Appendix 1
Caprock Mini-Frac Summary Report
MINI-FRAC ANALYSIS REPORT

Well Name: Thickwood 1AA/09-23-090-15W4/00
Report Date: April 2, 2012
Prepared For: Grizzly Oil Sands ULC

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Mini-Frac Analysis for 1AA/09-23-090-15W4/00

BACKGROUND

Primary purpose of this report is to present the results and findings from a series of mini-frac tests in the subject well. Mini-fracs can provide critical information such as in-situ stresses, pore pressure, leakoff data and other reservoir characteristics in the vicinity of the wellbore.

Summary of Test & Results

A series of mini-frac tests was conducted by Big Guns Energy Services on behalf of Grizzly Oilsands to determine the fracture closure pressure (or the minimum in-situ stress) in the caprock layer and oil sands payzone. Key results are tabulated below:

<table>
<thead>
<tr>
<th>Test Interval (mKB)</th>
<th>Formation</th>
<th>$S_{Hmin}$ (kPa)</th>
<th>$S_{Hmin}$ Gradient (kPa/m)</th>
<th>$S_v$ (kPa)</th>
<th>$S_v$ Gradient (kPa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>138-139</td>
<td>Clearwater Shale</td>
<td>2876</td>
<td>20.8</td>
<td>3140</td>
<td>22.7</td>
</tr>
<tr>
<td>150-151</td>
<td>Clearwater Shale</td>
<td>3324</td>
<td>22.1</td>
<td>3421</td>
<td>22.7</td>
</tr>
<tr>
<td>158-159</td>
<td>Wabiskaw A Sand</td>
<td>2323</td>
<td>14.7</td>
<td>3598</td>
<td>22.7</td>
</tr>
<tr>
<td>166-167</td>
<td>Wabiskaw Capping Shale</td>
<td>2520</td>
<td>15.1</td>
<td>3770</td>
<td>22.6</td>
</tr>
</tbody>
</table>

According to the stress profile derived from log processing, the min. in-situ stress at the depth of 174 mKB in the Wabiskaw D Sand is approximately 2373 kPa(a) or 13.6kPa/m.

Fig. 1 In-situ stresses in 1AA/09-06-075-08W4
In the Wabiskaw member, the minimum in-situ stresses are significantly less than the calculated overburden stresses, thus a vertical fracture regime is expected. In the Clearwater shale, the measured closure stress is slightly below but close to the overburden stress, indicating a potential horizontal fracture regime.

**Location**

The subject well is located at LSD 09-23-090-15W4 in the Thickwood Hills area, approximately 45km northwest of Fort McMurray, Alberta.

![Fig. 2 Location of test well](image)

**Test Intervals**

In this series of mini-fracs, intervals in the caprock layer were tested to determine the minimum in-situ stress, and one interval in the oil sands payzone was selected to obtain the minimum in-situ stress and estimated pore pressure. More than one interval in the Clearwater formation was tested in order to ensure data consistency.

In the original test plan, an additional interval in the Wabiskaw D Sand payzone was included. However, due to potentially significant near-wellbore damage and the restricted pressure rating of wellhead equipment, it was not possible to achieve a formation breakdown without risking overpressuring the wellhead. The log also shows cement loss in the zone. Since the test interval was chosen at the top of the formation, it was not physically possible to test another interval within the same zone. As a result, a stress value for this zone will be derived from a stress profile.
**METHODOLOGY**

**In-situ Stress Theory**

The in-situ stresses in the subsurface can be described by the magnitudes and orientations of three orthogonal principal stresses, $\sigma_1$, $\sigma_2$ and $\sigma_3$ listed in descending order of magnitude. Compressive stress is commonly defined as positive. These stresses are influenced by many factors, including weight of the overburden, tectonic movements, creep flow and plasticity, fluid pressure, etc.

By definition, one principal stress will always be oriented perpendicular to a free surface. Because the present-day topography across the Western Canada Sedimentary Basin is horizontal, it is reasonable to describe one of the principal stresses as near-vertical, or perpendicular to the topography. The remaining two principal stresses, being orthogonal to the vertical principal stress, would lie on the horizontal plane. The vertical stress is commonly referred to as $S_v$, while the two horizontal stresses are denoted by $S_{H_{\text{max}}}$ and $S_{H_{\text{min}}}$.

---

<table>
<thead>
<tr>
<th>Test Intervals</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 – 139 mKB</td>
<td>Clearwater Shale</td>
</tr>
<tr>
<td>150 – 151 mKB</td>
<td>Clearwater Shale</td>
</tr>
<tr>
<td>158 – 159 mKB</td>
<td>Wabiskaw A Sand</td>
</tr>
<tr>
<td>166 – 167 mKB</td>
<td>Wabiskaw Capping Shale</td>
</tr>
</tbody>
</table>

Fig. 3 Test intervals
$S_{\text{Hmin}}$. Figure 4 below illustrates the typical orientation of fracture in the Western Canada Sedimentary Basin, assuming $S_{\text{Hmin}}$ is the minimum in-situ stress. In this study, magnitudes of $S_v$ will be calculated from density logs, and the $S_{\text{Hmin}}$ will be derived from mini-frac tests.

**Principle of Mini-fracs**

The purpose of a mini-frac test is to measure reservoir stresses and properties by injecting test fluid into the reservoir to create a small fracture that establishes communication between the wellbore and the true formation. Fractures naturally follow the path of least resistance, thus opening in the direction of the minimum principal stress. In other words, the plane of fracture is perpendicular to the direction of the minimum principal stress. Since the pressure at which a fracture closes corresponds to the least pressure required to keep that fracture open, the fracture closure pressure represents the smallest compression against the rock. Therefore it is equivalent to the smallest principal stress acting on it.

A mini-frac test consists of an injection and a fall-off period. During the injection phase, a controlled-volume of water is injected into the well to create a short fracture in the formation. The created fracture penetrates the near-wellbore damaged area and has the undamaged formation exposed to the flow transients. The fracture directly connects the undamaged formation with the wellbore and forms an efficient flow passage for the pressure response of the true formation to the injection. Once the fracture is open, the pumps are shut down. Subsequently, the pressure declines and the fracture closes. Pressure data is recorded before and after the fracture closure. The next figure shows typical pressure response during a mini-frac test.
When the injection fluid pressure exceeds the wellbore hoop stress, the formation breakdown occurs and a fracture is initiated. The fracture propagates as the injection continues. At the end of the injection, the pumps are shut down. There is a rapid pressure drop due to friction in the wellbore and across perforations. The pressure at which all frictional effects have dissipated is called the ISIP, or the instantaneous shut-in pressure. Fluid begins to leak from the fracture into the formation immediately before closure happens. The fracture closure pressure is the pressure required to hold the fracture open after initiation, or to keep the fracture from just closing. After fracture closure, the pressure transient established around the wellbore propagates into the reservoir, transitioning into pseudo linear and pseudo radial flow periods.

Analysis & Interpretation

Fracture diagnostic techniques described in SPE paper 107877, “Holistic Fracture Diagnostics” are applied in the interpretation of test data. Objective of the analysis is to provide consistent interpretation that helps to give the most useful information available from the mini-frac tests. The prescribed diagnostic post shut-in pressure decline transient analysis includes a suite of analytical techniques through which bottomhole pressures and delta-pressures are plotted against different time scales. More than one method is used to identify the fracture closure. Instead of picking any individual diagnostic plots for interpretation, it is important to look at the whole suite of plots in order to gain a more comprehensive understanding on what information the test data is conveying.

G-Function

One important method that minimizes ambiguity and provides useful in-situ stress and leakoff information is the G-function analysis. The G-function is a dimensionless time function relating shut-in time to total pumping time. This process uses derivative curves to
identify leakoff mechanisms and fracture closure point through the characteristic shapes of the curves. The G-function plot features a pressure vs. G-time curve and semilog derivative of pressure vs. G-time curve. In many cases, the expected signature of the semilog curve is a straight line that passing through the origin. Fracture closure point is identified at the point when the G-function derivative curve starts to deviate from its straight tangent line in a normal leakoff (most ideal) case.

![G-function plot showing fracture closure](image)

This technique was introduced by Kenneth G. Nolte in 1979 and has been universally recognized in the industry. G-function does not assume a single planar fracture and will show the effects of multiple fracture planes propagating against different closure stresses. The normal leakoff model is applied to the sole case of perfectly linear pressure decay on the G-function P vs. G plot. This is the solution of the diffusivity equation for one dimensional linear flow with constant pressure boundary conditions. However, deviation from this ideal behavior is generally expected. The other pressure fall-off scenarios are pressure dependent leakoff, fracture extension, height recession, variable storage, etc. The G-function curves for each of these scenarios display a different signature, therefore analysis and interpretation for each case are also handled differently.

**Other Diagnostic Plots**

In order to consistently interpret test results, the commonly used pressure vs. squareroot of time plot can often be used for confirming the closure pressure identified by the G-function plot.

On a sqrt(t) plot, it has been commonly accepted that the p vs. sqrt(t) curve should form a straight line during fracture closure. However, exactly where on this straight line does closure occur has not been rigorously defined. Numerous sources define the correct
closure pick as the inflection point on this p vs. sqrt(t) curve. Since a change in pressure response indicated by its first derivatives is the only signal available for interpretation, we plot the inverse of the first derivative of p vs. sqrt(t) and the minimum of this derivative clearly shows the inflection point.

The log-log plot of change in pressure with change in time after shut-in features a pressure difference vs. change in time curve and its semilog derivative. It is common for the pressure difference and derivative curves to be parallel immediately before closure. It is also typical that the derivative curve changes from a positive slope to a negative slope when closure occurs. Because this plot lacks a distinct and clearly identifiable signature for closure, it is used only as a verification tool in this analysis. It is, on the other hand, a powerful tool in determining the transient flow regime in addition to the fracture closure. The slopes of the derivative curve are diagnostic of the flow regimes before and after fracture closure. For instance, a slope of >0.5 before closure indicates a period of fracture linear flow coupled with changing fracture or wellbore storage. A slope of 0.5 around the closure event indicates a period of formation linear flow. After closure a slope of -1 indicates a fully developed pseudoradial flow.

<table>
<thead>
<tr>
<th>Slope</th>
<th>Flow Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>¼</td>
<td>Bilinear</td>
<td>Fluid flows from the fracture along linear flow paths normal to the fracture and along the fracture</td>
</tr>
<tr>
<td>½</td>
<td>Fracture linear</td>
<td>Fluid flows along the fracture thus increasing fracture width</td>
</tr>
<tr>
<td>After Closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-¾</td>
<td>Bilinear</td>
<td>Fluid flows from the fracture along linear flow paths normal to the fracture and along the fracture</td>
</tr>
<tr>
<td>-½</td>
<td>Formation linear</td>
<td>Fluid flows into the formation in paths normal to the fracture plane</td>
</tr>
<tr>
<td>-1</td>
<td>Pseudo radial</td>
<td>Fluid flow radially into the formation from the wellbore</td>
</tr>
</tbody>
</table>
**After-Closure Analysis**

Once closure is consistently identified, the after-closure flow data can be used to estimate reservoir properties if the pressure fall-off is long enough to reach either a formation linear flow or, ideally, a pseudoradial flow. In a formation linear flow, fluid flows into the formation in a direction normal to the fracture plane. Pressure gradients within the fracture become negligible. Given time, the pressure transient progresses far enough into the reservoir, and flows radially away from the wellbore. This flow regime is known as pseudoradial flow. Under this condition, the far-field reservoir properties can be more accurately estimated from the decline of pressure transient. After a pseudo linear and/or pseudo radial flow regime has been identified, a Cartesian plot of pressure v. linear/radial flow time function can be constructed. On this plot, a straight line is drawn through appropriate data in the identified flow period. The y-intercept of this line gives an estimated pore pressure. Transmissibility can be calculated from the slope of this line. With a known net pay height and reservoir fluid viscosity, permeability can also be estimated.

**Software Basis**

The software used for the diagnostics, GOHFER, is a planar 3-D geometry fracture simulator with a fully coupled fluid/solid transport simulator. GOHFER stands for Grid Oriented Hydraulic Fracture Extension Replicator. It uses a planar grid structure to perform elastic rock displacement calculations and a planar finite difference grid for the fluid flow solutions. It incorporates the effects of secondary shear fractures and dilation of shear & existing natural fractures. In order to account for friction effects that skew mini-frac data, the software can determine pipe friction, friction loss across perforations, and near-wellbore tortuosity when used in combination with a step-rate (down) injection scheme at high rates.

The software was developed by Dr. Bob Barree of Barree & Associates in collaboration with Stim-Lab, a division of Core Laboratories. It is used extensively in many applications, such as hard rock/tight gas, naturally fractured reservoirs and moderate permeability oil sands, without requiring special tuning. Besides mini-frac analyses, GOHFER is commonly used in the oil & gas industry for the design, analysis and optimization of hydraulic fractures.

**TEST DESIGN & PROCEDURE**

**Design Considerations**

The design of a mini-frac includes defining the objectives and outputs of the test, establishing adequate injection rates and volumes, selecting test intervals, as well as defining perforating requirements. The selected injection rate must be substantially larger than the leak-off rate to establish fracture, but an excessive volume may overpressure the surrounding rocks, thereby altering the in-situ stress states.

Multiple cycles in a test are strongly supported as a means of ensuring quality data and achieving consistency in the closure pressure interpretation. Nevertheless, one must be aware
of the potential increase in closure stress in the later cycles due to pressurizing of the surrounding rocks by earlier injection cycles.

Perforation damage due to compaction and stress cage is real and has been documented even in unconsolidated sands. It will mostly affect which and how many perforations break down. Once breakdown is achieved, and if a fracture is generated, then the leakoff, closure stress, and formation flow capacity measurements will not be affected by the perforation damage as they are controlled by the properties along the face of the fracture. What may be altered is the total height of formation accessed by a small volume, low rate injection test so that estimation of permeability may not be possible.

**Data Quality Control**

In order to ensure the accuracy and quality of data obtained, the following measurement and procedural quality control methods are practised:

- Multiple points of measurements are taken at the wellhead and bottomhole with additional backup bottomhole recorders.
- Both bottomhole and surface sensors have high resolutions and current calibration certificates.
- A pressure memory recorder is set with every wireline retrievable isolation plug to detect communication between test intervals.
- More than one injection cycle is performed for repeatability and in case of anomalies. In some cases, a falloff may not be valid for analysis due to anomalies caused by fluid expansion in wellbore, mechanical artifacts, communication with other layers, or simply noise.

**Equipment**

**Injection System**

Constant and controlled injection of test fluid is accomplished through the use of a specialized low-rate injection unit designed to inject 0.2 to 120 L/min. up to 21 MPa. The system provides an automated flow rate control by means of a Digital Control System. This injection system eliminates fluctuations in flow rate thus yielding better-quality pressure response data.

**Instrumentation**

Due to wellbore dynamics and the delicacy of the tests, high precision and multi redundancy monitoring system is critical to the success of the tests. High resolution data is required to detect very subtle changes. Both bottomhole and surface pressure sensors used in these tests have a resolution of ±0.0003% full scale and an accuracy of ±0.025% full scale. Multiple pressure, temperature and flow measurements are taken from downhole and at the surface to ensure accurate and reliable data. It is important to have bottomhole measurement as it can provide more information about the true reservoir
response. Grease injector and pressure head are used to ensure a solid seal on the wireline connecting to the downhole instrumentations.

Test Procedure

Prior to testing, it is critical to ensure that only clean and formation compatible water is injected into the test zones. This prevents any formation damages from the injection of unknown wellbore fluid which will impact the results of the tests.

Perforations are made at 0.5m or 1.0m interval at the target depths with shallow penetration charges. These charges are just enough to break through the casing and cement sheath to ensure good communication with the formations without creating deep perforation channels.

One important means to verify the consistency of test data is to conduct multiple injection cycles with combination of the various diagnostic injections. The induced fracture is opened and closed several times so that successive pressure declines can be monitored to obtain consistent fracture closure pressure. There are instances when the falloff data becomes invalid for analysis due to noise, fluid expansion in the wellbore, and mechanical artifacts. The mini-frac tests presented in this report consist of a series of injections at slightly varying rates and natural pressure declines. One of the test cycles involves an extended fall-off until radial flow is reached. This falloff is used to determine a fracture closure pressure. Another cycle at slightly differing rate is chosen for verification. Whenever possible, two cycles are chosen for analysis and the results are compared for consistency and repeatability.

After testing each interval, an isolation plug is set with memory pressure and temperature recorders to continue monitoring the interval. This allowed for identification of any communications when testing subsequent intervals above the isolated interval.
DATA ANALYSIS BY TEST INTERVAL

The following analyses are presented in the same order as the intervals were tested. Please note that all analyses have been done in gauge pressures, while the final results and gradients are presented in absolute pressures. In the original test plan, an additional interval in the Wabiskaw D Sand payzone was included. However, due to potentially significant near-wellbore damage and the restricted pressure rating of wellhead equipment, it was not possible for the injection to break through the formation damage without overpressuring the wellhead. Since the test interval was chosen at the top of the formation, it was not physically possible to test another interval within the same zone. Therefore, a log-derived stress profile will be used to approximate the minimum in-situ stress in this zone. Results will be discussed at the end of this section.

Mini-Frac Test Interval #1: Wabiskaw Capping Shale @ 166.0mKB

A mini-frac test was conducted in the 166.0 – 167.0 mKB on February 18-19, 2012.

![Fig. 9 Test interval in the Wabiskaw caprock](image)

![Fig. 10 Plot of pressure and rate vs. time](image)
Three injection cycles were conducted in this interval. The first injection cycle and the second cycle with an overnight falloff are analyzed in detail. Note that the falloff behaviors are slightly different between the two cycles. The first cycle apparently experienced pressure disturbance during the falloff period.

![Fig. 11 Cycle 1 Job Data](image-url)
**G-Function Analysis**

The G-function is a dimensionless function of shut-in time normalized to pumping time. This diagnostic plot features a pressure curve displayed in blue and its diagnostic G-function derivative curve displayed in red. The semilog derivative is nearly straight, suggesting constant permeability and fracture area. The closure event is marked by the vertical line [C]. According to this plot, a closure is indicated at G-time = 29 and the bottomhole pressure = 2,420 kPa(g).

![G-Function Plot](image)

**Fig. 12** G-function derivative plot for test interval @ 166mKB
**Sqrt(t) Analysis**

On a pressure vs. squareroot of time plot, the pressure vs. sqrt(t) curve forms a straight line during fracture closure. Our closure pick is at the inflection point on the straight-line section of this curve. Because the change in pressure response indicated by a derivative is the only signal available for interpreting the closure, the best way to observe the closure is to plot the first derivative of p vs. sqrt(t) and find the point of maximum amplitude of the derivative. The software used for this analysis plots the inverse of the derivative, therefore, the minimum on the derivative curve represents the closure event. A slight derivative minimum is shown by this Sqrt(t) plot and this coincides with the closure determined by the G-function. Vertical line [C] marks this closure point. The earlier derivative minimum corresponds to the “spike” on the G-function semilog derivative.

![Sqrt(T) Analysis](image)

**Closure Events**

<table>
<thead>
<tr>
<th>Sqrt(T)</th>
<th>BHCP</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closure</td>
<td>17.242</td>
<td>2419.27</td>
</tr>
</tbody>
</table>

![Fig. 13 Pressure vs. Sqrt(t) plot for test interval @ 166mKB](image)
Log-Log Pressure Derivative Analysis

The log-log plot of change in pressure from ISIP versus shut-in time features a change in pressure curve in blue and its semilog derivative curve in red. It is common for the pressure difference and the semilog derivative curves to be parallel immediately before closure, which is clearly the case. The closure pick based on this curve is marked by the vertical line [C]. This closure pick is consistent with the G-function. The slope of this semilog derivative curve is diagnostic of the flow regime established before and after fracture closure. After closure the semilog derivative curve shows a brief radial flow period, as indicated by the -1 slope.

Fig. 14 Log-log plot of ΔP vs. time for test interval @ 166mKB
**Confirmation Test**

To test reproducibility of results, the second injection was also analyzed. Closure in this cycle occurs at $G=35$ and $BHP=2430\ \text{kPa(g)}$, with signs of wellbore storage. This serves as a good verification for the 2420 kPa(g) resulted from the previous analysis.
The $\sqrt{t}$ derivative does not have a distinct minimum.

On the log-log plot, the unique closure pick [C] is at the point where the slope of its derivative changes from positive to negative. This can be regarded as a closure confirmation.
Summary of Test @ 166.0 mKB
Data from two injection cycles are analyzed with consistent results. Based on data from the first and second injection cycles, closure stress was determined based on the G-function diagnostic plot with confirmations by the \( \sqrt{t} \) plot and/or log-log plot. All key parameters calculated from this test are tabulated below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP at Closure:</td>
<td>2419 kPa(g) or 2520 kPa(a)</td>
</tr>
<tr>
<td>Closure Gradient:</td>
<td>15.1 kPa(a)/m</td>
</tr>
<tr>
<td>ISIP:</td>
<td>3953 kPa(g) or 4054 kPa(a)</td>
</tr>
<tr>
<td>ISIP / Fracture Gradient:</td>
<td>24.3 kPa(a)/m</td>
</tr>
<tr>
<td>Reservoir Pressure:</td>
<td>2005 kPa(g) or 2106 kPa(a)</td>
</tr>
</tbody>
</table>
**Mini-Frac Test Interval #2: Wabiskaw A Sand @ 158.0mKB**

An injection fall-off test was conducted in the 158.0 – 159.0 mKB interval on February 19-20, 2012.

![Fig. 19 Mini-frac test interval in the Wabiskaw A oil sands payzone](image)

The first injection cycle, which is not displayed on the plot above, experienced an unusually slow leakoff that was almost stagnant. Therefore, the second and third injection cycles (as shown in the above figure) are chosen for analysis in detail.

![Fig. 20 Plot of pressure and rate vs. time](image)

![Fig. 21 Cycle 2 job data](image)
**G-Function Analysis**

The G-function plot features a pressure curve displayed in blue and its diagnostic G-function derivative curve displayed in red. For this test, closure is subtle and difficult to pick with accuracy because of potential wellbore storage. The closure is picked in conjunction with the Sqrt(t) plot at G=0.155 and BHP=2395 kPa(g). The closure event is marked by the vertical line [C]. The Sqrt(t) plot will be used to confirm this closure pick.

![G-Function Analysis Diagram]

**Fig. 22** G-function derivative plot for test interval @ 158mKB
**Sqrt(t) Analysis**

The sqrt(t) plot features a pressure vs. sqrt(t) curve in blue and its 1st derivative in green. Our closure pick is at the minimum point of its inverse first derivative curve. According to this plot, the derivative has a distinct minimum at BHP = 2395 kPa(g).

![Graph showing Sqrt(t) Analysis](image)

**Fig. 23** Pressure vs. Sqrt(t) plot for test interval @ 158mKB
Log-Log Pressure Derivative Analysis

The log-log plot of pressure versus shut-in time features a pressure difference curve in blue and its semilog derivative with respect to shut-in time displayed in red. The closure pick based the Sqrt(t) and G-function is marked by the vertical line [C] on this plot. After closure, there is a long period of linear flow.

**Fig. 24** Log-log plot of $\Delta P$ vs. time for test interval @ 158mKB

After-Closure Analysis

Due to the nature of the mini-frac tests with limited volume injected into the formation, only a rough estimate of the pore pressure can be extracted from this analysis. It is suggested to use this number with caution and to verify with other tests or methodologies.

Since a long formation linear flow regime was identified, the Cartesian Linear Flow plot can be used to determine reservoir parameters. This Cartesian plot gives an extrapolated pore pressure estimate of 1327 kPa(g).
Confirmation Test

To test reproducibility of results, the third injection cycle was also analyzed.

Fig. 25 After-Closure Linear Analysis for test interval @ 158mKB

Fig. 26 Cycle 3 job data
The G-function displays a very similar characteristics as the previous cycle. In conjunction with the Sqrt(t) diagnostic plot, the closure is found at 2222 kPa(g). It is slightly lower than the 2395 kPa(g) determined from the previous injection.

Fig. 27  G-function plot for the confirmation cycle @ 158mKB

Fig. 28  Sqrt(t) plot for the confirmation cycle @ 158mKB
The log-log plot for this injection cycle also shows a long linear flow period after closure.

![Log-log plot for the confirmation cycle @ 158mKB](image1)

The after-closure linear analysis gives an extrapolated pore pressure of 1281 kPa(g).

![ACA Linear Analysis for the confirmation cycle @ 158mKB](image2)
Summary of Test @ 158.0mKB

Two injection cycles have been analyzed in detail. The final cycle shows a slightly lower closure pressure at 2222 kPa(g) than the previous cycle at 2395 kPa(g). Both values were determined based on the G-function and Sqrt(t) plots. All key parameters calculated from the last cycle of this test are tabulated below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP at Closure:</td>
<td>2222 kPa(g) or 2323 kPa(a)</td>
</tr>
<tr>
<td>Closure Gradient:</td>
<td>14.7 kPa(a)/m</td>
</tr>
<tr>
<td>ISIP:</td>
<td>2528 kPa(g) or 2629 kPa(a)</td>
</tr>
<tr>
<td>ISIP / Fracture Gradient:</td>
<td>16.6 kPa(a)/m</td>
</tr>
<tr>
<td>Reservoir Pressure:</td>
<td>1281 kPa(g) or 1382 kPa(a)</td>
</tr>
</tbody>
</table>
Mini-Frac Test Interval #3: Clearwater Shale @ 150.0mKB

A mini-frac test was conducted in the 150.0 – 151.0 mKB interval of the subject well on February 20-21, 2012.

Due to pressures disturbances from unknown sources, the first falloff is not analyzable. The second injection is also not normal and shows signs of pressure communication. The final cycle also showed signs of abnormal falloff and was therefore ended early. Memory pressure recorders attached to the isolation plug showed significant pressure responsne in the last tested zone below while mini-frac tests were conducted in this interval. This communication thus impacts the quality of the falloff data.
G-Function Analysis

This G-function plot displays a pressure curve in blue and its diagnostic semilog derivative in red. According to this plot, the fracture closure likely occurred at G=6.35 and BHP=3223 kPa(g). After that there is a long storage period with a second possible closure at G=32 and BHP=2420 kPa(g).
**Sqrt(t) Analysis**

On a pressure vs. sqrt(t) plot, the closure is indicated by the minimum amplitude of the inverse derivative curve. In this case, the unique closure pick based on the G-function is shown by the vertical line [C]. This occurred roughly around the same time but slightly later than the first derivative minimum.

![Sqrt(t) Analysis](image)

**Log-Log Pressure Derivative Analysis**

The log-log plot of pressure derivative is used for after-closure flow regime identification. In this graph, the blue curve is the pressure difference, ΔP, and the red curve is its semilog derivative with respect to shut-in time. The vertical line [C] denotes the closure point determined from the G-function plot. This point coincides with a change of derivative slope from positive to negative. The after-closure slope steeper than -1 may indicate a mechanical problem during the falloff.
Summary of Test @ 150.0mKB

Data from the second injection cycle has been analyzed by three different diagnostic methods and yielded fairly consistent results. Quality of the first and final cycle falloff data have been interfered by pressure disturbances in this zone. All key parameters calculated from this test are tabulated below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP at Closure:</td>
<td>3223 kPa(g) or 3324 kPa(a)</td>
</tr>
<tr>
<td>Closure Gradient:</td>
<td>22.1 kPa(a)/m</td>
</tr>
<tr>
<td>ISIP:</td>
<td>3516 kPa(g) or 3617 kPa(a)</td>
</tr>
<tr>
<td>ISIP / Fracture Gradient:</td>
<td>24.0 kPa(a)/m</td>
</tr>
</tbody>
</table>
Mini-Frac Test Interval #4: Clearwater Shale @ 138.0mKB

A mini-frac test was conducted in the 138.0 – 139.0 mKB interval of the subject well on February 22-23, 2012.

Fig. 37 The second test interval in the Clearwater Shale

Three injection cycles were conducted. The first and last cycles are analyzed in detail. The second cycle experienced obvious pressure disturbance in the falloff phase.
G-Function Analysis

This G-function plot displays a pressure curve in blue and its diagnostic semilog derivative in red. The plot shows a closure at G=3.2 and BHP=2827 kPa(g). The derivative continues to rise but is irregular and unpredictable.
Sqrt(t) Analysis

On a pressure vs. sqrt(t) plot, the closure is indicated by the minimum amplitude of the inverse derivative curve. This Sqrt(t) diagnostic plot does not show any distinct signs of closure for interpretation.

![Sqrt(t) Analysis](image)

**Log-Log Pressure Derivative Analysis**

In this graph, the blue curve is the pressure difference, ∆P, and the red curve is its semilog derivative with respect to shut-in time. The change in derivative slope from positive to negative suggests a possible fracture closure. This point coincides with the closure pick based on G-function, and is marked by the vertical line [C]. After closure, there is a period of linear flow. The late time data fall on a positive ¼ slope, suggesting continued fracture tip extension.

![Log-Log Pressure Derivative Analysis](image)
Fig. 42  Log-log plot of ΔP vs. time for test interval @ 138mKB.

**Confirmation Test**

To test reproducibility of results, the third injection cycle was also analyzed.
In this final test cycle, a well-defined closure is observed at $G=3.1$ and $BHP = 2755 \text{ kPa}(g)$. This is quite consistent with $2827 \text{ kPa}(g)$ determined previously.
The Sqrt(t) plot shows no useful data, while the log-log plot shows a consistent closure. It is common for the pressure difference and the semilog derivative curves to be parallel immediately before closure, which is clearly the case.

**Summary of Test @ 138.0mKB**

Data from two injection cycles have been confirmed by two different diagnostic methods and yielded very consistent results between cycles. This demonstrates a good repeatability of test results. All key parameters calculated from this test are tabulated below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP at Closure:</td>
<td>2775 kPa(g) or 2876 kPa(a)</td>
</tr>
<tr>
<td>Closure Gradient:</td>
<td>20.8 kPa(a)/m</td>
</tr>
<tr>
<td>ISIP:</td>
<td>3388 kPa(g) or 3489 kPa(a)</td>
</tr>
<tr>
<td>ISIP / Fracture Gradient:</td>
<td>25.2 kPa(a)/m</td>
</tr>
</tbody>
</table>
**Stress in Wabiskaw D Sand @ 174.0mKB**

The Wabiskaw D Sand formation was removed from the scope of the tests due to a number of operational issues as well as poor hydraulic isolation indicated by the RCBL. As an alternative, a log analysis is conducted to compute a stress profile in order to approximate the closure stress. Processed logs for the Wabiskaw member from approximately 155 mKB to 180 mKB is shown below. Log section on the left is the computed stress profile for this well. To the right are the intermediate curves used for this calculation. The next log section shows the lithology model. Finally, the section on the right shows the imported reference curves.

![Log-derived stress profile](image)

Based on mini-frac results, the closure stresses at 158-159 mKB and 166-167 mKB are 2323 kPa(a) and 2520 kPa(a) respectively. These two intervals are marked with red circles on the stress profile above. By interpolation, the estimated minimum closure stress at the 174-175 mKB interval, as highlighted with orange on the log section, would be close to 2373 kPa(a) or 13.6 kPa/m.
EVALUATION OF PRINCIPAL STRESSES & FRACTURE REGIME

A critical part of mini-frac tests is to determine the minimum in-situ principal stress in the tested intervals, which is then used to determine the fracture orientation.

Because the topology of the subject region is horizontal, one of the principal stresses can reasonably be generalized as vertical and equivalent to the overburden stress. The other two principal stresses will therefore be oriented horizontally, perpendicular to the vertical overburden stress.

According to the Geological Atlas of Western Canada Sedimentary Basin published by the Alberta Geological Survey, the minimum horizontal principal stress in this general region is commonly running in the NW-SE direction, while the maximum horizontal principal stress is oriented NE-SW. In order to confirm fracture orientation in the subject well, borehole image logs or coring is recommended.

![Stress Trajectories Determined from Breakouts](source: Alberta Geological Survey)

A hydraulic fracture will usually penetrate the formation in a plane normal to minimum stress, or parallel to the plane of maximum stress. After shut-in occurs, the fluid leaks off from the fracture to the formation and the pressure declines. At one point when the fluid pressure can no longer hold the fracture open, or is high enough to keep the fracture from just closing, the closure pressure (or stress) is obtained. This stress is therefore considered as the minimum stress acting normal to the fracture and therefore the minimum principal stress.
In the following plots, overburden stresses, $S_v$, were calculated from a density log taken from the subject wells and are represented by the blue line. From the depth of 80m to 214m the $S_v$/depth gradients average at 22.5 kPa/m.

**Fig. 48** Magnitude of stresses at 1AA/09-23-090-15W4

**Fig. 49** Zoomed-in view of stresses at 1AA/09-23-090-15W4
These plots imply that in the Wabiskaw zones, the minimum in-situ stresses are significantly less than the calculated overburden stresses. As a result, a vertical fracture regime is expected. On the other hand, in the Clearwater shale the measured closure stress is close to but slightly below the overburden stress, indicating a potential horizontal fracture regime.
TEST CONCLUSIONS

From the interpretation of the radial cement bond log, there was cement to surface. The log indicates good hydraulic isolations above and below all four mini-frac intervals. However, the memory pressure and temperature recorders attached to the isolation plug showed pressure response between test intervals. The RCBL log also indicates poor hydraulic isolations in 170mKB down to 185mKB, in the Wabiskaw D Sand. A mini-frac was attempted in the interval of 171 – 172mKB but unsuccessful. As a result, the minimum in-situ stress for this formation is computed from open-hole logs.

Four mini-frac tests were successfully completed in this subject test well. The collected mini-frac data is used to estimate a number of key parameters critical to the design of the SAGD operation. Data analysis consisted of a combination of graphical and numerical techniques.

In each of the mini-frac tests conducted, fractures were clearly initiated and closure of the induced fractures was confirmed. Closure pressures were determined based on the G-function derivative curve and confirmed by the Sqrt(t) and/or log-log curves. Finally, late time pressure fall-off data analysis was used to estimate reservoir pressure and after-closure behavior.

It is recommended that the steam injection recovery operation be designed to operate well below the minimum in-situ stresses of the oilsands caprock in order to ensure and maintain caprock integrity. Failure to maintain it can have severe safety, environmental and economic consequences. Since steam injection can have an impact on stress and volumetric strain on the cap rock (due to cyclical compaction or expansion), cap rock porosity and permeability will change over the course of production. As a result, caprock fracture pressure must be re-evaluated and monitored over the life of a project.

Interpretations, analyses, recommendations, advice or interpretational data furnished by Big Guns Energy Services are opinions based upon inferences from measurements, empirical relationships and assumptions, and industry practice, which inferences, assumptions and practices are not infallible. We cannot, and we do not guarantee the accuracy or the correctness of any interpretation. The Customer assumes full responsibility for the use of such interpretations and/or recommendations and for all decisions based thereon.
REFERENCES

DFIT analyses were conducted by Barree & Associates, Denver, CO.


APPENDIX A  RCBL INTERPRETATION

Interpretation Summary

Background:

Company: Grizzly Oil Sands
Well: 100/09-23-090-15W4
Date: Feb 28, 2012.
Recorded Log: Radial Cement Bond Analysis, Gamma Ray, Casing Collar Locator ran by Big Guns on Feb 15, 2012.
Interpreted Interval: PBTD to Surface

Summary:

1. Radial Cement Bond Log
   a. Variable density log shows minor casing arrivals except for constructive inference in surface casing
   b. Some sections have good formation and cement waves
   c. Radial bond log shows low amplitude readings and minimal variance between max/min amplitudes throughout the well

Discussion:

According to the interpretation of the radial cement bond log, there is cement to surface. Cement integrity is good to excellent from PBTD to surface except for 185-170m. Since mini-frac tests will be performed at 171m, 166m, 158m and 150m independently to determine minimal in-situ stresses, hydraulic isolations in these test intervals are critical for the success of the tests. From the interpretation of the radial cement bond log, there are good hydraulic isolations above and below the test intervals 166m, 158m and 150m, but poor hydraulic isolations at the test interval 171m. There seems to be loss cement into the formation and potentially damaging the zone.