The Conklin SAGD Project; The application of Simultaneous inversion to pre-stack gathers

- **Ronald M. Weir ***
  - **P. Geoph. (Alberta), Professional Geoscientist (Texas)**

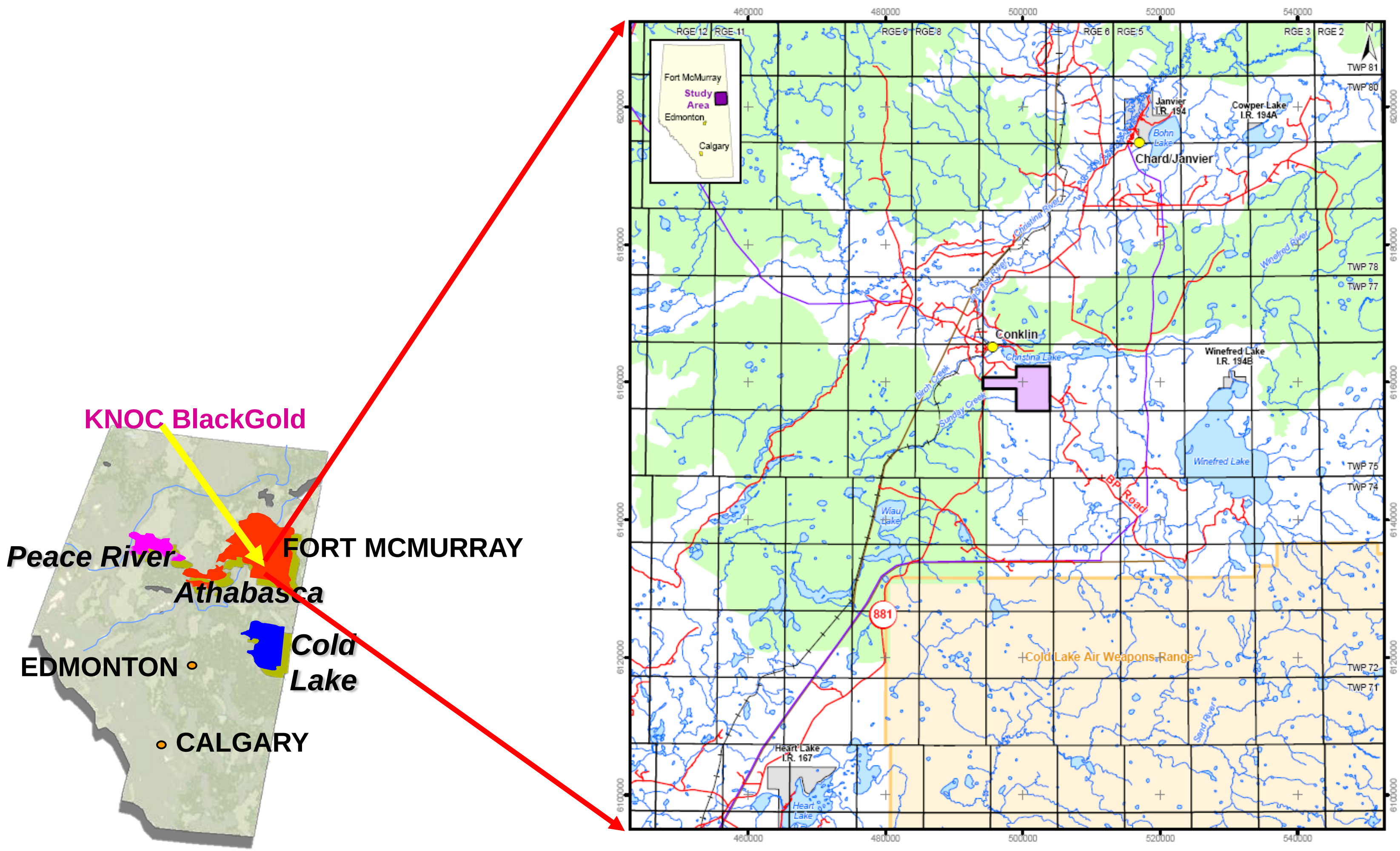
Korea National Oil Corporation

Harvest Operations Corp

Contents

- Regional Setting
- Geological/ Geophysical Challenges
- Post Stack Seismic Inversion
- Pre Stack Seismic inversion
- Geological model without seismic.
- Results of the Pre Stack seismic Inversion
- The Potential reserve addition using The Pre Stack Inversion

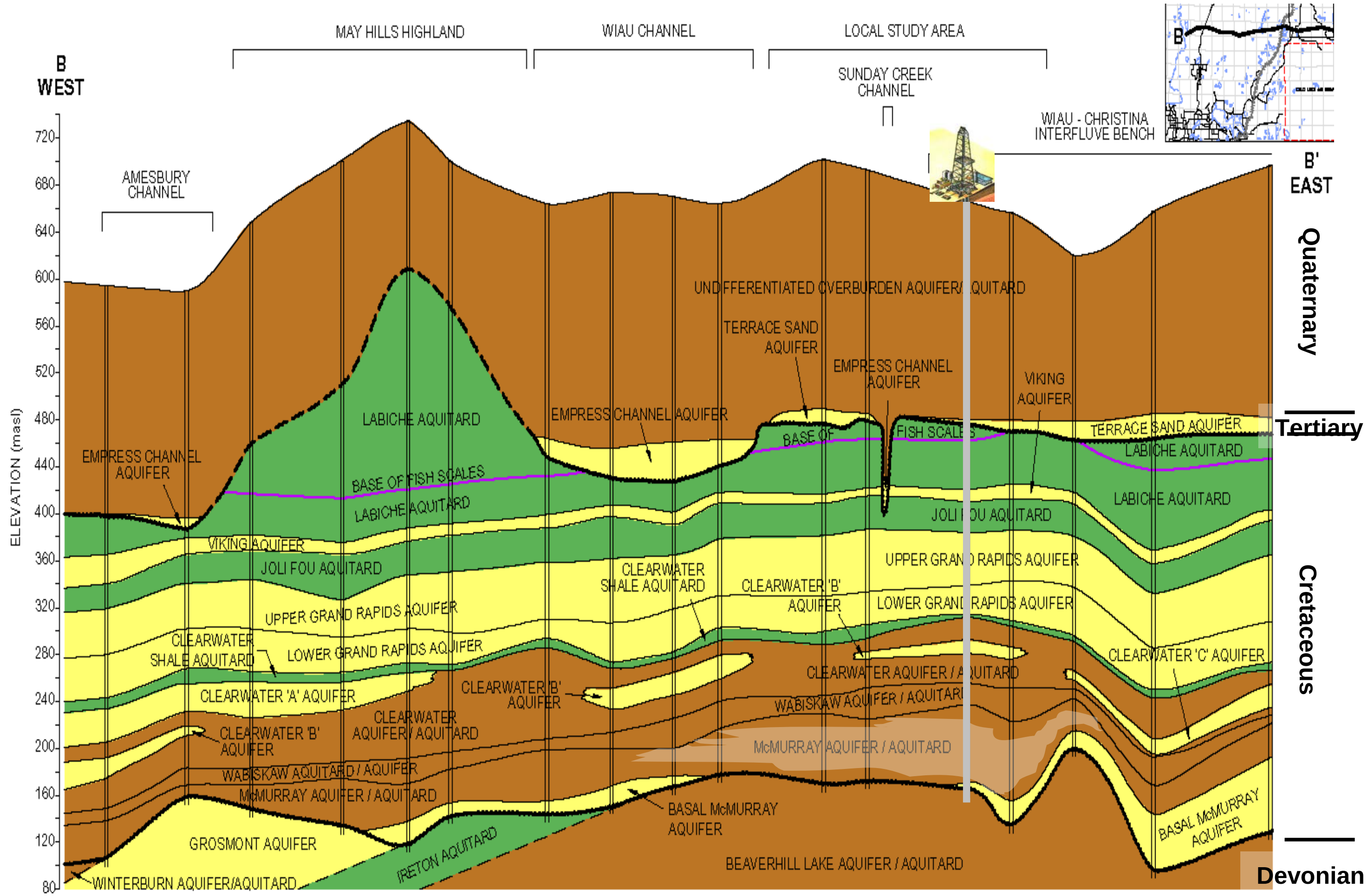
Area of Alberta, South of Fort McMurray



Korea
National Oil Corporation

Harvest
OPERATIONS CORP

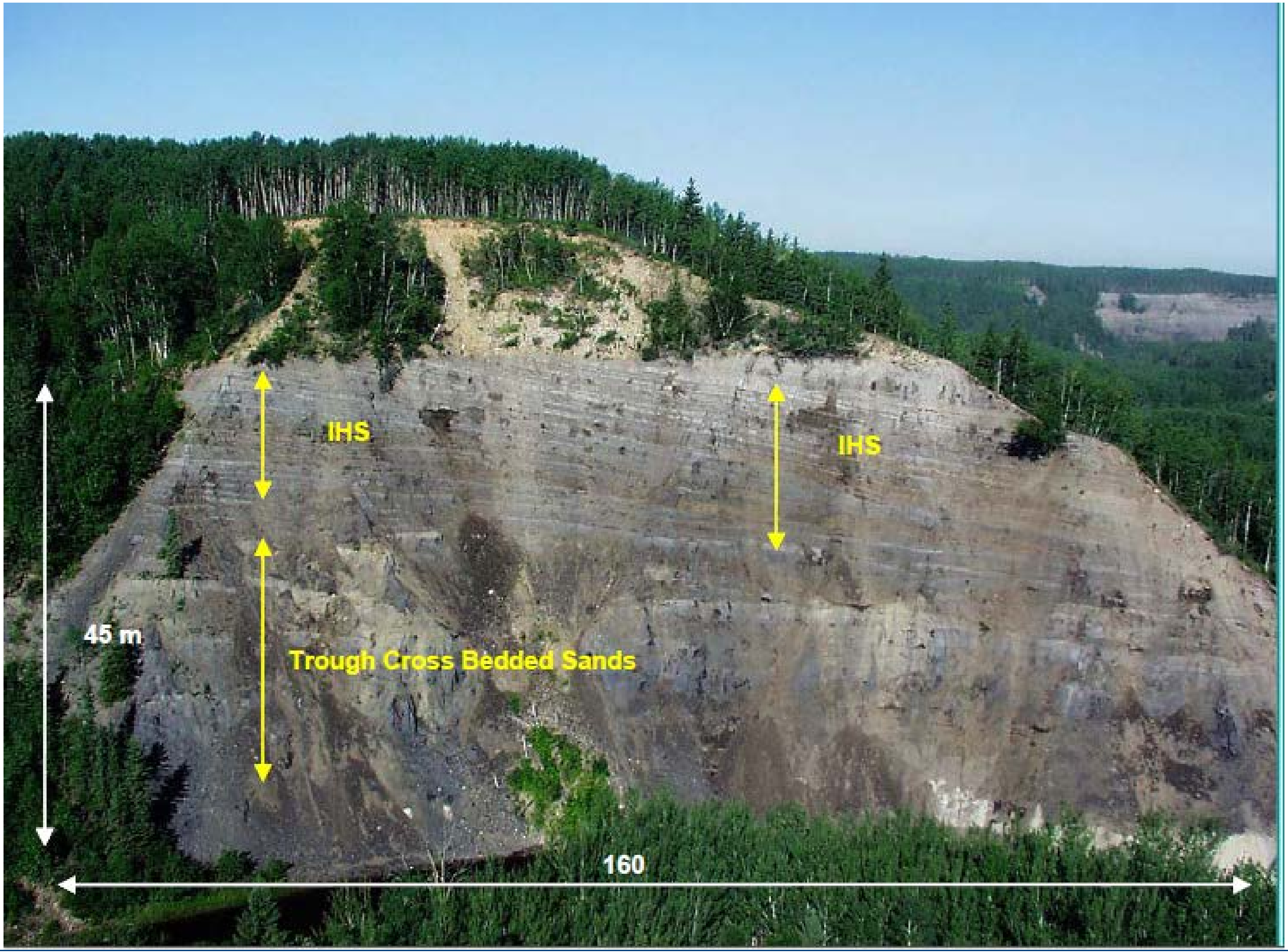
Geological Cross Section



Korea National Oil Corporation

Harvest OPERATIONS CORP

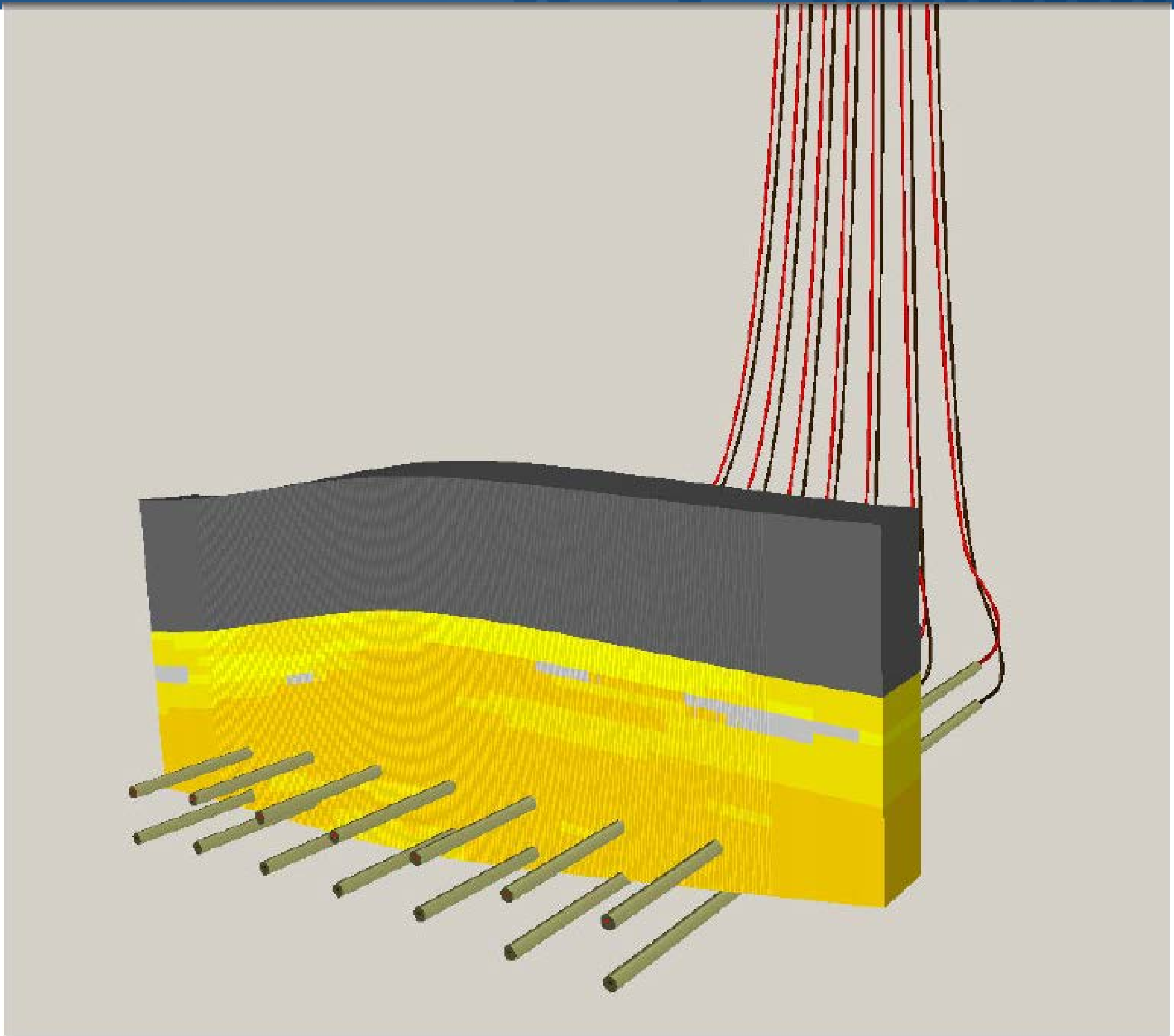
McMurray Outcrop



Korea National Oil Corporation

Australia Example, Estuary

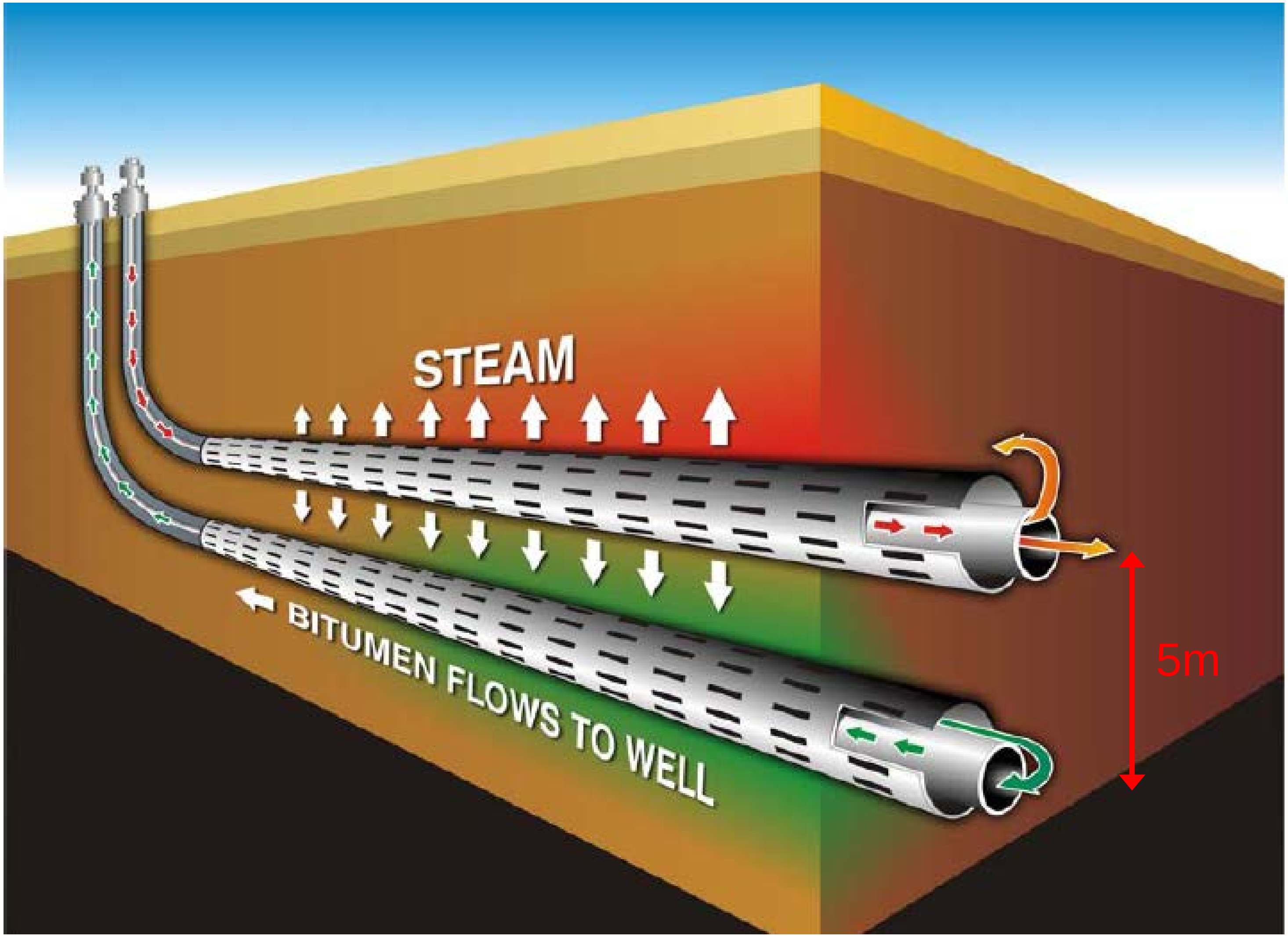
Horizontal Well Pairs



Korea
National Oil Corporation

Harvest
OPERATIONS CORP

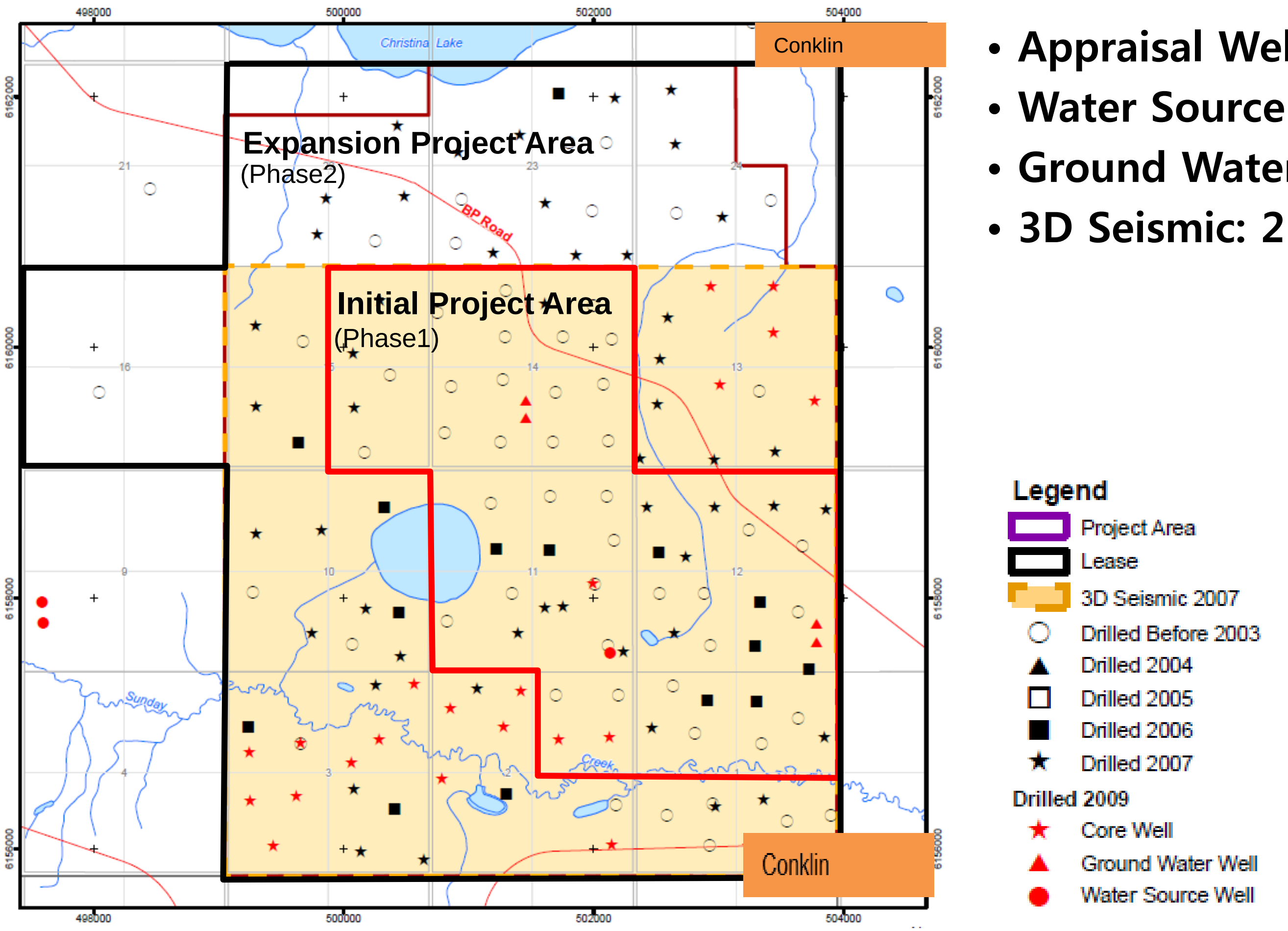
SAGD Schematic



Korea National Oil Corporation

Harvest OPERATIONS CORP

Project area Detail

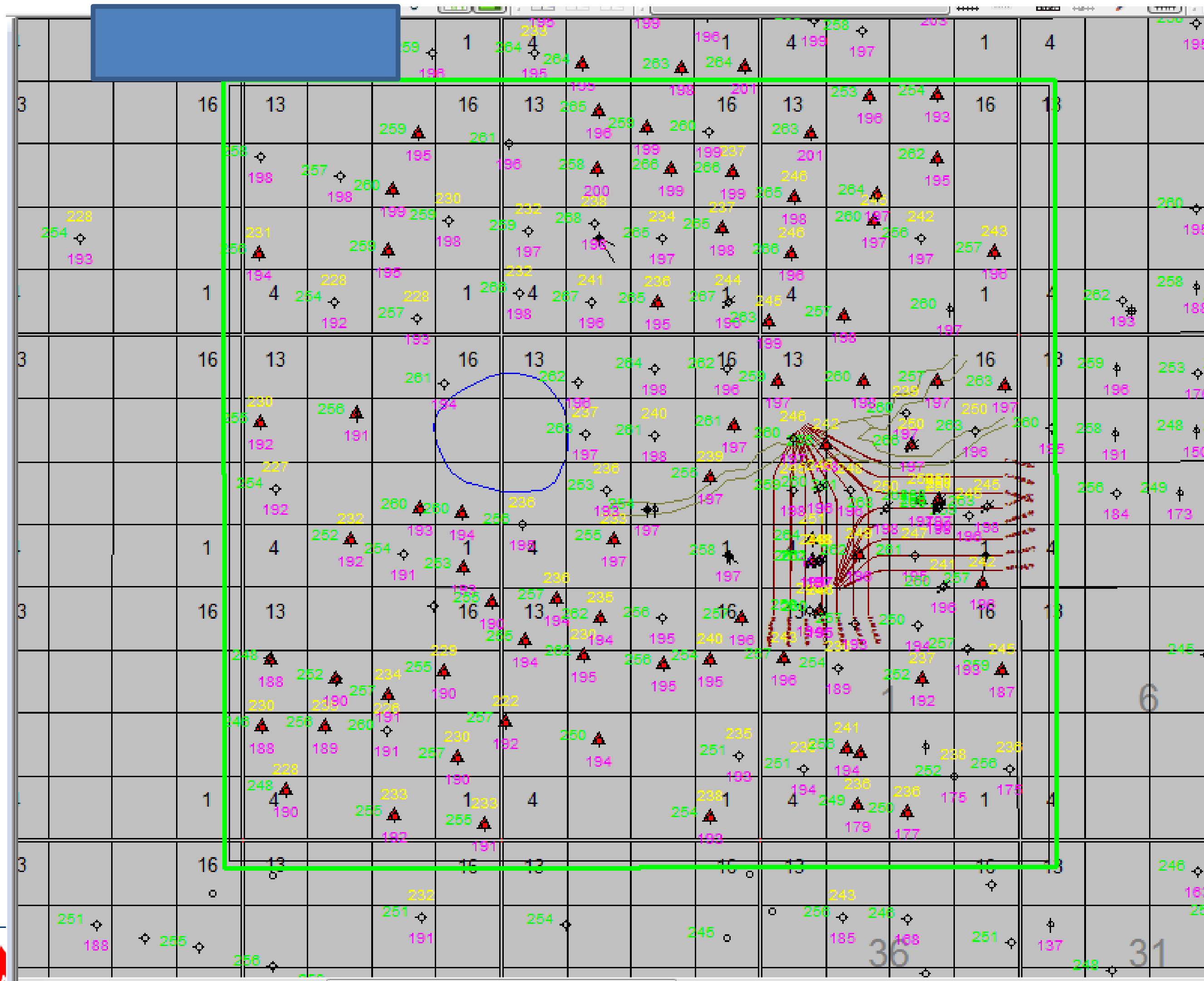


- Appraisal Well: 140
- Water Source Well: 12
- Ground Water Monitoring: 4
- 3D Seismic: 23㎢ (9 Sections)

Korea
National Oil Corporation

Harvest OPERATIONS CORP

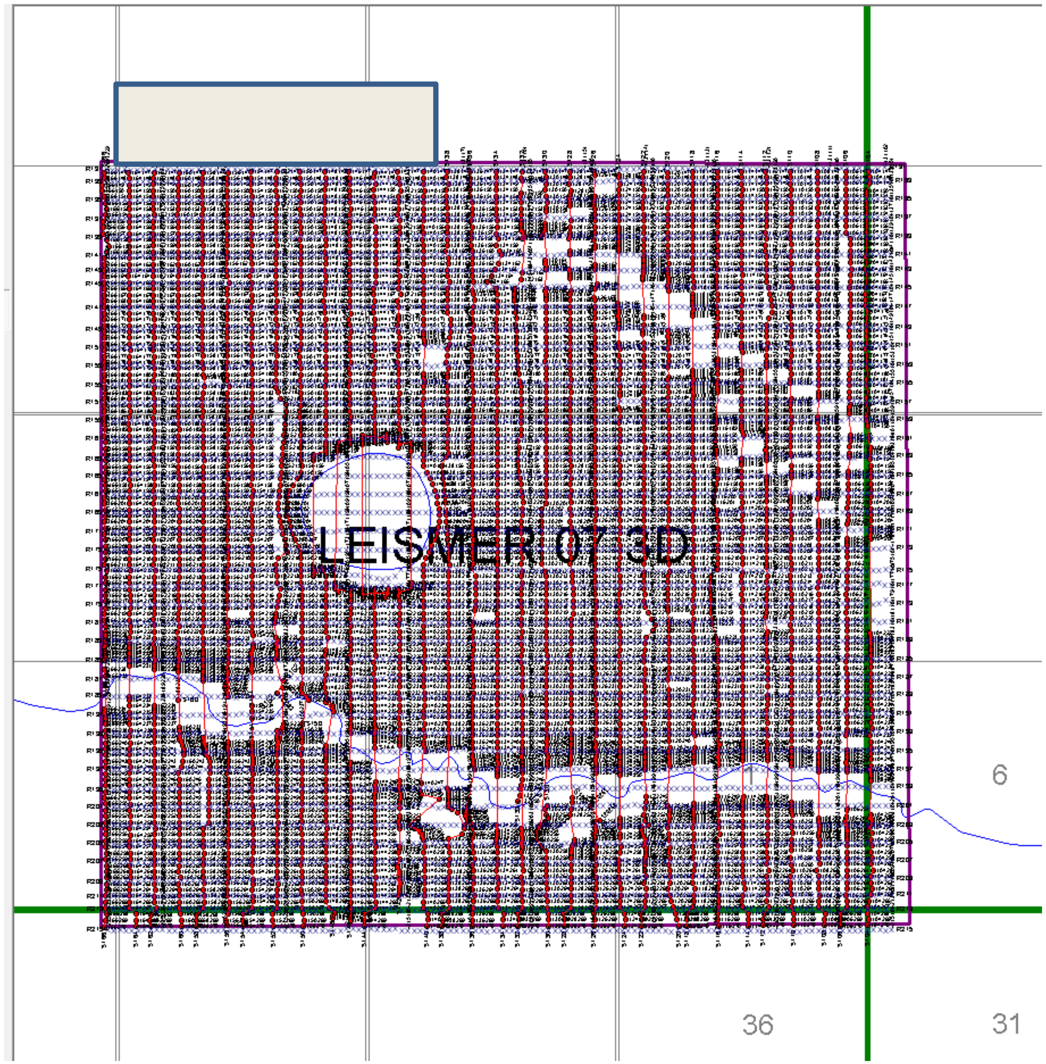
3-D outline with well control



Korea
National Oil Corporation

Harvest
OPERATIONS CORP

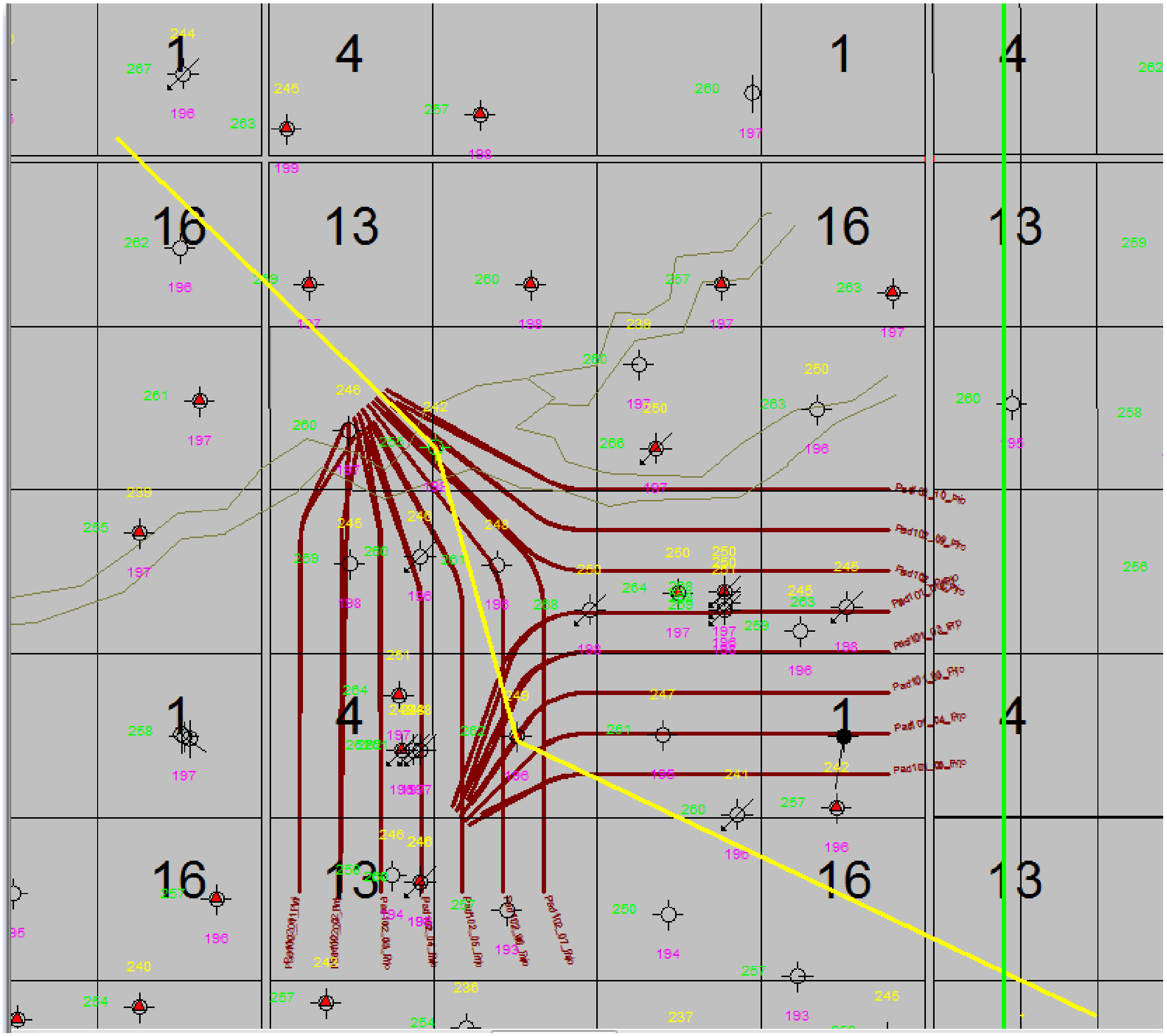
Seismic Survey



Korea National Oil Corporation

Harvest OPERATIONS CORP

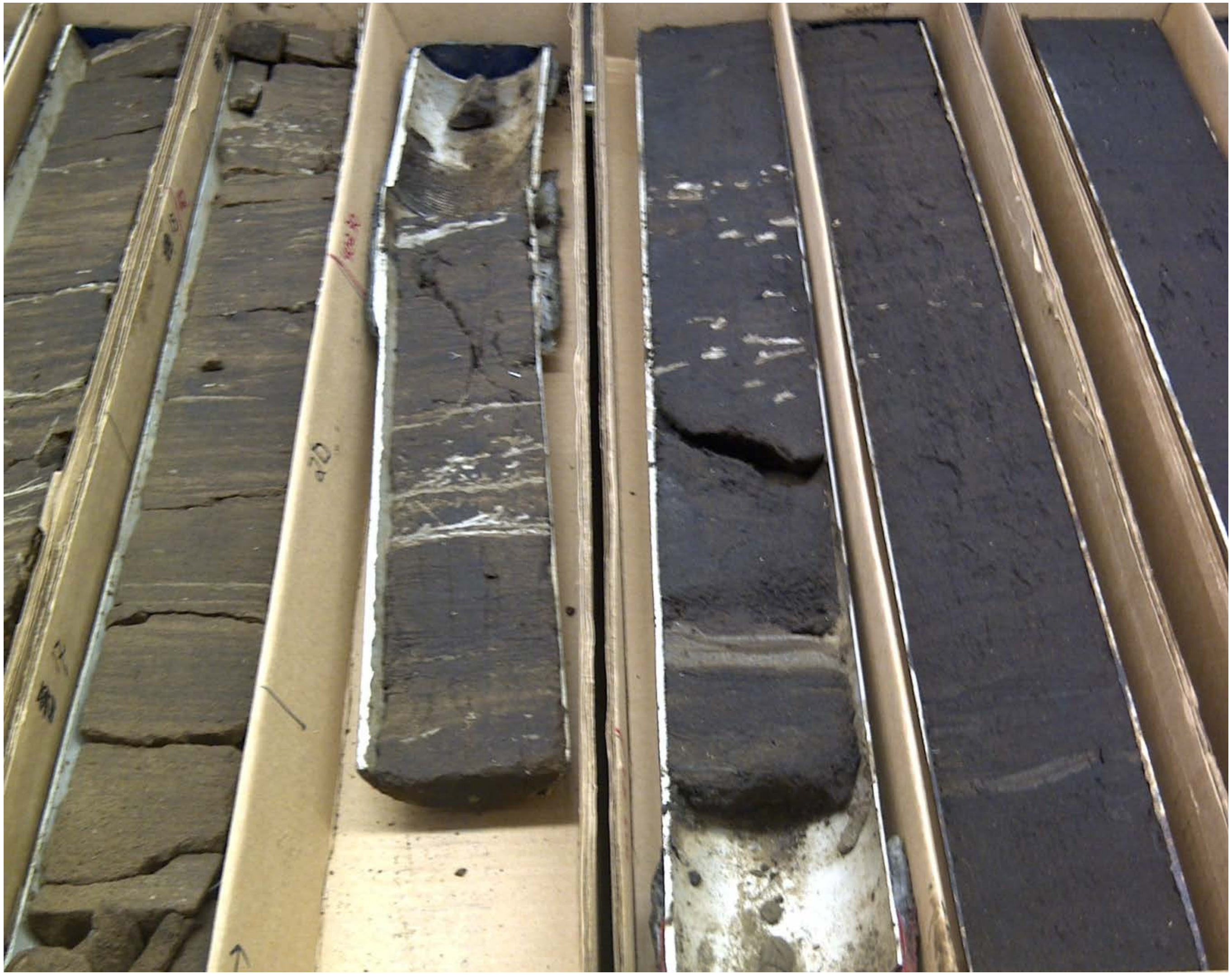
Horizontal Program Plan With Seismic Cross Section



KNOC
Korea
National Oil Corporation

Harvest
OPERATIONS CORP

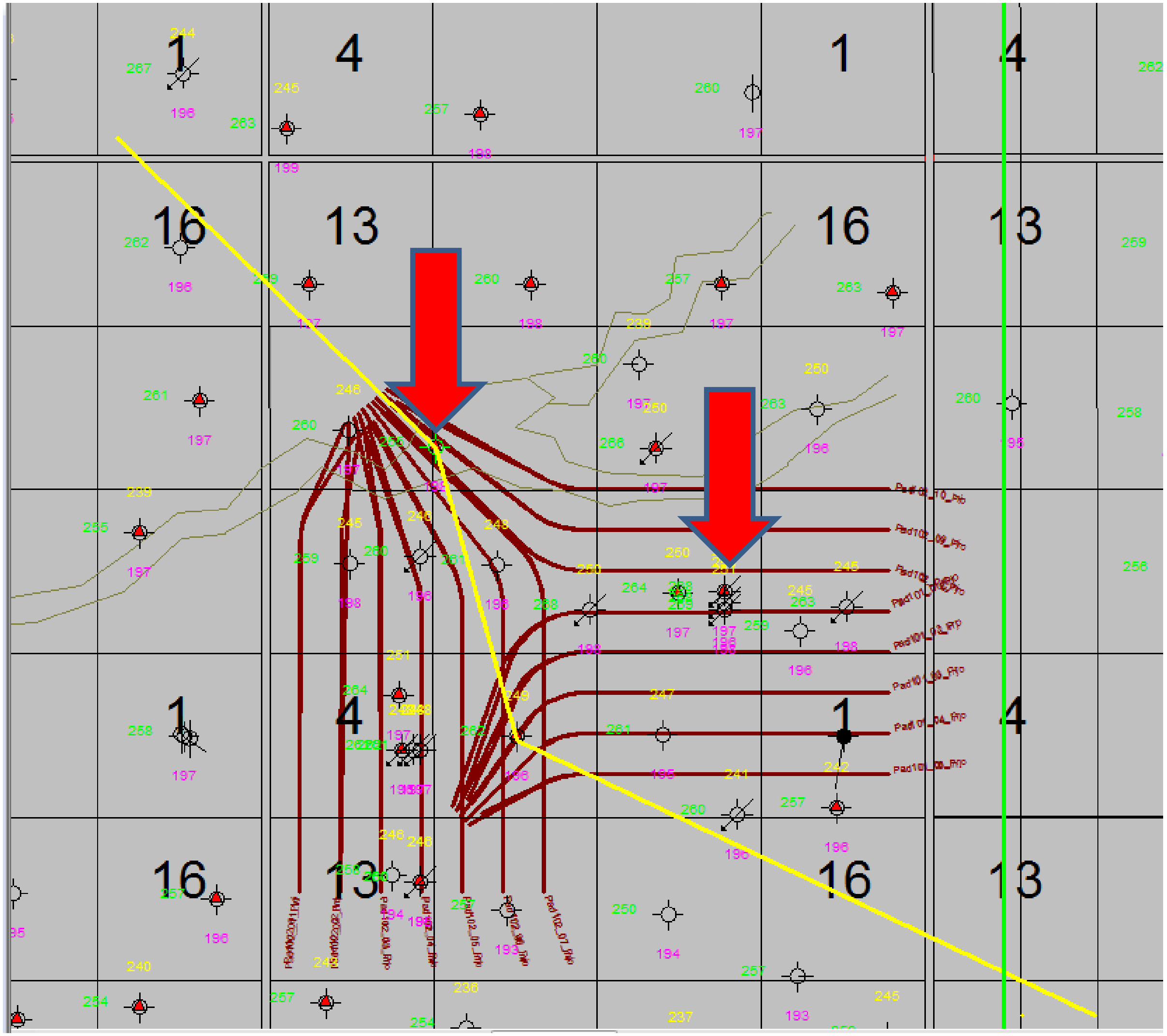
Core Showing Shale / Sand interface



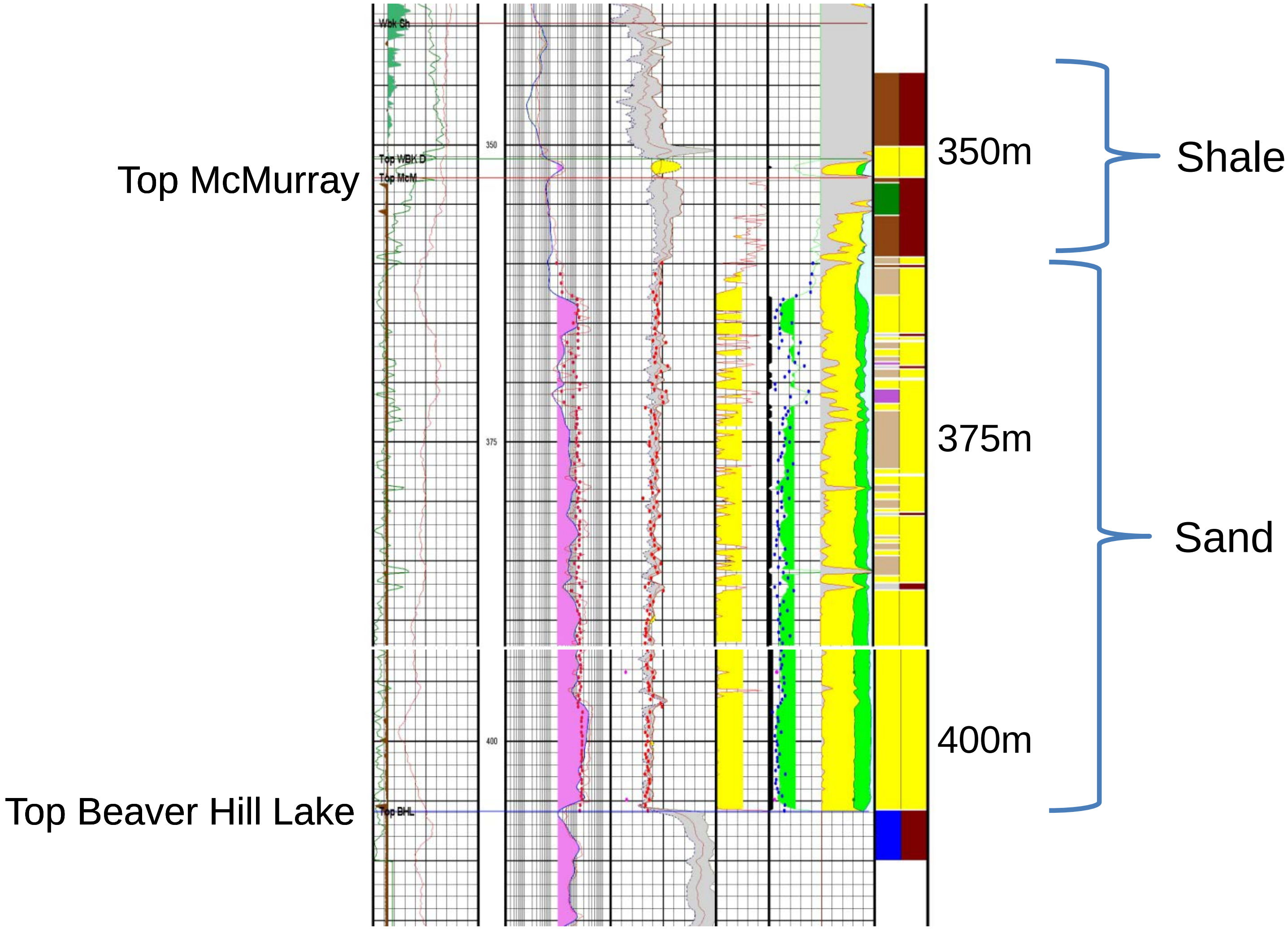
Korea
National Oil Corporation

Harvest
OPERATIONS CORP

Two Key Well Ties Initial well plan, Seismc cross section

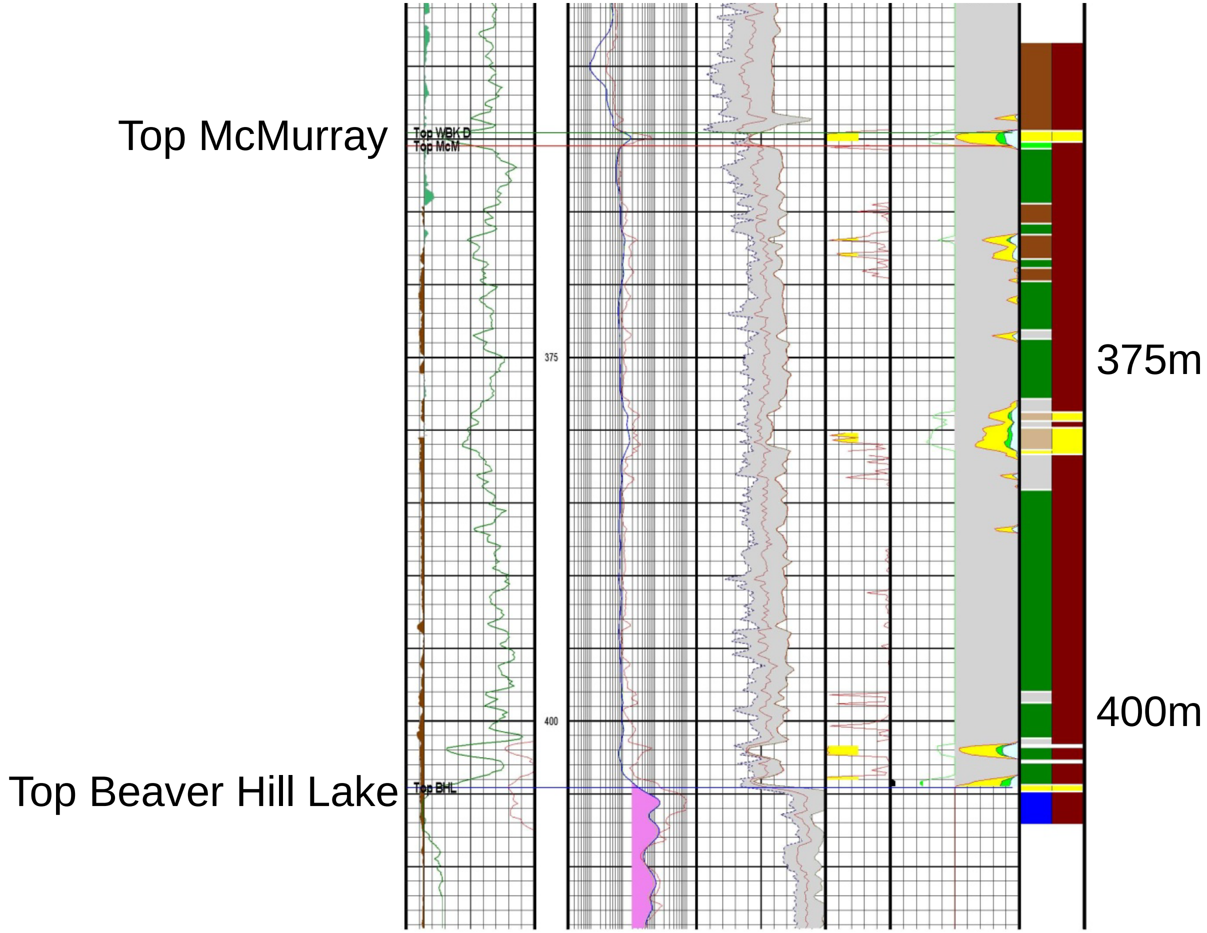


07-12-



Top McMurray
Top Beaver Hill Lake
Wbk Sh
Top WBK D
Top McM
Top BHL
350
375
400
350m
375m
400m
Shale
Sand

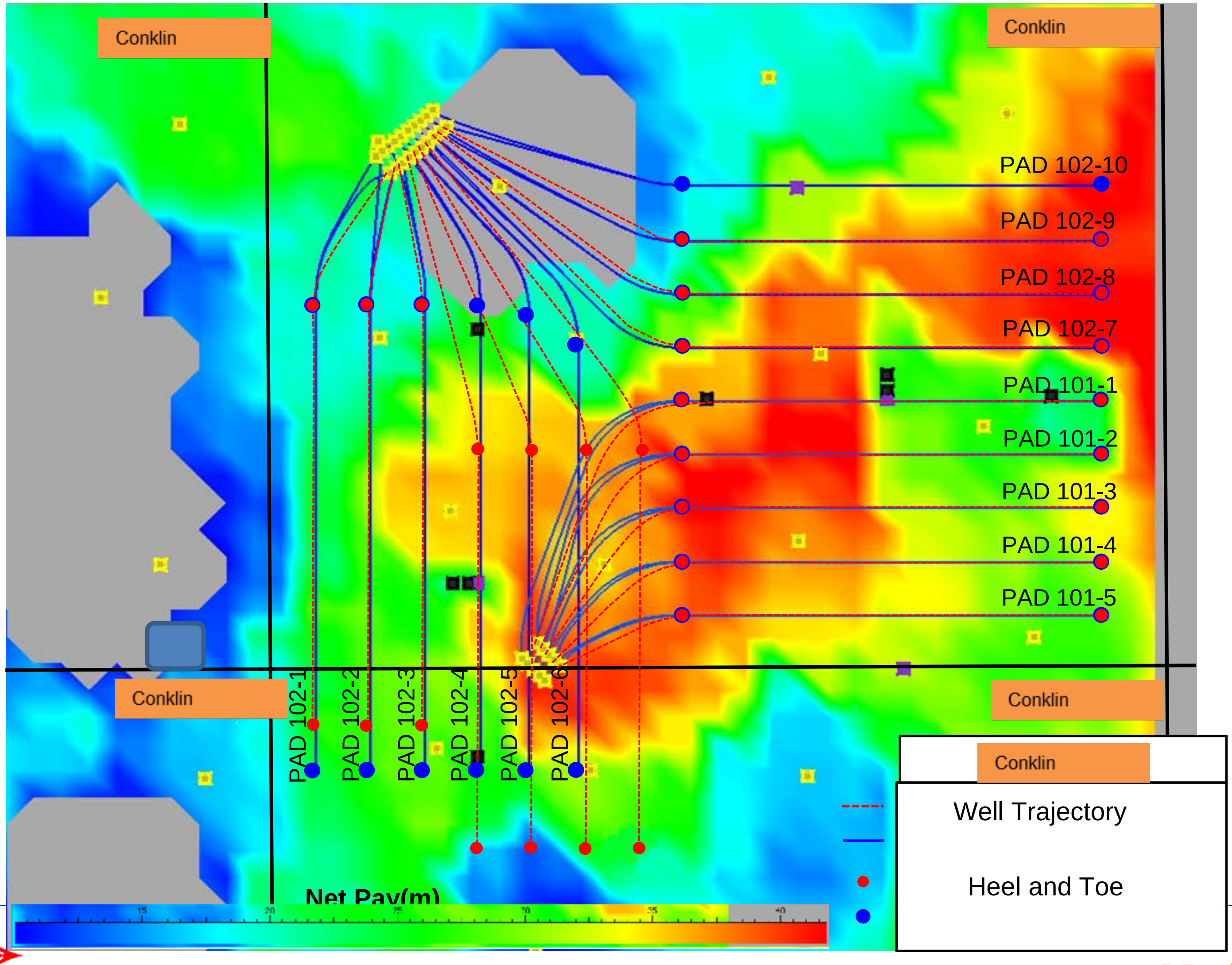
11-12



Korea National Oil Corporation

Harvest OPERATIONS CORP

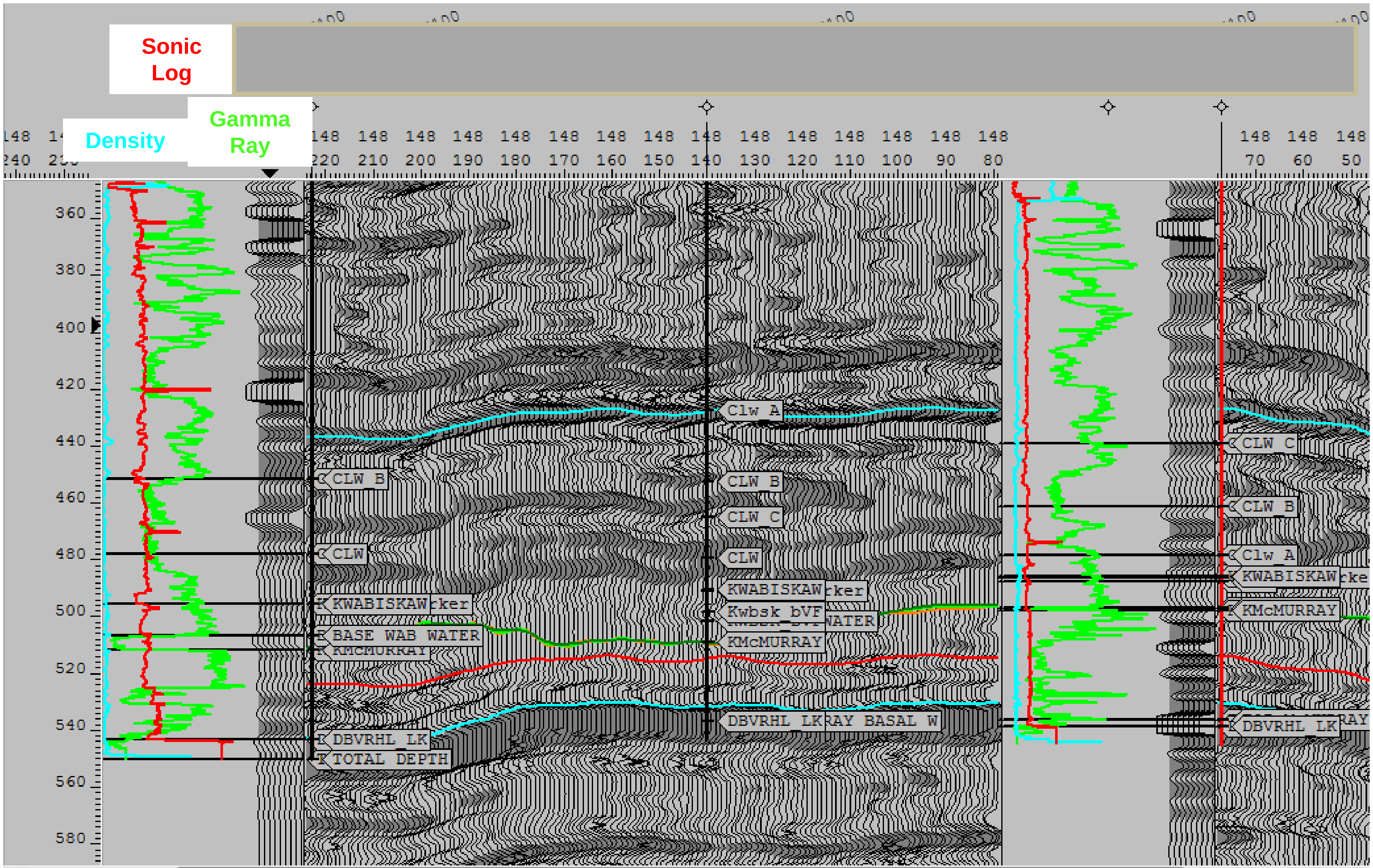
Shale plug defined by geomodeling, McMurray isopach.



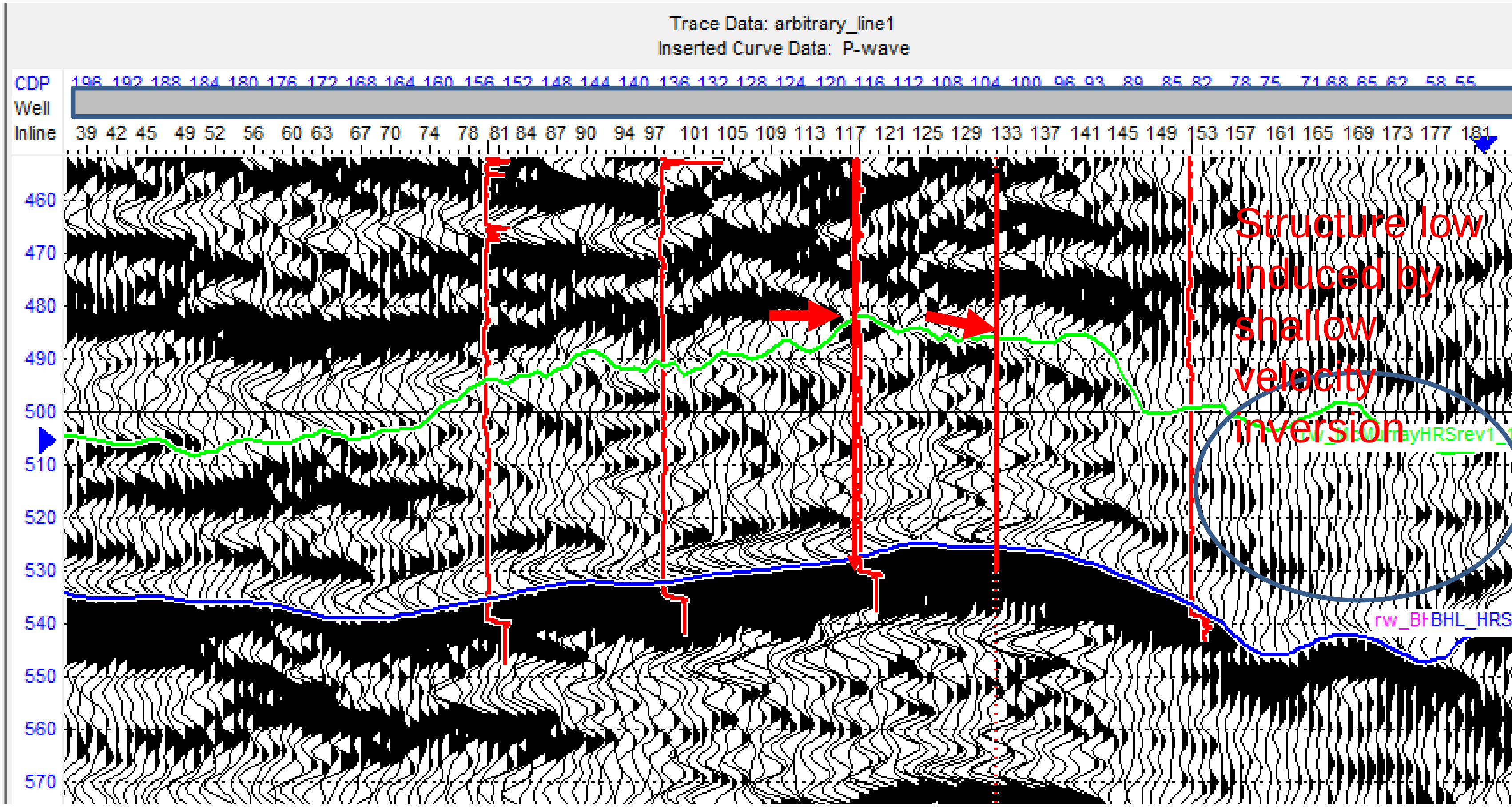
Korea National Oil Corporation

Harvest OPERATIONS CORP

General Seismic Correlation



11-12 and 04-13 stack comparison



Korea National Oil Corporation

Post stack (zero offset) equation

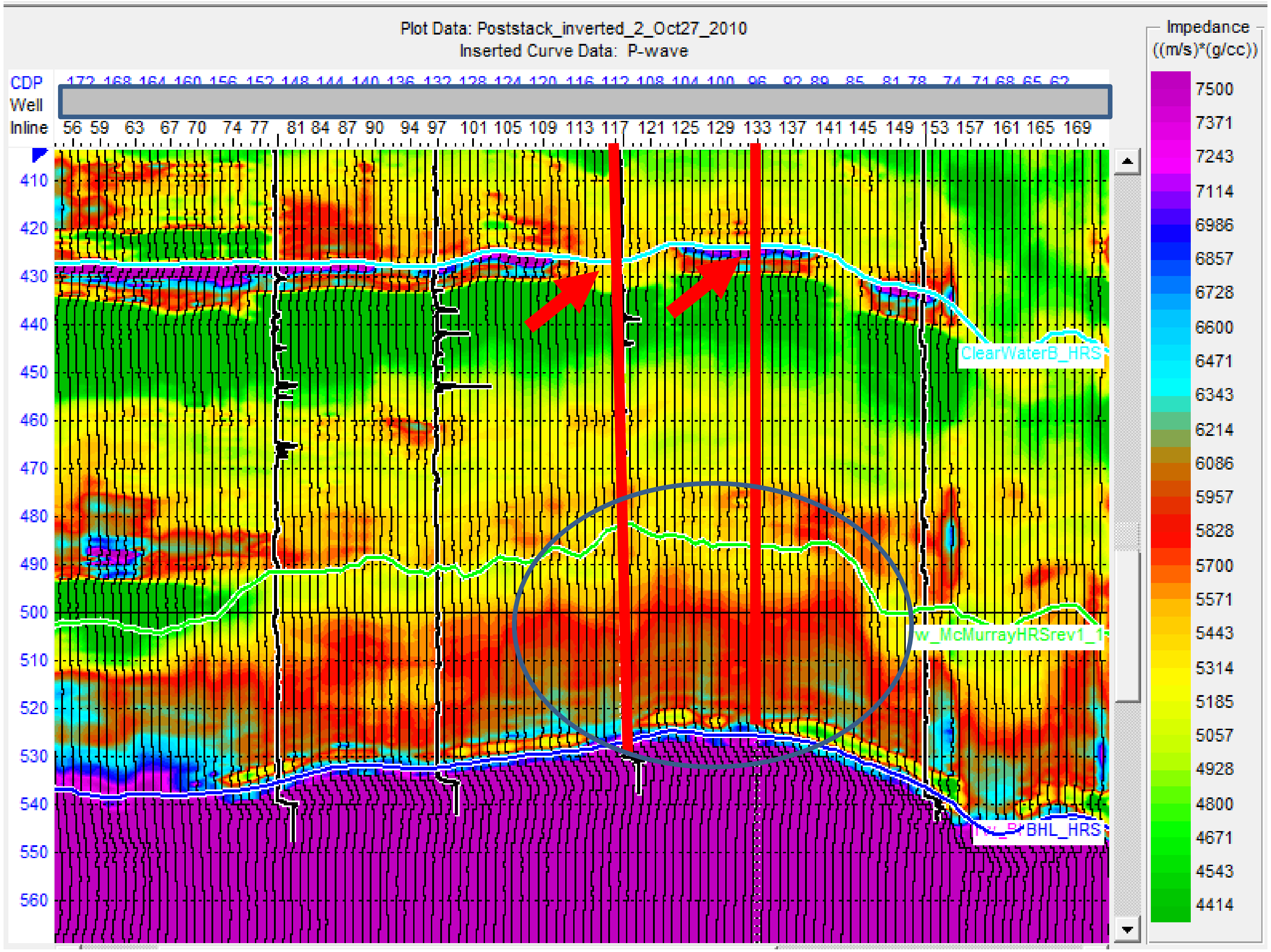
Post-stack seismic inversion

$$s_t = w_t * r_t$$

$$r_{Pi} = \frac{Z_{Pi+1} - Z_{Pi}}{Z_{Pi+1} + Z_{Pi}},$$

$$Z_{Pi+1} = Z_{Pi}\left[\frac{1 + r_{Pi}}{1 - r_{Pi}}\right].$$

Post stack inversion was not diagnostic of lithology in this case



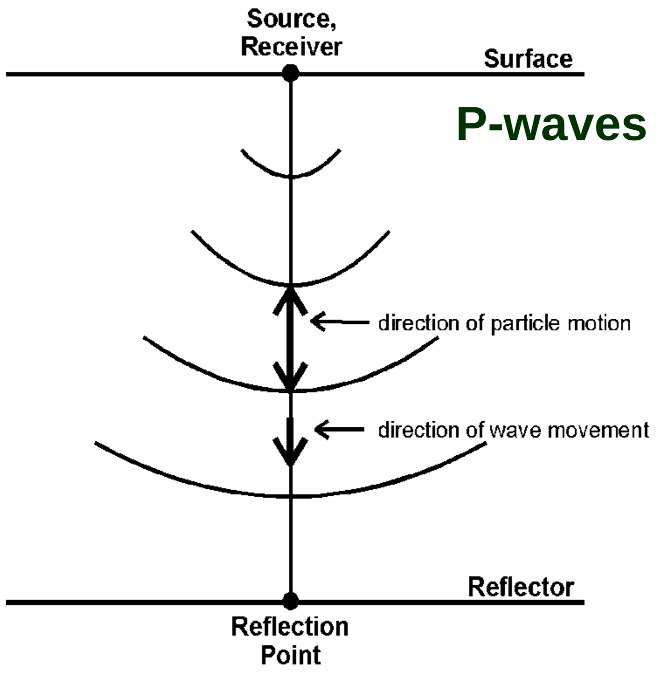
Korea
National Oil Corporation

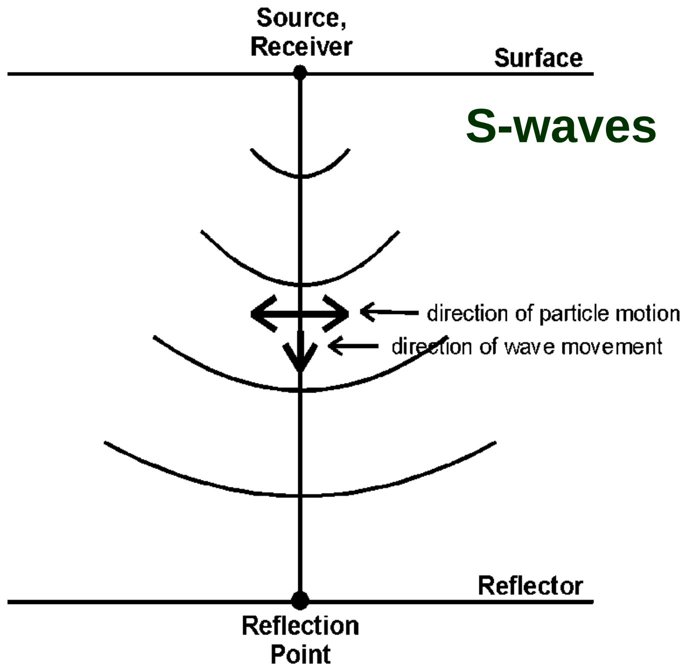
P and S-Wave Velocities

This lead to two different types of velocities:

***P-wave, or compressional wave velocity*, in which the direction of particle motion is in the same direction as the wave movement.**

***S-wave, or shear wave velocity*, in which the direction of particle motion is at right angles to the wave movement.**

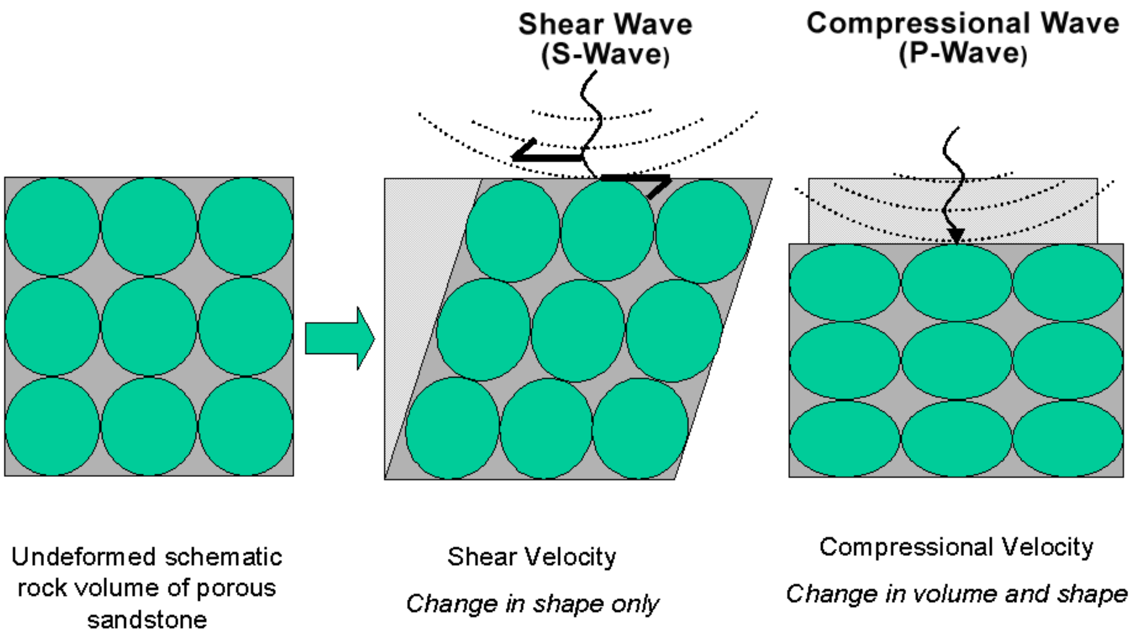




Korea
National Oil Corporation

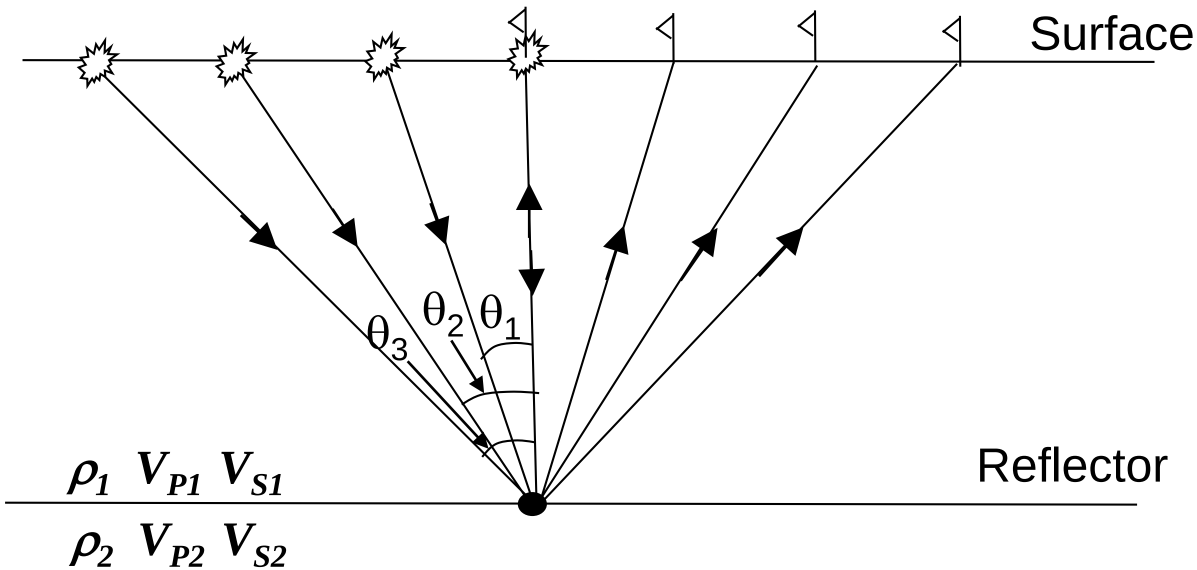
P and S-Wave Velocities

•Unlike density, *seismic velocity* involves the deformation of a rock as a function of time. As shown below, a cube of rock can be *compressed*, which changes its volume and shape or *sheared*, which changes its shape but not its volume.



After Goodway (CSEG Recorder 06/2001)

What causes the AVO Effect?



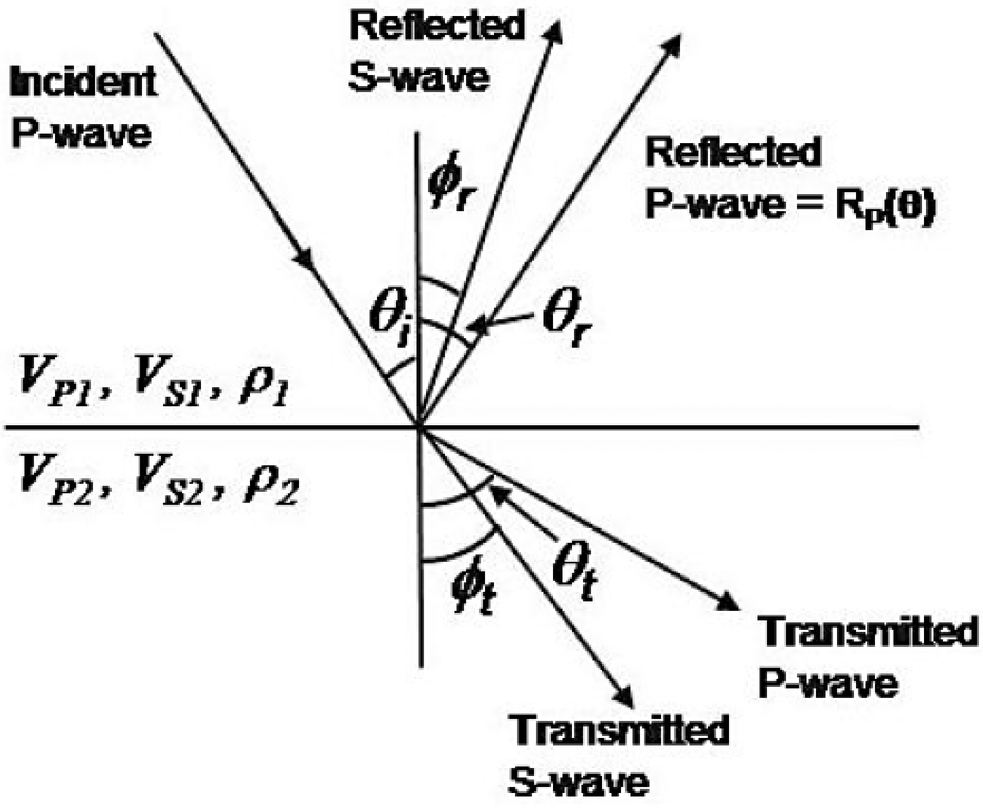
•The traces in a seismic gather reflect from the subsurface at increasing angles of incidence *q*. The first order approximation to the reflection coefficients as a function of angle is given by adding a second term to the zero-offset reflection coefficient:

$$R(\theta) = R_0 + B\sin^2\theta$$

B **is a gradient term which produces the AVO effect. It is dependent on changes in density, ρ, P-wave velocity, V_P, and S-wave velocity, V_S.**

Korea National Oil Corporation

Harvest Operations Corp


Reflected
S-wave
Incident
P-wave
ϕ_r
Reflected
P-wave = $R_p(\theta)$
θ_i
θ_r
V_{P1}, V_{S1}, ρ_1
V_{P2}, V_{S2}, ρ_2
ϕ_t
θ_t
Transmitted
P-wave
Transmitted
S-wave

Aki-Richards equation

We start with Fatti's version of the Aki-Richards' equation. This models reflection amplitude as a function of incident angle:

$$R_{PP}(\theta) = c_1 R_P + c_2 R_S + c_3 R_D$$

where:

$$c_1 = 1 + \tan^2\theta$$
$$c_2 = -8\gamma^2 \sin^2\theta$$
$$c_3 = -\frac{1}{2}\tan^2\theta + 2\gamma^2 \sin^2\theta$$
$$\gamma = \frac{V_S}{V_P}$$

$$R_P = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} + \frac{\Delta\rho}{\rho}\right]$$
$$R_S = \frac{1}{2}\left[\frac{\Delta V_S}{V_S} + \frac{\Delta\rho}{\rho}\right]$$
$$R_D = \frac{\Delta\rho}{\rho}.$$

Aki-Richards equation

A problem with this equation is that the coefficients are not equal in size. This makes the solution for R_S and Density unstable at small angles:

		$\theta = 30^0$	$\theta = 60^0$
$c_1 = 1 + \tan^2\theta$	=	1.330	4.000
$c_2 = -8\gamma^2 \sin^2\theta$	=	-0.500	-1.500
$c_3 = -\frac{1}{2}\tan^2\theta + 2\gamma^2\sin^2\theta$	=	-0.041	-1.125

$$\gamma = \frac{V_S}{V_P} = 0.5$$

Conclusion: the direct solution can be unstable.

Transforming variables

Relationship of Variables

We want to use the fact that the basic variables, Z_P, Z_S, and ρ are related.

We start with two relationships which should hold for the background "wet" trend:

$$V_S / V_P = \gamma = \text{constant}$$
$$\rightarrow \ln(Z_S) = \ln(Z_P) + \ln(\gamma)$$

Constant γ

and:

$$\rho = a V_P^b$$
$$\rightarrow \ln(\rho) = \frac{b}{1+b} \ln(Z_P) + \frac{\ln(a)}{1+b}$$

Generalized Gardner

Korea National Oil Corporation

Harvest Operations Corp

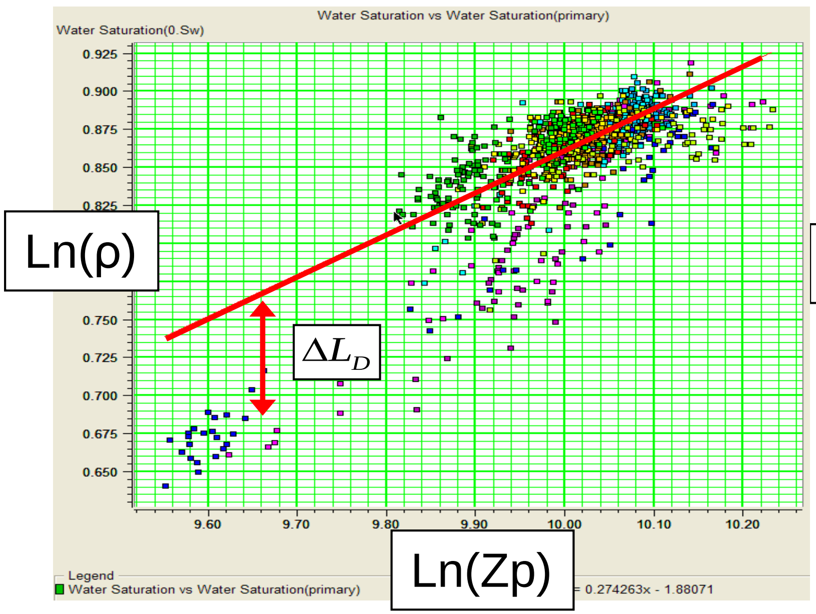
Transforming variables

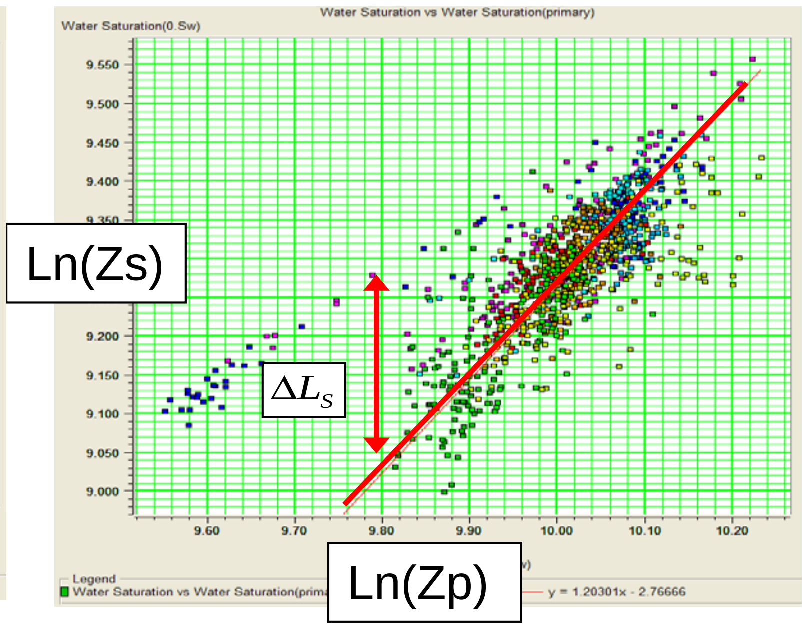
Model constraints

Both these relationships lead us to the more general model for the background trend:

$$\ln(Z_S) = k\ln(Z_P) + k_c + \Delta L_S$$

$$\ln(\rho) = m\ln(Z_P) + m_c + \Delta L_D$$





Korea
National Oil Corporation

The new equation

Normalised Equation

This changes Fatti's equation to:

$$\mathrm{R}(\theta) = \tilde{c}_1 W(\theta) D L_P + \tilde{c}_2 W(\theta) D \Delta L_S + c_3 W(\theta) D \Delta L_D$$

where:

$$\tilde{c}_1 = (1/2)\, c_1 + (1/2)\, k c_2 + m c_3$$

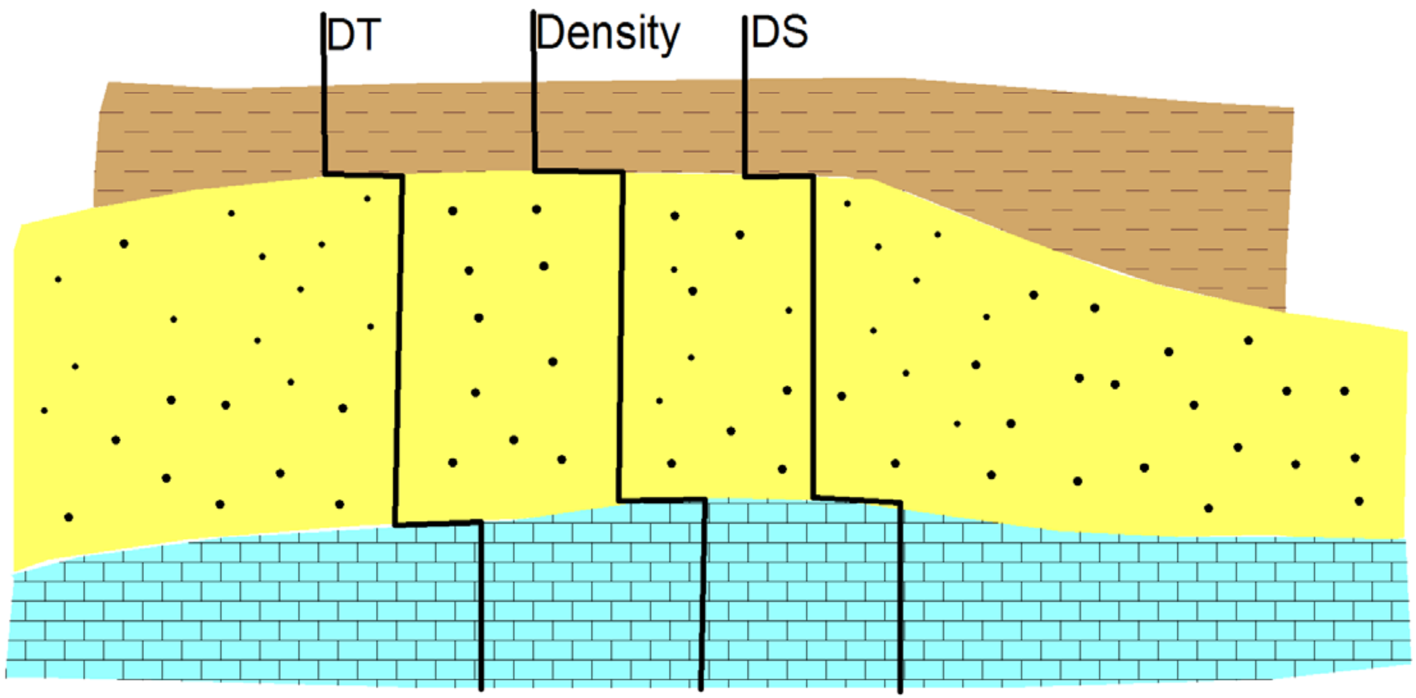
$$\tilde{c}_2 = (1/2)\, c_2$$

$$W(\theta) = \text{wavelet at angle } \theta$$

$$D = \text{Derivative operator}$$

$$L_P = \ln(Z_P)$$

General Sand Shale Logs
McMurray

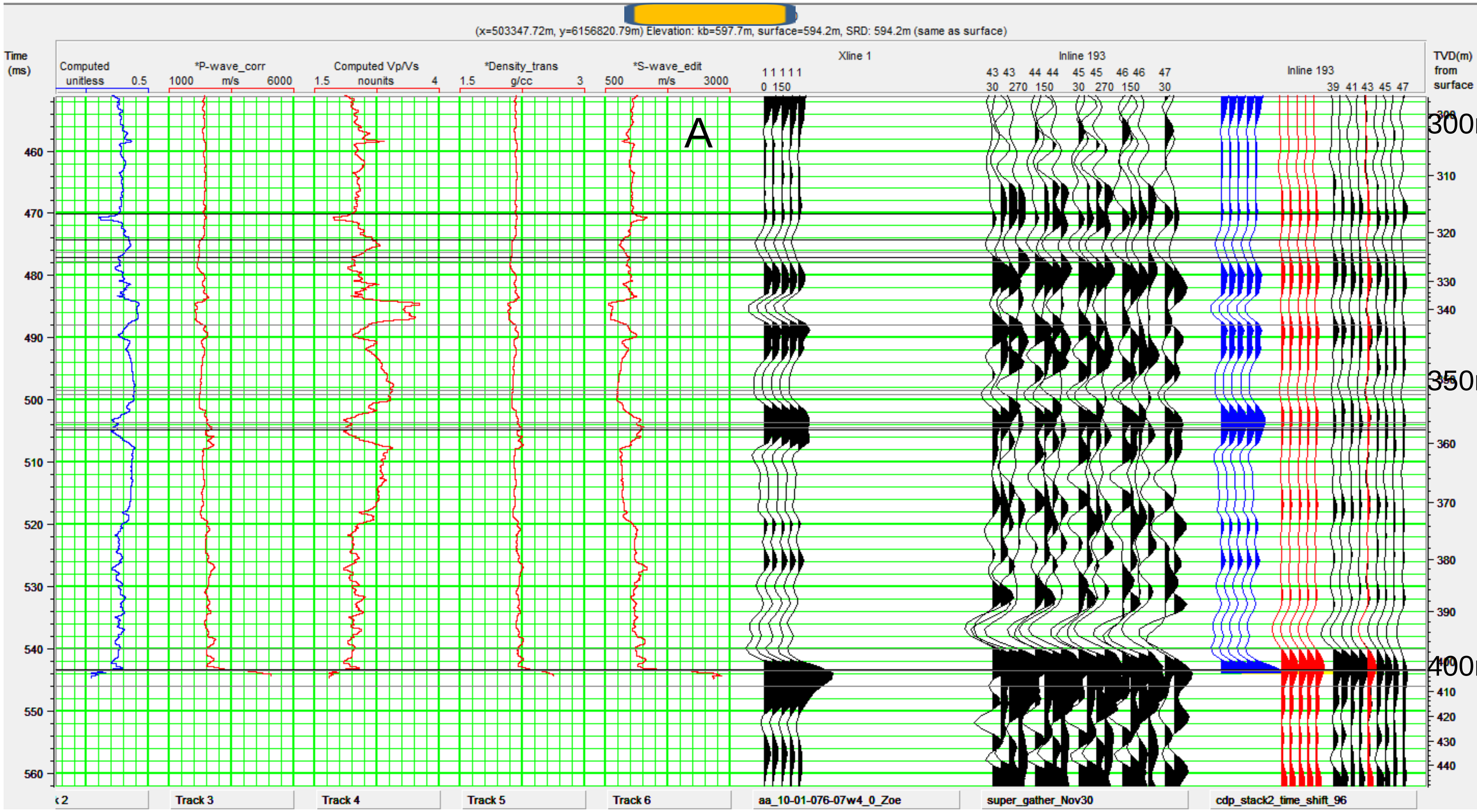


Korea
National Oil Corporation

Processing Considerations

- The 3-D was reprocessed in 2011 using an AVO compliant flow.
- The data was normalized to the bin center using 5-C interpolation. This served to condition the data for AVO and removed the acquisition footprint.
- 72 Synthetic seismograms were used for the McMurray Surface correlation
- The McMurray top was picked on the seismic data using the well control, this was used to constrain the pre stack inversion.

Well: [redacted] W4/0 AVO Model



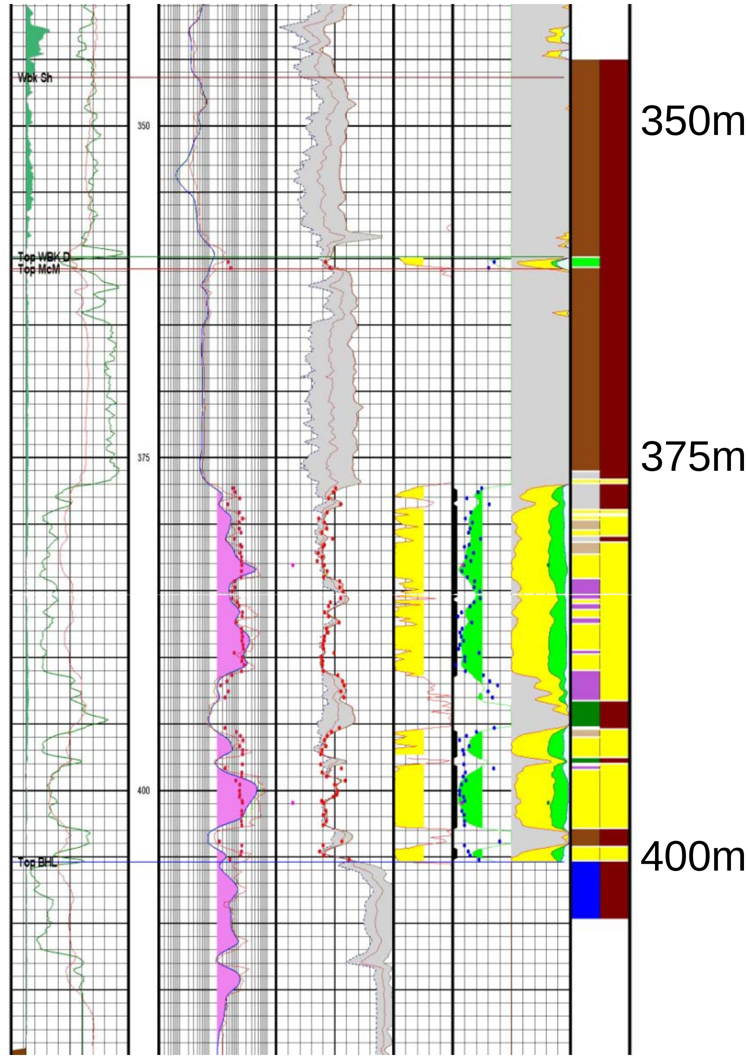
AVO synthetic

CMP Gathers

CMP Stack

Korea National Oil Corporation

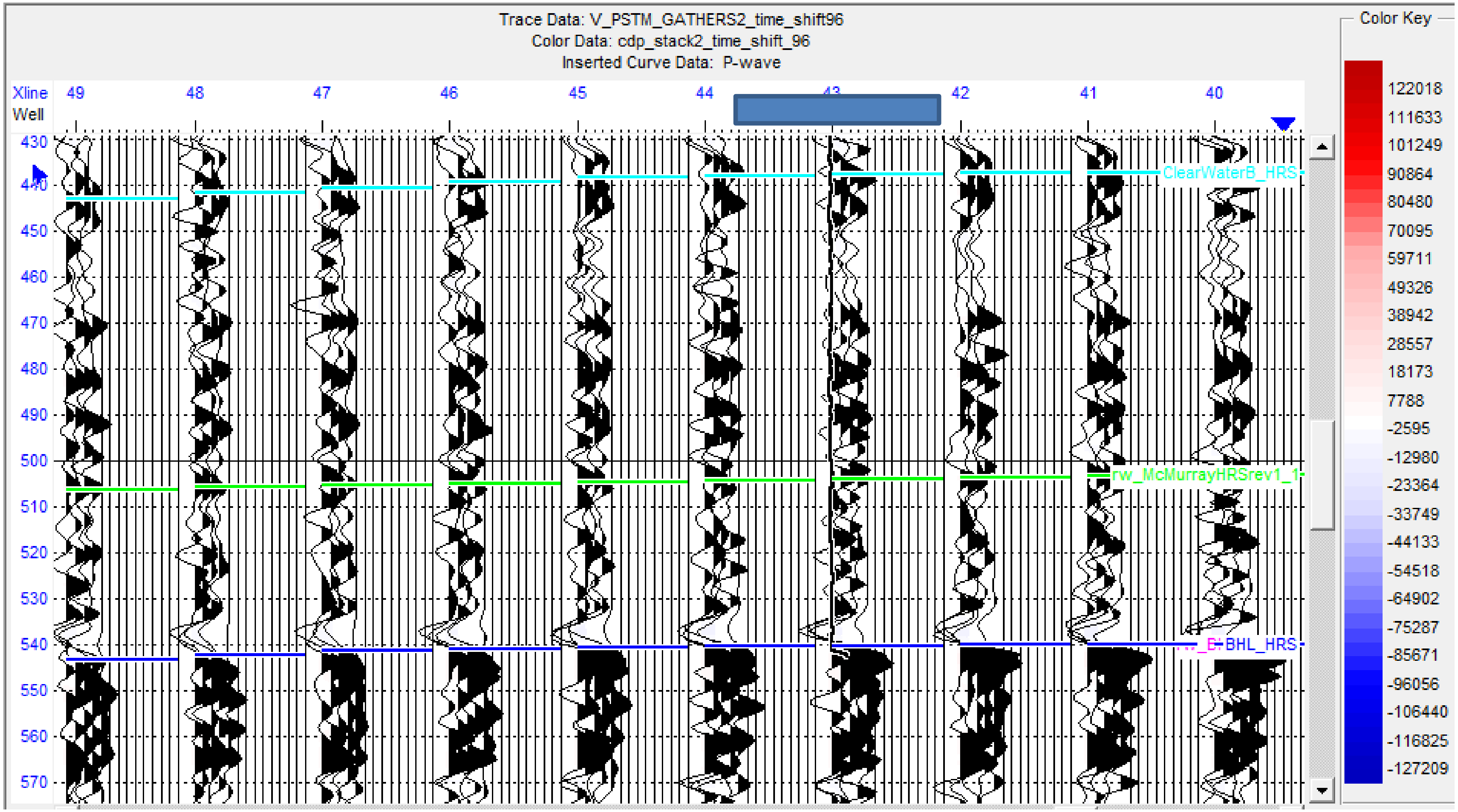
10-01 [redacted] location used for inversion



Korea
National Oil Corporation

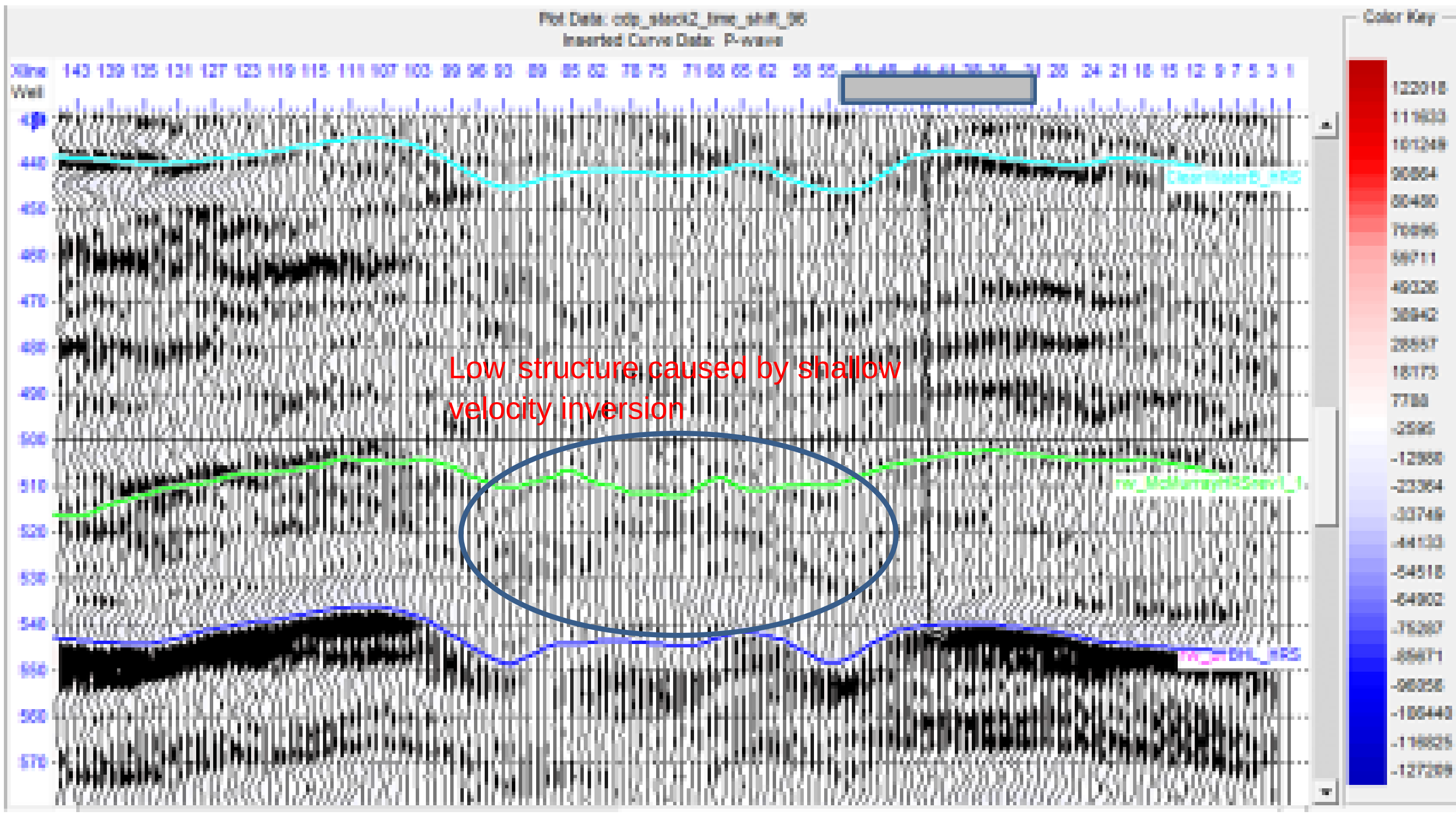
Harvest
OPERATIONS CORP

Gathers used for inversion input



Near surface velocity inversion

AVO scaled stack

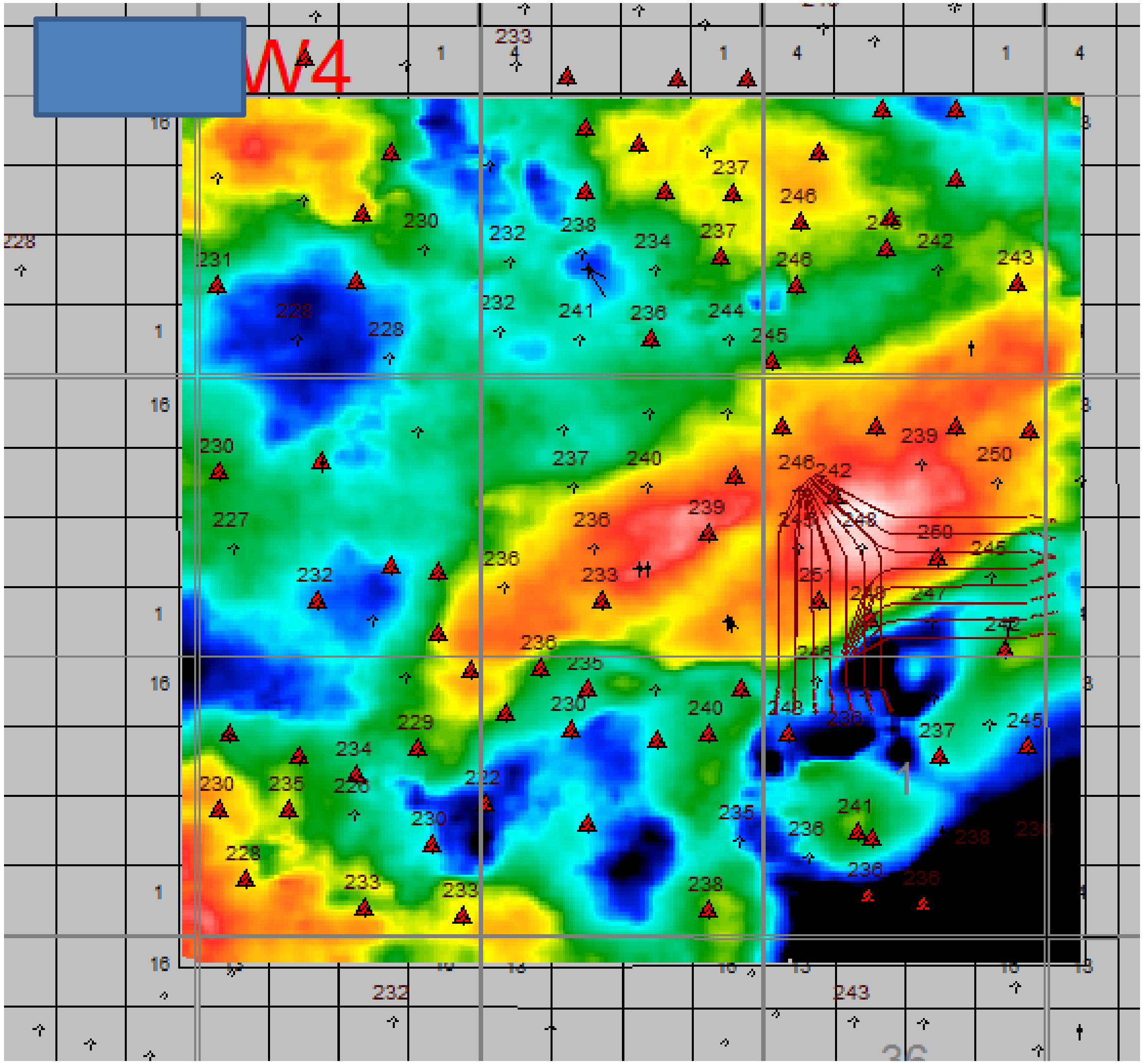


Korea National Oil Corporation

Beaver Hill Lake Time Structure

526 ms.

549 ms.

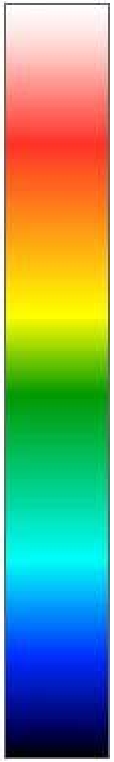


Korea
National Oil Corporation

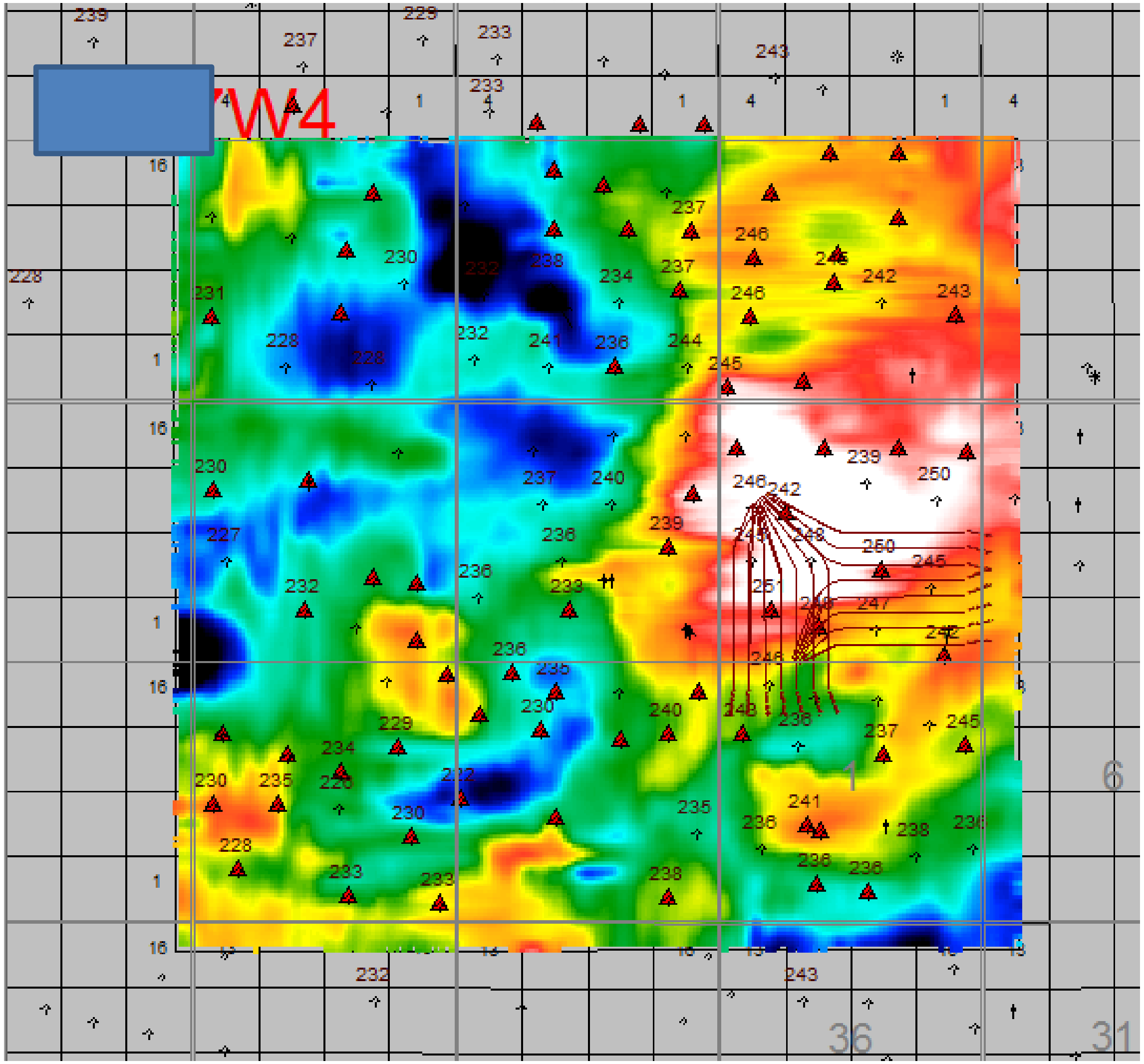
Harvest
OPERATIONS CORP

McMurray Time Structure

472
ms.



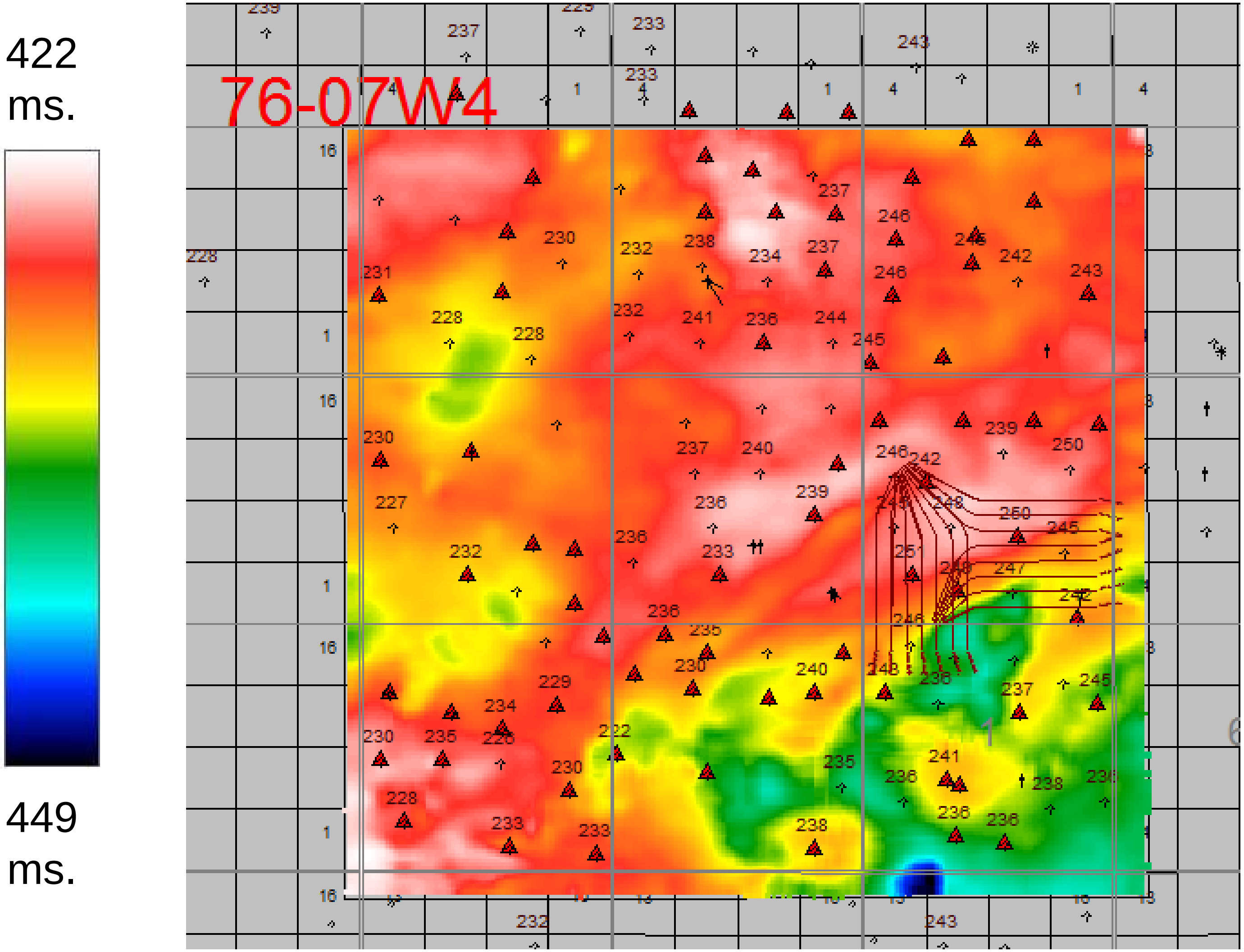
522
ms.



Korea
National Oil Corporation

Harvest
OPERATIONS CORP

Clearwater Time Structure

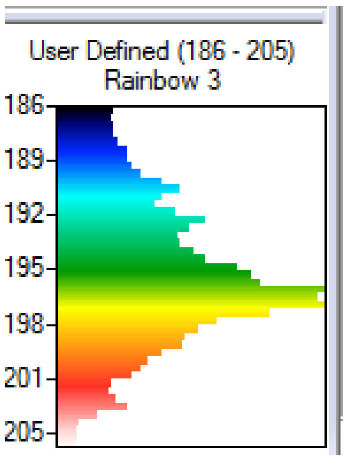


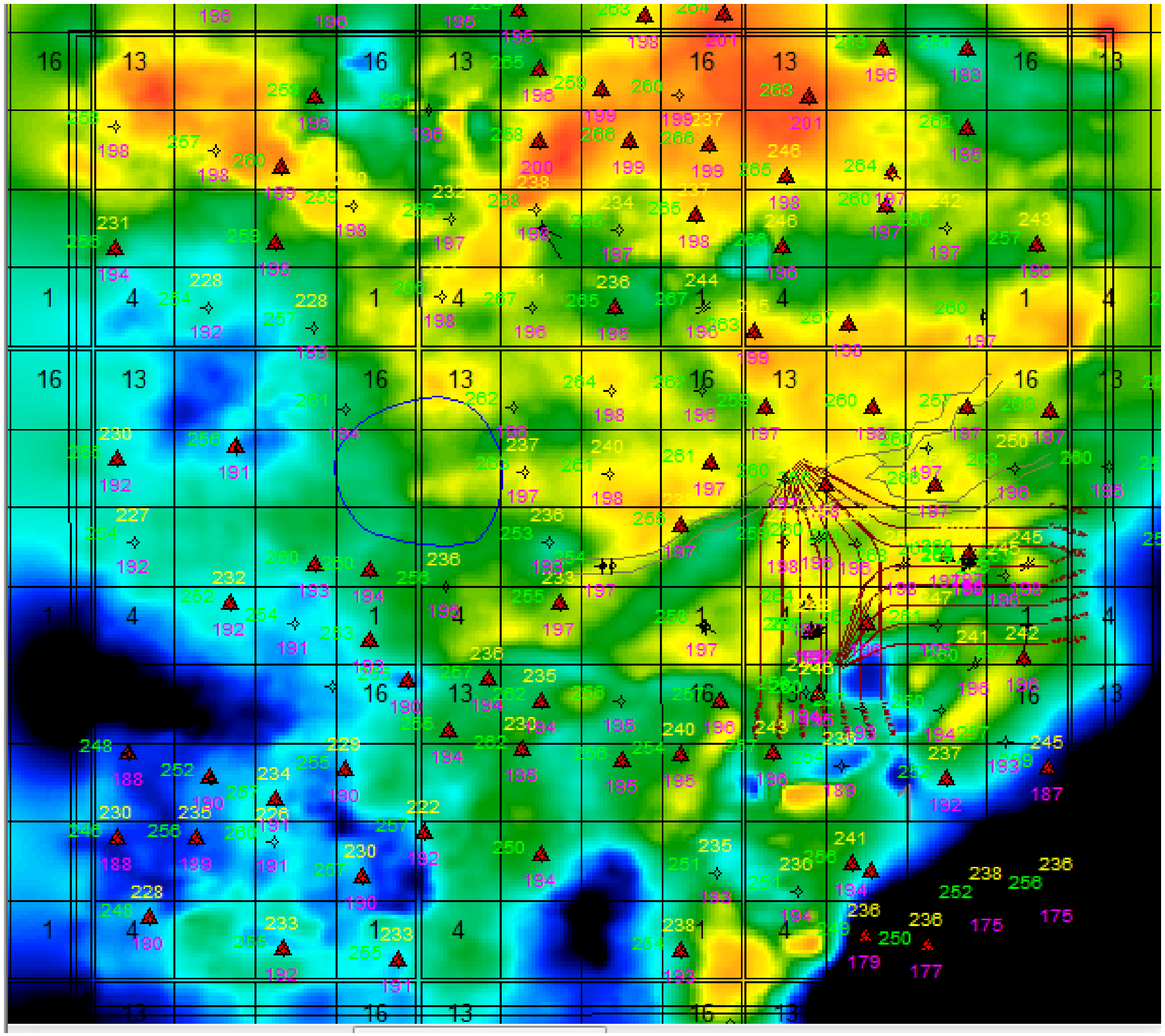
KNOC Korea National Oil Corporation

Harvest OPERATIONS CORP

Beaverhill Lake Depth Map

BHL Depth converted.

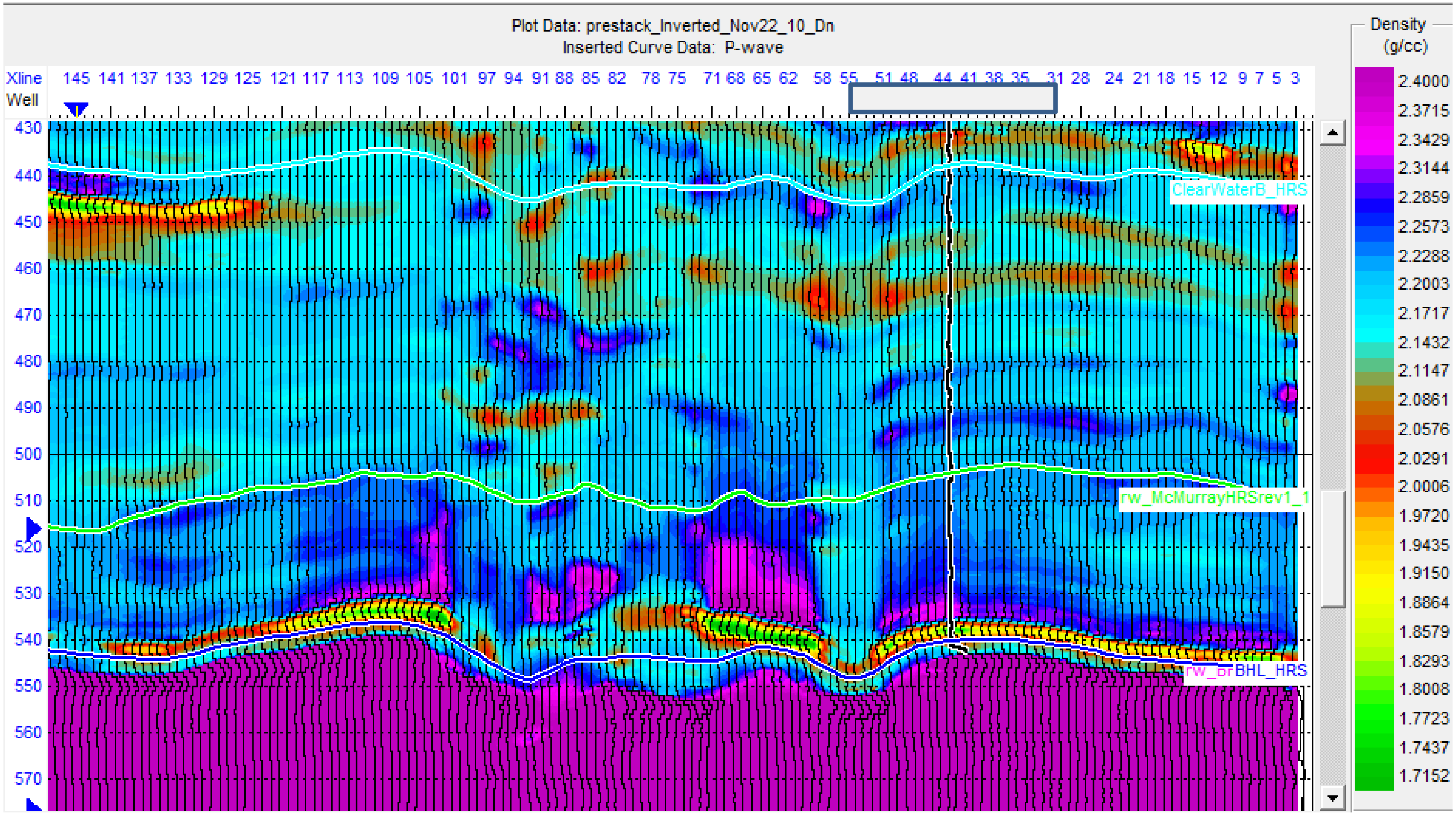




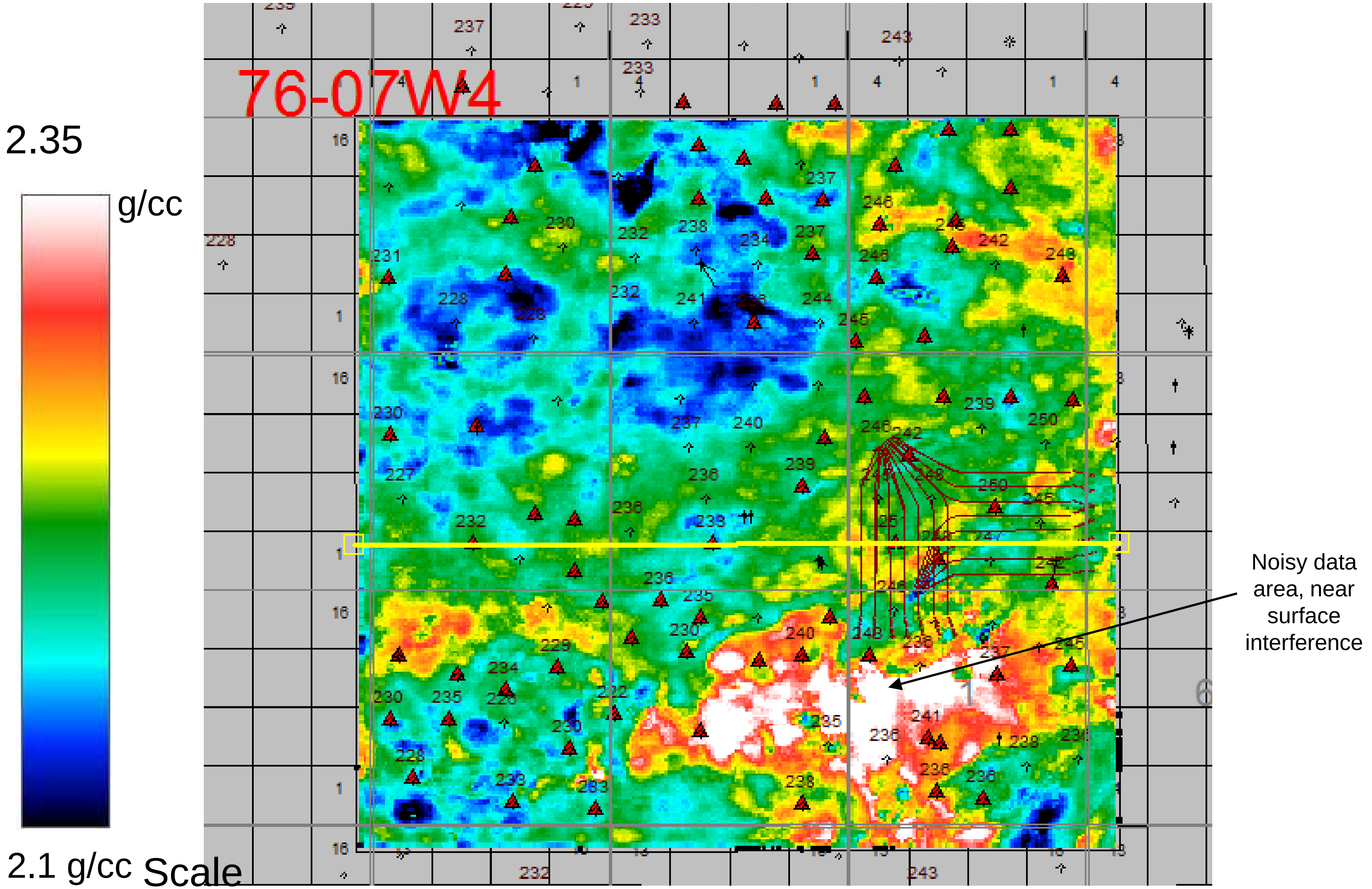
Korea National Oil Corporation

Harvest Operations Corp

Prestack Inversion Output Before scaling

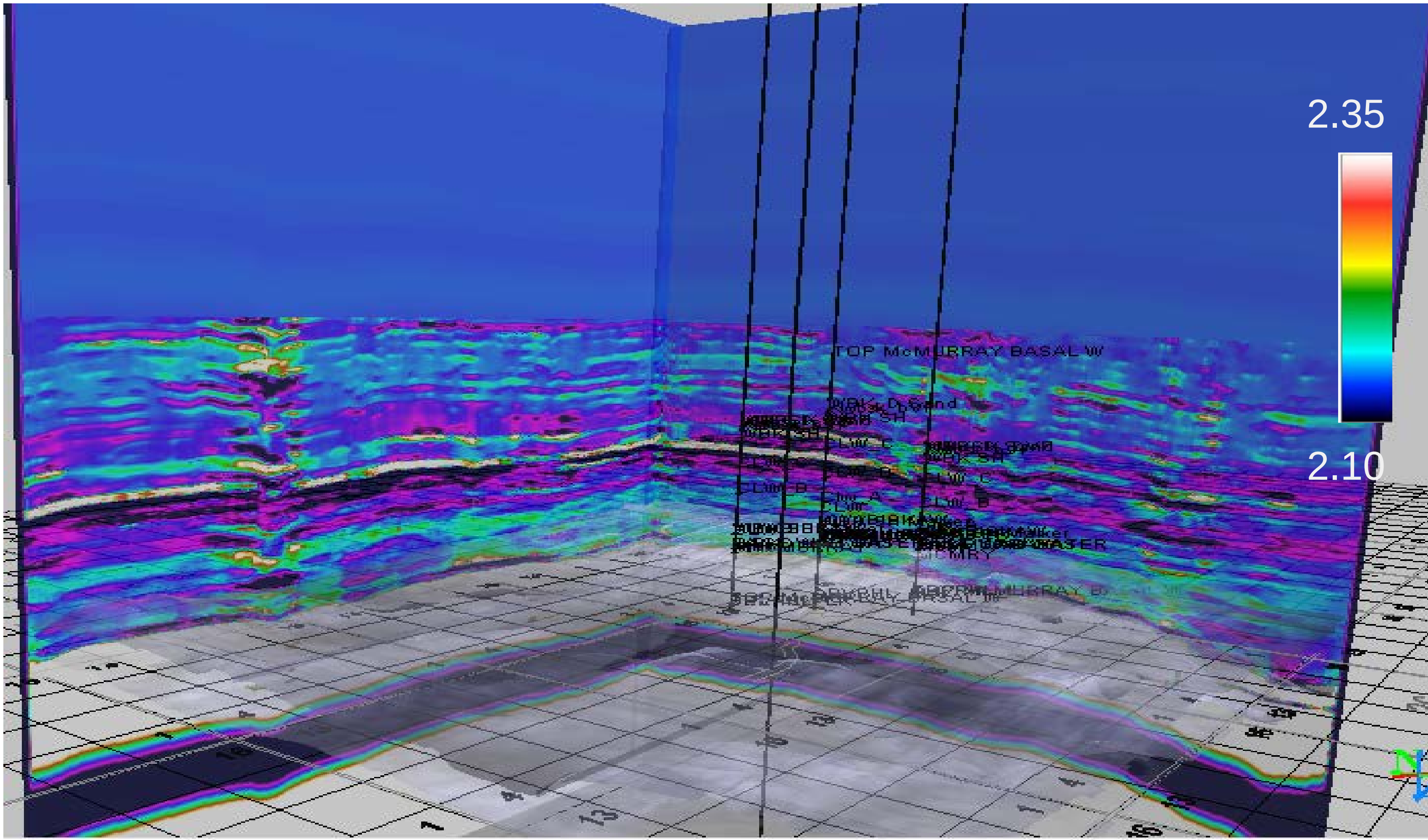


Clearwater B 83 AMP Inversion Time Slice

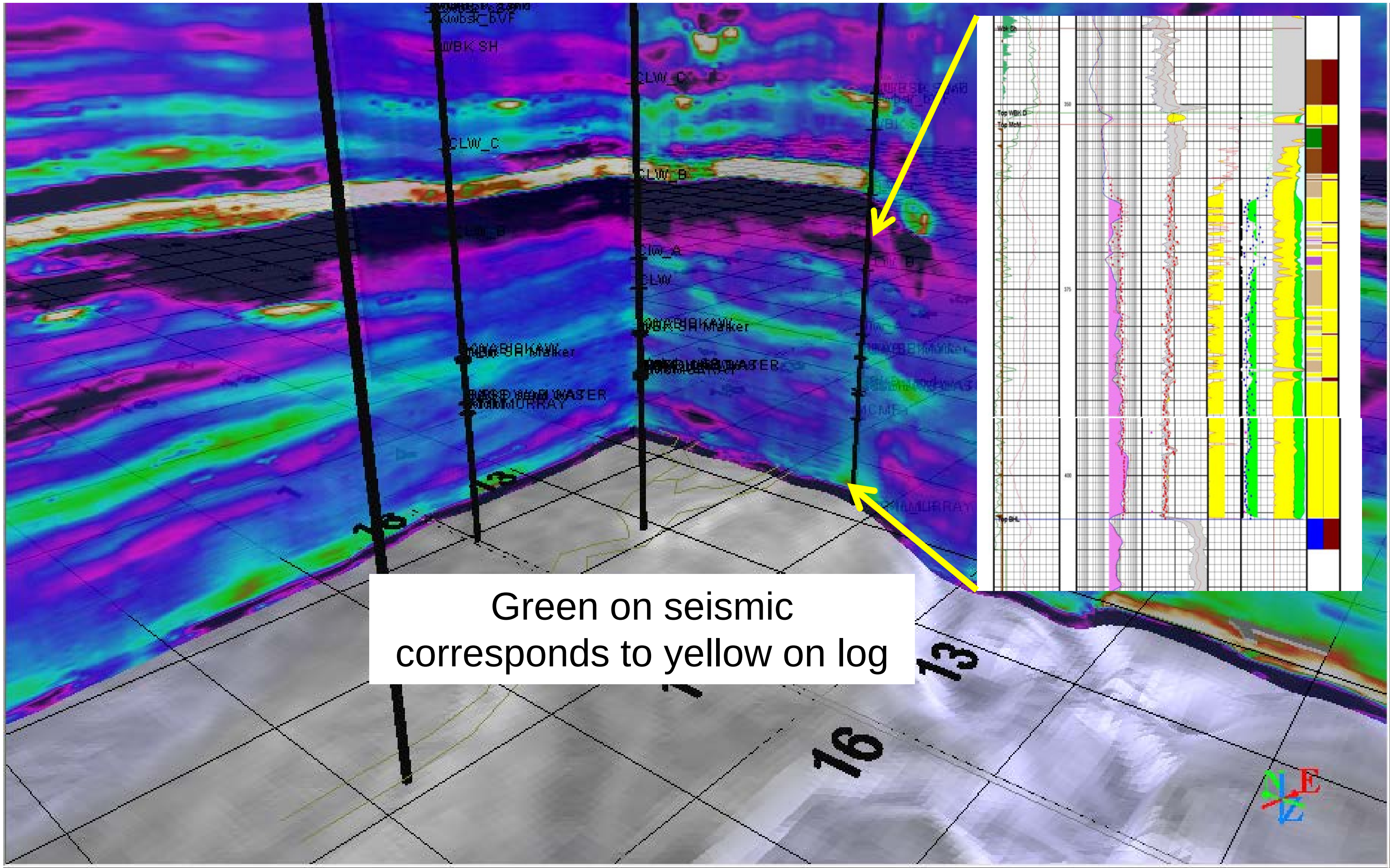


Korea
National Oil Corporation

3-D Volume using density



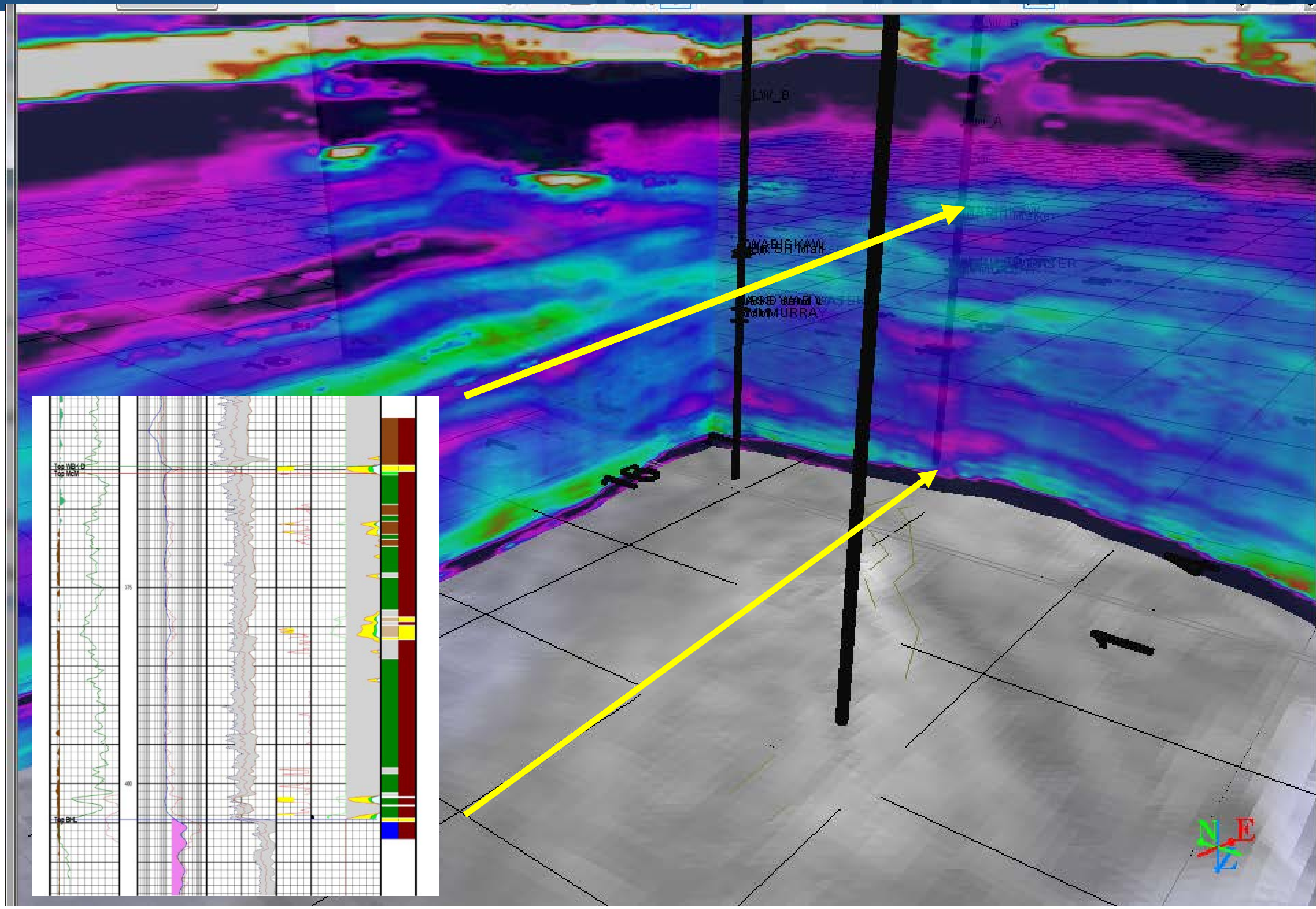
07-12-[redacted]W4 Inversion PS



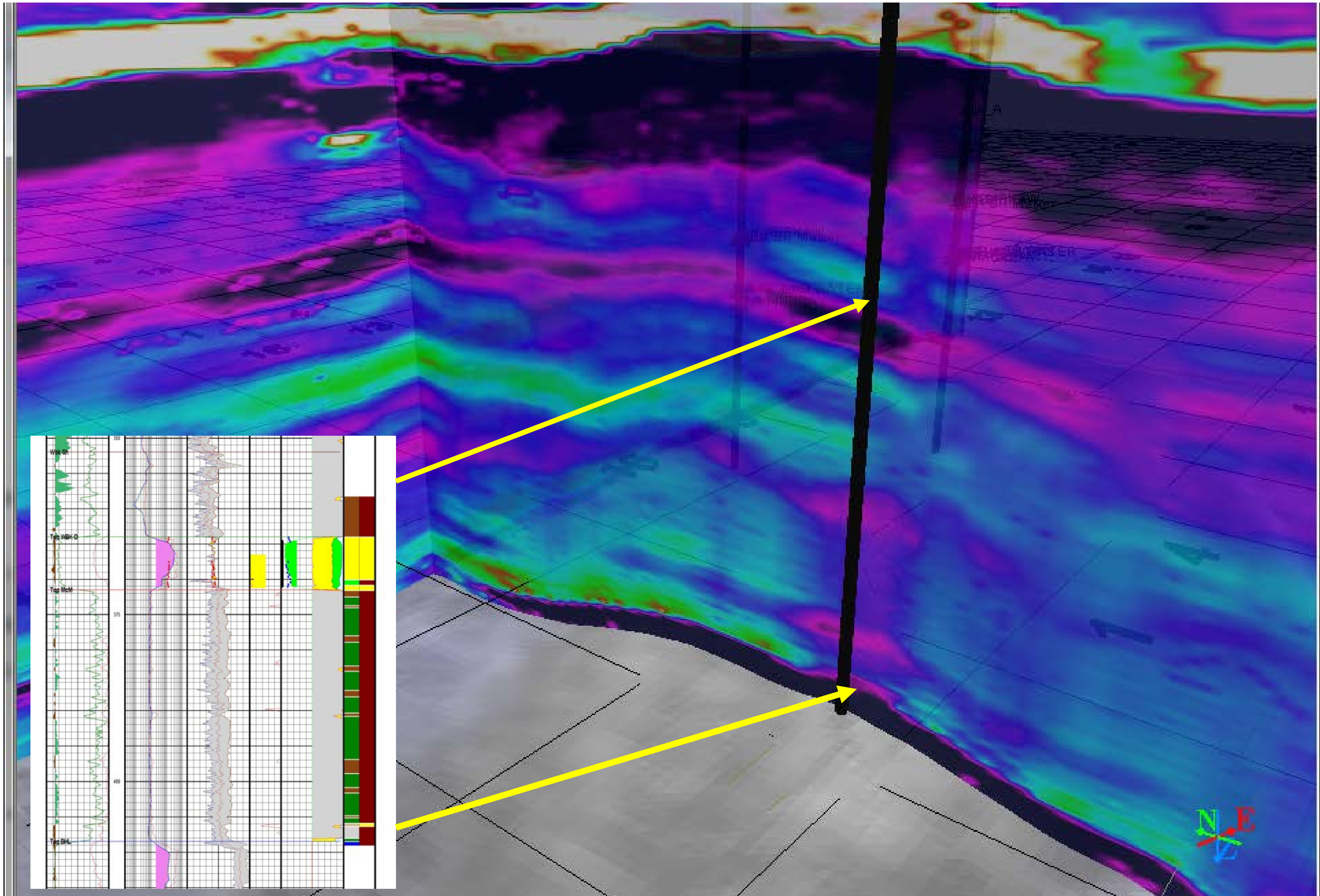
Korea
National Oil Corporation

Harvest
OPERATIONS CORP

11-12-[redacted]



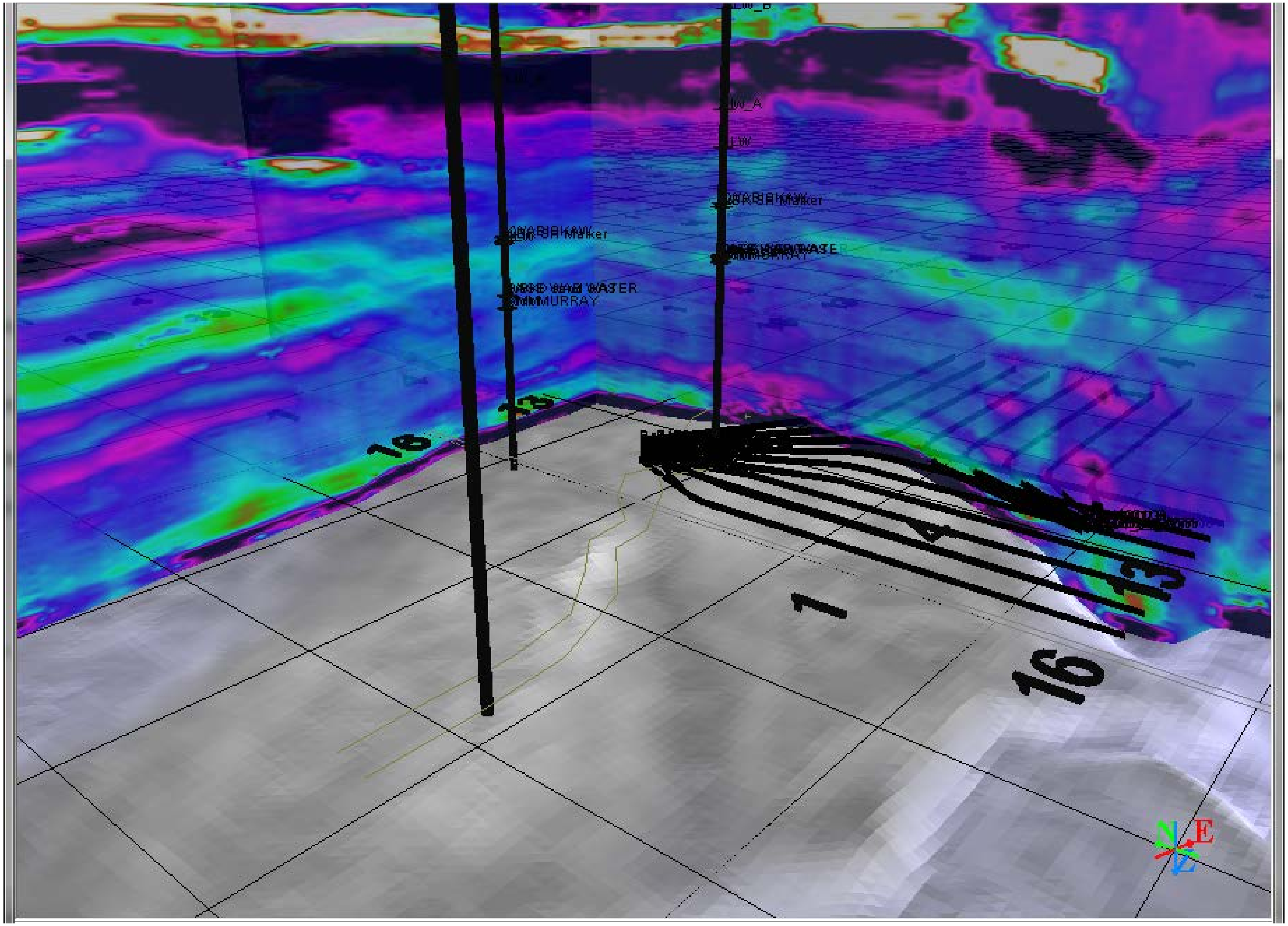
07-11-[redacted] Tie



KNOC
Korea
National Oil Corporation

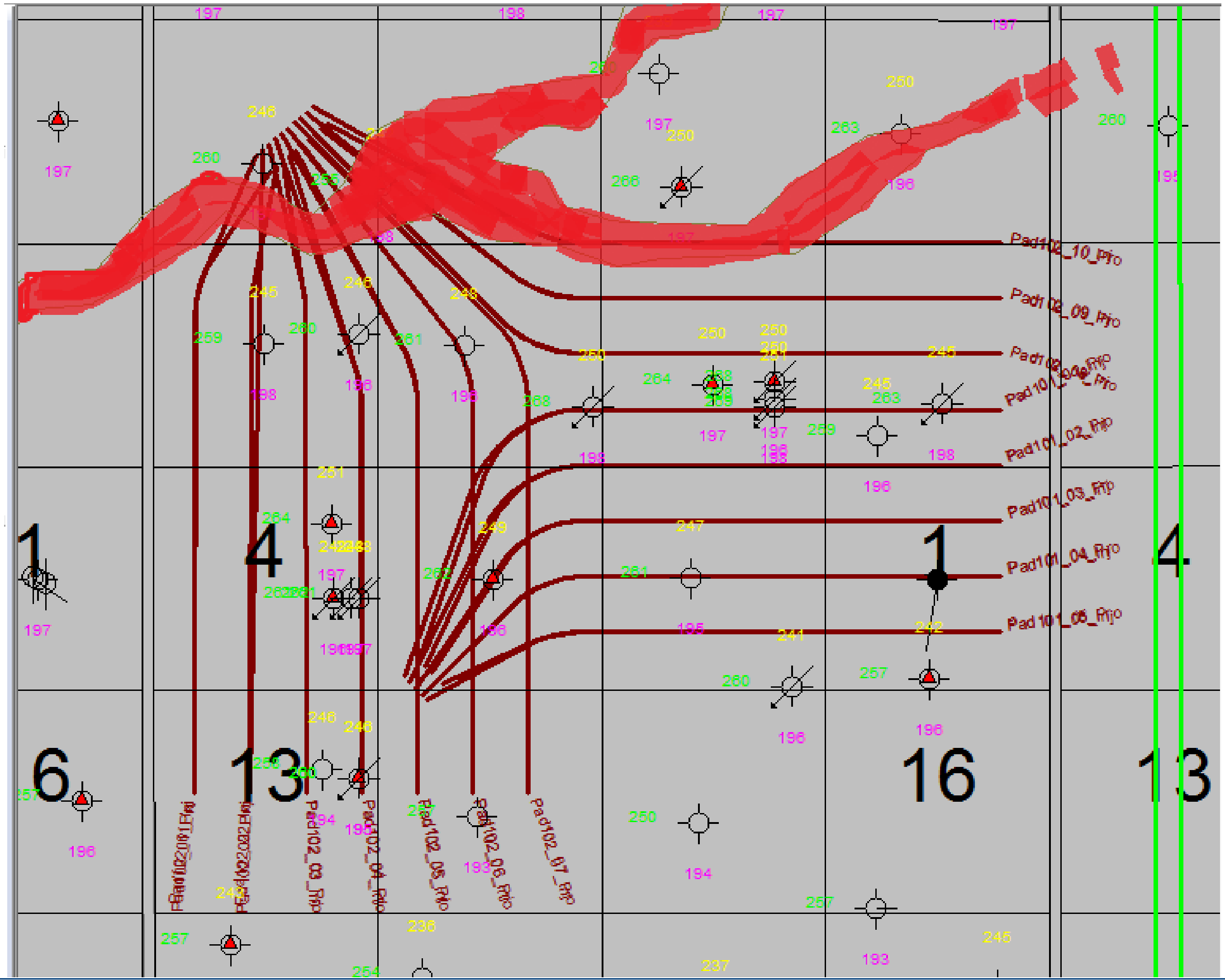
Harvest
OPERATIONS CORP

Horizontal plan



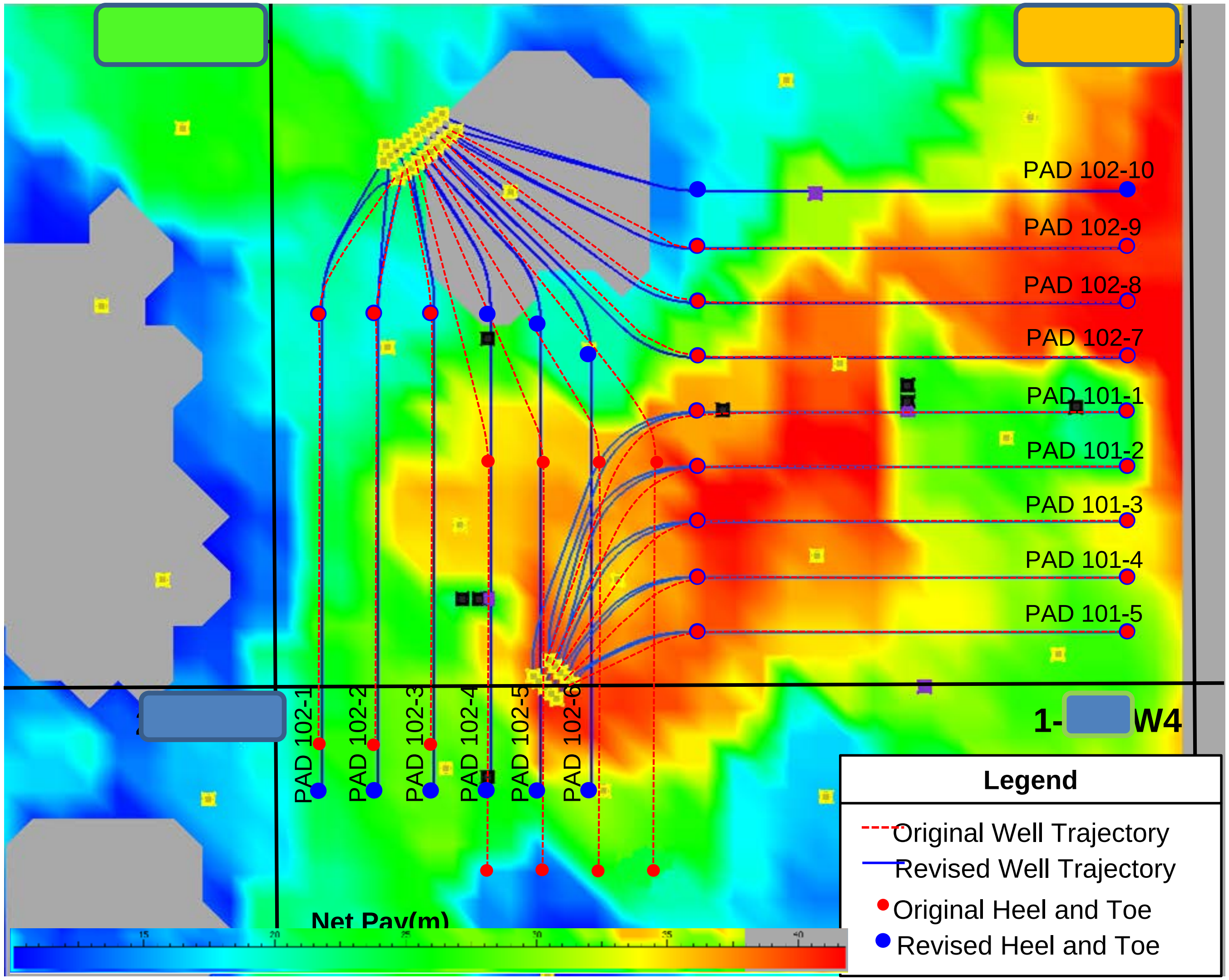
Korea
National Oil Corporation

Shale Plug defined by seismic



Korea
National Oil Corporation

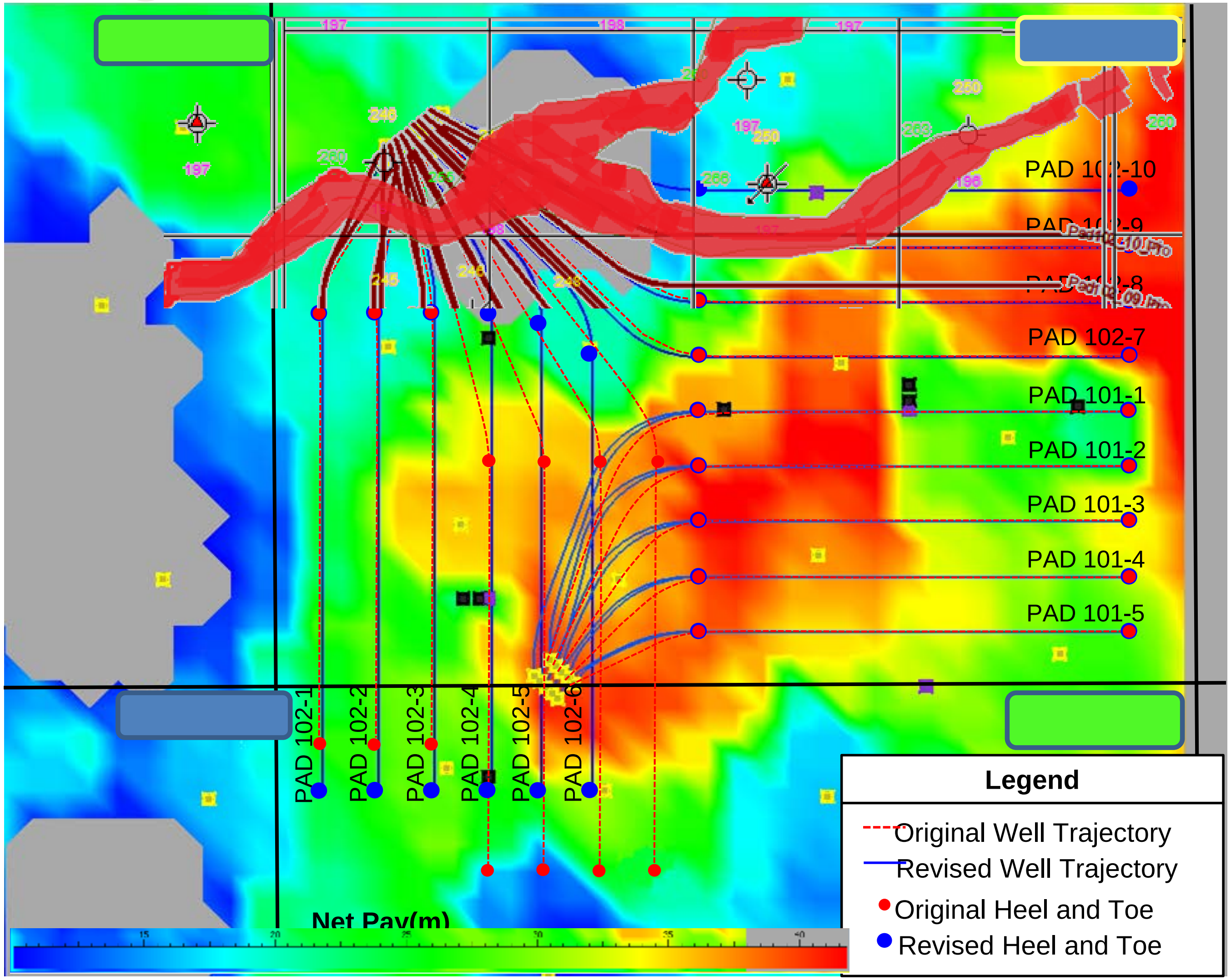
Shale plug defined by geomodeling



KNOC
Korea
National Oil Corporation

Harvest
OPERATIONS CORP

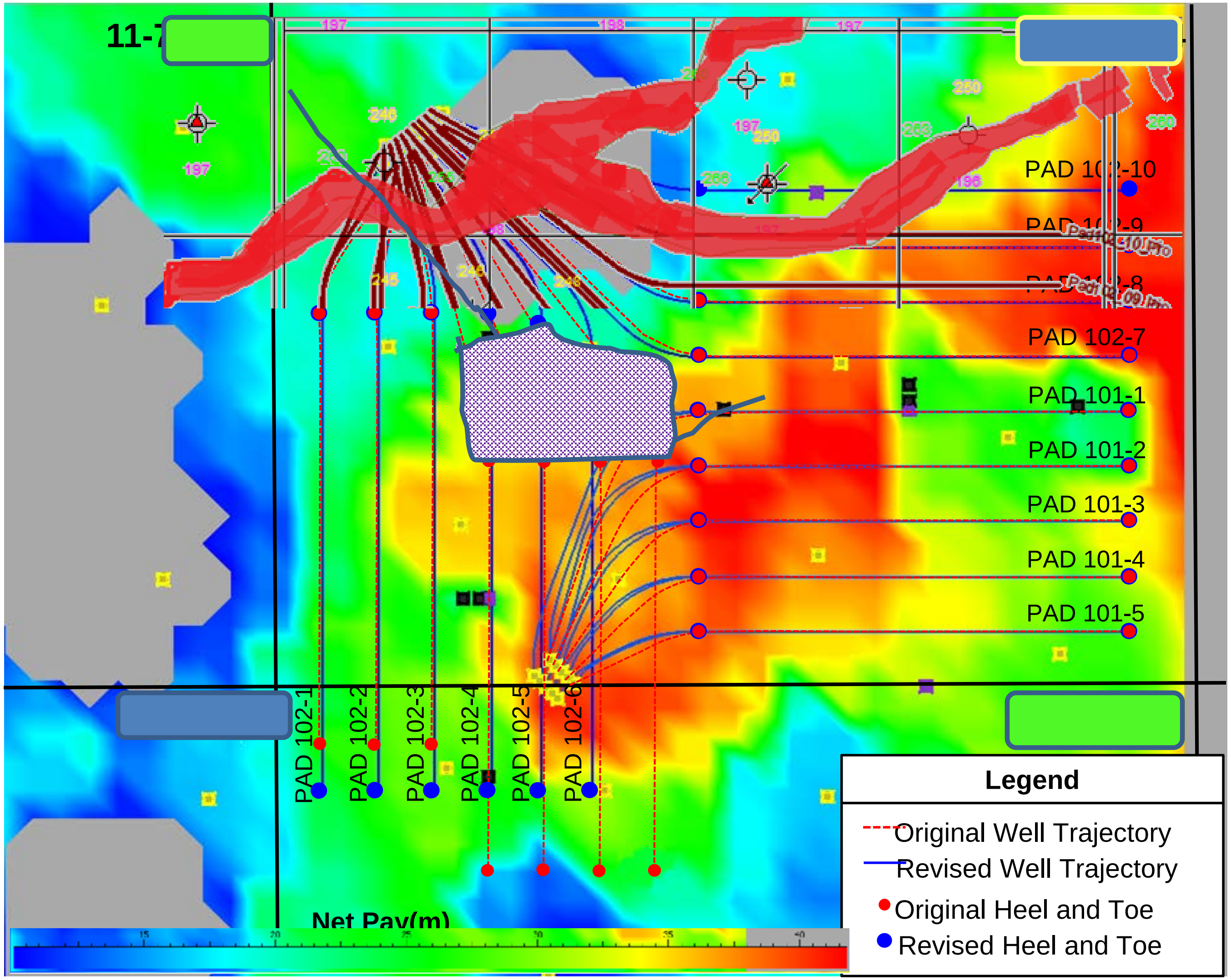
Change of Trajectories using seismic and geomodeling



Korea National Oil Corporation

Harvest OPERATIONS CORP

Reserve add using seismic and geomodeling



Korea National Oil Corporation

Harvest OPERATIONS CORP

Benefits of 3-D

- Based on the mapping, the repositioning of the well added reserves
  - 400 m X 200 m X 35 m pay X 30 % porosity, using a 50 % recovery factor.
  - ~ .84 million cubic meters or 5.7 million barrels in place.
    - Depending on recovery factor and oil price, this alone adds 50 to 100 million in value to the project

- The seismic benefits the well planning by avoiding shale hazards and improving well positioning

Conclusion

- Post Stack inversion was not useful for this project, even when constrained by interpretation and well control.
- The Geomodel in itself cannot accurately predict the nature of shale channels, reserves may be left behind.
- Conventional Seismic interpretation is not useful in the differentiation of Sand and Shale in the McMurray formation in this area
- Pre stack inversion is very useful, careful attention must be paid to the colour scheme to bring out the correct level of detail. It combines geological and geophysical data to make a complete picture.
- There is a major value add in using Prestack inversion in the McMurrary.

References

**SAGD Fundamentals – Application of core and outcrop analogues, geology,
geophysics and geochemistry to oil sands recovery.**

Strobl, R.S., Short course presentation, CSPG may 2011

Simultaneous inversion of pre-stack seismic data

Brian Russell, Dan Hampson, and Brad Bankhead
CGG / Hampson-Russell
Gary Boukall, Harvest Operations Corp.

KNOC
Korea
National Oil Corporation

Harvest
OPERATIONS CORP.

Thanks to:

- Hampson – Russell Software
- Black Gold Business Unit, Harvest Operations Corp.
- Beth Adams for the graphics and design
- Dave Wardlaw, Gary Boukal, Harvest Operations corp.
- Wayne Nowry, CGG

Harvest OPERATIONS CORP.

2100, 330-5th Avenue SW
Calgary, Alberta,
Canada T2P 0L4

Telephone: 403-265-1178
Fax: 403-265-3490
www.harvestenergy.ca

KNOC
Korea
National Oil Corporation