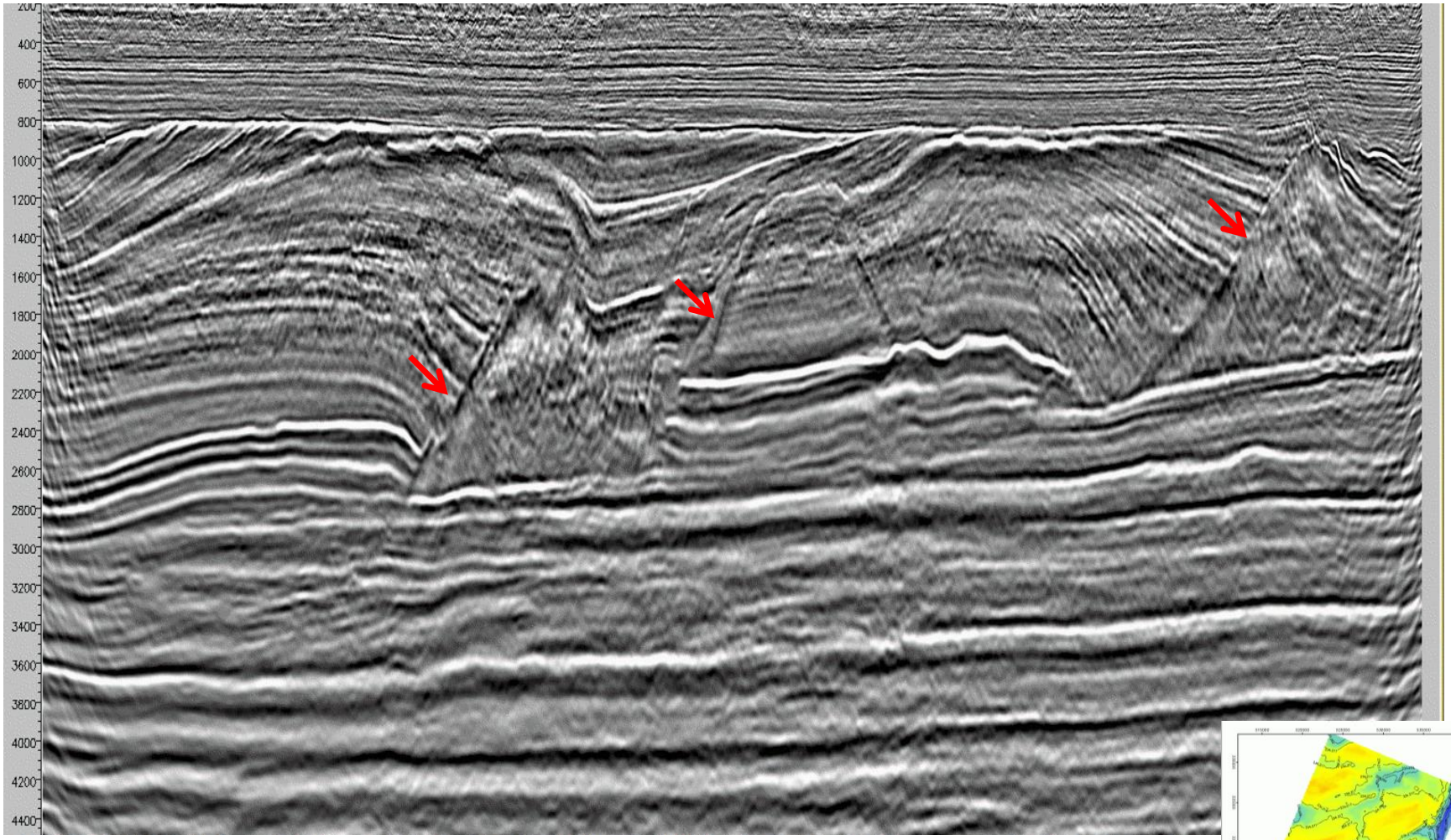
Comparison of legacy and WHB data

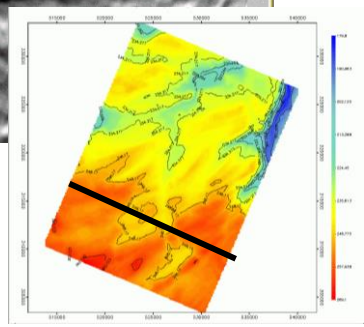




WHB 3D_PSTM（INL7040）

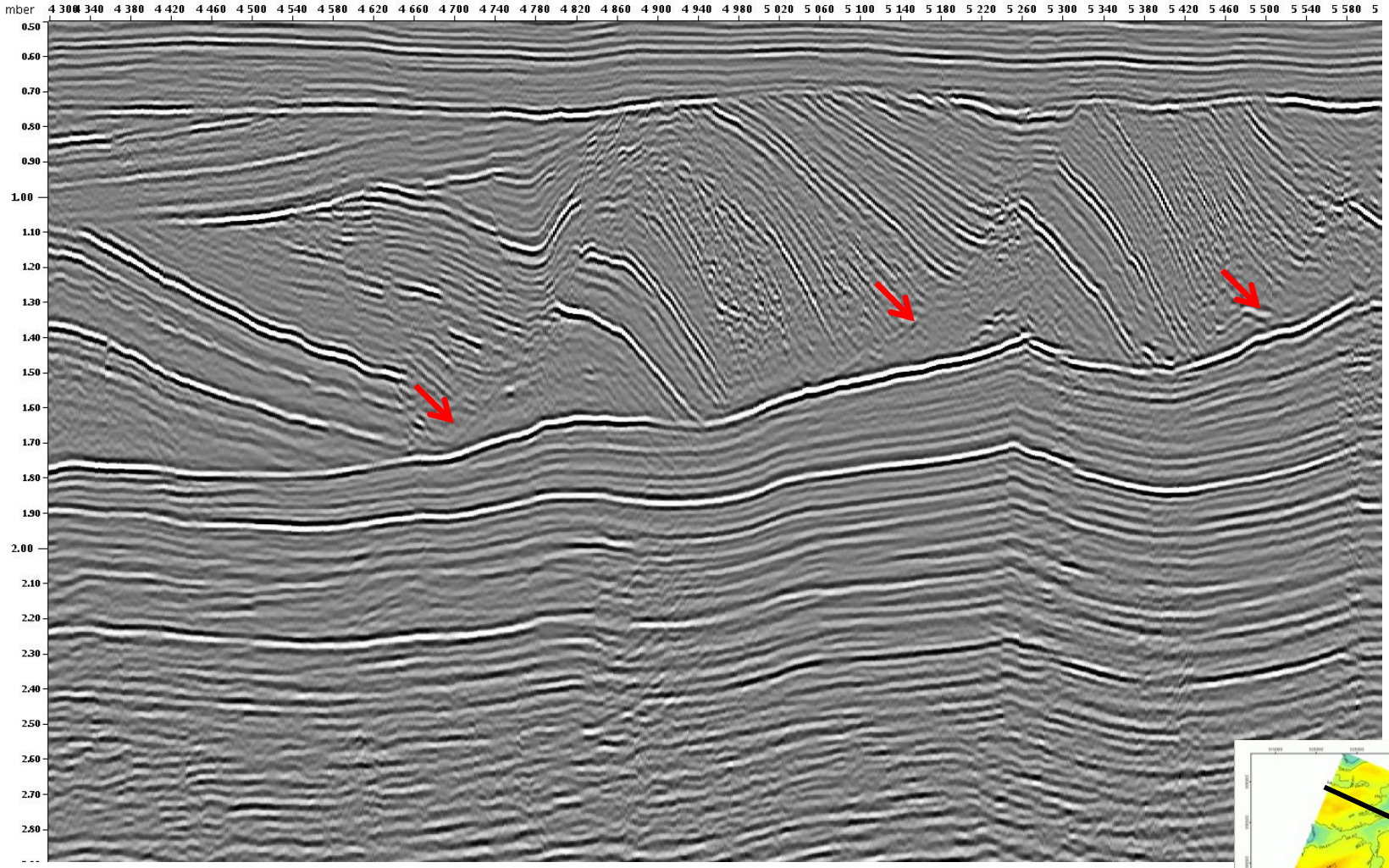
Comparison of legacy and WHB data

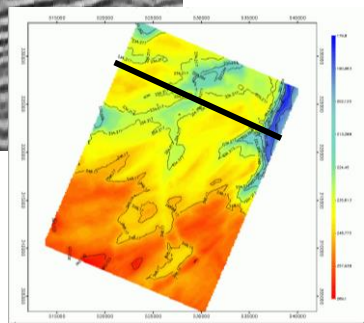




WHB 3D_PSDM（INL7040）

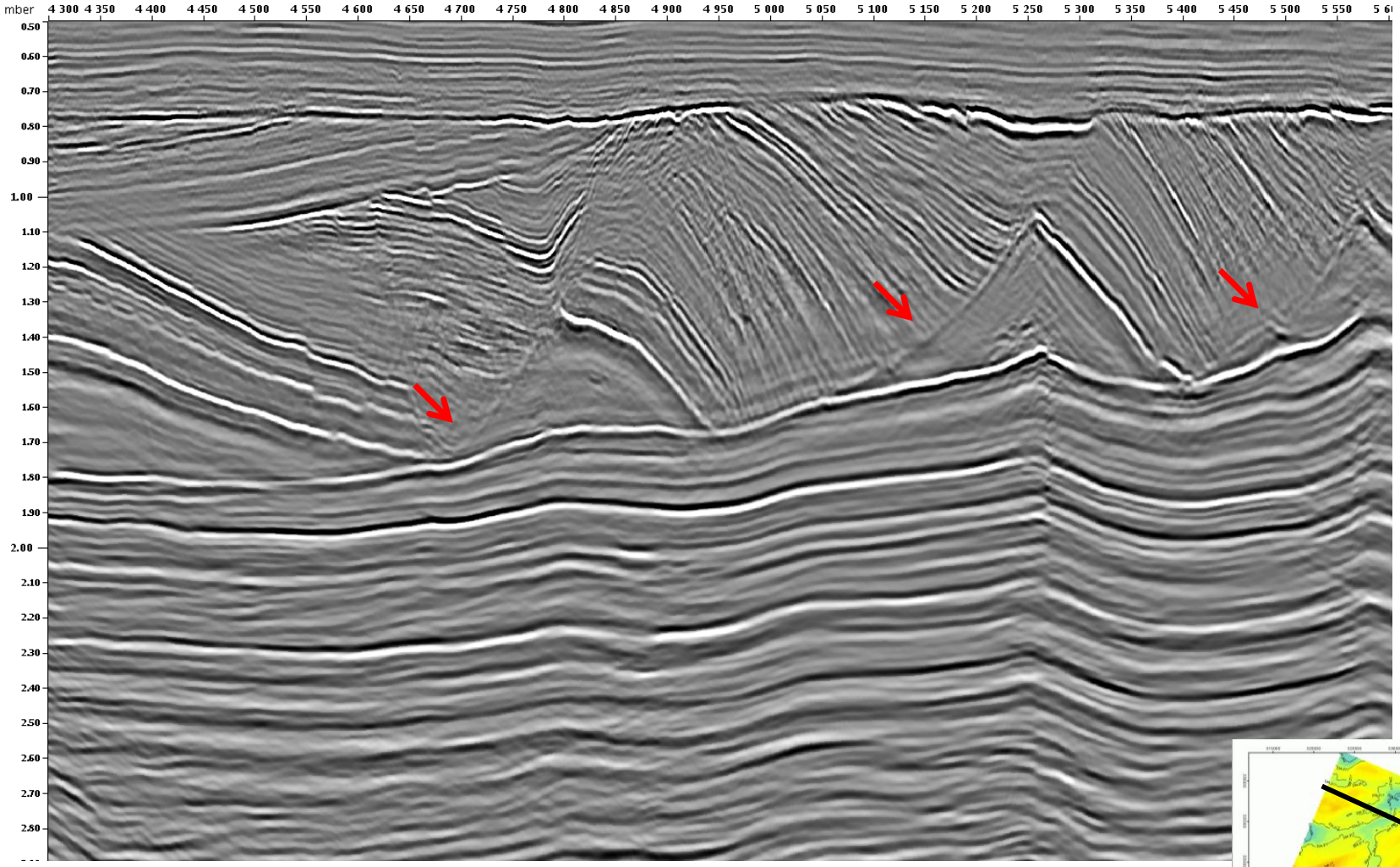
Comparison of legacy and WHB data

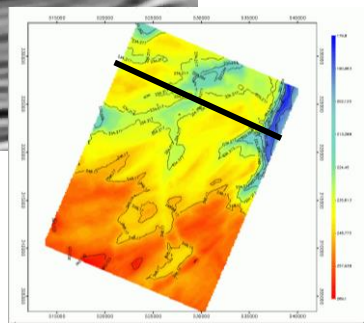




Legacy 3D_PSTM（INL8080）

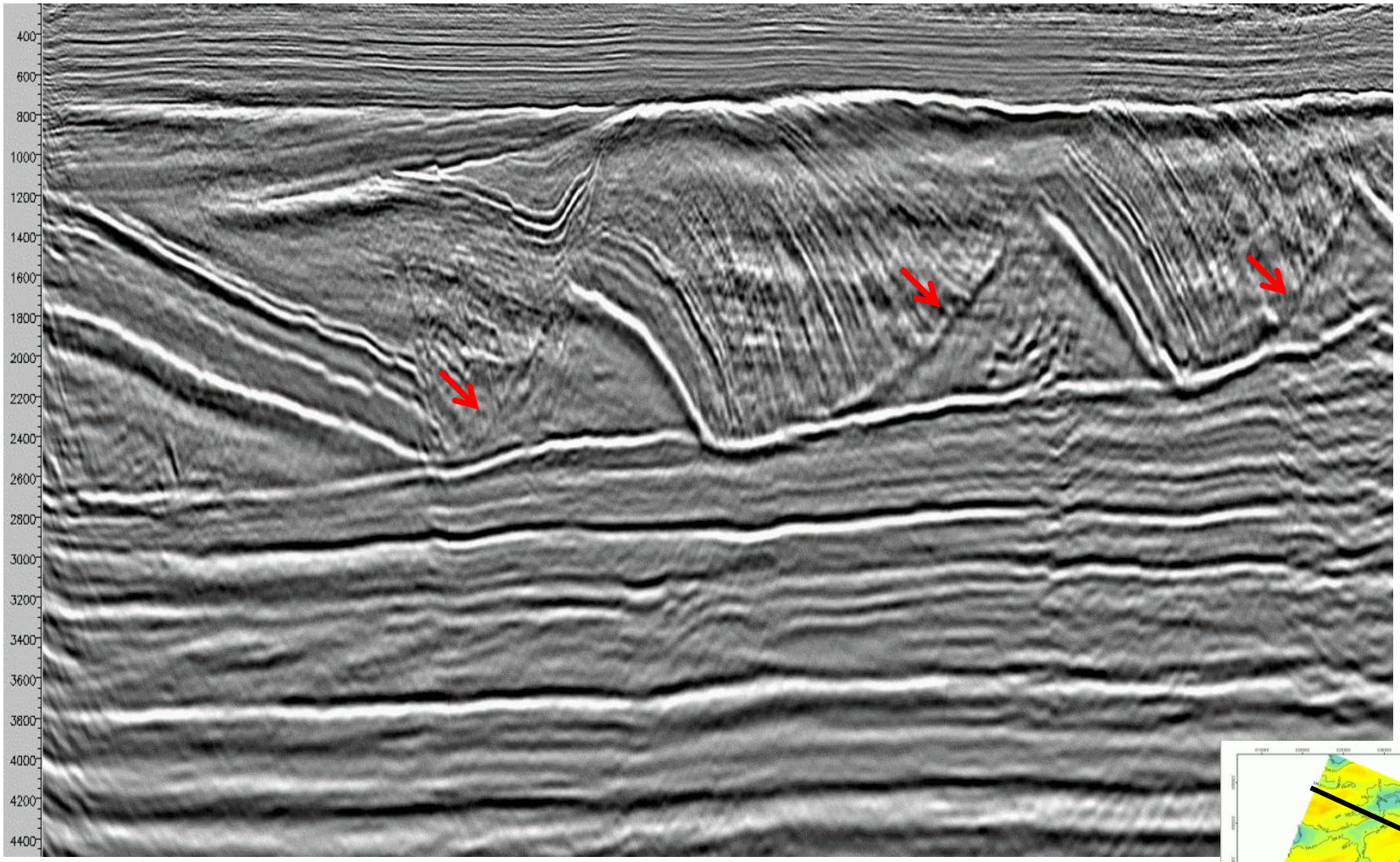
Comparison of legacy and WHB data

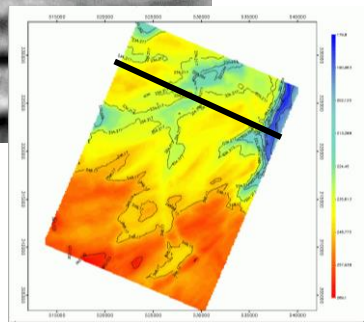




WBH3D_PSTM（INL8080）

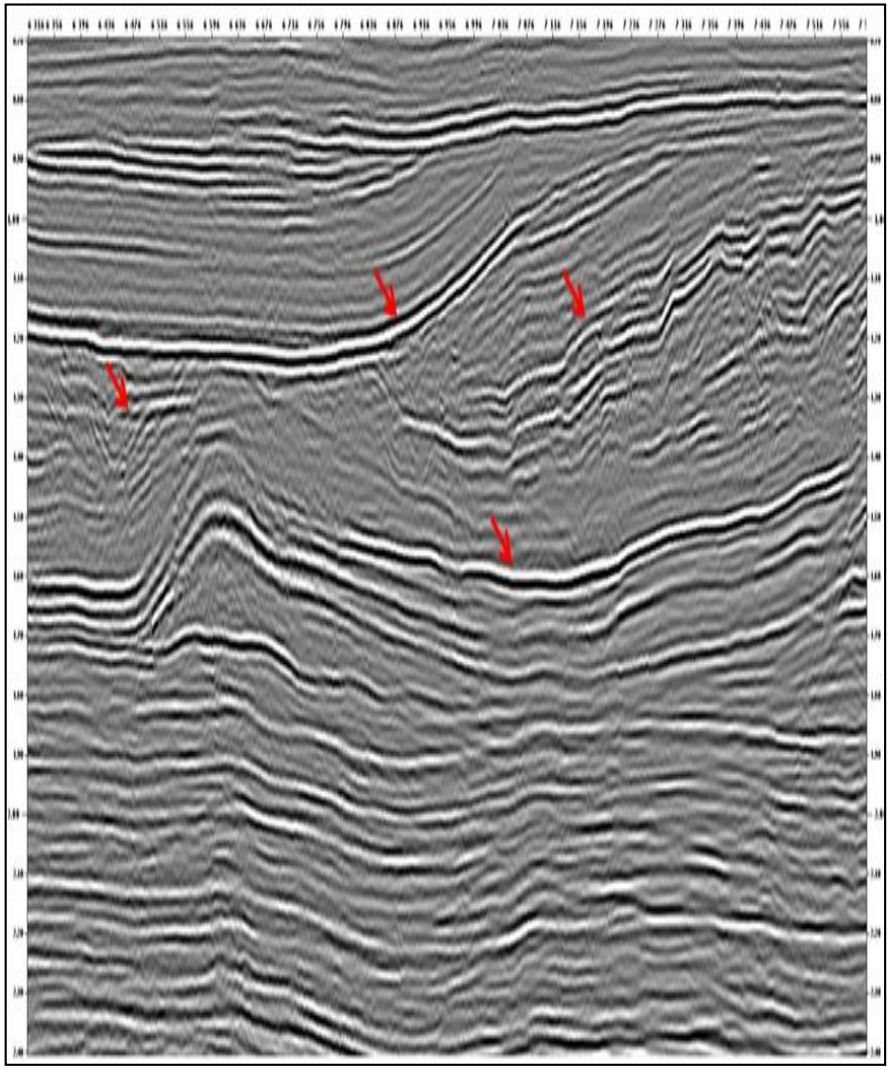
Comparison of legacy and WHB data

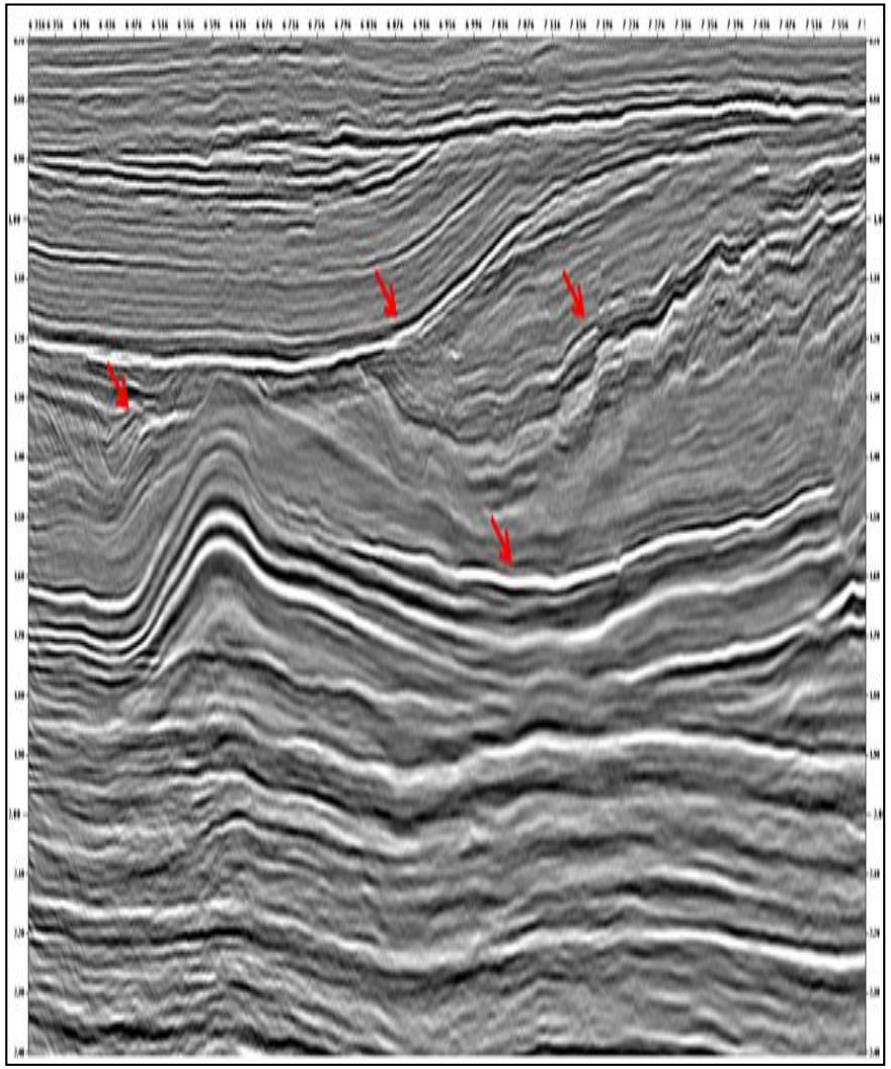




WBH 3D_PSDM（INL8080）

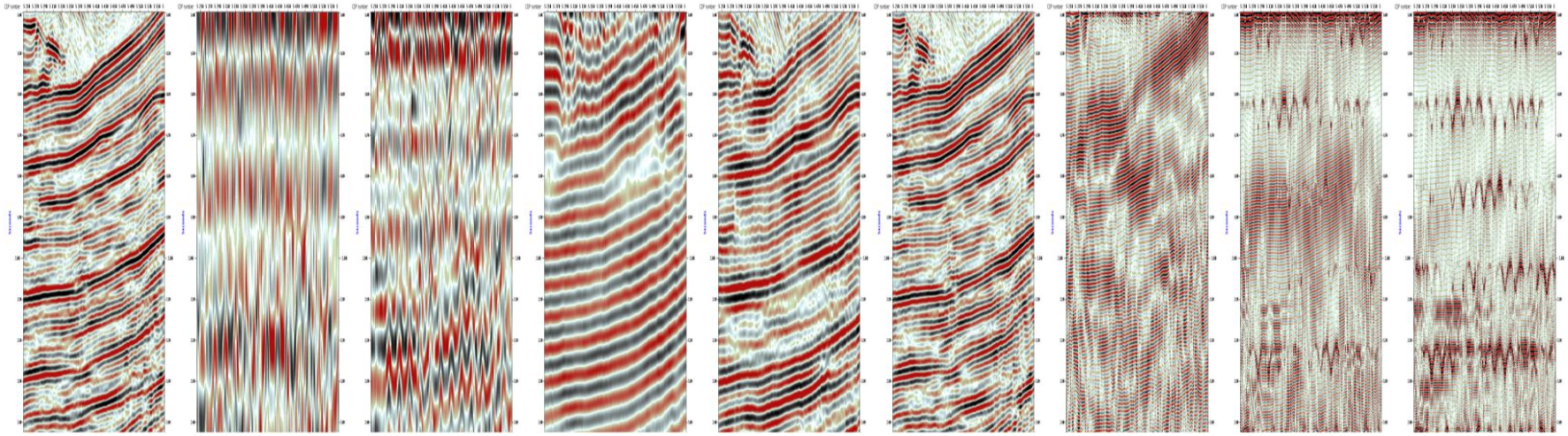
Comparison of legacy and WHB data





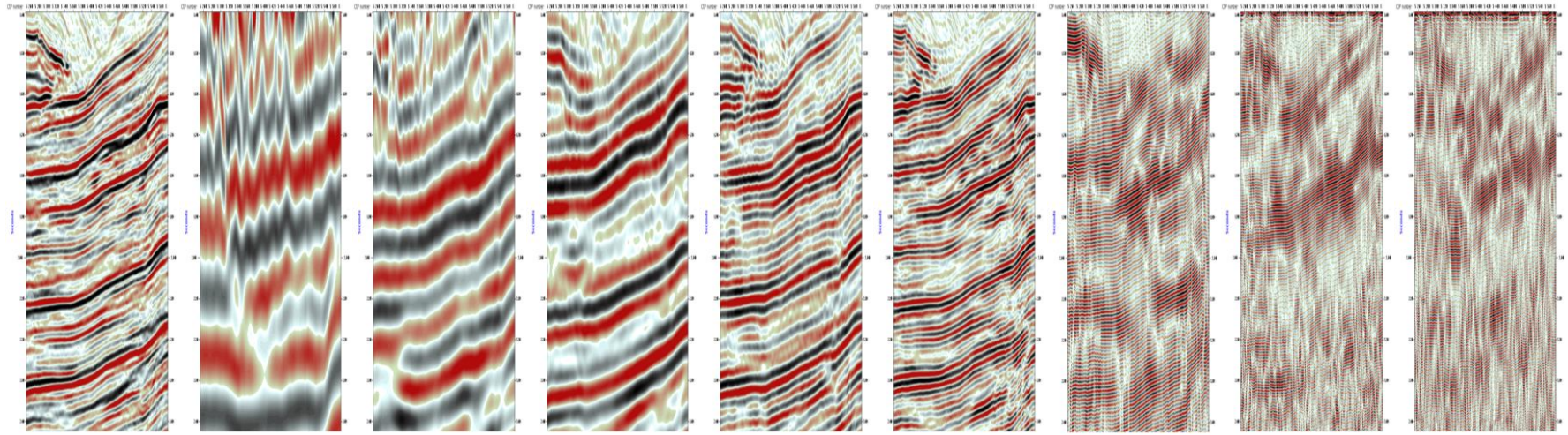
Comparison of legacy and WBH data

Legacy data

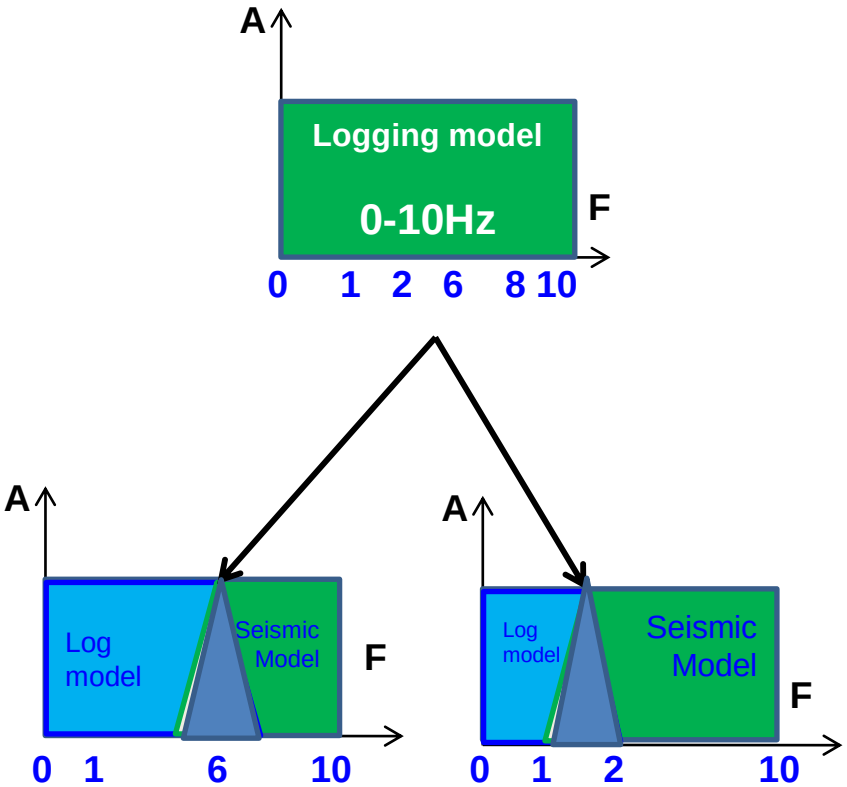


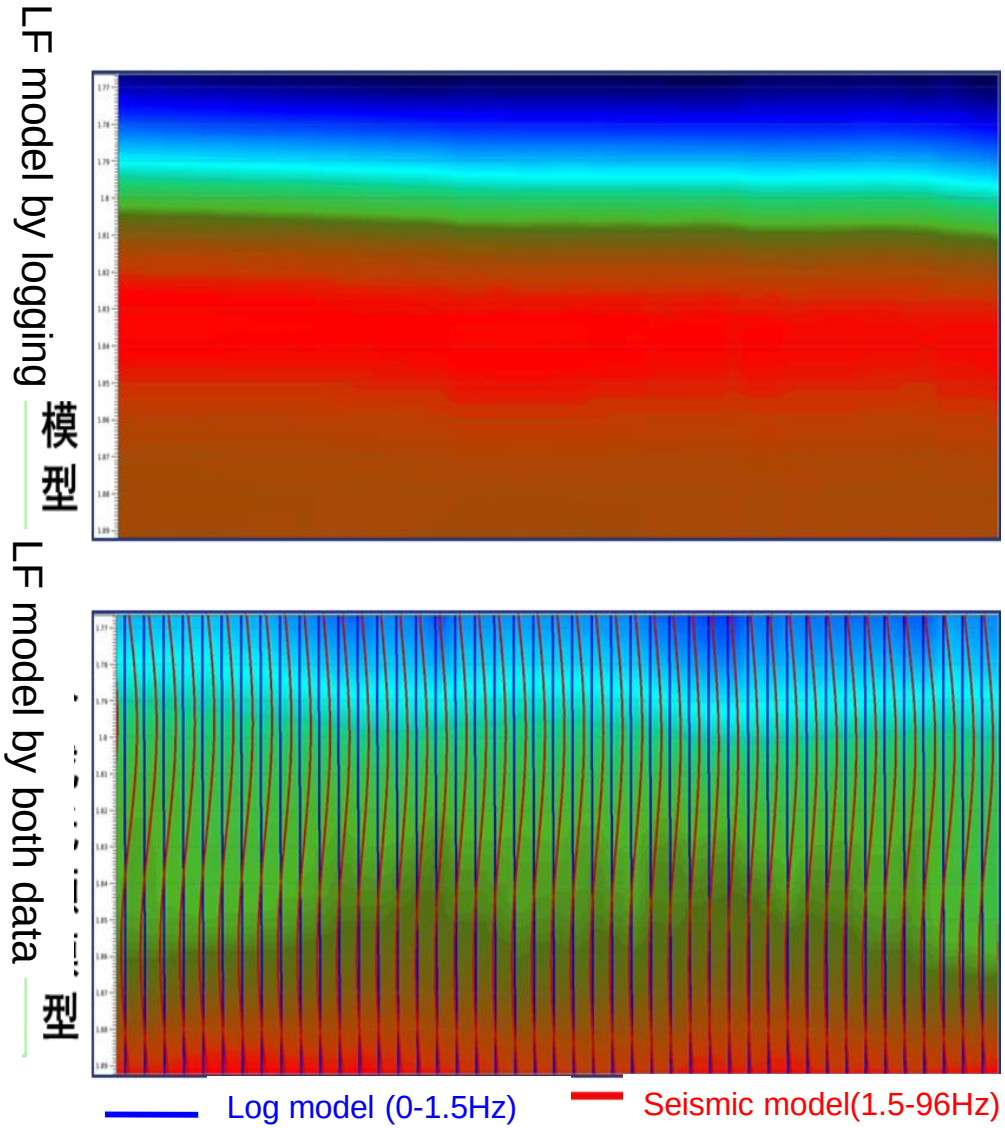
Raw 1.5-3.0Hz 3.0-6.0Hz 6.0-12Hz 12-24Hz 24-48Hz 48-96Hz 65-140Hz 70-150Hz

WBH data

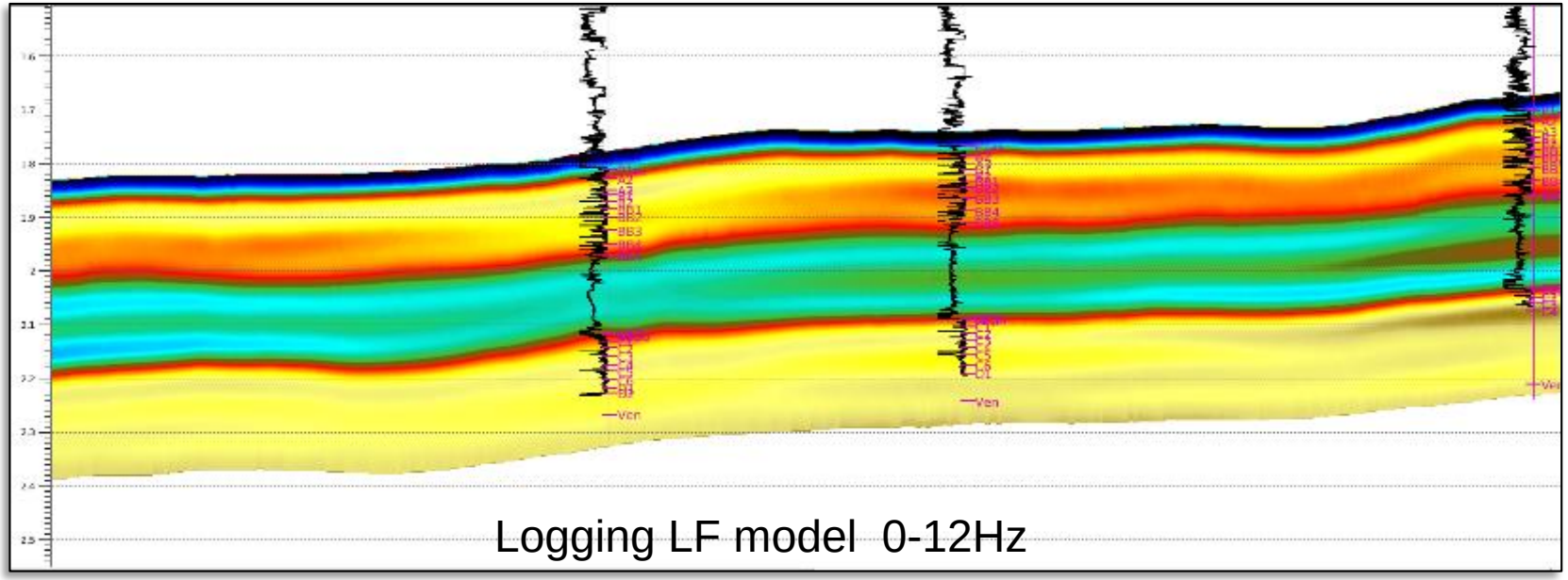


LF model building with logging and seismic data

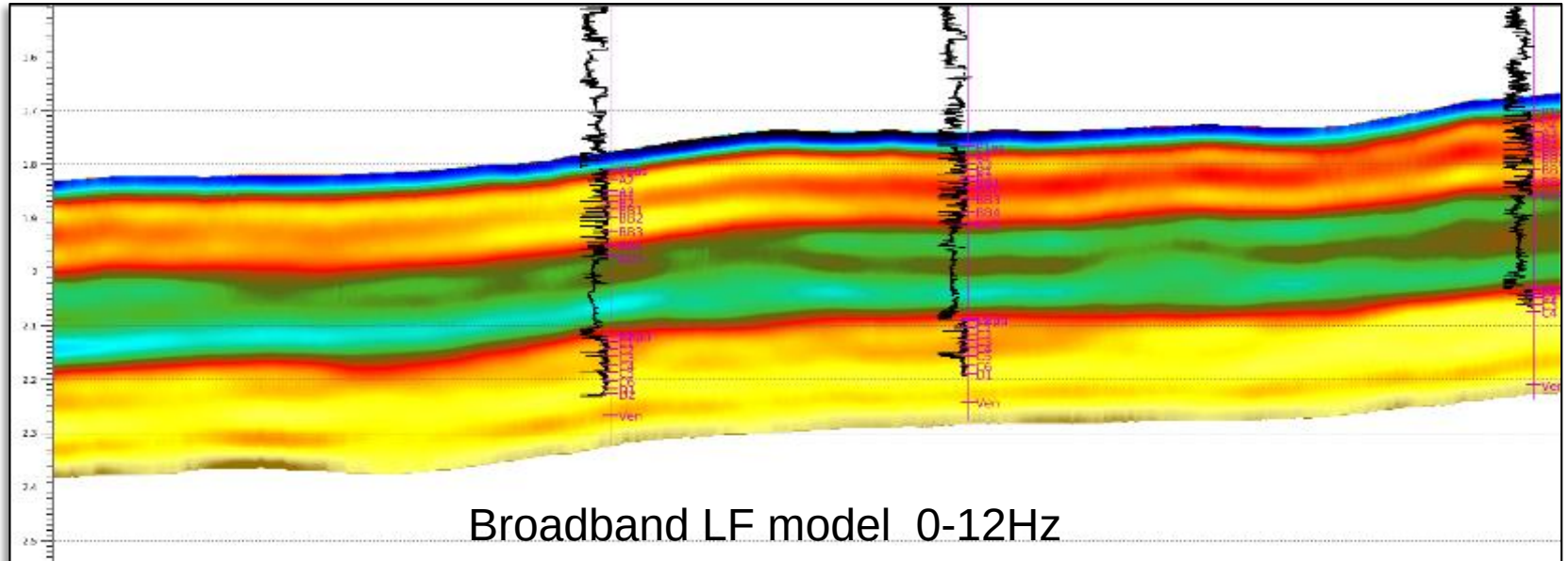




LF models with logging and seismic data

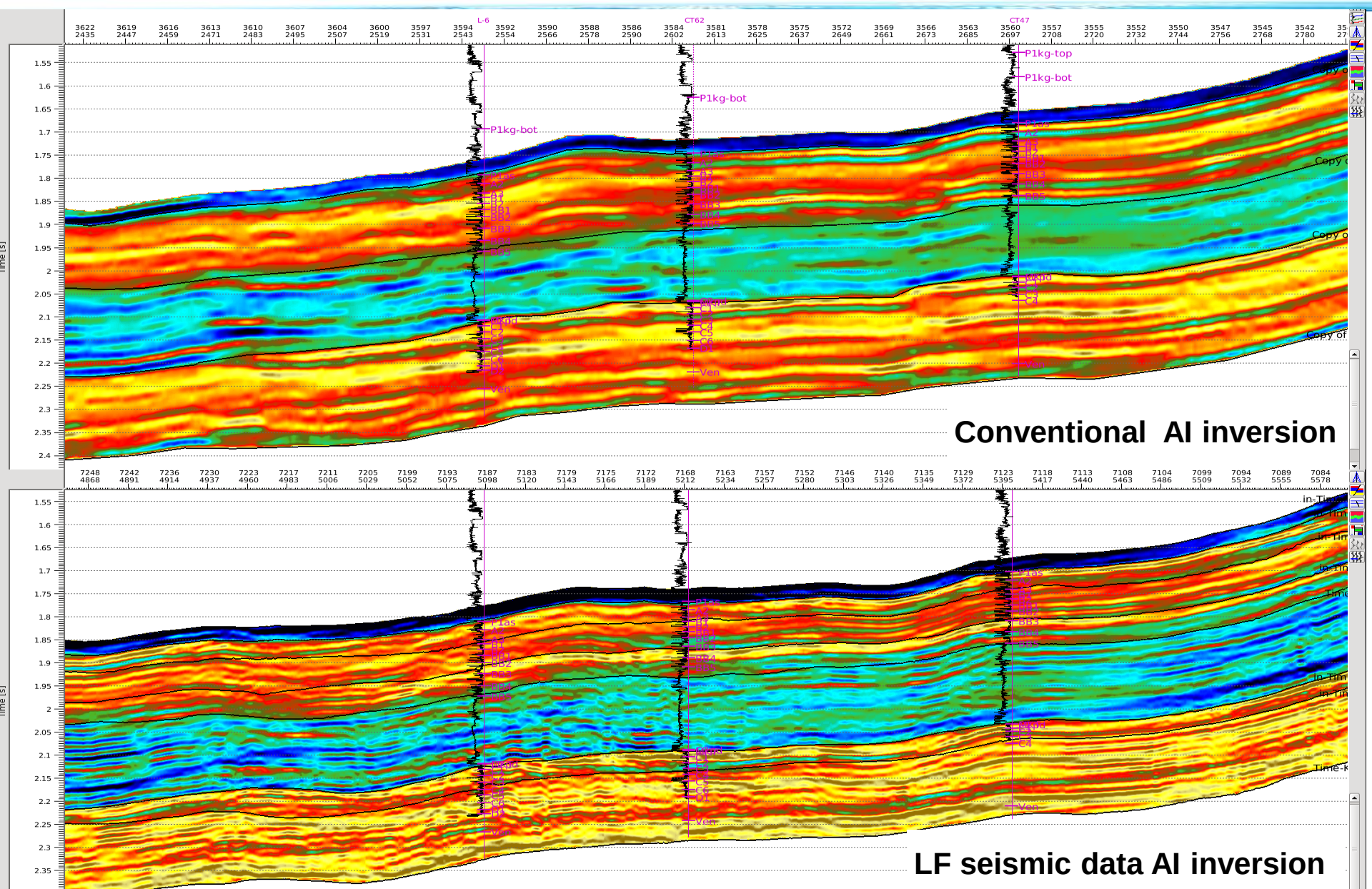


Logging LF model 0-12Hz

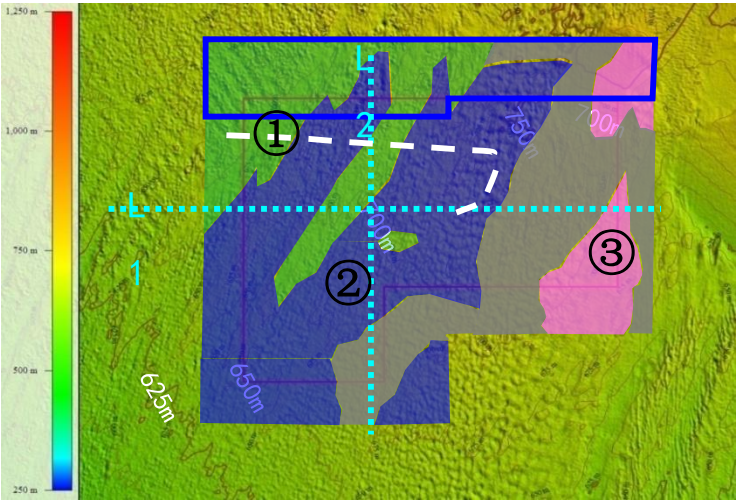


Broadband LF model 0-12Hz

Acoustic impedance inversion with logging & LF seismic data



Applications in Junggar Basin, Xinjiang



Great sand dune

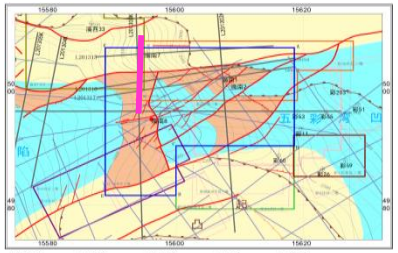
Striped sand dune

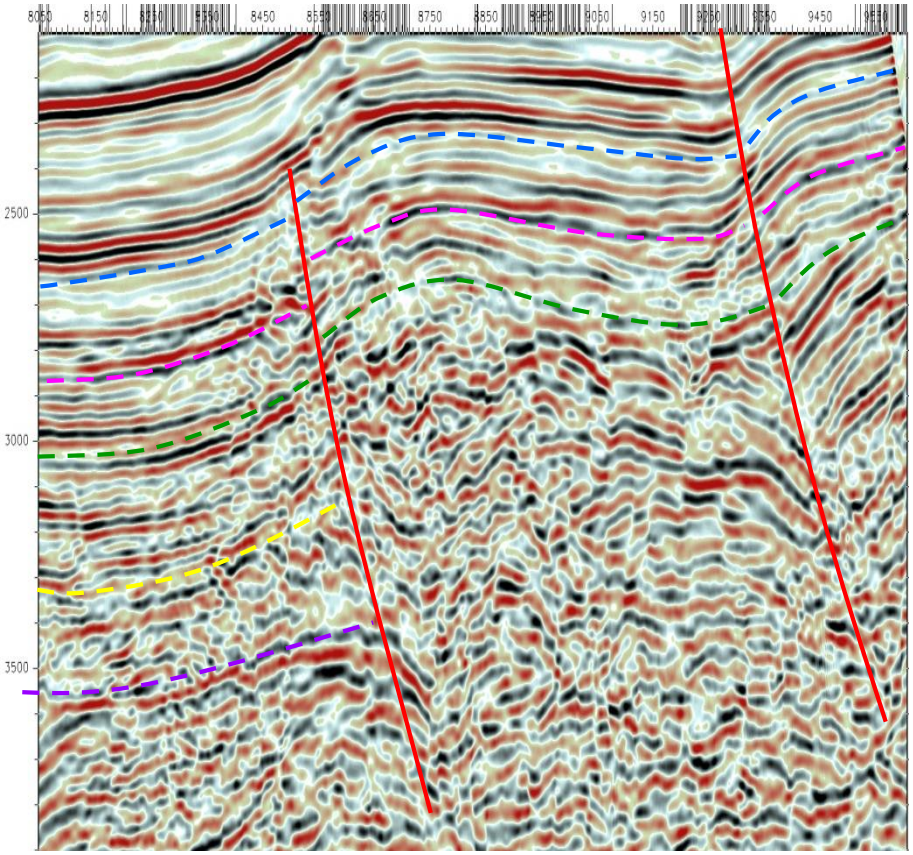
Small sand dune

Topography of 3D project

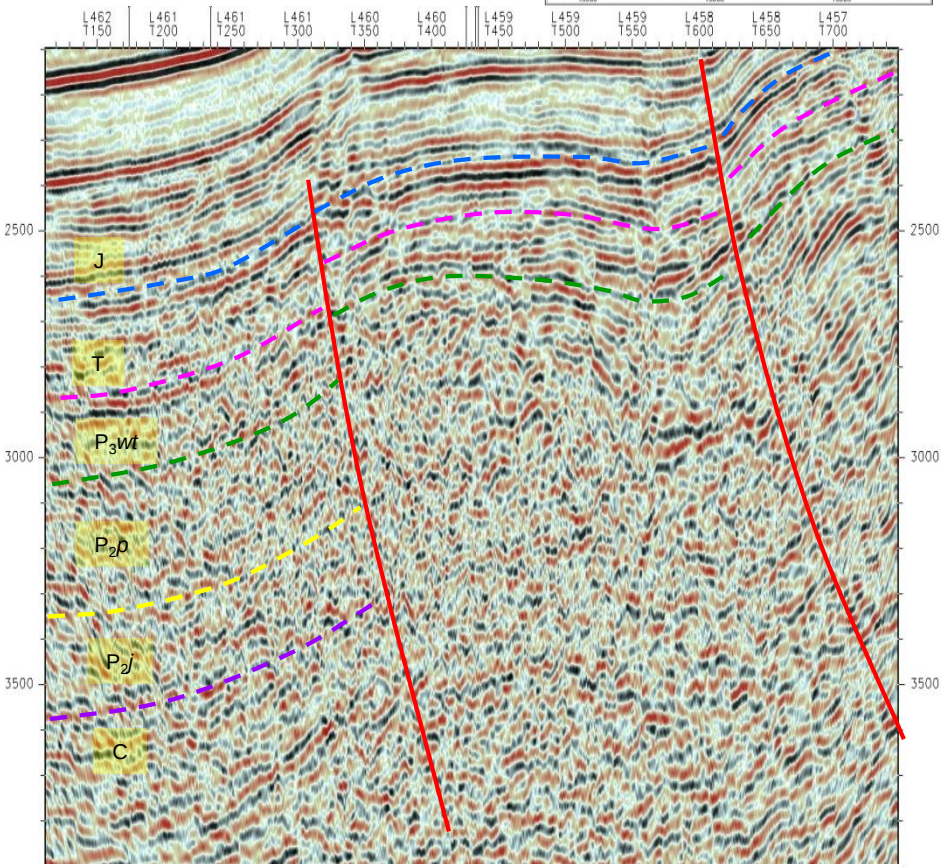
Geological and geophysical issues

Main issues：Low S/N, hard to delineate the faults and fractures in Triassic and Permian systems, poor imaging the top of Carboniferous system





2D: 2L1S800, F:400, MO: 7990,8x3kg-6m(2013)



3D: 2L9S152R, F:3x19=57, bin:25x50, MO:4475m, 10x2kg-6m(2002)

Acquisition parameters

Sources

Vibrator：BV-620LF

Sweep length：16/20s

Array pattern：2 Vibs x 1 sweep

Start slop：0.5s

Sweep type：linear

End slop：0.25s

Frequency：1.5-84Hz

Shooting type：slip-sweep

Drive force：65%

Slip time：15s

Receivers

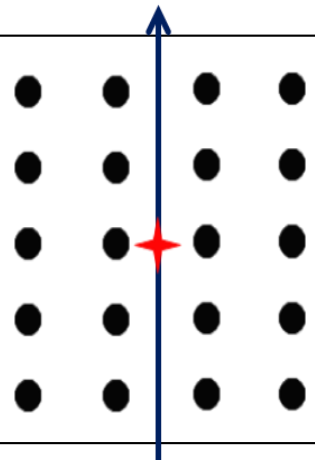
Type：30DX-10

Pattern：rectangle

Num. of phone：2x20

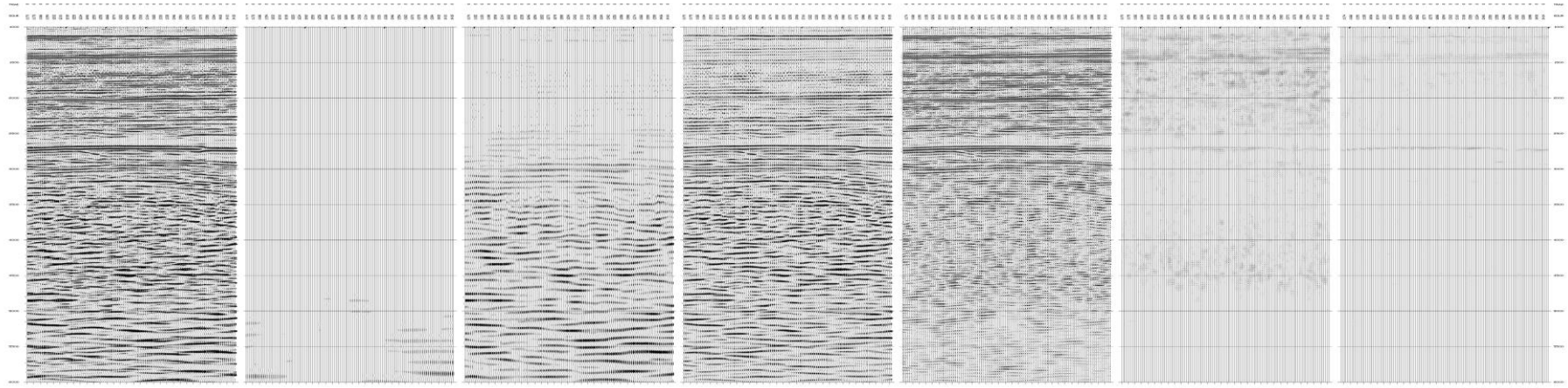
Element interval：4m

Array area：16m×12m

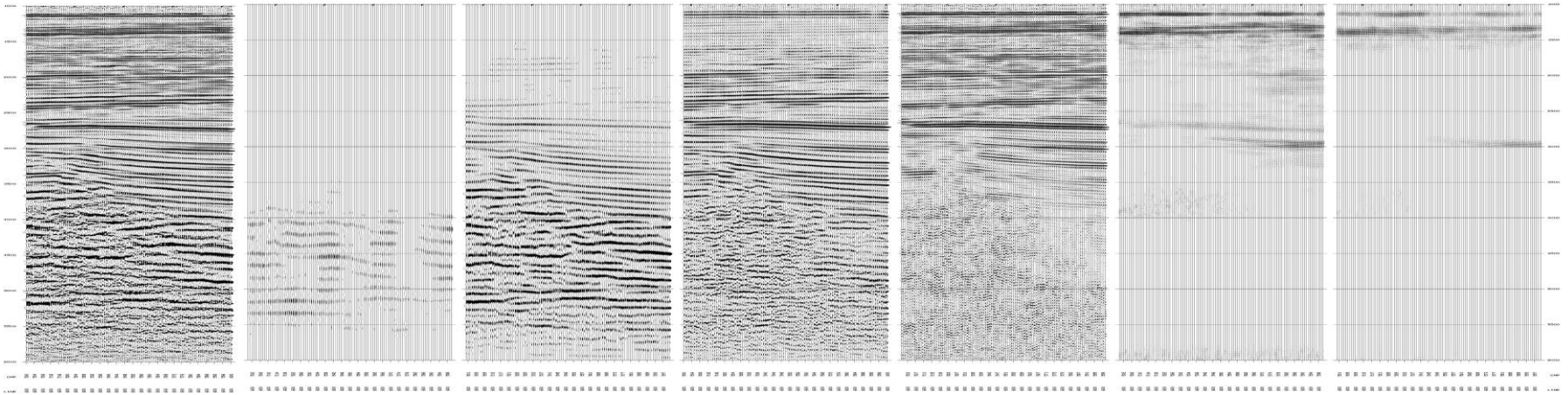


Frequency contents of dynamite and vibrator

Dynamite: 2L2S800R, 7990-10-20-10-7990, fold 800, 6m×8hole×3kg

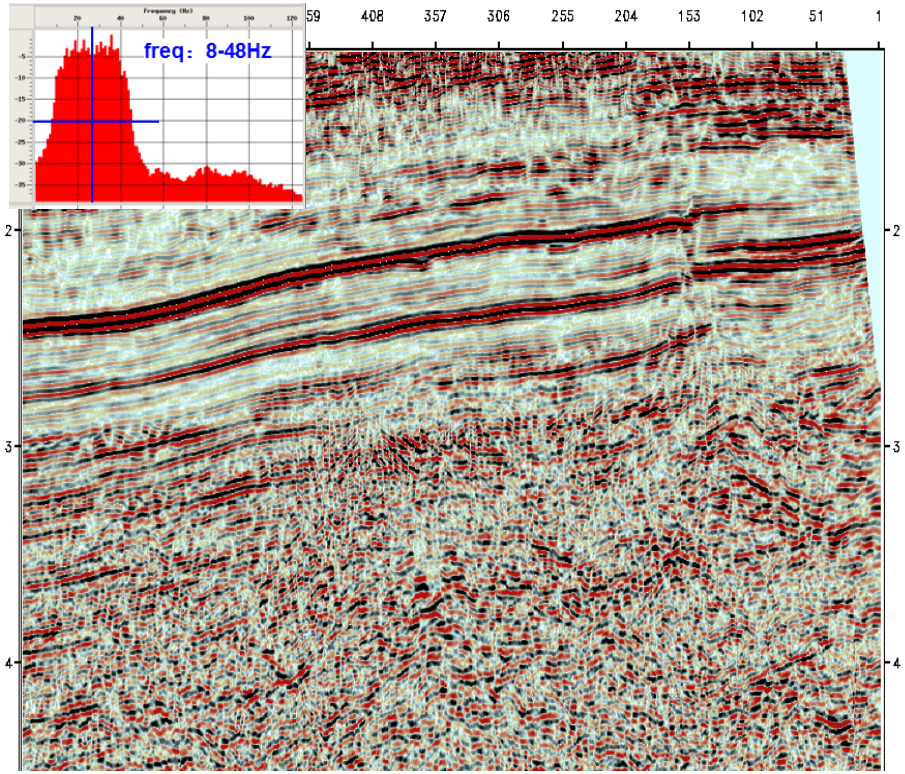


LFV3: 2sets x 1sweep，bin 25m×25m, fold 1152

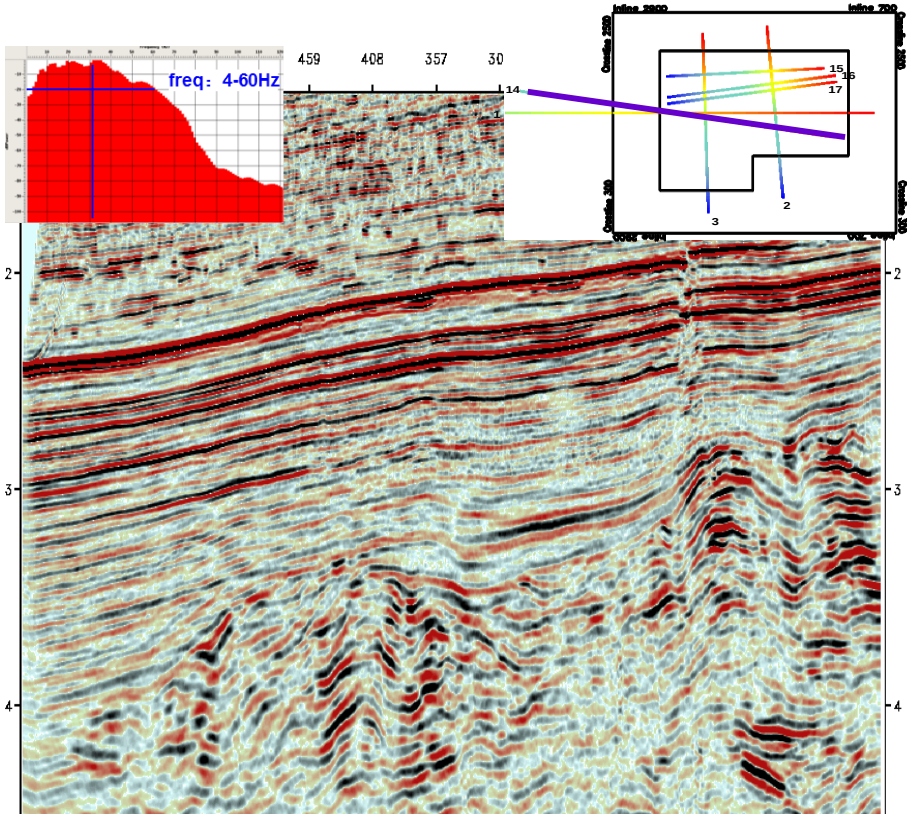


Raw data (3-6)Hz (6-12)Hz (12-24)Hz (24-48)Hz (48-84)Hz (60-120)Hz

Comparison of 2D dynamite and WBH 3D Vibroseis



2D line 14 in 2013

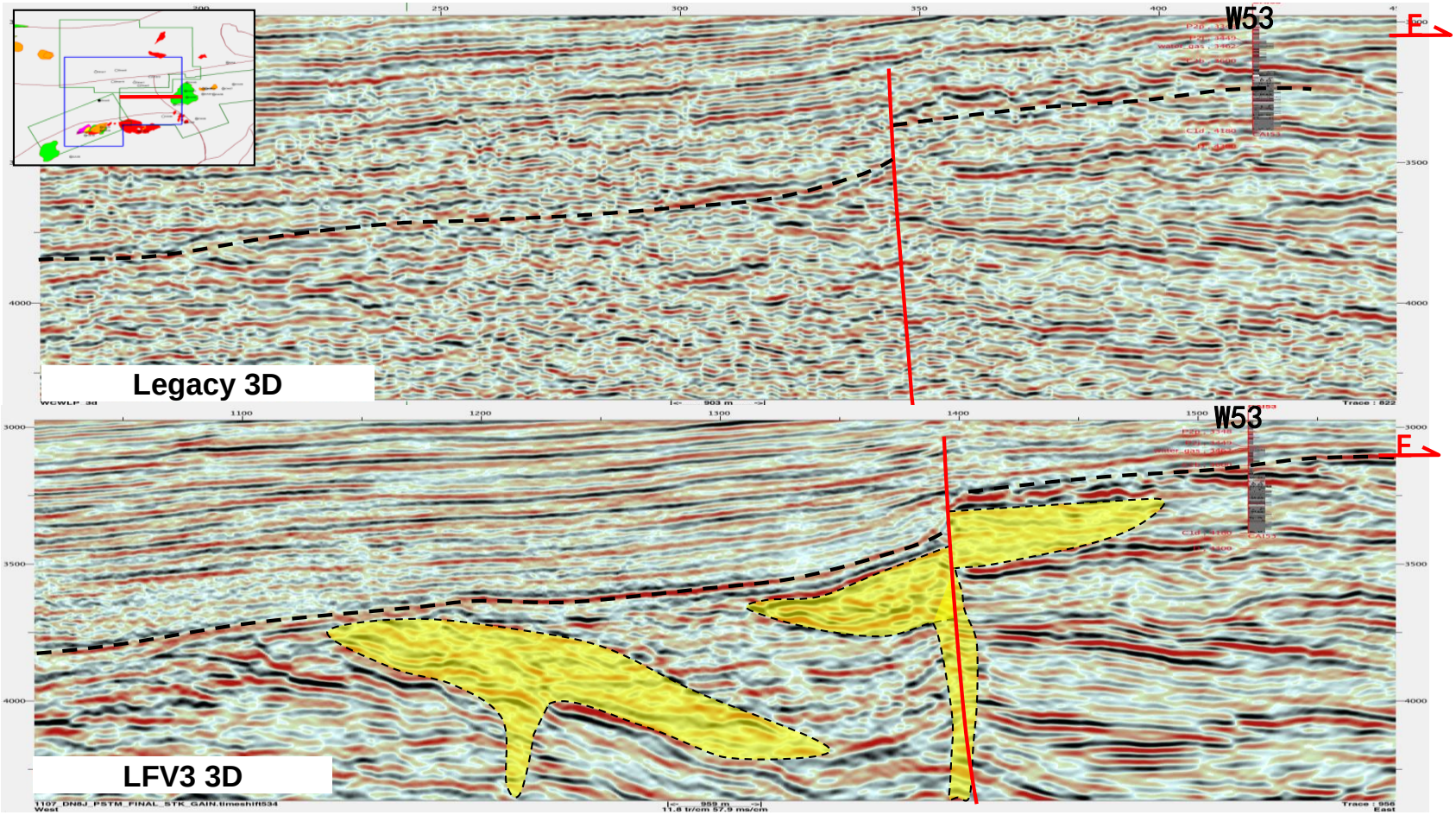


WBH 3D in 2014

2L1S800R，7990-10-20-10-7990
Fold: 400
Dynamite: 8holes×6m×3kg

48L3S288R, 7175-25-50-25-7175
Bin size:25*25, LI150m
Fold: 1152
Vibroseis (LFV): 1.5-96 Hz

Comparison of legacy 3D and new 3D



Contents

Conclusions

- The broadband vibrator can provide the subsurface with a linear sweep 1.5-160 Hz.
- The stability, repeatability, accuracy, and efficiency of low-frequency/broadband vibrator series are tested and verified with both downhole and surface programs.
- WAZ, Broadband, Long-offset, and high-density 3D seismic survey is an optimum selection for prospecting of deep and igneous rocks, as well as pre-salt targets.
- The use of broadband data with FWI demonstrates its powerful ability in velocity model building, imaging, and AI inversion.

Thank you for your attention !