Presentation Outline

• Introduction to Read Well Services
• 3D VSP Acquisition and Processing Capabilities
• 3D VSP Case Examples and Benchmark Results
• Preliminary Proposal to CNOOC 3D VSP at Bohai Field
The READ Group of Companies

READ ASA
(17 Sept 1986 -)

RESERVOIR TECHNOLOGY

READ Well Services Ltd
Aberdeen, U. K.

READ Well Services
Bergen, Norway

READ Well Services
Oslo, Norway

READ Well Services LLC
Houston, USA

READ Servicios Geofisicos
Rio de Janerio, Brasil

PROCESS TECHNOLOGY

READ Process Engineering
Oslo, Norway

READ Systems Ltd
London, U. K.
Operational Areas

(Total 1750 VSP Projects Worldwide)
READ has acquired/processed ~ 50 3D VSP projects world-wide since it started business in 1987. READ has more experience than ANY contractors in acquiring larger VSPs and is continuously breaking new ground in advancing the technique.

READ was first to use multiple sources to reduce rig time and the first to acquire 3DVSP “offline” while drilling. READ has deployed the longest wireline logging string ever (2,700ft or 845m), used more levels of Geochain tool than any other contractors on standard wireline (28 levels). In addition, READ has acquired the largest deepwater 3DVSP in the Gulf of Mexico with ever 40,000 shot points, and is the benchmark proven leader in both 3D and 2D borehole seismic processing.
3D VSP Survey Design & Acquisition
Pre Survey Planning Procedure

**Discussion with client:**
- Define target
- what information is wanted.
- Primary objectives
- Secondary objectives

**Modeling**
- Ray tracing
- Synthetic data
- Processing data
- amplitudes
- coverage
- P-S

**Reporting:**

**Recommendations for:**
- Geometries
- Geophone positions
- Shot Positions
- Sources

**Estimated:**
- Seismic coverage
- Resolution
- Noise Problems
- P to S conversion
- Survey / Rig time

**Display of:**
- Depth model
- Ray tracing results
- Synthetic data
- Processing results of synthetic
- Estimated refl. coeff. and AVO
3D Advanced Modeling Tools for Survey Designs
Multi-wells Survey
Multi-source Shooting Pattern

- Cutting rig time to 1/3 (1/2) using continuous spiral shoot with 3 (2) sources fired consecutively
- Cutting rig time to 1/4 with more efficient tool strings
## VSP Acquisition Borehole Tools

<table>
<thead>
<tr>
<th>Special tools</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geolock-S</td>
<td>Slim high temperature tool, drill pipe conveyance</td>
</tr>
<tr>
<td>Geolock</td>
<td>Large hole, drill pipe conveyance</td>
</tr>
<tr>
<td>ASR</td>
<td>Dual level high temperature, drill pipe conveyance</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Multilevel tools</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELTA</td>
<td>4 or 8 satellite drag and shoot system.</td>
</tr>
<tr>
<td>Slim DELTA</td>
<td>4 or 8 satellite drag and shoot system.</td>
</tr>
<tr>
<td>SYGMA</td>
<td>Up to 32 satellites.</td>
</tr>
<tr>
<td>HDSeis</td>
<td>Up to 40 satellites</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pump down tool</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESR</td>
<td>1-11/16&quot; Dual level gimbaled</td>
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</tbody>
</table>

All tools are combinable with GR for depth correlation
Multilevel tools can be combined with hydrophone
Multilevel tools can be combined with tractor (VSPXpress)
Gulf of Mexico – 7 Surveys - NO downhole failures – 300 hours continuous operation.
3D VSPs Acquired by READ in GOM During Past 3 Years

The Thunder Horse 3D VSP (2002)

Water depth: > 7000ft; No. of Shots: ~ 30,000;
No. of shutter levels: 16;
Source Vessel: two separate supply boats; dual source arrays; spiral survey
3D VSPs Acquired by READ in GOM During Past 3 Years

The Mad Dog 3D VSP (2003)

Water depth: > 7000ft; No. of Shots: ~ 40,000;
No. of shutter levels: 25;
Source Vessel: Bai Hai 512 of CNOOCS, dual source arrays, spiral survey
Tubular Bells 3D VSP (2003)

Water depth: > 9600ft; No. of Shots: 12,300;
No. of shutter levels: 20;
Source Vessel: Condor Explorer of Seabird; dual source arrays; spiral survey
Stones 3D VSP (2005)

Water depth: > 9700ft; No. of Shots: ~ 14,400;
No. of shutter levels: 28;
Source Vessel: Polar Venture of Fugro; dual source arrays; spiral survey
READ’s Strengths in 3D VSP Acquisition

- The most experienced engineers
- Always well planned and tested before operations begin
- State of the art of equipment
- Plenty of backup personnel and equipment in field
- High efficiency and low cost
- READ always reached project objectives in any previous 3D VSP survey
3D VSP Data Processing

GENERAL PROCESSING SEQUENCE:

1. Pre-processing (format conversion, geometry/navigation, Regularizing etc.)
2. First –Break Picking
3. Three-Component Rotation
4. Align data with first arrival time and extract down-going P wave
5. Remove down-going P and P-S waves
6. Deterministic deconvolution (design deconvolution operator from down-going P-wave)
7. Wave field separation and up-going P-P and/or P-S waves enhancement
8. Initial velocity model from surface, check shot and zero-offset VSP data etc.
9. Initial forward FB modeling and prestack depth migration
10. Velocity model tomographic updated and anisotropic parameter estimation
11. Final pre-stack anisotropic depth migration (finite difference or Kirchhoff)
WHY 3 COMPONENT DATA?
3-COMPONENT ROTATION

Vertical Component Data

Scalar Wavefield

Down P

Common Shot Gather (80 Receivers)
FROM VECTOR TO SCALAR WAVEFIELDS
MEDIAN FILTERING TO REMOVE DOWN WAVEMODES

Aligned Raw Data  Remove Down P  Remove Down S
P-S SEPARATION, MODEL OR DATA BASED
P-S SEPARATION, MODEL OR DATA BASED

P-P

P-S
3D VSP Case Examples

THE EKOFISK FIELD 3D VSPs by READ

SURFACE SEISMIC

3D VSP DEPTH MIGRATION
THE EKOFISK FIELD 3D VSPs by READ
SUBSALT VSP, GOM

Surface seismic through walkaway profile

Anisotropic FD depth migration of VSP
Note: The 3D VSP section has been band-passing filtered to match the surface data.
HIGH RESOLUTION 3D VSP

2D Surface Seismic

3D VSP profile along same line

30 Hz dominant frequency

>50 Hz dominant frequency
HIGH RESOLUTION 3D VSP

2D Surface Seismic

3D VSP Finite Difference Migration
Anisotropy Effect on Small Faults Imaging - Small fault is mis-imaged approximately 50m by vertical anisotropy axis
HIGH RESOLUTION 3D VSP – PS Wave Imaging
VSP MAP PINCH-OUT TOWARD UNCOMFORMITY

Surface Seismic with VSP Finite Difference P-P Migrations Splice.
18 levels in 3 wells:
1LA-2 (8 levels)
CAM885 (8 levels)
CAM858 (2 levels)

Receiver Depths:
Below the Jandaira Fm.
Top geophone @ 560 m (below MSL)

~1850 shots,
Elliptic pattern
60 by 60m grid
HIGH RESOLUTION 3D VSP - Petrobras Multiwell 3D VSP
NOTE:

Petrobras Drilled New Wells Based on the 3D VSP Imaging Results, and They Gained More than 1000 Barrels/Day Increase in Oil Production!
• “Correct” model - all data generated in this model (ZO, Offset VSP, WA)
• All Parties (Schlumberger, Baker, CGG and READ) is given the “Input” model for initial velocity model.
• Contractor B (READ) recreated the “Correct model” with less than 10 m error margin throughout the model.
GREEN LINE is the correct fault position

Migration results from READ Well services as Contractor B

Other results from Schlumberger, Baker and CGG.
Other International Benchmarks

- READ Well Services benchmarked for BP (US) for 3D VSP processing (2001) and became top ranked contractor.
- READ Well Services benchmarked for an European Company (2004) and become top ranked.

Correct model

Input model
Other International Benchmarks 2004

Contractor A

Contractor B - READ

Contractor C

Contractor D
Geological Background:
Target depth 1300-1600m, delta deposits with lake facies, sand and mud layering, and highly lateral inhomogeneity due to mini-faults and other mini-structures etc.

Typical Well:
1798m(TVD 1635m), casing 13”3/8 at 478m + 9”5/8 at 1798m

Water depth:
32m
Geological Objectives:

To resolve the sequences and those thin sand/mud interleave layers, to identify the mini-faults and other micro-structures through high resolution 3D VSP data, and therefore to increase oil production based on the new and more accurate geological model and its corresponding new development plan.
GEOPHONE SPACING - RULES OF THUMB

One wavelength must be sampled twice to avoid aliasing

Example:
If $V_p = 3000\text{m/s}$, geophone spacing = 15 m, then
Highest Frequency

$$= \frac{3000}{2 \times 15} = 100\text{Hz}$$
16 Level SYGMA with 15m Spacing

- Wireline Company Head, Adapter
- Gamma ray Tool (GRT) 0.8 m, 51 lbs
- Telemetry Adaptor Section, 0.96 m, 39 lbs
- 4.1m Interconnect Wireline Cable, 20 lbs

Satellite 1 0.9 m, 38 lbs

14.1m Interconnect Wireline Cable, 48 lbs

Satellite 16 0.9 m, 38 lbs
- 4.1m Interconnect Wireline Cable, 20 lbs

Voltage Regulator Section (VRS) 4.22 m, 199 lbs, Includes VRS, Motion Detector, Bull Nose

2ms sampling rate
SOURCE – RECEIVER OFFSET - RULES OF THUMB

no more than ~ 2 times receiver depth

550 m

1500 m offset

Target @ ~1200 m depth

TRAVEL PATHS
SOURCE – RECEIVER OFFSET - RULES OF THUMB

Direct arrival angle, no more than ~ 70-75 degrees

Target @ ~1200 m depth
TARGET LAYER COVERAGE - RULES OF THUMB

\[ R = X \times \frac{(H - H_g)}{(2H - H_g)} \]

Target @ ~1200 m depth

\[ R = \sim 420 \text{ m} \]
Spiral Survey with Dual Source Arrays

For 3km maximum offset and 25m source spacing:
Total ~45,000 shots

Or 50m source spacing:
Total ~11,500 shots
If Shot of Survey with ~45,000 shot points:
122 hours
If Shot of Survey with ~11,500 shot points:
40 hours

Final Survey Parameters and Number of Shots should be Determined by Pre-survey Modeling Study!
3D Geological Model Example for Survey Design
Survey Geometry
Imaging Coverage for Target Layer

HitMap [Hits/bin cell]
Major Deliverables of 3D VSP Project at ShuaiZhong 36-1 Field:

(1) High-resolution P-P Anisotropic Migration Imaging Cube
(2) High-resolution P-S Anisotropic Migration Imaging Cube
(3) Final Velocity Model
READ IS A LEADER IN 3D VSP TECHNOLOGY!