General Overview of IBDP Microseismicity

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This is a general overview of the IBDP microseismicity showing some of its characteristics.

This site/project is one with a very low increase in formation pressure associated with injection, mainly because of the formation characteristics.

Will present:

Stratified pressure response
Stress directions
Monitoring arrays
Microseismicity development through time
Map View of IBDP wells

- VW1: 916 ft (≈180 m)
- GM1: 196 ft (≈60 m)
- CCS1: 1000 ft (≈300 m)
Formation pressure readings in VW1
900 feet from Injection borehole @ 1.5 yrs

% Increase of Original Formation Pressures

0%  2.00%  4.00%  6.00%

Down hole Injection pressure @ CCS1
14% increase above original formation pressure
VW1 - Verification Well Pressure Monitoring Data (update to 7/1/14)

Zone 2: $\Delta p \approx 151$ psi (10.4 bar) or $\approx 5\%$ Formation increase

Zone 6: $\Delta p \approx 21$ psi (1.4 bar) or $<1\%$

Cumulative: 863,577 tonnes

from Schlumberger Carbon Services
\[ \Delta P_{\text{max at VW1}} = 5\% \text{ over original formation pressures} \]

At about 65\% of fracture pressures of Mt. Simon

Pressures are stratified
Formation Microimager

Induced Fractures (137) & Breakouts (25) VW-2

Depth FT

- 5400
- 5600
- 5800
- 6000
- 6200
- 6400
- 6500
- 6800
- 7000
- 7200

- Eau Claire - shale
- Mt. Simon Sandstone
- Pre Mt. Simon - sandstone
- Precambrian - crystalline basement

Joe Magdits – Log Analyst @ Schlumberger
Pre Mt. Simon – Induced Fractures
In fine grained stiffer layers
Mt. Simon, Pre Mt. Simon and part of Precambrian basement
Fullbore Formation Microimager

Induced fracture

Breakout

Maximum horizontal stress direction based on induced fractures and breakouts.

Joe Magdits – Log Analyst @ Schlumberger
Maximum Horizontal Stress Directions showing measurement techniques

Green – Hydrofracturing
Red – strain gages
Black – break out

IBDP Well configuration and geophones

Oblique View looking north

SMC 1850 10 Hz

Omni 2400 15 Hz

Valerie Smith
Schlumberger Carbon Services
Local Microseismic Events: Pre-Injection
(May 1, 2010 to Nov. 15, 2011)

8 Events
Max: - 1.52
Avg: - 1.83
Min: - 2.16

Valerie Smith
Schlumberger Carbon Services
Additional Geophones in VW2 near end of 2013

Five Omni 2400 15 Hz
200 ft apart down to 6,950 ft
Dec 2011

Each Division in X & Y
= 1,000 Ft or
≈ 300 m
Aug 2012

CCS1
Sep 2012
Jan 2012

[Graph with data points labeled CCS1]
Why did Cluster 1 form at about 1,800 feet (550 m) from CCS1 first before Cluster 2 at an average of 1,160 feet (350 m) from CCS1?

Estimates are that Cluster 1 Δ pressures were about 50 psi (3.5 bars) or 0.35 MPa at the time of first formation.
Pre-existing fractures close to 30 degrees from the maximum horizontal stress direction are optimally oriented in the direction expected for strike-slip movements (King, 1994).

From hydraulic fracturing, microearthquakes are triggered along pre-existing natural fractures that are favorably oriented for slip (Pearson 1981; Rutledge and Phillips 2003; and Shapiro et al., 2006).
Baig et al., (2012) found for hydraulic fracturing of some wells that events tended to fall along two main trends, the early events follow a trend roughly 30 degrees from SHmax and the later events follow a lineation approximately parallel to SHmax.

Yang et al., (2013) found similar trends for hydraulic fracturing in the Bakken formation where detected microseismic events from many stages trend ~30 degrees from the direction of SHmax.
Optimally oriented to slip: strike-slip
Each Division in X & Y = 400 Feet or ≈ 120 m
Cluster 1 & 11 development

Time – Dec 2011 to April 2013

Depth below MSL Feet

-6000
-6100
-6200
-6300
-6400
-6500
-6600
-6700
Cluster 2 development

Time – Dec 2011 to April 2013

Depth below MSL Feet
Cluster 3 development

Time – Dec 2011 to April 2013

Depth below MSL Feet
Cluster 4 development

Time – Dec 2011 to April 2013
Depth thru Time

Vertical depth divisions = 300 feet ≈ 100 meters

Dec 2011 to April 2014

Eau Claire – 1st seal

Mt. Simon Sandstone

Injection Zone

Pre Mt. Simon

Precambrian crystalline basement
Depth vs Distance from Injection well - CCS1

Increasing distance from Injection well

Vertical depth divisions = 300 feet ≈ 100 meters

Eau Claire

Mt. Simon Sandstone

Pre Mt. Simon

Precambrian crystalline basement
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from Schlumberger Carbon Services
Reaction @ VW1 to Two week shut in

- CCS1 Injection @ +14%
- ΔP

1 day into shut in – CCS1 @ +5.4%

4 days into shut in – CCS1 @ +4.5%

8 days into shut in – CCS1 @ +4.0%

12 days into shut in – CCS1 @ +4.0%

14 days into shut in – CCS1 @ +3.8%
Locatable Events – March 2013

Avg. 4.2 per day  Avg. 1.15 per day

William Graham Payne - SCS
Two week injection
Two week injection
Two week shut in
Microseismic Cluster Activity: Relationship to Pre-Mt. Simon Structure

from Schlumberger Carbon Services
Microseismic Cluster Activity: Cluster Locations in Relation to Surface Features

from Schlumberger Carbon Services
Richter – Gutenberg or b-value plot suggests tectonic reactivation

\[ b = 1.007 \]

from Schlumberger Carbon Services
Microseismic Activity: Overview

- Stratified pressures and Max. Δ P of 5% increase for one “layer”
- Pressures far below fracture pressures
- Lower permeability layers near top of injection restrict pressure increases upward, restricting seismic development
- Locations determined using geophone arrays in CCS1, GM1, and VW2
- Form distinct clusters along undetected pre-existing structures
- Distributed between Lower Mt. Simon Sandstone, Pre-Mt. Simon Unit, and Precambrian basement
- Magnitudes range from -2.14 to 1.14 & 94% are less than 0
- Magnitude range does not change much through time
- b values of about 1 indicate reactivation of pre-existing features
- Overall project average of microseismic events is 4 per day


