Apex Spectral Technology, Inc

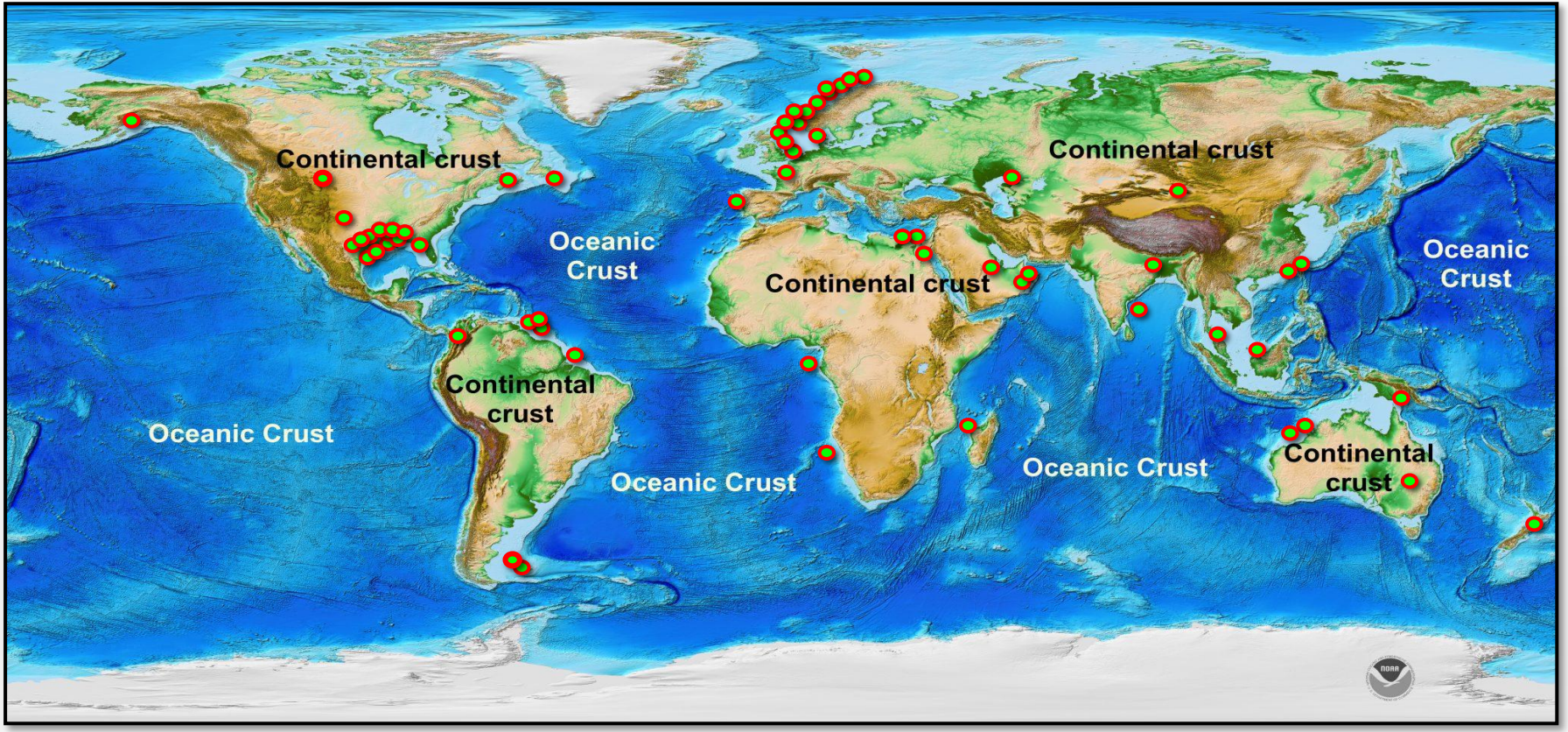
Presents

Imaging KH from Seismic to Leverage E&P Success

Apex Spectral Technology

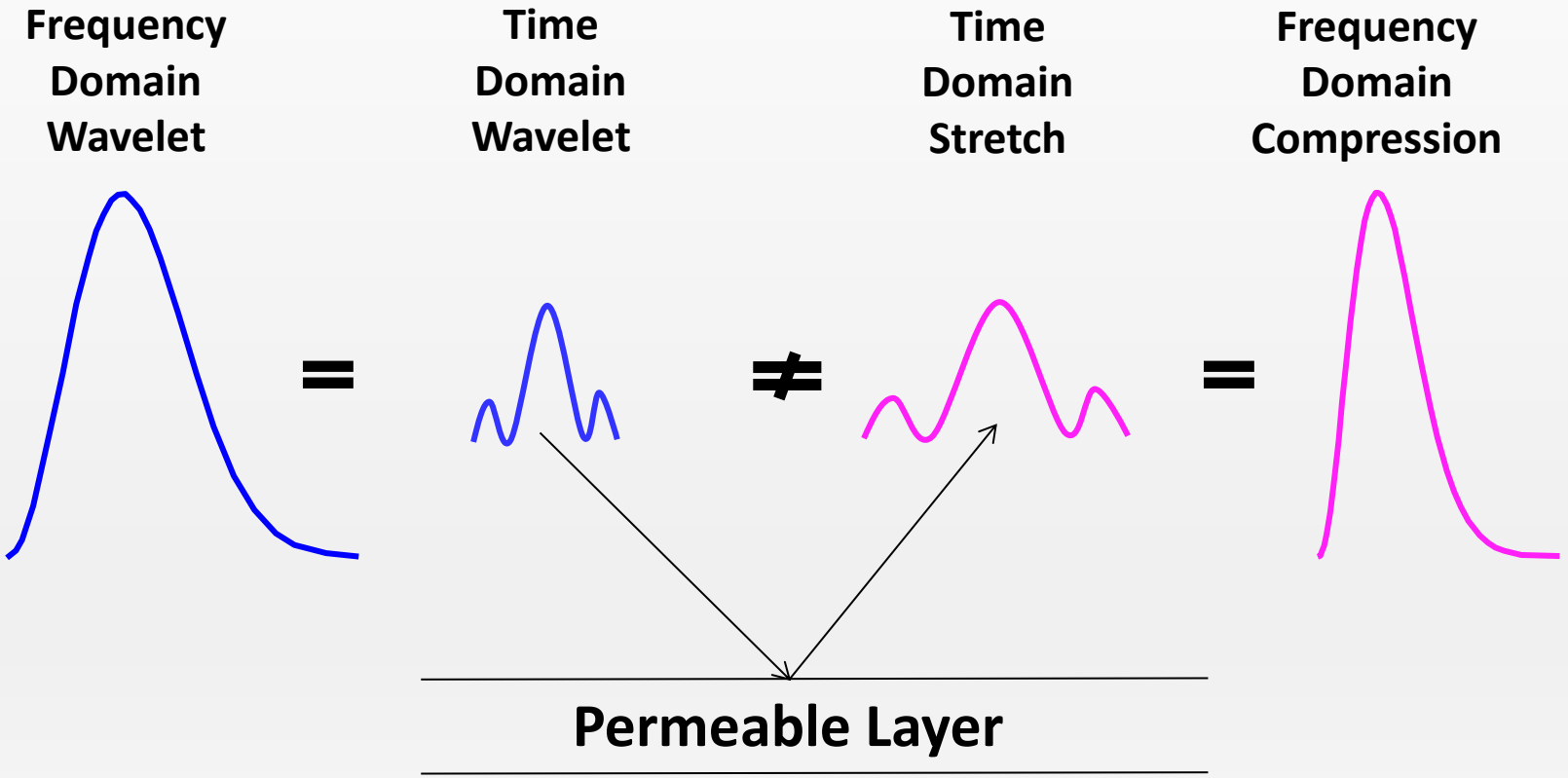
- Founded in 2002
- Invented ADF® KH imaging from seismic data
- Performed ADF® projects worldwide
- Published blind test ADF® results in a paper sponsored by Shell at 2021 EAGE
- Published the science that explains the KH frequency effect at Image 2024

ADF® KH Imaging Projects

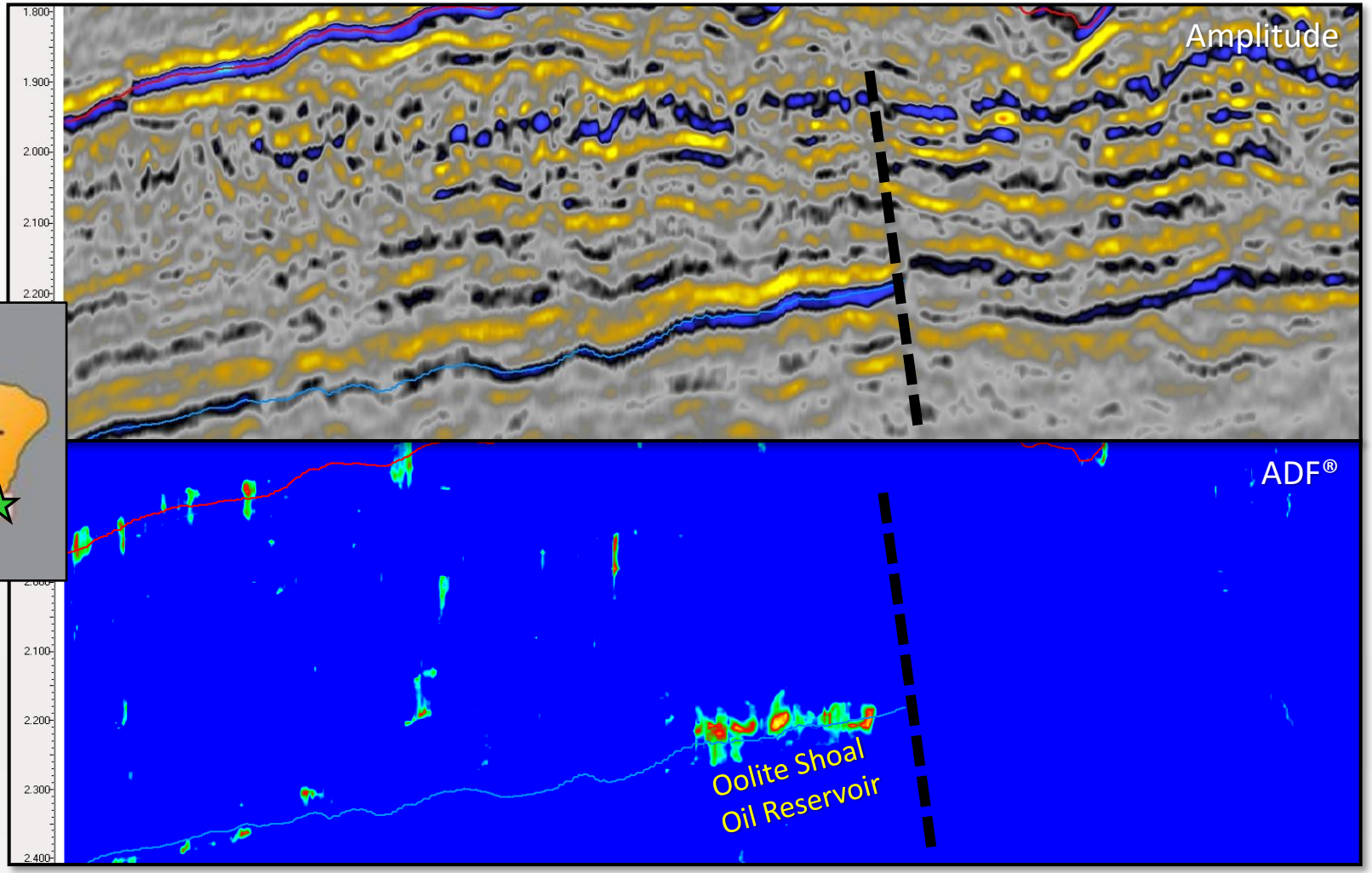


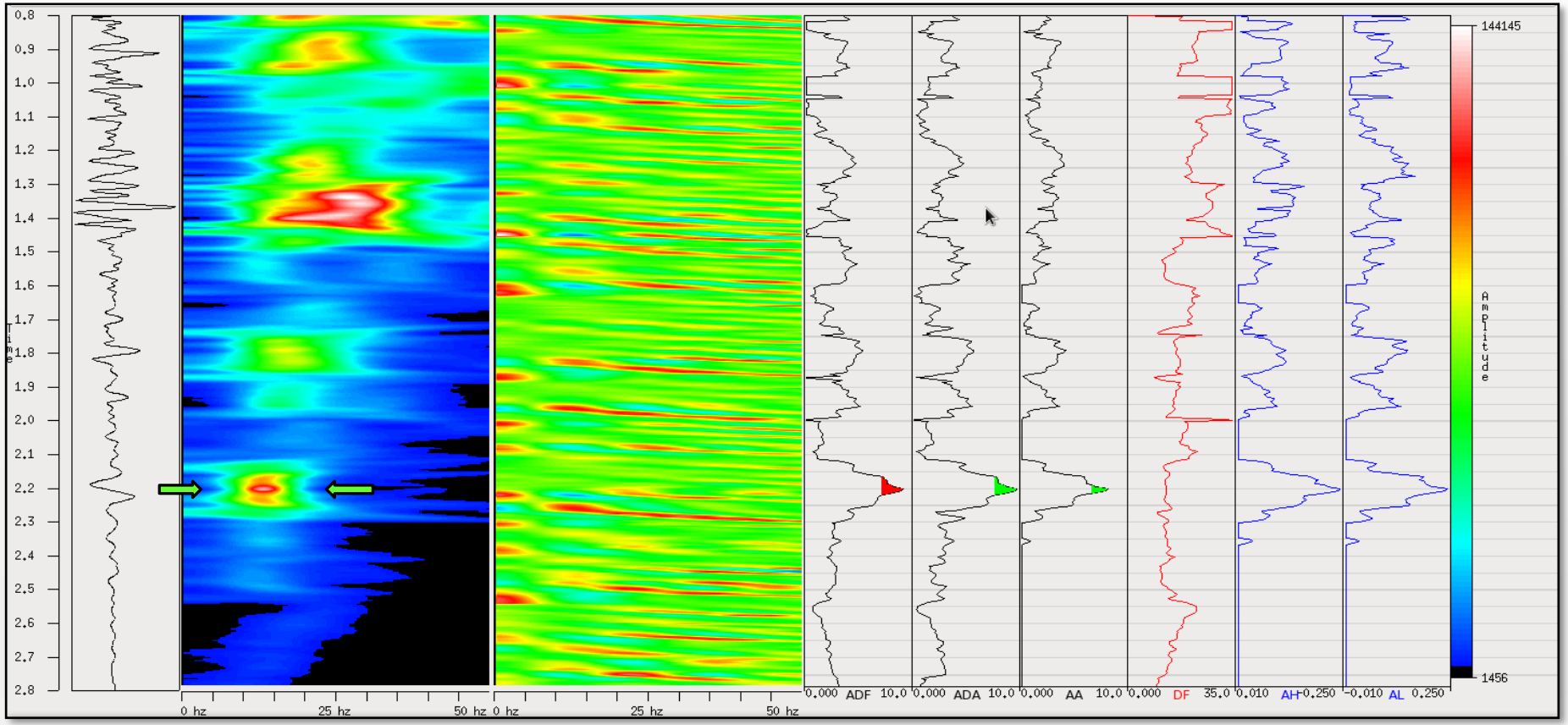
The end is the beginning – where we are going…

KH causes time domain stretch which is frequency domain compression

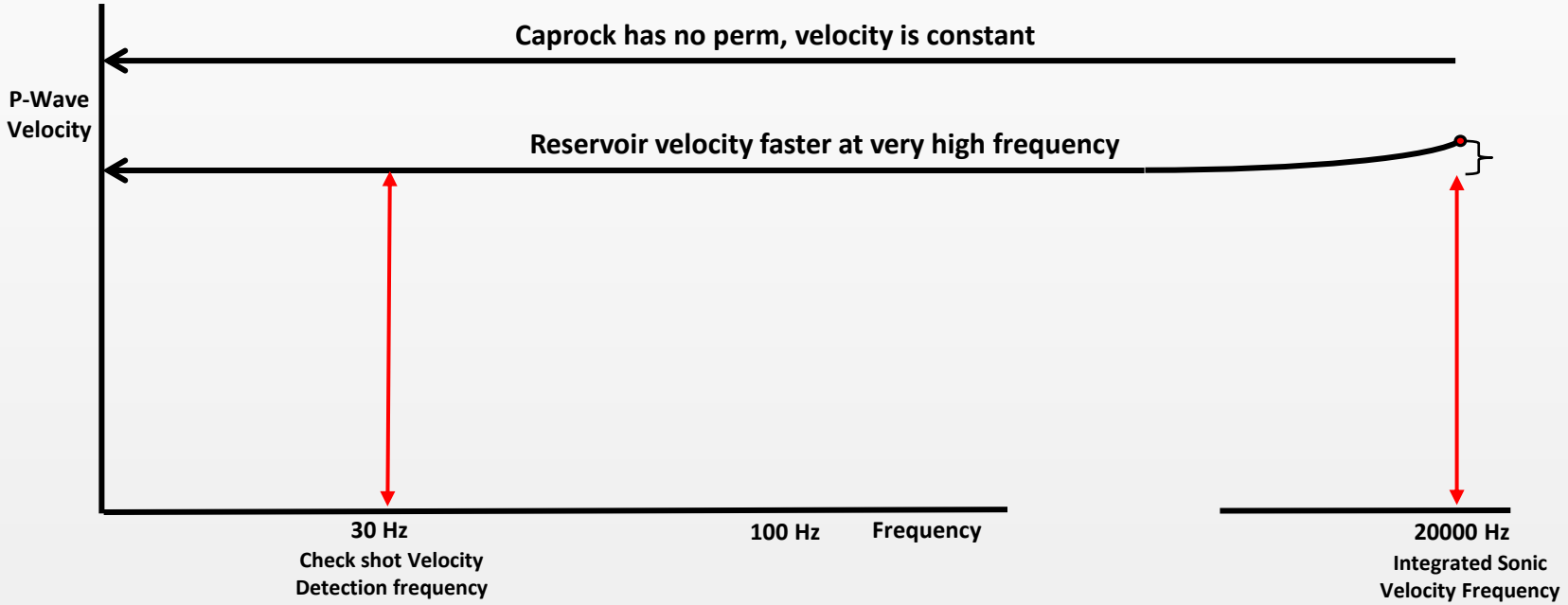



BRAZIL

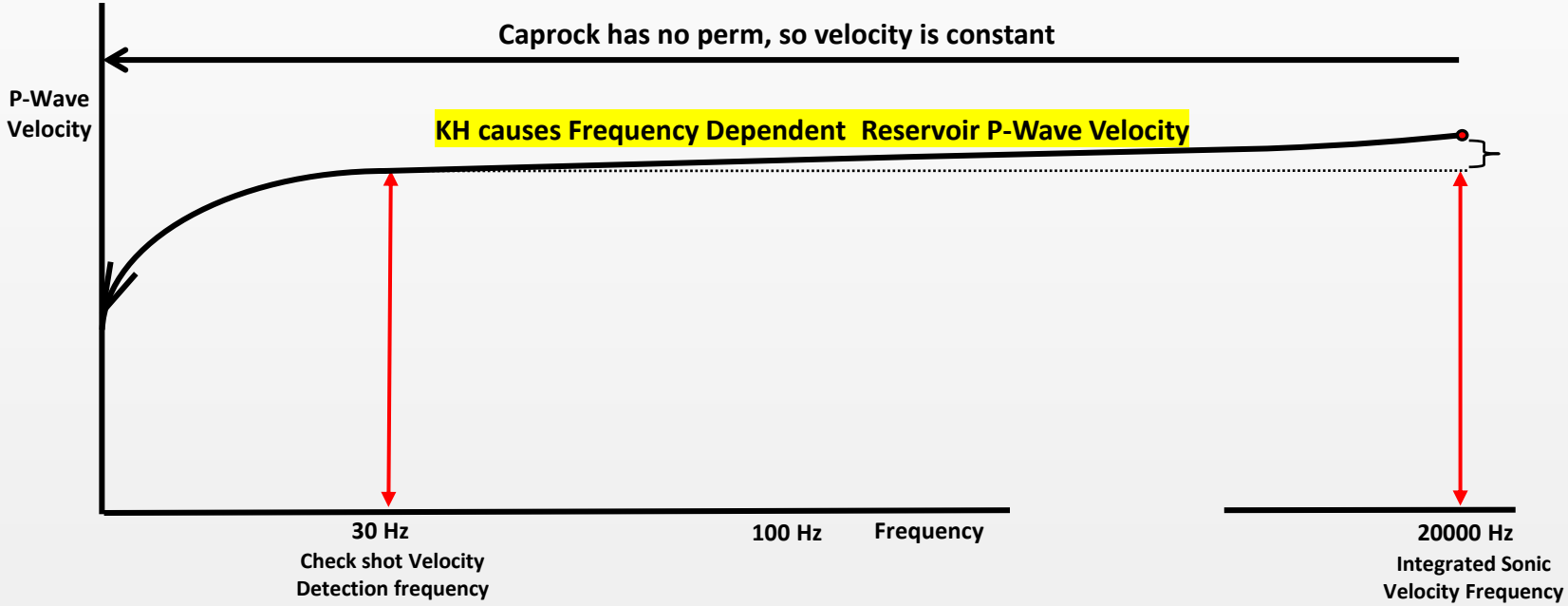

1.800
1.900
2.000
2.100
2.200
Amplitude
2.100
2.200
2.300
2.400
ADF®
Oolite Shoal
Oil Reservoir


Time
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
0 hz
25 hz
50 hz
0 hz
25 hz
50 hz
0.000 ADF 10.0
0.000 ADA 10.0
0.000 AA 10.0
0.000 DF 35.0
0.010 AH 0.250
-0.010 AL 0.250
144145
Amplitude
1456

1975 first principal over simplification

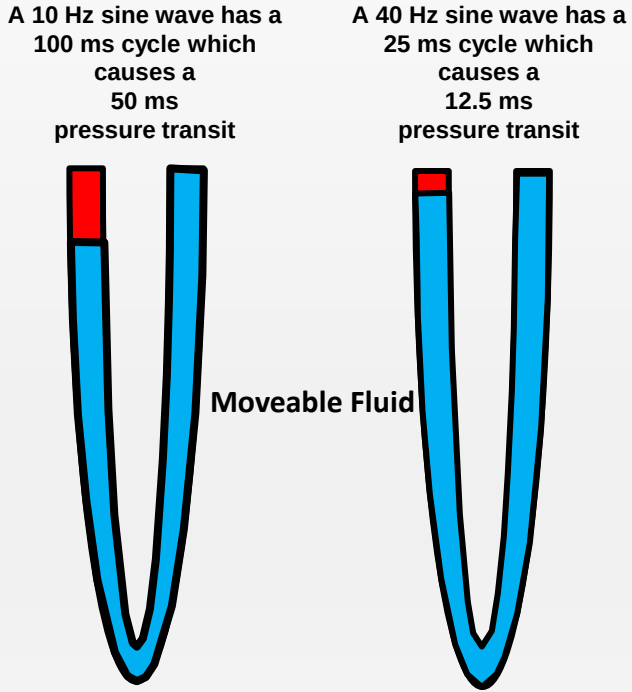


2025 Understanding



What causes lower frequencies to travel slower?

Darcy's Law: A longer pressure transient will cause more fluid movement



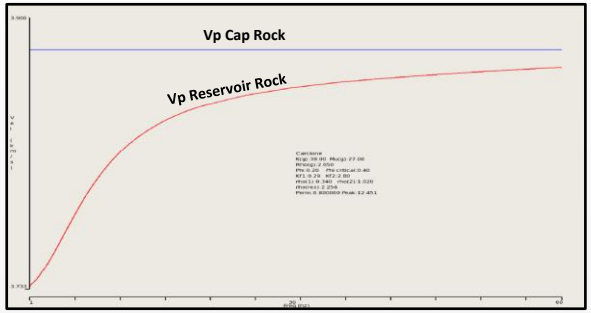
Reflection Coefficients are frequency dependent because reservoir velocity is frequency dependent

$$(D2 * V2) - (D1 * V1)/(D2 * V2) + (D1 * VI) = Rc$$

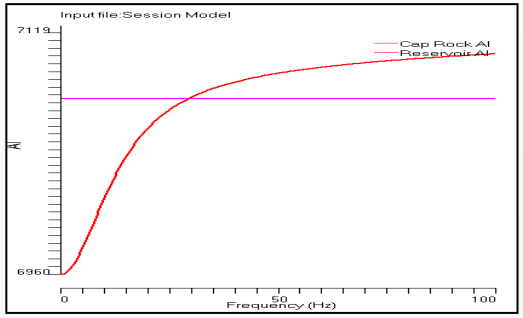
Frequency Dependent Rc

D1 is density above
D2 is density below
V1 is velocity above
V2 is velocity below
Rc is reflection coefficient

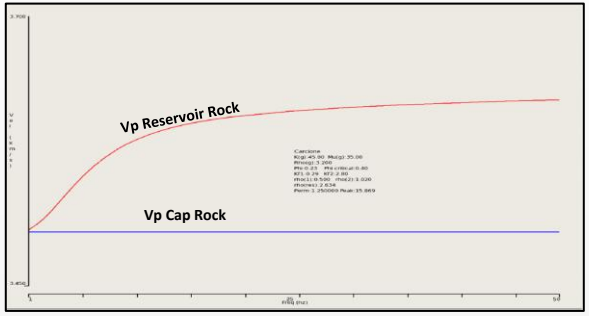
Class III AVO – reservoir is slower than above layer



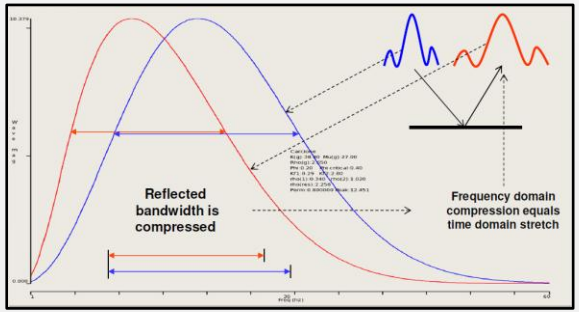
Class II AVO – reservoir velocity is close to that of above layer



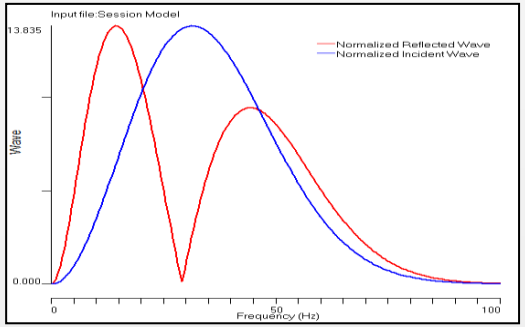
Class I AVO – reservoir velocity is faster than of above layer



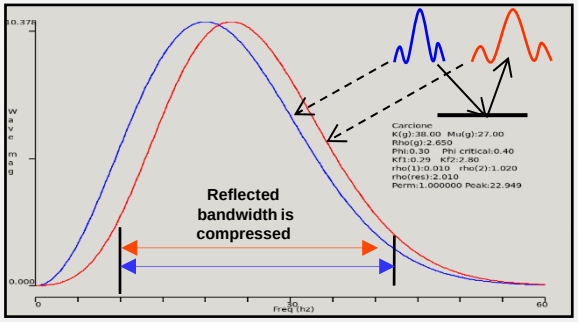
DF decrease with dispersion



Depending on crossover point the DF will increase or decrease



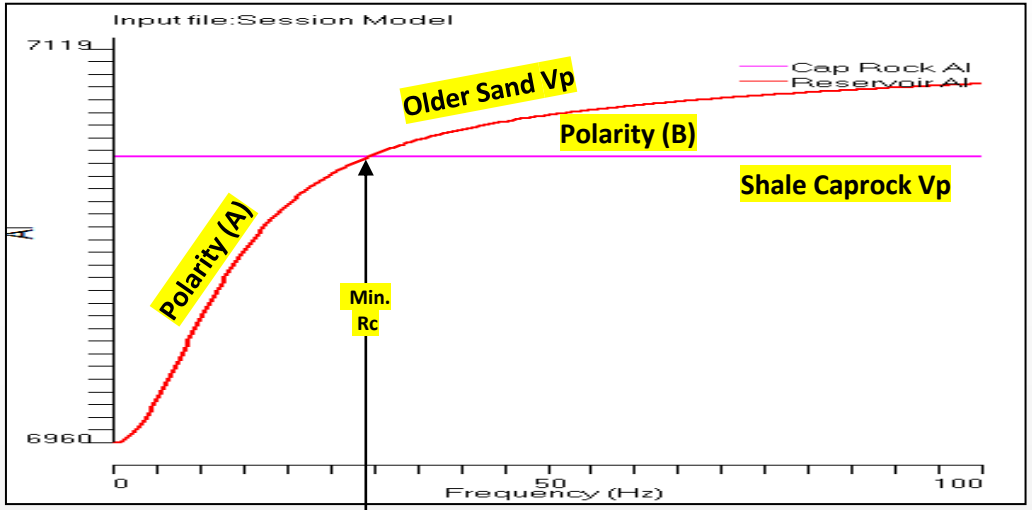
DF increases with dispersion

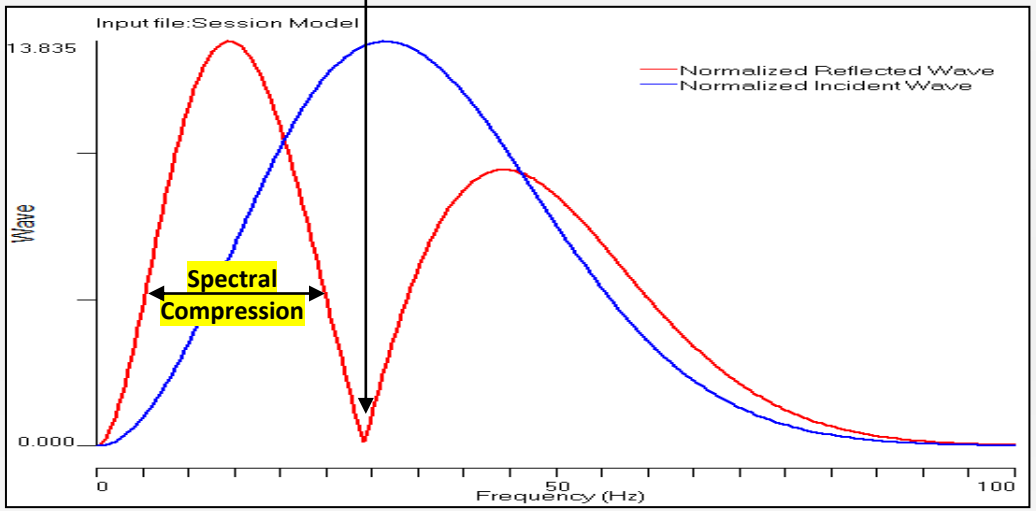


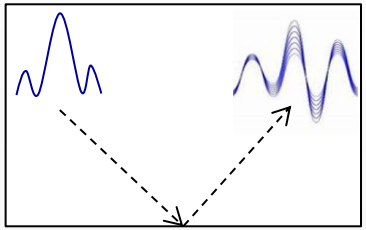
Class C ADF®

Class B ADF®

Class A ADF®



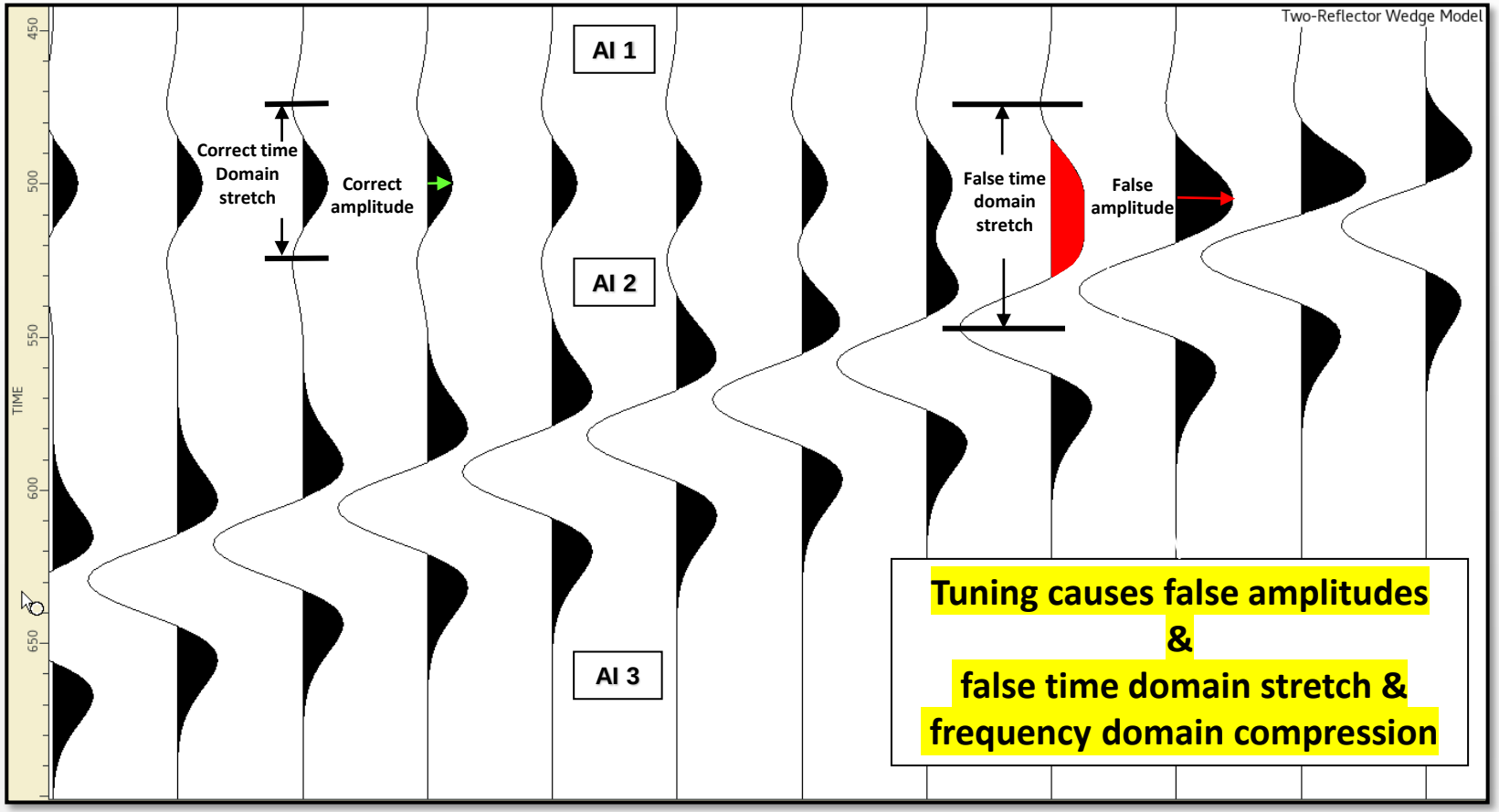




KH Causes Dynamic Wavelets & Spectral Compression

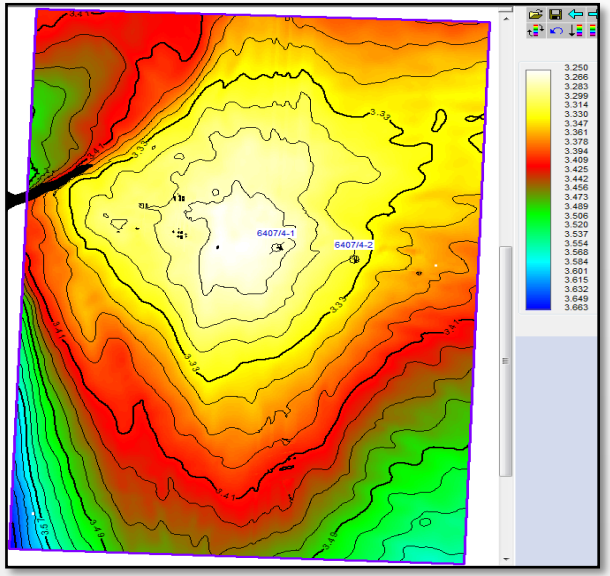
ADF® Measures Spectral Compression

Similar to Amplitude, Tuning is a Challenge – the Wedge Model

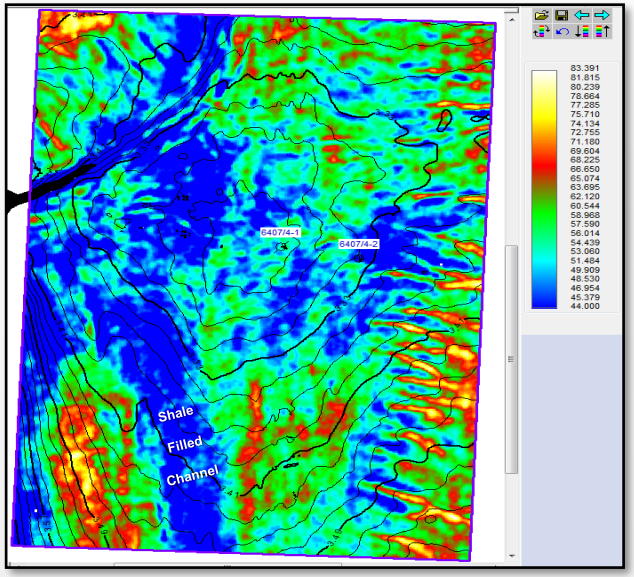


Acoustic Impedance ("AI") = P wave velocity * density

Time Structure

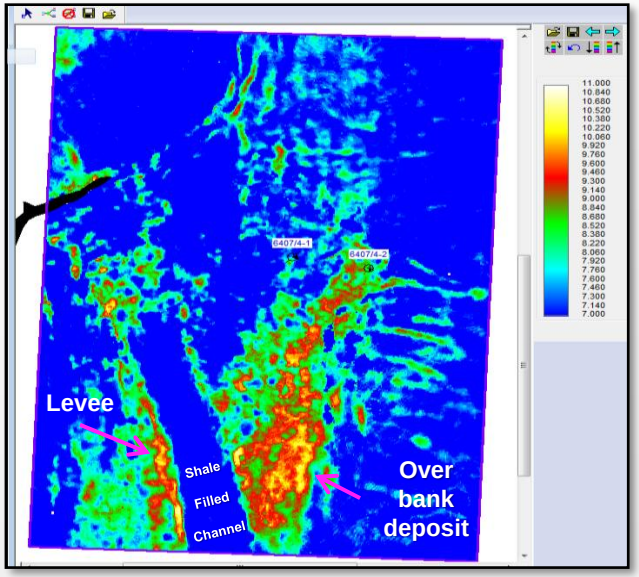


Amplitude is replete with tuning



Tuning blurs geology on amplitude

ADF® is measured after tuning is removed



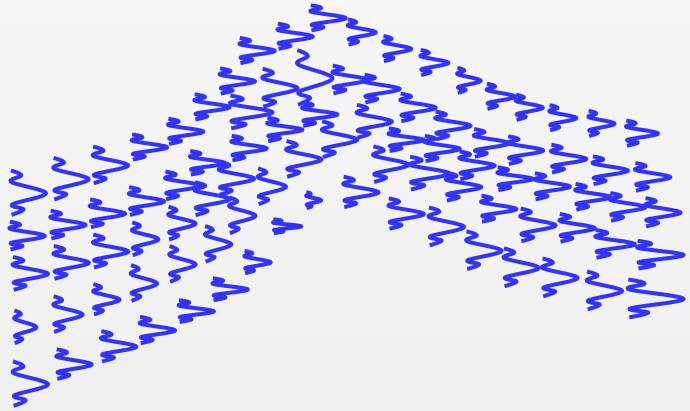
ADF® clarifies geology

ADF® is the opposite of inversion

Inversion calculates a wavelet using well data

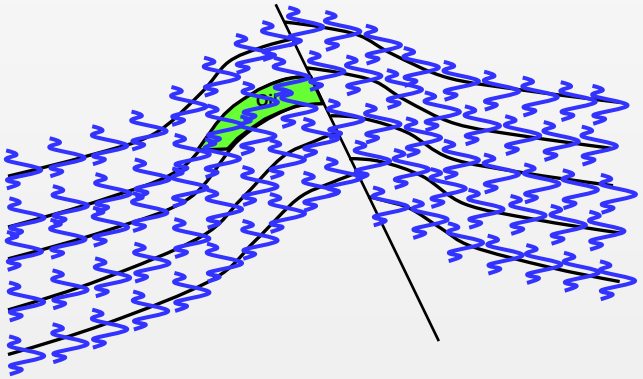
Or

ADF® calculates wavelets without using well data



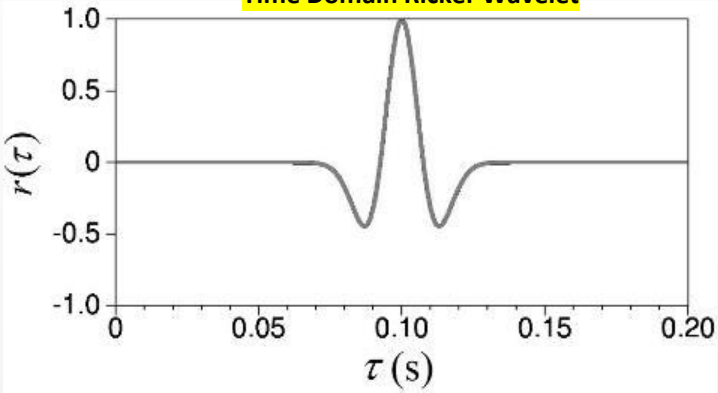
&

Geology

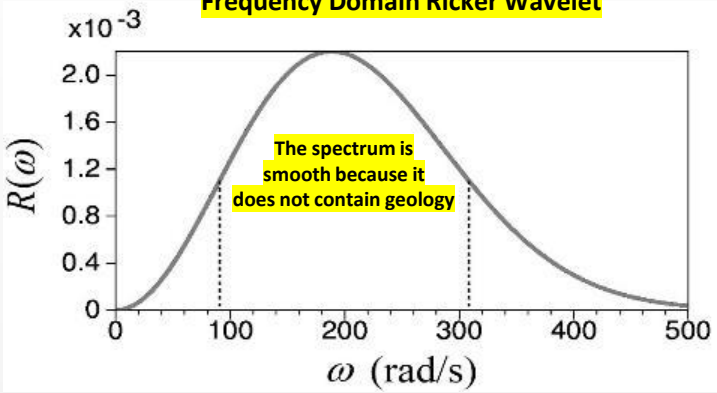


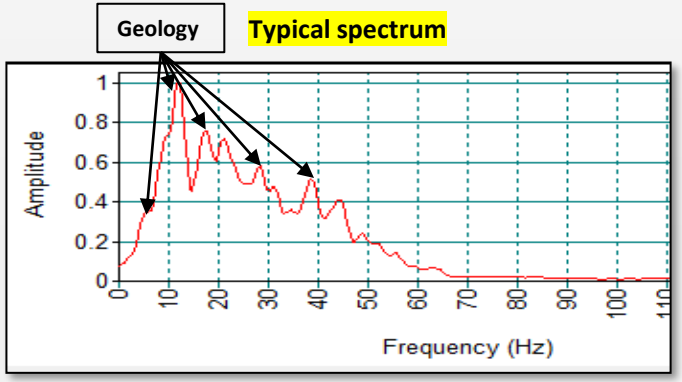
Removing Tuning Effects

Time Domain Ricker Wavelet



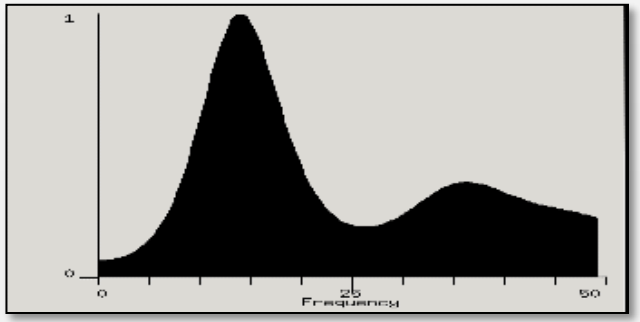
Frequency Domain Ricker Wavelet





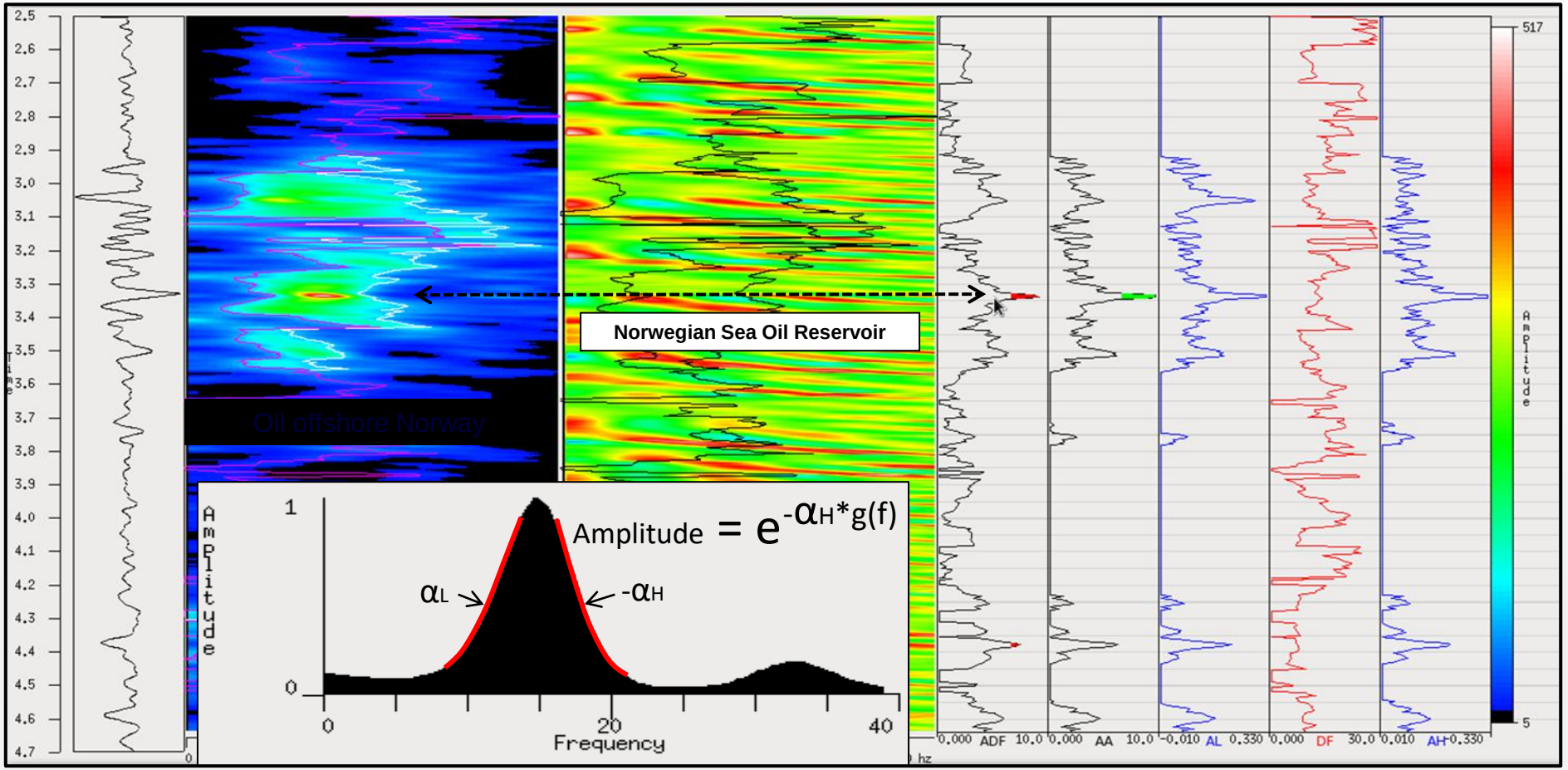
Geology prevents accurately measuring compression

Apex Spectrum

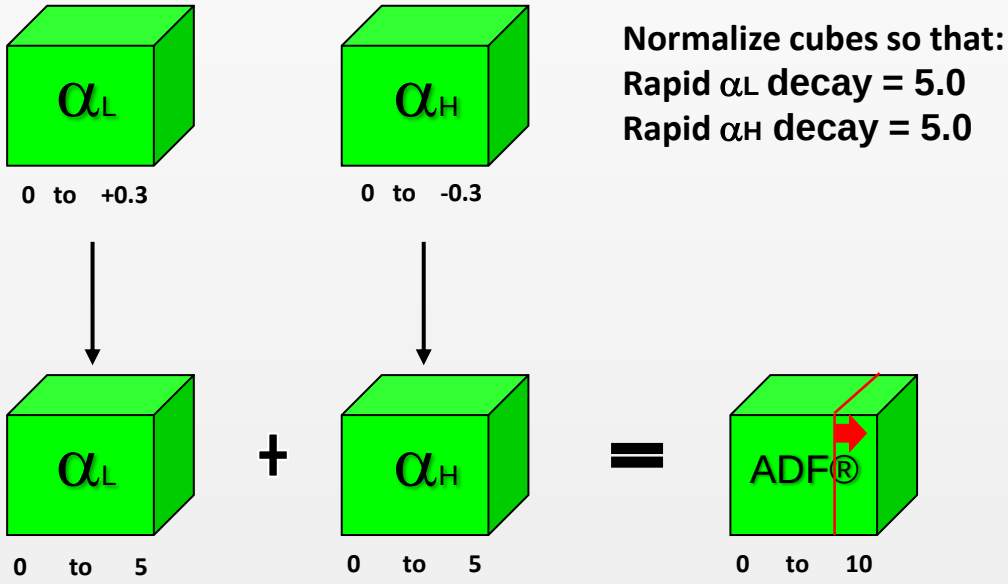


Apex transform removes geology allowing for accurate measurements of compression

KH Causes Spectral Compression; ADF® measures Spectral Compression



ADF® KH Cubes



An ADF® cube is computed by summing the two alpha cubes to get one cube scaled 0 to 10

Industry Tools that Remove the KH Frequency Effect

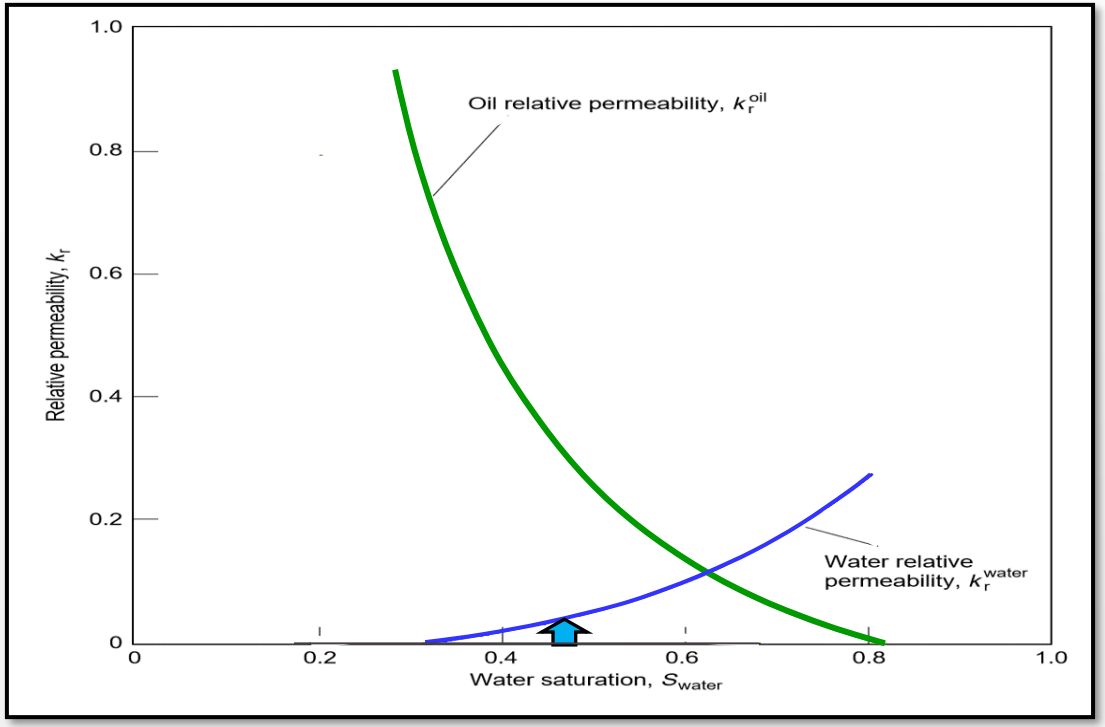
- Spiking & Gap Deconvolution
- Amplitude Q compensation
- Whitening

ADF® Summary Points

- In sands, ADF® is largely a KH sand map
- In carbonates, ADF® shows where KH within the layer
- ADF® uses only seismic as input
- ADF® is independent of amplitude

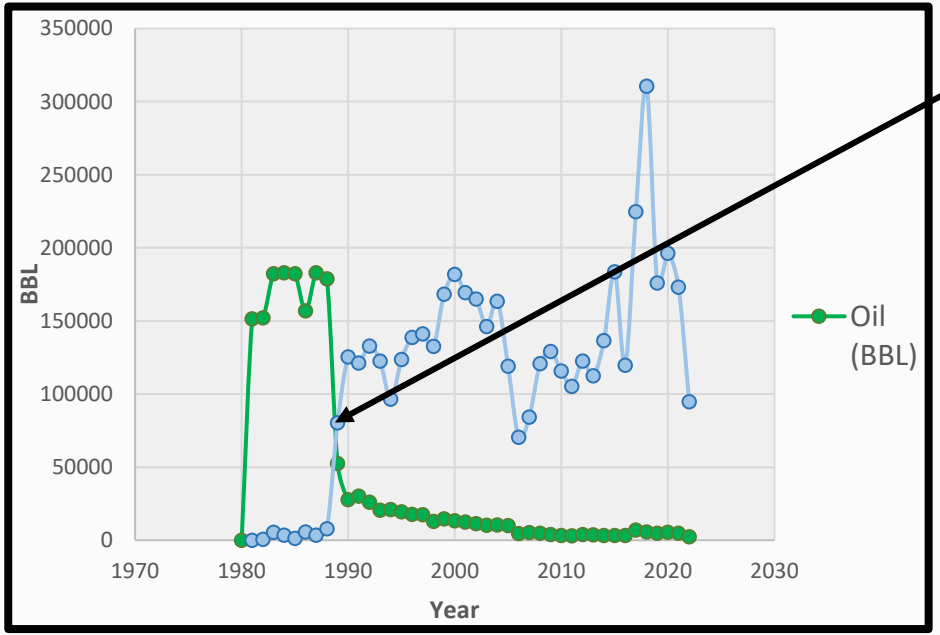
ADF® 4D Effects

Relative permeability drops as a reservoir is produced causing *an* ADF® 4D effect

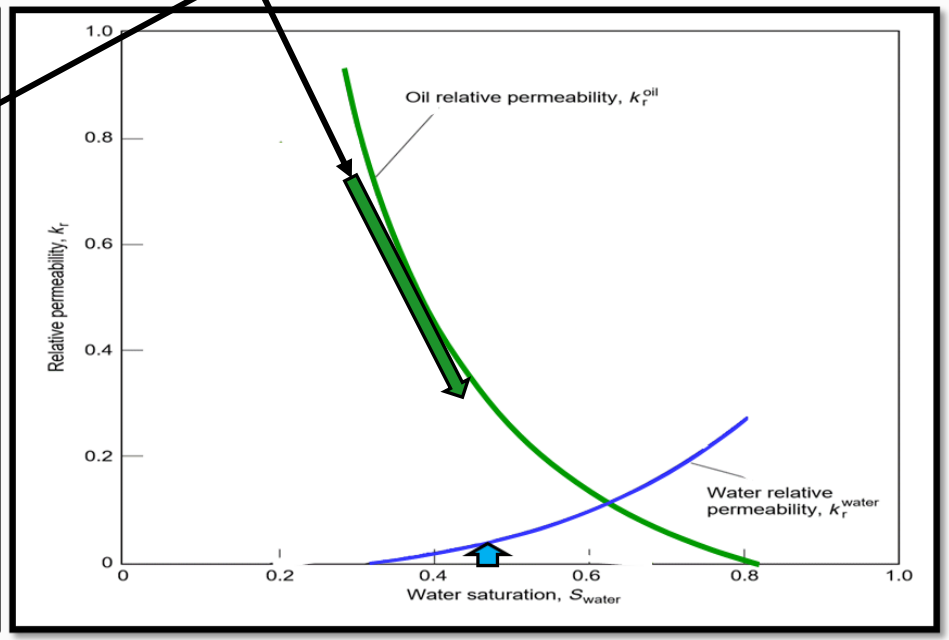


Toward Improved Prediction of Reservoir Flow Performance; John J. Buckles, Randy D. Hazlett, et al

Normal pressure well with a strong water drive

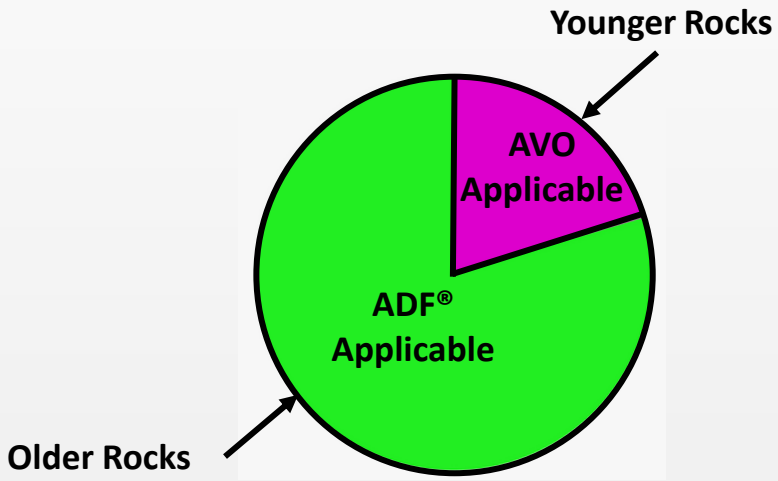


The drop in oil production is due to the drop in relative permeability



This causes a KH 4D effect and makes ADF® a weak DHI in some cases

AVO is highly effective In young rocks

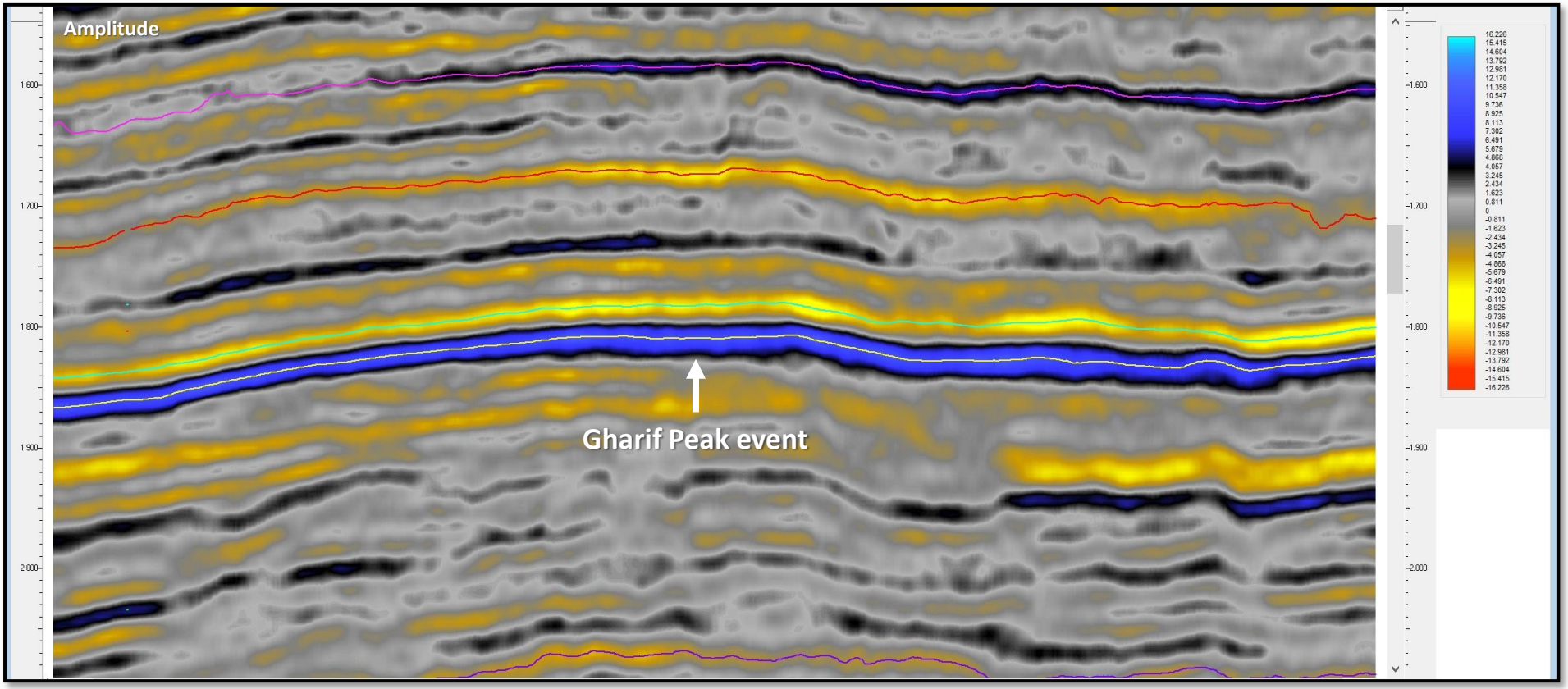


ADF® is highly effective in older rocks like most reservoirs

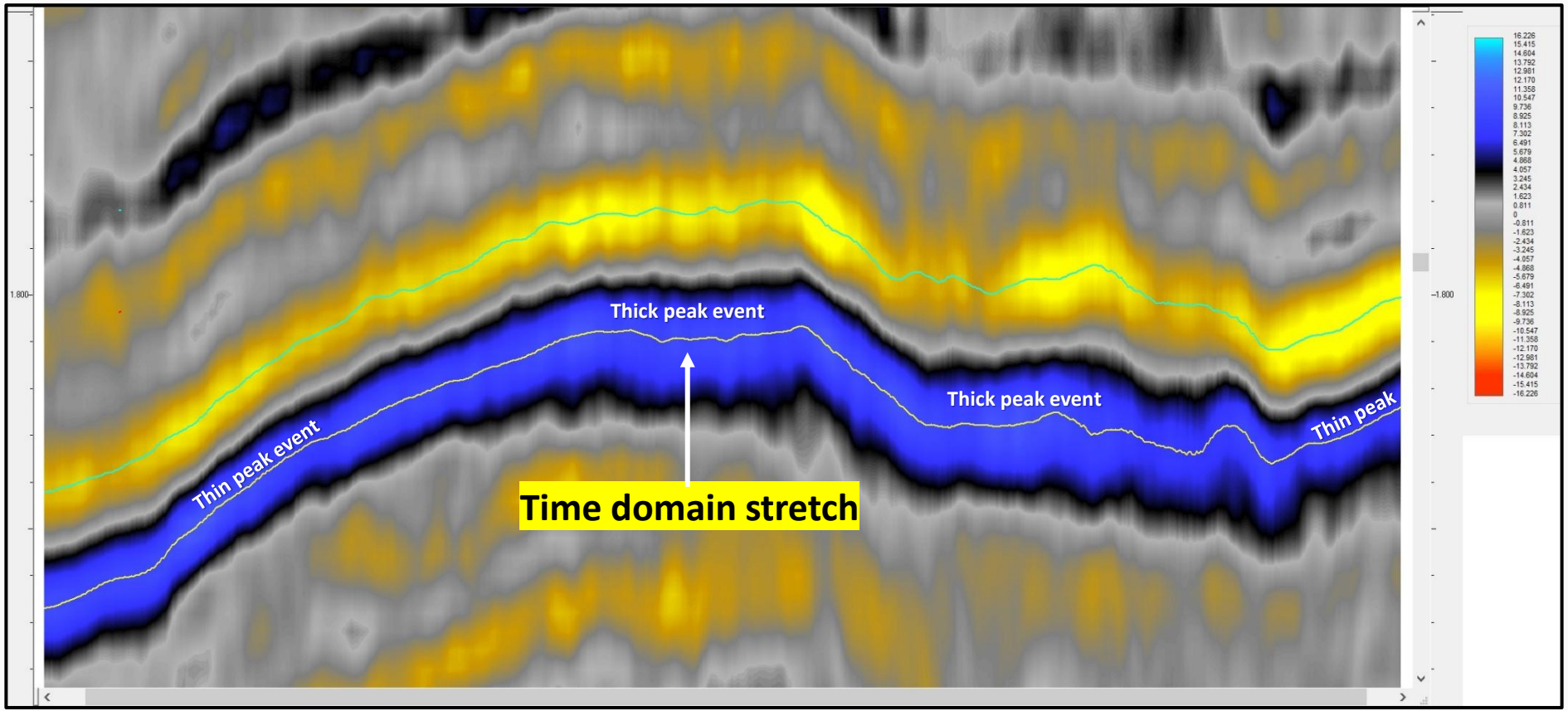
Shell/PDO Oman Blind Test Proof of Concept Project

"Dispersion Imaged Field with No Amplitude DHI"

Published October 21, 2021

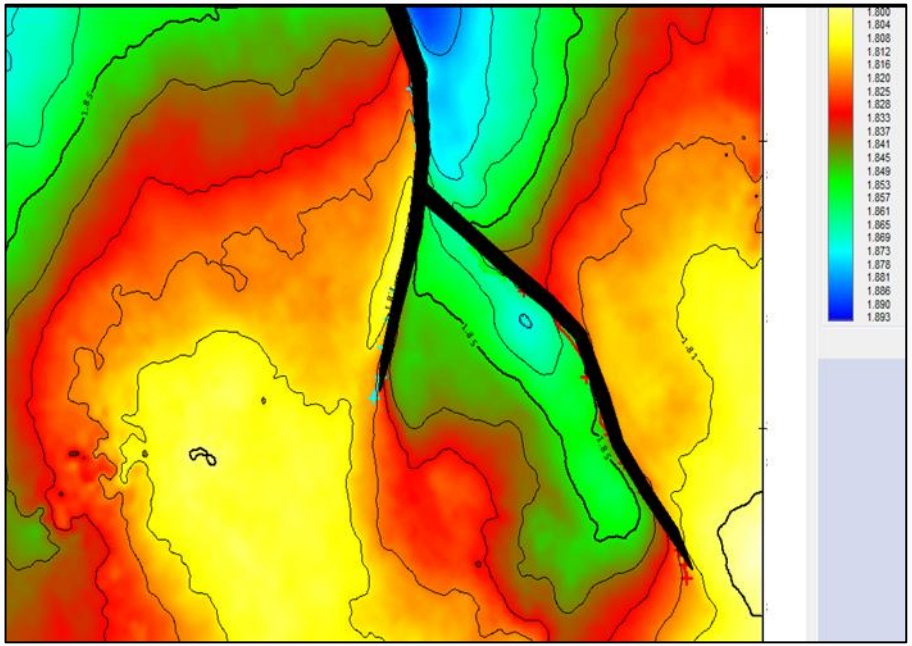

Amplitude
Gharif Peak event
1.600
1.700
1.800
1.900
2.000
16.226
15.415
14.604
13.792
12.981
12.170
11.358
10.547
9.736
8.925
8.113
7.302
6.491
5.679
4.868
4.057
3.245
2.434
1.623
0.811
0
-0.811
-1.623
-2.434
-3.245
-4.057
-4.868
-5.679
-6.491
-7.302
-8.113
-8.925
-9.736
-10.547
-11.358
-12.170
-12.981
-13.792
-14.604
-15.415
-16.226

Zoom-In of Previous Slide

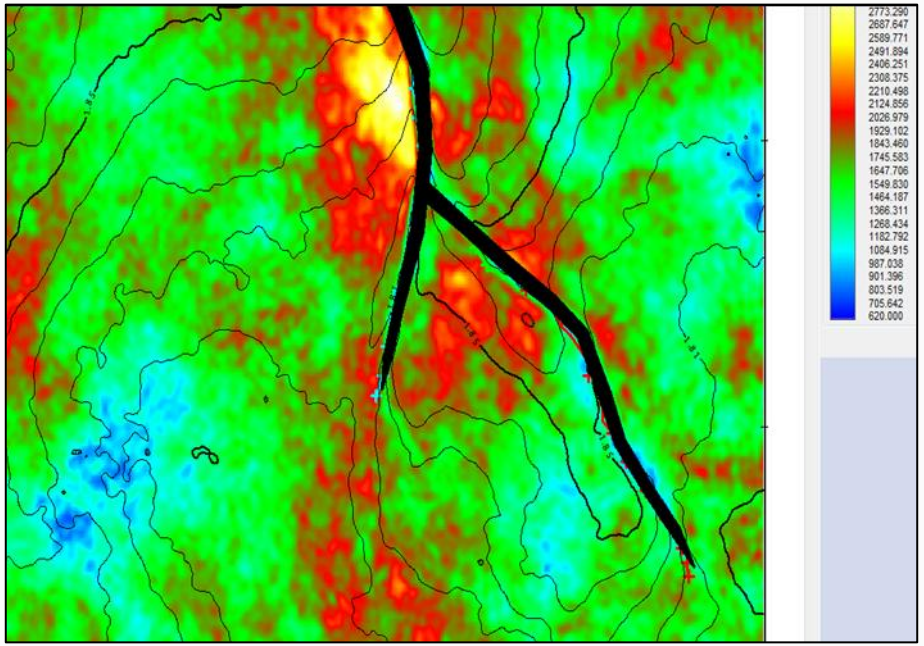


Courtesy of Petroleum Development Oman

Gharif Structure Map



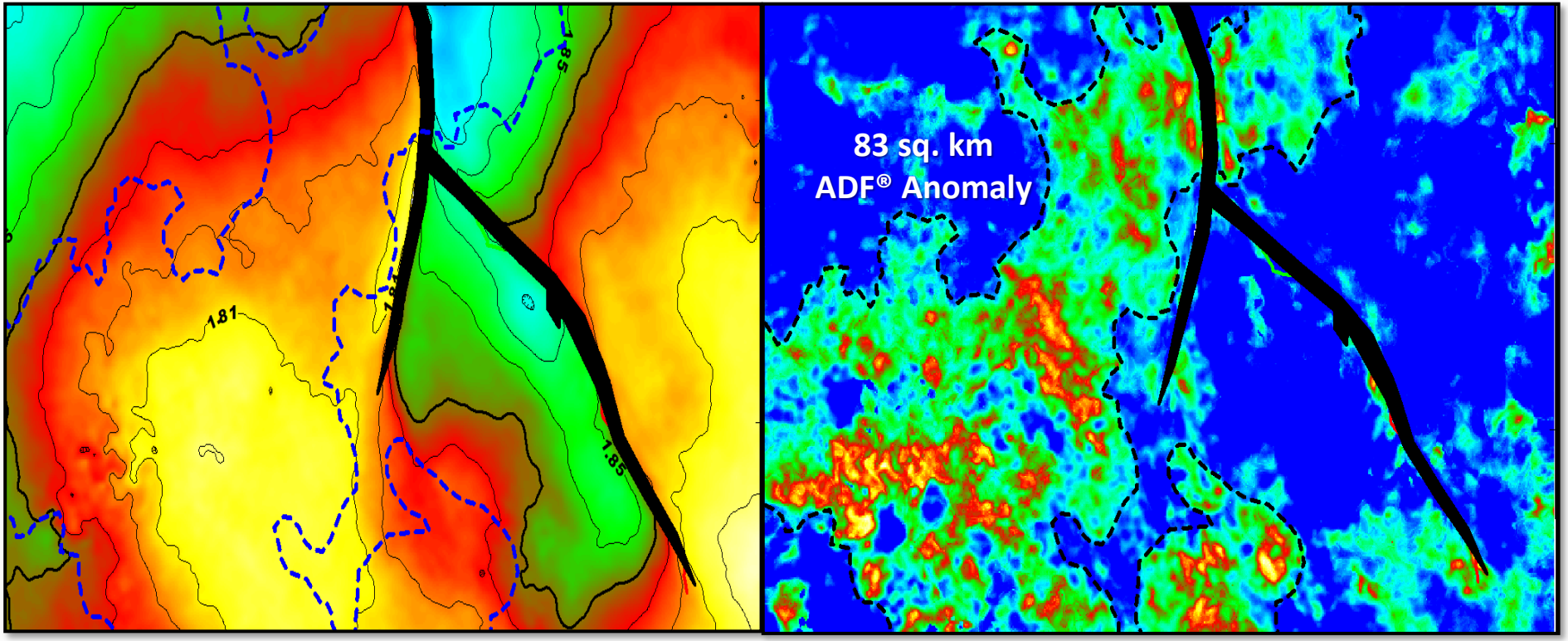
Gharif Peak Amplitude



Amplitude shows no correlation to structure

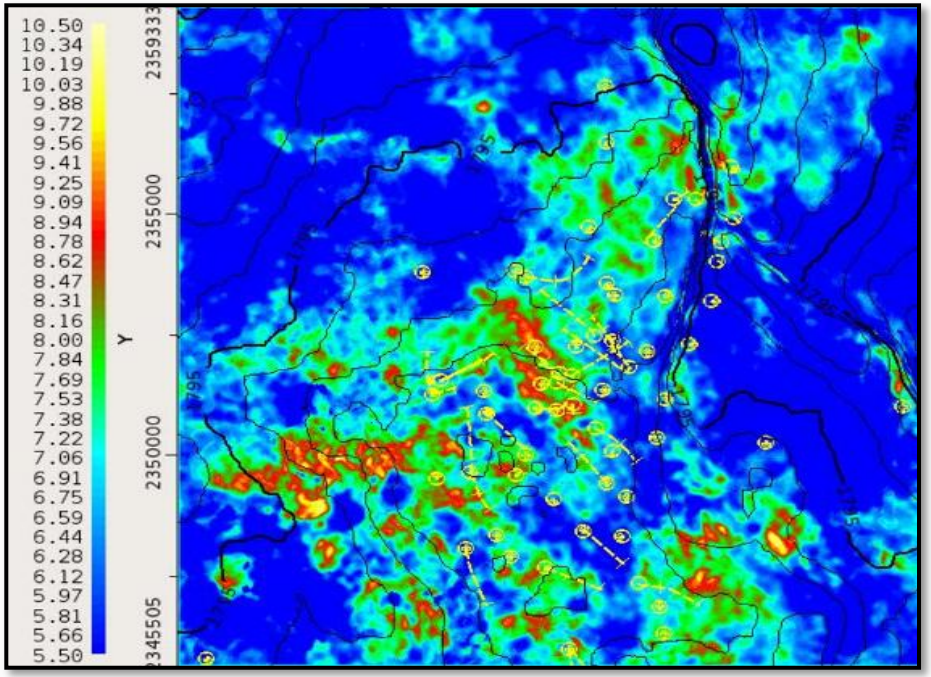
Gharif Structure Map

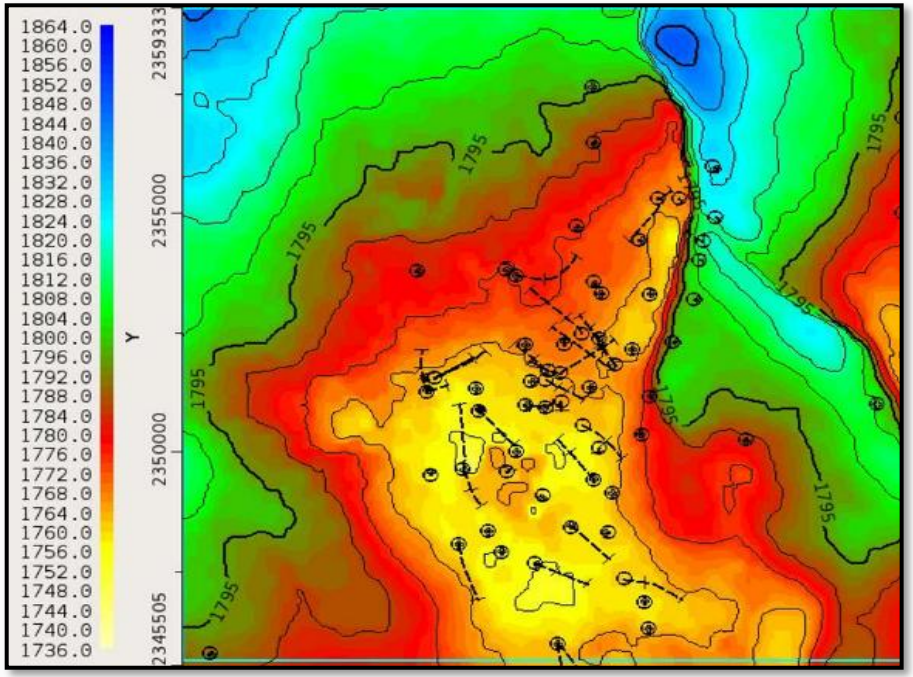
Gharif ADF®



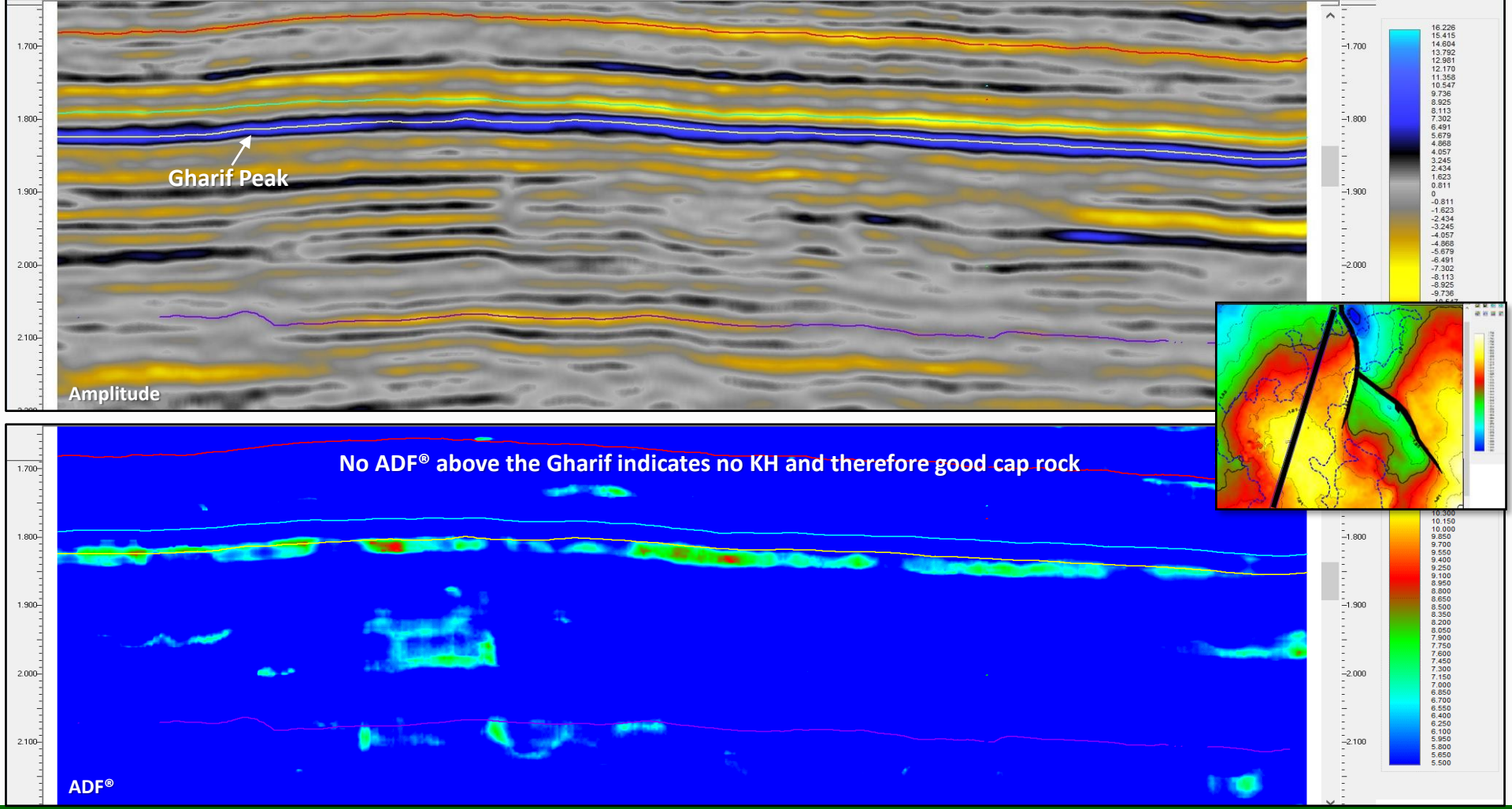
ADF® shows correlation to structure

After ADF® results were delivered PDO provided the wells

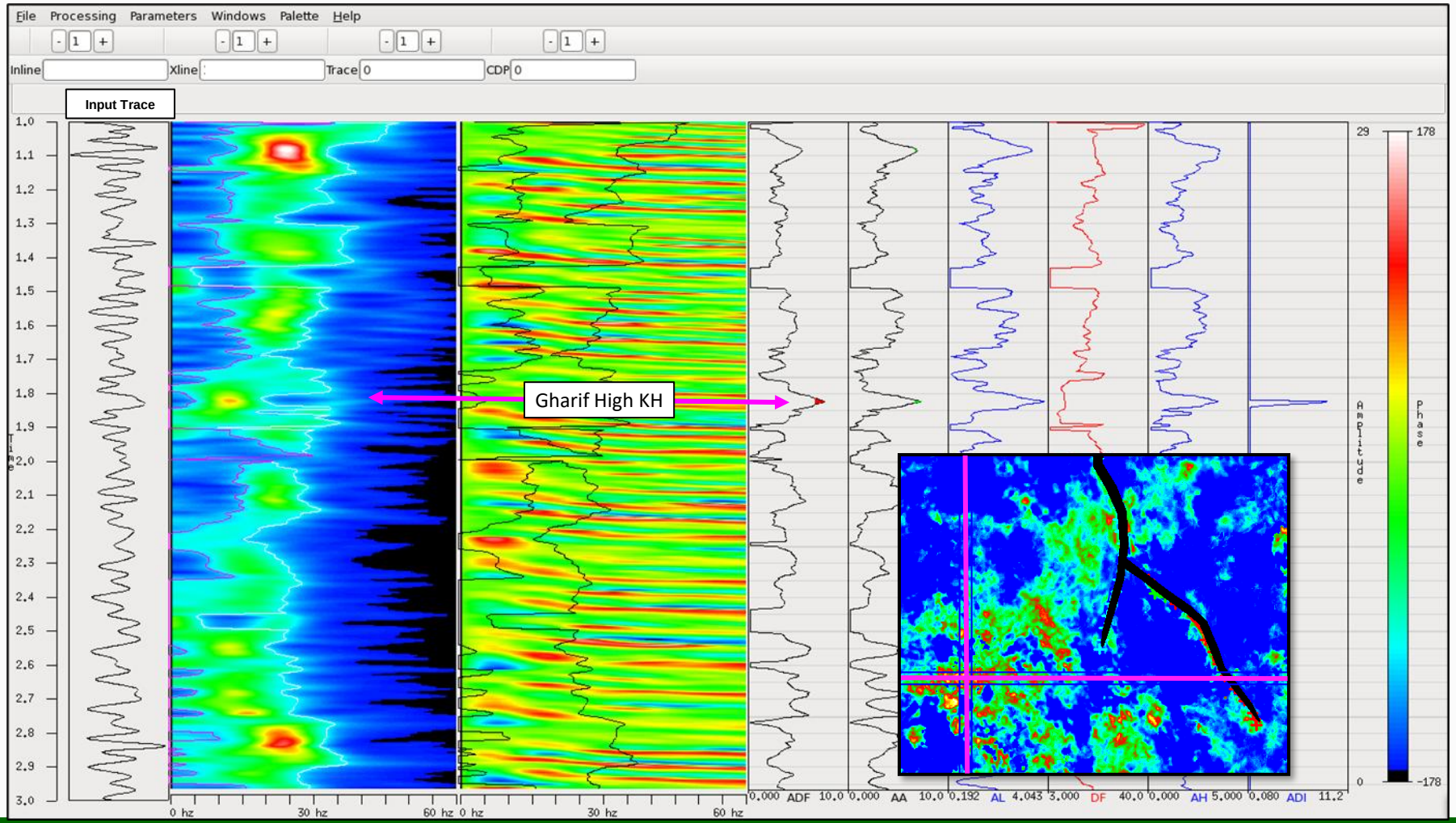




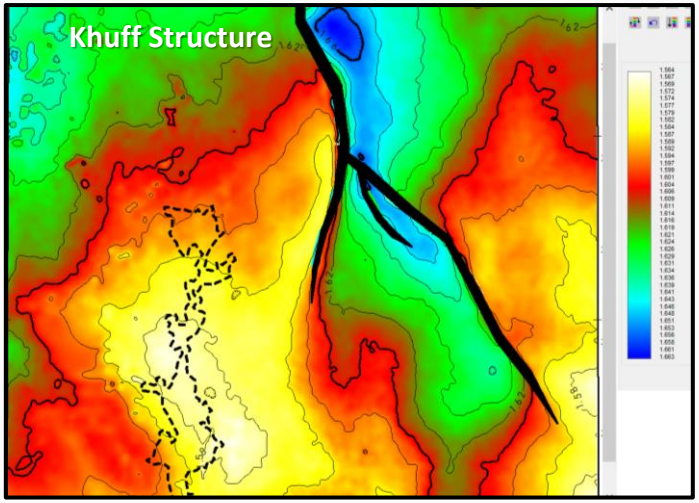
ADF® correlates to the field because it correlates to KH and early hydrocarbon migration helped preserve porosity and perm

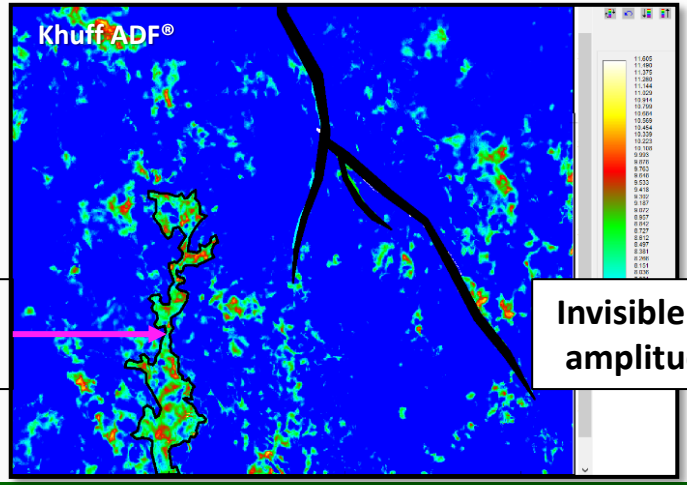


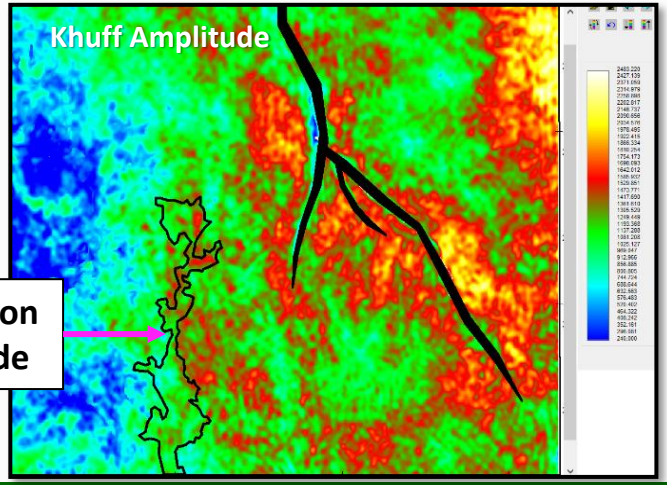
Courtesy of Petroleum Development Oman


File Processing Parameters Windows Palette Help
Inline
Xline
Trace 0
CDP 0
Input Trace
Gharif High KH
0 hz
30 hz
60 hz
ADF
AA
AL
DF
AH
ADI
Amplitude
Phase

Khuff Carbonate ADF®



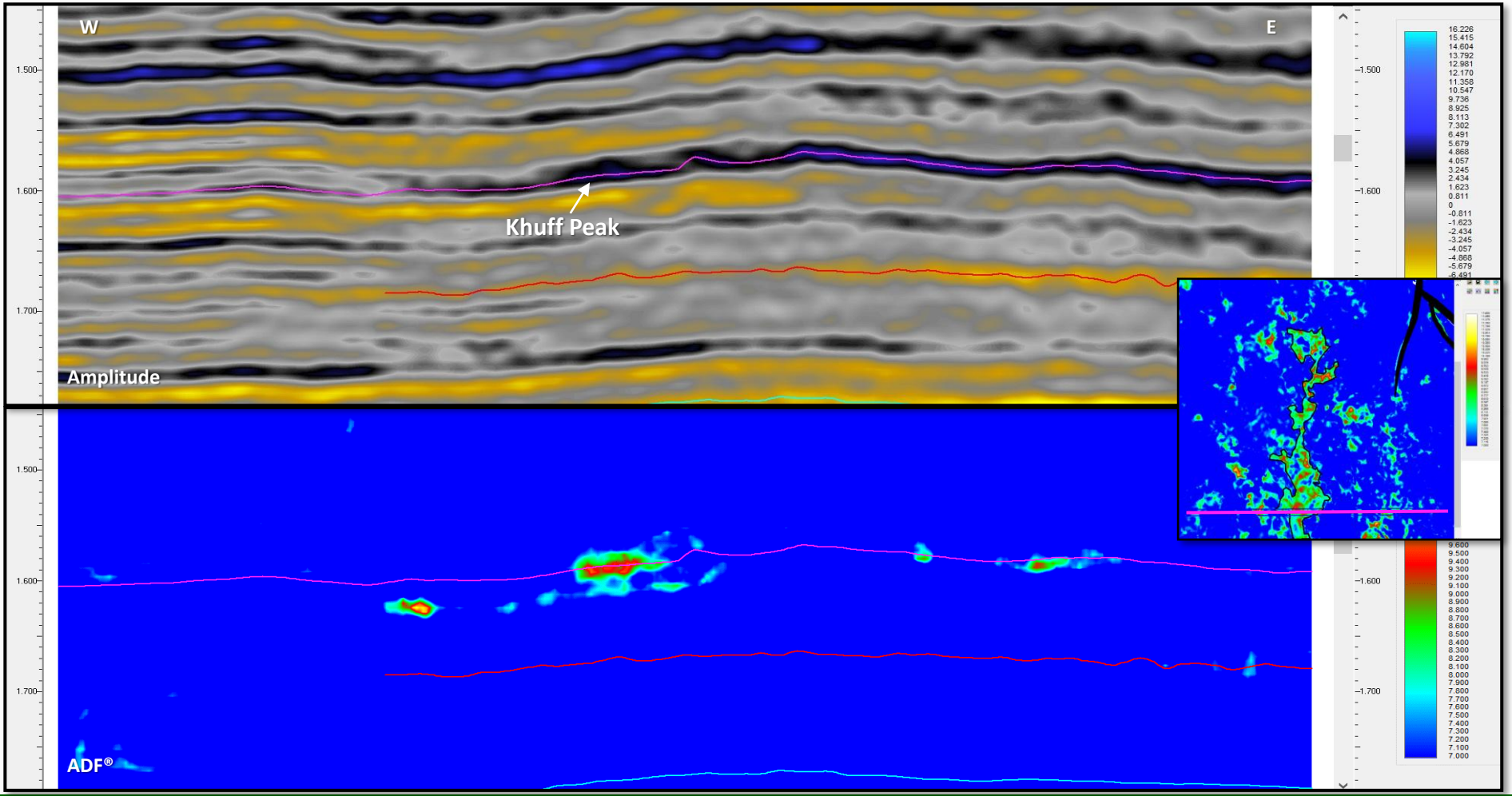




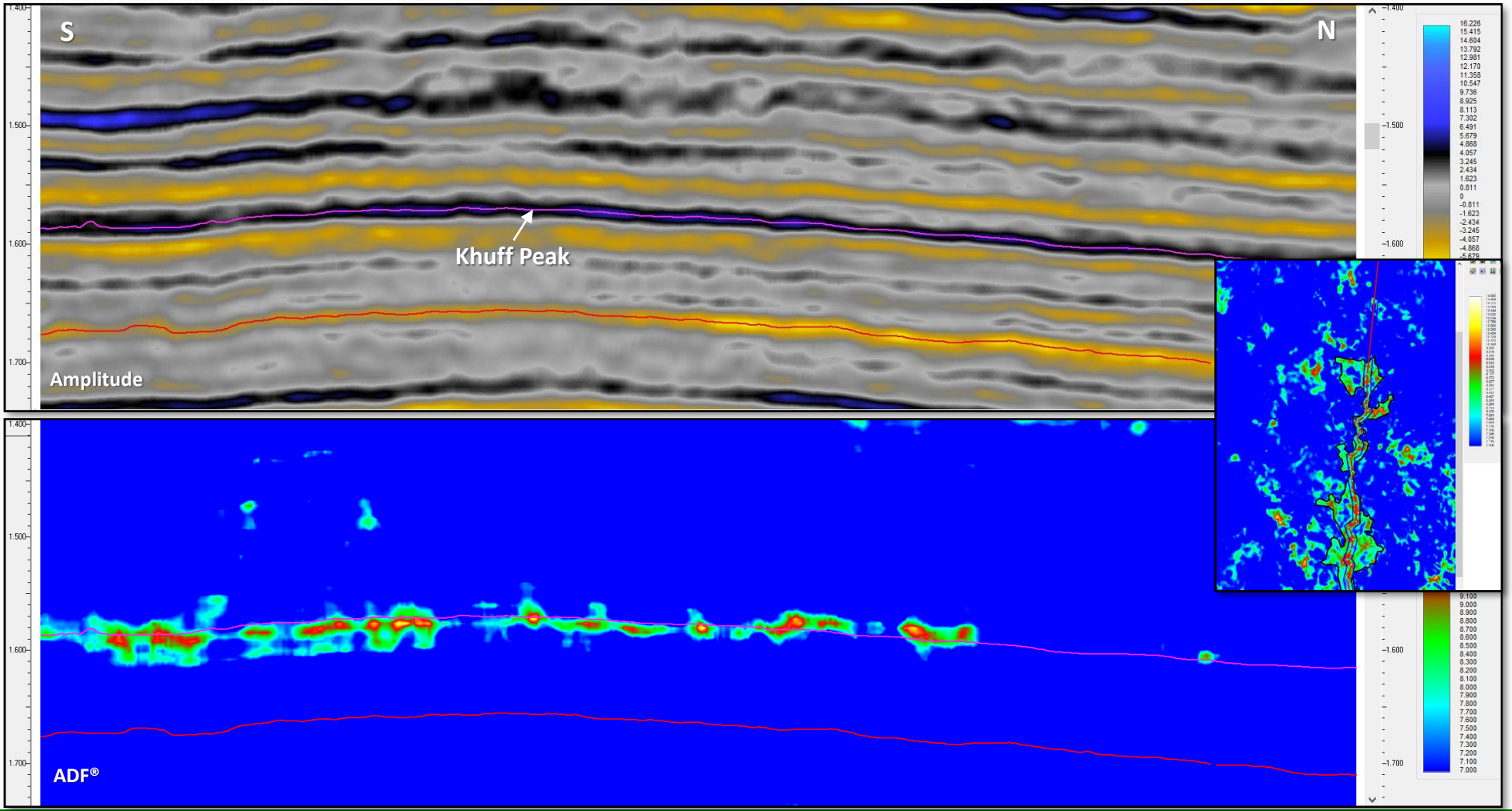
9 sq. km ADF® Anomaly

Invisible on amplitude

Courtesy of Petroleum Development Oman

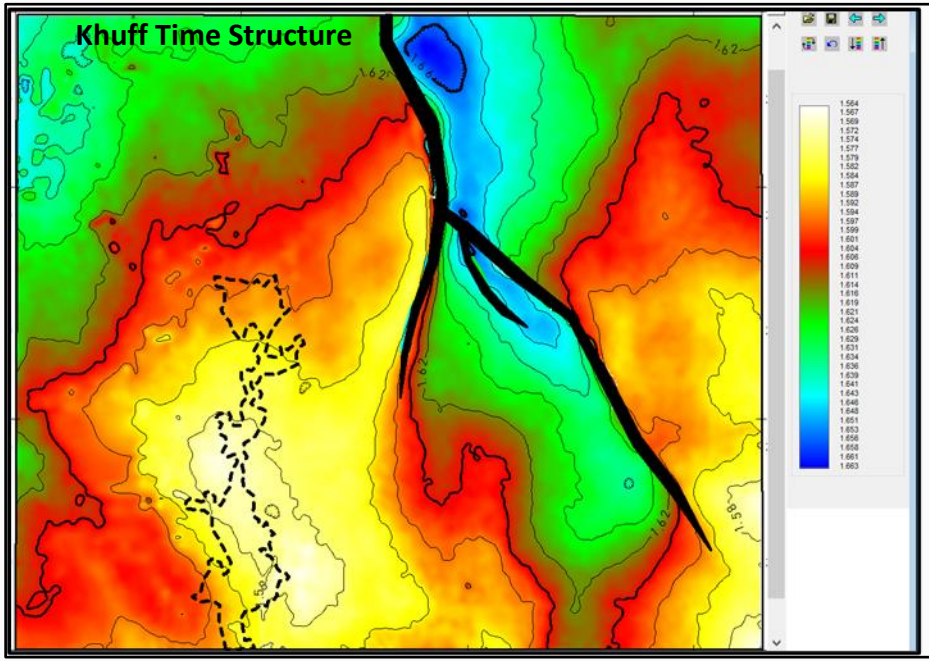


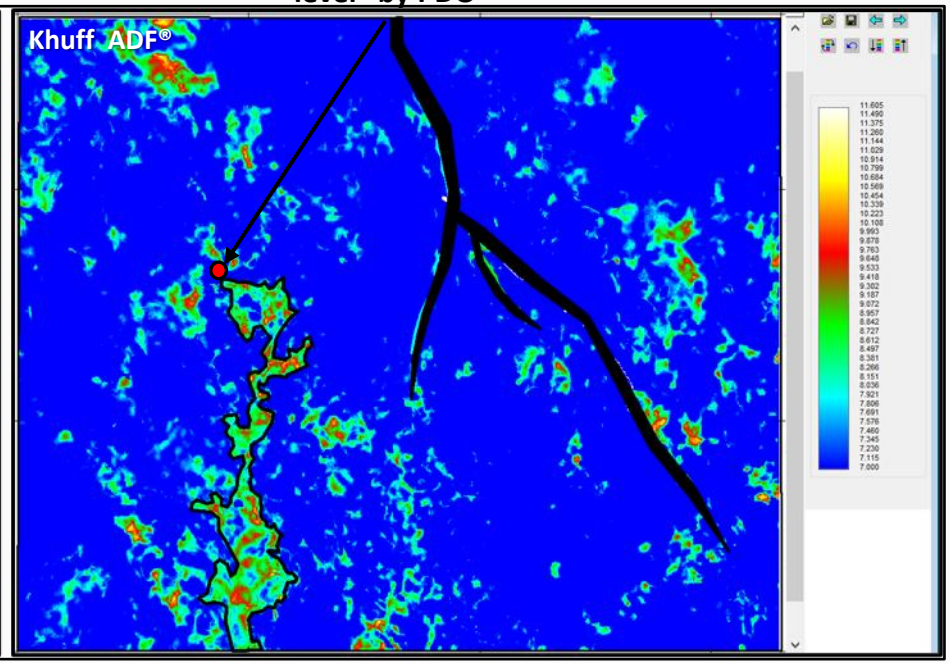
Courtesy of Petroleum Development Oman



Courtesy of Petroleum Development Oman

Well MBR35 was interpreted to be "Hydrocarbons at Khuff level" by PDO



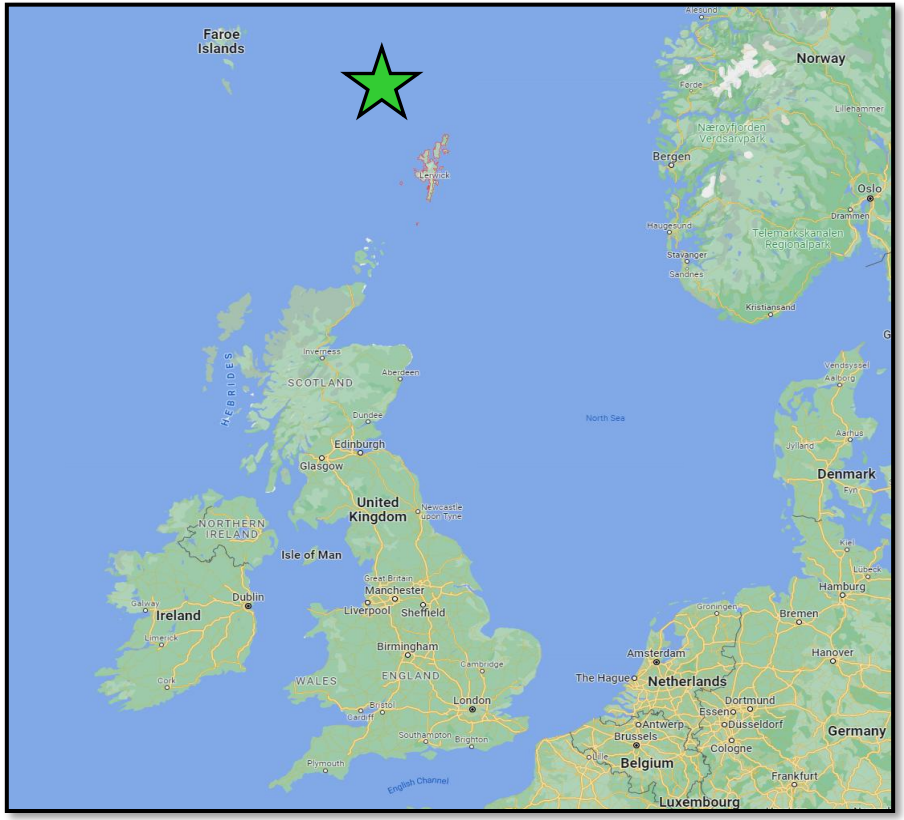


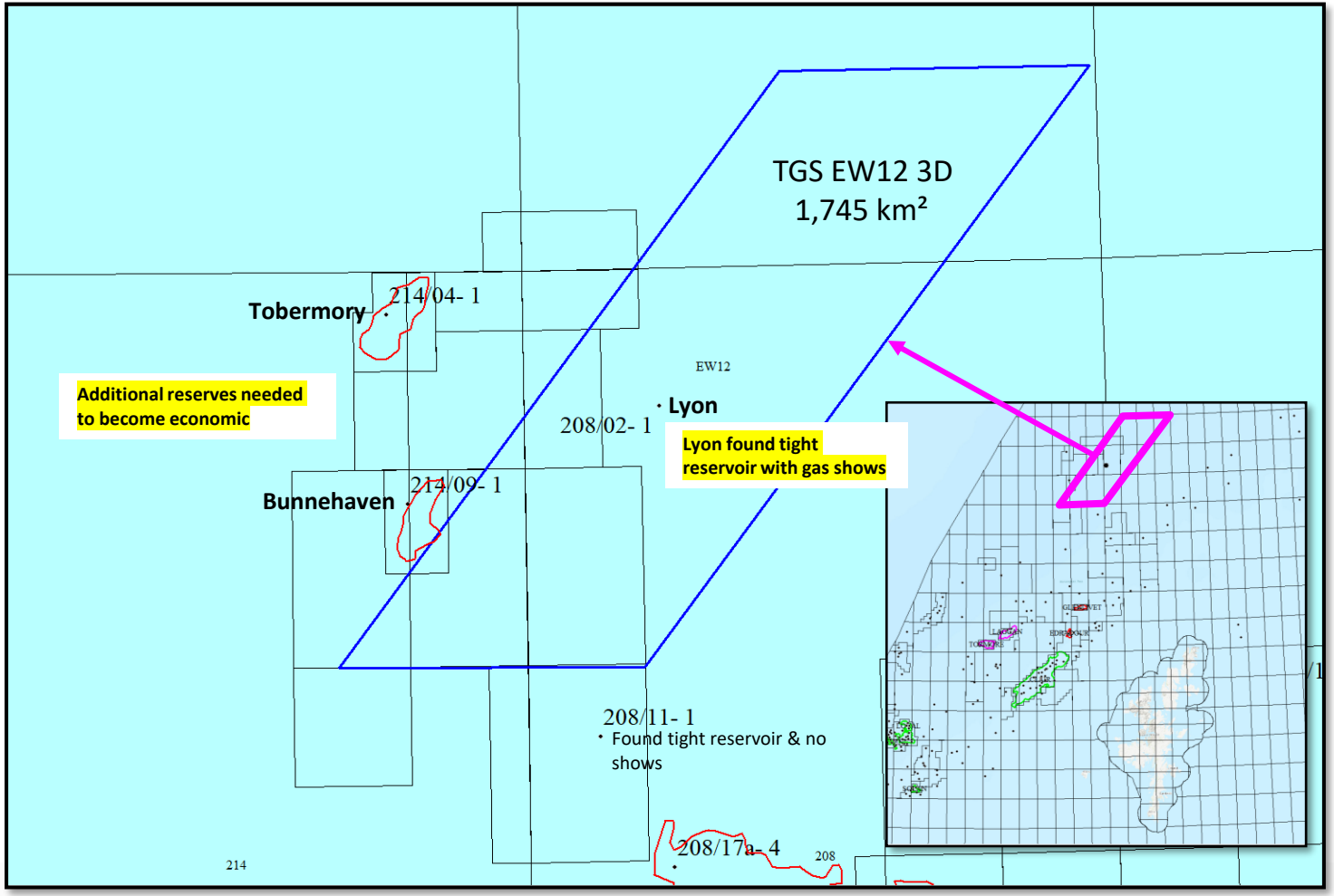
Blind Test Summary Points

- **ADF® imaged KH corresponding to the Mabrouk Oil and Gas Field (a Gharif sandstone) due to early hydrocarbon migration preserving porosity and perm.**

- **ADF® imaged KH in the Khuff carbonate which as we learned was later drilled resulting in an oil discovery above the Gharif.**

West of Shetlands TGS EW12 3D Results

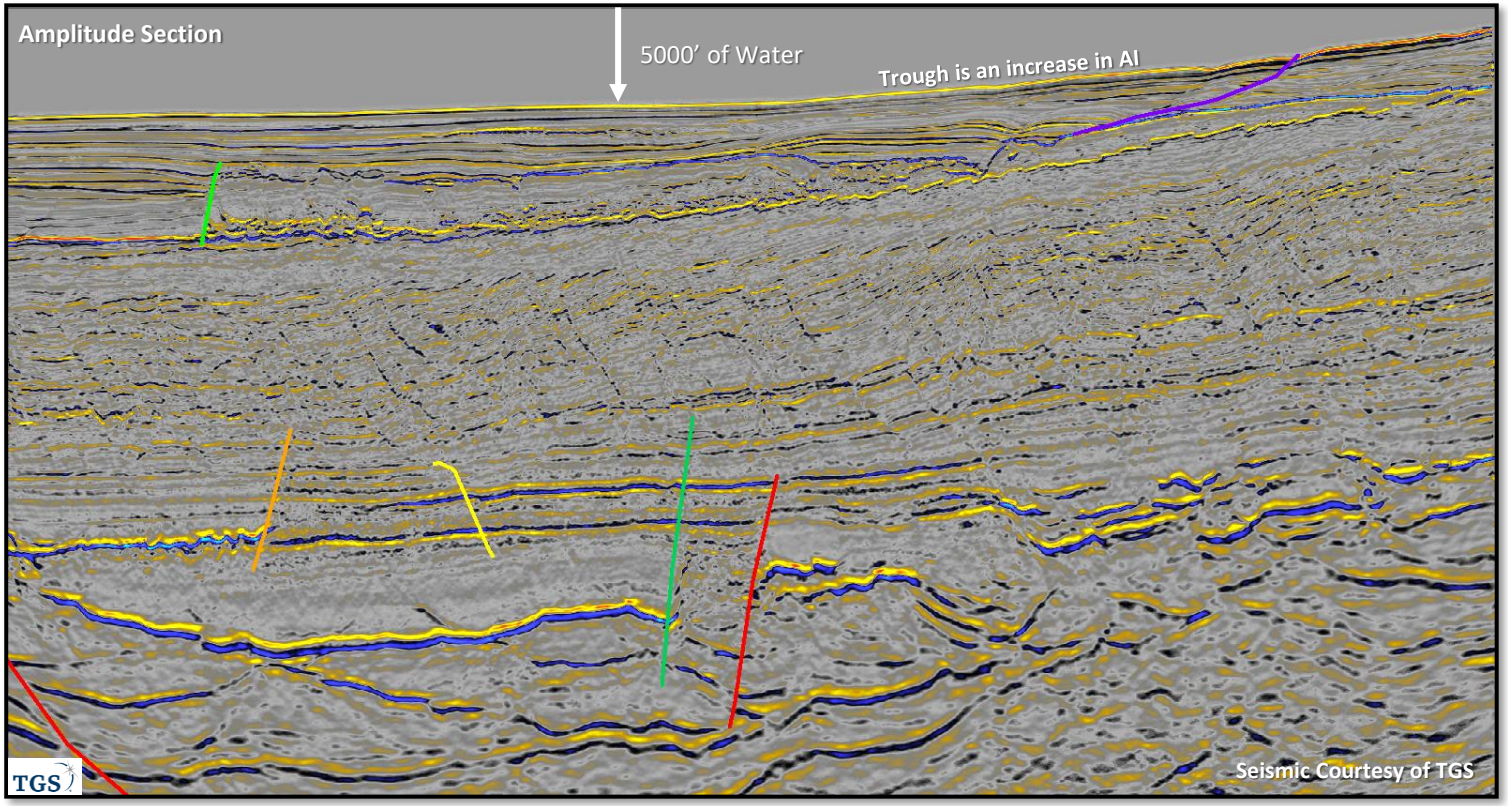


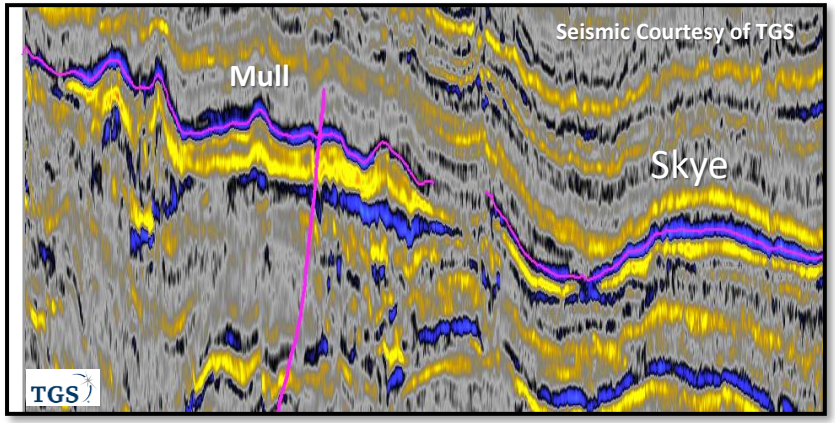

TGS EW12 3D
1,745 km²
Tobermory
214/04- 1
Additional reserves needed to become economic
EW12
Lyon
208/02- 1
Lyon found tight reservoir with gas shows
Bunnehaven
214/09- 1
208/11- 1
Found tight reservoir & no shows
208/17a- 4
214
208

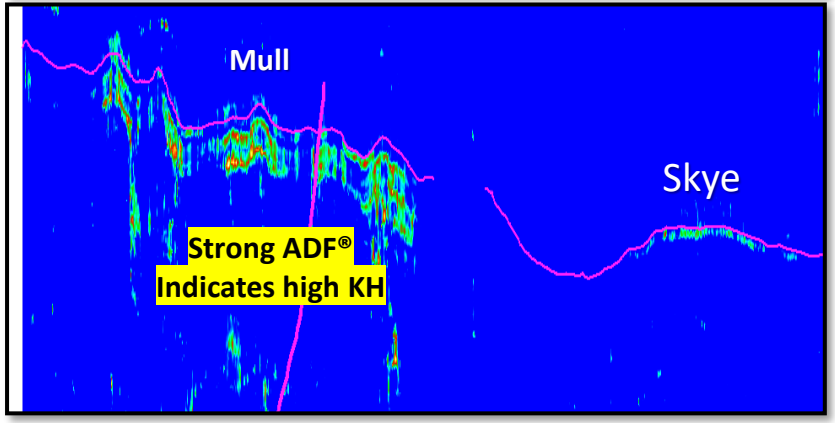
Shallow distal sands

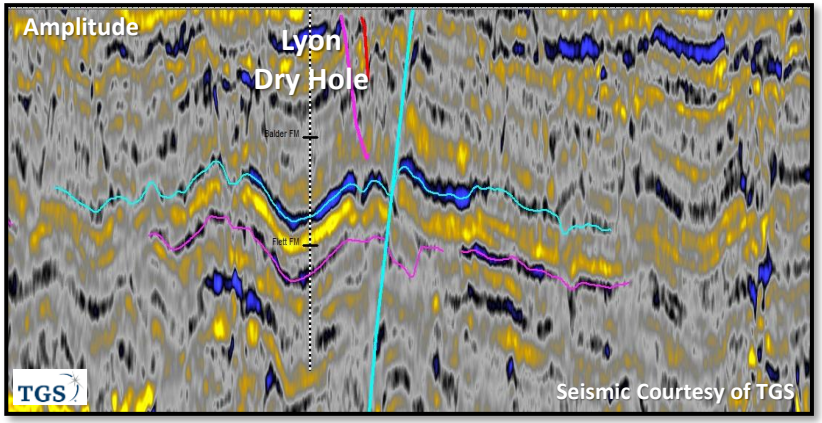
Eocene/Paleocene distal sands

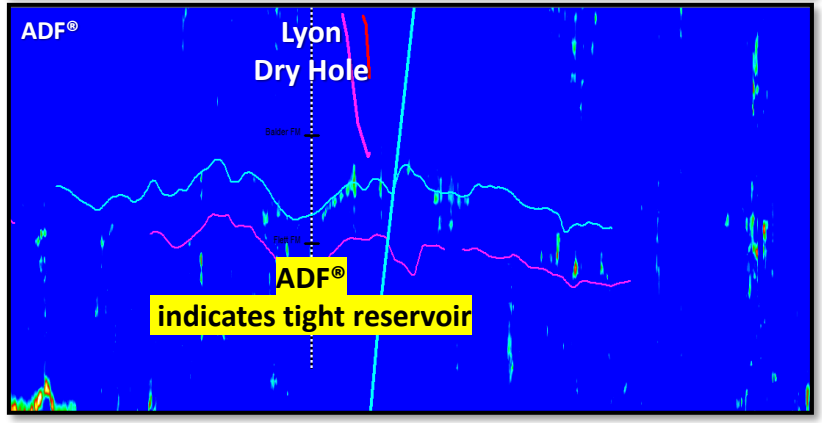
High amplitude volcanic sills & sands



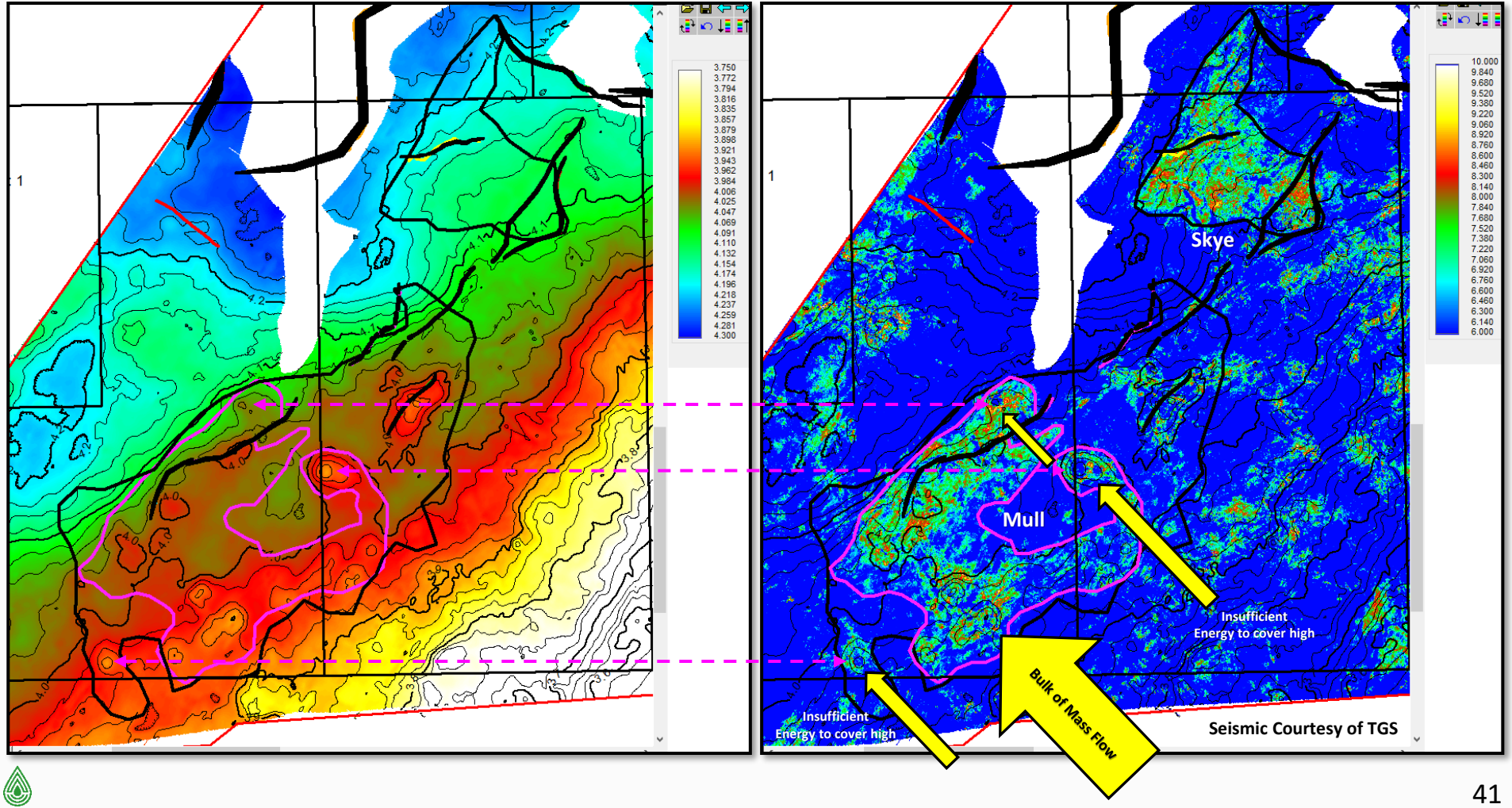

Seismic Courtesy of TGS
Mull
Skye
TGS


Mull
Skye
Strong ADF®
Indicates high KH


Amplitude
Lyon
Dry Hole
Balder FM
Flett FM
TGS
Seismic Courtesy of TGS


ADF®
Lyon
Dry Hole
Balder FM
ADF®
indicates tight reservoir

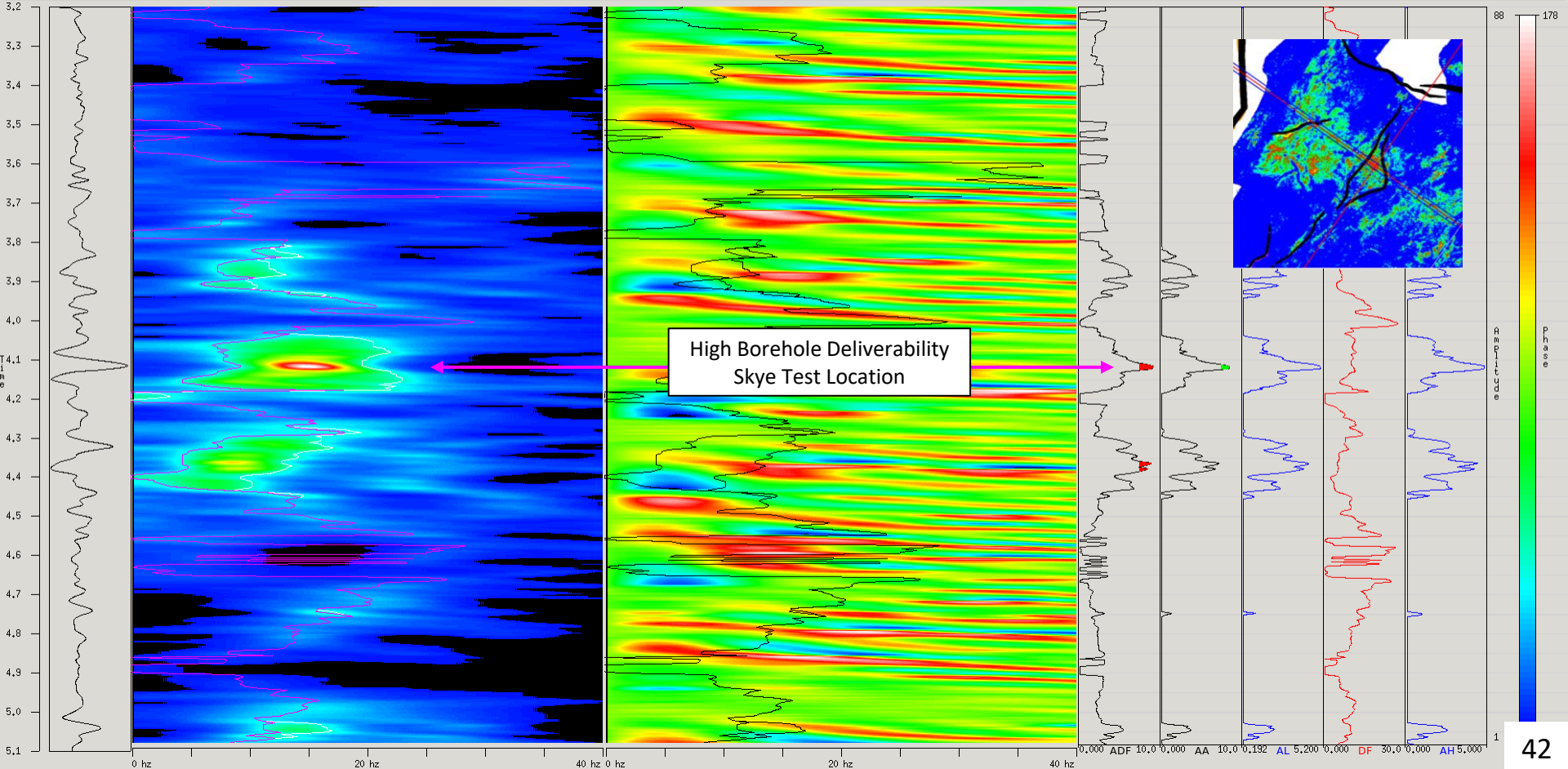
Strong ADF® in front of bald on top paleo highs where sands would stack up is consistent with ADF® measuring KH

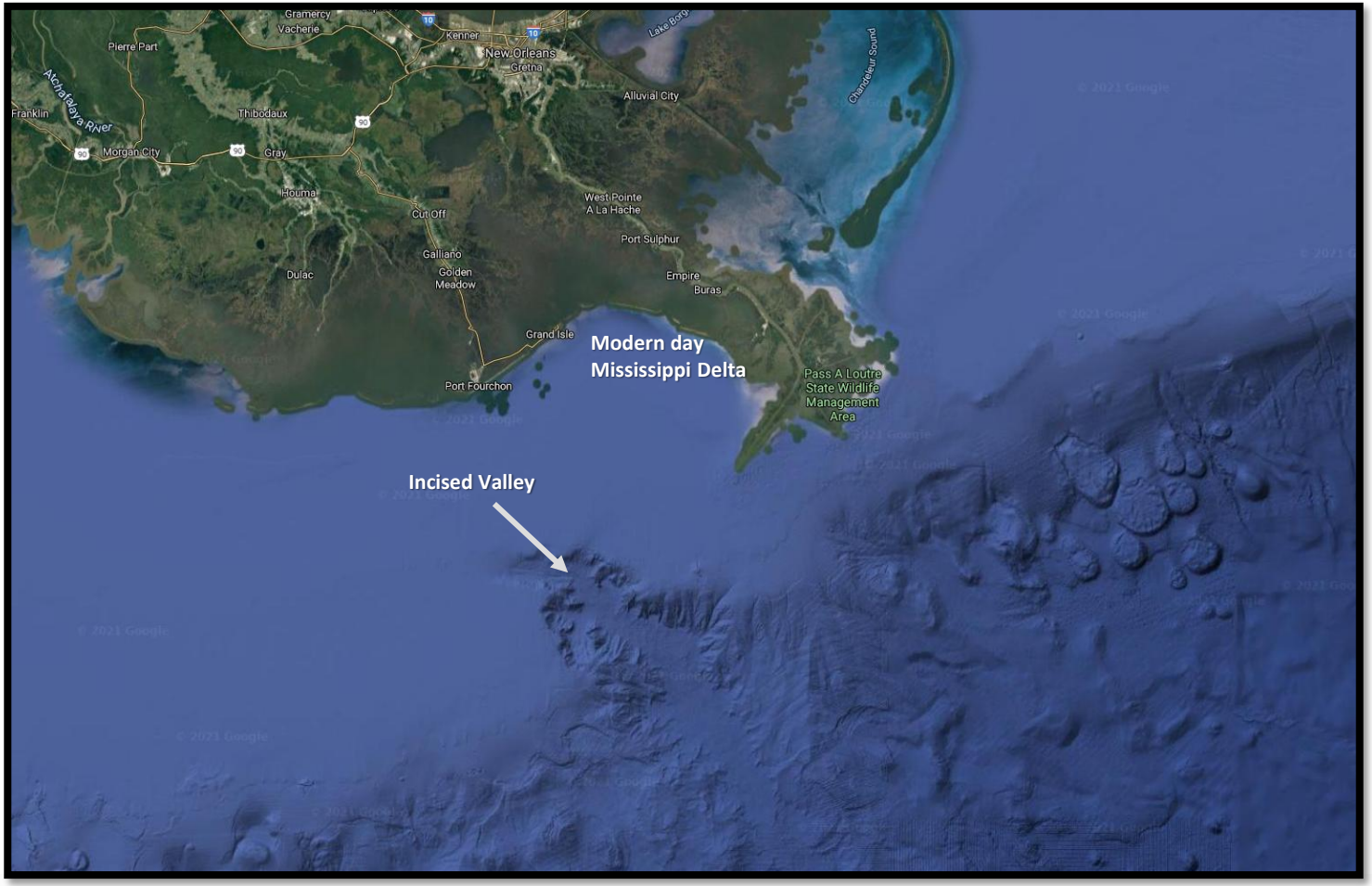


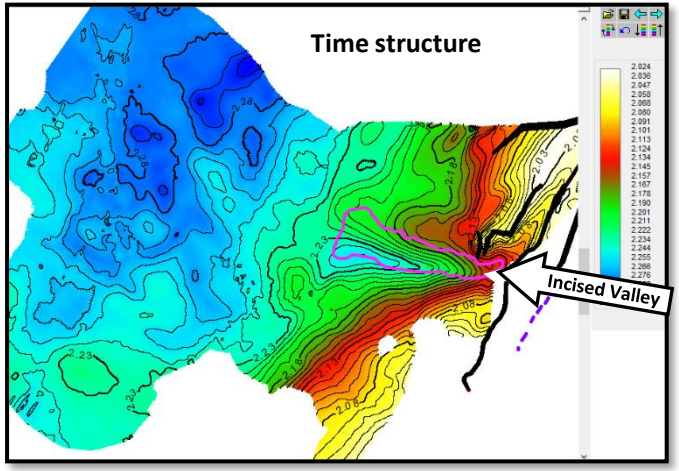
Apex Spectral Technology - Spectral Tools 4.13.000 (on laplace)

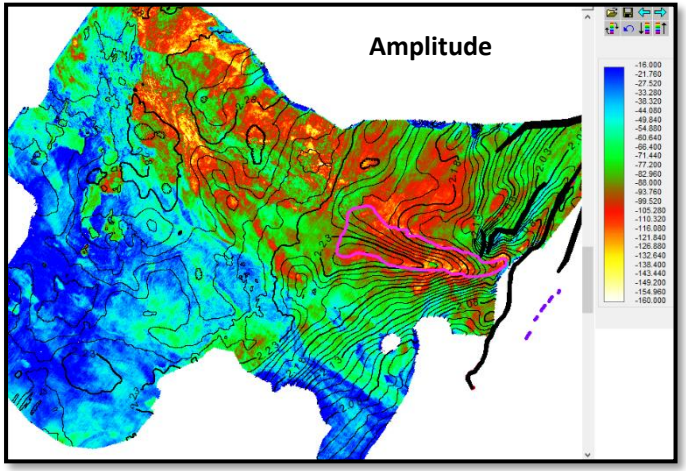
File Processing Parameters Windows Palette Help

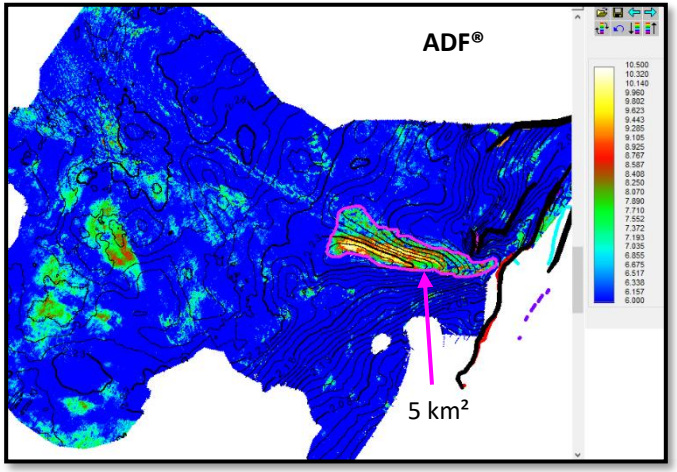
Inline 15220 Xline 11790 Trace 0 CDP 0

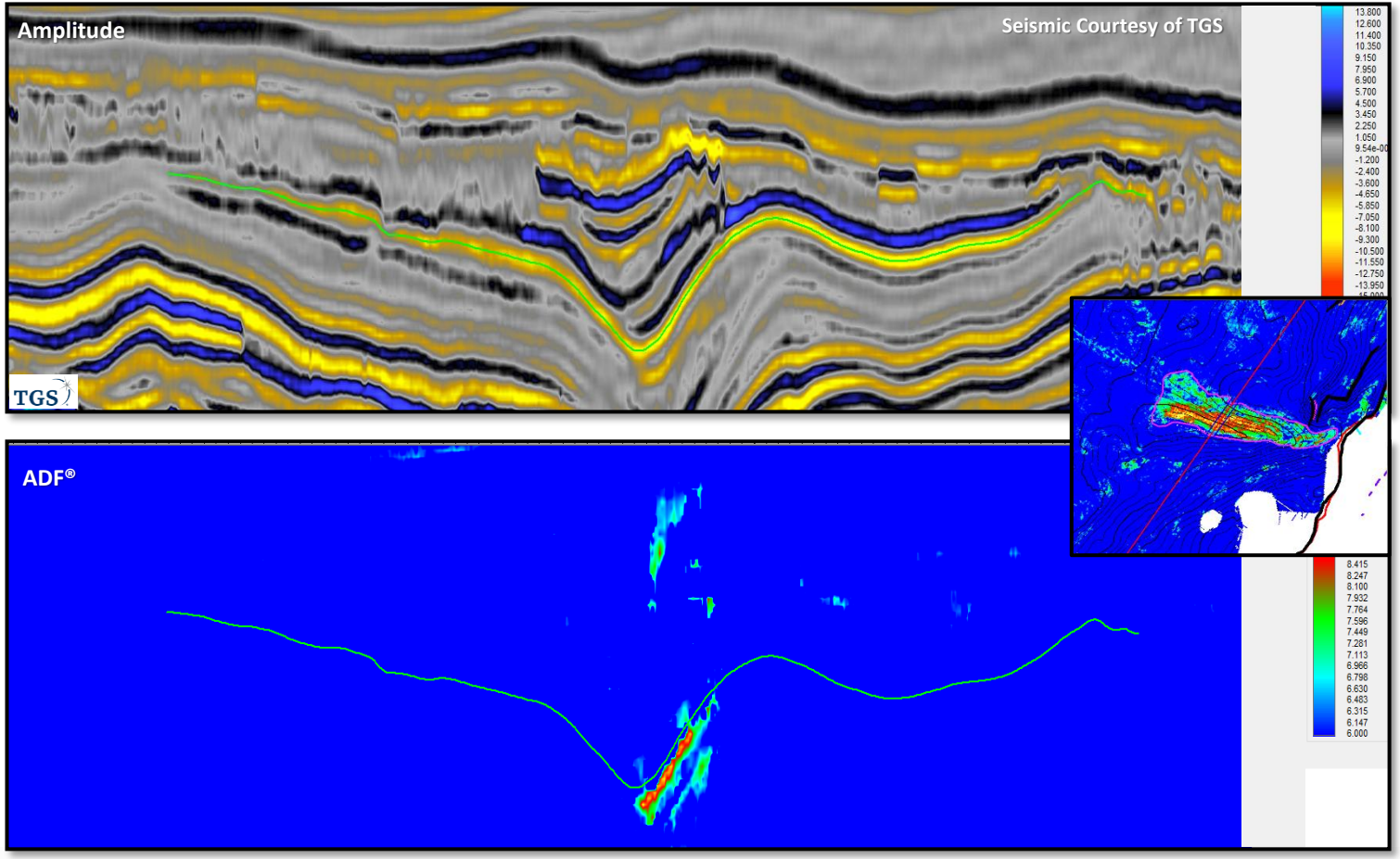



Gramercy
Vacherie
Kenner
New Orleans
Gretna
Lake Borgne
Chandeleur Sound
Pierre Part
Alluvial City
Franklin
Atchafalaya River
Thibodaux
Morgan City
Gray
Houma
Cut Off
West Pointe
A La Hache
Port Sulphur
Galliano
Golden
Meadow
Dulac
Empire
Buras
Grand Isle
Modern day
Mississippi Delta
Port Fourchon
Pass A Loutre
State Wildlife
Management
Area
Incised Valley

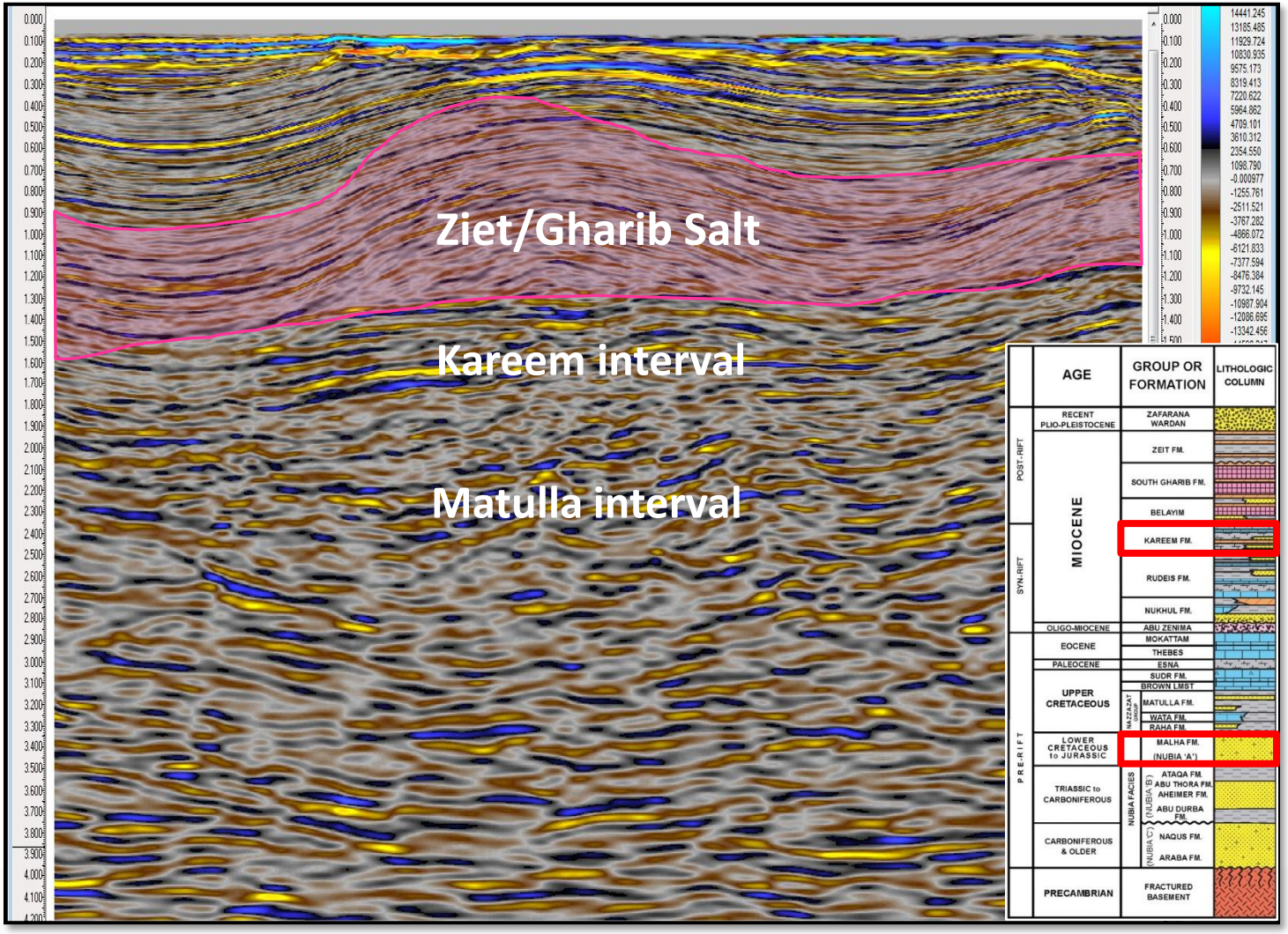

Time structure
Incised Valley

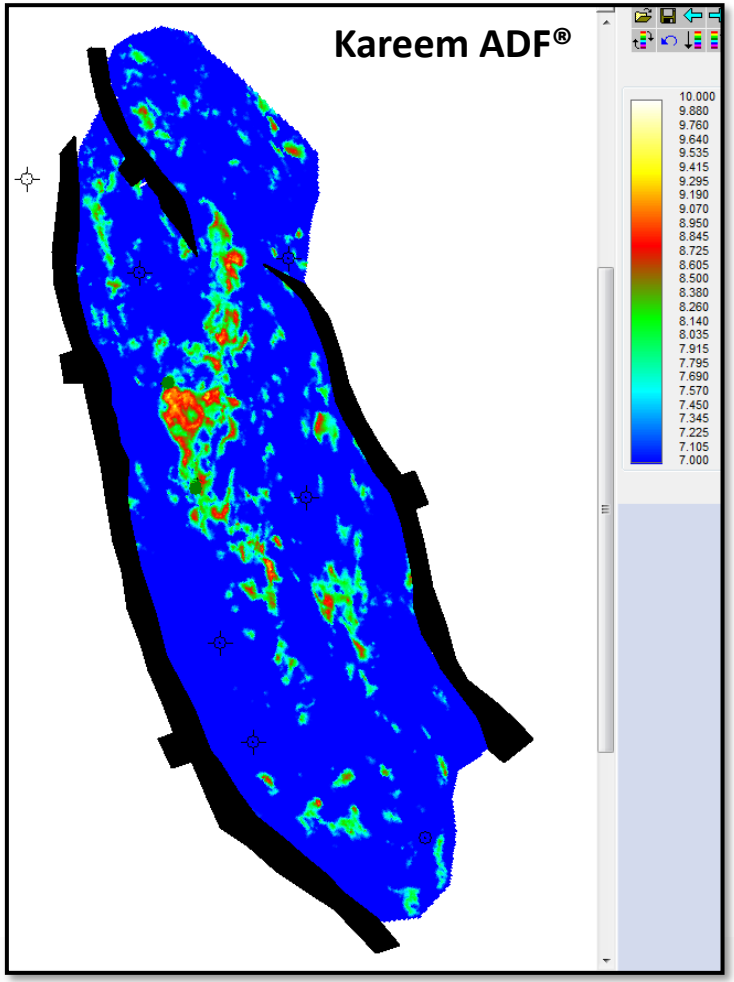

Amplitude

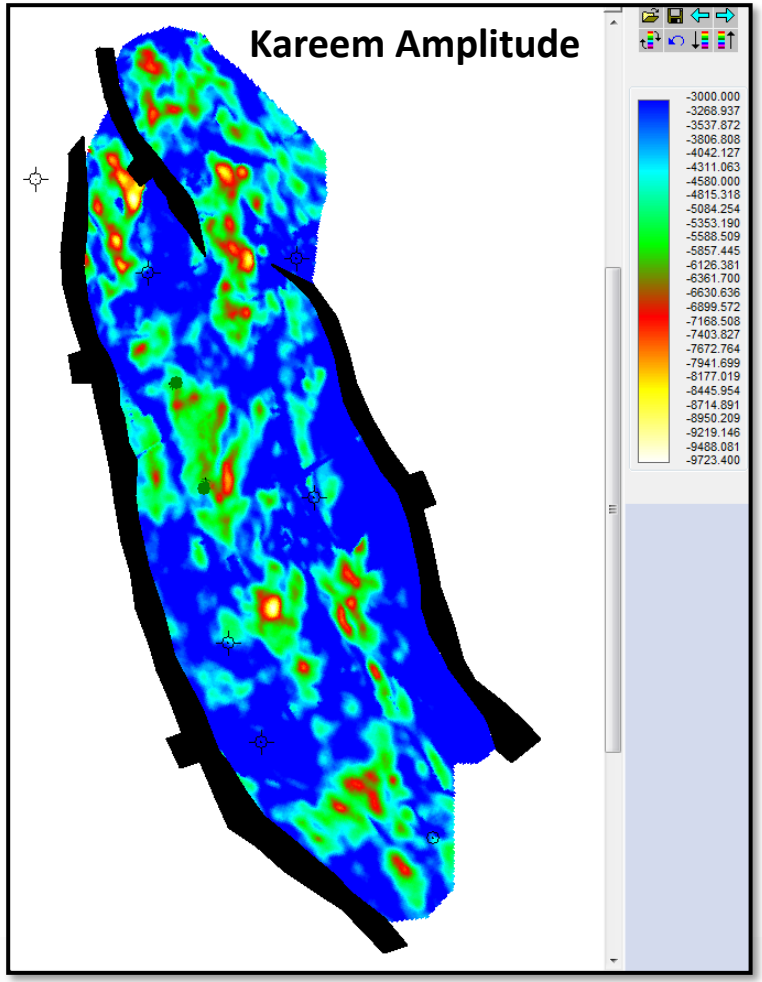

ADF®
5 km²

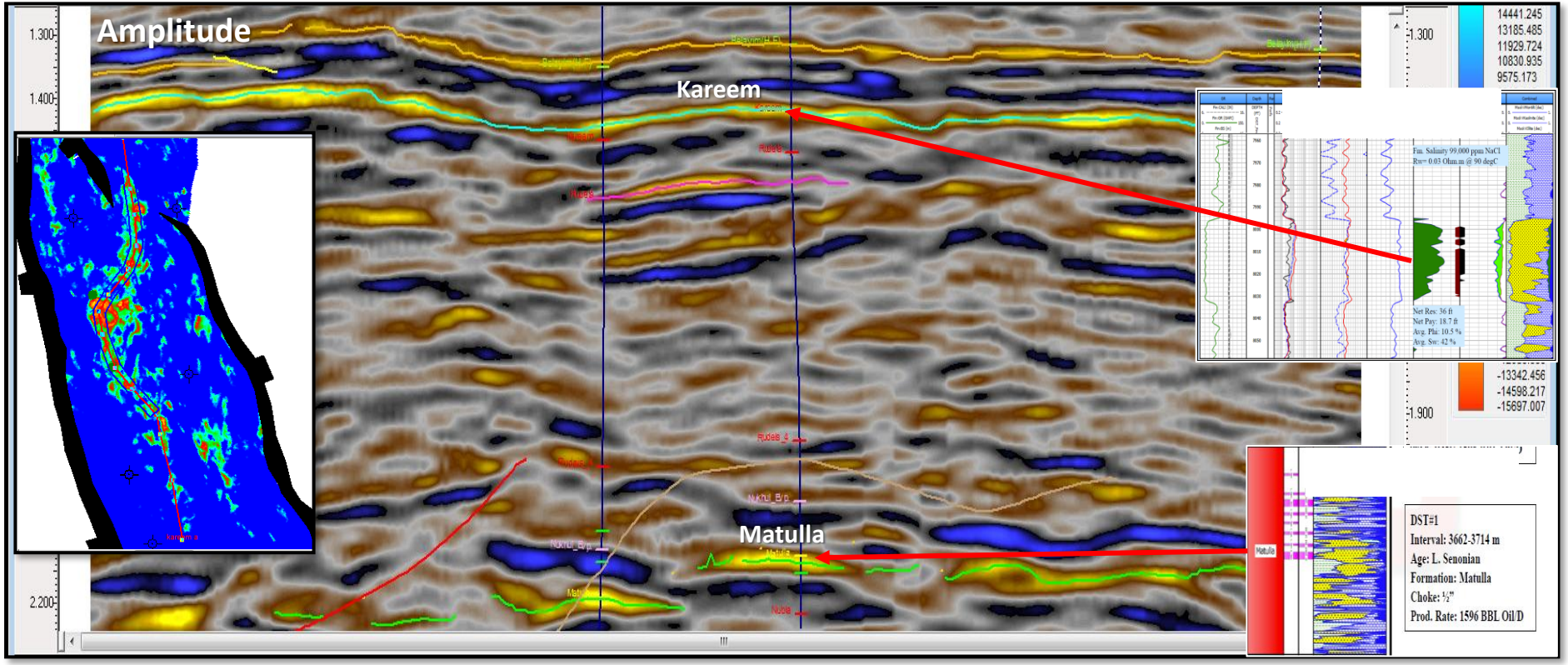

Amplitude
Seismic Courtesy of TGS
TGS
13.800
12.600
11.400
10.350
9.150
7.950
6.900
5.700
4.500
3.450
2.250
1.050
9.54e-00
-1.200
-2.400
-3.600
-4.650
-5.850
-7.050
-8.100
-9.300
-10.500
-11.550
-12.750
-13.950
ADF®
8.415
8.247
8.100
7.932
7.764
7.596
7.449
7.281
7.113
6.966
6.798
6.630
6.483
6.315
6.147
6.000

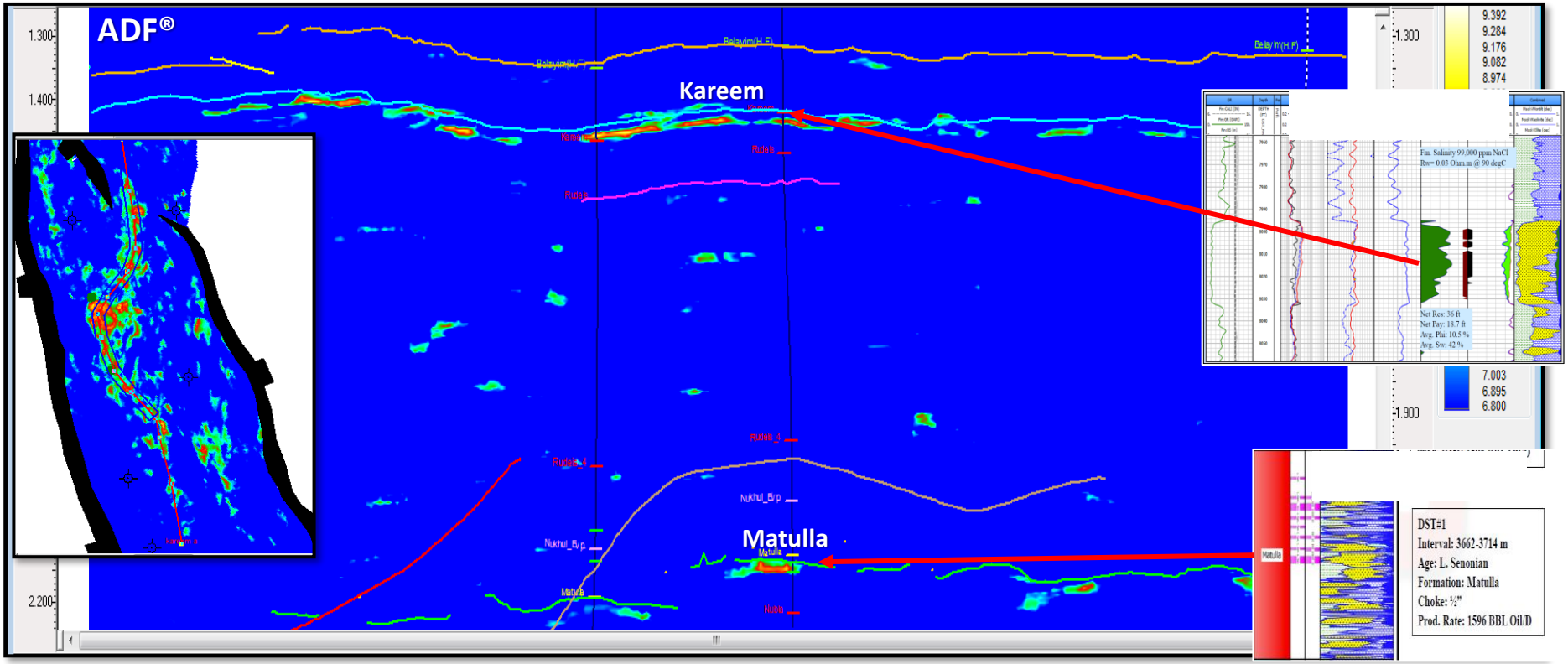
Subsalt Gulf of Suez ADF® Blind Test Results

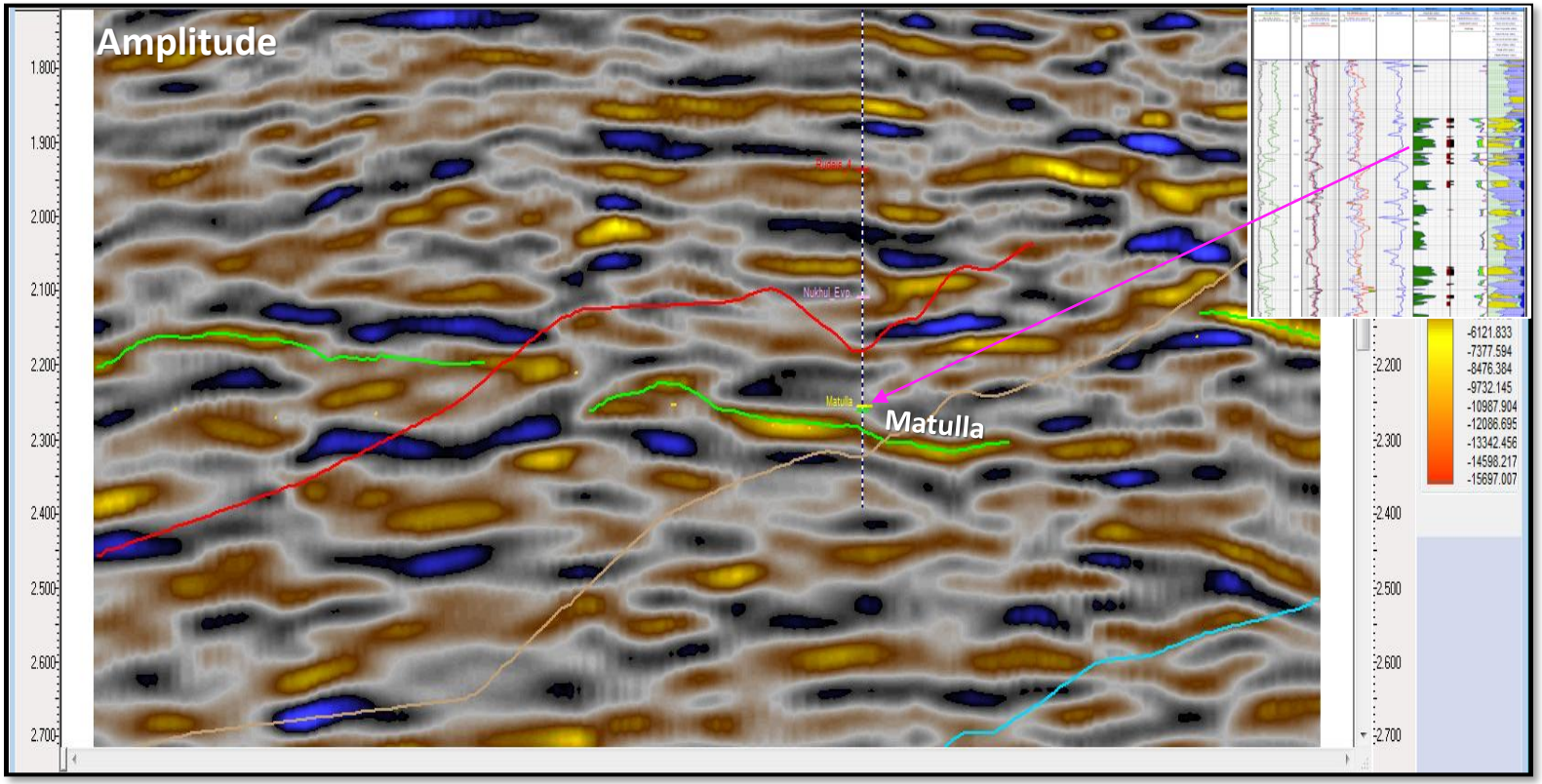

Ziet/Gharib Salt
Kareem interval
Matulla interval
AGE
GROUP OR FORMATION
LITHOLOGIC COLUMN
RECENT
PLIO-PLEISTOCENE
ZAFARANA
WARDAN
MIOCENE
ZEIT FM.
SOUTH GHARIB FM.
BELAYIM
KAREEM FM.
RUDEIS FM.
NUKHUL FM.
POST-RIFT
SYN-RIFT
OLIGO-MIOCENE
ABU ZENIMA
EOCENE
MOKATTAM
THEBES
PALEOCENE
ESNA
UPPER CRETACEOUS
SUDR FM.
BROWN LMST
MATULLA FM.
WATA FM.
RAHA FM.
NAZZAZAT GROUP
LOWER CRETACEOUS to JURASSIC
MALHA FM. (NUBIA 'A')
TRIASSIC to CARBONIFEROUS
NUBIA FACIES
(NUBIA 'B')
ATAQA FM.
ABU THORA FM.
AHEIMER FM.
ABU DURBA FM.
CARBONIFEROUS & OLDER
(NUBIA 'C')
NAQUS FM.
ARABA FM.
PRE-RIFT
PRECAMBRIAN
FRACTURED BASEMENT

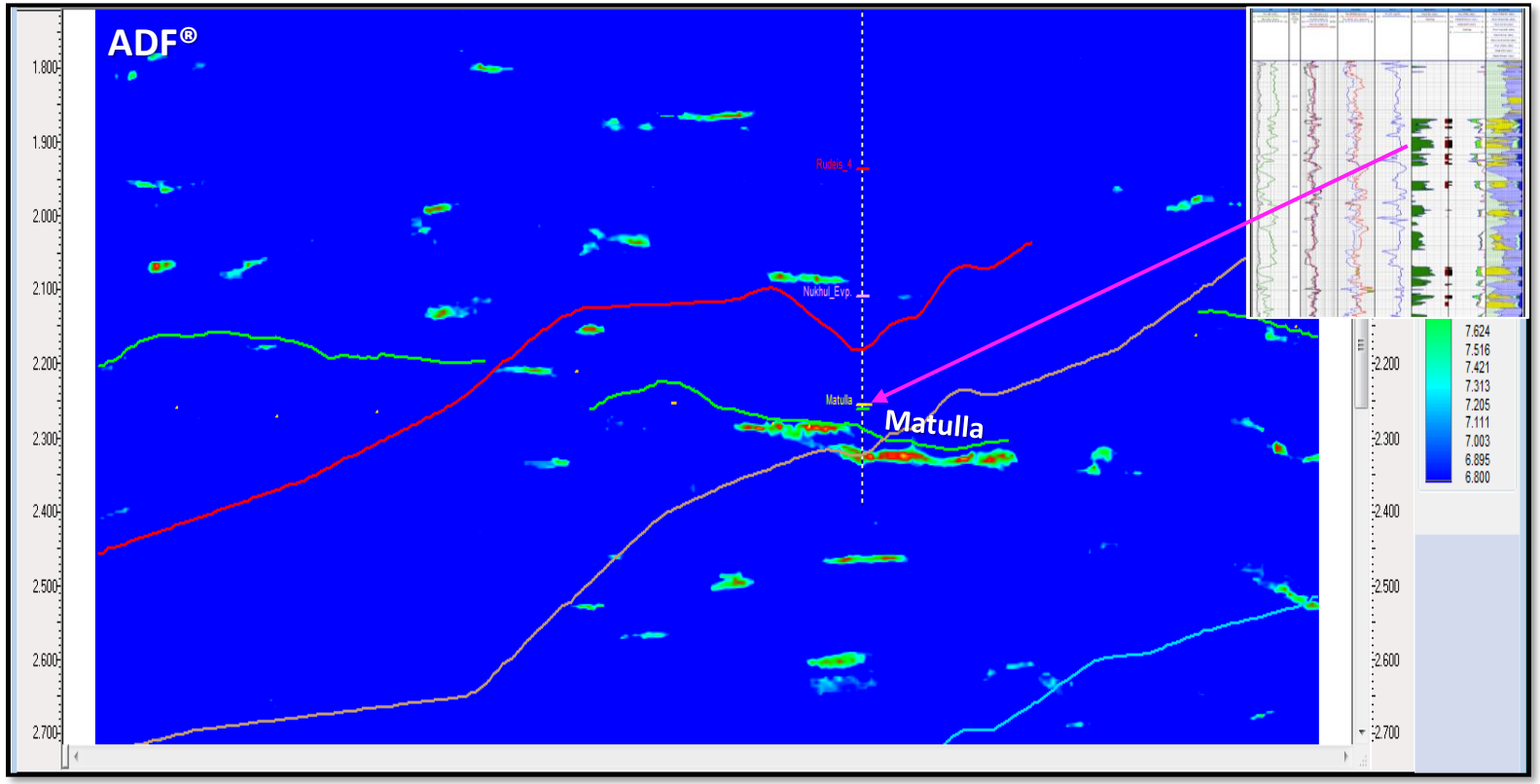

Kareem ADF®
10.000
9.880
9.760
9.640
9.535
9.415
9.295
9.190
9.070
8.950
8.845
8.725
8.605
8.500
8.380
8.260
8.140
8.035
7.915
7.795
7.690
7.570
7.450
7.345
7.225
7.105
7.000

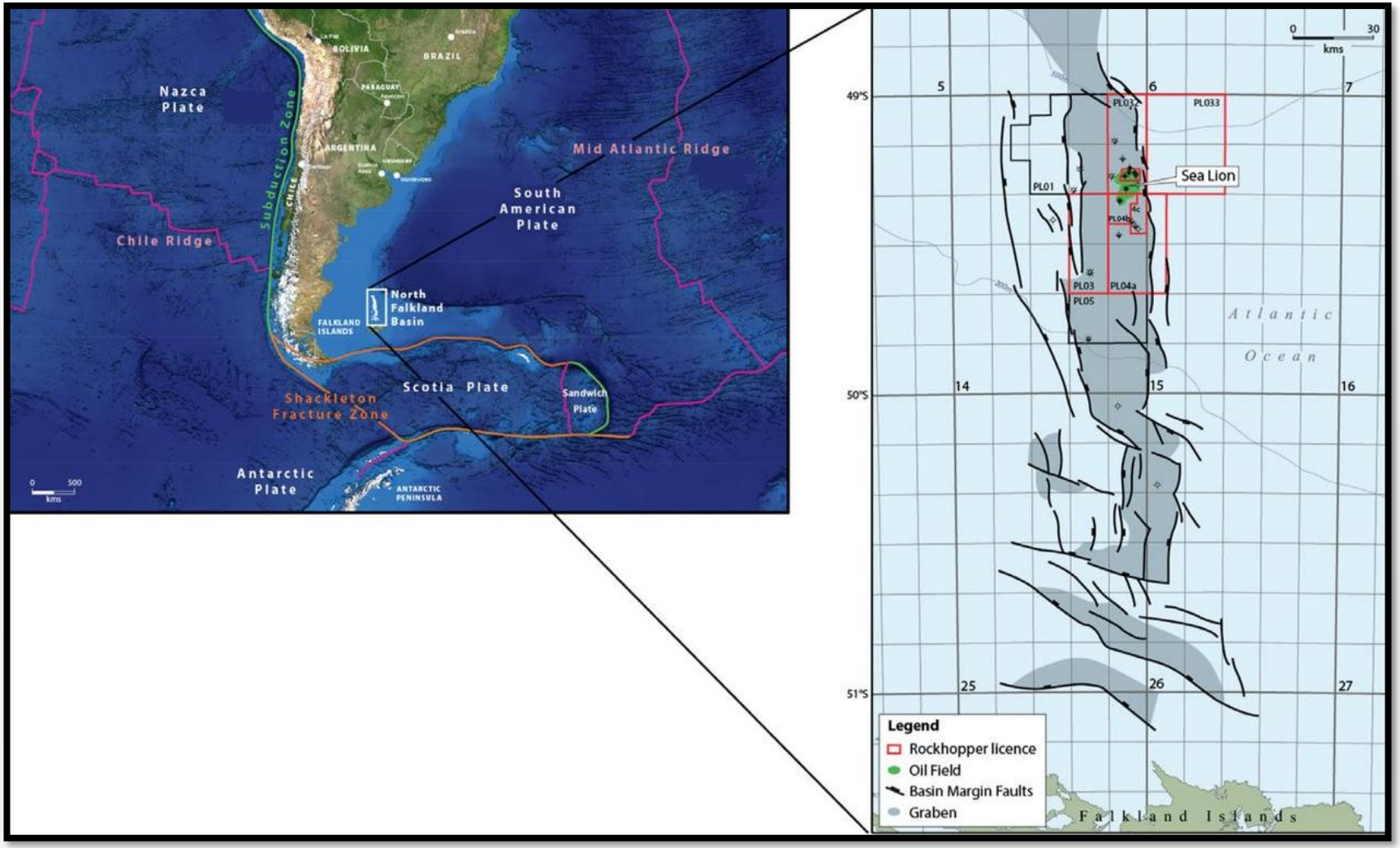

Kareem Amplitude
-3000.000
-3268.937
-3537.872
-3806.808
-4042.127
-4311.063
-4580.000
-4815.318
-5084.254
-5353.190
-5588.509
-5857.445
-6126.381
-6361.700
-6630.636
-6899.572
-7168.508
-7403.827
-7672.764
-7941.699
-8177.019
-8445.954
-8714.891
-8950.209
-9219.146
-9488.081
-9723.400


Amplitude
Kareem
Matulla
1.300
1.400
2.200
1.300
1.900
14441.245
13185.485
11929.724
10830.935
9575.173
-13342.456
-14598.217
-15697.007
DST#1
Interval: 3662-3714 m
Age: L. Senonian
Formation: Matulla
Choke: ½"
Prod. Rate: 1596 BBL Oil/D


ADF®
Kareem
Matulla
1.300
1.400
2.200
1.300
1.900
9.392
9.284
9.176
9.082
8.974
7.003
6.895
6.800
Fm. Salinity 99,000 ppm NaCl
Rw= 0.03 Ohm.m @ 90 degC
Net Res: 36 ft
Net Pay: 18.7 ft
Avg. Phi: 10.5 %
Avg. Sw: 42 %
DST#1
Interval: 3662-3714 m
Age: L. Senonian
Formation: Matulla
Choke: ½"
Prod. Rate: 1596 BBL Oil/D


Amplitude
Matulla
1.800
1.900
2.000
2.100
2.200
2.300
2.400
2.500
2.600
2.700
-6121.833
-7377.594
-8476.384
-9732.145
-10987.904
-12086.695
-13342.456
-14598.217
-15697.007


ADF®
1.800
1.900
2.000
2.100
2.200
2.300
2.400
2.500
2.600
2.700
Rudeis_4
Nukhul_Evp.
Matulla
Matulla
7.624
7.516
7.421
7.313
7.205
7.111
7.003
6.895
6.800


Nazca Plate
Subduction Zone
Chile Ridge
Mid Atlantic Ridge
South American Plate
North Falkland Basin
FALKLAND ISLANDS
Scotia Plate
Shackleton Fracture Zone
Sandwich Plate
Antarctic Plate
ANTARCTIC PENINSULA
BOLIVIA
BRAZIL
PARAGUAY
ARGENTINA
CHILE
0 500 kms
0 30 kms
49°S
50°S
51°S
5
6
7
14
15
16
25
26
27
PL032
PL033
PL01
Sea Lion
PL04b
PL03
PL04a
PL05
Atlantic Ocean
Legend
Rockhopper licence
Oil Field
Basin Margin Faults
Graben
Falkland Islands

Nov. 2024 Letter of Reference

JHI

130 Adelaide Street West
Suite 3002
Toronto, Ontario M5H 3P5
Canada
416.433.6047
www.jhiassociates.com

November 8, 2024

Sea Lion Field as an Exploration Analogy for PL001

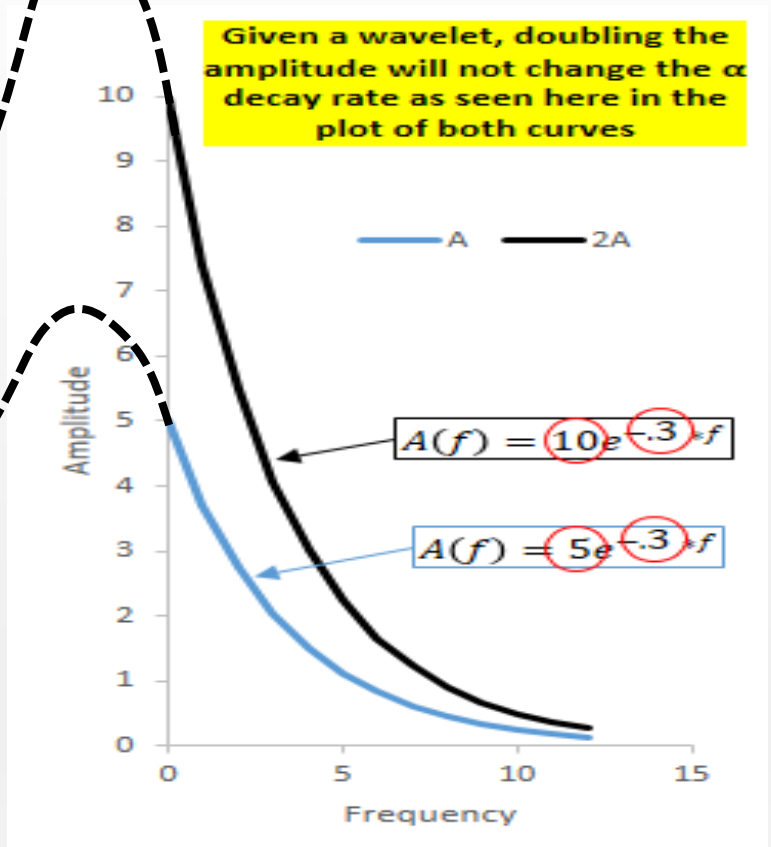
Apex Spectral Fluid Mobility Studies in the North Falkland Basin

The Sea Lion ADF® field study demonstrated that this technique correctly identified seven appraisal wells that contained oil pays while also showing that two dry holes (14/5-1 and 14/10-1) might have been avoided by relying on the ADF® response at these locations. However, one false anomaly was indicated, related to the 14/10-8 well which exhibits an anomalously thick stacked sand section which is water wet but has very high permeability.

Based on the results of the Sea Lion field study, JHI extended the ADF® analysis across the eastern portion of PL001. The results of this work indicate that ADF® could have been used to avoid the drilling of two dry holes by the previous operators in PL001 (14/9-1 and 14/9-2) while redirecting exploration attention to other potential hub-class prospects not previously identified using conventional amplitude analysis. These undrilled prospects tie into oil shows observed in the previous dry holes and now target up-dip locations in the same formations that will soon be put into production at the Sea Lion Field.

ADF® imaged 7 pay sands, would have avoided 4 tight dry holes and imaged 1 thick KH wet sands

ADF® is *Independent* of Amplitude



$A(f) = A_0 e^{-\alpha * f}$	**α =**	**0.3**
f	A	2A
0	5	10
1	3.7	7.4
2	2.7	5.5
3	2.0	4.1
4	1.5	3.0
5	1.1	2.2
6	0.8	1.7
7	0.6	1.2
8	0.5	0.9
9	0.3	0.7
10	0.2	0.5
11	0.2	0.4
12	0.1	0.3

END