Single-sensor 3D land seismic acquisition in Kuwait

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My talk will cover the following:

- **Introduction**
- **A brief capture of some relevant concepts**
- **Why single-sensor data**
- **Data acquisition**
- **Data processing**
- **Data comparisons**
- **Conclusion**

Introduction

Land seismic data acquisition in Kuwait has to address the following issues:

- **Scattered source generated coherent noise**
- **Flair noise**
- **High amplitude noise trains (ground roll)**
- **Noise wavelengths in the order of 8 meters**
- **Image a shallow horizon for statics determination**
- **Image deep reservoirs for which offsets in the order of 6,000 meters are desirable**
- **Achieve high vertical resolution for reservoir characterization**
- **Minimize geometry footprints to enable successful attribute analysis, AVOA, inversion, etc.**

Introduction

To address the land 3D seismic acquisition challenges we have reviewed the publications of several authors who have discussed issues relating to better sampling of the seismic wavefield and improving seismic data quality and resolution.

In the following slides I will capture some of the concepts that we have considered prior to embarking onto the use of single-sensor acquisition.

Vermeer, Marschall, Baeten, Ongkiehong, Mougenot, Blacquière, Galbraith, Cooper and others

Concepts

- **The signal to random noise (S/N) in a 3D volume is a function of the trace density seen by the migration operator. By increasing the acquisition trace density, the S/N in the final volume would be improved.**

- **To achieve improved imaging and minimize acquisition geometry footprint in the 3D volume, trace multiplicity needs to build consistently with sources to receivers offset and azimuth.**

- Krey, Th C. 1987, Attenuation of Random Noise by 2-D and 3-D CDP Stacking and Kirchhoff Migration, Geophysical Prospecting 35, 135-147.
- Robinson Don K. and Al-Hussaini, Moujahed, 1982, Techniques for reflection prospecting in Rub" Al-Khali, Geophysics, Vol 47 No 8. .

Concepts

Adequate Sampling

Baeten et al. (2000) introduced the concept of spatial adequate sampling which is the use of a sampling distance that prevents the noise wavefield from aliasing into the signal passband.

Thus, it is possible to adequately spatially sample with sensor spacing a little more than half of the ground roll wavelength.

Baeten, G.J.M, Belougne, V., Combee, L., Kragh, E., Laake, A., Martin, J., Orban, J., Özbek, A., and Vermeer, P.L, 2000, Acquisition and processing of point receiver measurements in land seismic, 70th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, p 41-44.

Concepts

Uncommitted Acquisition

Ongkiehong et al. (1988) defined universal land acquisition as a scheme in which we are not forced to commit to a final processing and/or interpretation sampling grid during the acquisition process, but have the ability to change the processing/interpretation bin dimensions at various later times and called this "uncommitted acquisition", i.e., in the field no irreversible step should be carried out such as group forming by conventional arrays.

Ongkiehong, L. and Askin, H. J., 1998, Towards the universal seismic acquisition technique, First Break, Vol. 6, No.02, p 46-63.

Concepts

An even, finely sampled distribution of source-receiver offsets over all azimuth ranges is extremely critical when AVO analysis or fracture detection is to be performed.

Concepts

Array forming in the field by straight analog summation provides suboptimal performance:

- **The responses of such arrays are distorted by the presence of intra-array perturbations which are differences in amplitude, phase and timing.**
- **Residual ground-roll will alias and consequently will not be effectively removed in processing.**
- **Uncorrected intra-array perturbations could introduce pseudo-random noise, cause loss of signal and increased leakage of coherent noise.**

Concepts

- **The initial sampling interval in space is constrained by the availability of a sufficient number of sensors and the capacity and dynamic range of the recording instruments. These factors have cost and operational considerations.**

- **The spatial sampling of the coherent noise wavefield must be appropriate to ensure un-aliased recording of the noise energy.**

Concepts

The VectorSeis push by Input/Output

- **Full-wavefield recording is described to be the use of single multi-component MEMS based sensors (3C).**

- **In the acquisition of compressional (P-wave) seismic, the horizontal components are used to attenuate noise using adaptive filtering. Hence, arrays are claimed to be not required.**

❖ **We are planning to test this concept as soon as possible.**

Why Single Sensor

- **Single sensor recording is the only way to avoid the potential errors of array forming in the field by straight analog summation.**

- **Proper processing can reduce intra-array perturbations and consequently improve the quality of seismic data.**

- **With single sensor we can achieve uncommitted acquisition.**

Why Single Sensor

- **The use of single-sensor recording in an orthogonal geometry enables the exploitation of the three-dimensional nature of the data representation within the cross-spread gather to suppress noise prior to group forming.**
- **Effective attenuation of noise in the cross-spread gather decouples the source array from the receiver array.**

Data acquisition

As I have previously mentioned, land seismic data acquisition in Kuwait has to address the following issues:

- **Scattered source generated coherent noise**
- **Flair noise**
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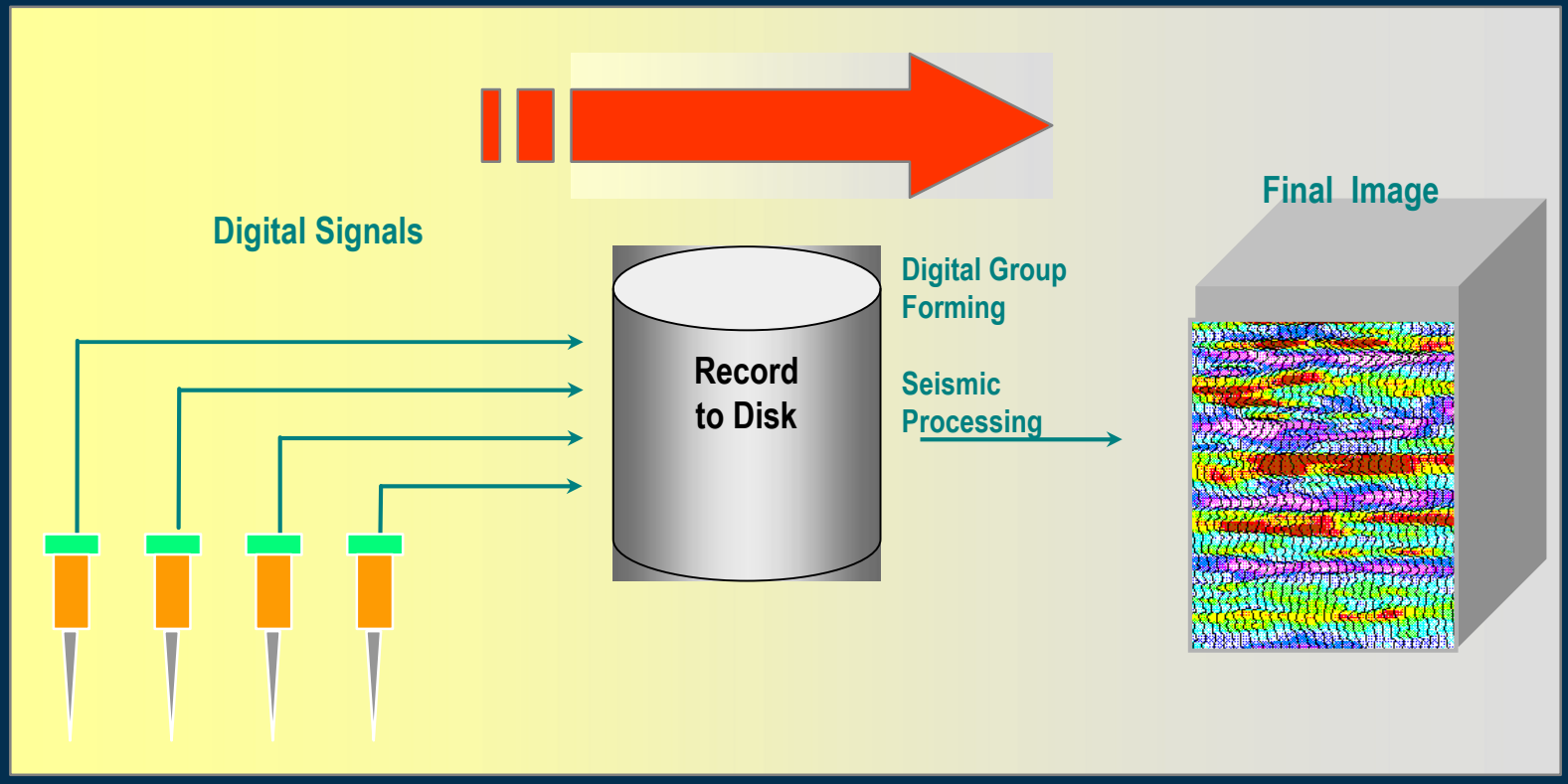
- **Noise wavelengths in the order of 8 meters**
- **Image a shallow horizon for statics determination**
- **Image deep reservoirs for which offsets in the order of 6000 meters are desirable**
- **Achieve high vertical resolution for reservoir characterization**
- **Minimize geometry footprints to enable successful attribute analysis, AVOA, inversion, etc.**

Data acquisition

- **The first test in Kuwait to investigate the value of single-sensor seismic recording was conducted in October 1998.**
- **KOC interest in single-sensor recording culminated in mobilizing in October 2003, under a Joint Technology Agreement with WesternGeco, a single-sensor 3D land crew (Q-land).**
- **The single-sensor acquisition and processing system is capable of recording 20,000 live channels at 2ms sample rate or 30,000 live channels at 4 ms sample rate.**

Data acquisition

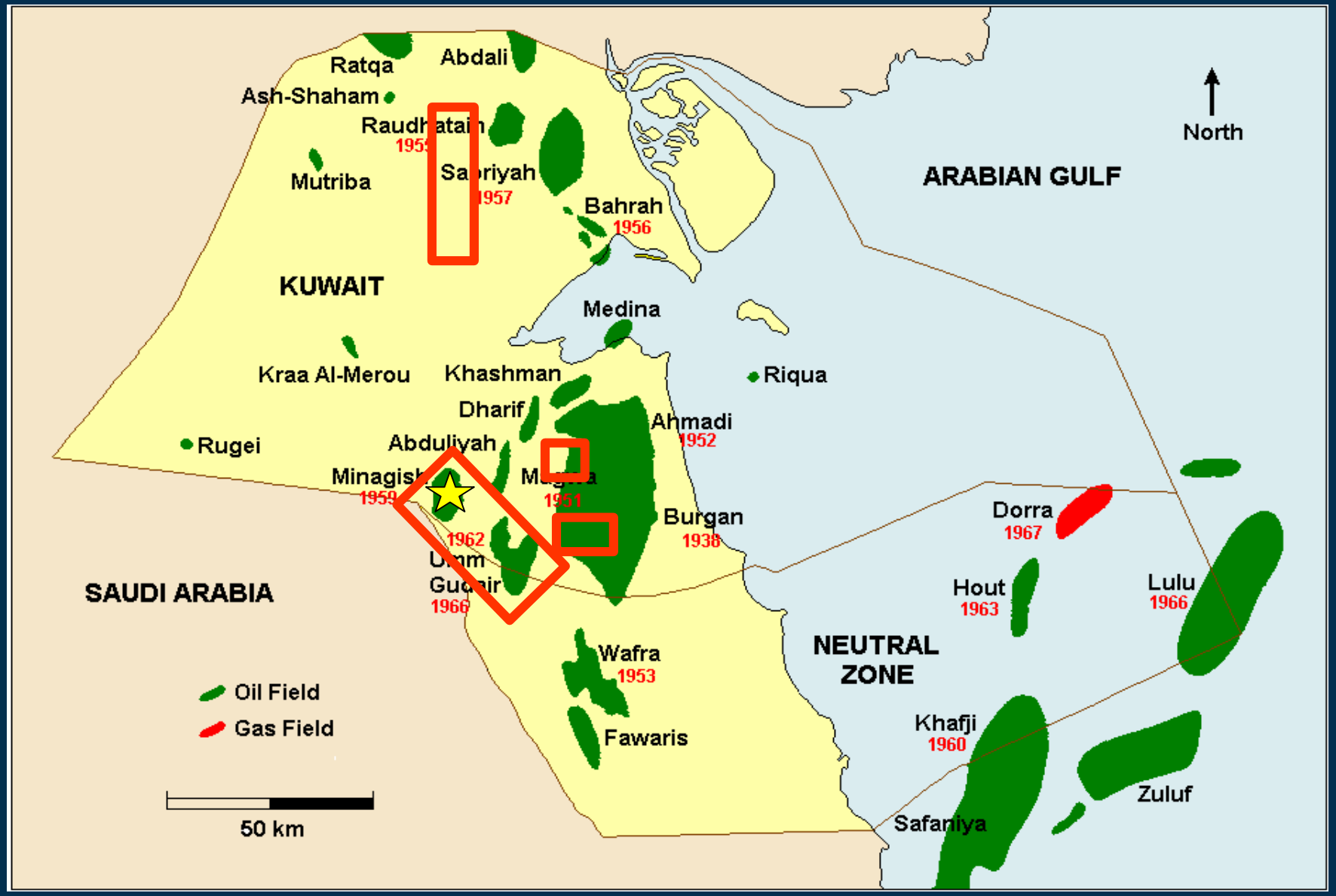
The acquisition system architecture records directly on disk to enable the handling of the increased data volume prior to grouping.



Data acquisition

- **Various noise and comparative tests were performed.**
- **The first single-sensor 3D onshore pilot study which was the first in the Middle East was completed In March 2004.**
- **This was followed by:**
  - **an exploration/appraisal 3D project targeting deep Jurassic reservoirs**
  - **two additional 3D pilots whose main objective was the resolution of a sand/shale sequence.**
  - **survey of two major oil fields.**

Data acquisition



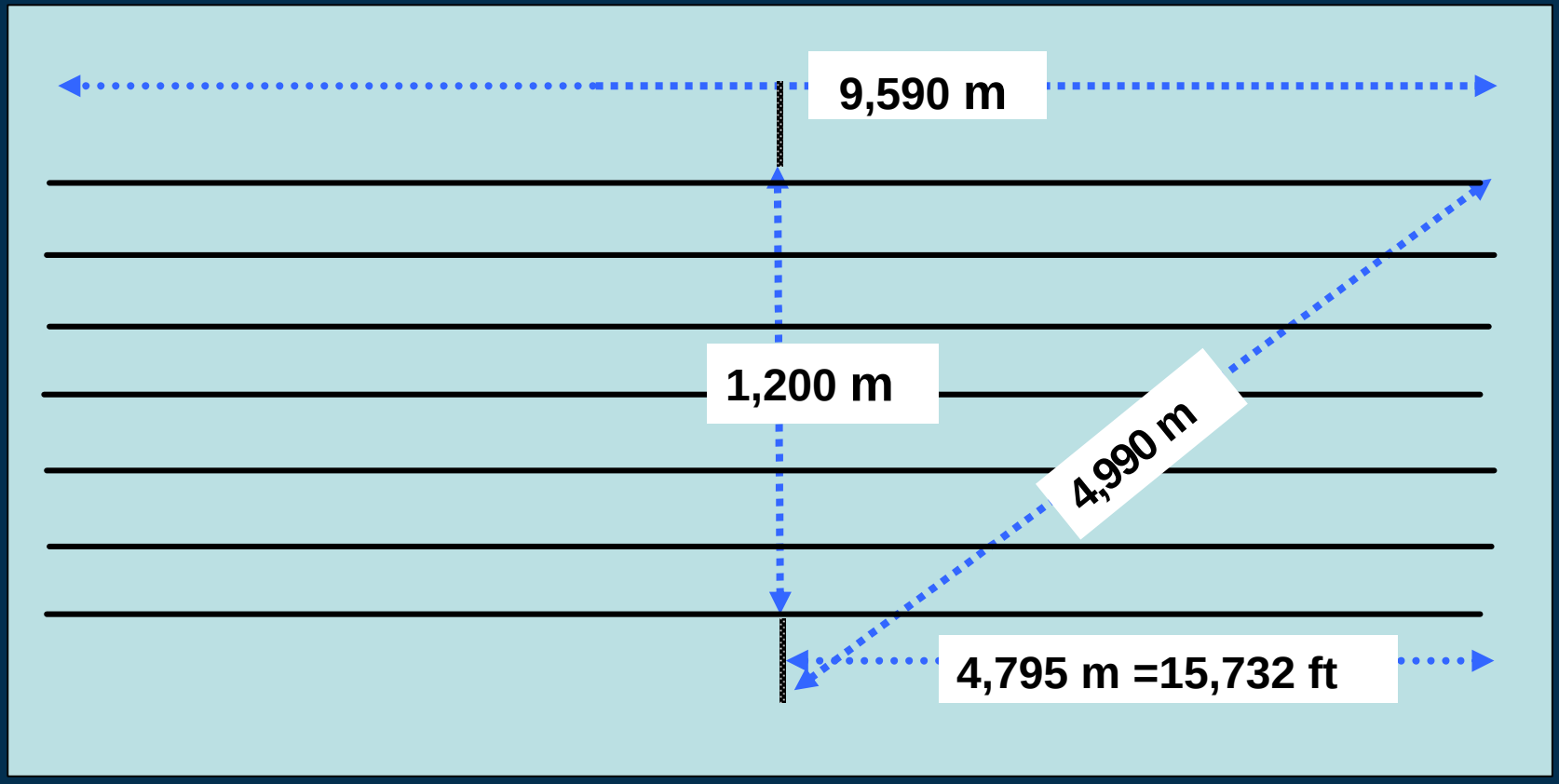
Data acquisition

Key acquisition parameters recently used were:

- **Orthogonal Geometry**
- **7 receiver lines, spacing of 200 m**
- **Sensors' inline spacing: 10m (single sensors in 4 sub-lines with 5 m stagger and separation)**
- **Cross-line roll: one**
- **Source line interval: 200m**
- **Sources: Outside both sides of the template**
- **Source interval: 20m, 2 Vibrators, 10 m apart**

Data acquisition

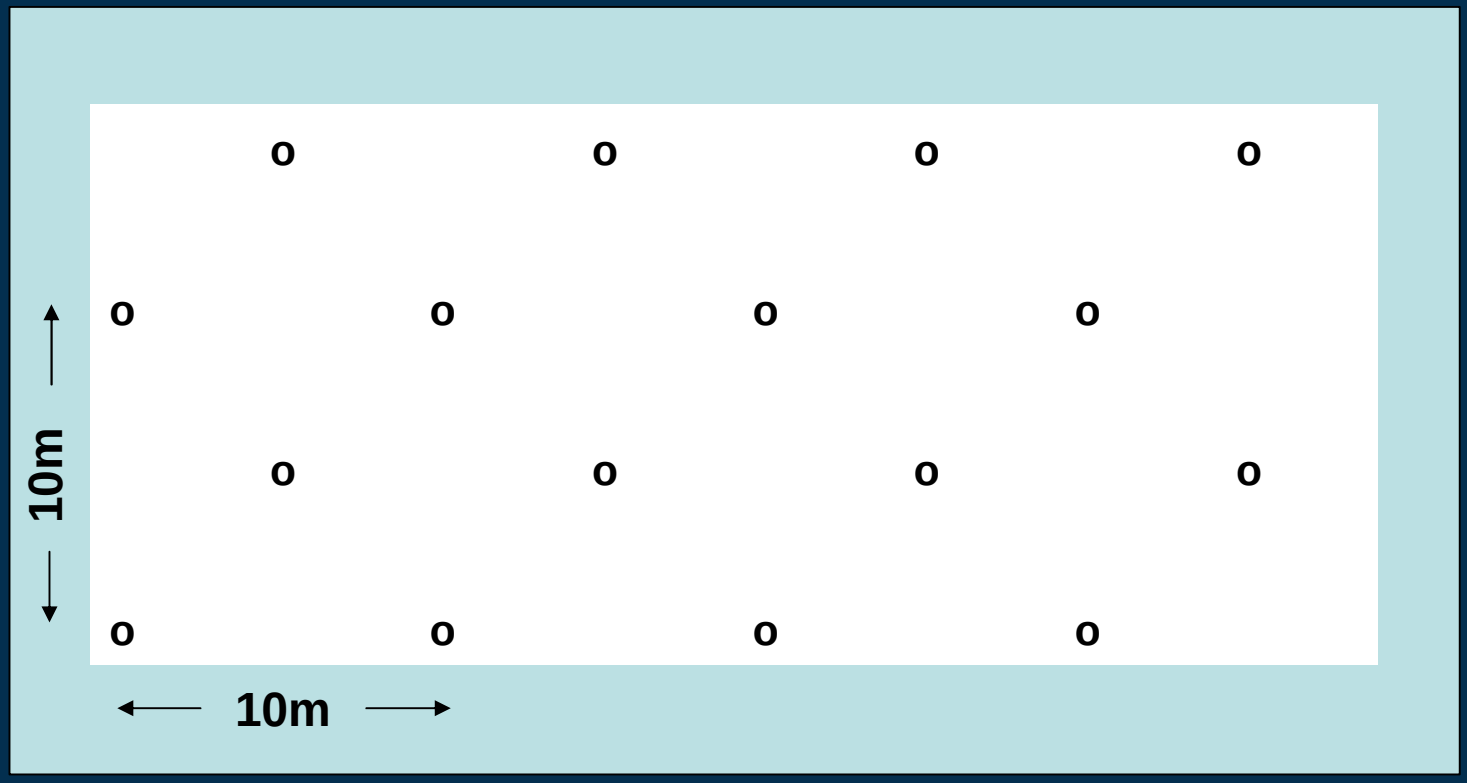
The geometry recently used utilized 26,880 active single-sensors in 7 lines each composed of 4 sub-lines.



This scheme is effectively a scheme of 14 lines as each source location is used twice.

Data acquisition

Single sensors in 4 sub-lines 10 m inline separation, 5m stagger and 5 m cross line separation,



Data processing

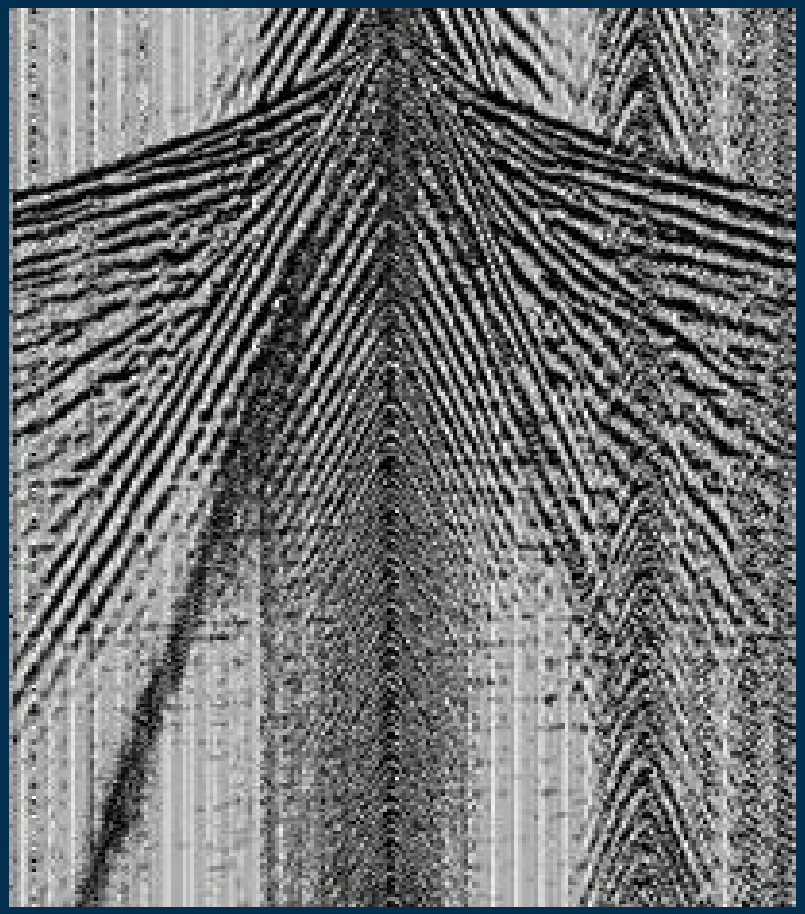
- **The acquired data offered the opportunity to apply, prior to grouping in the DGF process:**
  - **corrections for intra-array perturbations including proper correction for intra-array statics which attenuate high frequencies.**
  - **schemes that effectively attenuated coherent noise while leaving the underlying signal intact using a proper spatial anti-alias filter.**
- **An output trace from a number of sensors is then produced at the desired output spatial sampling.**

Data processing

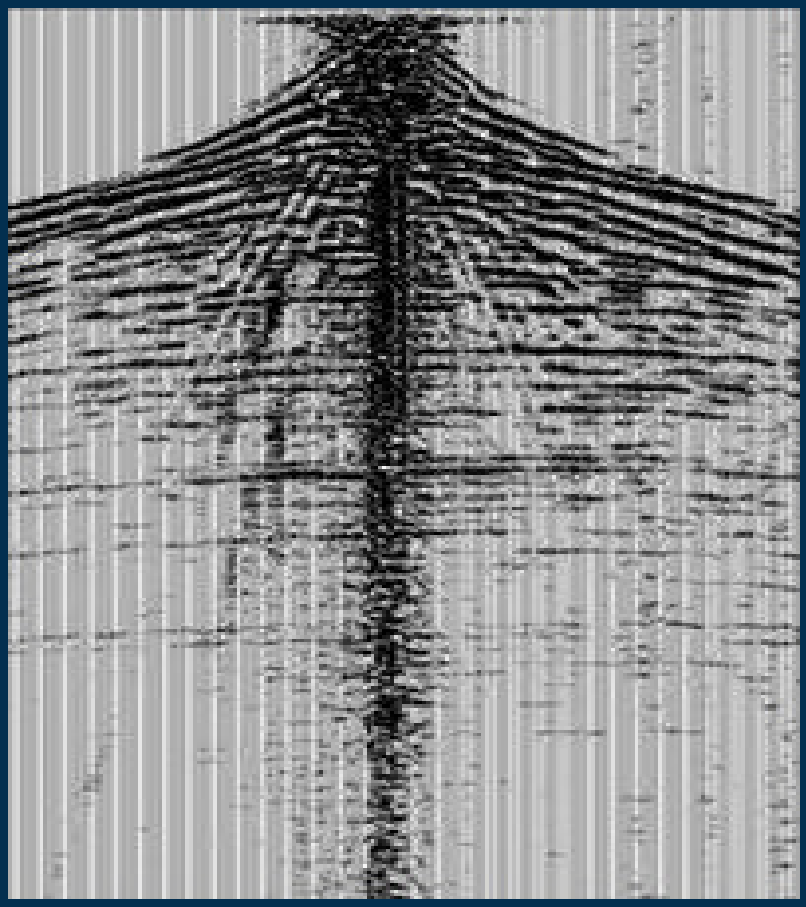
Data processing applied on single-sensor data included the following:

- **Flare Noise Attenuation**
- **Air Wave and Ambient Noise Attenuation**
- **Surface Consistent Amplitude Compensation**
- **Intra-array Statics Corrections**
- **Digital Filter to address Ground Roll Noise**
- **Spatial Resample Filter**

Data processing



Raw single-sensor cross-spread record



Noise attenuation applied within the DGF process.

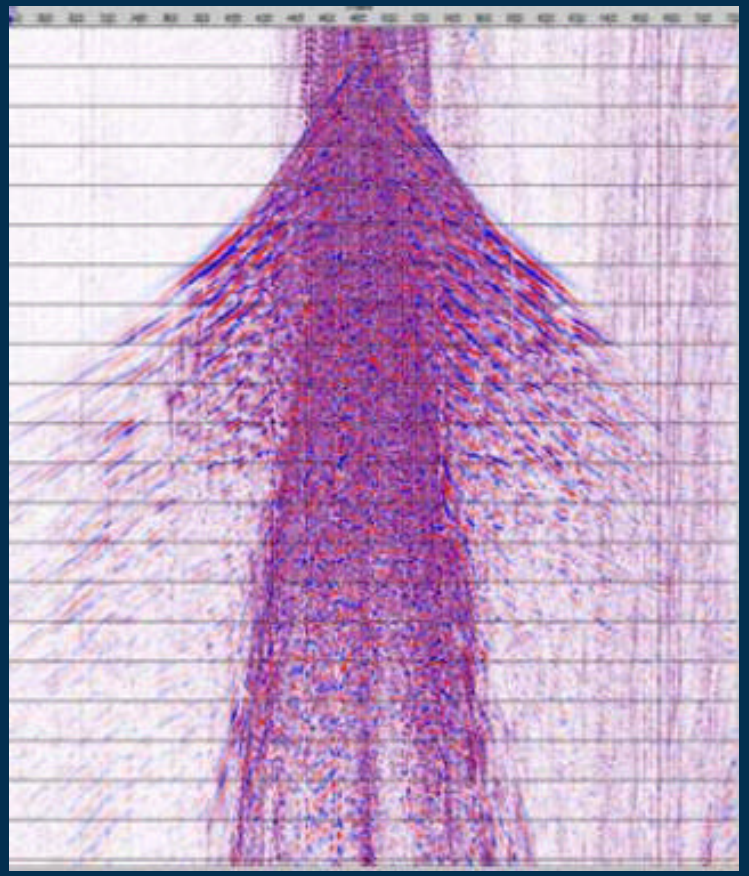
Data processing

Initial ground roll attenuation, anti-alias spatial filtering and subsequent grouping in a digital group forming (DGF) process of these processed gathers produced output shot records:

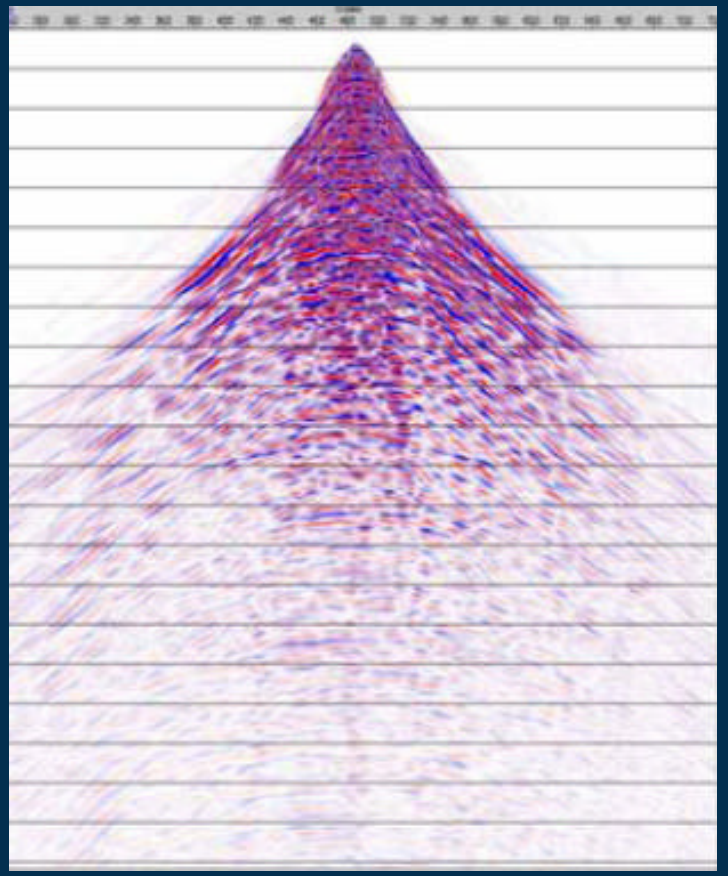
- **with better anti-alias protection**
- **improved random noise attenuation**
- **a more accurate correction for amplitude and statics perturbations**

Data processing

Raw Single-Sensor Data

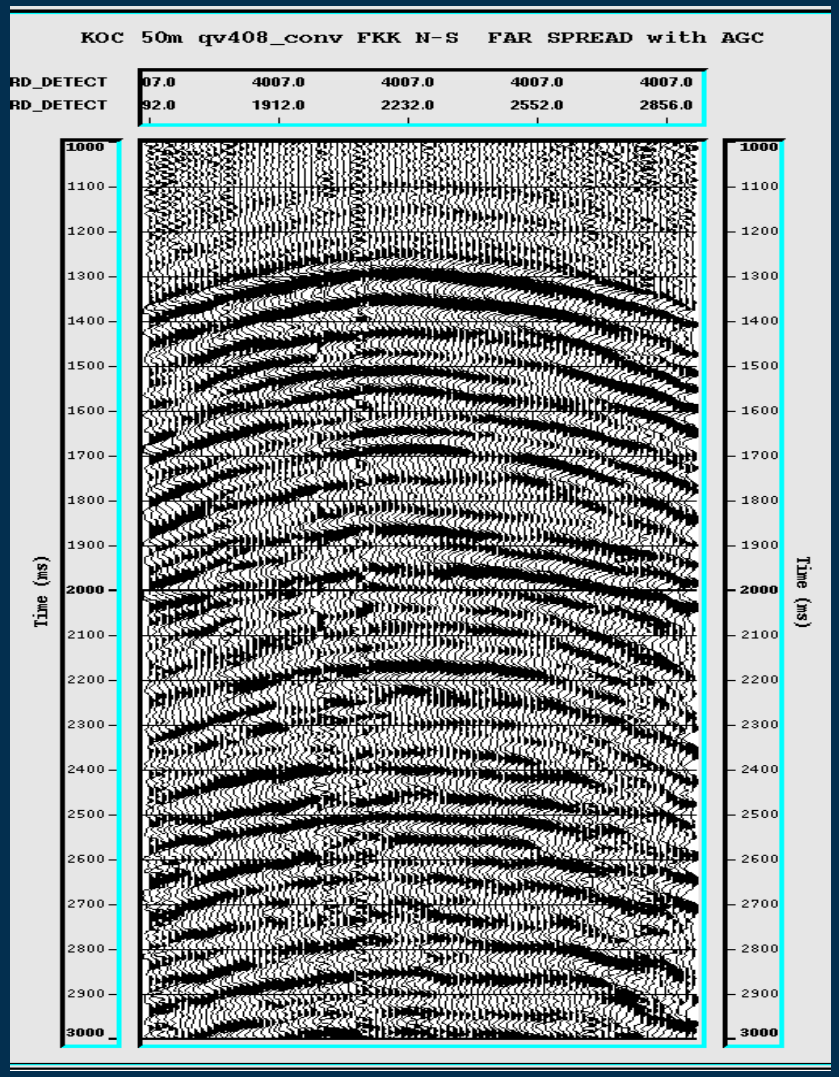


Raw Single-Sensor Data
After Digital Group Forming

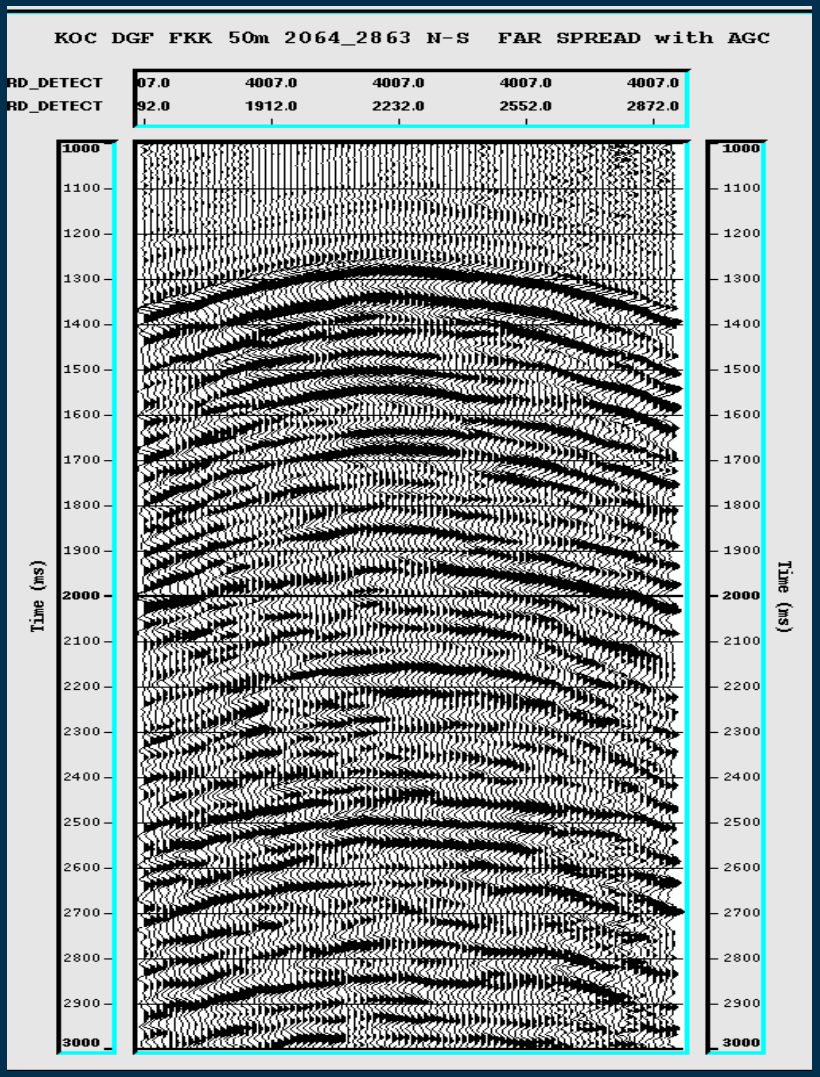


Improvement in data quality

Array X-spread Crossline

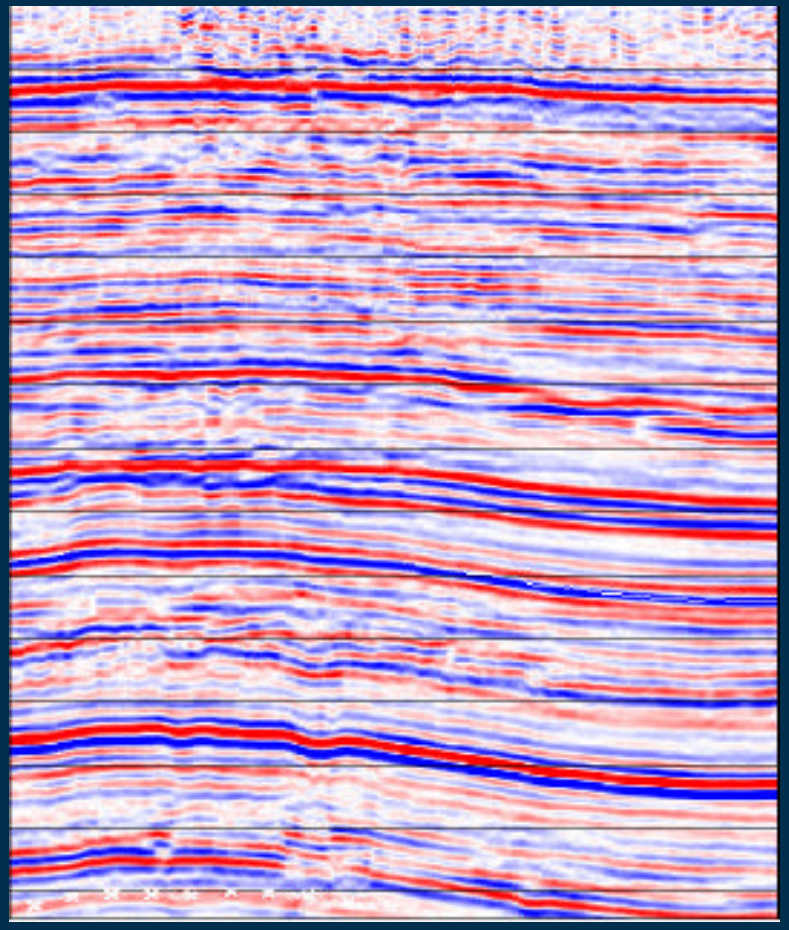


Single Sensor X-spread Crossline

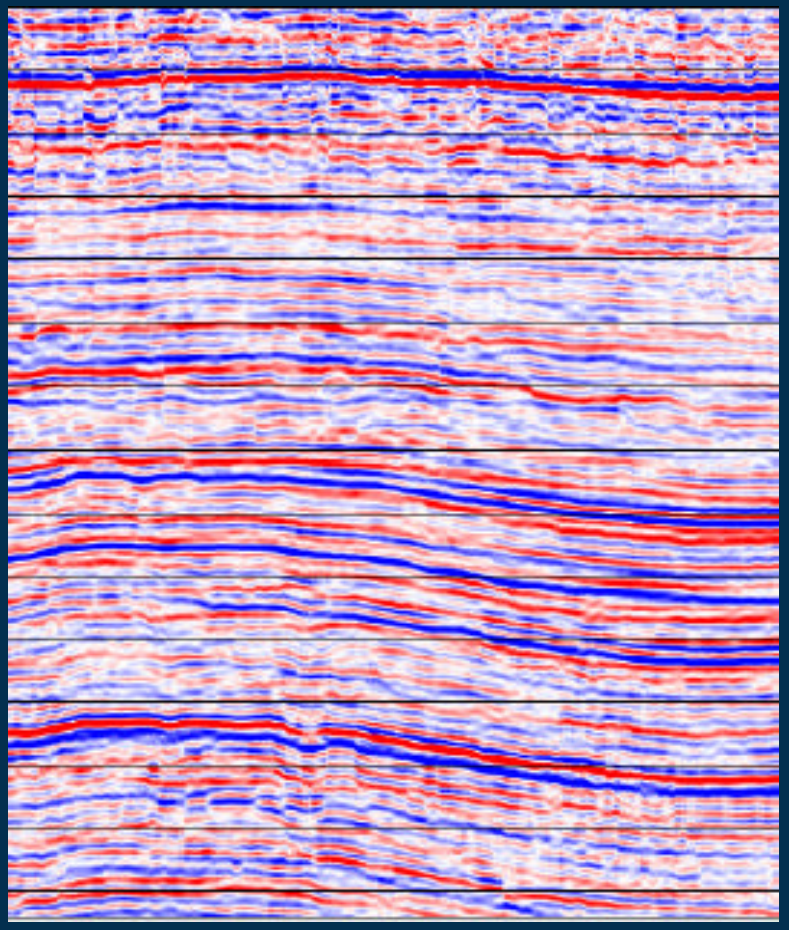


Improvement in data quality

conventional array data

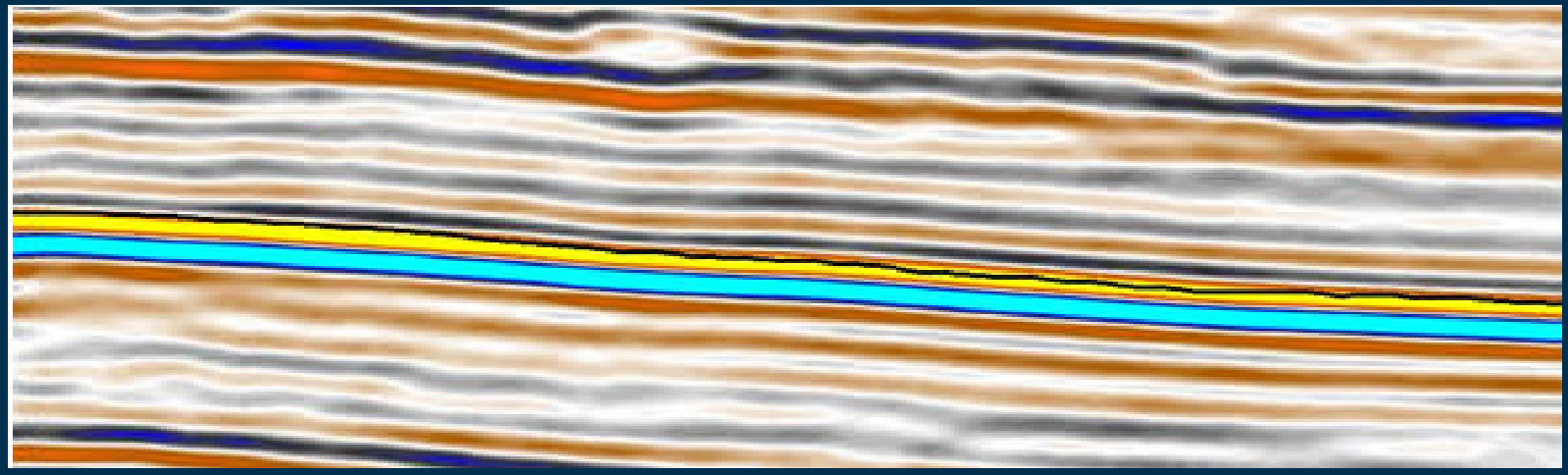


single-sensor data

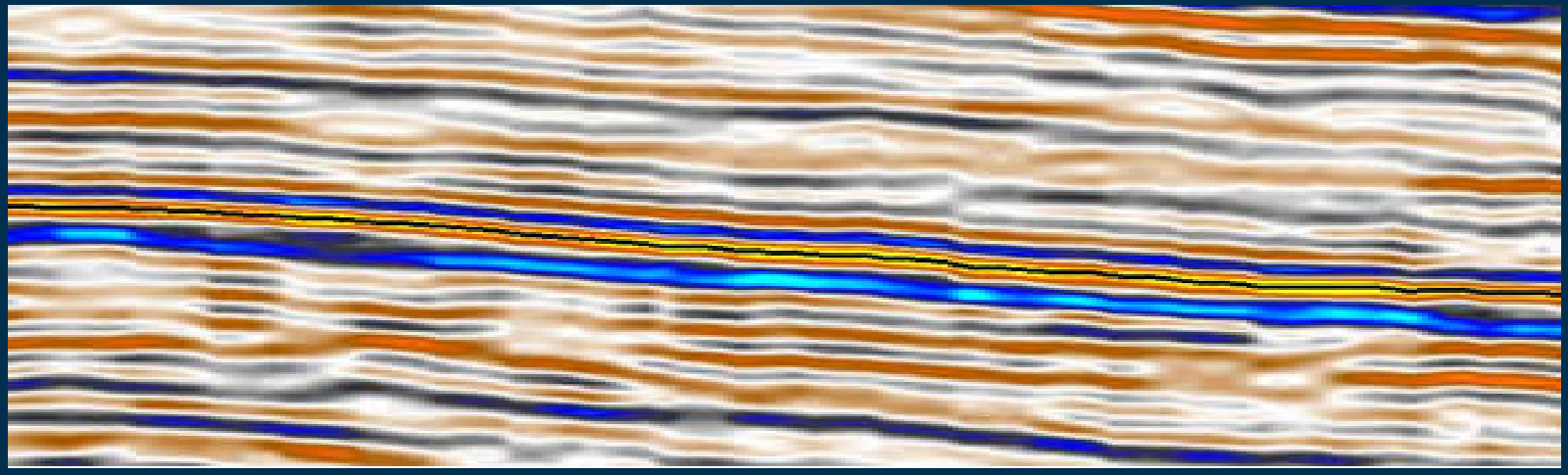


Improvement in data quality

conventional array data

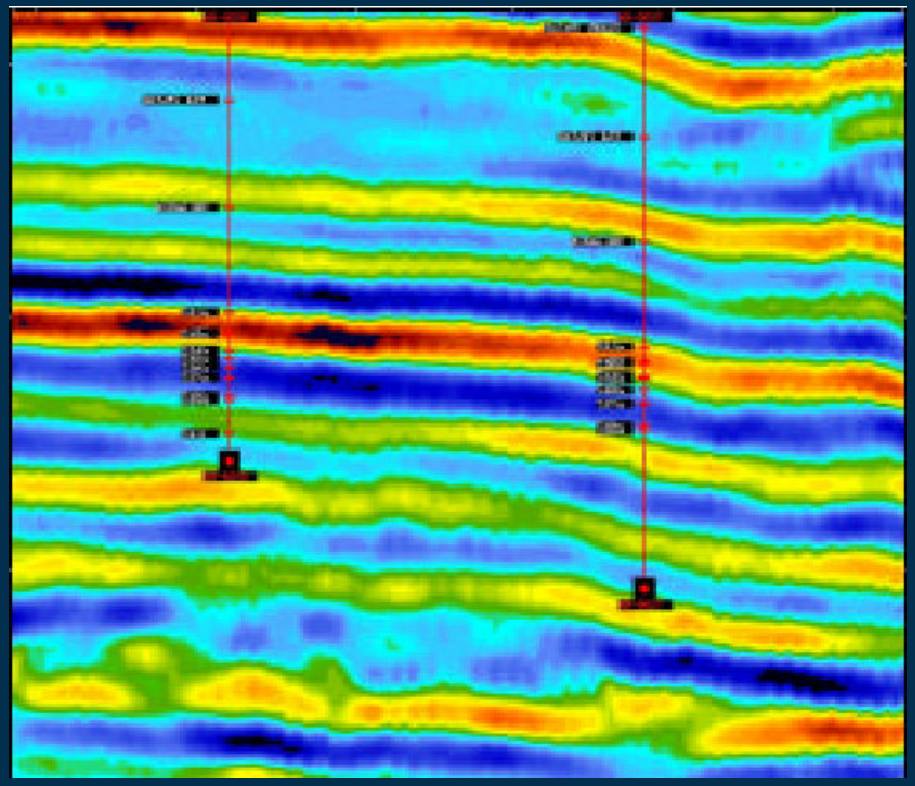


single-sensor data

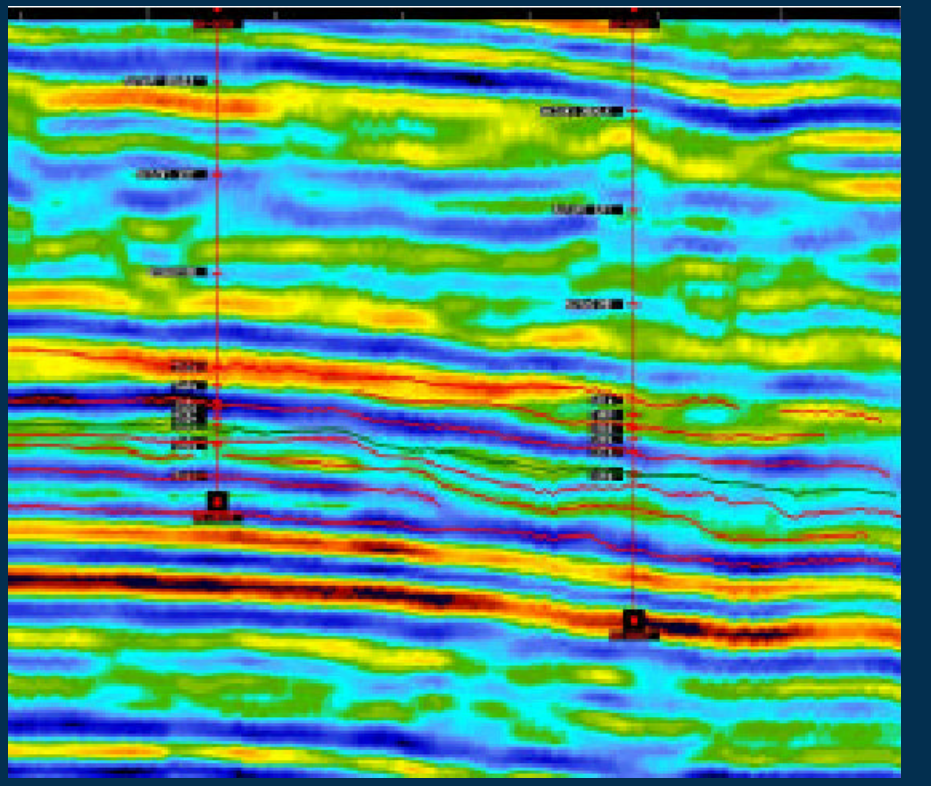


Improvement in data quality

conventional array data



single-sensor data

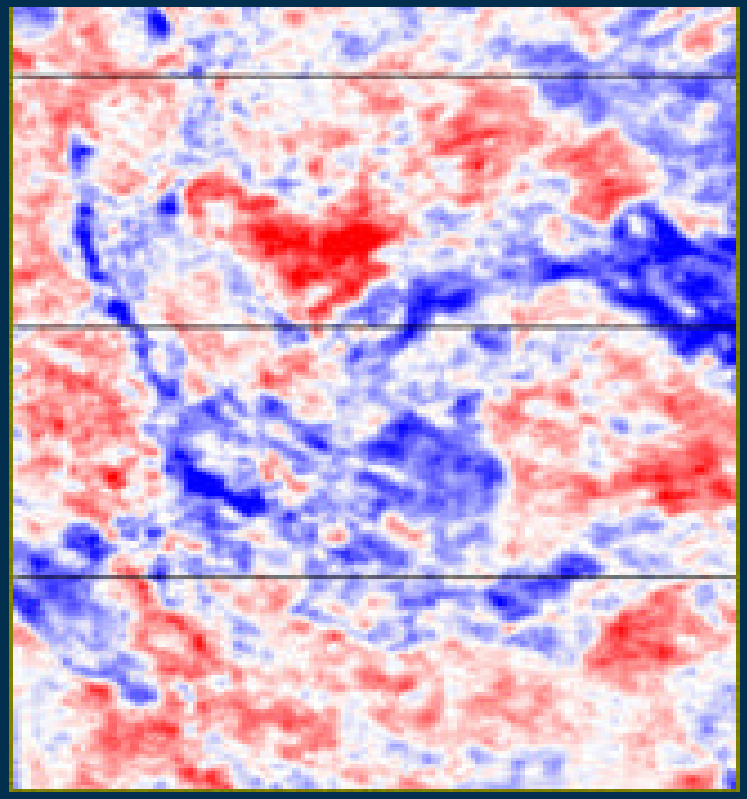


Acoustic impedance inversion

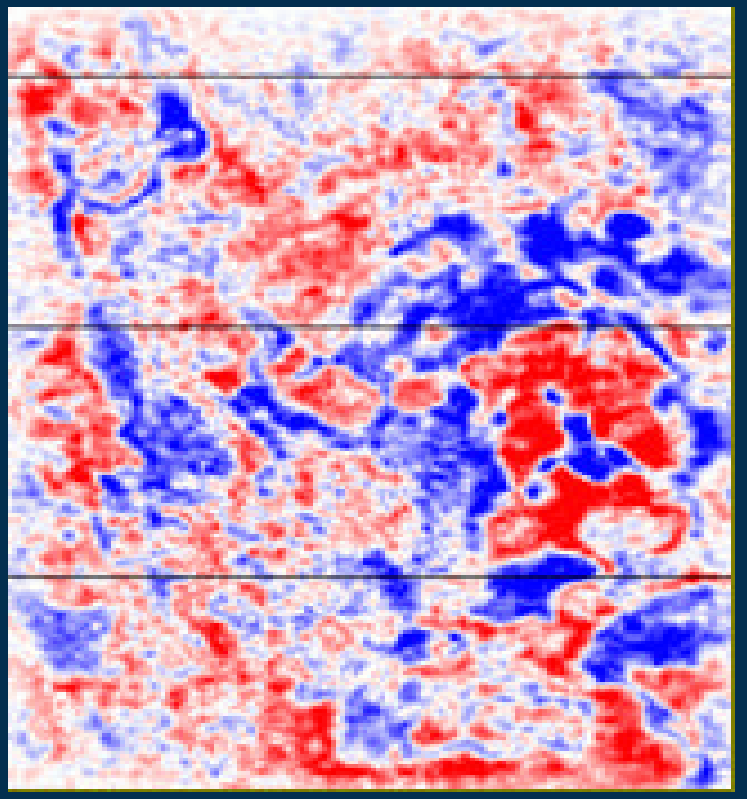
From: Time lapse (4D) seismic studies in the State of Kuwait: History and future *Adel El-Emam, Kuwait Oil Company KSC. TL P1 -- Time-Lapse Seismic*
Wednesday, October 4, 2006

Improvement in data quality

conventional array data



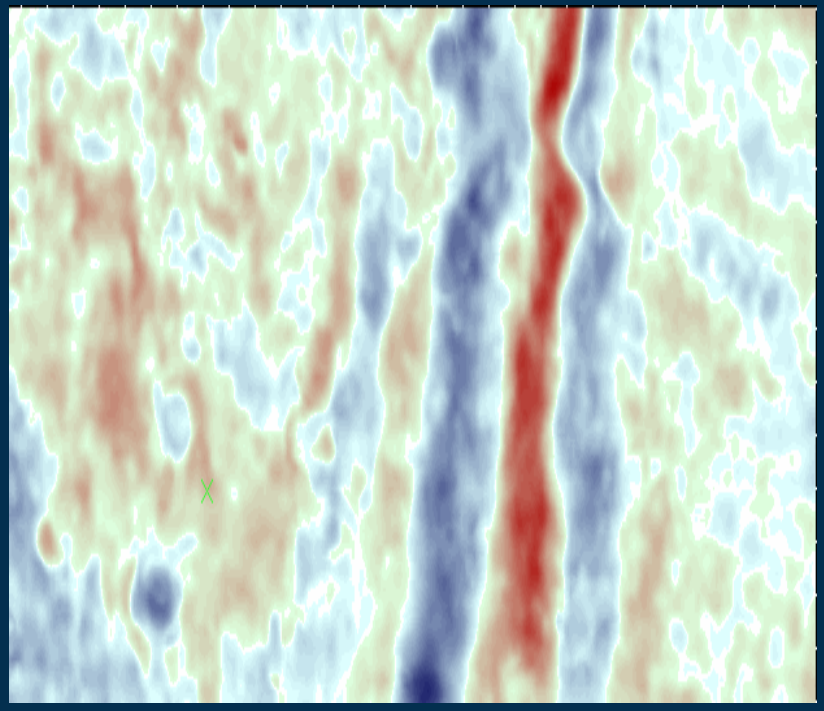
single-sensor data



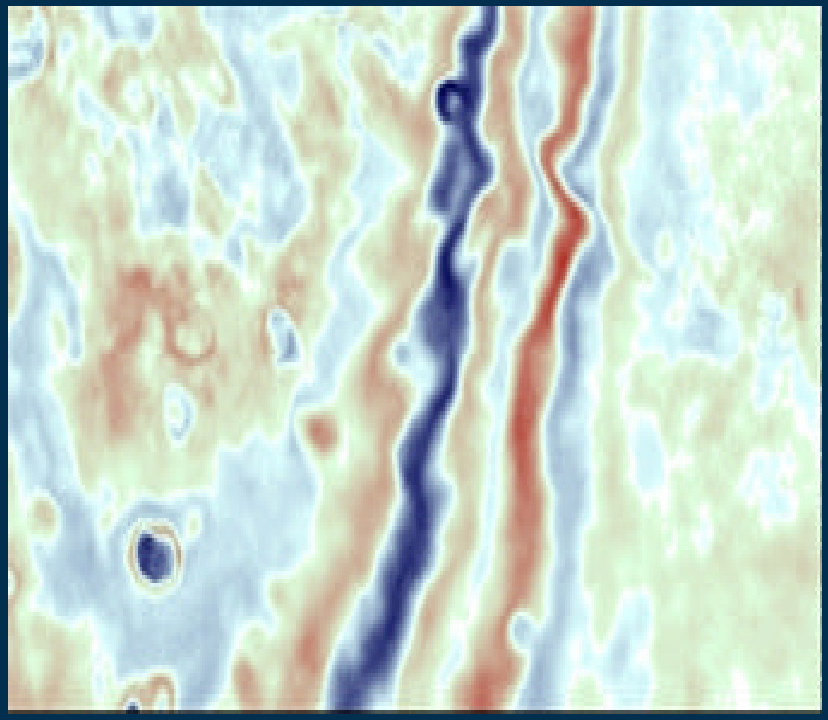
time-slices

Improvement in data quality

conventional array data



single-sensor data



time-slices at 1192 msec

Conclusion

- **The final processed data of the five surveys using single-sensor recording totaling 1608 sq. kms. exhibited, compared to conventional array data:**
  - **increased frequency bandwidth**
  - **better signal-to-noise ratio**
- **A higher channel-count system would be more appropriate to simultaneously meet all our objectives.**

The Future

- **A single-sensor recording system capable of handling 96, 000 channels is what we need to meet all our objectives without much compromises.**

- **The drive of Input/Output for their 3C MEMS system labeled VectorSeis is under consideration. We are planning to test this concept as soon as possible.**

The Future

- **A single-sensor recording system capable of handling 96, 000 channels is what we would like to meet all our objectives without much compromises.**

- **The drive of Input/Output for their 3C MEMS system labeled VectorSeis is under consideration. We are planning to test this concept as soon as possible.**

The Future

- **Acquiring a perfect uncommitted full fold 3D land P-wave survey, as per the concepts previously mentioned, to meet all requirements in Kuwait, even after relaxing the sampling requirement to adequate sampling, would require a large number of active channels that is still unrealizable in spite of all the recent technological advances in high channel count recording systems. Consequently, compromises have still to be made.**

The Future

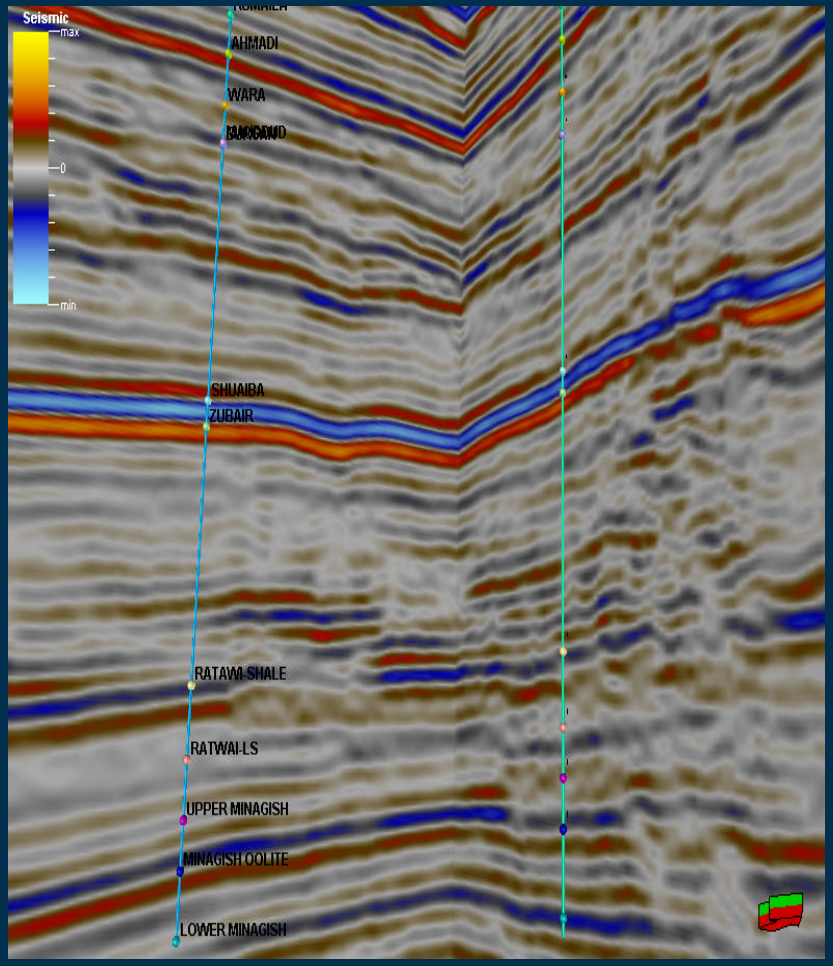
To acquire a perfect uncommitted alias-free full fold 3D (complete sampling of the 5-D wavefield) land seismic in Kuwait to meet all objectives would require a staggering number of shots and receivers:

- **2, 250,000 single sensors, and**
- **62,500 source points per square Kilometer**

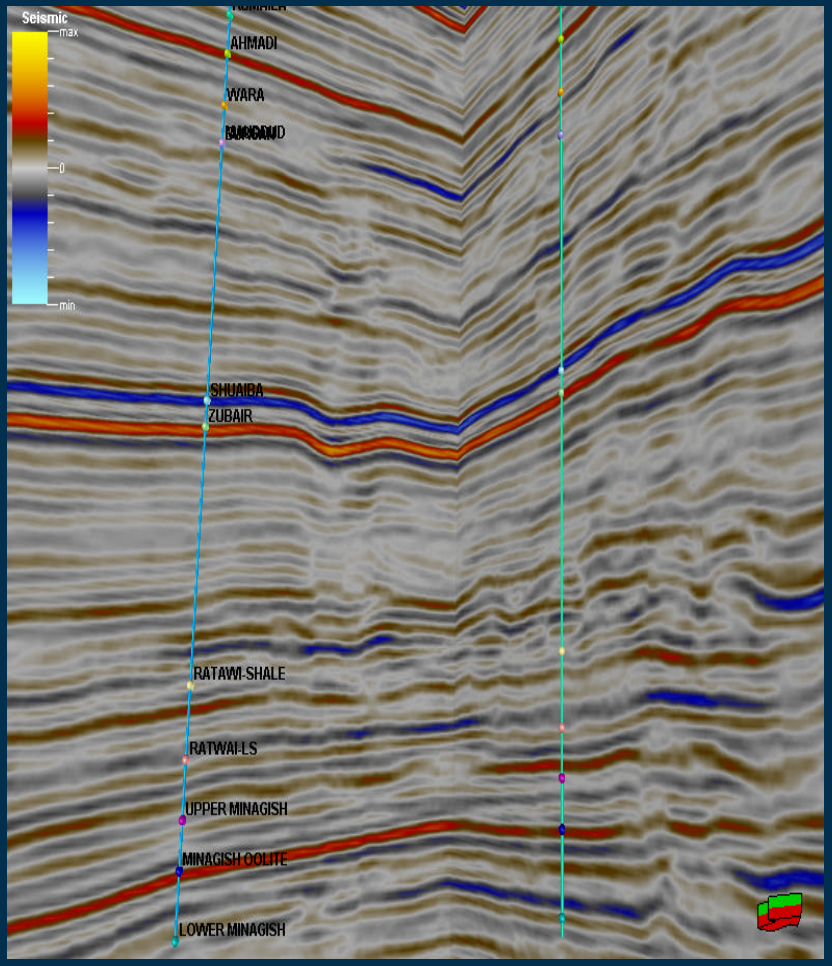
Will this become achievable?

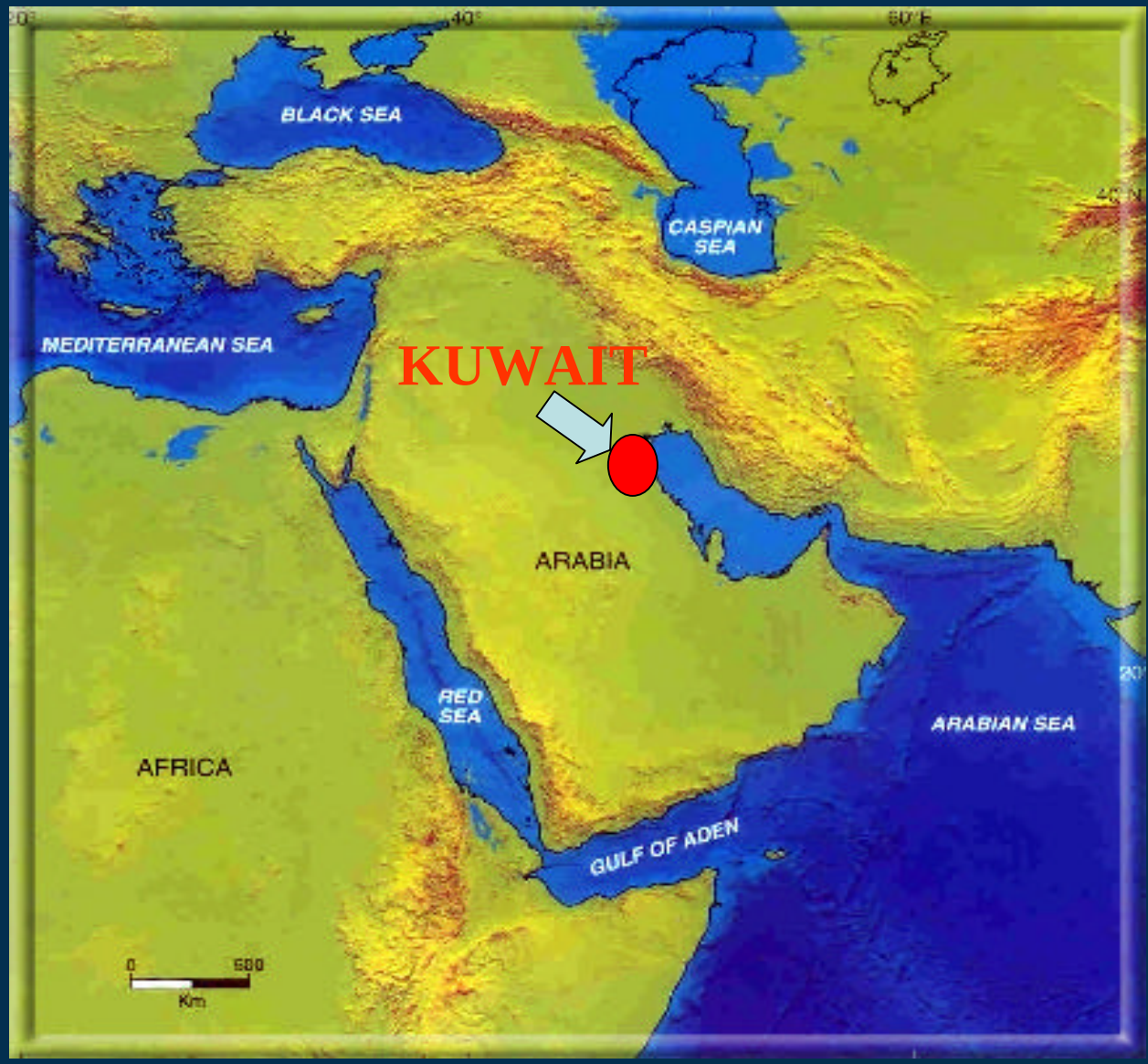
Improvement in data quality

conventional array data



single-sensor data




BLACK SEA
CASPIAN SEA
MEDITERRANEAN SEA
KUWAIT
ARABIA
RED SEA
AFRICA
ARABIAN SEA
GULF OF ADEN
0
600
Km

Concepts

Nominal 3D Full Fold Acquisition

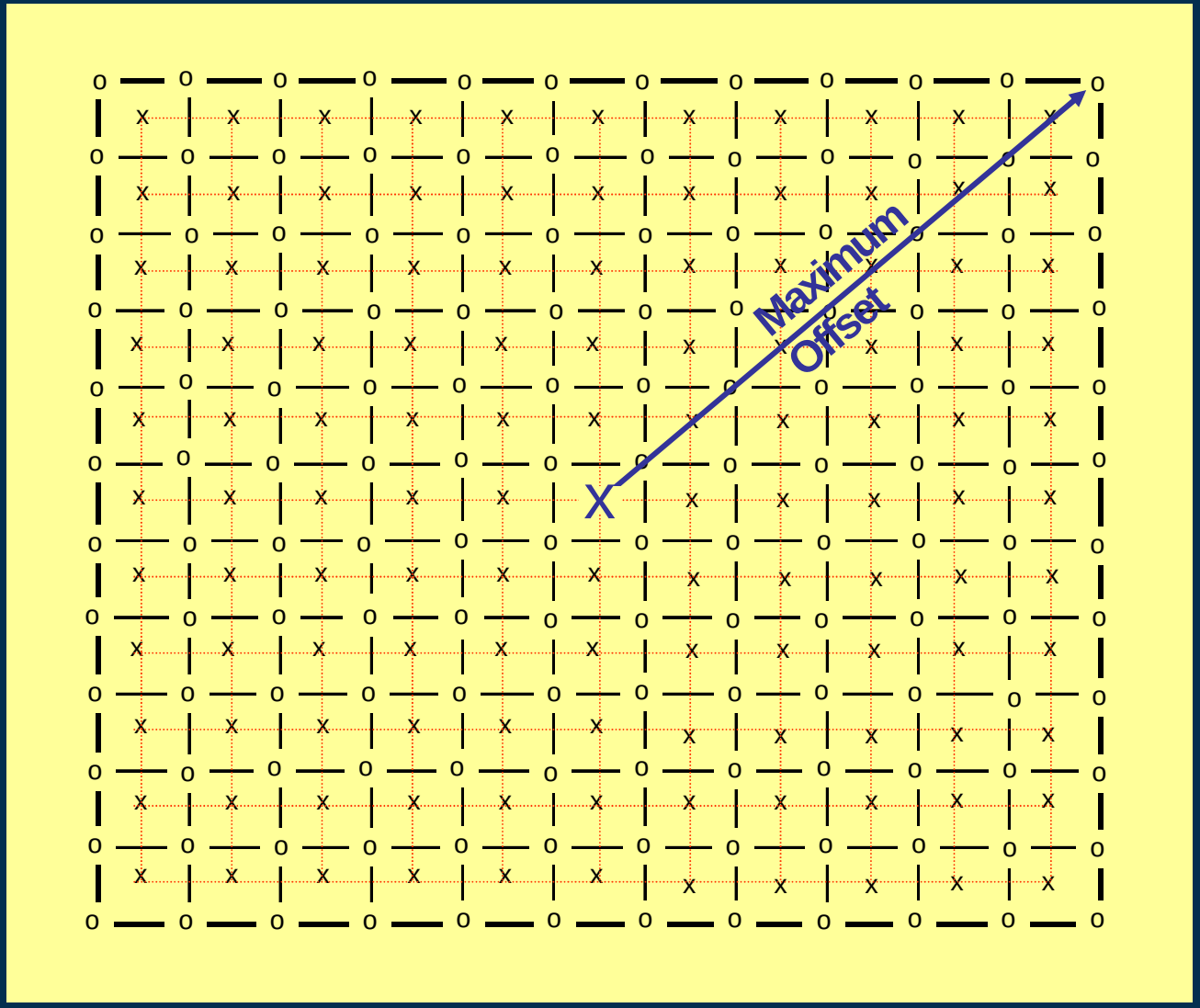
Marschall (1999) defined Nominal 3D Full Fold Acquisition in 3D land acquisition as the case in which:

- **the surface acquisition template consists of two square grids with equal bin sizes (source grid and receiver grid).**
- **an active channel is located at each grid point within a square with side length equal to a single receiver line and the source at the center.**
- **roll-along in x- and y-direction is with increment of one grid point.**

Marschall R., 1999, 4D Seismics-Principles and Applications, Journal of Seismic Exploration, Vol. 8, No. 4, 1999, p 309-346.

Concepts

Nominal 3D Full Fold Acquisition



Concepts

5-D Wavefield and 3-D symmetric sampling:

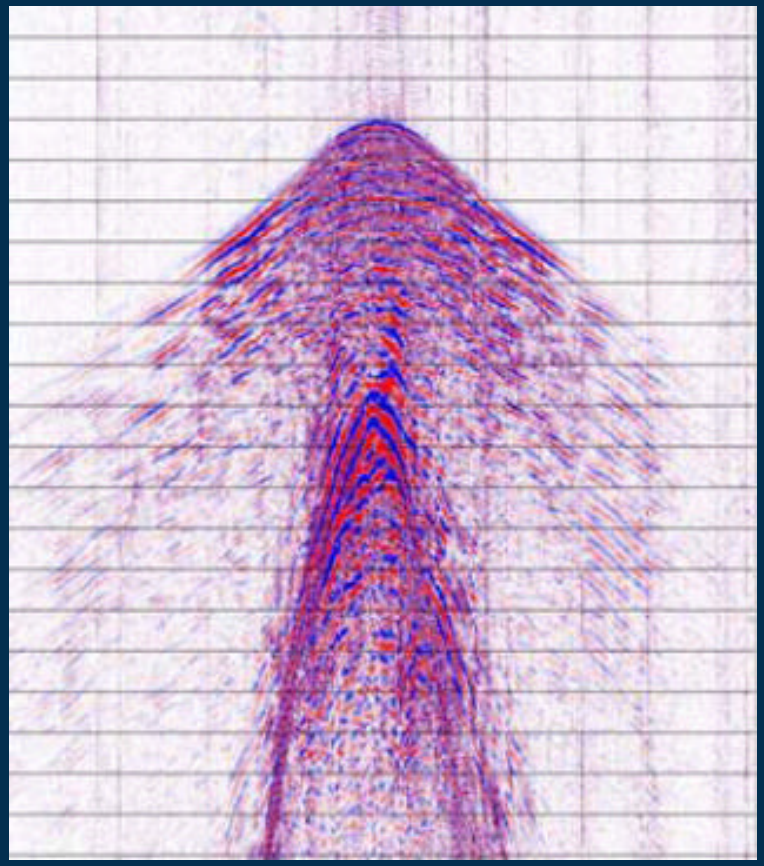
- **Vermeer defines proper 5-D prestack wavefield sampling as alias free sampling of temporal and all four spatial coordinates.**

- **Proper 3-D symmetric sampling is defined as the proper sampling of the single-fold subsets of the chosen geometry. A single data set whose midpoints area extends across the area of interest would be sufficient to fully construct the underlying continuous wavefield (not the whole wavefield).**

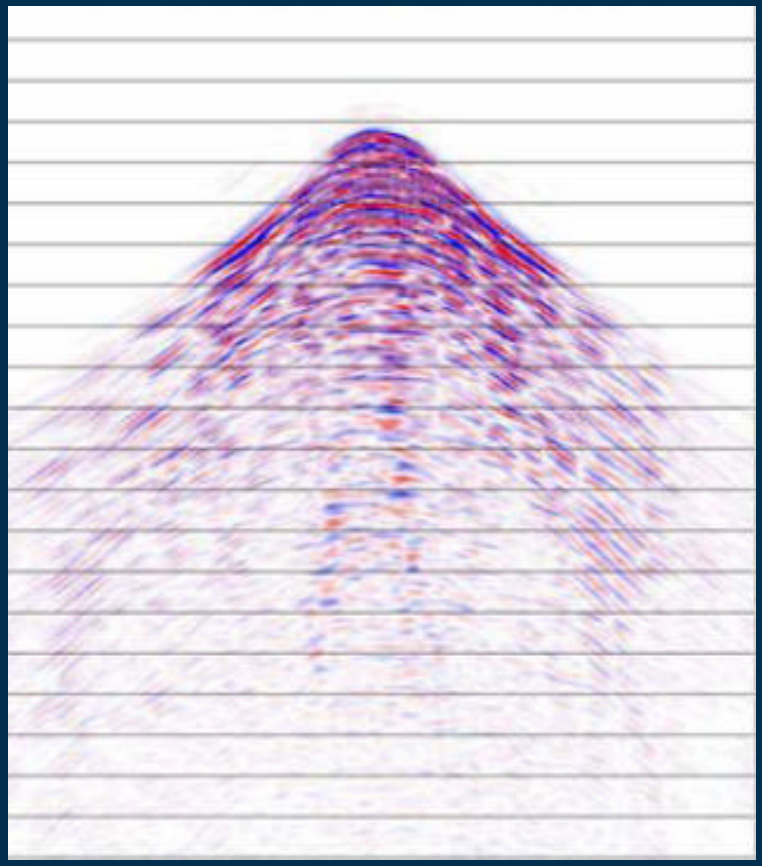
Vermeer, G.J.O, 2002, 3-D Seismic Survey Design , SEG

Data processing

Raw Single-Sensor Data

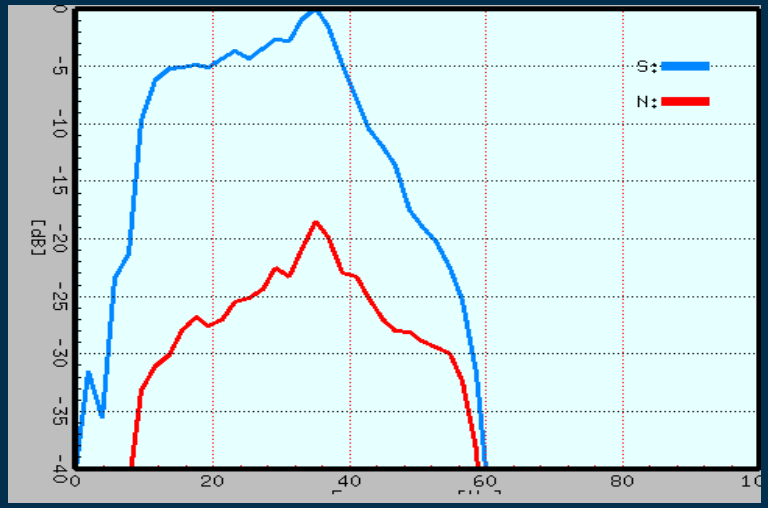


Raw Single-Sensor Data
After Digital Group Forming

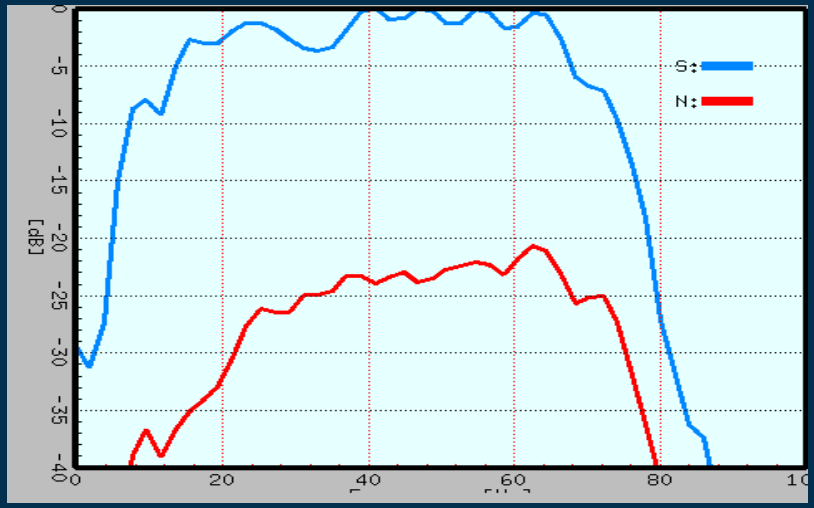


Improvement in data quality

Signal-to-noise ratio



conventional array data



single-sensor data