Application of Pre-stack Seismic Anisotropy for Fracture Detection, in Oseil Field Carbonate Reservoir, Seram Island, Eastern Indonesia*

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Abstract

The main production unit in Oseil field, East Indonesia, is fractured carbonate in Manusela Formation, . The main storage and accumulation space of the carbonate is fractured porous media and the reservoir distribution possesses strong heterogeneity. Studies of fracture intensity of the reservoir in Oseil field, using pre-stack 3D seismic data, are based on P-wave reflection amplitude, P-wave seismic amplitude exhibiting variable attenuation with difference in fracture orientation, or seismic anisotropy.

Vertically aligned fractures generated seismic anisotropy, and its analysis is most important in application of seismic data for fracture detection.

Several steps were used to generate fracture intensity cube from well and 3D seismic data: (1) reserved amplitude processing, well and seismic correlation, modeling of fractured reservoir; based on rock-physics properties, to understand seismic anisotropy; (2) four azimuth seismic data sets prepared by selecting and combining seismic data set in the range of 0-2000 meters offset and 0-180 degree azimuth, and calculation of different azimuth amplitudes and analysis of their azimuth variations; (3) determination of spatial distribution of amplitude azimuth ellipse, with representative amplitude decay along different directions, and converting this anisotropy curvature attribute to fracture intensity.

Three wells in Oseil field were designed and drilled, based mainly on fracture intensity distribution map; these are Oseil-12, Oseil-18, and Oseil-2ST (two in 2010 and one in 2011); they proved that the technology worked well in detection of Manusela fractured carbonate reservoir.

Keys to the success in applying pre-stack seismic-anisotropy fracture determinations in drilling are as follows:

1. Manusela fractured carbonate reservoir properties are mainly vertically fractured, and P wave seismic amplitude reflections are varied spatially, seismic-energy reflected, converted and absorbed by fractured-carbonate-reservoir-created amplitude changes.
2. Seismic anisotropy and fracture intensity modeling from well data have a good correlation.
3. Having enough fold coverage of 3D seismic data to generate azimuthally stacked and seismic data processed to amplitude preservation.
4. Well design by using fracture intensity cube is used for identifying porous and barrier zones for prediction in drilling.

Oseil field drilling proved that the pre-stack seismic anisotropy method was able to detect fractured carbonate reservoir.

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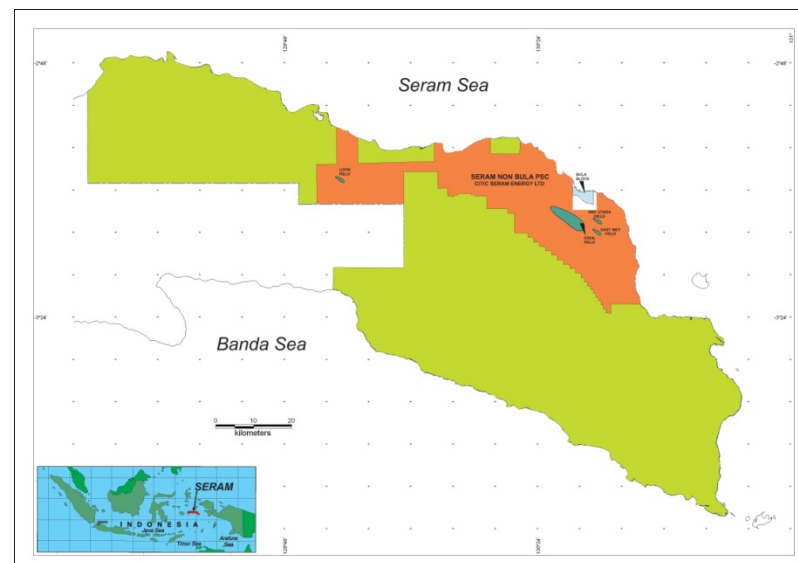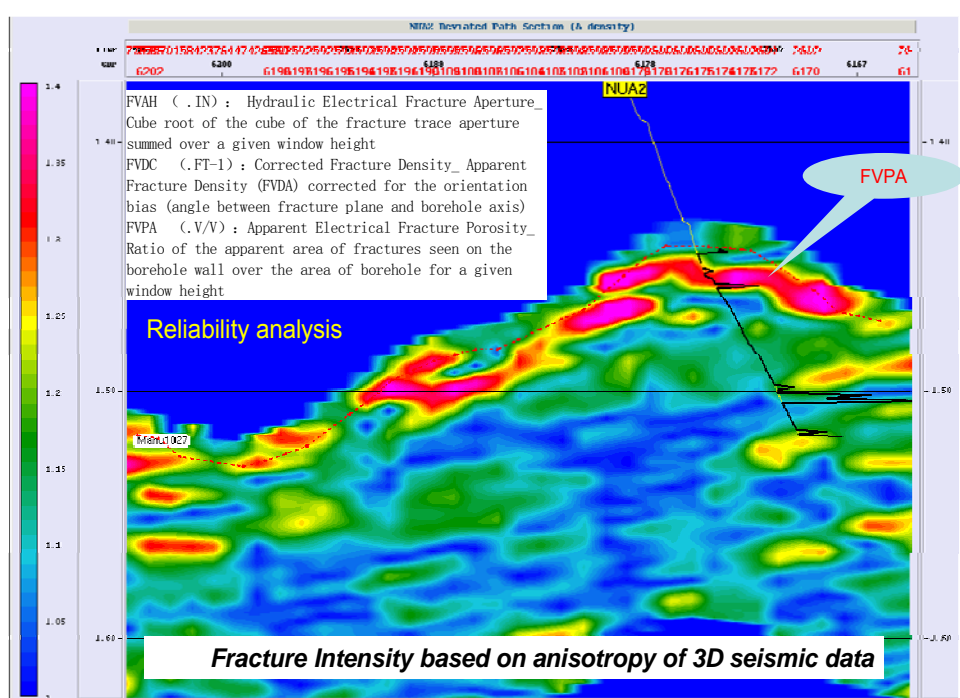
Fracture Intensity based on anisotropy of 3D seismic data

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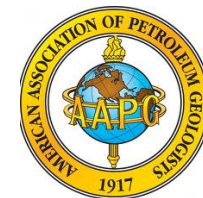
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Geosciences Technology Workshop

Fractured Carbonate Reservoirs
15-17 February 2012 | Bali, Indonesia

Tectonics and Structure

The objective of the study is to identify new favorable hydrocarbon accumulation zones in Manusela fractured carbonate reservoir.
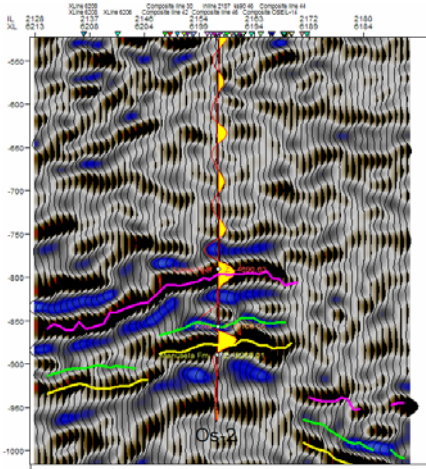
To achieve new break-through in oil production is by application of AVAZ (Amplitude versus azimuth) to perform analysis and identification of fractured carbonate reservoir zones

Manuela Depth Structure Map

Regional Structural Cross Section of Oseil Field

Manusela fractured carbonate reservoir.

P wave traveling varies with offset and wave traveling perpendicular to fracture strike generating isotropic AVO response.

P wave traveling varies with offset and parallel to fracture strike generating anisotropic AVO response
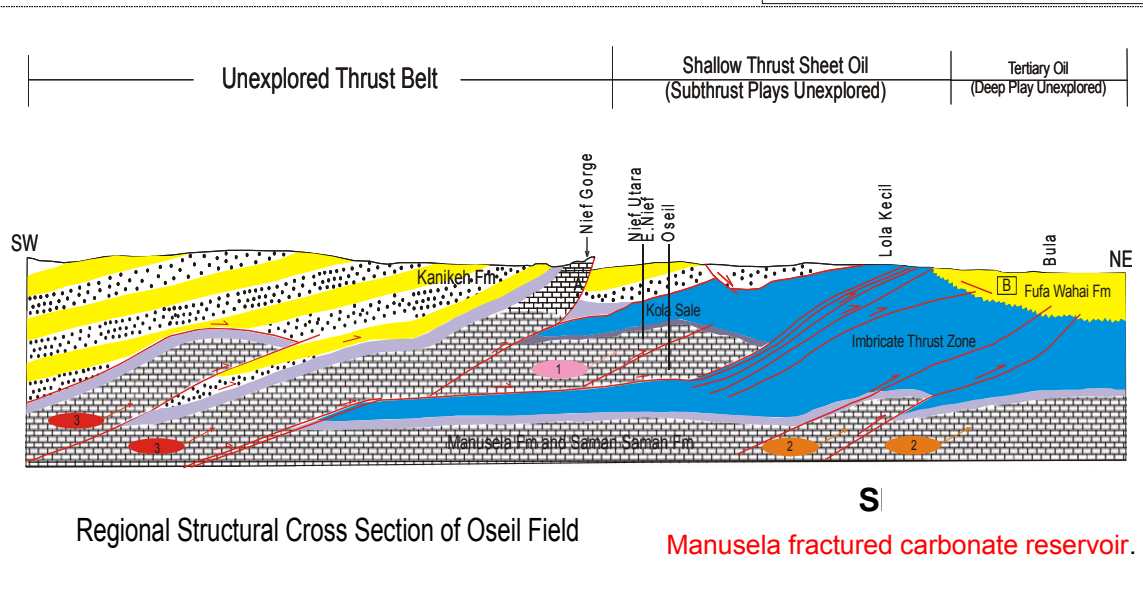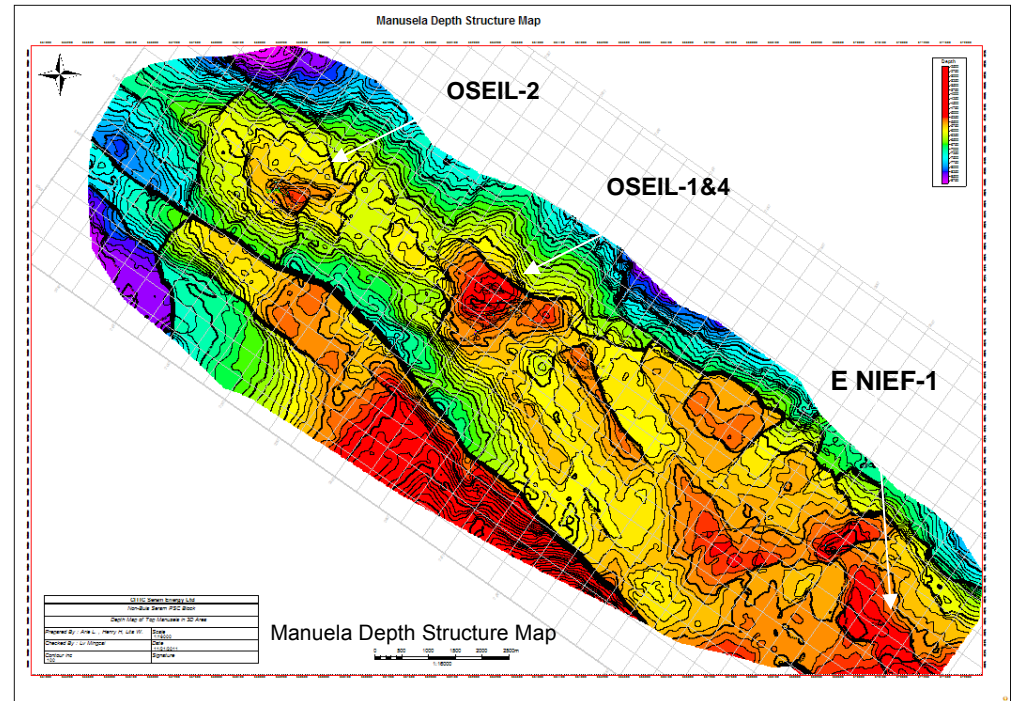
Synthetic Seismogram
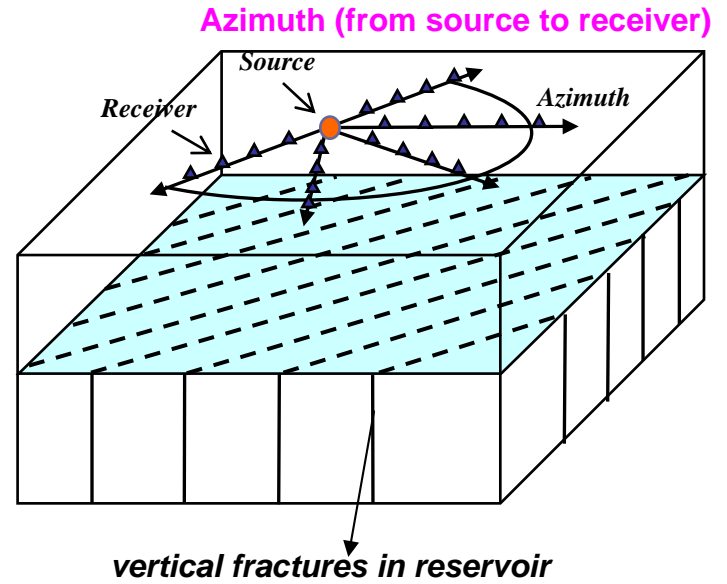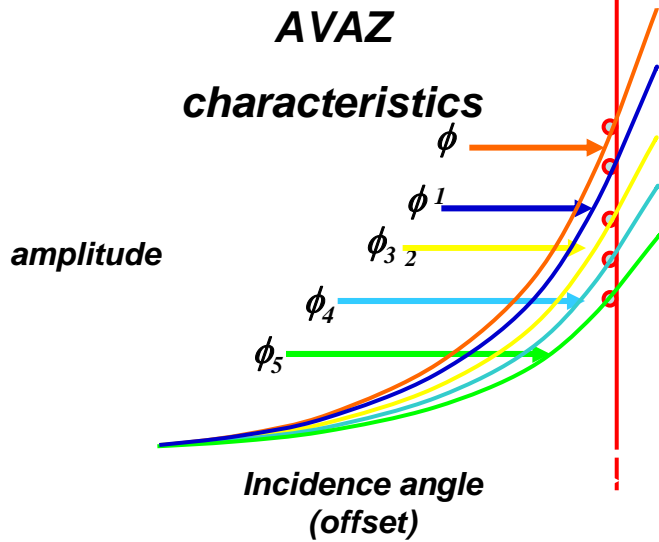**S(t)=Ro(t) * W(t)**

Amplitude Versus Offset (AVO)

$$Rpp(\theta) = Rpp(0) + \left(ARpp(0) + \frac{\Delta v}{(1-v)^2} \right) \sin^2 \theta$$

Inline2280 Xline6200: Velocity Spectrum and Gather
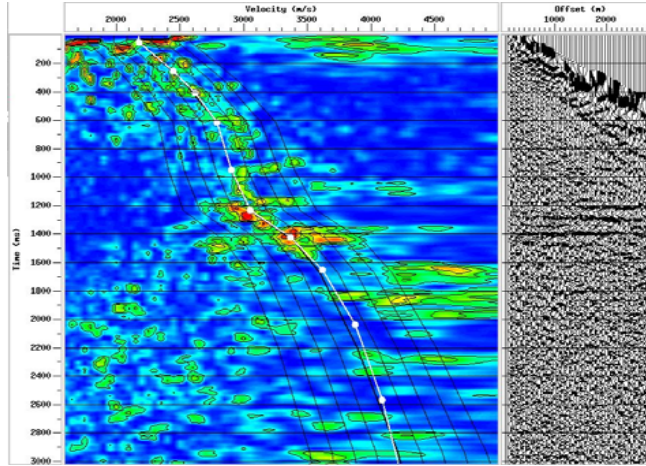
AVO Reflectivity Methods

Far Offset   **Near Offset**
Geophones
Shots

Seismic Ray Paths

Common Reflection Point
Multiple Shots and Receivers
Offset Gather with Reflection Amplitude Variation with Offset

← Increasing Offset

3D seismic acquisition and fractures

S   R

Core fracture orientation

azimuth sectors

S_i R_i

AVAZ:
Anisotropic AVO

INDONESIA
OSEIL-1
CORE 1   CORE 1
6797.00 – 6800.00   6800.00 – 6803.00

0 FT

1 FT

2 FT

3 FT

Based on the core analysis data, logging and seismic data, the development of fracture can be described by the result of seismic anisotropy analysis; the characteristic of the fracture distribution and development degree can be predicted.

Azimuth Seismic Amplitude Analysis

AVAZ characteristics

amplitude

ϕ

ϕ_1

ϕ_3 $_2$

ϕ_4

ϕ_5

Incidence angle (offset)

Azimuth (from source to receiver)

Source

Receiver

Azimuth

vertical fractures in reservoir

FRS-fracture is used to detect fractures based on seismic anisotropy.
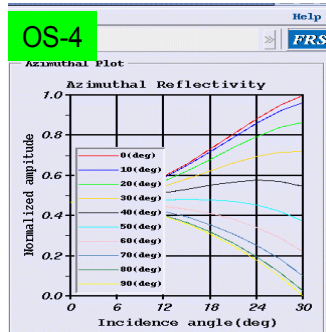
The anisotropy will be detected by amplitude changes.

Hudson fracture ellipse theory
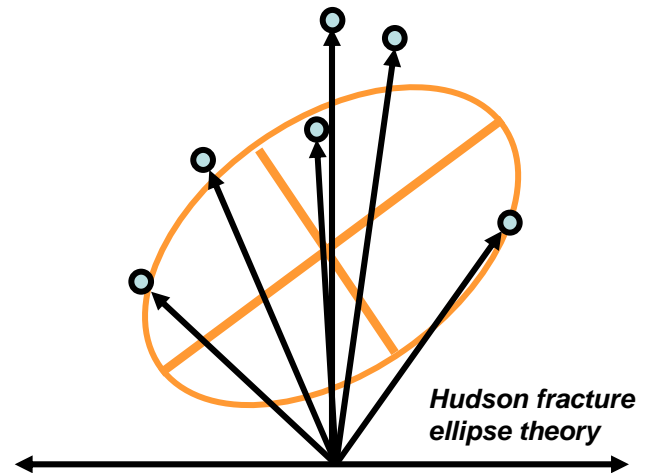
Fractured reservoir simulation in Manusela

Fracture Forward Modeling

Fractured Reservoir Seismic Characteristic Response Analysis
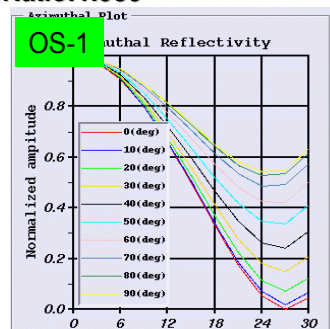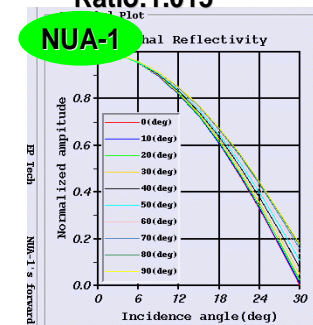

OS-2

Ratio:1.139

OS-4

Ratio:1.080

EN-1

Ratio:1.015

OS-1

Ratio:1.092

NUA-1
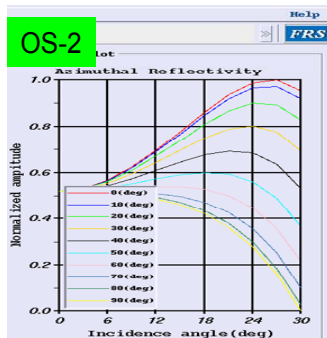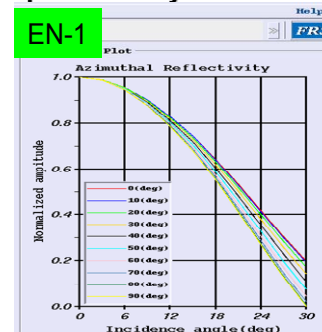
Ratio:1.030

Ratio:
Seismic Anisotropy Intensity

Isotropic AVO = P wave zero offset + Isotropic AVO term

Anisotropic AVO = P wave zero offset + Isotropic AVO term +Fracture anisotropic AVO term

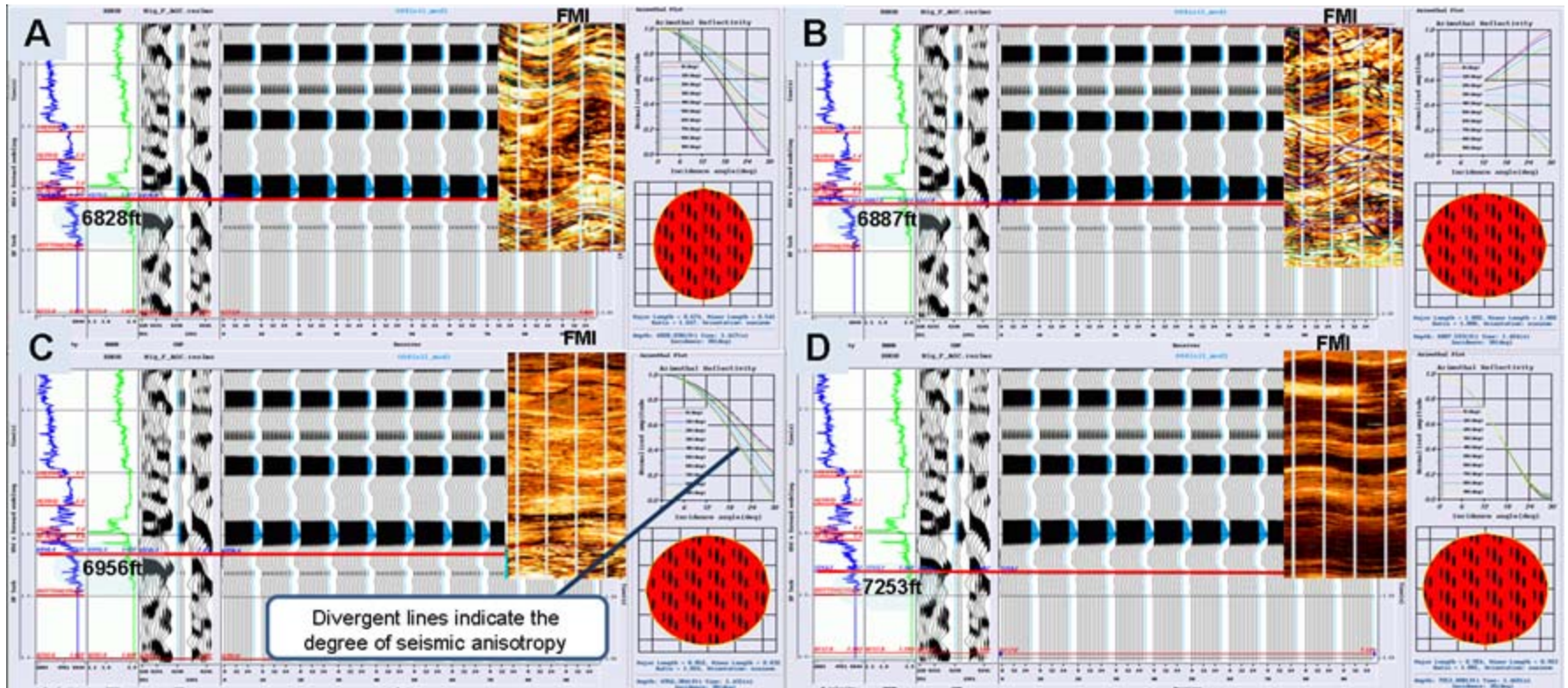Seismic Anisotropy = Anisotropic AVO / Isotropic AVO

Seismic Anisotropy = 1 + (Fracture anisotropic AVO term) / (Isotropic AVO)

Seismic Anisotropy   = 1   isotropic, fracture not developing
 1 < Seismic Anisotropy < 1.3   anisotropic fracture developing

Increasing fracture anisotropic AVO term defines increasing fracture intensity

Seismic Anisotropy = Fracture intensity

Petrophysical forward modeling in Oseil 4 at different depths
(A. anisotropy modeling at depth 6828ft; B. anisotropy modeling at depth 6887ft;
C. anisotropy modeling at depth 6956ft; D. anisotropy modeling at depth 7253ft. Fractured reservoir can induce the seismic anisotropy, as the left parts of A, B, C and D show differentiation of azimuthal amplitude)
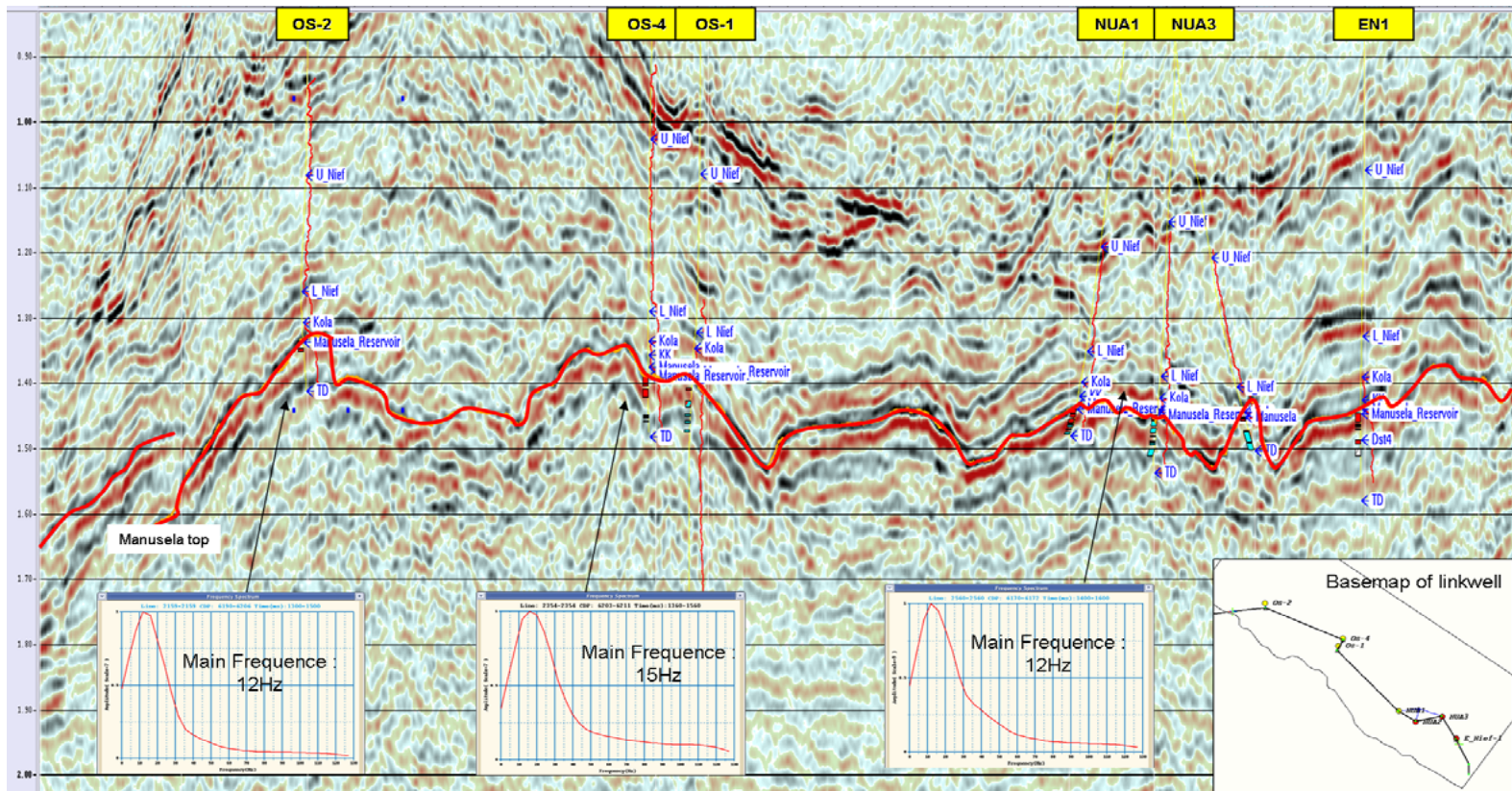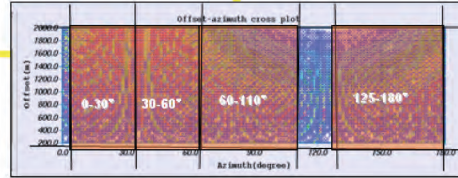
Seismic data quality analysis

Oseil Field is in a complex structure that is difficult to interpret in large measure to thrusting; also it has large volume with Low S/N ratio. The seismic data quality varies considerably from northwest to southeast of survey

key technique: **Fracture Characterization**

Technology Flow of fracture prediction based on pre-stack anisotropy

| Pre-stack amplitude Preserved processing | → | CMP gathers |

Offset-azimuth cross plot

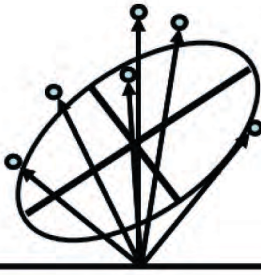| Azimuthal gather1 | | Azimuthal gather n |

extract attribute such as frequency, amplitude, attenuation and impedance

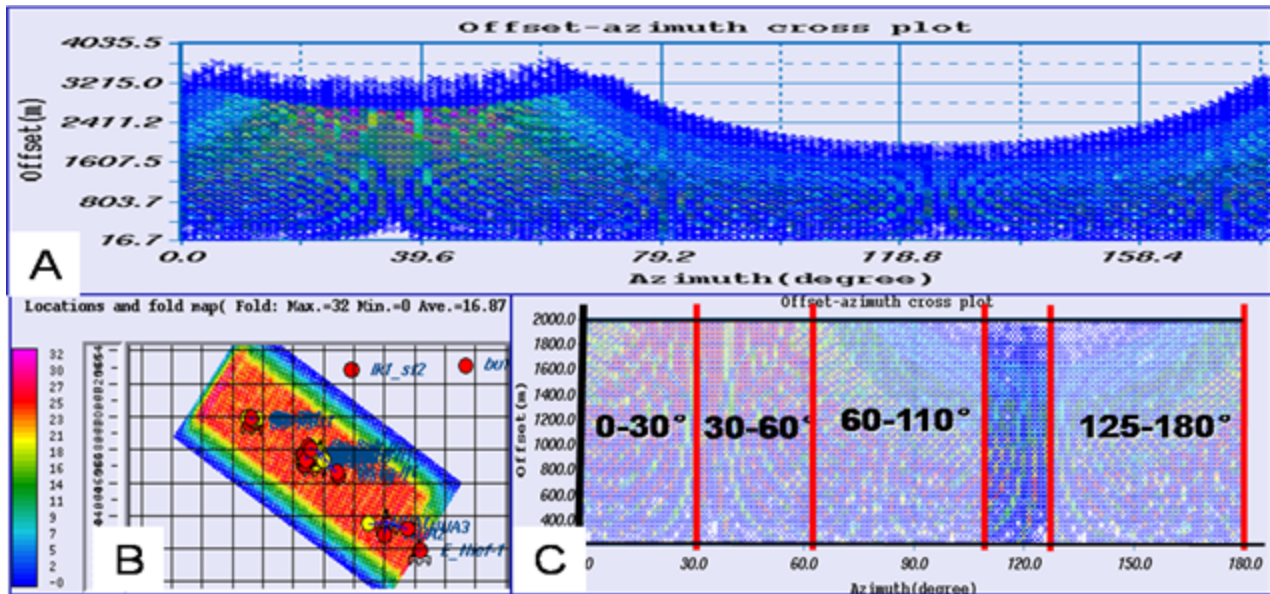extract attribute such as frequency, amplitude, attenuation and impedance

Azimuthal ellipse fitting

Ellipse Ratio (a / c) and orientation (a or c)

Fracture Characteristics (Density and Orientation)

Azimuthal Seismic Data Distribution Map
(A: pre-stack gather analysis; B: fold distribution map; C: azimuthal division on effective offset)

The main steps of azimuthal seismic process including:
(1) Determine and optimize the division of azimuthal bins;
     for example, the data can be divided into: 0° -30°, 30° -60°, 60° -125° and 125°-180°;
(2) Sort gathers based on the azimuthal bins;
(3) Stacking of gathers within the same azimuthal bin. Separately;
(4) Migration of each azimuth stacking volume. Separately;
(5) Merging the four migrated azimuthal stack cubes together.
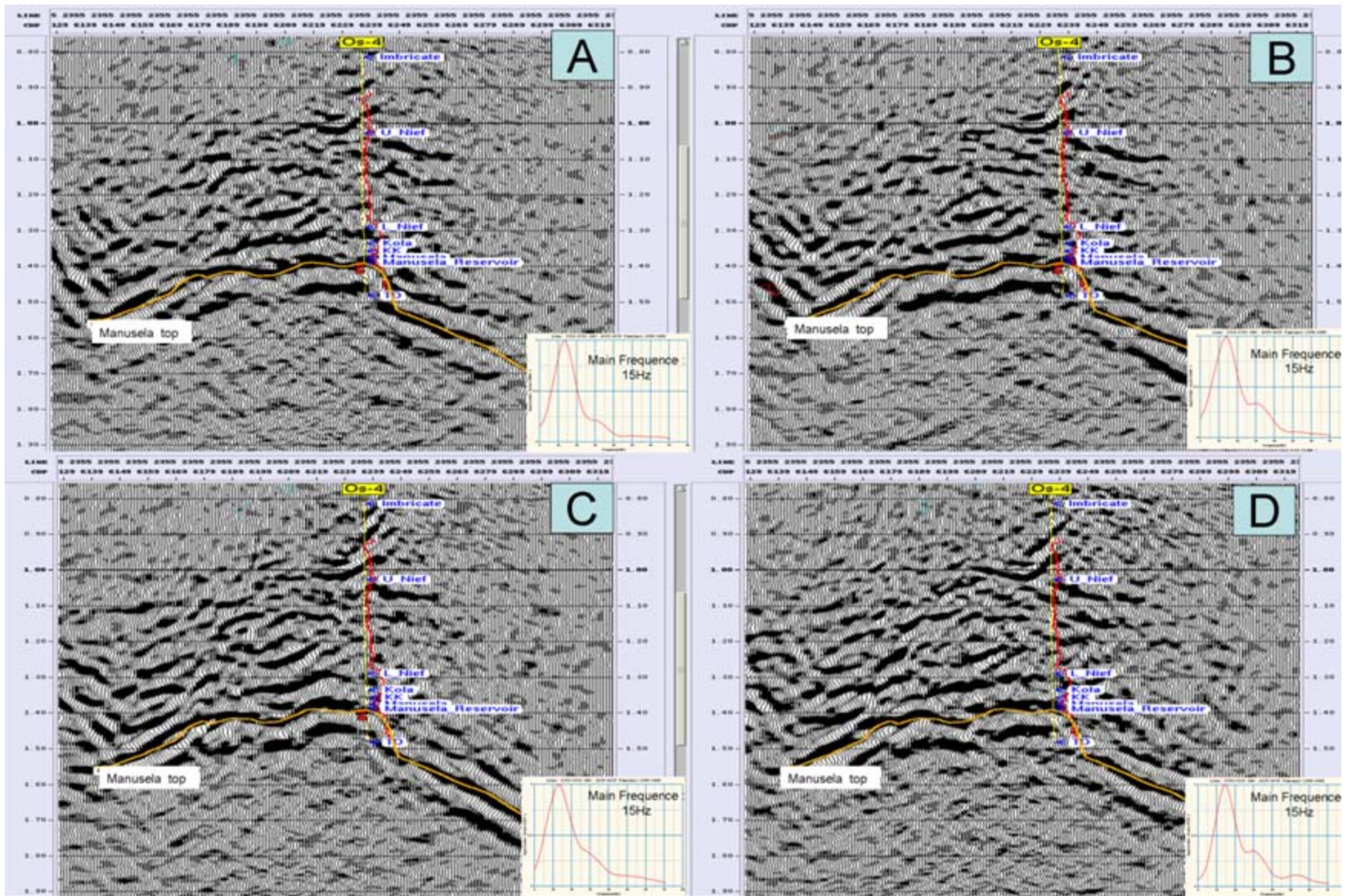
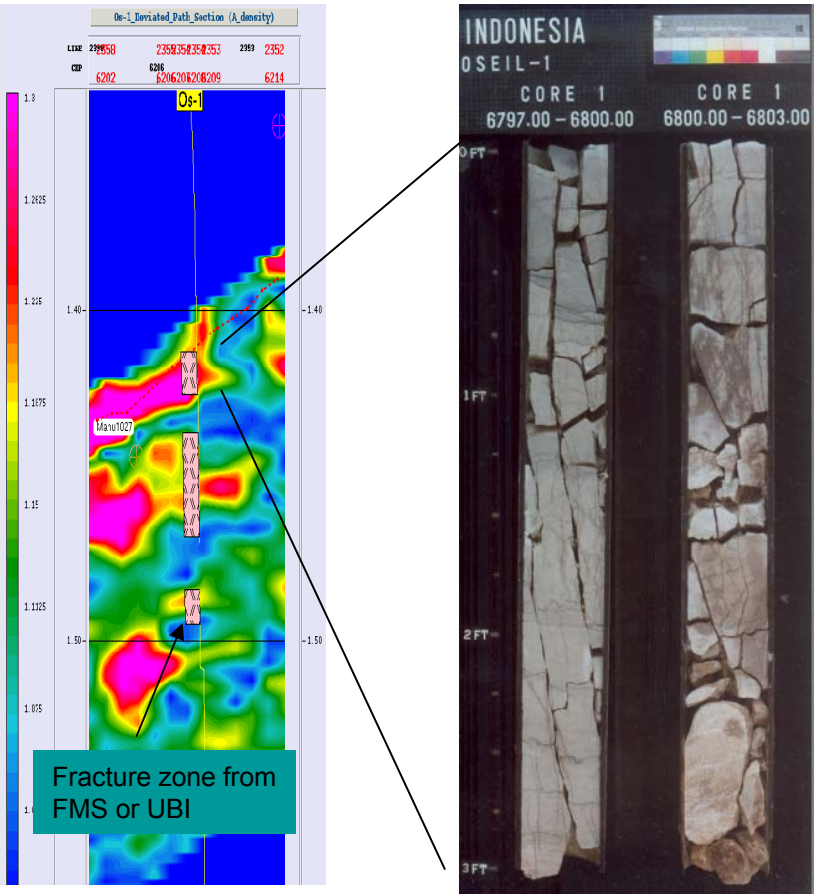Part of azimuth stack seismic profile (inline 2355, azimuth range 15°, 45°, 85°, 152°)

Fracture Intensity based on anisotropy of 3D seismic data

Reliability analysis

Fracture zone from FMS or UBI
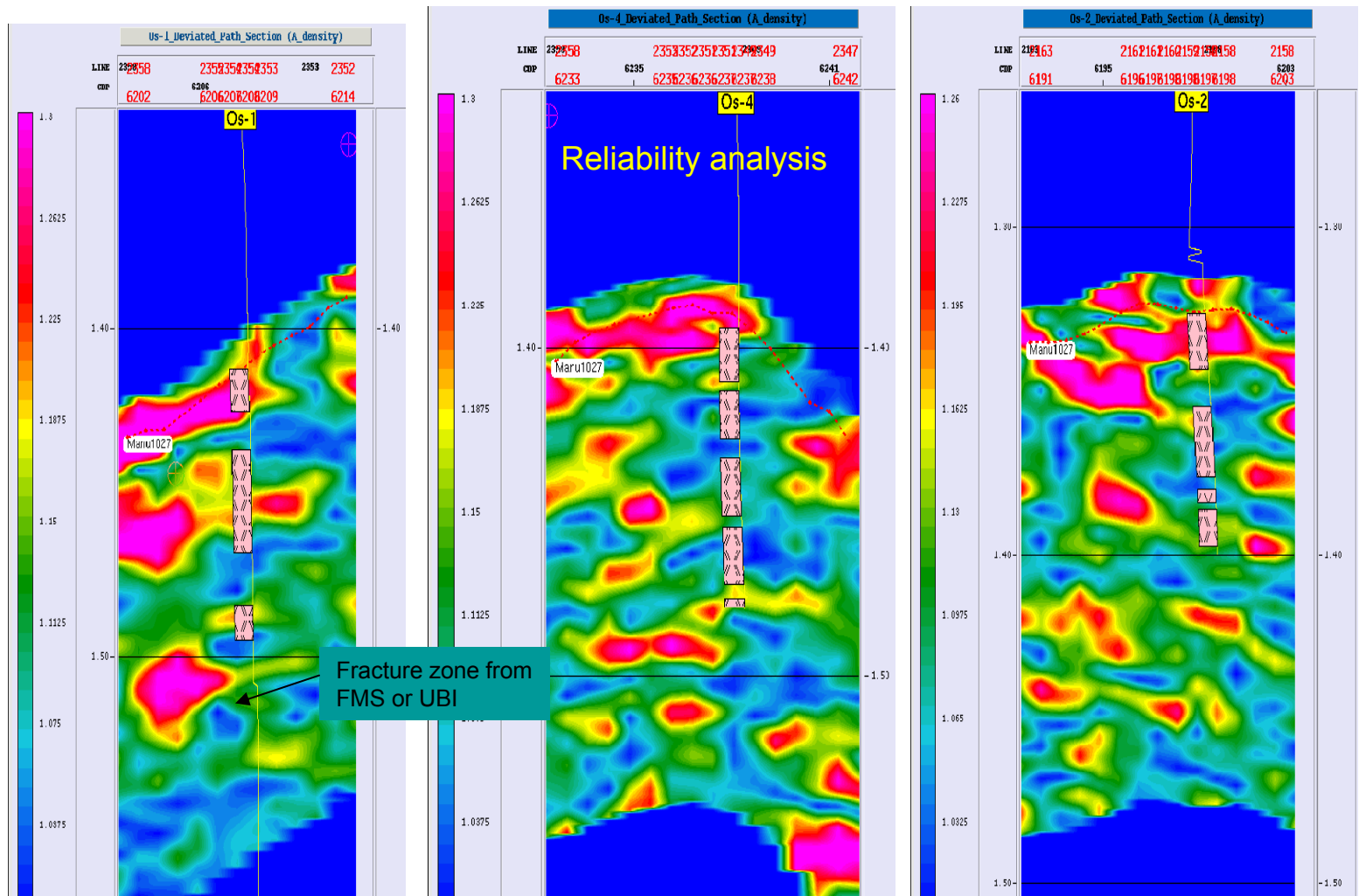
The red color indicates fracture developing area; the pre-stack seismic data sample interval is 4ms.
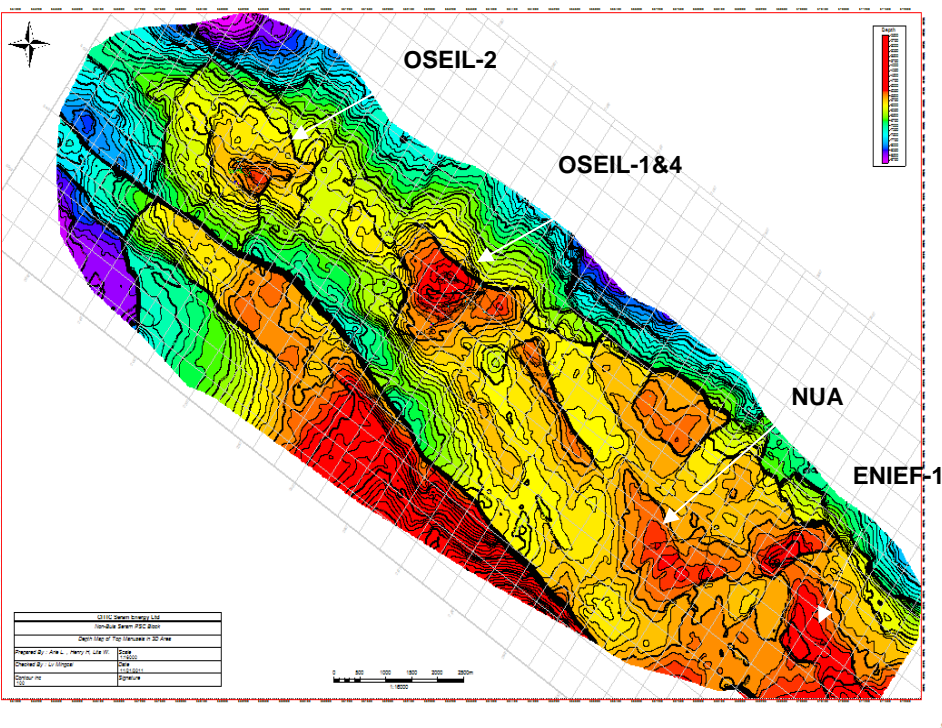
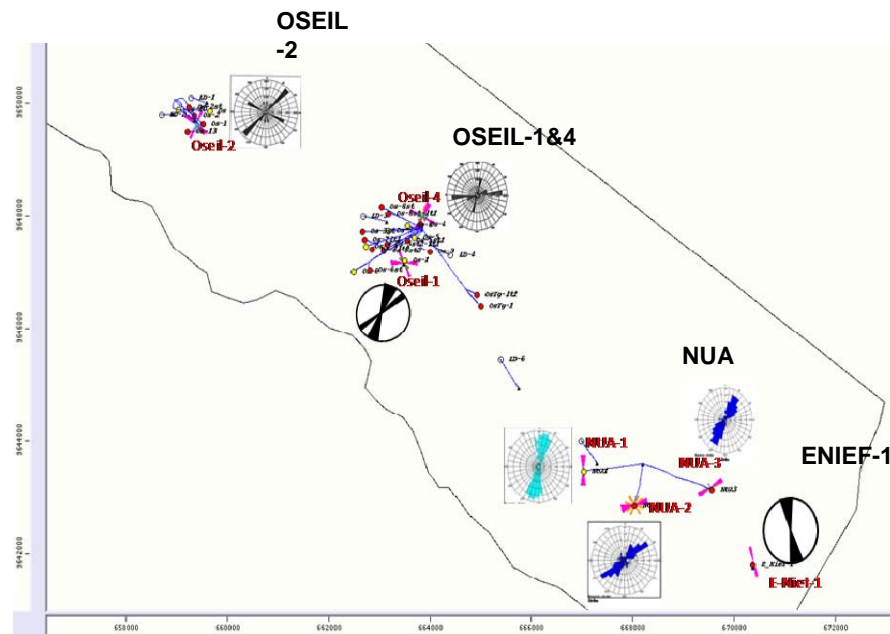Core and seismic anisotropy of Oseil-1 upper zone showing high fracture intensity of Manusela carbonate reservoir.
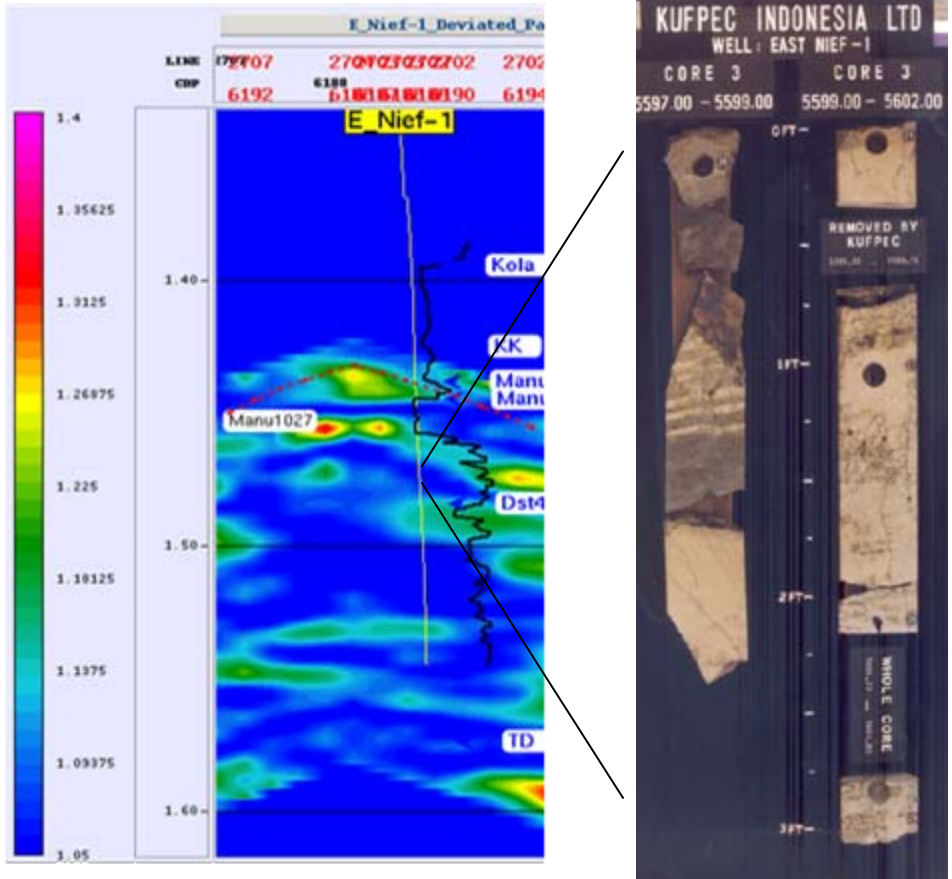
E Nief-1 core and seismic anisotropy showing Manusela fractured carbonate reservoir not developed.

Depth structure map, top Manusela Formation

Fracture strike map comparing anisotropy analysis and FMI log
(Rose diagrams represent the anisotropy analysis results; Schmidt map is from the FMI/UBI log)

Oseil field, located in the foreland thrust belt, experienced several thrust movements in NE-SW direction; so the stress field is relatively complicated. Under the complex influence of different periods of extension and compression, the fracture strike tends to have dual directions; the major orientation is ENE, but fracture strike in Nief-Utara is dominantly single-oriented; the major direction is NNE.
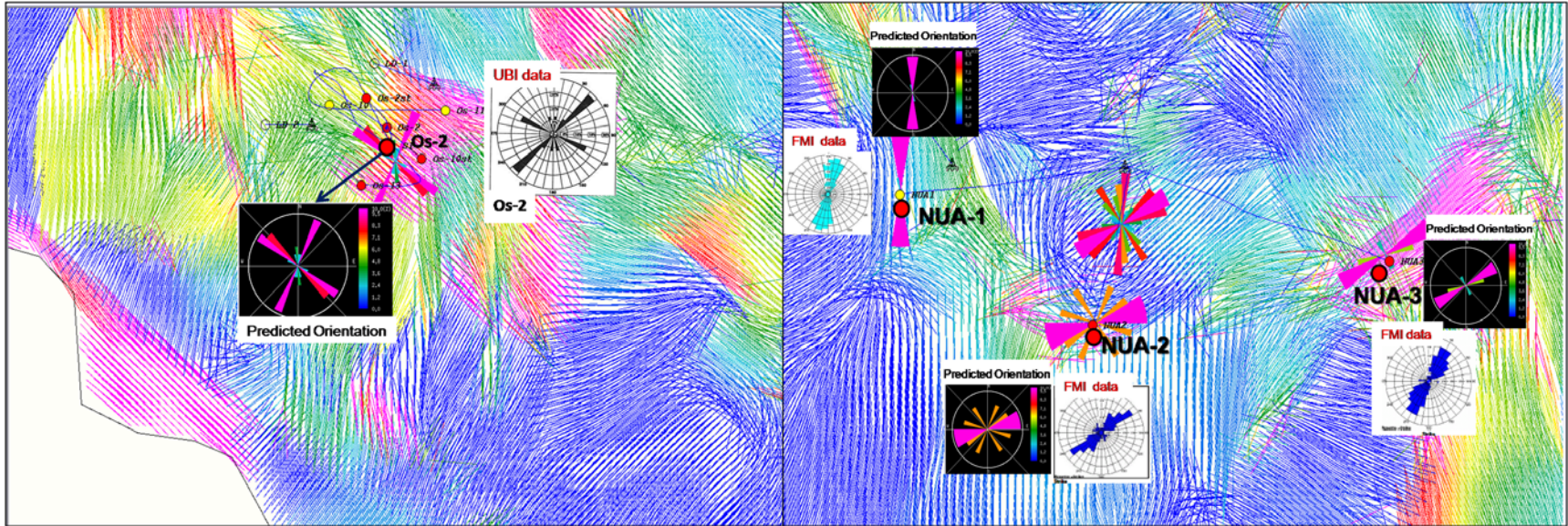
Fractured reservoir description in Oseil2 & Nief-Utara block
(Color indicates the fracture intensity, the warmer color the stronger; "sticks" indicate the strike of the fracture)

Compared with FMI data the well location, the seismic-based fracture orientation shows high credibility and reliability
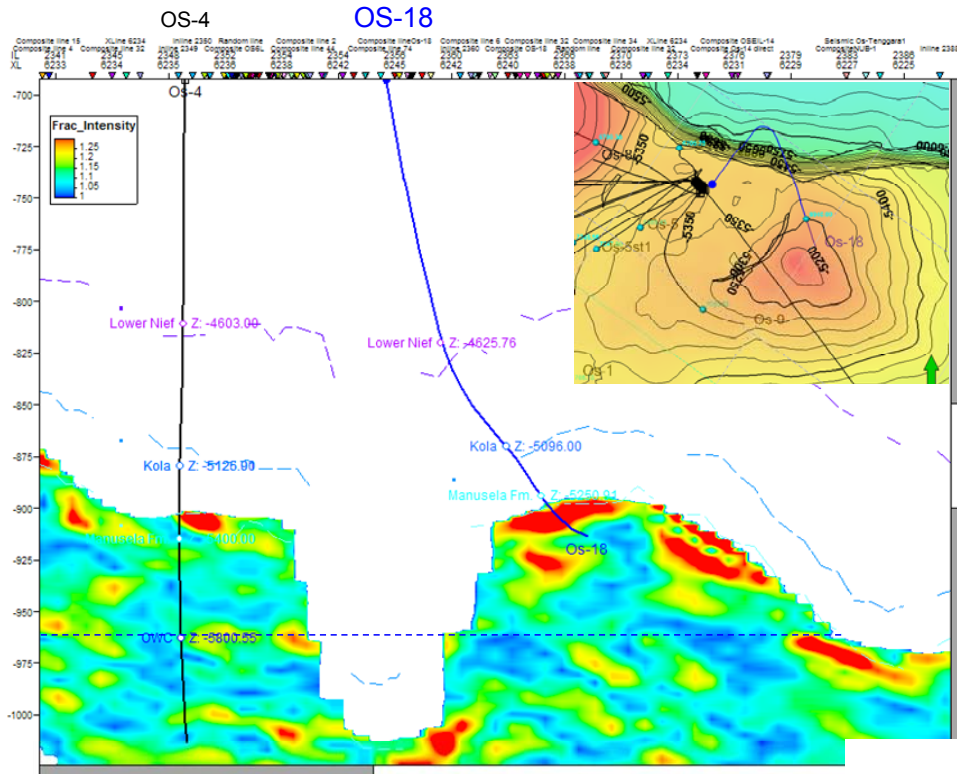
OS-18 located in OS1/4 most favorable area; main criteria for designation of this well position are as follows:

- High Oil column;
- High fracture intensity;
- Fold with relative simple structure;
- High productivity of adjacent well;
- Undrained area.

In Oseil-18 oil is produced from Manusela fractured reservoir and has been producing since November 2010; initial production was 100 BOPD with water-cut nearly 95%.

Water shut-off program successfully increased oil production up to 200 BOPD with water-cut 20% by isolating dissolution breccias zone; currently the well produces 300 BOPD with water-cut around 35% as shown in production profile of Oseil-18 (to the right).

SE

OS-2

OS-2ST2

NW
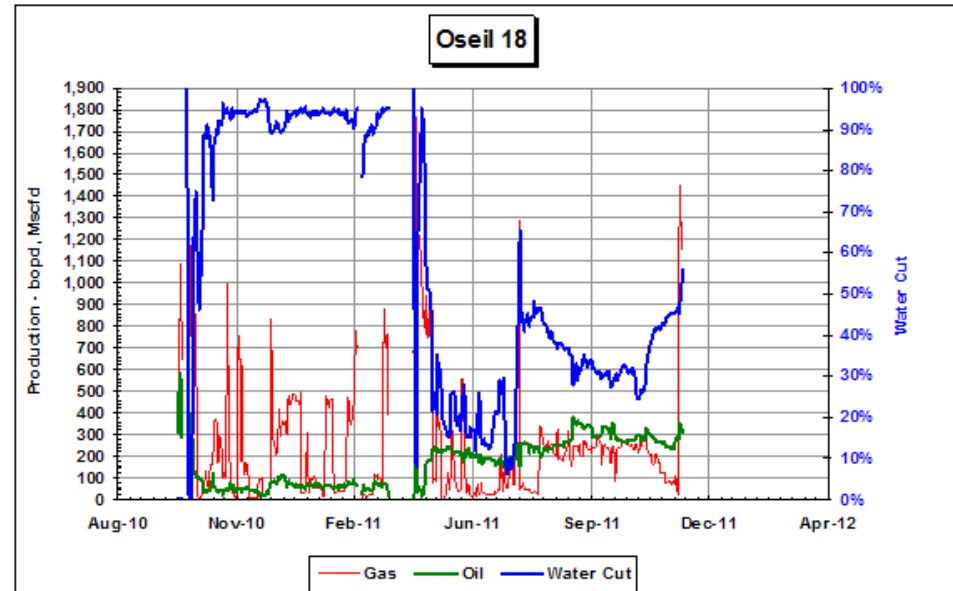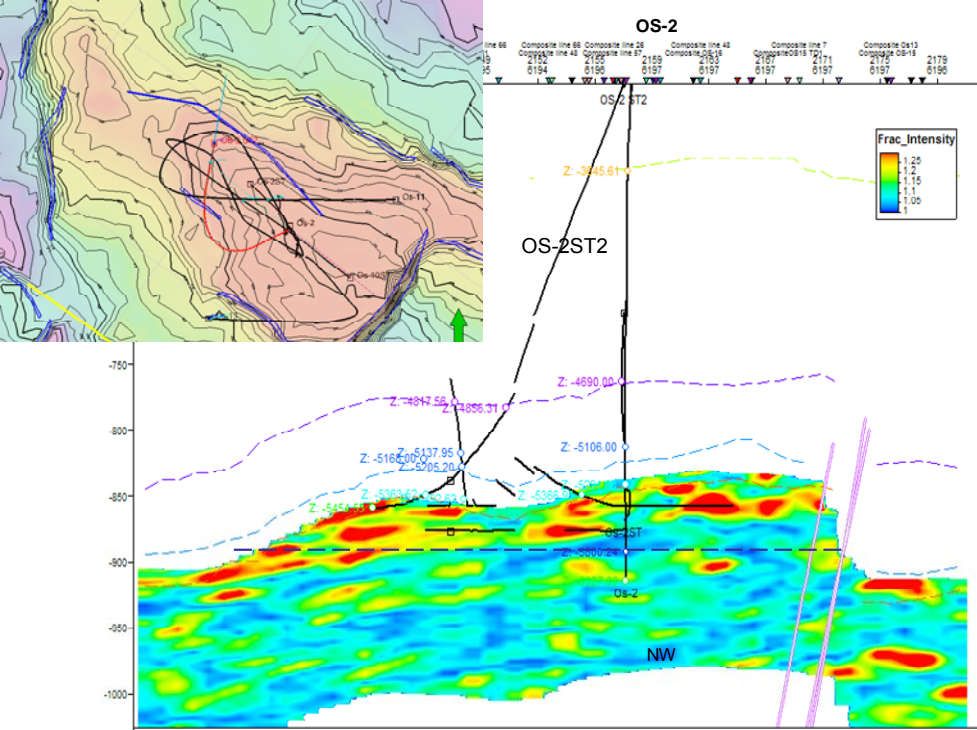
Fracture intensity across OS-2ST2

Development well OS-2ST2 is located on flank OS-2 area; the main criteria for selection of this well location are:
- Undrained area
- High /medium high-fracture intensity
- Downdip on the flank area
- Relatively removed from adjacent high productive zone.

Oil Production in OS-2ST2 well is from upper part of Manusela structure; production rate has remained stable since April 11, 2011, up to now.

Although the well location is on the flank of Oseil-2 structure, water-cut is less than 5% and gas production tends to decline.
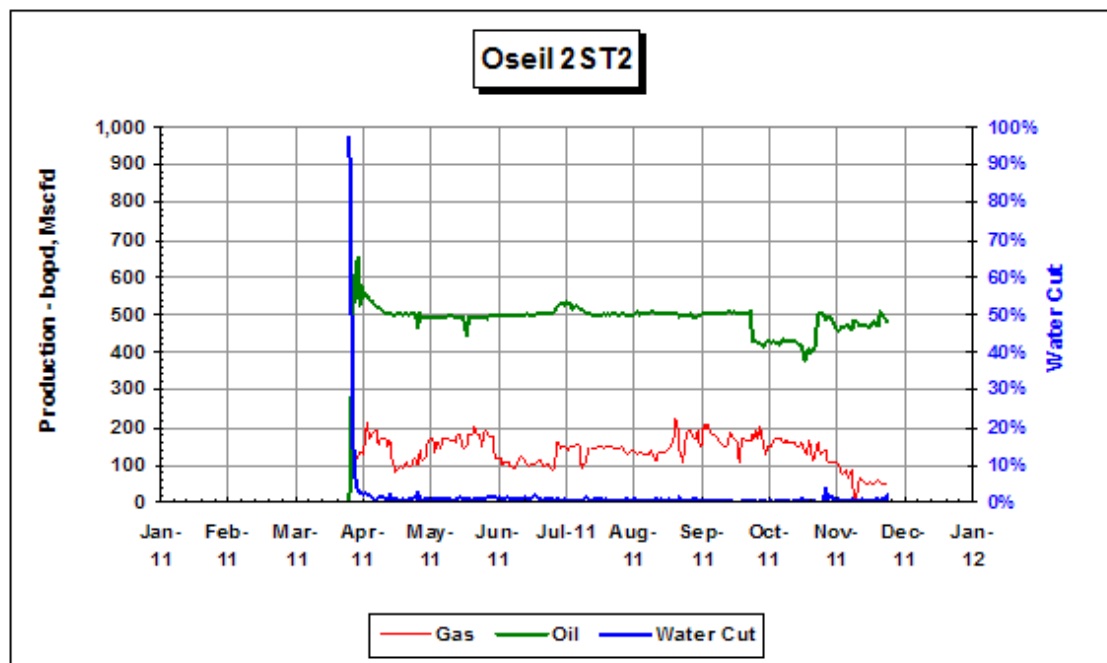
Oseil 2 ST2

Conclusions

1. Three wells in Oseil field were designed and drilled, based mainly on fracture-intensity distribution; these are Oseil-12, Oseil-18 and Oseil-2ST; it proved that the technology has been working well for detection of Manusela fractured carbonate reservoir.

2. Key to success of application of pre-stack seismic anisotropy:
Manusela carbonate fractures are mainly vertical; seismic energy reflected, absorbed and converted by carbonate-fracture-created amplitude changes; good correlation between well forward modeling and seismic amplitude; enough fold coverage of 3D seismic data; 3D seismic reprocessing to preserve amplitude and binning of CMP gather.

3. Osel-2ST2, the well drilled on the flank of OS-2 area, proved that the fracturing is also developed on the flank of the structure; the fracturing is not necessarily related to the present-day structure. In Oseil area vertical fractures were mainly generated during Jurassic extensional stress field.