Seismic Acquisition Optimization for Exploration in Thrust Belts and Foreland Basins*

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Abstract

Nodal systems technology introduced a very important uplift in operational efficiency in seismic acquisition. The primary goal of the survey design was to optimize geometries to take advantage of the operational efficiency from the nodal systems. We present examples of optimized nodal acquisition from Peru and Bolivia. A further step in this evolution is the development of the compressive technology integrated supported by nodal systems. This more cost-efficient 3D seismic acquisition allows us to improve the signal/noise and image quality by the integration of non-uniform optimal sampling acquisition and its reconstruction by compressive sensing techniques. This process requires the use of reconstruction techniques combined with forward modeling to ensure proper wavefield sampling to keep the integrity of seismic recovery from a sparser subset. Therefore, a new survey design workflow is required to support feasible non-uniform geometries for effective noise removal and enhanced pre-stack migration imaging. The application of this new methodology will need to challenge the irregularities from complex surface conditions existing in the Andean basins for the non-uniform optimal sampling acquisition to support data reconstruction.

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Seismic Acquisition Optimization for Exploration in Thrust Belts and Foreland Basins

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REPSOL Exploration Americas

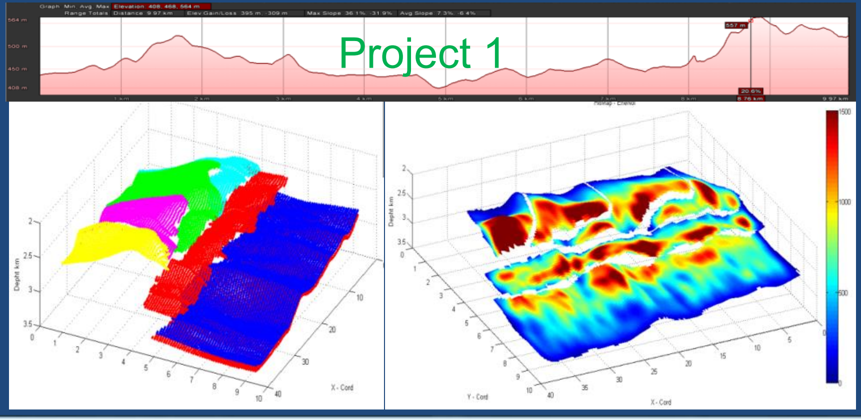
REPSOL

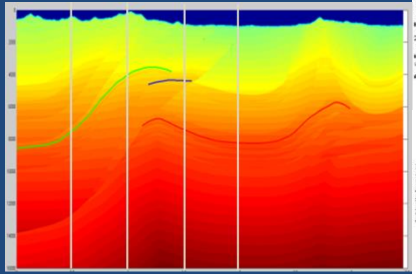
Outline

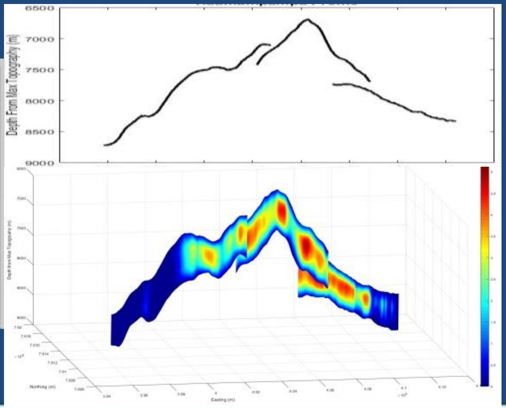
1. Challenges: The Andean Thrust Belts Characteristics
2. Coherent Noise Sampling Requirements
3. Geological Sampling Requirements
4. Imaging/Model Building
5. Other Considerations
6. Survey Design Solutions
7. How CS can help? / Conclusions

The Andean Thrust Belts Characteristics

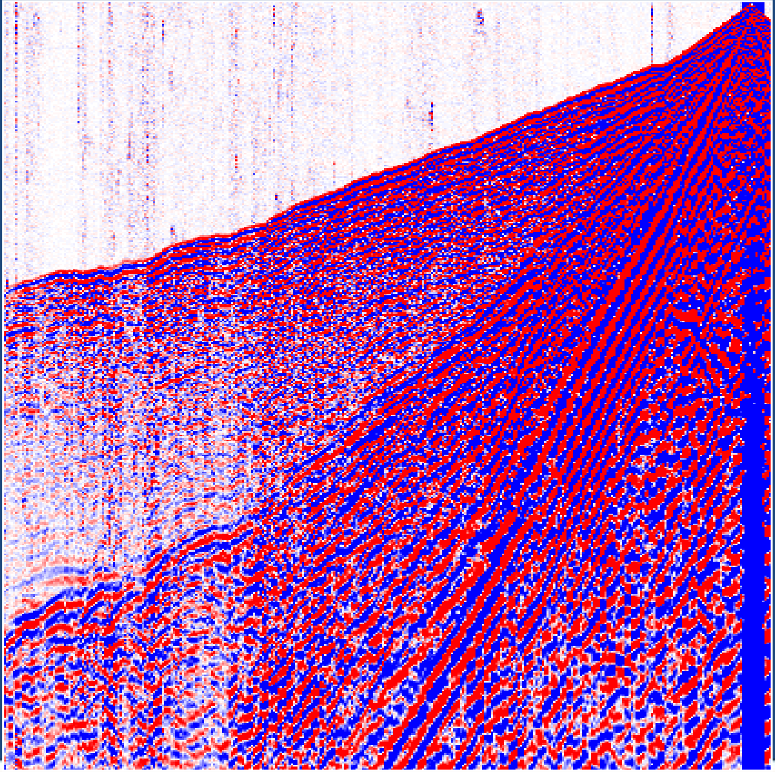
- Very rough topography
- Complex near surface and subsurface.
- Irregular surface /near surface scattering of seismic signal & noise
- Intricate Tectonics
- High velocity variations
- Deep targets
- Environmental Concerns







Noise: need for Adequate Sampling of the Seismic Wavefield

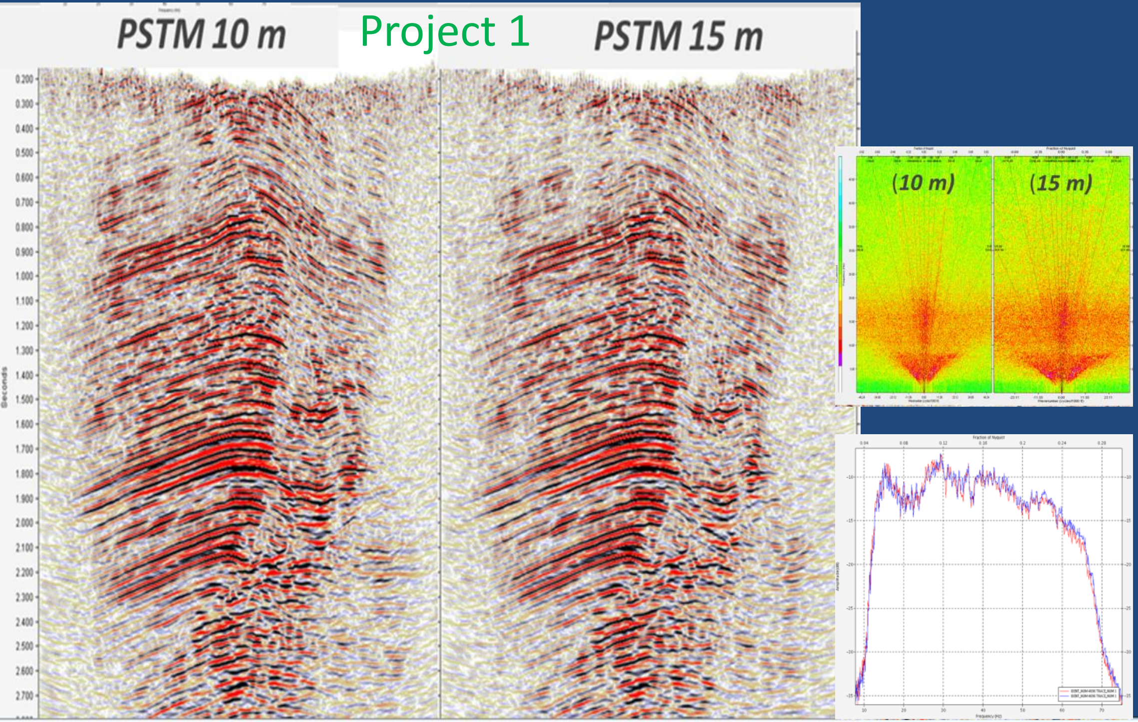


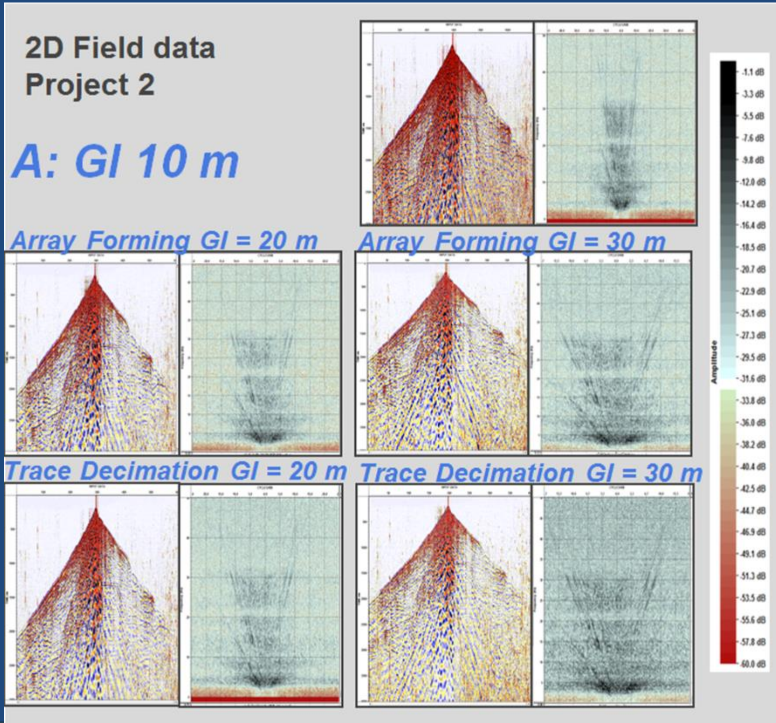
GR Vel (m/s)	GR Comp Freq (hz)	GR Wavelength (m)	Min Required Sampling (m)
450	10	45	22
650	10	65	32
1250	10	125	62
450	15	30	15
650	15	43	21
1250	15	83	41
450	20	22	11
650	20	32	16
1250	20	62	31

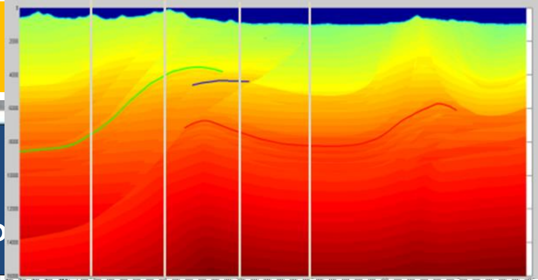
Minimum Required

10 to 20 meter sampling (Group Interval) for *well behaved* Rayleigh waves

Noise: 2D Tests for Parameter Confirmation

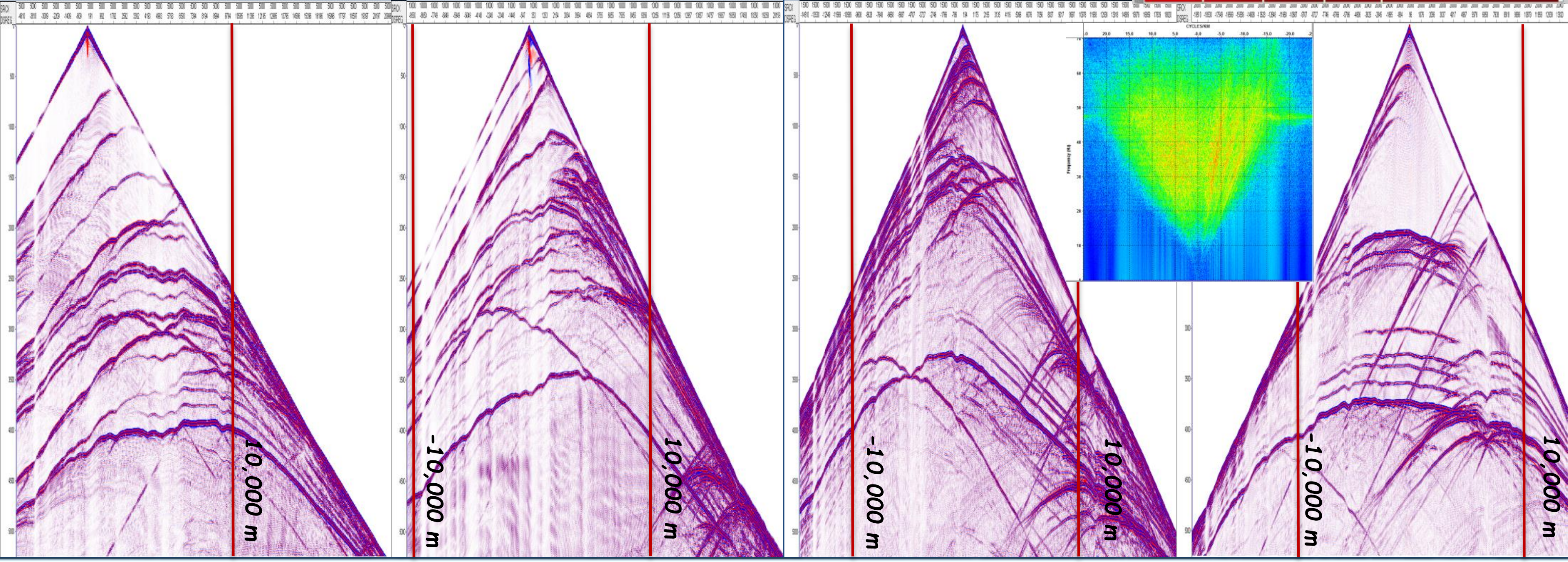


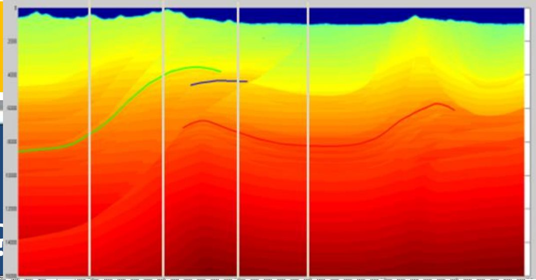




Synthetic records ACFEFM: GI 20 m

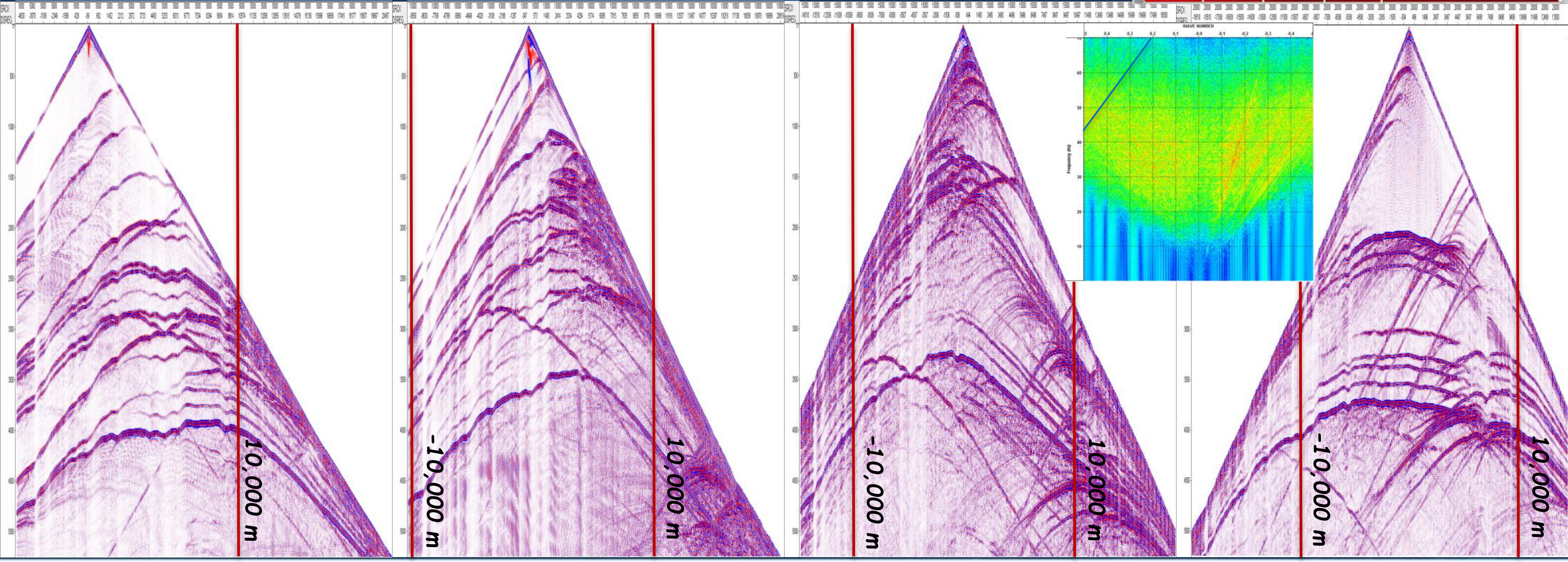
COMPLEX GEOLOGY: can the geology be interpolated – reconstructed?



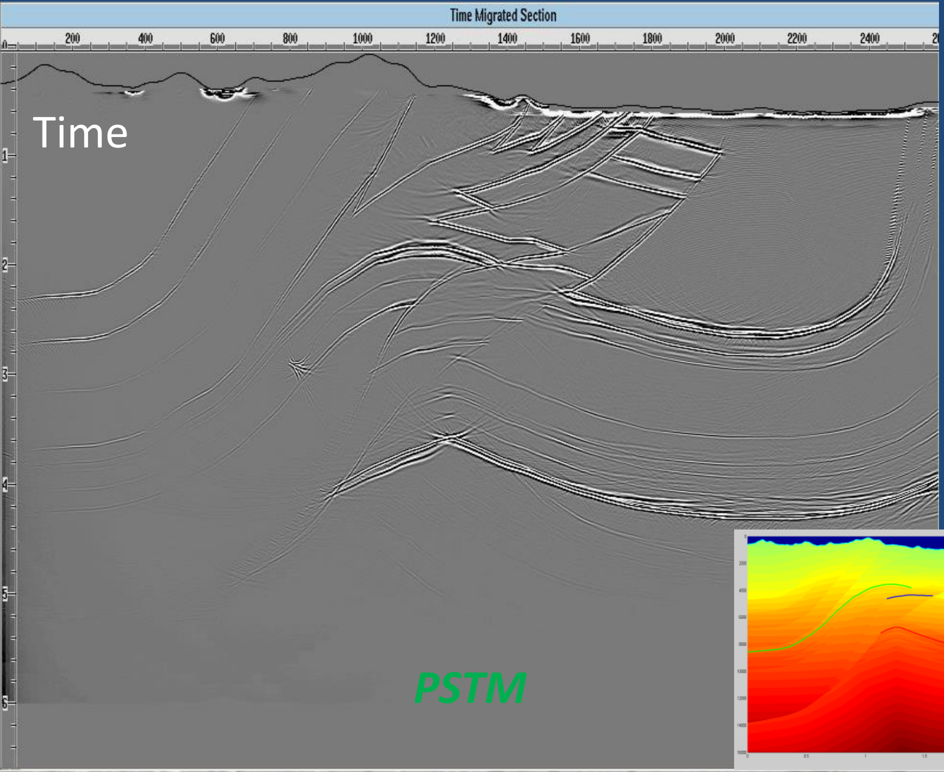


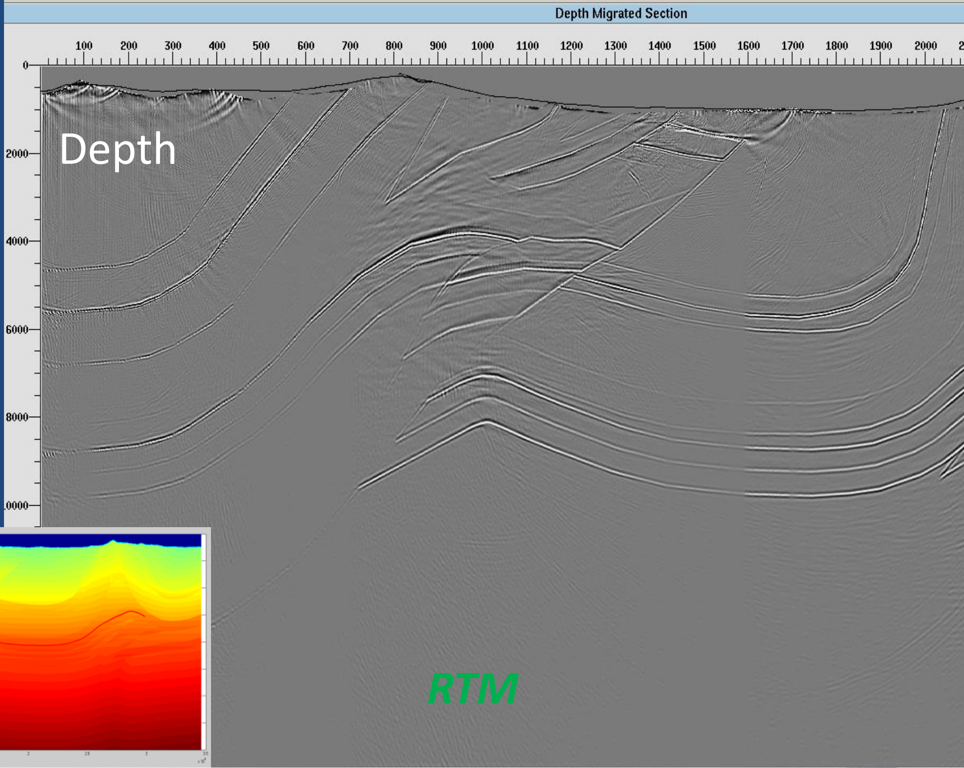
Decimated Synthetic records ACFEFM:GI 40 m

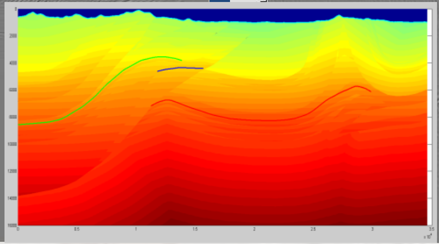
COMPLEX GEOLOGY: Can the geology be interpolated – reconstructed?



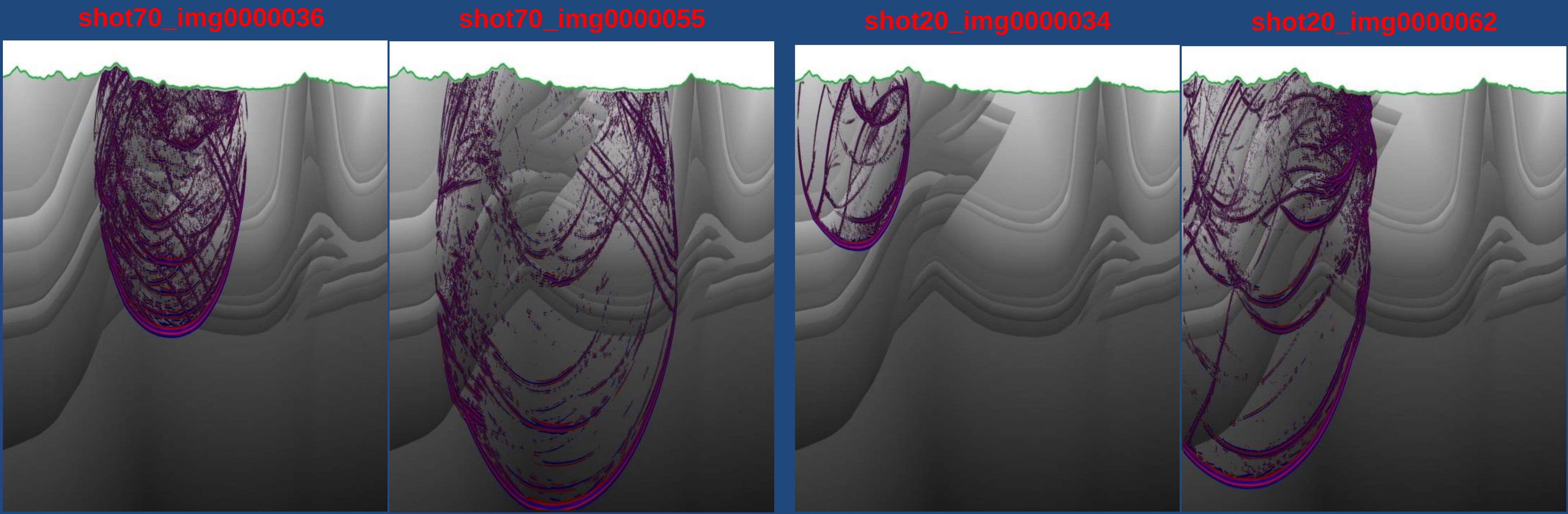
Resulting Images from ACFEFM





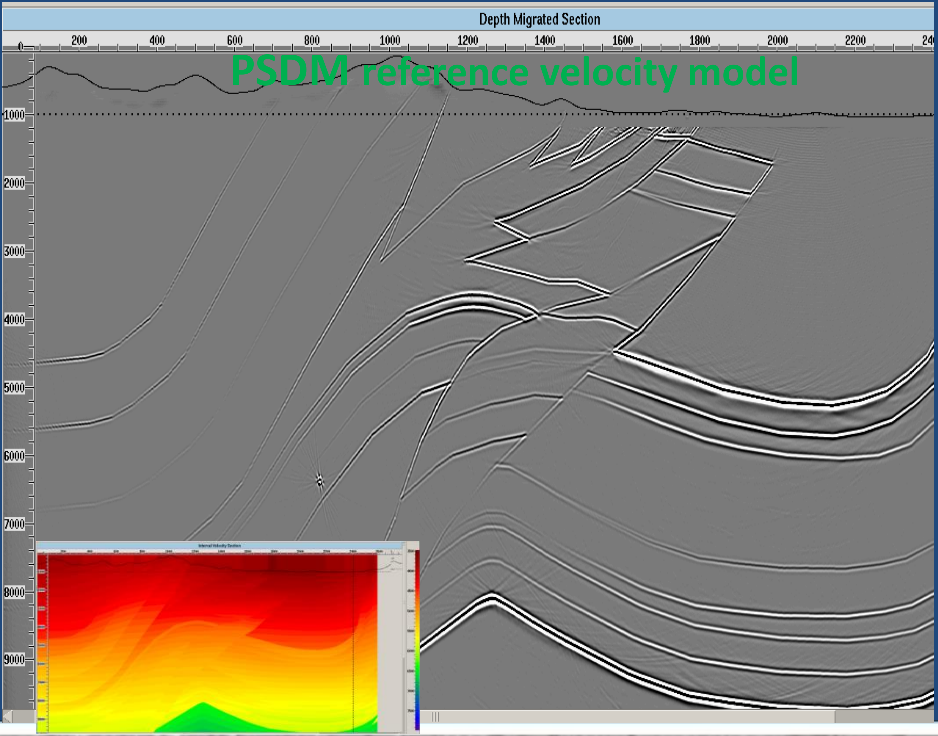


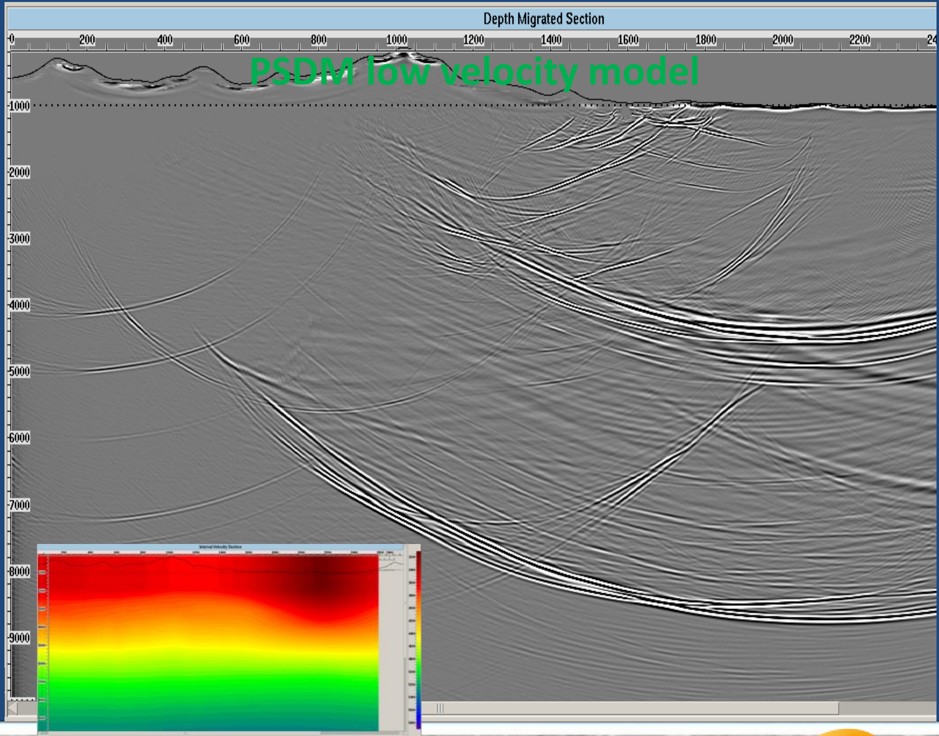
Seismic Wavefield Snapshots



These snapshoots illustrate wavefront propagation indicating accomplished illumination.

Need for data to support model building





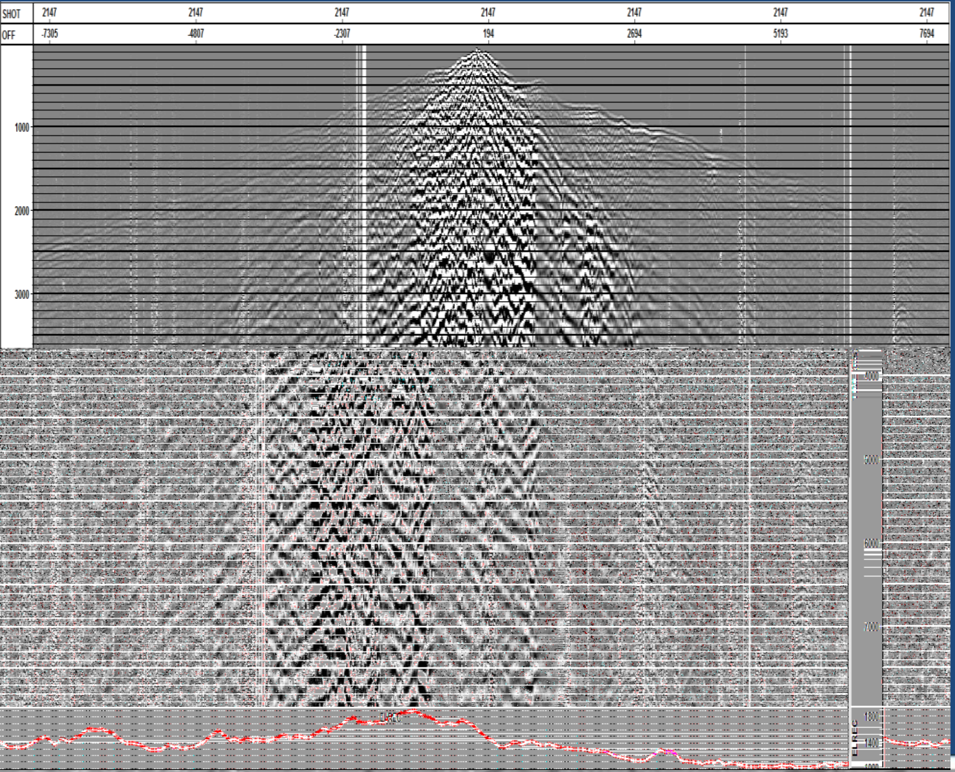
Other Considerations

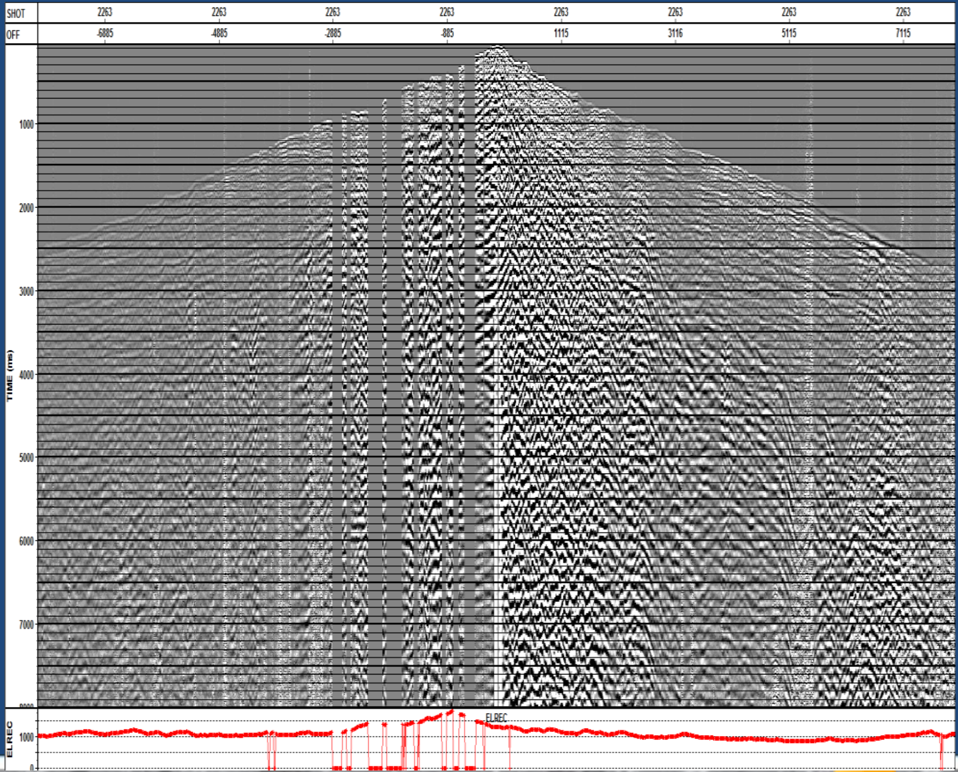
Conventional 2D Acquisition Parameters	
Recording method	Split Spread/ Symmetric, Roll On–Roll Off
Record length	12 Seconds
Number of lines	12
Shotpoint Interval	20 meters
Sources (# SPs) per Km	50
Charge parameters	holes 18 meters, carga 15 kg
Explosive source	Pentolita
Receiver Interval	10 meters
Receivers per Km	100
Array of geophones	6 x station
Number active channels per record	2000
Cell size (bin)	5 m
Maximum offset	10000 meters
Nominal Coverage (Fold)	400

NODAL 2D Acquisition Parameters	
Recording method	Fix spread/nodes
Record length	12 Seconds
Number of lines	12
Shotpoint Interval	25 meters
Sources (# SPs) per Km	40
Charge parameters	holes 15 meters, carga 15 kg
Explosive source	Pentolita
Receiver Interval	12.5 meters
Receivers per Km	80
Array of geophones	1x station
Number active channels per record	1400
Cell size (bin)	6.25 m
Maximum offset	8000 meters
Nominal Coverage (Fold)	350

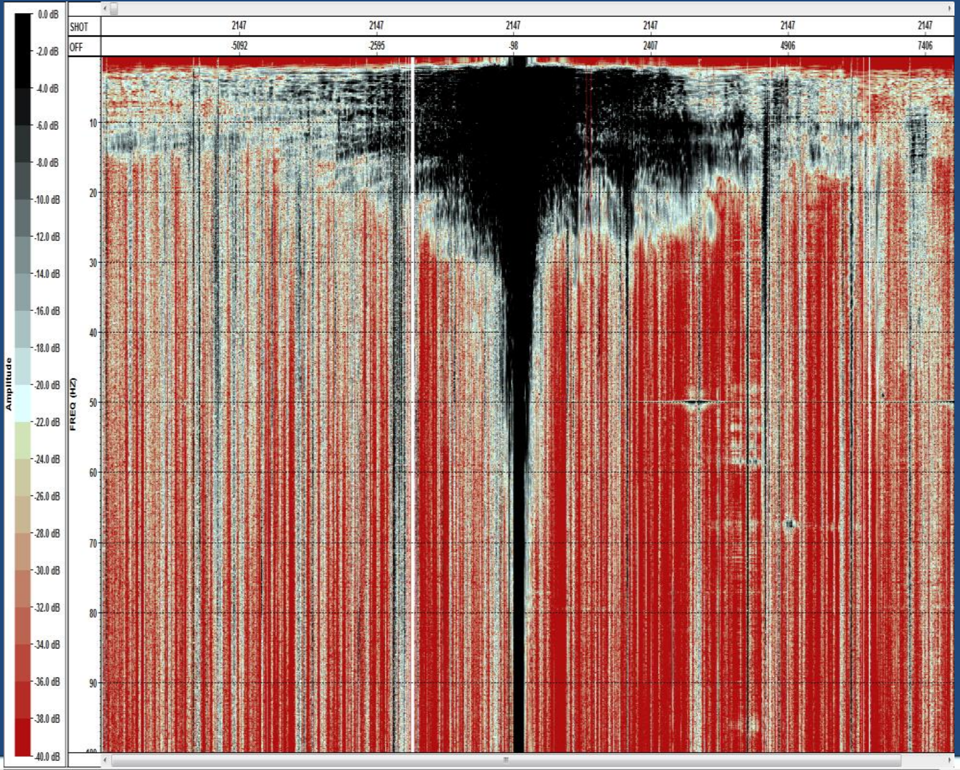
REPSOL

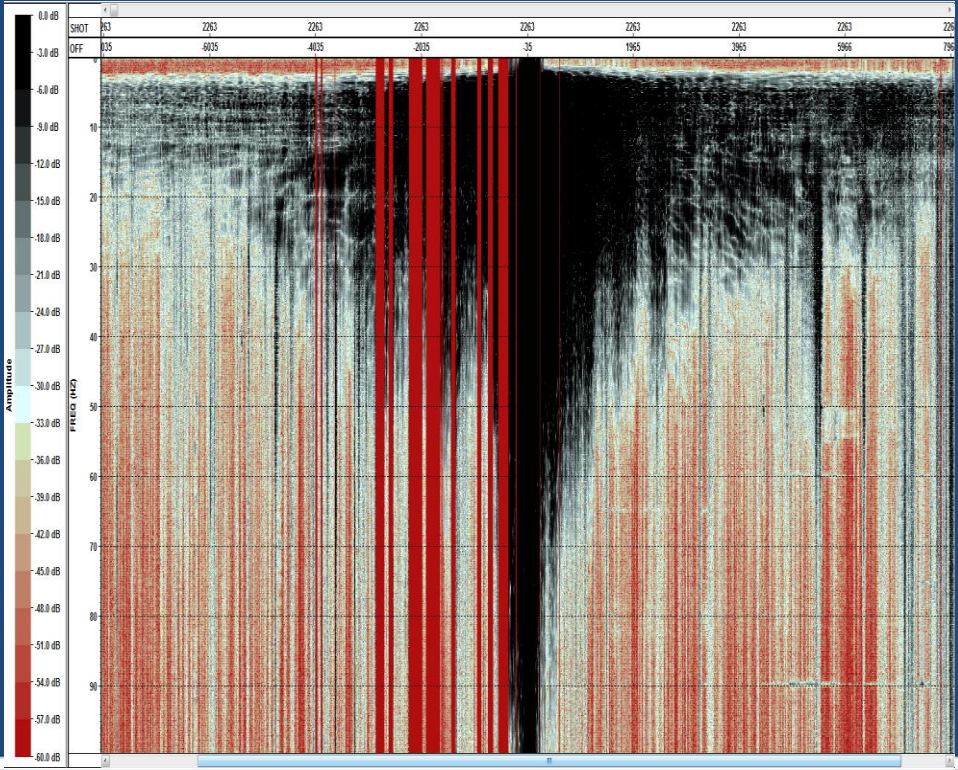
Nodal 2D vs. Legacy Conventional 2D





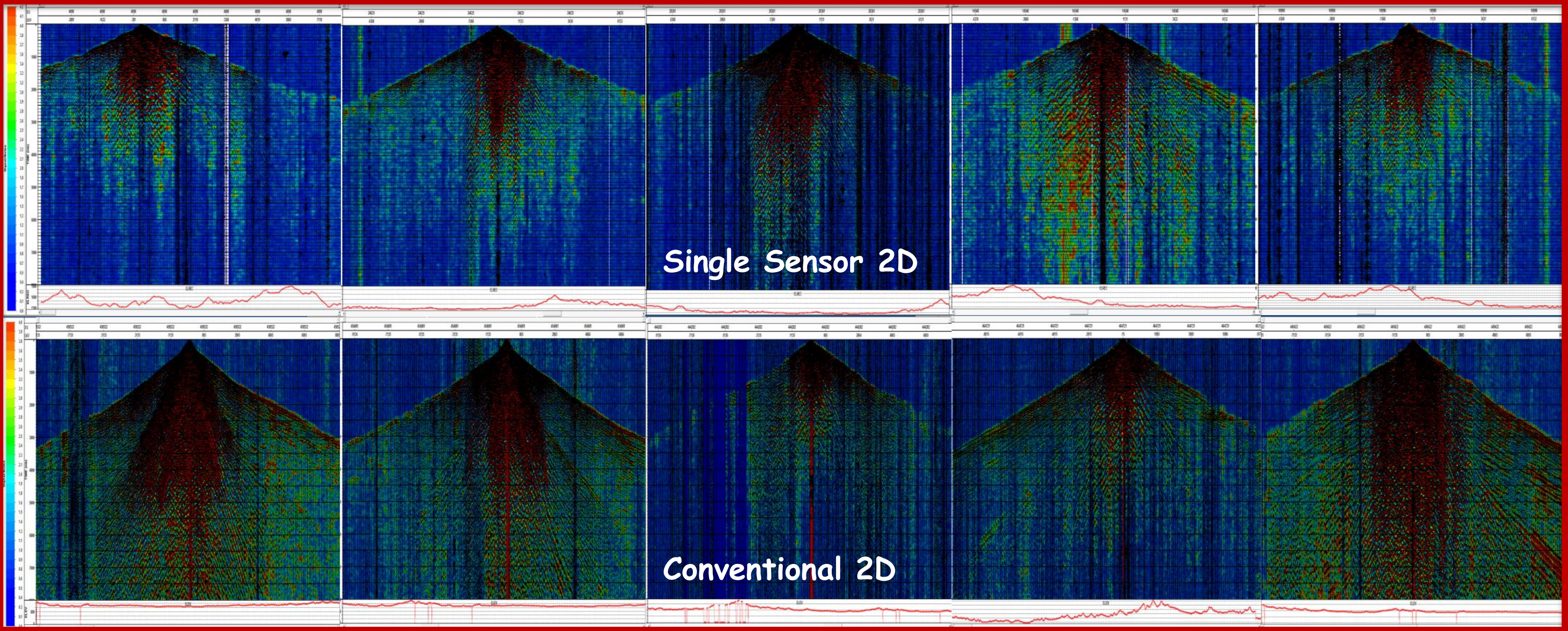
Nodal 2D vs. Legacy Conventional 2D





REPSOL

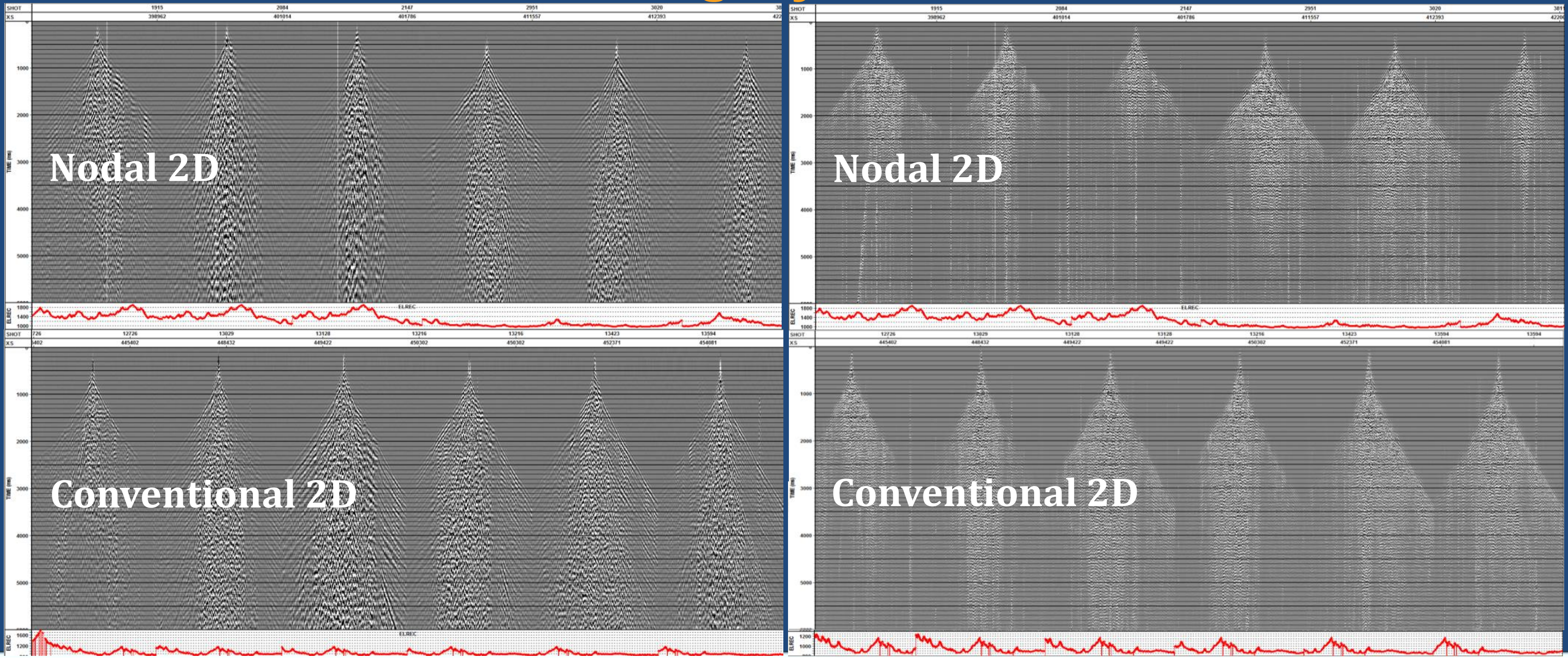
Nodal 2D vs. Legacy Conventional 2D



Nodal 2D vs. Legacy Conventional 2D

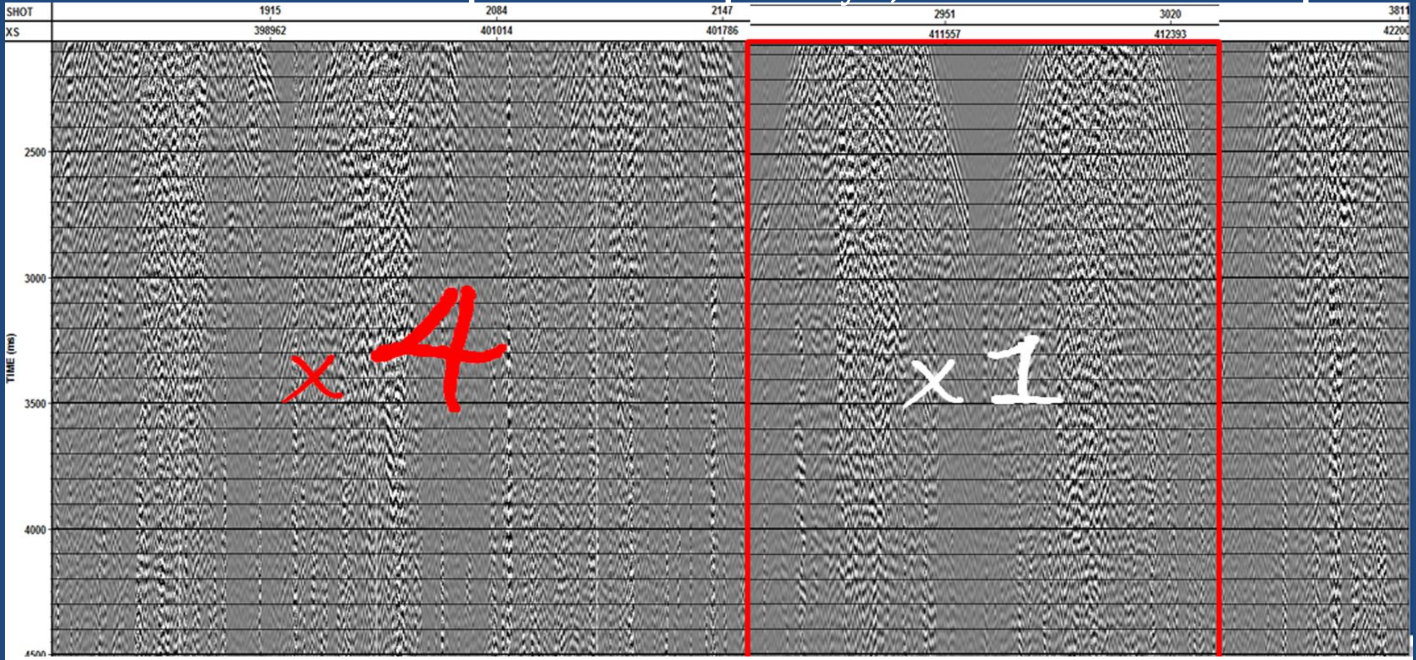
< 8 Hz

> 16 Hz, *Amplitude* x 2



Nodal 2D 16-30 Hz x 4 Conventional x1

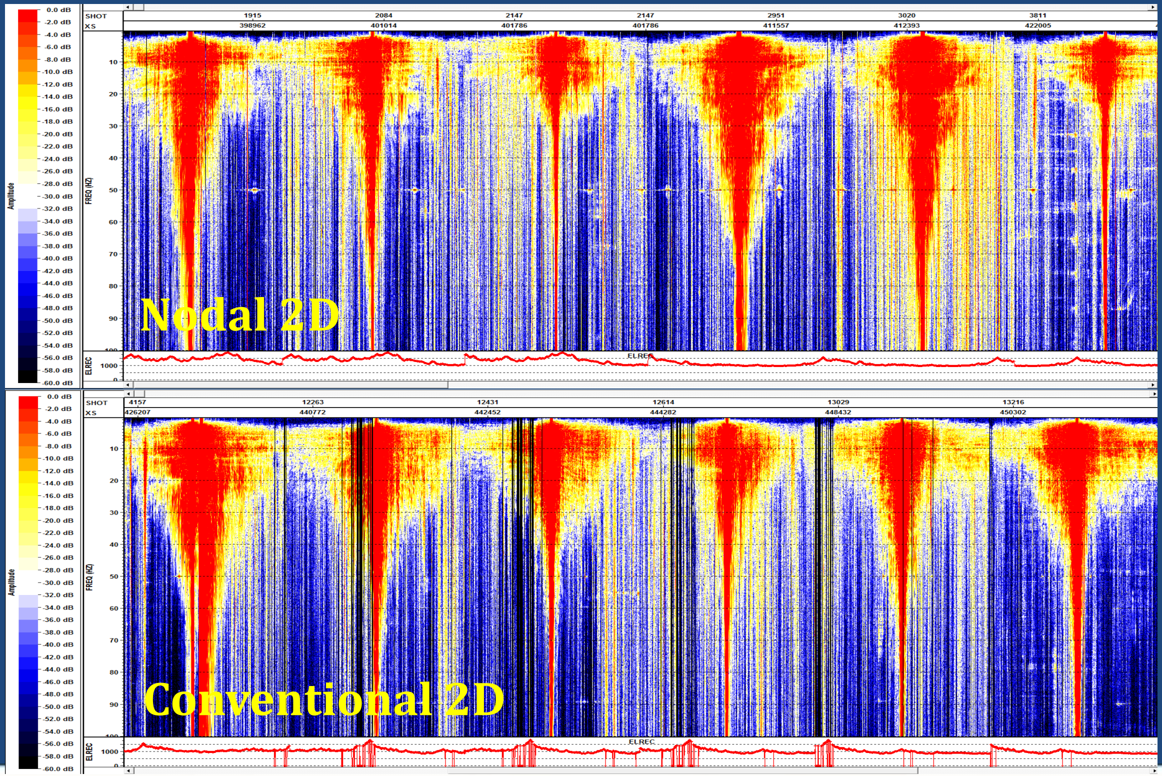
The records inside the red square are multiplied by 1, all the others are multiplied by 4.



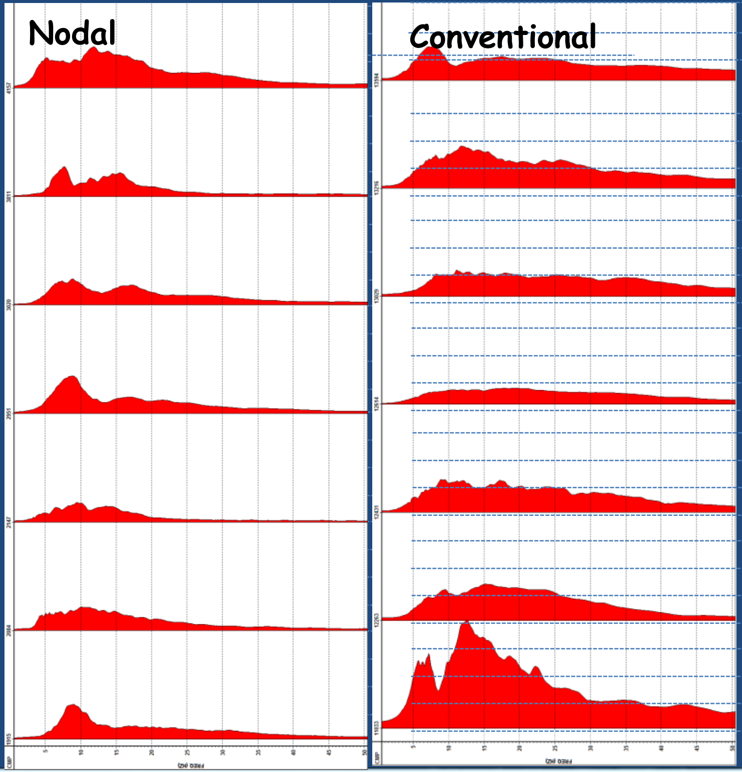
Nodal 2D 16-30 Hz x 4 Conventional 16-30 Hz x1

Nodal 2D vs. Legacy Conventional 2D

FX analysis

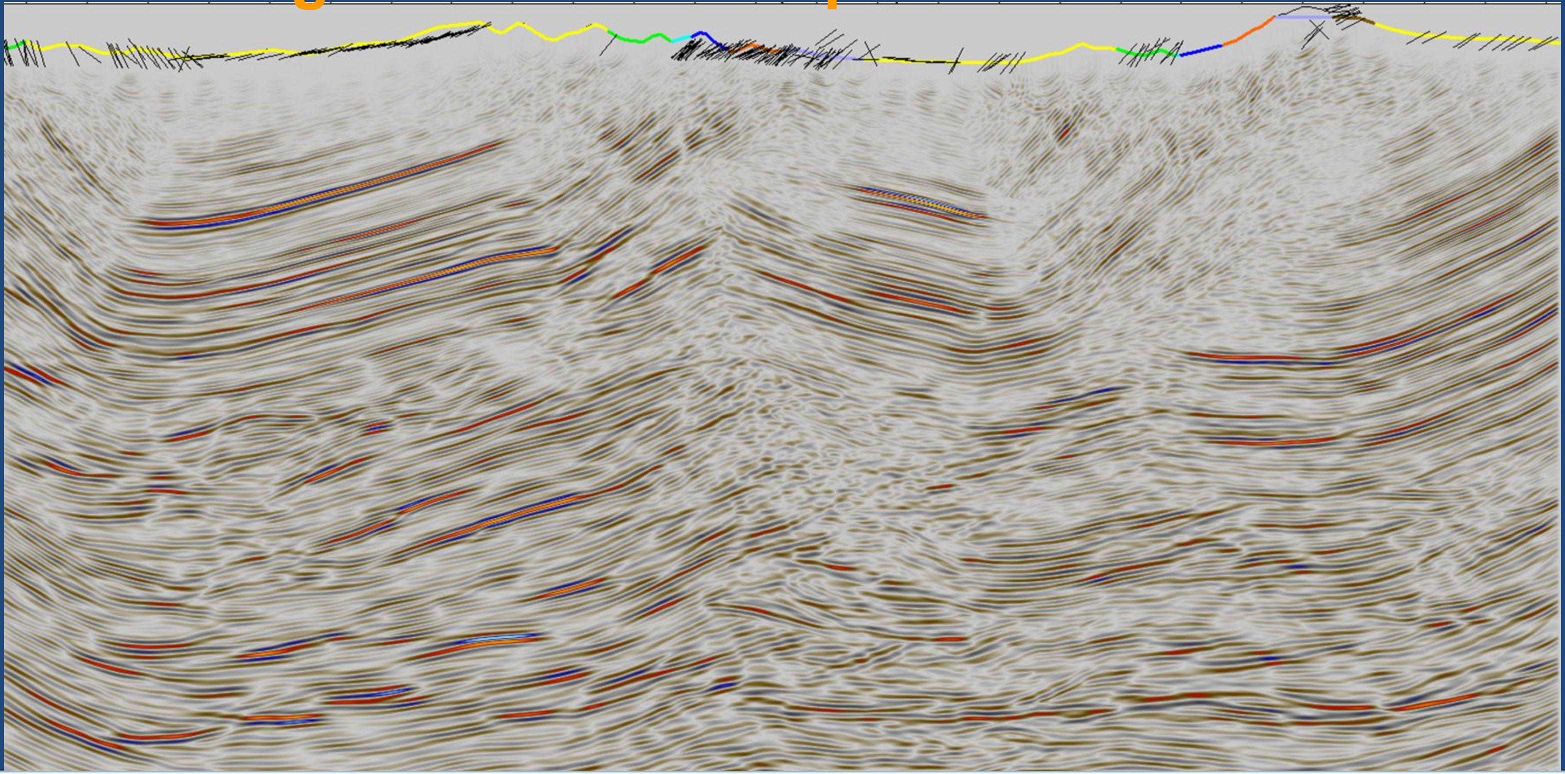


Amplitude Spectra



REPSOL

RTM image from nodal acquisition



* Courtesy of REPSOL DP

REPSOL

- The results show the impact of topography and source paramaters in record amplitudes and frequency bandwith. These differences make it difficult to make a comparison between six geophone arrays and some single sensors.

- The response of typical single sensors is about 2-3 dB lower than the response of 6 conventional elements in series. However, the sampling requirements for coherent noise need a higher sampling for single sensors. This higher sampling will not only compensate the potential differences in signal but also provide a data processing solution for coherent noise attenuation of noise modes with short wavelengths.

- Coupling of the geophones to the hard surfaces represents a problem for the amplitude stability of adjacent traces, which is very important to support noise attenuation.

Present Survey Design Solutions

Our best legacy

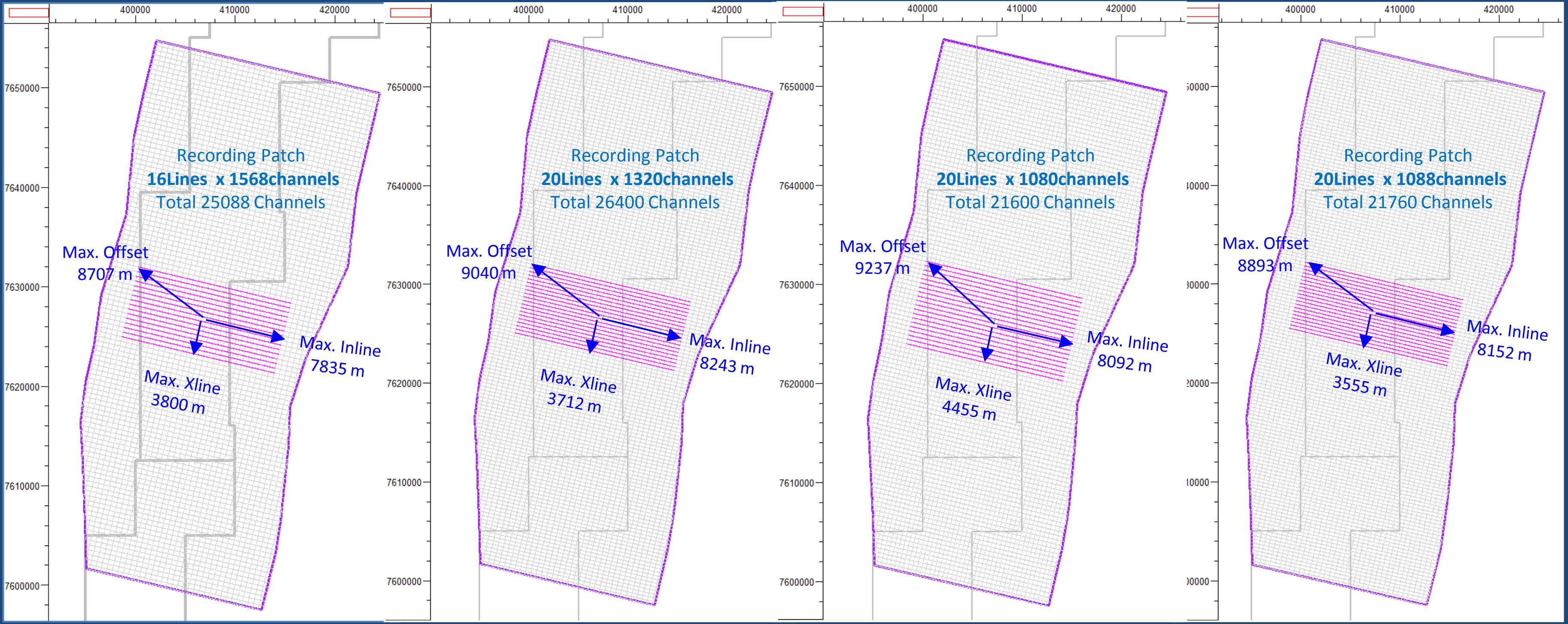
Legacy 849 m

Legacy 5962 m

Max. legacy 373000

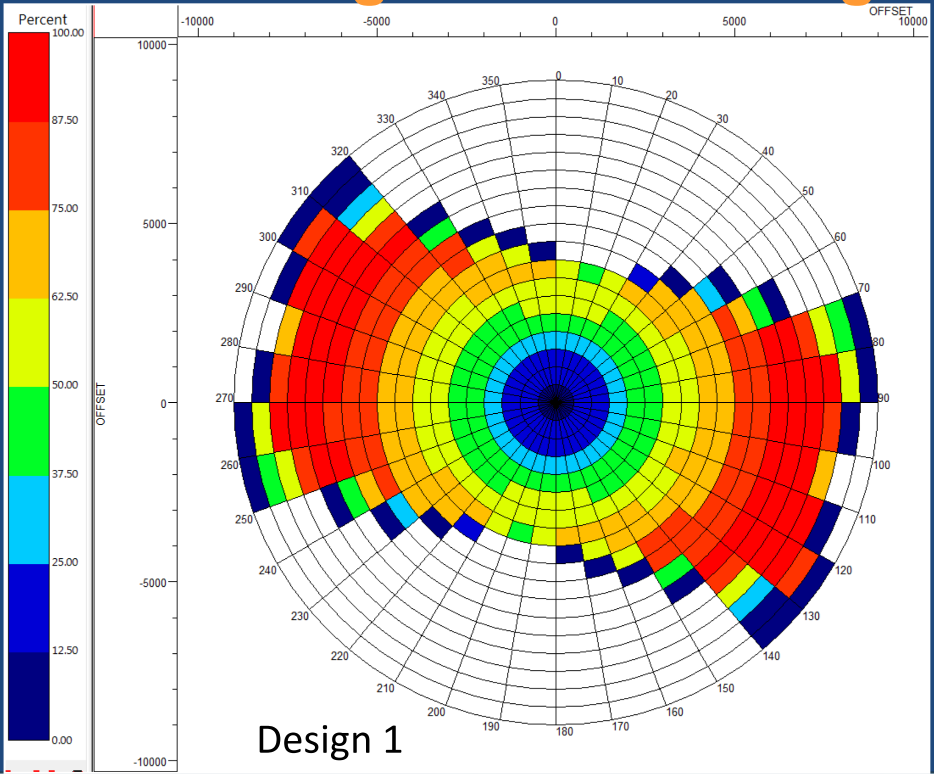
	D1 480x560	D3 375x550	D5 450x450	D6 360x510
Receiver lines per swath	16	20	20	20
Live channels per receiver line	1568	1320	1080	1088
Total channels per patch	25088	26400	21600	21760
Receiver Line Interval	480	375	450	360
Receivers Interval	10	12.5	15	15
In-Line Fold	14.0	15.0	18.0	16.0
Source points per salvo	6.0	5.0	5.0	4.0
Source point Interval	80	75	90	90
Source Line Interval	560	550	450	510
X-Line Fold	8.0	10.0	10.0	10.0
Binsize (In-Line) natural	5	6.25	7.5	7.5
Binsize (X-Line) natural	40	37.5	45	45
Full Fold natural bin	112.0	150.0	180.0	160.0
Inline to Crossline Ratio	0.49	0.45	0.55	0.44
Maximum minimum offset	738	666	636	624
Maximum offset (In-Line).	7835	8243	8092	8152
Maximum offset (X-Line).	3800	3712.5	4455	3555
Maximum Offset.	8707	9040	9237	8893
Source points / Km^2	22	24	25	22
Receiver points / Km^2	208	213	148	185
Densidad de Trazas / km^2	560,000	640,000	533,333	474,074
Channels Required for Operation	42,228	41,290	34,408	34,408

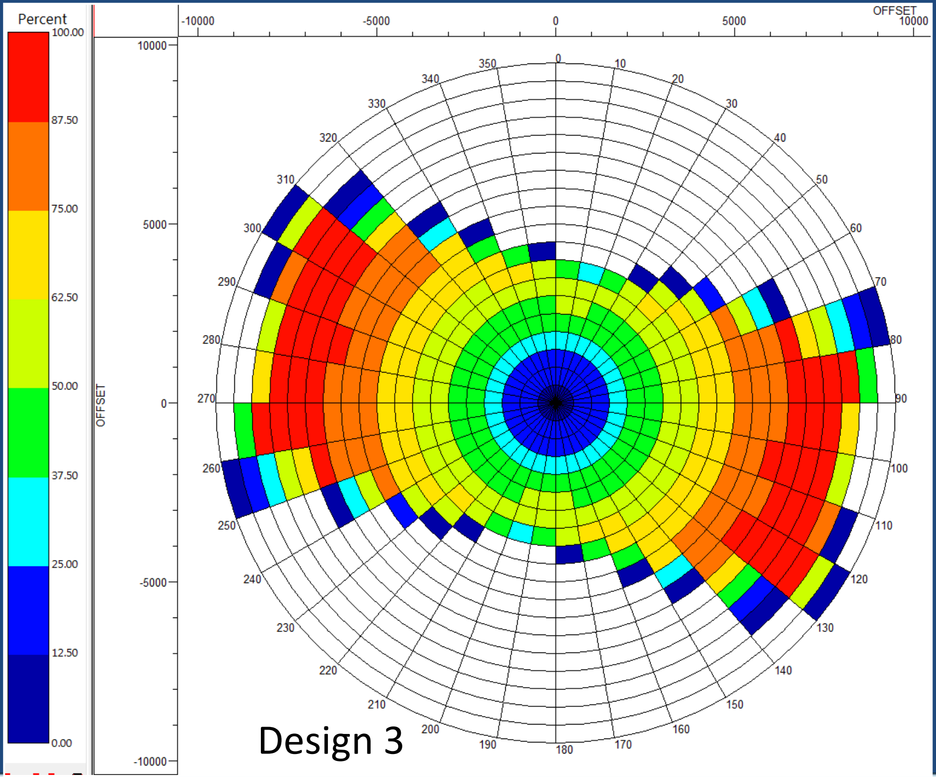
3D Designs & Recording Patch



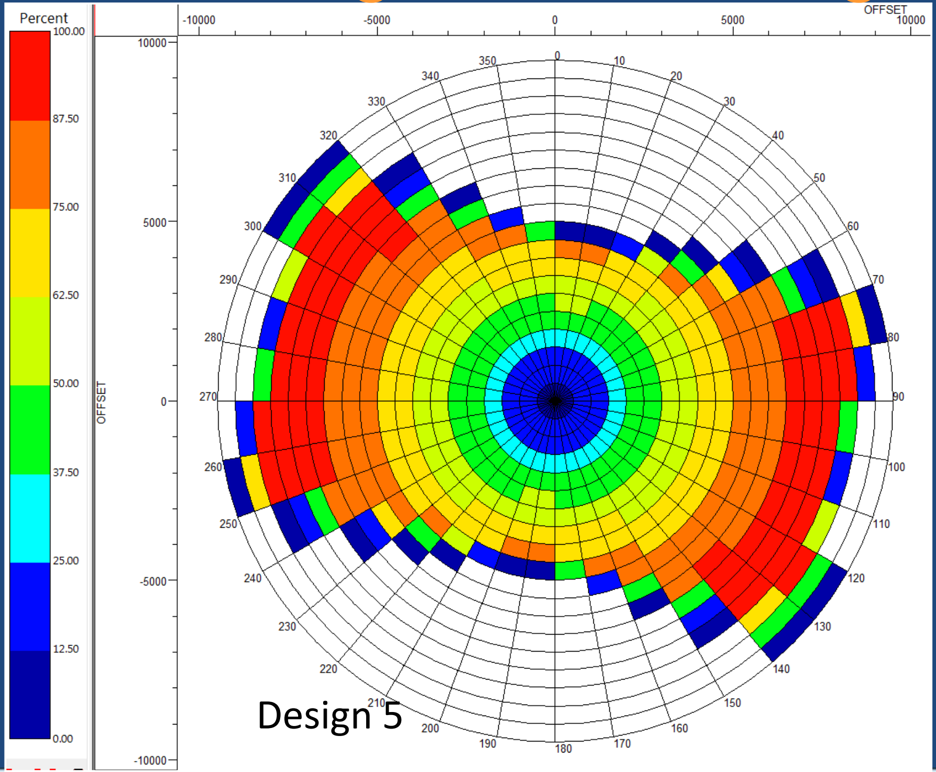
Design 1 | Design 3 | Design 5 | Design 6

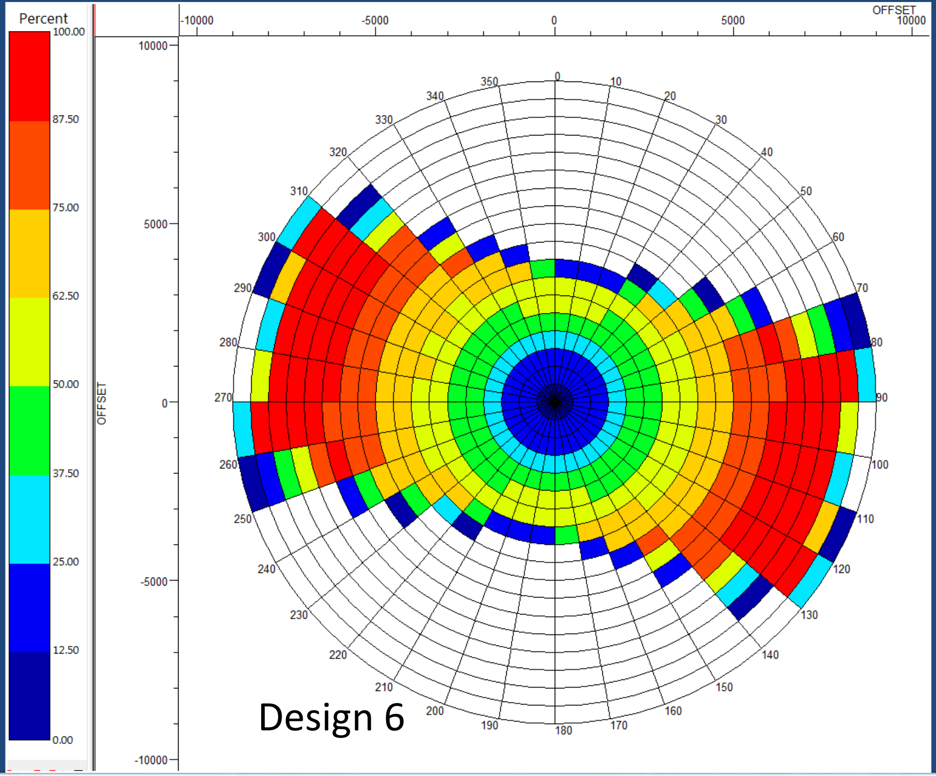
3D Designs & Rose Diagrams





3D Designs & Rose Diagrams





Survey Design Solutions: Compressive Sensing (CS)

Wikipedia: Compressed sensing is a signal processing technique for efficiently acquiring and reconstructing a signal, by finding solutions to underdetermined linear systems. This is based on the principle that, through optimization, the sparsity of a signal can be exploited to recover it from far fewer samples than required by the Shannon-Nyquist sampling theorem.

CS has many applicactions in communications, space based imaging, medical imaging, …, and recently seismic acquisition (Herrmann, et al, 2007-2012, Jiang, et al, 2017 SEG, etc.)

Premises:

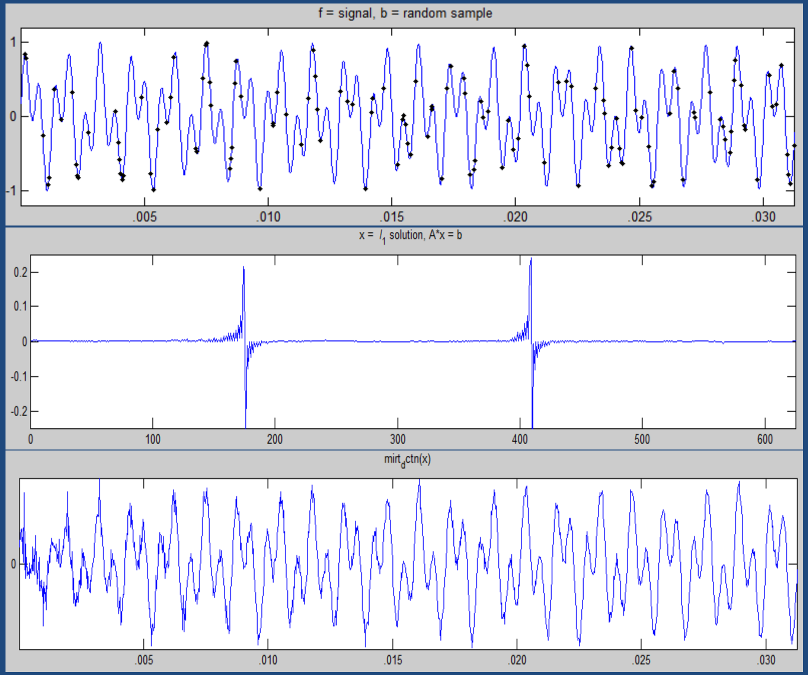
- Sparseness property of signal in some domain
- Incoherence isometric property sufficient for sparse signals.

Optimization of SLI, RLI, SPI & RPI with/without obstacles

Recoverable under-sampling

- Lower cost for CS-Acquisition
- Higher quality for CS-Processing

$f(t)=\sin(1394\pi t)+\sin(3266\pi t)$ *"A key touch-tone phone"*



Cleve's Corner, MathWorks, "Magic" Reconstruction: Compressed Sensing.

Conventional vs CS Option 1 *(Operational Parameters)*

Conventional

CS1 operational effort executed in the field

REPSOL / Survey : Boyuy 3D	D3 375x550	D3
Receiver lines per swath	20	28
Live channels per receiver line	1320	660
Total channels per patch	26400	18480
Receiver Line Interval	375	375
Receivers Interval	12.5	25
Source point Interval	75	75
Source Line Interval	550	550
Binsize (In-Line) natural	6.25	12.5
Binsize (X-Line) natural	37.5	37.5
Full Fold natural bin	150.0	210.0
Inline to Crossline Ratio	0.45	0.63
Maximum minimum offset	667	667
Maximum offset (In-Line).	8243	8237
Maximum offset (X-Line).	3712.5	5212.5
Maximum Offset.	9040	9747
Source points / Km^2	24	24
Receiver points / Km^2	213	107
Trace Density / km^2	640,000	448,000
Channels Required for Operation	41,290	28,152

Acquisition is performed with irregular Source and Receiver locations

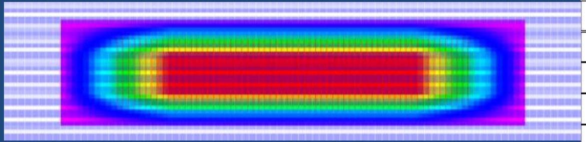
Conventional vs CS Option 1 *(w/ reconstruction)*

	Reference Design (slide 25)	CS1 effort executed in the field	CS Option1 after CS reconstruction
REPSOL / Survey : Boyuy 3D	**D3 375x550**	**D3**	**D3**
Receiver lines per swath	**20**	**28**	**28**
Live channels per receiver line	**1320**	**660**	**1320**
Total channels per patch	26400	18480	36960
Receiver Line Interval	375	375	375
Receivers Interval	12.5	25	12.5
Source point Interval	75	75	37.5
Source Line Interval	550	550	550
Binsize (In-Line) natural	6.25	12.5	6.25
Binsize (X-Line) natural	37.5	37.5	18.75
Full Fold natural bin	150.0	210.0	210.0
Inline to Crossline Ratio	0.45	0.63	0.63
Maximum minimum offset	667	667	667
Maximum offset (In-Line).	8243	8237	8243
Maximum offset (X-Line).	3712.5	5212.5	5231.25
Maximum Offset.	9040	9747	9762
Source points / Km^2	24	24	48
Receiver points / Km^2	213	107	213
Trace Density / km^2	640,000	448,000	1,792,000
Channels Required for Operation	**41,290**	**28,152**	56,304

REPSOL

SWATH CS Option2 – Operational Parameters

Application and effects of swath 3D technique in marine carbonates in western Sichuan Basin, W. Xiaoyang et al 2017



	Swath 3D survey in 2016	Conventional 3D survey in 2015
Geometry type	Orthogonal	Orthogonal
Geometry mode	24L48S560R	22L8S440R
Receiver channels	13440	9680
Fold	20×12	11×11
Inline bin size (m)	12.5	12.5×25
Group interval (m)	12.5	25
Receiver line spacing (m)	100	400
Source spacing (m)	25	50
Source line spacing (m)	350	500
Max cross-line offset (m)	1737.5	4375
Max offset (m)	7200.3	7018.07
Aspect ratio	0.25	0.8
Trace density (Trace/km^2)	1536000	387200

CS2 operational effort executed in the field

	D6
Receiver lines per swath	**32**
Live channels per receiver line	**544**
Total channels per patch	17408
Receiver Line Interval	180
Receivers Interval	30
Source point Interval	90
Source Line Interval	510
Binsize (In-Line) natural	15
Binsize (X-Line) natural	45
Full Fold natural bin	256.0
Inline to Crossline Ratio	0.35
Maximum minimum offset	541
Maximum offset (In-Line).	8145
Maximum offset (X-Line).	2835
Maximum Offset.	8624
Source points / Km^2	22
Receiver points / Km^2	185
Densidad de Trazas / km^2	379,259
Channels Required for Operation	26,588

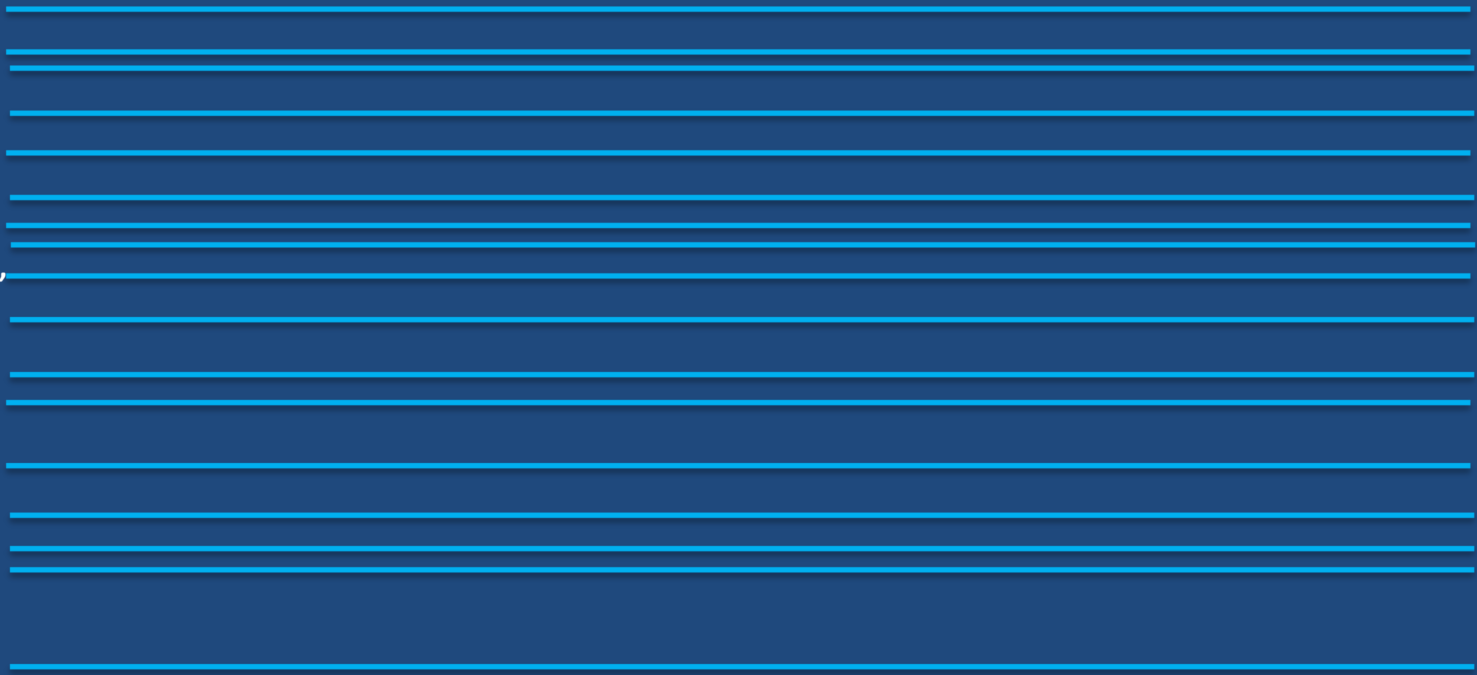
Acquisition is to be performed with irregular Source and Receiver locations

Conventional vs CS Option 2 *(w/ reconstruction)*

	Reference Design (slide 27)	CS2 effort executed in the field	CS Option2 after CS reconstruction
REPSOL / Survey : Boyuy 3D	**D6 360x510**	**D6**	**D6**
Receiver lines per swath	**20**	**32**	**32**
Live channels per receiver line	**1088**	**544**	**1088**
Total channels per patch	21760	17408	34816
Receiver Line Interval	360	180	180
Receivers Interval	15	30	15
Source point Interval	90	90	45
Source Line Interval	510	510	510
Binsize (In-Line) natural	7.5	15	7.5
Binsize (X-Line) natural	45	45	22.5
Full Fold natural bin	160.0	256.0	256.0
Inline to Crossline Ratio	0.44	0.35	0.35
Maximum minimum offset	624	541	541
Maximum offset (In-Line).	8152	8145	8152
Maximum offset (X-Line).	3555	2835	2857.5
Maximum Offset.	8893	8624	8638
Source points / Km^2	22	22	44
Receiver points / Km^2	185	185	370
Trace Density / km^2	474,074	379,259	1,517,037
Channels Required for Operation	**34,408**	26,588	53,176

Other options: irregular line spacing (viable?)

Non-uniform Acquisition Design for Foothill Environment,
M. Luo et al 2017



How CS can help? - Conclusions

- Implementation of CS technique is intended to deliver uplift in data quality rather than reducing the source and receiver effort of the surveys. Reconstructed gathers shall provide the spatial sampling to effectively remove the typical noise Andean Thrust Belts seismic data.
- It is expected that CS technique also shall provide improved image of the complex near mid geology to support model building.
- Compressive Sensing (CS) acquisition proposals allow the implementation of WAZ acquisition or implementation of NAZ acquisition with smaller receiver line intervals.
- Design options consider CS acquisition with both irregular source and receiver locations. It is assumed that reconstructed gathers are generated for reference nominal design with half the IL bin size and half the XL bin size.

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