Advances in Vibroseis Technology Enhance Low-Frequency Recording and Provide Significant Operational Benefits*

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Search and Discovery Article # 41736 (2015)
Posted November 30, 2015

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015

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Abstract

Advancements in source and receiver technology in recent years will have a dramatic impact on low-frequency data. Substantial improvements have been made by modifying the Vibroseis with the goal of eliminating generated noise and enhancing and understanding the force output of the Vibroseis. Combining this technology with the low-frequency performance characteristics of the digital sensors, high quality, low-frequency results are possible in nearly any environment. Together these technologies provide a distinct added value to seismic acquisition. Using Vibroseis technology to sweep smarter rather than harder can mean superior seismic data with no additional cost or effort.

Vibroseis technology has undergone extensive improvement in recent years. Modern engineering methods have been systematically applied to meet the basics of mechanical constraints. By studying all the components of the Vibroseis system, it has been possible to improve low- and high-frequency performance, reduce harmonics, and increase the accuracy of sweeps in terms of fundamental ground force. In production shooting, the benefit of current technology combined with sweeps designed to meet low-frequency requirements produces significant energy output as low as 1-3 Hz. The integration of multiple innovations makes this achievement possible. One result of Vibroseis technology development can be seen in the benefits possible with sweep design. Designing a Vibroseis sweep based only on the desired outcome of the frequency content of the final data is a common practice. However, it can be shown that by designing a sweep with the desired frequencies filtered by the performance characteristics of the Vibroseis, a better result can be obtained. This particularly applies to the low-frequency portion of the frequency spectrum. Examples show one such case in point. The customer designed a linear sweep from 5-86 Hz. The low-frequency portion of this sweep design is not consistent with performance characteristics of the Vibroseis utilized, so an alternative sweep design was proposed to limit the amplitude effort in the lower portion of the frequency spectrum to the Vibroseis characteristics. Sweeping with the modified sweep and correlating, achieves a superior result. Most noticeably, there is a dramatic decrease in ground roll in the shot that is correlated with the modified sweep. The impact of the reduction in ground roll cannot be overstated.

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Advances in Vibroseis Technology and Digital Sensors Enhance Low Frequency Recording and Provide Operational Benefits

AAPG/SEG – ICE 2015 – Melbourne, Australia

C. J. Criss – INOVA

Outline

- A brief review of vibrator theory
- A look at some of the modifications and the impact
- Field examples
- Digital sensor testing
- Field examples

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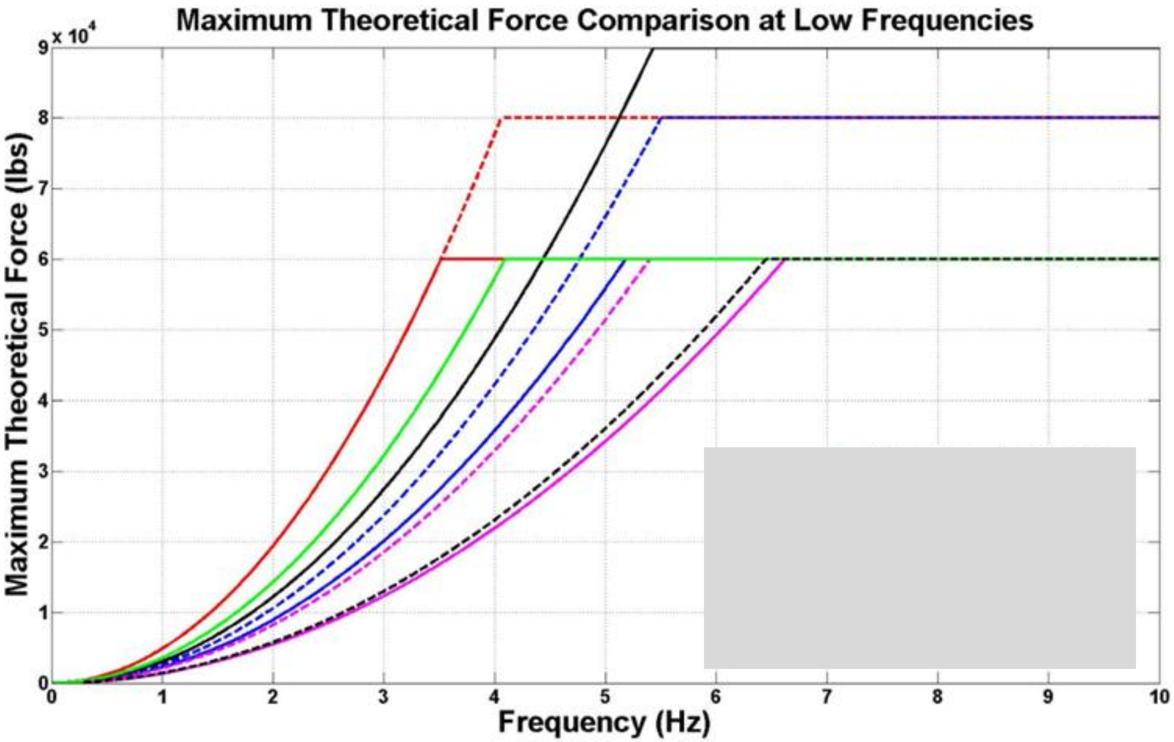
Vibroseis Technology

Fundamental Equation (Newton 2nd law)

$$F_{max} = 4\pi^2 M_{rm} X_{rm} f^2$$

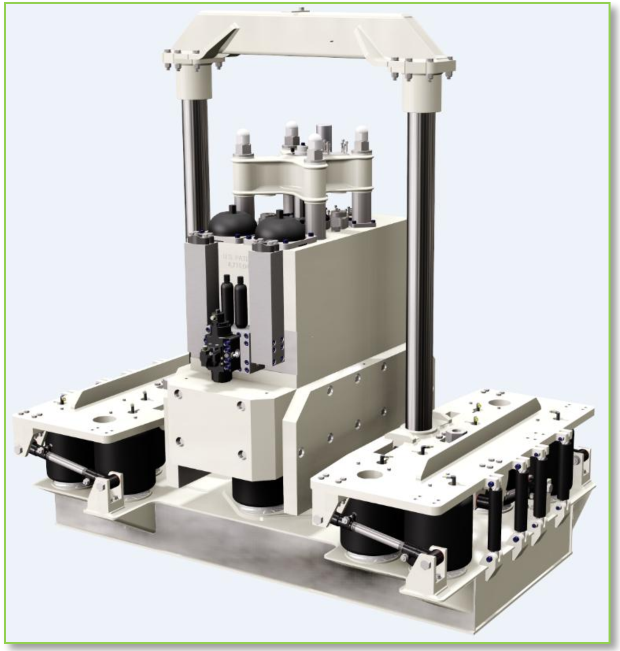
- F_{max} is the maximum force produced by the vibrator;
- f is the frequency;
- M_{rm} is the mass of the reaction mass ;
- X_{rm} is the maximum travel distance of the reaction mass;

Theoretical Low Frequency – Commercial Vibes

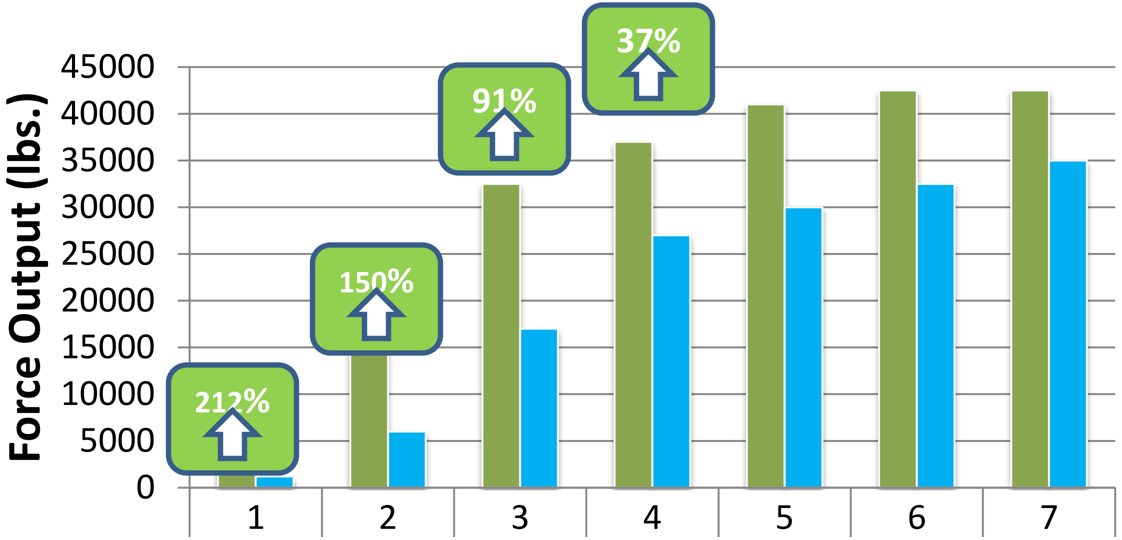


Specification Comparison

Physical Specs	Commercial Vibrator	Prototype Vibrator
MASS (lbs.)	10861	13460
BASEPLATE (lbs.)	4451	4787
RATIO	2.44	2.81
BASEPLATE AREA (ft^2)	26.83	28.29
ROD (in)	3.999	3.999
BORE (in)	6.499	6.999
PISTON AREA (in^2)	20.62	25.92
STROKE (stop/stop)	4.12	7.12
SYSTEM PRESSURE (psi)	3200	3200
OUTPUT FORCE (lbf)	65971	82933



Force Output Results with Prototype



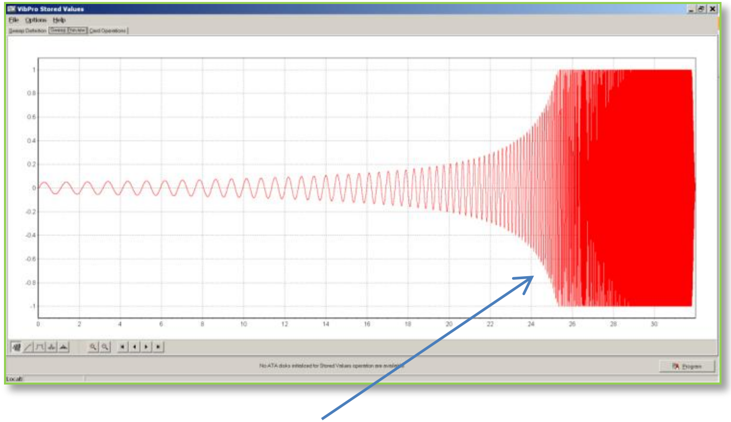
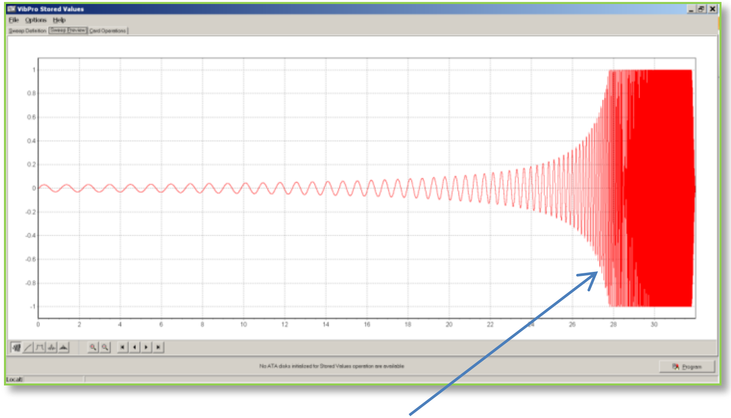
Notes:

- 70% of Peak Force (60K)

Field Test Examples – Oman

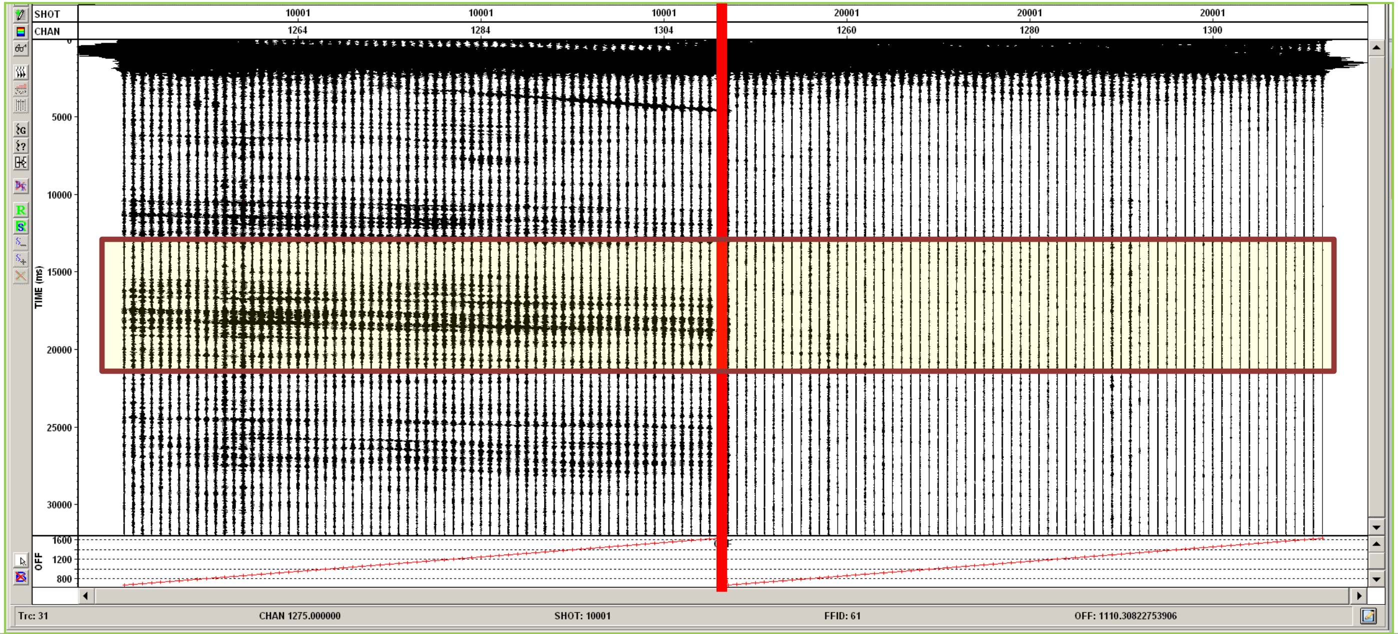
June 2015

Sweep Comparison

Prototype Vibrator	Commercial 80000lb Vibrator
	
Low dwell period ends ~25 seconds	Low dwell period ends ~28 seconds

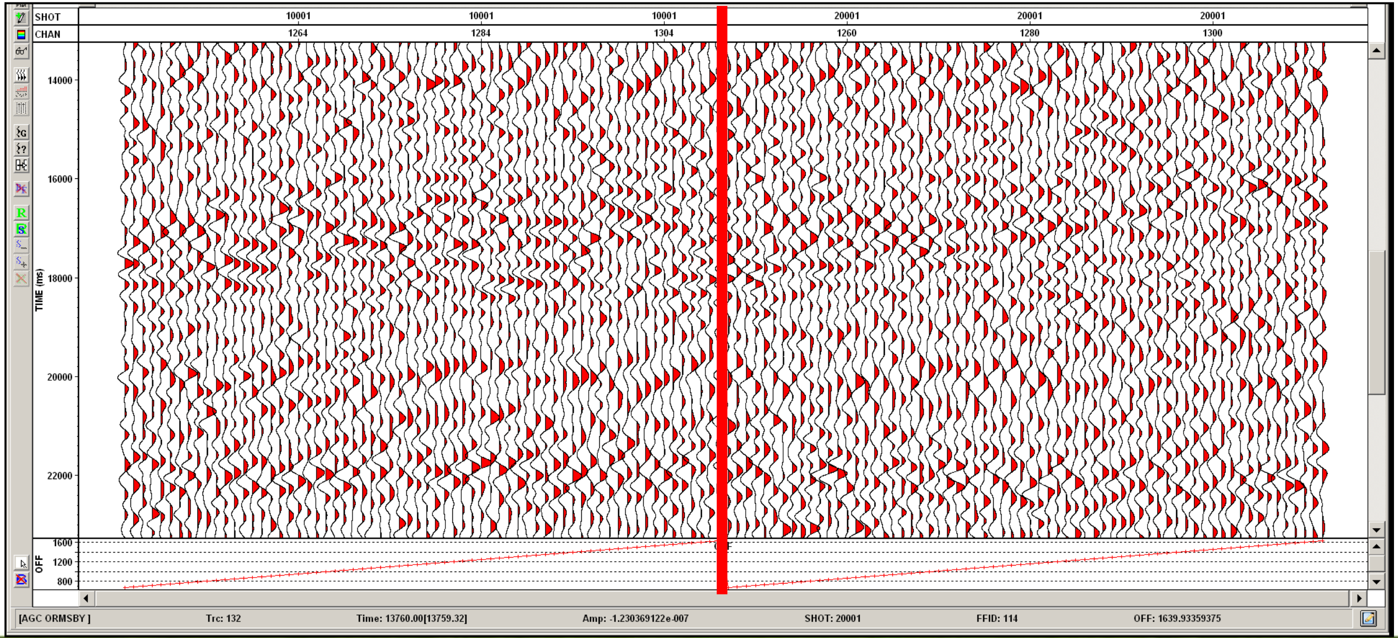
Input 1-85 Hz Sweep

Prototype Vibrator **80000lb Commercial Vibrator**



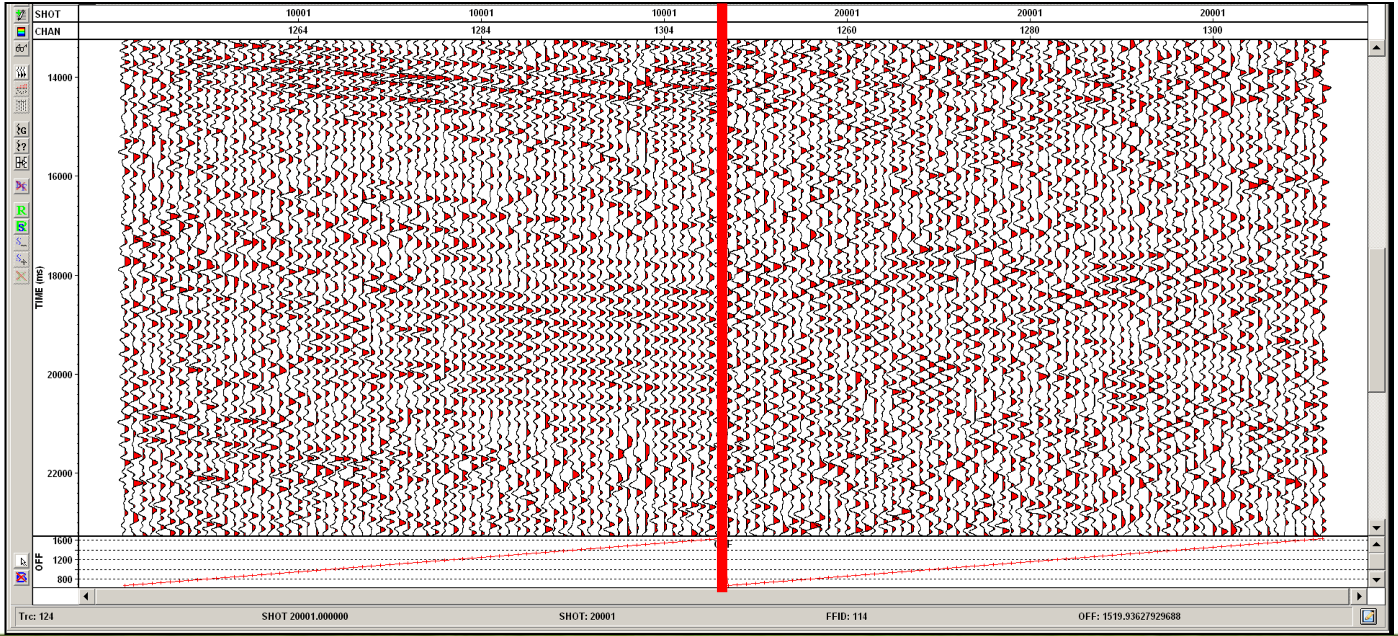
0-1-2-4 Hz 3sec AGC

Prototype Vibrator **80000lb Commercial Vibrator**



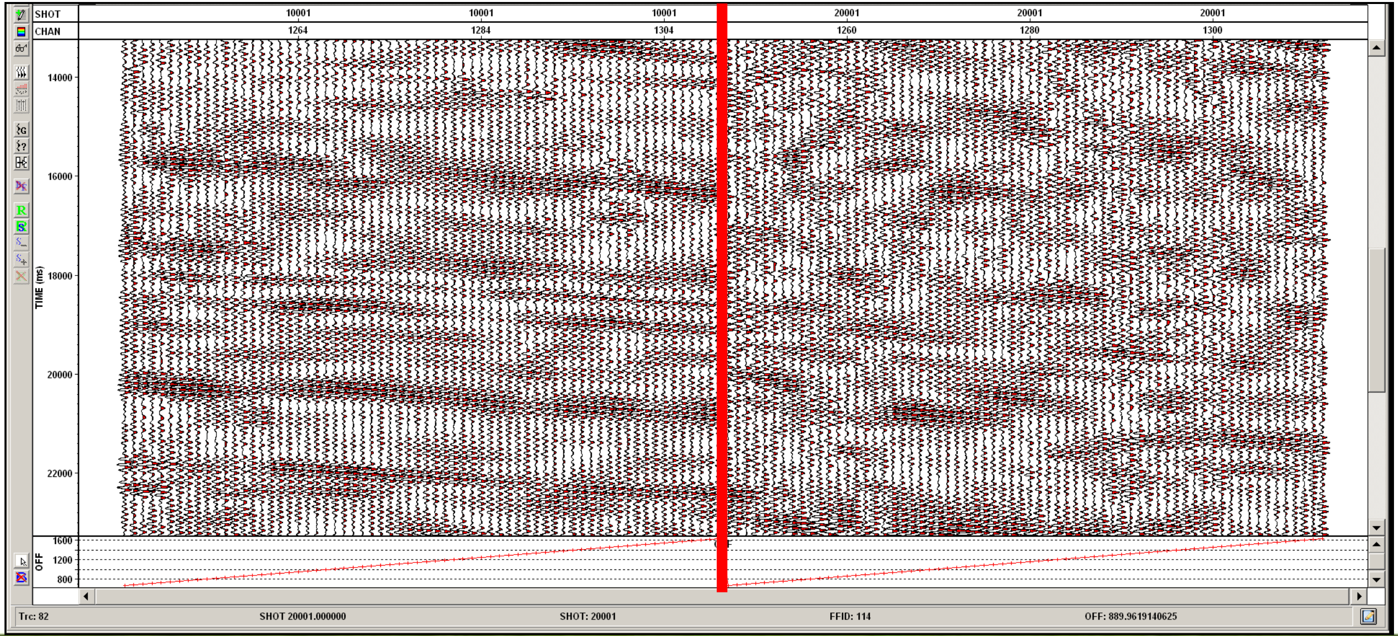
0-1-4-8Hz 3sec AGC

Prototype Vibrator | **80000lb Commercial Vibrator**



0-1-8-12Hz 3sec AGC

Prototype Vibrator **80000lb Commercial Vibrator**

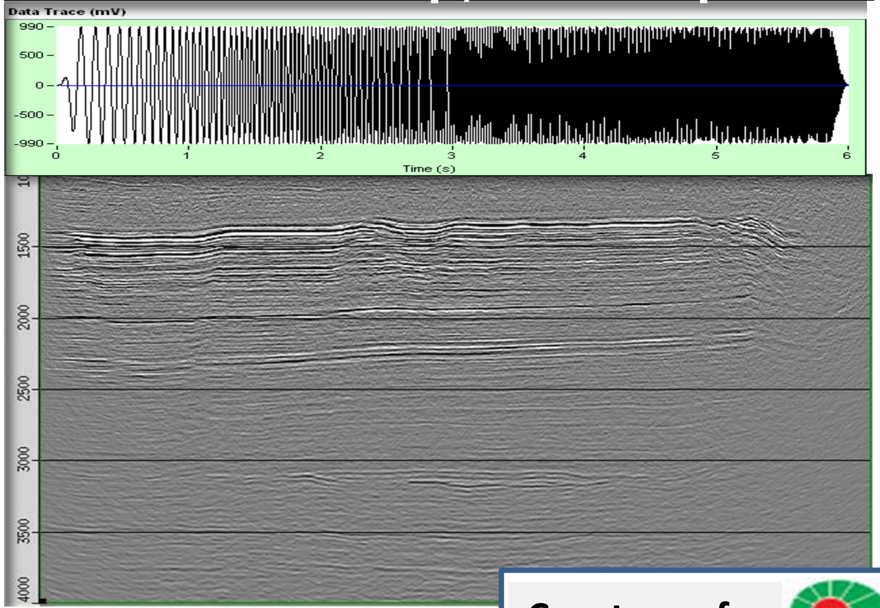


Oman Production Example
Sabkha Region

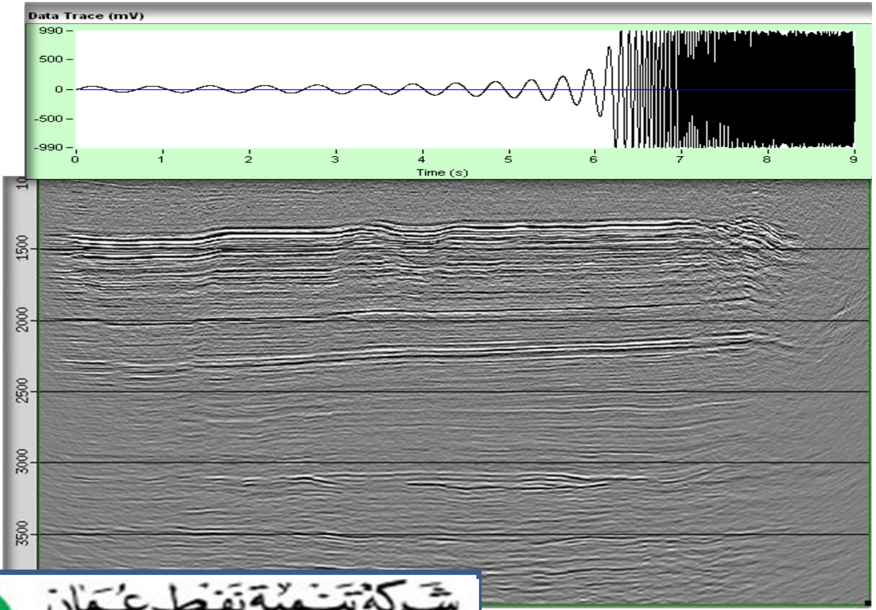
Project: Sabkha Regions, Oman

LF Testing

**6-86 Hz, linear 'Production'
6 sec sweep, 7 sec slip**



**1.5-86 Hz, Customized
9 sec sweep, 7 sec slip**

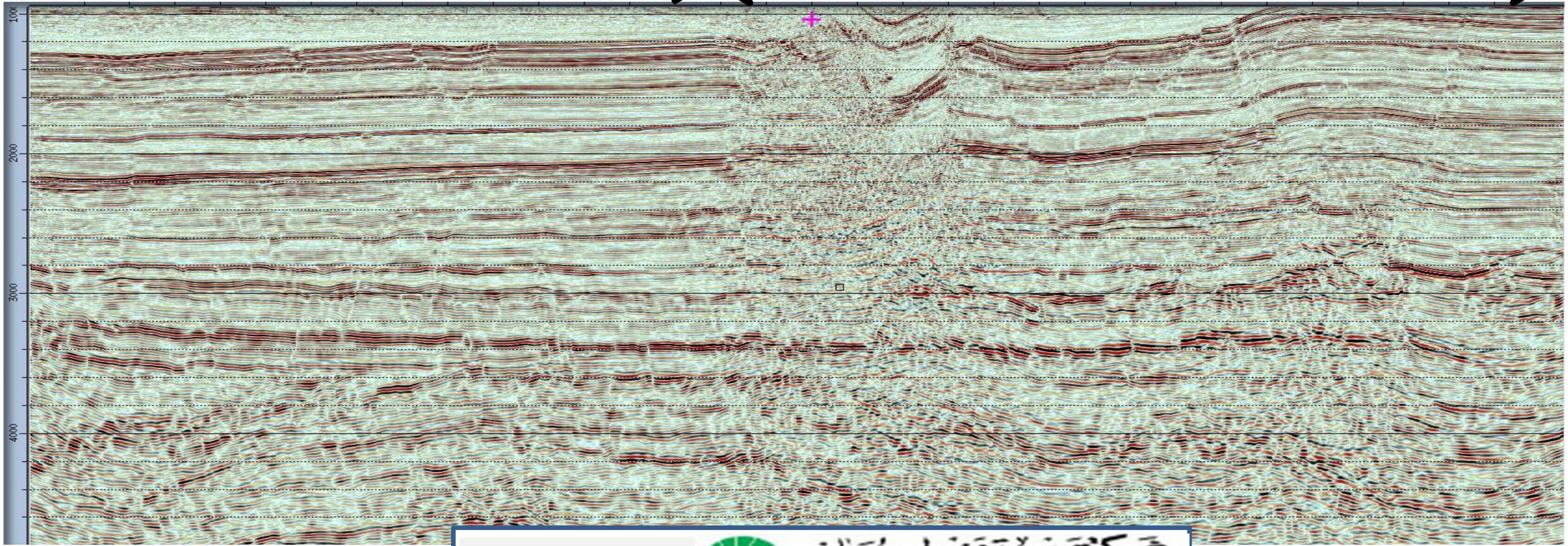


Courtesy of شركة تنمية نفط عمان Petroleum Development Oman

Project: Sabkha Regions, Oman

Data Example, North Oman

6-86 Hz | **1.5-86 Hz**



Courtesy of

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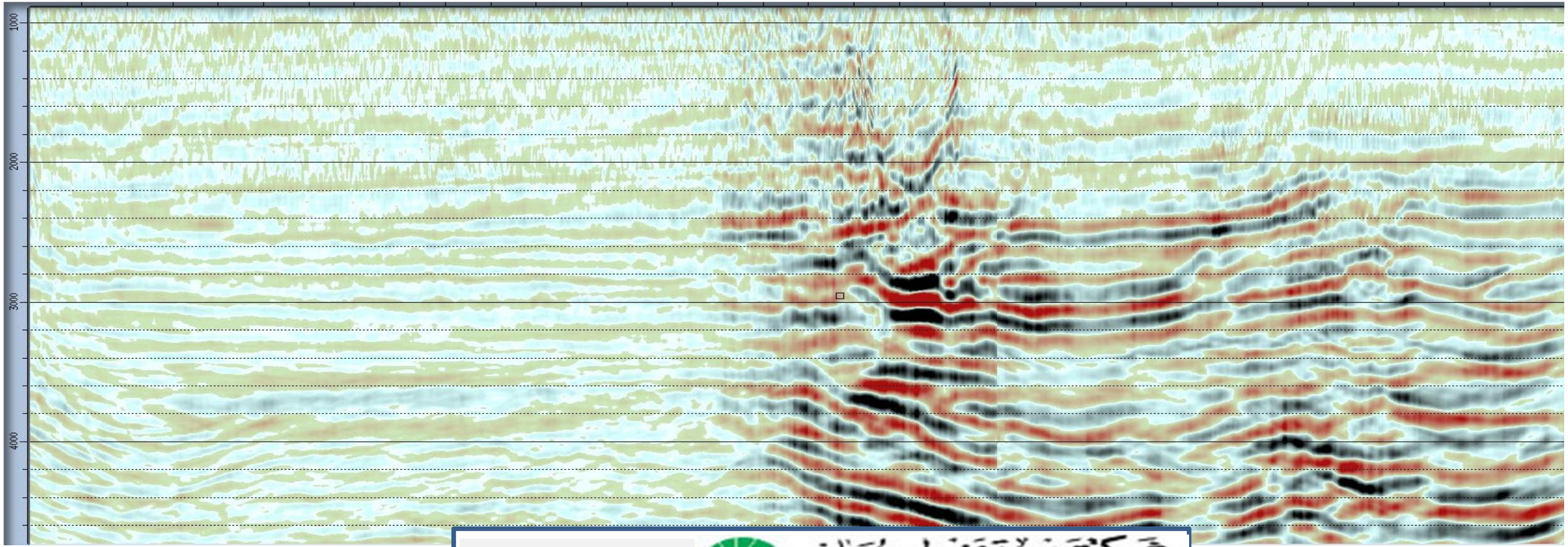
Petroleum Development Oman

Project: Sabkha Regions, Oman

Data Example, North Oman

Band Pass 1.5 - 6 Hz



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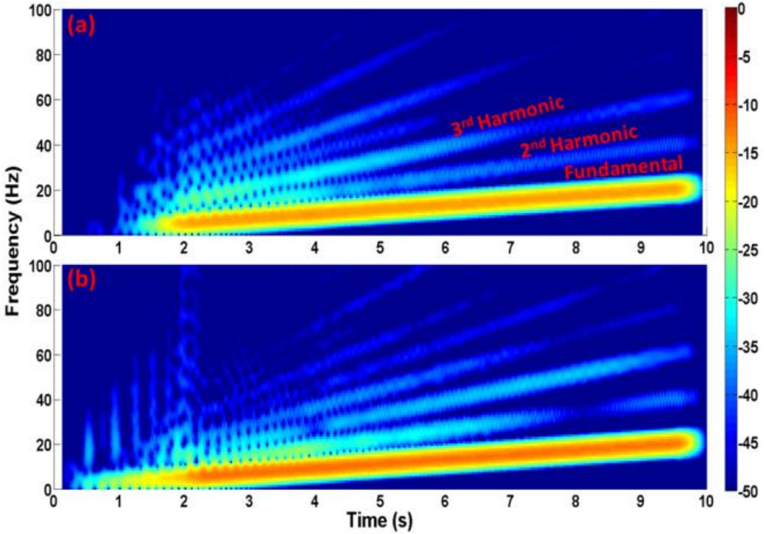
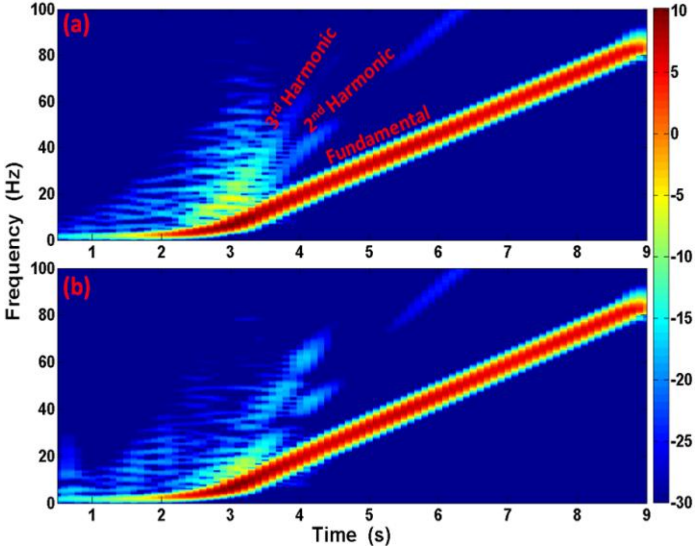
Harmonic Distortion Reduction Control

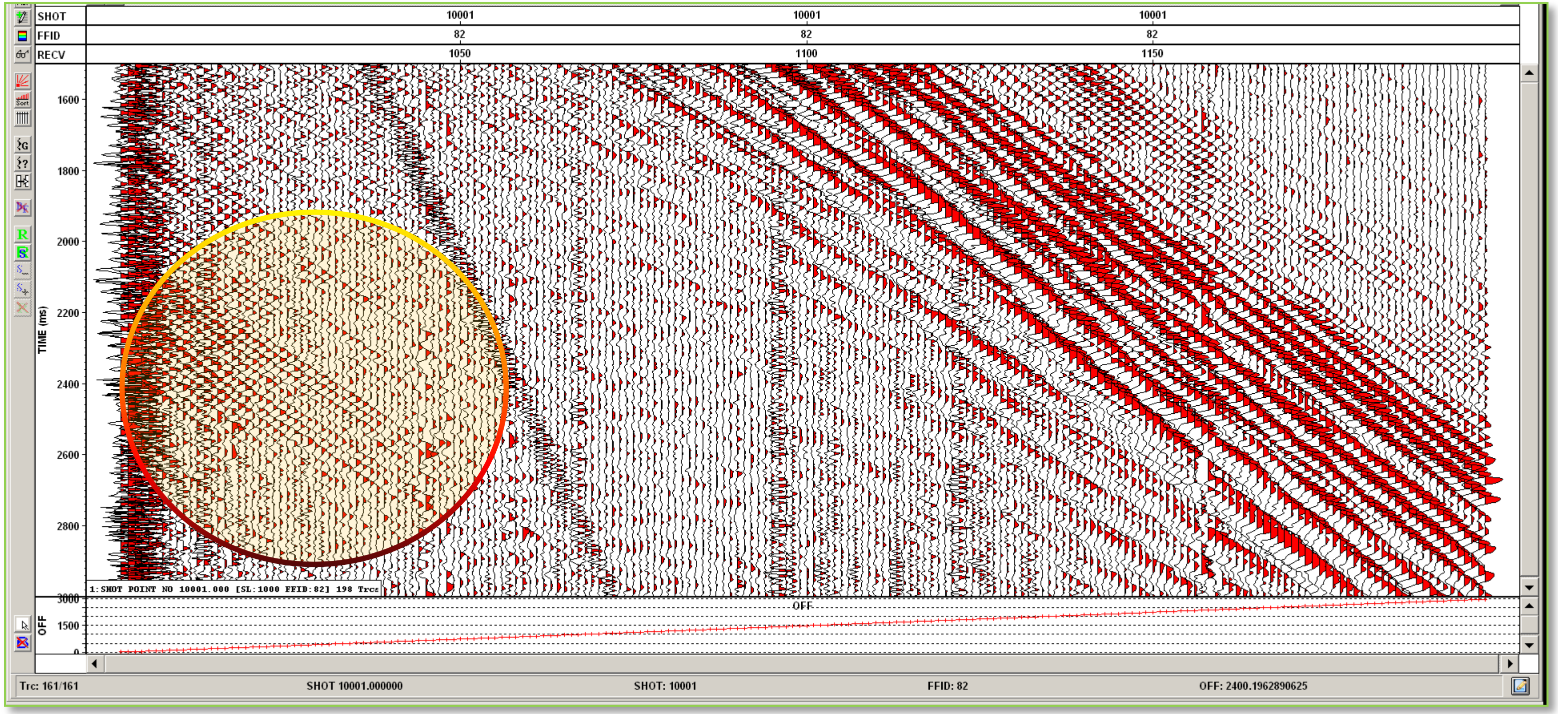


Frequency-Time plot of weighted-sum ground force using linear sweep from 1 to 21 Hz in 10s;
(a) with standard control;
(b) with HDR control.

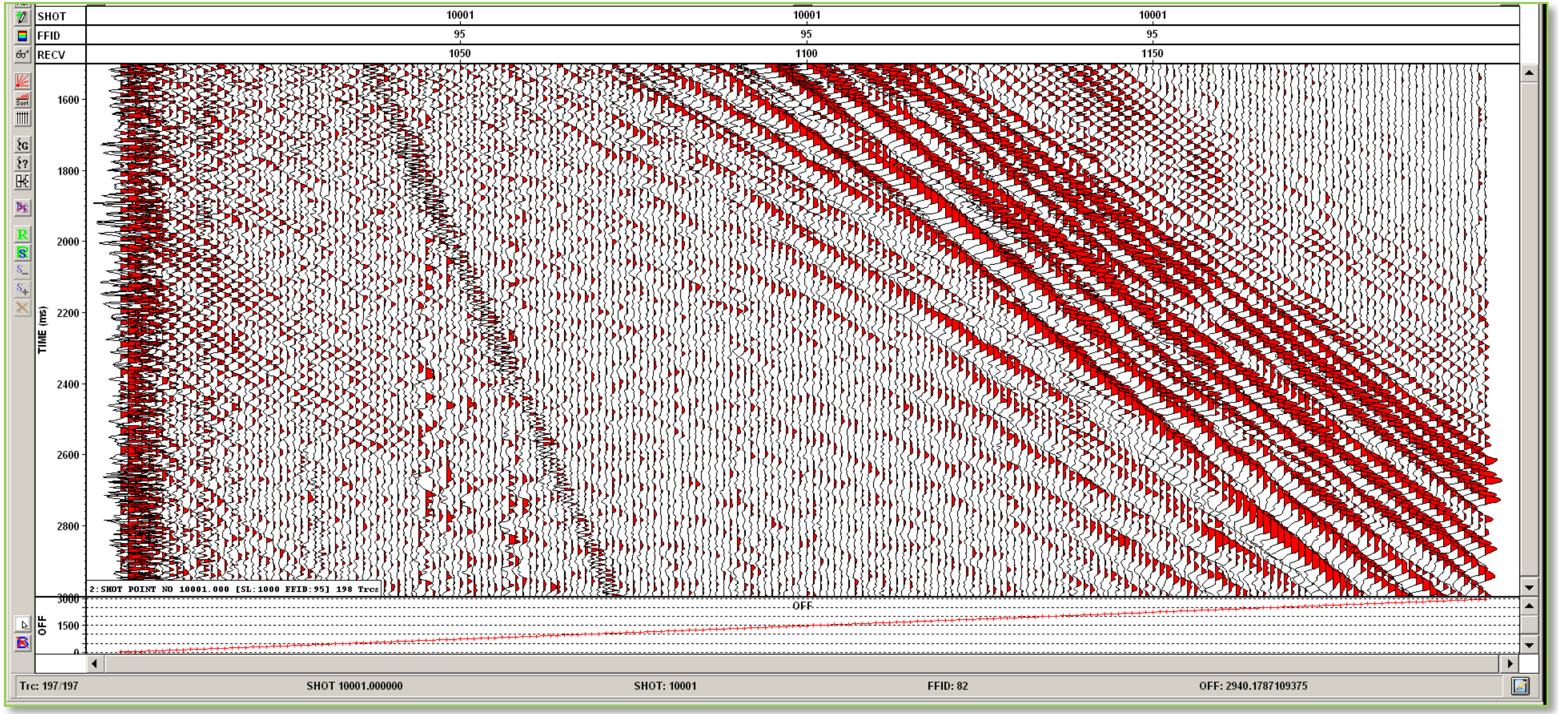


Weighted-sum ground force with low frequency sweep from 1.5 to 86 Hz in 9s;
(a) with standard control;
(b) with HDR control.

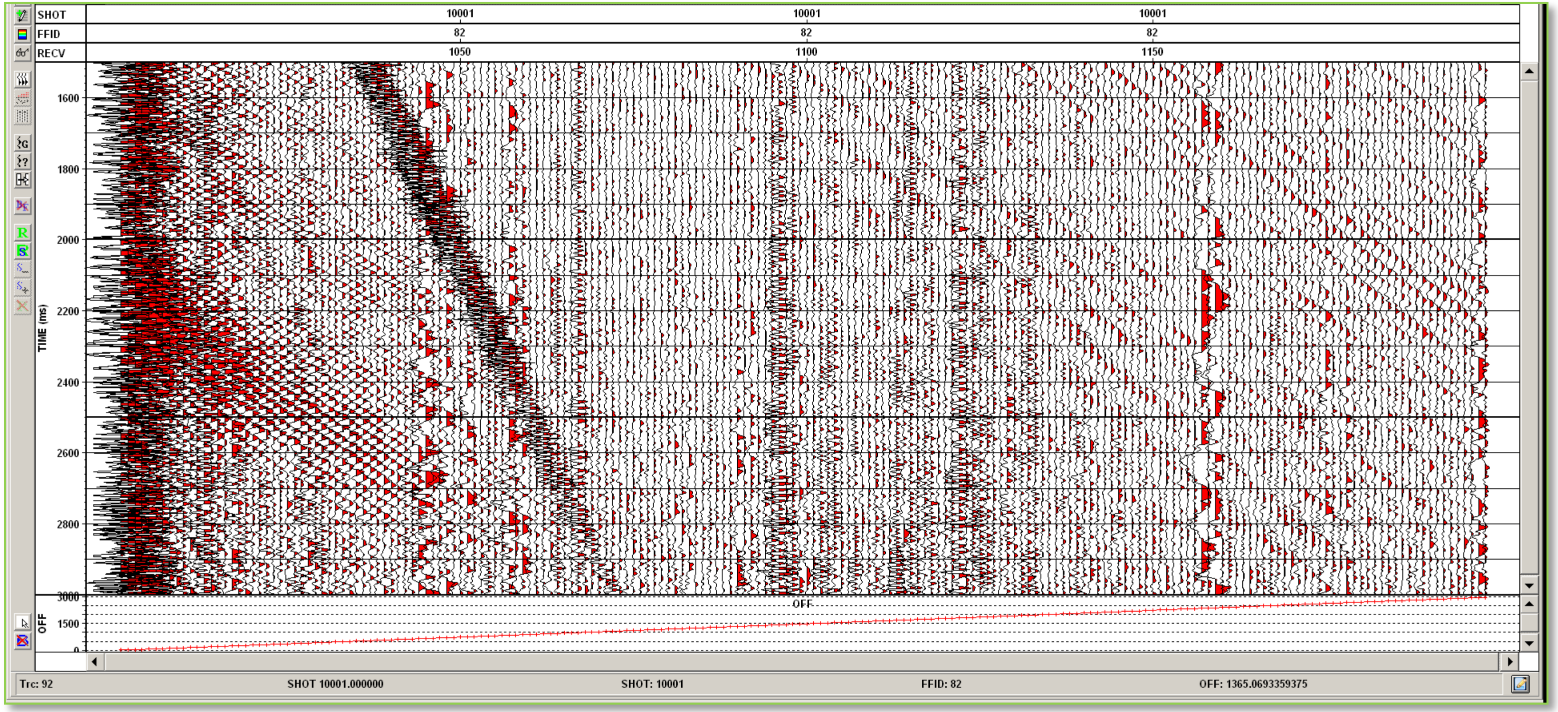
Harmonic Distortion Reduction OFF



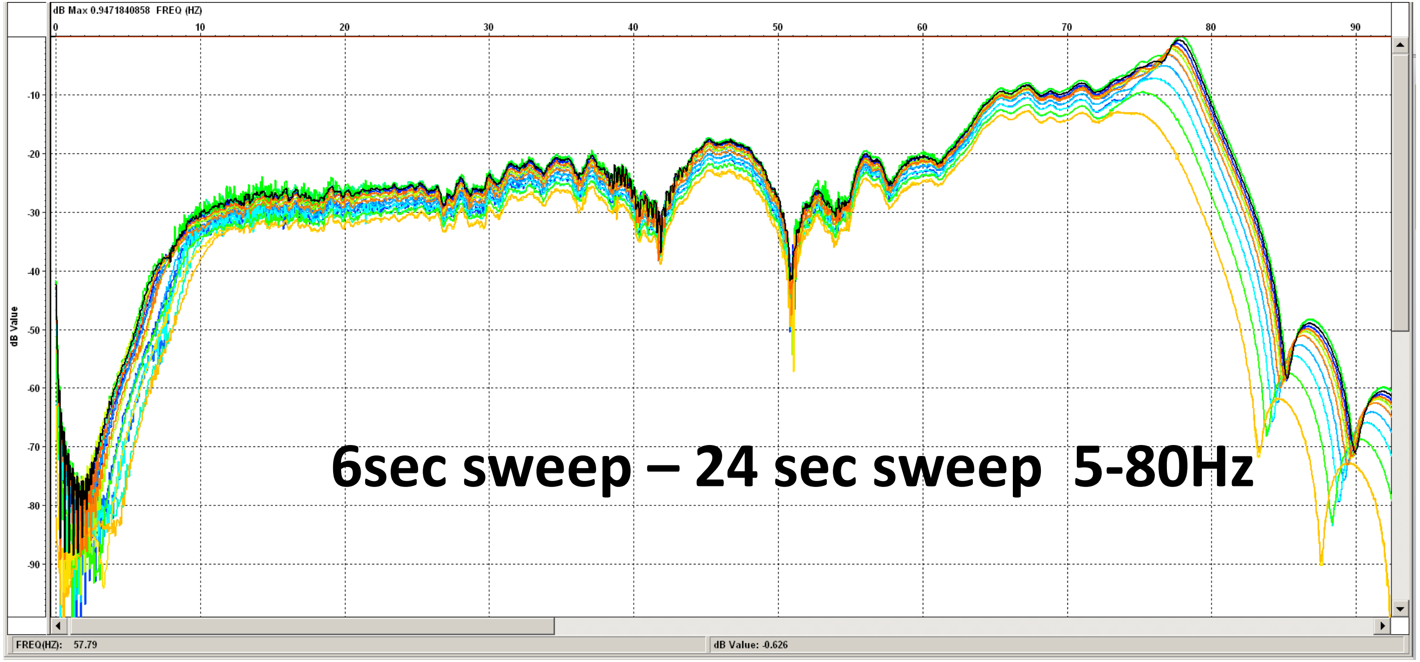
Harmonic Distortion Reduction ON



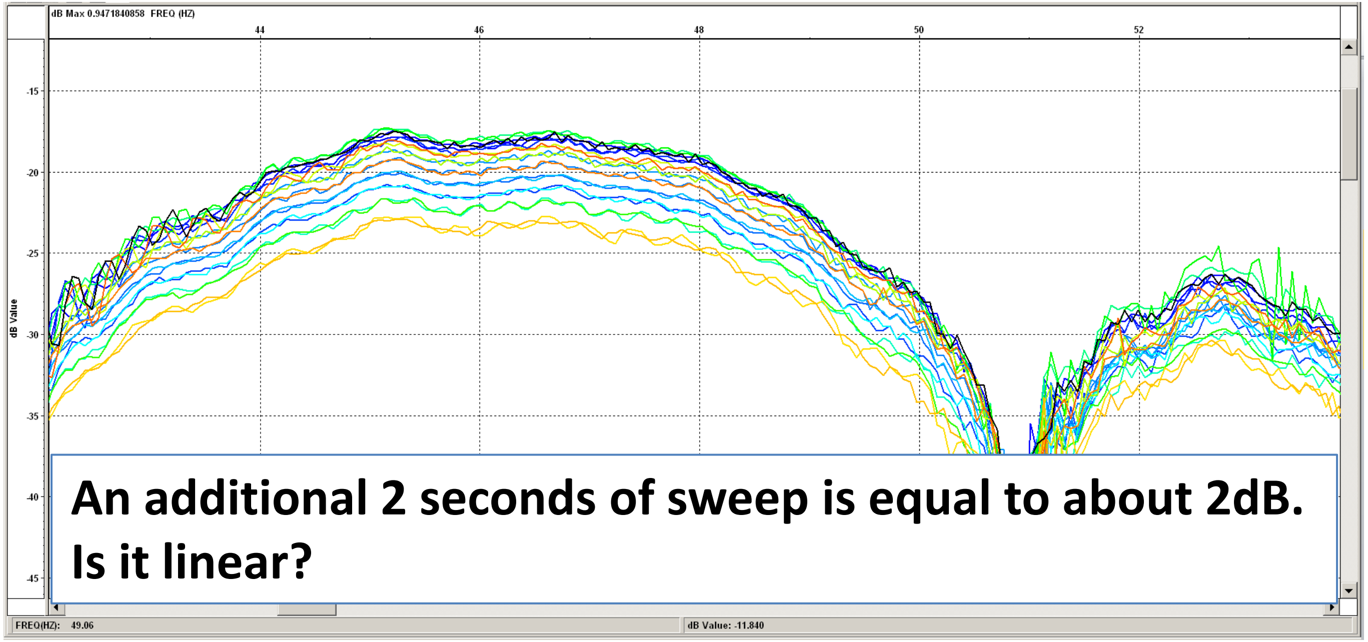
Harmonic Distortion Reduction - Difference



Variations in Sweep Length

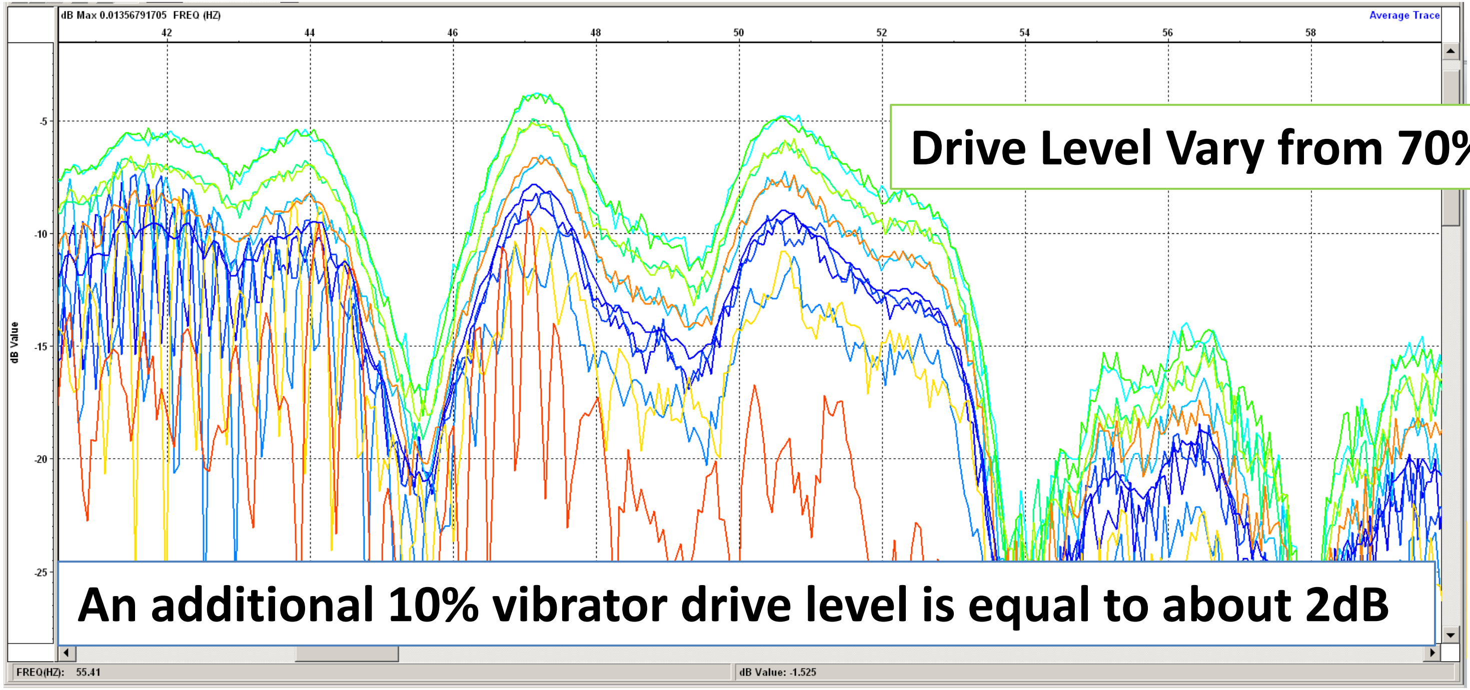


Variations in Sweep Length - zoom



An additional 2 seconds of sweep is equal to about 2dB. Is it linear?

Variations in Maximum Drive Setting - zoom



Drive Level Vary from 70% to 20%

An additional 10% vibrator drive level is equal to about 2dB

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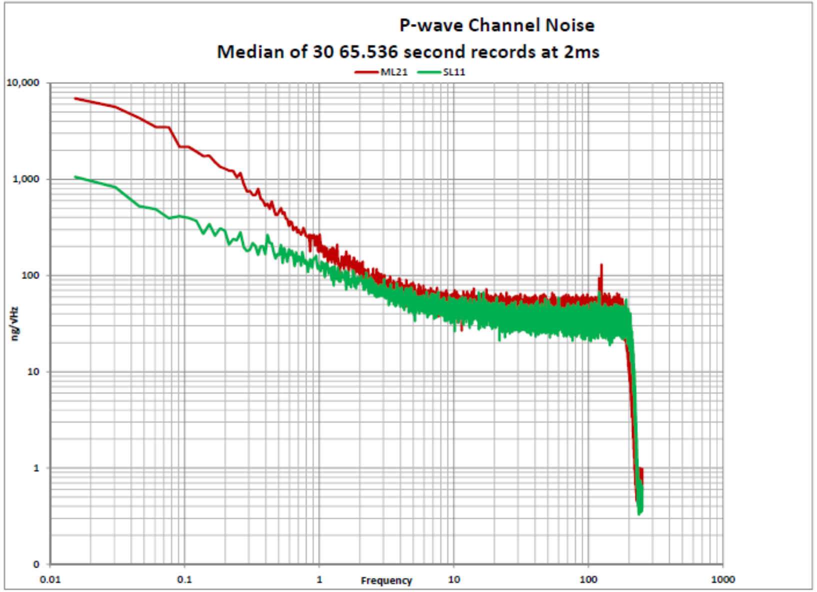
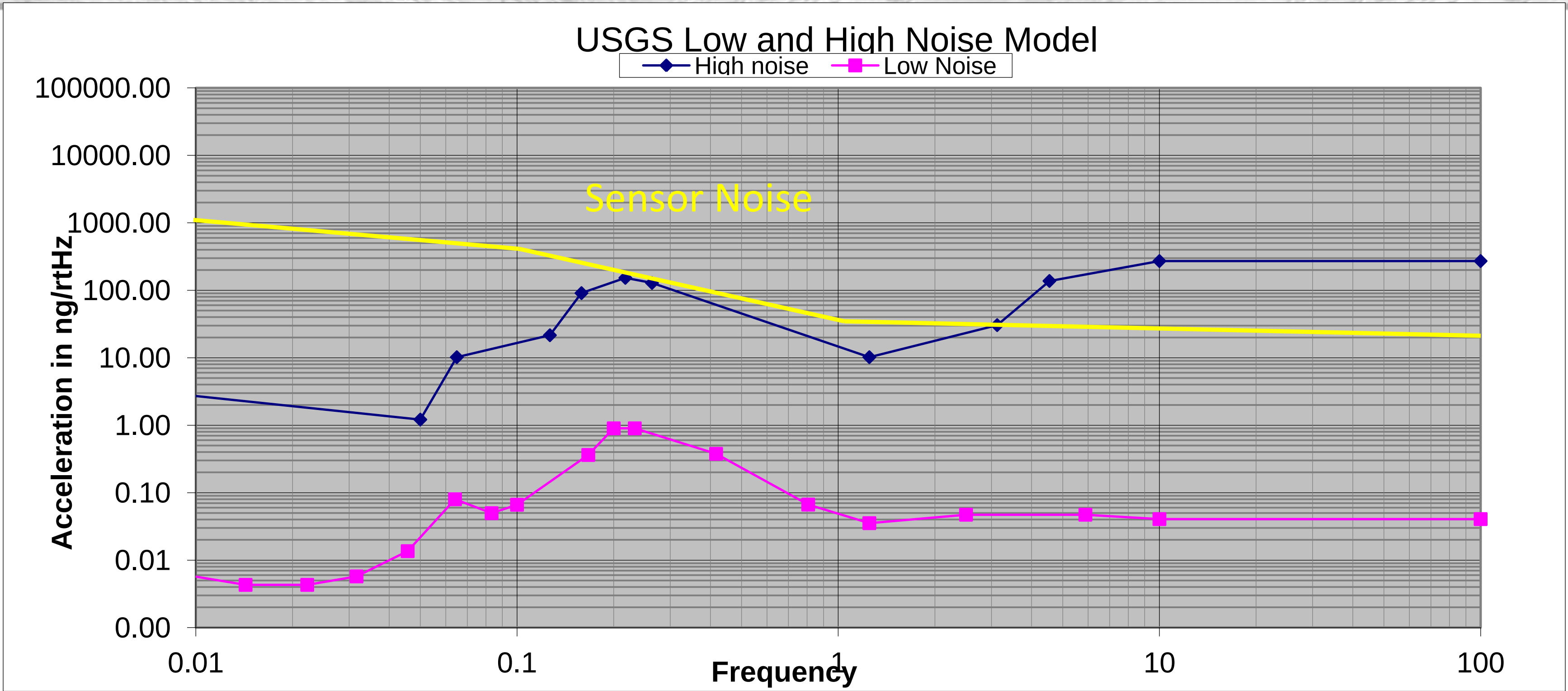
Sensor Technology

Single Sensor Technology for Broadband Operations
Noise Floor Testing

- Noise tests conducted in vaults at Albuquerque Seismological Laboratory (ASL)
- Gen5 (green) tested side-by-side with Gen4 (red)
- Gen5 matches Gen4 and shows improvement in low frequencies (sub-1Hz)
- 120Hz peak is from power transformer at test site

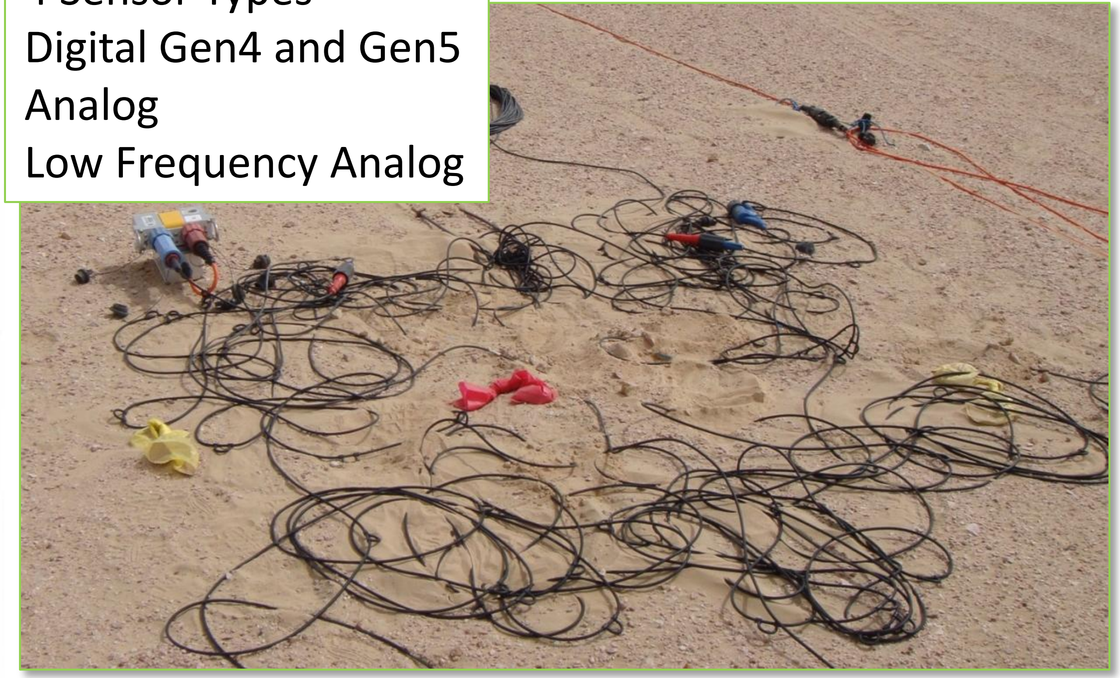


Peterson Earth Noise Model 1993



Sensor Test Comparison- Oman

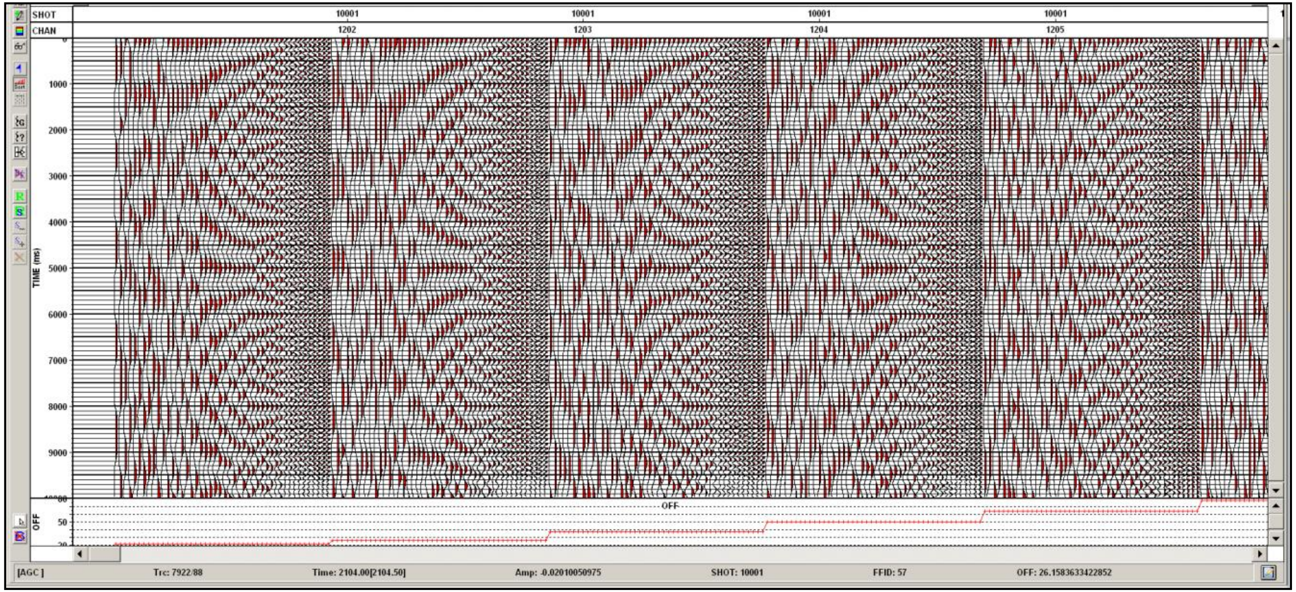
4 Sensor Types
Digital Gen4 and Gen5
Analog
Low Frequency Analog



June 2015

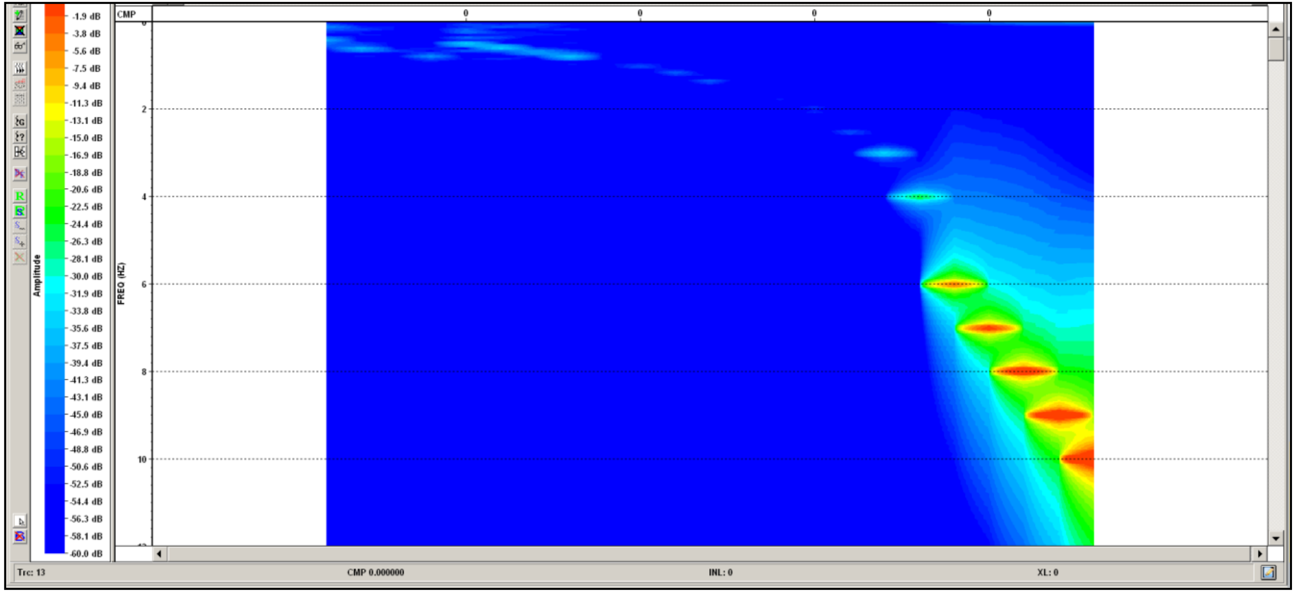
Monochromatic Sweeps

Receiver Station Gathers with increasing frequency monochromatic sweeps .5-10Hz



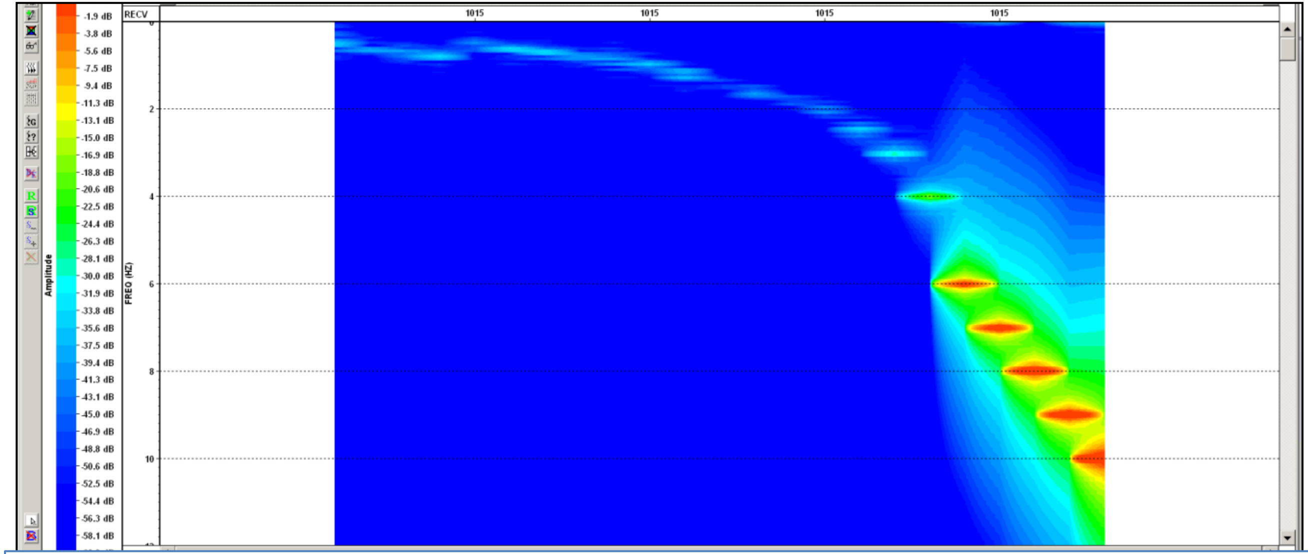
Monochromatic Sweeps-Digital Sensor – Gen. 4

Sweep .5Hz → **10Hz**



Monochromatic Sweeps-Digital Sensor – Gen. 5

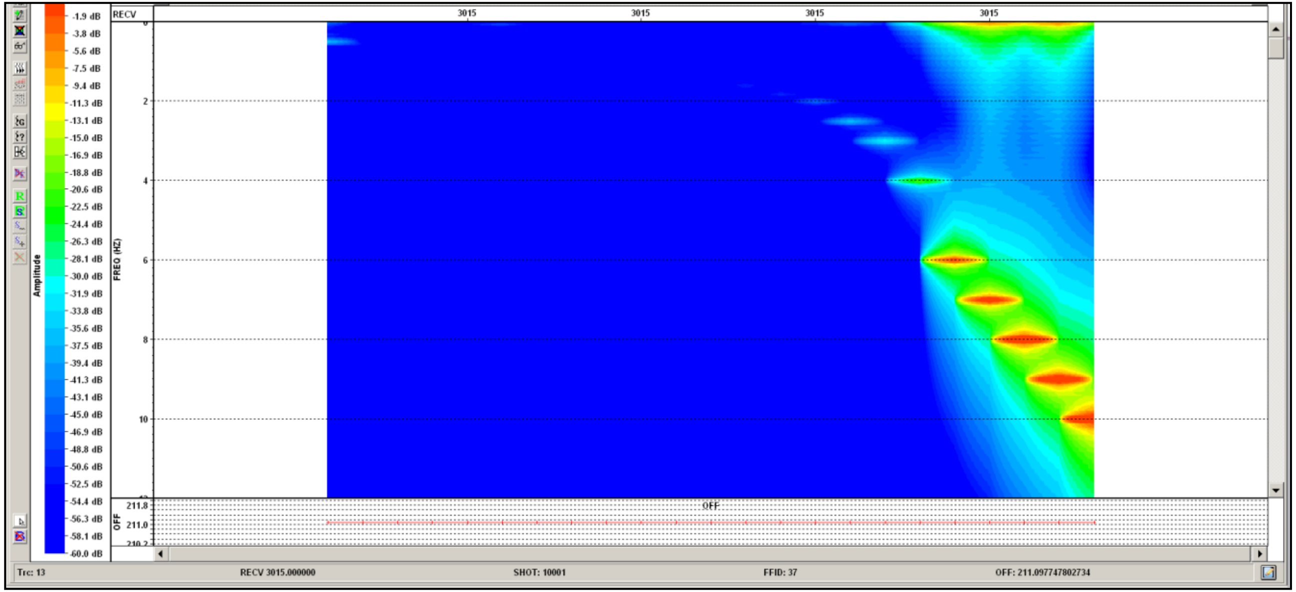
Sweep .5Hz → **10Hz**



Generation 5 Digital Sensor is 20-30 dB better response below 3Hz

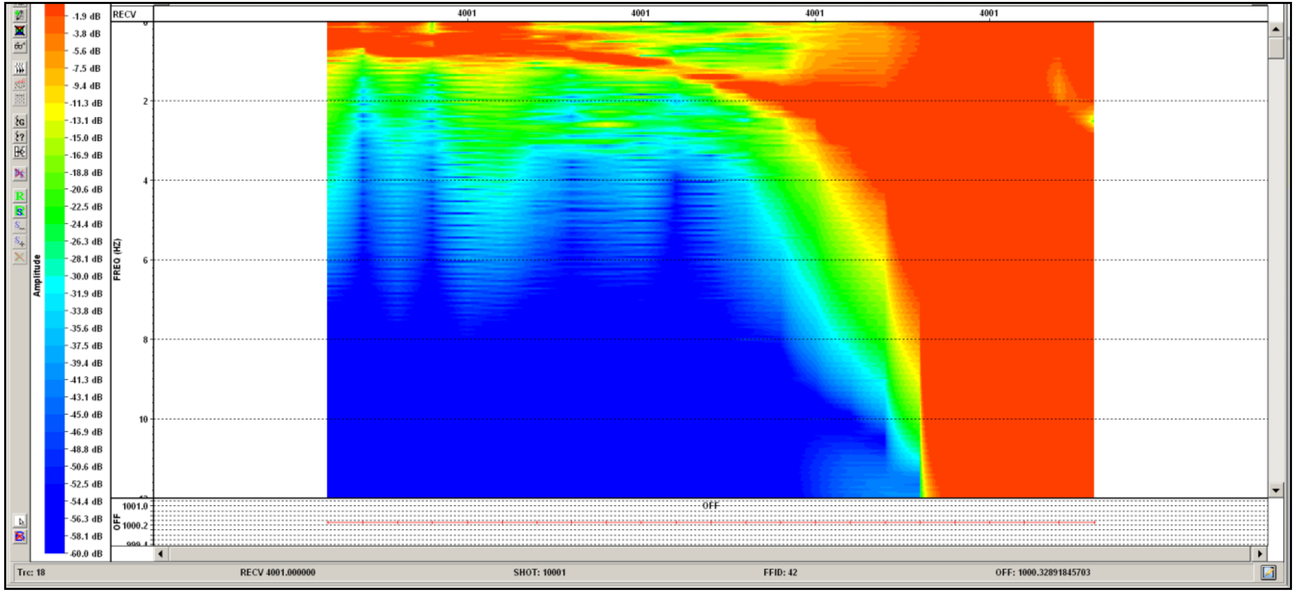
Monochromatic Sweeps-10Hz Analog Sensor (accel.)

Sweep .5Hz → **10Hz**

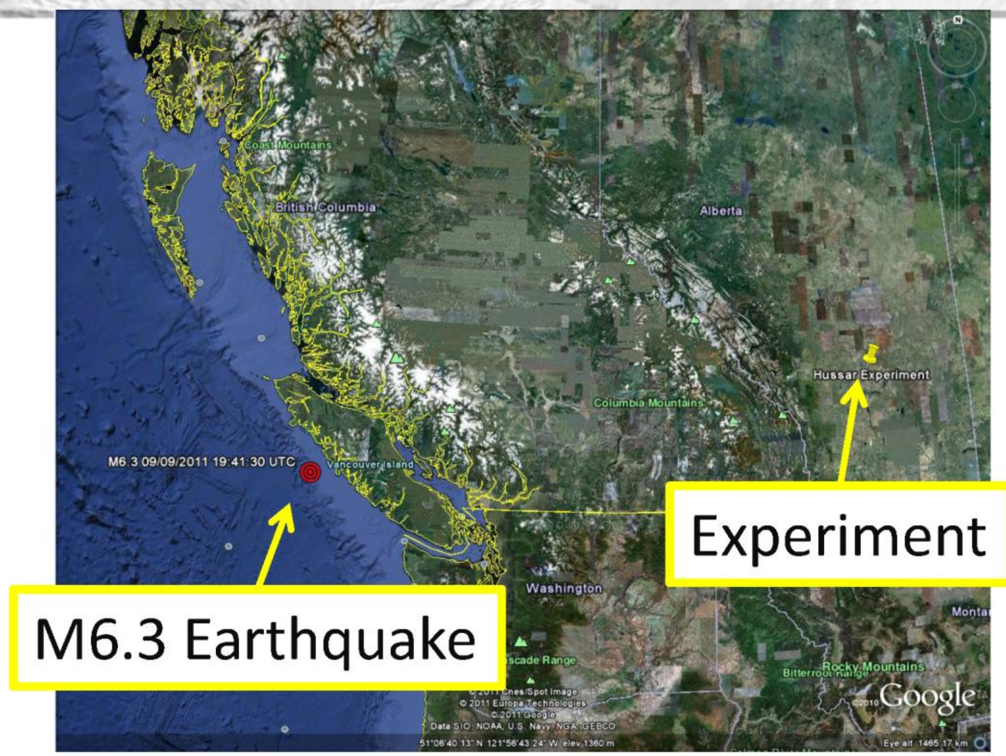


Monochromatic Sweeps- Lennartz

Sweep .5Hz → **10Hz**

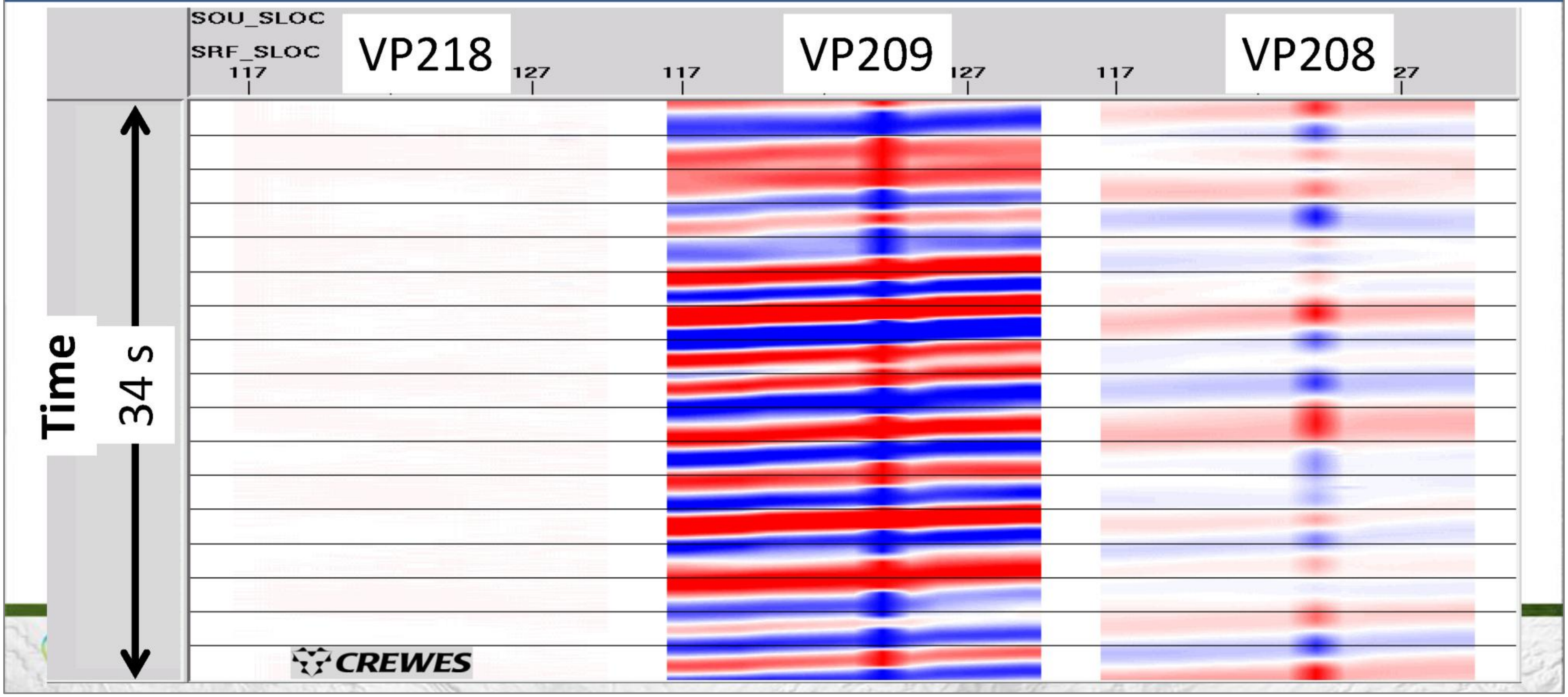


Earthquake epicenter 1050 km from experiment



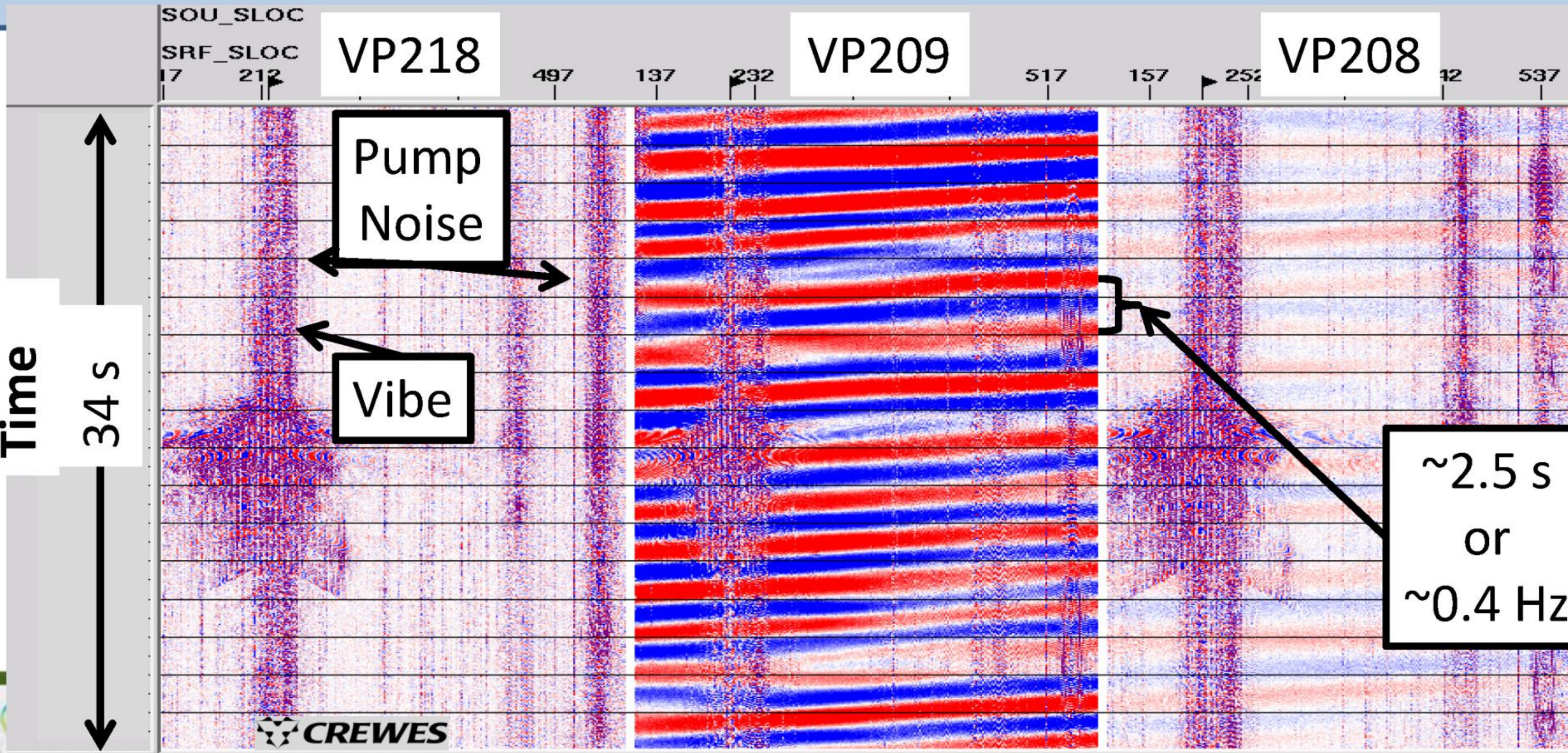
Presenter's notes: Earthquake (red bulls-eye) and Hussar low-frequency experiment (yellow push-pin) locations. © 2011 Cnes/Spot Image and © 2011 Europa Technologies and © 2011 Google, Data SIO, NOAA, U.S. Navy, NGA, GEBCO (Google Earth, 2011 and Natural Resources Canada, 2011).

Seismometer, V component



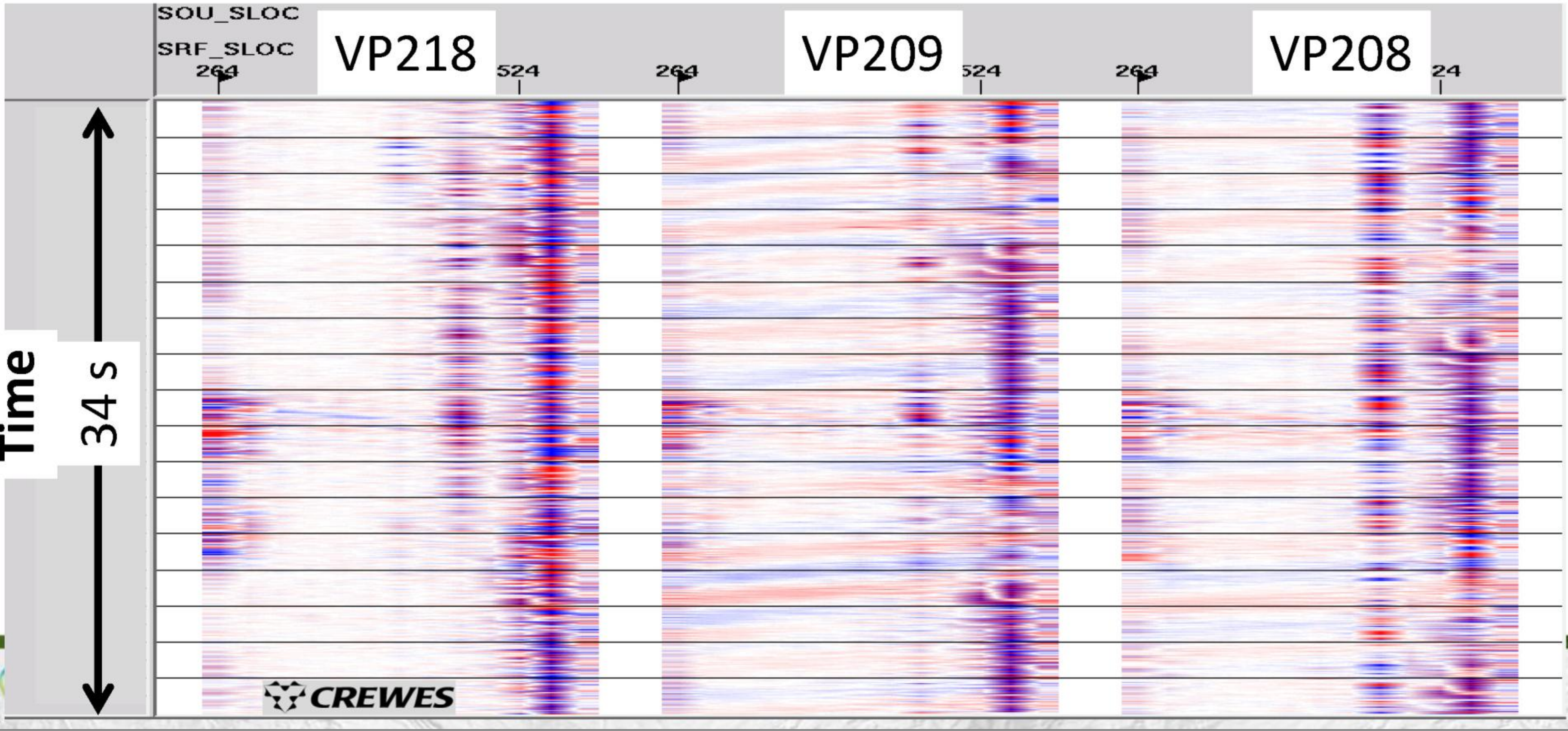
Presenter’s notes: Uncorrelated data from the vertical component of seismometers for VPs 218, 209, and 208. Trace length is 34 seconds. ProMAX trace display scaling: entire screen with gain set to one. Trace fold is one.

Digital, V component



Presenter's notes: Uncorrelated data from the vertical component of VectorSeis accelerometers for VPs 218, 209, and 208. Trace length is 34 seconds. ProMAX trace display scaling: entire screen with gain set to fifteen. Vertical fold is two.

10 Hz 3C geophones, V component



Presenter's notes: Vertical component of uncorrelated data from 10 Hz 3-C geophones at thirteen seismometer stations for VPs 218, 209, and 208. Trace length is 34 seconds. ProMAX trace display scaling: entire screen with gain set to one. Vertical fold is one.

Acknowledgements

- Petroleum Development of Oman (PDO)
- Shell
- University of Calgary
- AAPG / SEG