ENERGY FORENSICS

ConocoPhillips Resources Canada Limited

WO: 16082

Mirror Lake N-20 65-00 126-45

Cut/Capped/Abandoned/Buried Well Stub

Vapour Intrusion Assessment (VIA), Gas Leakage in Soils Outside Casing (AGM)

August 15-16, 2016

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FORENSIC SOLUTIONS FOR ENERGY CHALLENGES

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1.0 Executive Summary

On August 15-2016, a Vapour Intrusion Assessment (VIA) was conducted by GCHEM Ltd. at COPRC Mirror Lake N-20 65-00 126-45. The well is cut, capped, and abandoned and the lease is in the process of being reclaimed. COPRC Mirror Lake was previously impacted with surface casing vent flow (SCVF). Soils outside of casing (AGM) were never investigated for natural gas leakage prior to the down hole abandonment.

As part of the VIA, soils at surface were investigated for light hydrocarbon gas contents using several methods that include a 12m x 12m grid-144 site location CH_4 surface scan using a Portable Methane Detector (PMD) and hand augering a series of 5-cm soil vapour test holes to 1.5m depths and installation of Soil Vapour Probes (SVPs). A 1.5m x 0.5m hole was hand excavated in an attempt to expose the buried well stub. A Soil Vapour FLUX Chamber (SVFC) was installed over the hole, isolating gases at depth from atmosphere. A soil vapour FLUX was conducted for 35-minutes. The FLUX chamber was left on location overnight and re-tested for CH_4 gas contents after 18.5 hours. Gases were collected from SVPs and SVFC for chemical and isotopic analysis and characterization of light hydrocarbon gas contents (LHG).

Soils 3m from the buried well stub were comprised of ~0.3m of peat and moss overlying water saturated muskeg. Within a 3m radius of the buried well stub, soils were comprised of silty clay transported to site from Norman Wells to backfill the 6m diameter abandonment excavation. Peat soils outside the backfill were water saturated below ~0.3m (water table at ~0.3m below surface). The silty clay backfill was also very wet and water saturated soils prevented installation of Soil Vapour Monitoring Probes (SVMPs) at and near the buried well stub and collection of stabilized soil gas contents for geochemical measurements.

CH_4 gas levels measured at surface by the PMD were low, ranged from 1 to 3 ppmv and were similar to background levels established 25m from the corners of the PMD grid. CH_4 gas levels were measured with the PMD from SVPs installed at 0.5m depths. 3-SVPs contained elevated CH_4 gas contents however, anomalous CH_4 values did not repeat upon subsequent testing conducted 10 and 20-minutes after the initial test. Water invaded the sample ports at depth and filled the auger test holes to 0.3m below surface. Gas samples were available for collection from only one SVP (E 2.0m).

Gases obtained from SVP E 2.0m were dominated by atmospheric gases (79 vol% N_2 and 20 vol% O_2). Total LHG contents were low and accounted for only 0.06 vol% of total gas contents. CH_4 gas was low, was 551 ppmv (1% LEL) and accounted for 99.7 vol% of total LHG contents. C_2+ thermogenic gas contents were also low and accounted for 0.27 vol% of total LHG. $\delta^{13}C$ CH_4 and $\delta^{13}C$ CO_2 were measured and were -22.27 and -23.57 ‰ VPDB, respectively, and suggest CH_4 generation via bacterial fermentation processes that have undergone extensive primary and secondary bacteriogenic oxidizing and alteration processes.

During the initial 35-minute gas FLUX conducted on August 15-2016, CH_4 increased from 29 ppmv to 288 ppmv. A CH_4 gas flow rate was calculated using two different methods and was 1.83×10^{-4} m^3/m^2/day volumetrically and 0.12 g/m^2/day gravimetrically. LHG contents in soils obtained from the SVFC on August 15-2016 were low and were dominated by atmospheric N_2 and O_2 gases (79 vol% and 20 vol% respectively). CO_2 was measured and was 1257 ppmv and accounted for 0.44 vol% of total gas. LHG contents accounted for only 0.03 vol% of total gas. CH_4 gases accounted for 99.62 vol% of total LHG while C_2+ thermogenic gases accounted for 0.38 vol%. Although water invaded the well stub excavation and ‘watered-out’ the SVFC, gases were collected from the GREEN and RED gas transfer lines. Gases obtained from the SVFC on August 16-2016 after 18.5 hours were similar to levels established on August 15-2016 however, C_2+ gases collected on August 16-2016 do not follow their order of molecular abundance (i.e. $C_1>C_2>C_3>C_4>C_5$) and suggest preferential bacterial oxidization of lighter weight hydrocarbon gas contents.

$\delta^{13}C$ CH_4 measured in the SVFC from gases obtained on August 15-2016 was -44.12 ‰ VPDB while corresponding $\delta^{13}C$ CO_2 was -23.28 ‰ VPDB. $\delta^{13}C$ CH_4 and $\delta^{13}C$ CO_2 collected on August 16-2016 were -48.88 and -24.02 ‰ VPDB, respectively, and suggest methane gas generation via bacterial fermentation processes and further oxidization by secondary biotic alteration processes. Low C_2+ gases are consistent with natural movement of LHG from hydrocarbon reservoirs at depth through subsurface fractures and micro-fractures to surface. Upon removal of the SVFC, no gas bubbling was observed in standing water above the buried well stub after 20-minutes.

With information available to date, and at the time of this investigation, soils above the buried well stub at COPRC Mirror Lake N-20 65-00 126-45 would be classified as BASELINE-NON IMPACTED or BIOGENC CH_4.

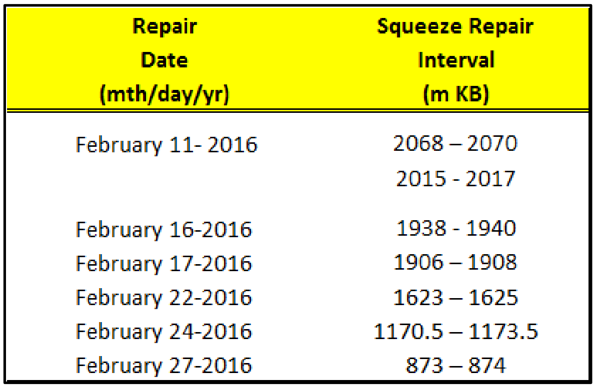
Wet soil conditions and a high water table affects VIA assessment protocol. Advanced Diffusion-Membrane Soil Vapour Probes (DM-SVPs) could be installed to confirm results in this assessment. DM-SVPs can be installed in wet or high moisture environments where gases will diffuse through a permeable membrane into an accumulation chamber allowing representative gas collection for high resolution chemical and isotopic measurements and classification and characterization of LHG contents.

2.0 Project Background CROPC Mirror Lake N-20 65-00 126-45

Drilling operations for COPRC Mirror Lake N-20 65-00 126-45 were completed on March 25-2013. CROPC N-20 is situated on a 120m x 120m lease located in the arctic boreal forest southwest of Normal Wells, NWT (Figure-1). The well was tested for hydrocarbon potential and the well was identified as being impacted with surface casing vent flow (SCVF). SCV gas flow rates were variable and fluctuated around 0.8m^3/day. A SCV stabilized shut-in pressure and stabilization time was not measured however, several short shut-in tests revealed positive gas pressure (pers. comm. ConocoPhillips).

Leaking SCV gases were fingerprinted (measured chemical and stable carbon isotopic compositions of light hydrocarbons and carbon dioxide gases and hydrogen isotopic compositions of light alkane gases) by GCHEM on two occasions: September 11-2013 and January 27-2016. Gas samples submitted from the September 11-2013 assessment were low quality and a geologic source could not be confidently identified. A second SCV geochemical assessment conducted on January 27-2016 revealed that leaking natural gas contained similar chemical and isotopic fingerprints to gases found in a deep thermogenic natural gas reservoir, the Canol Formation (Givetian-Mid Devonian) at a depth of 1968 to 2074mKB.

A summary of repair operations to retain zonal isolation and eliminate undesired SCVF was conducted by ConocoPhillips and is included in Table-1.



Repair Date (mth/day/yr)	Squeeze Repair Interval (m KB)
February 11- 2016	2068 – 2070 2015 - 2017
February 16-2016	1938 - 1940
February 17-2016	1906 – 1908
February 22-2016	1623 – 1625
February 24-2016	1170.5 – 1173.5
February 27-2016	873 – 874

Table-1. Remedial cement repair dates and intervals (mKB) at CROPC Mirror Lake N-20 65-00 126-45 winter operations 2016.

Repair operations were successful as the SCV tested negative (non-impacted) for natural gas flow post remediation (pers. comm. ConocoPhillips). The well casing was cut and capped and the 3m abandonment excavation was backfilled with soils transported from Norman Wells, NWT. Soils outside casing were not investigated for types and level of natural gas or sulfur gas contents pre or post cut and cap abandonment operations.

On August 15 & 16-2016, GCHEM Ltd. conducted a Vapour Intrusion Assessment (VIA) in soils above the buried well stub.

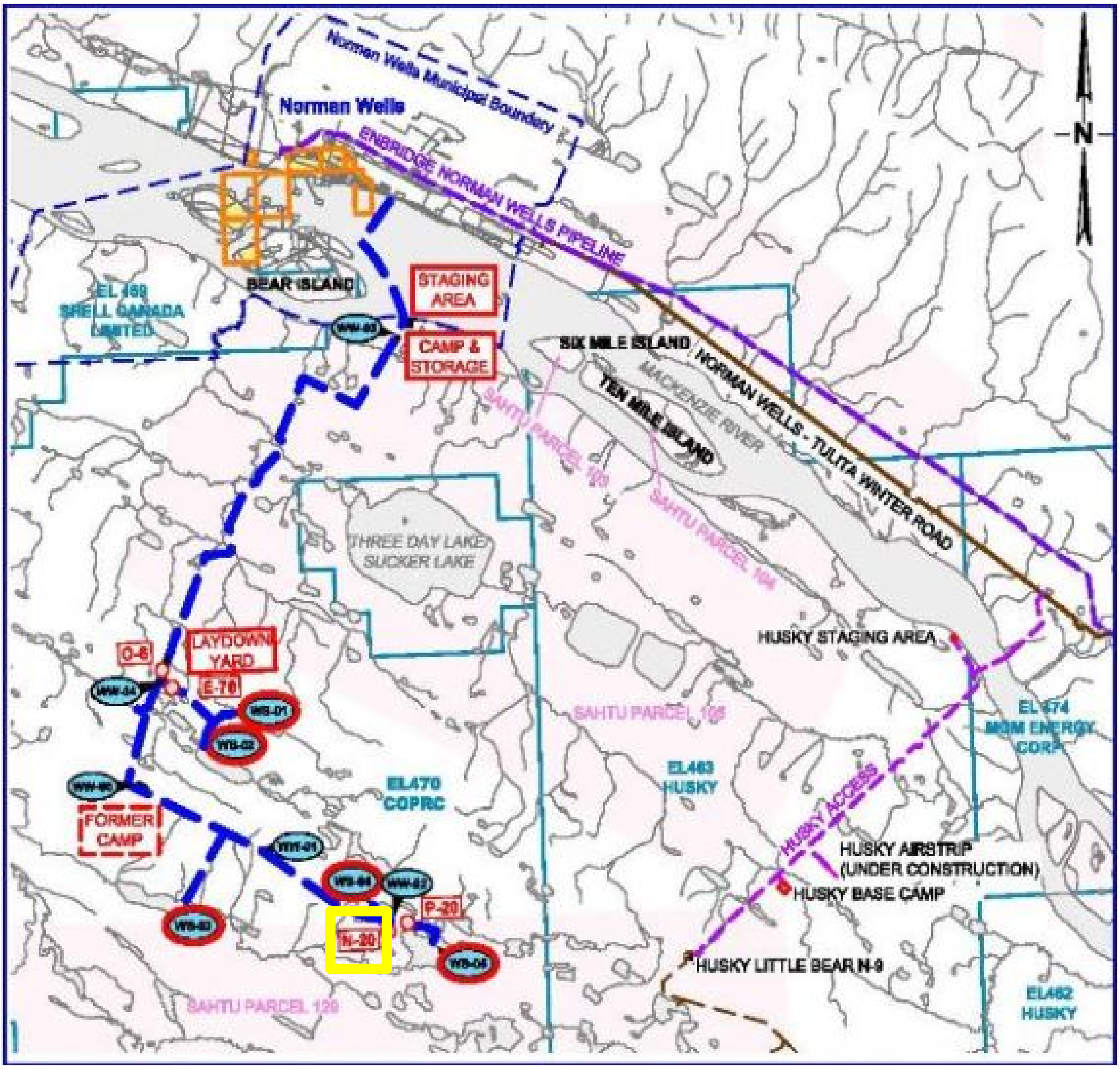


Figure-1. Base map showing the location of CROPC Mirror Lake N-20 65-00 126-45 (highlighted yellow box).

3.0 Background of Fugitive or Stray Gas-Vapour Intrusion Assessments (VIA) at Resource Wells

Undesired natural gas leakage from depth to surface at resource wells is becoming increasingly recognized and is a significant financial burden to the resource industry. Surface Casing Vent Flow (SCVF) is occurring when high levels of natural gas are found in the surface casing vent. When natural gases are detected in soils outside the casing, active gas migration (AGM) is occurring. Identifying the source of leaking gas, maintaining zonal isolation and eliminating gas leakage to surface has proven a challenging task. Industry success rates using conventional gas leakage identification tools (i.e. noise, temperature, cement bond-integrity, ultra-sonic imaging logs, etc.) to eliminate surface gas migration in the first attempt is approximately 15% to 20%. Since 1997, through collaboration with industry, government regulators and academic institutions, GCHEM Ltd. has developed 'Energy Forensics' and has accumulated extensive expertise in field testing, gas collection, containment and preservation, and analytical and interpretational techniques to pinpoint the geologic source of fugitive natural gases at resource wells.

It is important to note here that detection of elevated combustible gases at surface does not always indicate that a well is impacted with deep-sourced natural gas (thermogenic). Accurate gas characterization and classification at well sites (SCVF & AGM) is essential as elevated CH_4 (%LEL) contents measured at or near surface may not indicate anthropogenic natural gas leakage (false-positive), but rather combustible gases present may be the result of biogenic activity or hydrocarbon contamination, lateral dispersion, aquifer gas, naturally occurring or combinations of.

Thermogenic hydrocarbon gases have unique chemical and isotopic signatures based on many variables including the isotopic composition of the original organic material (source rock), the chemical processes that cause transformation to the current form, temperature, pressure, water rock interaction, biogenic alteration, mixing and effects of migration from origin to current trap. For example, molecular and isotopic composition ($\delta^{13}C$ and δD) of an immature, low temperature, shallow-sourced natural gas is significantly different when compared to mature natural gas, generated at high temperature and pressures. The systematic variation of chemical and stable carbon and hydrogen isotope compositions of natural gas reservoirs at depth allows leaking natural gas collected at or near surface to be compared to a template of geochemical fingerprints of the subsurface and the leaking gas source, measured from the KB of the wellbore, to be identified.

3.1 Biogenic Methane Gas

As a normal part of soil respiration, methane may be generated via two biotic pathways (depending on substrate availability):

CO_2 reduction reaction	$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$
Fermentation Process	$CH_3COOH \rightarrow CH_4 + CO_2$

Biogenic methane gas may be oxidized by bacteria. Oxidizing bacteria in soils preferentially consume ^{12}C over ^{13}C, resulting in a residual gas enriched in ^{13}C (i.e. $\delta^{13}C$ values become less negative) with respect to the biogenic-source gas (isotope enriching effect). Therefore, biogenic oxidization may imprint a false signature of a 'mixture of biogenic and thermogenic methane' or 'thermogenic' gas (GCHEM, in prep). Biogenic CH_4 is generally prevalent in landfills or swamp gas.

3.2 Thermogenic Methane Gas

Methane gas can be generated by abiotic processes such as the thermo-degradation of organic matter at high pressure and temperature (thermogenesis). During thermogenic CH_4 generation, pending organic matter content, pressure, and temperature, associated C_2+ gases may also be formed. Thermogenic CH_4 and C_2+ gases contain enriched $\delta^{13}C$ and δD values depending on gas maturity, mixing, alteration, and the tortuosity of the pathway from source to trap.

Pristine naturally occurring venting gas from soils as a result of soil respiration processes are usually comprised of low, but variable levels of CH_4 & CO_2 with low trace levels of associated C_2+ thermogenic natural gases. C_2+ thermogenic gases cannot be generated by bacterial processes in great quantities and are naturally occurring in sedimentary basins around the world (naturally occurring gas leakage from hydrocarbon reservoirs at depth, through subsurface fractures and micro-fractures to surface (i.e. hydrocarbon surface seeps). Soils influenced by anthropogenic process (i.e. natural gas leakage at a well bore from natural gas reservoirs at depth, upward through compromised cement sheaths securing production casing to formation rock to surface) usually contain highly elevated (%), above background levels of CH_4 (thermogenic and/or biogenic) and associated C_2+ thermogenic gases.

Natural gas characterization and classification can determine if elevated %LEL at surface is the result of: biogenic CH_4, hydrocarbon contamination, thermogenic, mixture of thermogenic and biogenic, aquifer gas, or lateral dispersion of gas from an offset well.

4.0 Scope of Work

GCHEM was contracted by ConocoPhillips Canada to conduct a Vapour Intrusion Assessment at an abandoned oil well site at Mirror Lake N-20 65-00 126-45. Soils above the buried well stub were investigated for types and levels of natural gas and sulfur gas contents. An SOP provided by CPROC and approved by OROGO (ConocoPhillips Gas Migration Testing Program) is included as Attachment-1.

1) Field Services

a. Conduct a Vapour Intrusion Assessment: Non-Intrusive & Intrusive.
b. Non-Intrusive: test soils for the presence of CH_4 contents Surface CH_4 laser Scan (Portable Methane Detector & Data Logger).
c. Intrusive: assess soils by hand augering soil vapour test holes and installing Soil Vapour Monitoring Probes (SVMPs) and collect, contain and preserve representative stabilized gas samples.
d. Soil Vapour FLUX: conduct soil vapour FLUX to determine gas flow rates and volumes and aid in QA/QC for representative gas sample collection.

2) Analytical Services

a. High resolution compositional analysis (HRCA):
    i. He, H_2, O_2, N_2, CO_2, CH_4 to n-C_5H_{12} & C_6+
b. Stable carbon ($\delta^{13}C$) and hydrogen (δD) isotopic analysis:
    i. $\delta^{13}C$ CH_4 to n-C_5H_{12} & CO_2 and δD CH_4 to n-C_5H_{12}

3) Interpretation of Geochemical Data

a. Characterize & classify natural gas and sulfur contents found in soils above the buried well stub:
    i. Deep-Thermogenic
    ii. Thermogenic-Baseline
    iii. Biogenic-Baseline
    iv. Hydrocarbon contamination
    v. Mixtures of the above

b. If impacted, identify the origin of leaking gas contents:

    i. Geological Age & Formation
    ii. Depth of leaking natural gas (measured from the KB of the well bore)

5.0 Methodology

5.1 Detection of Methane Gas at Surface and Light Hydrocarbon Gases at Depth

Due to extremely wet conditions at the site, the ConocoPhillips Gas Migration Testing Program (Attachment-1) could not be followed.

5.1.1 Non-Intrusive Surface Soils CH_4 Scan-Portable Methane Detector (PMD)

On August 15, 2016, a surface scan of CH_4 gas levels was conducted over a 12m x 12m grid around the buried well stub (144-test locations). Background CH_4 levels at surface were established at 8 locations ~25m from the four corners of the well stub PMD grid (Figure-2). CH_4 gas levels were measured using a SENSIT Portable Methane Detector (PMD) while %LEL, H_2S, CO, and O_2 were measured using a SENSIT Trak-It 4-head gas monitor. Field instruments and gas monitors were calibrated (as per manufacturer specifications) and bump tested prior to mobilization to location. At each test location, atmospheric CH_4 gas levels (ATM) were recorded. The PMD gas sample wand was lowered and ground coupled to soils and CH_4 gas levels from soils were recorded. The difference between ATM CH_4 levels and PMD CH_4 levels after ground coupling was calculated.

PMD Residual Soil Vapour CH_4 Level = (Soil-Ground Coupled CH_4 – ATM CH_4)

5.1.2 Intrusive Soil Vapour Probes (SVPs) & Soil Vapour Monitoring Probes (SVMPs)

To establish light hydrocarbon gas contents in soils at and near the buried well stub, a series of 5-cm soil vapour test holes were hand augered to a depth of ~1.5m. Soil Vapour Probes (SVPs) were immediately inserted into each test hole and gas sample ports at depth were isolated from atmospheric gases. Vapour test holes were augered at the staked buried well stub (WC) and at 0.5m, 1.0m and 2.0m radiating outwards in four directions (N-E-S-W) at 90-degree phasing. SVPs were allowed to stabilize for ~20 minutes after which, CH_4 and H_2S gas levels were measured and recorded for each test site. Soils in auger returns to surface were inspected for hydrocarbon contamination. If hydrocarbon staining or petroliferous odour was detected, a soil sample would be collected and preserved for laboratory analysis.

To establish naturally occurring light hydrocarbon gas leakage levels in soils in background locations a distance away from the well stub, soil vapour samples were collected from SVPs at one background location: BKG 25m N of the staked buried well stub. The BKG sample was collected using the same methodology as samples at or near the well stub and were analyzed for molecular compositions.

Soil vapour samples were collected from one SVP at the well stub (SVP E 2.0m) for high resolution compositional analysis (HRCA). Pending levels of light hydrocarbons and CO_2 gases, stable carbon ($\delta^{13}C$) and hydrogen (δD) isotope ratios were measured for light alkanes.

5.1.3 Soil Vapour FLUX Measurements (SVF)

Soil vapour FLUX measurements can be conducted in soils to establish the rate and volume of gas leakage at surface. An enclosed chamber (known internal volume and soil area) is installed at surface. The Soil Vapour FLUX methodology utilizes an enclosed chamber with three gas ports: gas in, gas out and gas vent. Gases are cycled from the gas out port to a PMD and re-injected into the FLUX chamber. A pressure release valve allows leaking gas from soils to enter and displaces atmospheric gases within the chamber when installed. Typically, an inert gas (i.e. Helium or Argon) may be introduced to the FLUX chamber and cycled to displace atmospheric gas contents and lower CH_4 levels to near 0 ppmv, however, this could not be conducted due to transport restrictions of the compressed purge-gas canisters.

Pristine naturally occurring venting gas from soils as a result of soil respiration processes are usually comprised of low, but variable levels of CH_4 & CO_2 with low levels of associated C_2+ thermogenic natural gases. C_2+ thermogenic gases cannot be generated by bacterial processes in great quantities and are naturally occurring in sedimentary basins around the world (naturally occurring gas leakage from hydrocarbon reservoirs at depth, through subsurface fractures and micro-fractures to surface. If gas (or fluid) leakage rates are high, naturally occurring 'surface seeps' may be formed (Saunders et al., 1999). Soils influenced by anthropogenic processes (i.e. natural gas leakage at a well bore from natural gas reservoirs at depth, upward through compromised cement sheaths securing production casing to formation rock to surface) usually contain highly elevated, above background levels of CH_4 and associated C_2+ thermogenic gases.

CH_4 gas contents in the FLUX chamber was monitored (data logged) using a PMD. Gas FLUX in soils can be calculated either volumetrically or gravimetrically considering the following relationship:

Flux (F) = (dc/dt)*(volume) / (area)

Where:
c = concentration
t = time
dc/dt = change of concentration with respect to time that is the slope of a *concentration versus elapsed time* plot.

The volumetric FLUX is calculated from ppmv units (10^{-6} m^3 light alkanes/ m^3 air) and gravimetric FLUX is calculated by converting ppmv to g/m^3 of air considering the ideal gas law (PV=nRT) at 1 atmosphere pressure and 25°C.

5.2 Analytical: High Resolution Compositional (HRCA) & Stable Carbon ($\delta^{13}C$) & Hydrogen (δD) Isotopic Analyses

Compositional (molecular) analyses were conducted on Hewlett Packard 5890 and Agilent 7890 Gas Chromatographs (GC) configured for low (ppbv to ppmv) to high (vol%) level detection of light alkane/alkene gases and atmospheric gas components. Chemical analysis of gases measured and analytical error is shown in Table-2.

Stable carbon ($\delta^{13}C$) isotope ratios of light hydrocarbon gases (LHG) and carbon dioxide and hydrogen isotope ratios (δD) of LHG were measured on a Thermo-Scientific MAT-253 Gas Chromatograph-Combustion-Continuous Flow-Isotope Ratio Mass Spectrometer (GC-C-CF-IRMS). Carbon isotope ratios are reported in delta (δ) notation and per mil (‰, parts per thousand) with respect to VPDB (Vienna Pee Dee Belemnite). Hydrogen isotope ratios are reported in delta (δ) notation and per mil (‰) with respect to VSMOW (Vienna Standard Mean Ocean Water).

Gas Component (ppmv)	Molecular Formula	Analytical Error (%)	Stable Carbon Isotopic Composition ($\delta^{13}C$)	Analytical Error (‰ VPDB)	Hydrogen Isotopic Composition (δD)	Analytical Error (‰ VSMOW)
Hydrogen	H_2	±7%	-	-	$\delta D\ H_2$	±10
Helium	He	±7%	-	-	-	-
Nitrogen	N_2	±7%	-	-	-	-
Oxygen	O_2	±7%	-	-	-	-
Carbon Dioxide	CO_2	±7%	$\delta^{13}C\ CO_2$	±0.2	-	-
Hydrogen Sulphide	H_2S	±7%	-	-	-	-
Methyl Mercaptan	CH_4S	±7%	-	-	-	-
Ethyl Mercaptan	C_2H_6S	±7%	-	-	-	-
Thiophene	C_4H_4S	±7%	-	-	-	-
Dimethyl Disulfide	$C_2H_6S_2$	±7%	-	-	-	-
Methane	CH_4	±7%	$\delta^{13}C\ CH_4$	±0.1	$\delta D\ CH_4$	±10
Ethane	C_2H_6	±7%	$\delta^{13}C\ C_2H_6$	±0.2	$\delta D\ C_2H_6$	±10
Ethene	C_2H_4	±7%	$\delta^{13}C\ C_2H_4$	±0.2	$\delta D\ C_2H_4$	±10
Propane	C_3H_8	±7%	$\delta^{13}C\ C_3H_8$	±0.2	$\delta D\ C_3H_8$	±10
Propene	C_3H_6	±7%	$\delta^{13}C\ C_3H_6$	±0.2	$\delta D\ C_3H_6$	±10
iso-Butane	$i\text{-}C_4H_{10}$	±7%	$\delta^{13}C\ i\text{-}C_4H_{10}$	±0.2	$\delta D\ i\text{-}C_4H_{10}$	±10
normal-Butane	$n\text{-}C_4H_{10}$	±7%	$\delta^{13}C\ n\text{-}C_4H_{10}$	±0.2	$\delta D\ n\text{-}C_4H_{10}$	±10
iso-Pentane	$i\text{-}C_5H_{12}$	±7%	$\delta^{13}C\ i\text{-}C_5H_{12}$	±0.2	$\delta D\ i\text{-}C_5H_{12}$	±10
normal-Pentane	$n\text{-}C_5H_{12}$	±7%	$\delta^{13}C\ n\text{-}C_5H_{12}$	±0.2	$\delta D\ n\text{-}C_5H_{12}$	±10
Hexane and higher	C_6+	±7%	-	-	-	-

Table-2. Gas components and isotopic compositions measured (and the analytical error of the measurements) at GCHEM's Analytical Laboratory.

6.0 Results and Discussion

6.1 PMD Surface Laser Scan

Soils at surface were scanned for CH_4 gas contents covering a 12m x 12m grid (144 locations) at 1m intervals centered around the buried well stub. 8-background locations located 25m from the corners of the 12m x 12m grid were assessed for CH_4 gas levels. A CH_4 Surface Scan Location Base Map is shown in Figure-2. A CH_4 grid map with PMD CH_4 values is presented in Figure-2A.

Of the 144 surface soil locations tested for the presence of CH_4 gas contents, CH_4 levels were low, ranged from 1 to 3 ppmv CH_4, and were similar to background (BKG) levels established 25m from the corners of the 12m x 12m PMD CH_4 scan grid. A contour map of CH_4 levels at surface and a 3-D CH_4 contour map measured by the PMD is included as Figure-2B.

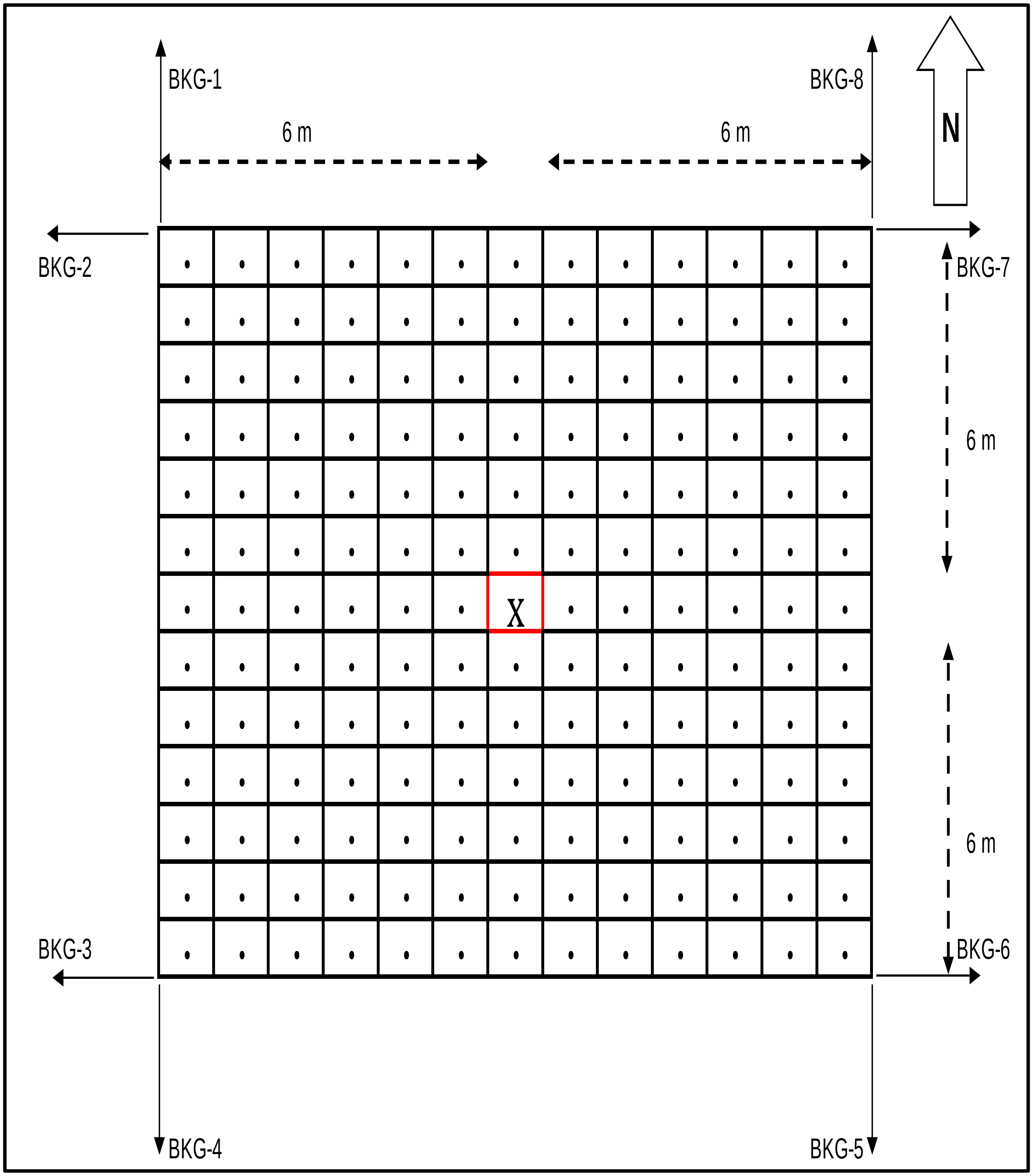
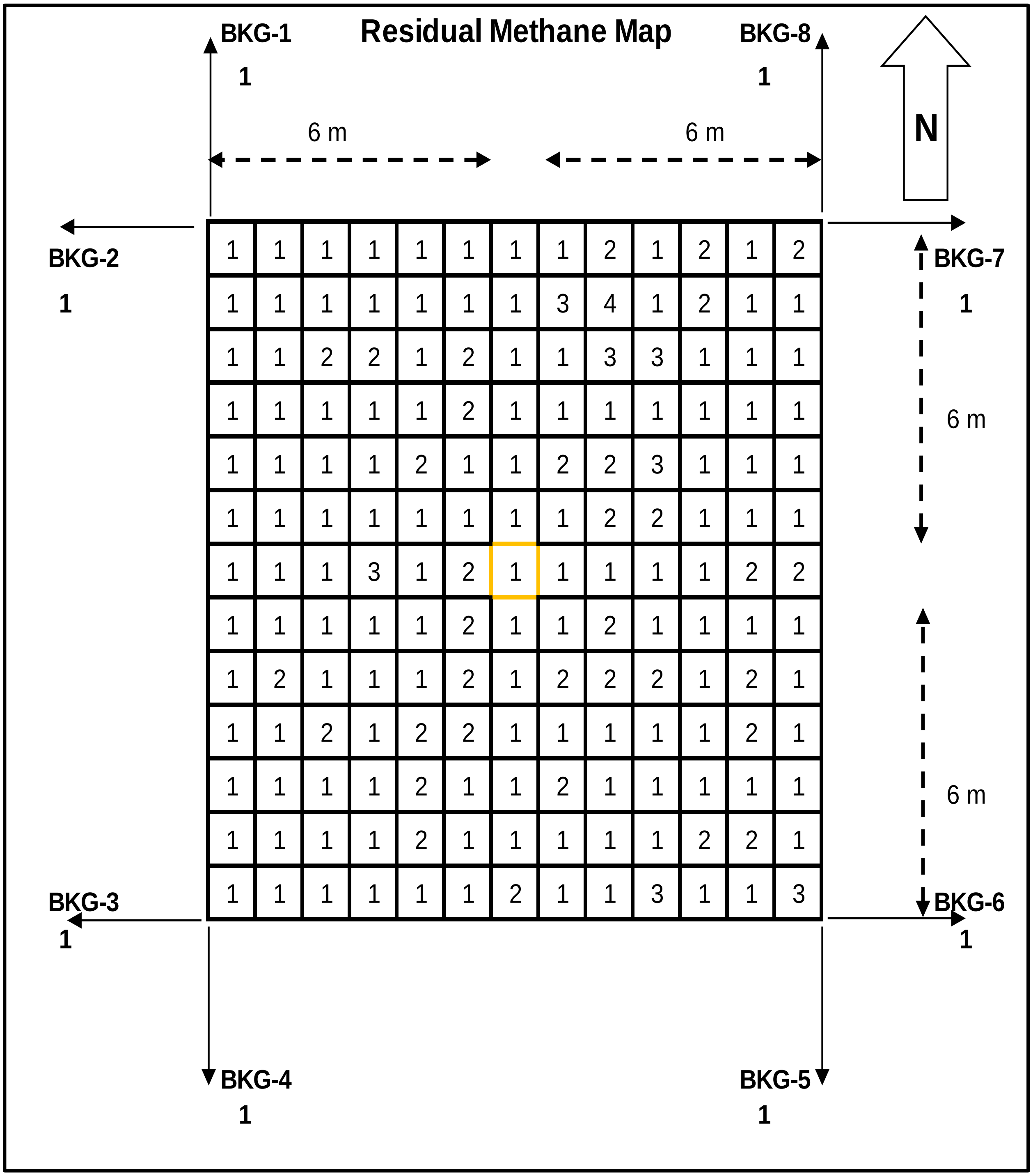


Figure-2. A base map image of the 12m x 12m grid pattern in which PMD measurements were made at surface. The X and highlighted red square marks the location of the buried well stub. A magnetic pin locator was used to verify the metal casing well stub. Background (BKG) test locations were established 25m in two directions from the four corners of the 12m x 12m grid pattern.



1	1	1	1	1	1	1	1	2	1	2	1	2
1	1	1	1	1	1	1	3	4	1	2	1	1
1	1	2	2	1	2	1	1	3	3	1	1	1
1	1	1	1	1	2	1	1	1	1	1	1	1
1	1	1	1	2	1	1	2	2	3	1	1	1
1	1	1	1	1	1	1	1	2	2	1	1	1
1	1	1	3	1	2	1	1	1	1	1	2	2
1	1	1	1	1	2	1	1	2	1	1	1	1
1	2	1	1	1	2	1	2	2	2	1	2	1
1	1	2	1	2	2	1	1	1	1	1	2	1
1	1	1	1	2	1	1	2	1	1	1	1	1
1	1	1	1	2	1	1	1	1	1	2	2	1
1	1	1	1	1	1	2	1	1	3	1	1	3

Figure-2A. CH_4 gas levels from the PMD surface scan on the 12m x 12m grid over the buried well stub spanning into background. The yellow highlighted box marks the location of the buried well stub. Background (BKG) soil vapour samples to establish pristine naturally occurring LHG levels were collected 25m from the four corners of the grid pattern (i.e. 25m N and 25m W of the NW grid corner were identified as BKG-1 and BKG-2, respectively).

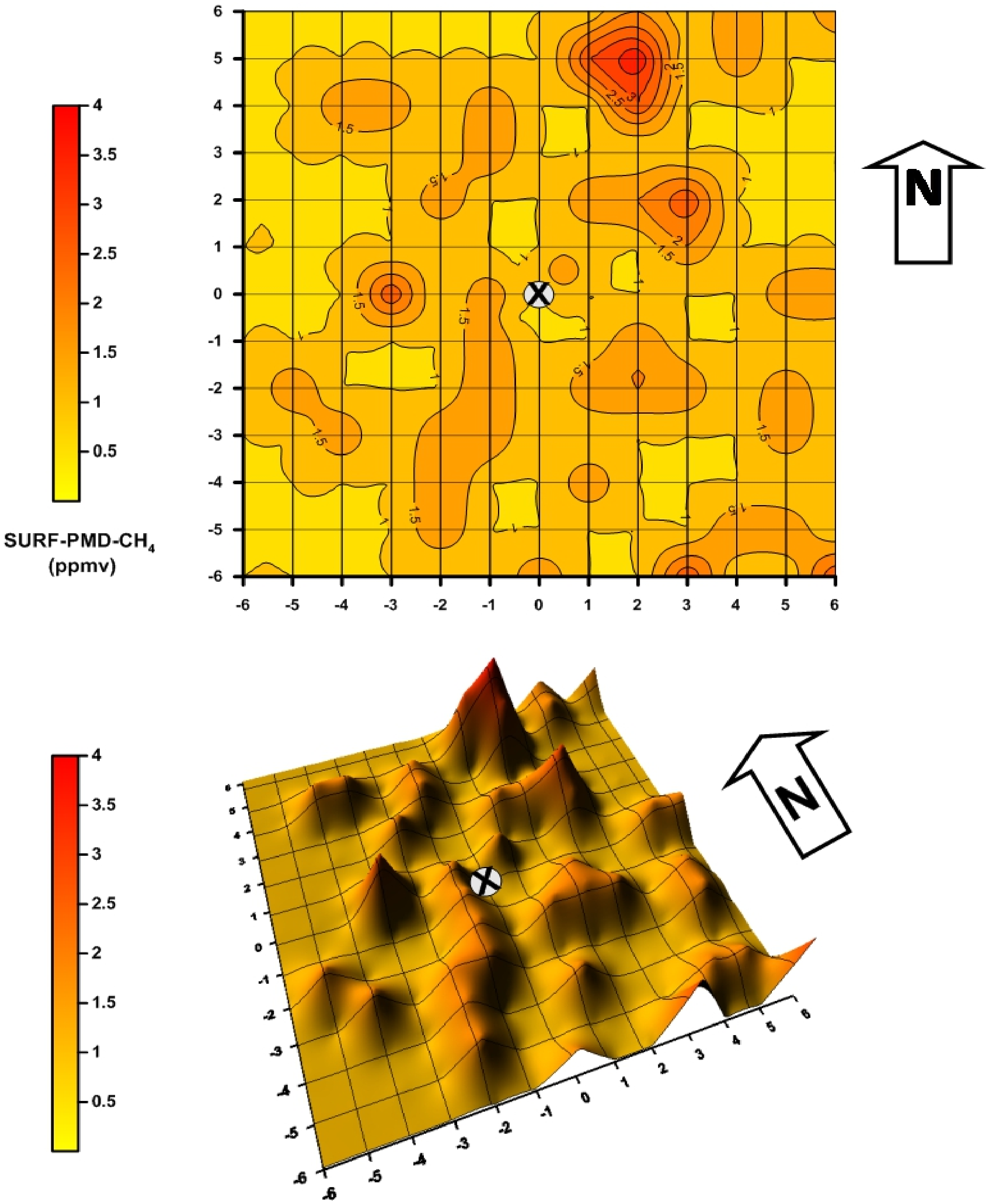


Figure-2B. Contour (top) and 3-D (bottom) maps showing CH_4 gas levels obtained from the 12m x 12m surface PMD CH_4 scan. Areas colored RED indicate higher CH_4 gas levels while areas highlighted yellow contain low CH_4 gas levels. CH_4 levels were low and comparable to BKG levels.

6.2 Soil Vapour Probes (SVPs)

A series of 13-soil vapour test holes were hand augered into soils to depths of 1.5m at 0.5m, 1.0m and 2.0m intervals North, East, South and West of the wellbore. 3-Background test holes were augered 25m N (6m east and 25m north) and two 25m S (6m east and 25m south and 6m west and 25m south) of the staked well stub, using the same methodology as well casing locations. Soil Vapour Probes (SVPs) were immediately inserted into the vapour test holes to isolate gas sample ports at depth from atmospheric gases. SVPs were allowed to stabilized for ~20 minutes before combustible (CH_4) and H_2S gas levels were measured on location and are included as Attachment-2.

Elevated, above background, CH_4 levels (up to 31.5 %LEL at SVP N 2.0m) were measured immediately after the ~20-minute SVP stabilization time (Attachment-2). SVPs were then re-tested and the original, elevated, readings could not be duplicated. Combustible gases (biogenic methane and/or thermogenic natural gases) may have been trapped beneath the surface of the soils and released during the augering or SVP installation procedure.

Water invaded SVP sample ports at all locations except E 2.0m. Due to the high water table (0.3m BGL), Soil Vapour Monitoring Probes (SVMPs) could not be installed and stabilized soil vapour gas contents could not be collected.

Gas samples were collected, contained and preserved from one SVP (E 2.0m) and one background SVP, BKG-N (25m N and 6m E). Chemical compositions were measured on both samples, $\delta^{13}C$ CH_4 and CO_2 on SVP E 2.0m and $\delta^{13}C$ CO_2 on BKG-N (Table-3). One test location, SVP E 2.0m contained elevated above background levels of CH_4 combustible gases (551.0 ppmv CH_4). H_2S gas levels at all test sites were below 0.1 ppmv (Attachment -2).

Soils within 3m of the well stub were comprised of medium to dark brown silty-clay. Soil from Norman Wells was transported to location and was used to backfill the well casing excavation from the down-hole abandonment. The backfilled well stub area is mounded and is approximately 1.0m higher elevation than ground level in the surrounding peat and moss on the lease. Outside the excavation and backfill area, ~0.3m of peat and moss covered unconsolidated, water saturated muskeg. Water saturated soils complicate soil vapour collection and at this location, the local water table was established at ~0.3m from surface. Soils on auger returns from drilling leaking gas test holes did not contain hydrocarbon staining or petroliferous odors. Soil samples were not collected for hydrocarbon or chemical contamination or soil type-matrix analysis.

Background test location BKG-25m N contains near atmospheric levels of N_2 (79 vol%) and O_2 (21 vol%) gases. Methane gas levels were low (5.80 ppmv) and account for 95% of total light hydrocarbon gas (TLHG). C_2+ gas levels measured in background were also low (0.18 ppmv) and account for 0.00002 vol% of TLHG. Sufficient levels of light hydrocarbon gases were not available for $\delta^{13}C$ and δD analysis however, CO_2 content was 2980 ppmv and $\delta^{13}C$ CO_2 was -20.73‰ VPDB.

CH_4 and CO_2 gas levels in soils in pristine background locations may be highly variable and can be the result of soil type and matrix, water content, temperature, atmospheric pressure, normal respiration processes (i.e. biogenic CH_4 generation via CO_2 reduction or fermentation processes) and naturally occurring methane movement from reservoirs at depth, through subsurface micro-fractures to surface.

C_2+ gas levels in pristine soils at background locations are also variable, usually low (under 100 ppmv C_2+ pending sampling methodology and area) and are controlled by the thickness and make-up (soil type) of overburden-till, biological oxidation (destruction), depth and type of hydrocarbon reservoirs below surface, vertical and lateral distribution of subsurface fracture and micro-fracture systems and the presence, thickness, structure and water gradient flow direction of shallow porous aquifers.

Gas Sample Point	Flux Chamber (FC)	E2 (SVP)	BKG-N	FC - Green Line	FC - Red Line
Date Collected	August 15-2016	August 15-2016	August 15-2016	August 16-2016	August 16-2016
Location	Mirror Lake N-20	Mirror Lake N-20	Mirror Lake N-20	Mirror Lake N-20	Mirror Lake N-20
Gas Component	(ppmv)	(ppmv)	(ppmv)	(ppmv)	(ppmv)
Hydrogen	4.14	4.28	4.14	3.91	4.16
Helium	2.72	2.46	3.36	2.68	2.48
Nitrogen	791930	794029	788692	791010	800983
Oxygen	206513	201008	208314	208138	196873
Carbon Dioxide	1257	4403	2980	664.6	1725
Methane	290.6	551.0	5.80	165.7	392.0
Ethane	0.18	0.45	0.10	0.29	1.02
Ethene	0.20	0.45	<0.01	0.16	0.59
Propane	0.14	0.26	<0.01	1.93	3.87
Propene	0.04	0.06	<0.01	<0.01	0.14
iso-Butane	0.11	0.07	0.04	3.03	3.95
n-Butane	0.16	0.09	0.06	3.00	4.74
iso-Pentane	0.15	0.07	0.07	2.68	3.44
n-Pentane	0.11	0.06	0.03	1.45	1.58
C_6+	0.69	0.65	0.72	1.99	1.39

C1/∑C2+	488.6	639.8	32.03	24.83	34.97
C2/∑C3+	0.43	1.08	1.12	0.05	0.10
C2+	0.59	0.86	0.18	6.67	11.21
ATM Ratio (N2/O2)	3.83	3.95	3.79	3.80	4.07
Vol % CO2 of TG	0.13	0.44	0.30	0.07	0.17
Vol % Lt. Alk.	0.03	0.06	0.001	0.02	0.04
Vol % Lt. Alk. CH4	99.62	99.73	95.23	92.96	95.30
Vol % Lt. Alk. C2+	0.38	0.27	4.77	7.04	4.70
Vol % C2+ of TG	0.0001	0.0001	0.00002	0.001	0.001

Stable Carbon Isotope Compositions (‰ VPDB)					
δ13C CH4	-44.12	-22.27	nd	nd	-48.88
δ13C C2H6	nd	nd	nd	nd	nd
δ13C C2H4	nd	nd	nd	nd	nd
δ13C C3H8	nd	nd	nd	nd	nd
δ13C C3H6	nd	nd	nd	nd	nd
δ13C i-C4H10	nd	nd	nd	nd	nd
δ13C n-C4H10	nd	nd	nd	nd	nd
δ13C i-C5H12	nd	nd	nd	nd	nd
δ13C n-C5H12	nd	nd	nd	nd	nd
δ13C CO2	-23.28	-23.57	-20.73	-19.96	-24.02

Hydrogen Isotopic Compositions (‰ VSMOW)					
δD H2	nm	nm	nm	nm	nm
δD CH4	nm	nm	nm	nm	nm
δD C2H6	nm	nm	nm	nm	nm
δD C3H8	nm	nm	nm	nm	nm
δD i-C4H10	nm	nm	nm	nm	nm
δD n-C4H10	nm	nm	nm	nm	nm

14C Concentration (pMC)	nm	nm	nm	nm	nm

Table-3. High resolution compositional and isotopic analytical results of samples collected at Mirror Lake N-20.

6.3 Soil Vapour FLUX Measurements over the Excavated Well Bore

Soils were hand excavated to a depth of ~1.5 meters below ground level at the well center. A FLUX chamber was installed and a 35-minute FLUX test conducted in the excavation. CH_4 gas levels increased from 29 ppmv to 288 ppmv over the duration of the test (Figure 3, Table 5). A FLUX gas sample was collected at the highest CH_4 concentration at the end of the test. Volumetric and gravimetric flow rates were calculated using the FLUX test data and are included as Table-4.

The FLUX chamber was left on site overnight (18.5 hours) for stabilized sample collection the following day. Upon returning to site, the FLUX chamber was invaded by ground water (water table ~0.3m below surface). Gas samples were collected from the inlet (Red) and outlet (Green) lines for geochemical analysis. After removal of the FLUX chamber, standing water in the excavation over the buried well stub was visually monitored for gas bubbling. No gas bubbles were observed after ~20 minutes (Attachment 4 -Picture 5).

The FLUX chamber gas sample collected at the end of the FLUX test (35 min) contained 290.6 ppmv CH_4, and after 18.5 hours, CH_4 levels in the gas sample collected from the inlet line (RED) of the FLUX chamber had increased to 392.0 ppmv. CO_2 concentrations in the FLUX chamber increased from 1257 ppmv on August 15-2016 (18:49) to 1725 ppmv on August 16-2016 (12:36). C_2+ gas levels increased over the 18.5-hour stabilization period, but the concentration of ethane remained low in the inlet (RED) and outlet (GREEN) lines, at 1.02 and 0.29 ppmv, respectively, and were similar to baseline levels.

Flux Units	Volumetric Flow Rate	Gravimetric Flow Rate
per minute	1.26 x10^{-7} (m^3/m^2/min)	8.30x10^{-5} (g/m^2/min)
per day	1.83 x10^{-4} (m^3/m^2/day)	0.12 (g/m^2/day)
per year	0.07 (m^3/m^2/year)	43.63 (g/m^2/year)
per 10 years	0.7(m^3/m^2/10 years)	0.43 (kg/m^2/10 years)

Table-4. The soil gas flow rate calculated from the buried well stub FLUX test data. Venting light hydrocarbon gas levels, primarily CH_4 are low however sufficient background vapour FLUX measurements in the study area are not available for comparison.

Date	Time	Elapsed Time (min)	CH_4 (ppmv)
2016-08-15	18:12:57	0	29
2016-08-15	18:13:27	0.5	167
2016-08-15	18:13:57	1	182
2016-08-15	18:14:27	1.5	189
2016-08-15	18:14:57	2	194
2016-08-15	18:15:27	2.5	197
2016-08-15	18:15:57	3	198
2016-08-15	18:16:27	3.5	198
2016-08-15	18:16:57	4	201
2016-08-15	18:17:27	4.5	204
2016-08-15	18:17:57	5	199
2016-08-15	18:18:27	5.5	201
2016-08-15	18:18:57	6	210
2016-08-15	18:19:27	6.5	208
2016-08-15	18:19:57	7	213
2016-08-15	18:20:27	7.5	217
2016-08-15	18:20:57	8	218
2016-08-15	18:21:27	8.5	219
2016-08-15	18:21:57	9	218
2016-08-15	18:22:27	9.5	219
2016-08-15	18:22:57	10	220
2016-08-15	18:23:27	10.5	220
2016-08-15	18:23:57	11	219
2016-08-15	18:24:27	11.5	219
2016-08-15	18:24:57	12	218
2016-08-15	18:25:27	12.5	216
2016-08-15	18:25:57	13	224
2016-08-15	18:26:27	13.5	229
2016-08-15	18:26:57	14	229
2016-08-15	18:27:27	14.5	231
2016-08-15	18:27:57	15	232
2016-08-15	18:28:27	15.5	234
2016-08-15	18:28:57	16	235
2016-08-15	18:29:27	16.5	236
2016-08-15	18:29:57	17	241
2016-08-15	18:30:27	17.5	238
2016-08-15	18:30:57	18	241
2016-08-15	18:31:27	18.5	244
2016-08-15	18:31:57	19	246
2016-08-15	18:32:27	19.5	249
2016-08-15	18:32:57	20	251
2016-08-15	18:33:27	20.5	254
2016-08-15	18:33:57	21	255
2016-08-15	18:34:27	21.5	257
2016-08-15	18:34:57	22	257
2016-08-15	18:35:27	22.5	258
2016-08-15	18:35:57	23	258
2016-08-15	18:36:27	23.5	259
2016-08-15	18:36:57	24	261
2016-08-15	18:37:27	24.5	263
2016-08-15	18:37:57	25	263
2016-08-15	18:38:27	25.5	266
2016-08-15	18:38:57	26	266
2016-08-15	18:39:27	26.5	270
2016-08-15	18:39:57	27	272
2016-08-15	18:40:27	27.5	273
2016-08-15	18:40:57	28	276
2016-08-15	18:41:27	28.5	275
2016-08-15	18:41:57	29	275
2016-08-15	18:42:27	29.5	277
2016-08-15	18:42:57	30	277
2016-08-15	18:43:27	30.5	279
2016-08-15	18:43:57	31	285
2016-08-15	18:44:27	31.5	280
2016-08-15	18:44:57	32	281
2016-08-15	18:45:27	32.5	281
2016-08-15	18:45:57	33	282
2016-08-15	18:46:27	33.5	284
2016-08-15	18:46:57	34	286
2016-08-15	18:47:27	34.5	287
2016-08-15	18:47:57	35	288

Table 5. CH_4 levels measured by the PMD during the FLUX test. CH_4 gas levels increased from 29 ppmv to a maximum of 288 ppmv after 35 minutes (at the end of the test). As CH_4 gas levels were low, the FLUX chamber was left overnight (~18.5 hours). The FLUX would be re-initiated to determine increasing CH_4 levels with time. During the stabilization time, water encroached the excavation and invaded the FLUX chamber and CH_4 levels could not be determined on location using the PMD.

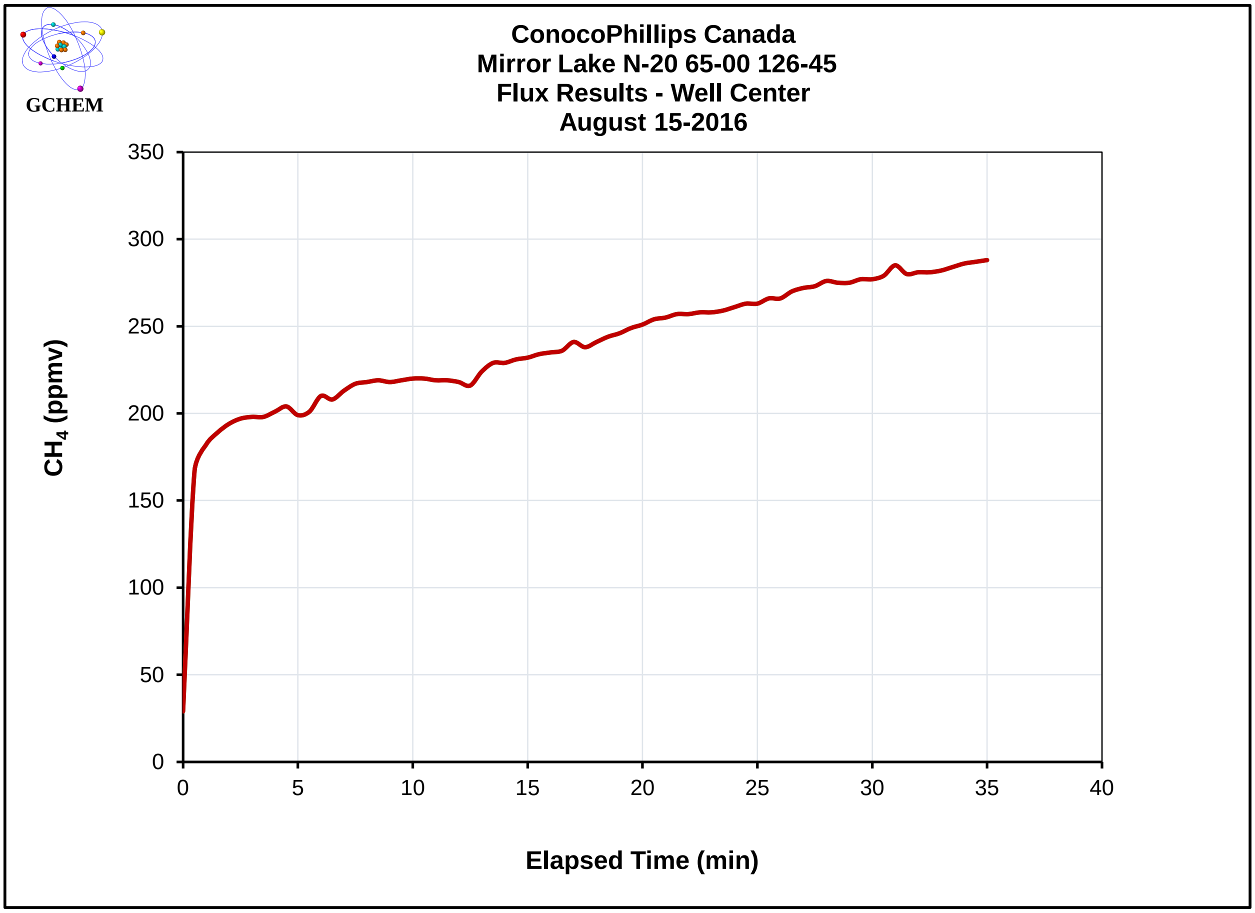


Figure-3. CH_4 (ppmv) vs. Elapsed Time (min). Results of FLUX-1 conducted in soils above the hand excavated buried well stub at Mirror Lake N-20. CH_4 contents are for the most part low but slowly increase throughout the duration of investigation (35 minutes).

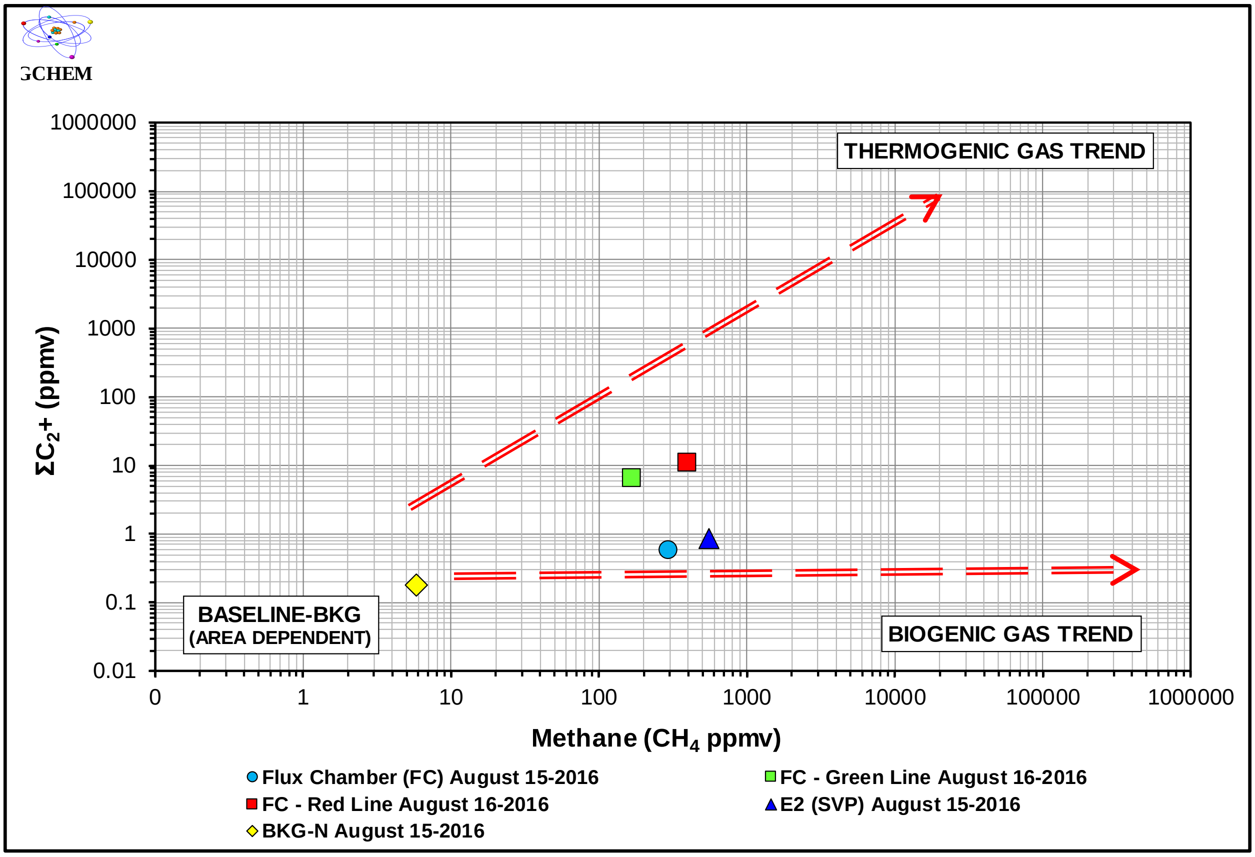


Figure-4. Natural Gas-Genetic Characterization #1 ΣC_2+ vs. Methane. Combustible gases detected in soils and SCVs at a wellhead may result from several origins. Natural gases indicative of SCVF or AGM are thermogenic in origin (natural gas in deep reservoirs), contain high methane and C_2+ contents and plot in the Upper RH Quadrant. Low natural gas levels in background, off lease areas are naturally present in soils, vary from region to region and plot in the Lower LH Quadrant (BASELINE). Biogenic gases (swamp gas) are produced by bacteria, are comprised of predominantly methane and plot in the Lower RH Quadrant. Samples plotting in the Lower LH and RH quadrants do not contain SCVF or AGM and would not require down-hole remediation.

Figure-4 NG-GC #1 Comments

CH_4 and ΣC_2+ concentrations of the natural gas samples collected at Mirror lake N-20 are shown on Figure-4. Two samples (FLUX Chamber and E2) plot in the lower portion of the graph, suggesting a biogenic gas source for CH_4 gases. Two samples (FLUX-Chamber inlet (RED Line) and outlet (GREEN Line) lines after 18.5 hours) contain low but slightly elevated, above background levels of ΣC_2+.

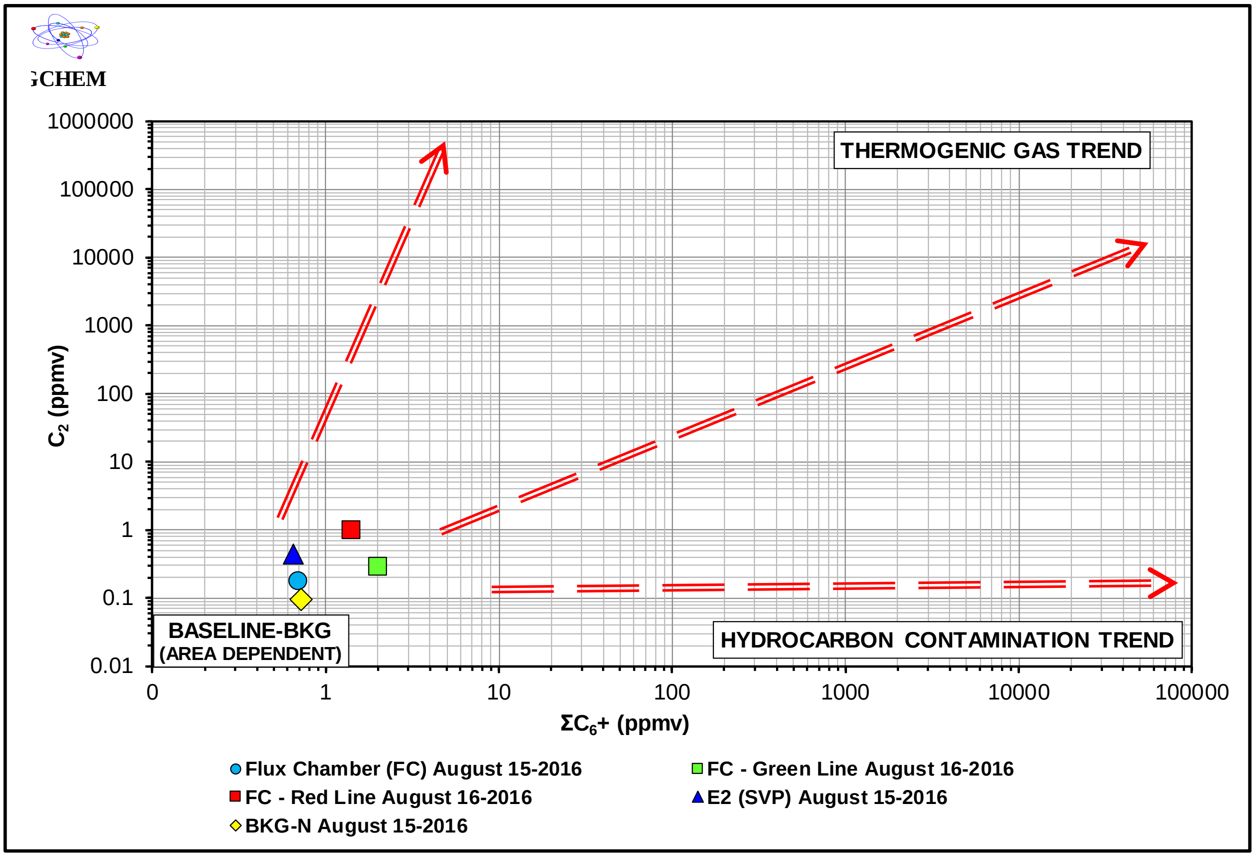


Figure-5. Natural Gas-Genetic Characterization #2 C_2 vs. ΣC_6+. C_6+ gases are relatively large molecules that do not readily or easily migrate in large quantities from depth upwards through subsurface fractures or micro-fractures to surface. Contamination by oil spills, fuels, and solvents is indicated by soil vapour samples that have high contents of C_6+ compounds and plot in the Lower RH Quadrant. Samples plotting in the Lower LH quadrant do not contain evidence of either SCVF or AGM and would not require down-hole repair operations.

Figure-5 NG-GC #2 Comments

The four natural gas samples collected at Mirror Lake N-20 plot near the BKG/Baseline sample that was collected at the site. Low C_6+ gas levels suggest that hydrocarbon contamination was not present at the test site at the time of this assessment.

CH_4 and ΣC_2+ concentrations of the natural gas samples collected from one SVP (E 2.0m), background (BKG-N) and FLUX tests (FLUX Chamber -35 min and after 18.5 hours-RED and GREEN lines) are shown in Figure-4. FLUX chamber gases obtained from the RED and GREEN lines contain slightly elevated, above background levels of ΣC_2+ gases. Typical natural gas light alkane compositions of thermogenic natural gases follow the trend or normal distribution of molecular abundance of $C_1 >> C_2 > C_3 > n\text{-}C_4 > n\text{-}C_5$. LHG in the FLUX chamber after 18.5-hrs do not follow their order of molecular abundance model, but rather $C_1 >> C_2 < C_3 < n\text{-}C_4 > n\text{-}C_5$ and suggests that the C_2+ light alkanes may be the result of thermogenic natural gases that have previously leaked to surface and trapped in soils near the surface around the wellbore before down-hole repair was performed February-2016 and were liberated during the excavation process.

C_6+ gas levels for SVP E 2.0m were low, similar to BKG locations and indicate that crude or refined hydrocarbons or hydrocarbon-based chemicals were not present in soils at SVP gas collection depths (Figure-5).

Sufficient levels of CH_4 was available for $\delta^{13}C$ measurement for three gas samples: FLUX sample at 35 minutes, after 18.5 hours (RED line), and from SVP E 2.0m and were -44.12, -48.88 and -22.27‰ VPDB, respectively. Sufficient levels of CO_2 gases were available for $\delta^{13}C$ measurement for all five samples collected during this investigation and were -23.28‰ (FLUX chamber- 35 minutes), -23.57‰ VPDB (SVP E 2.0m), -20.73‰ VPDB (BKG-N), -19.96‰ VPDB (FC-GREEN line), and -24.02‰ VPDB (FC-RED line).

SVP E 2.0m and the FLUX chamber gas samples (at 35-min and the RED line after 18.5 hours) contain low $CH_4/\Sigma C_2+$ ratios (639.8, 488.6, and 34.97, respectively) and plot in the lower right hand quadrant of Figure-6.

$\delta^{13}C$ CH_4 and $\delta^{13}C$ CO_2 isotopic compositions of SVP E 2.0m and the FLUX chamber samples (at 35-min and the RED line after 18.5 hours) plot in the lower right hand quadrant of Figure-

7 and are consistent with biogenically produced CH_4 gases that have undergone secondary biogenic alteration-oxidization (biogenic enriching effects).

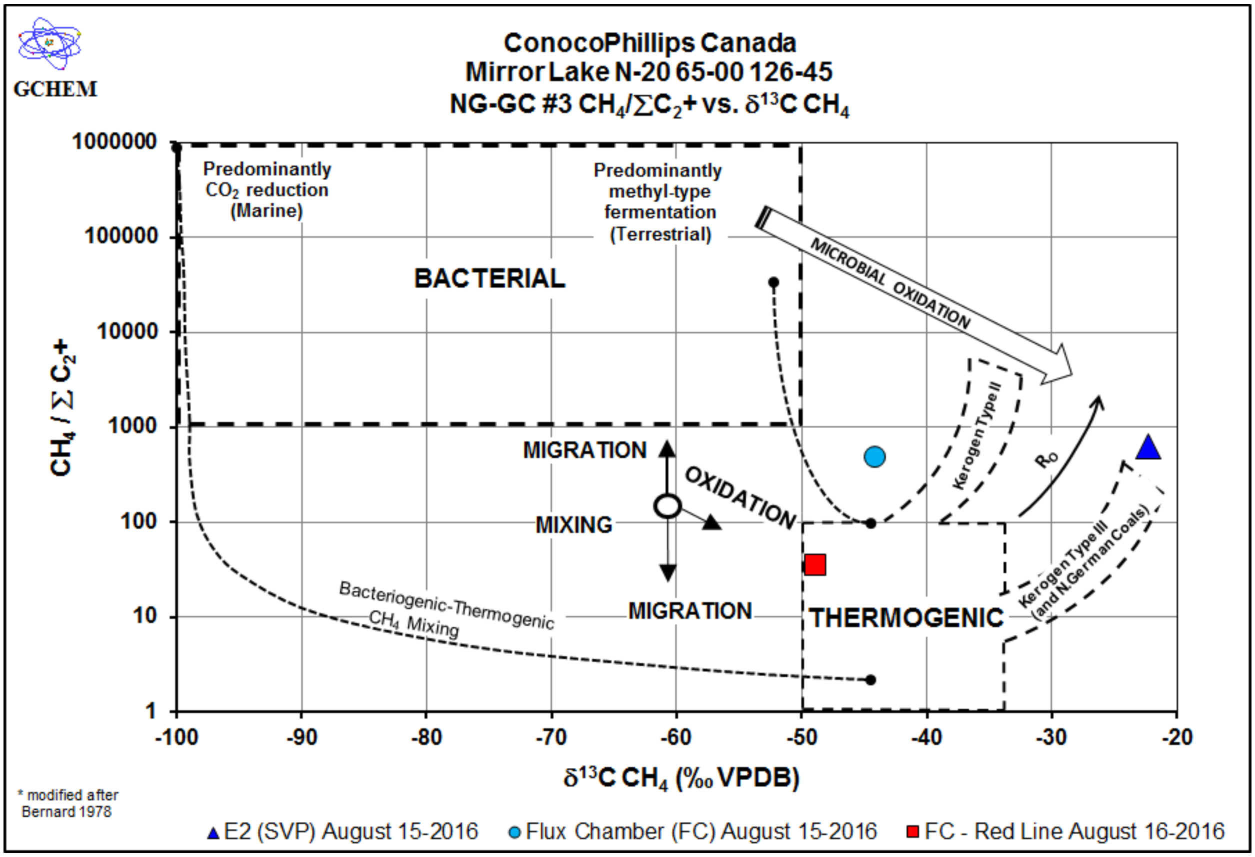
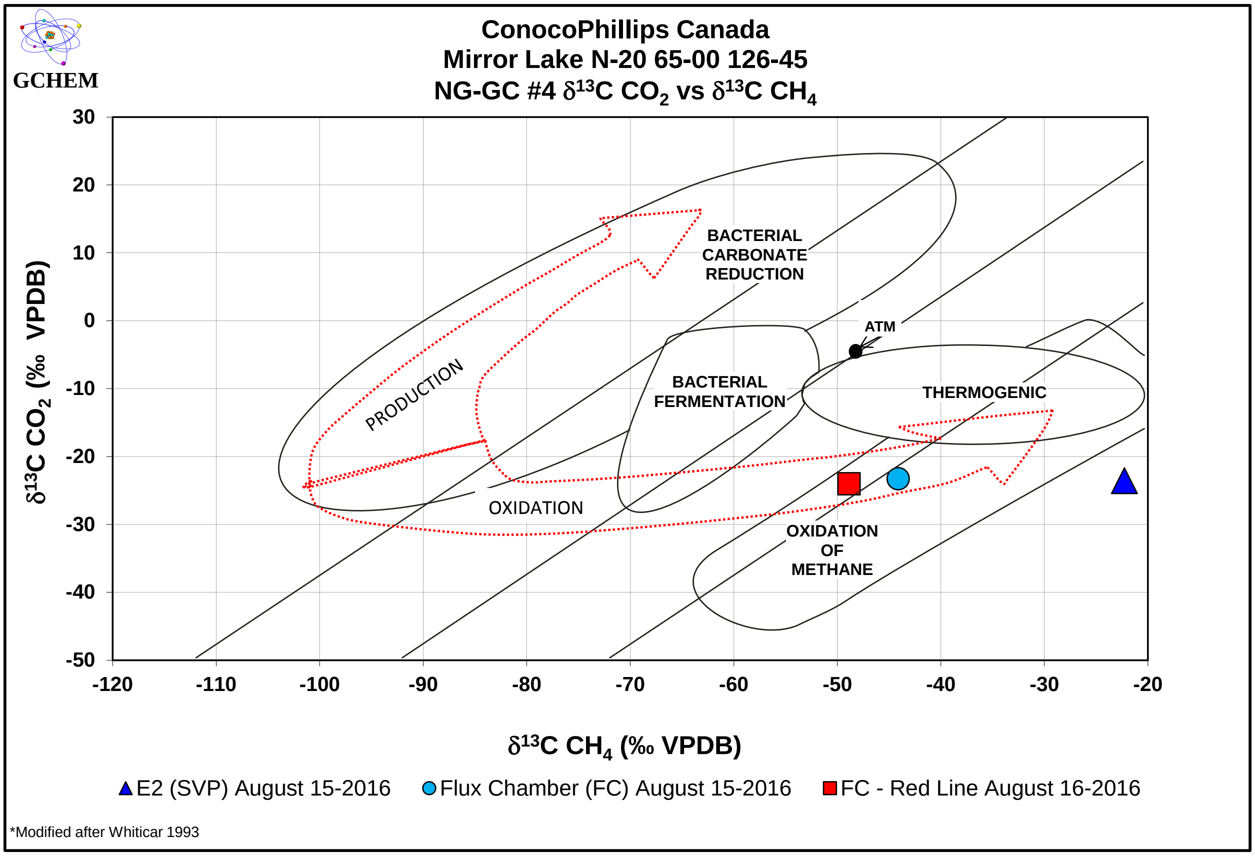


Figure-6. Natural Gas-Genetic Characterization #3 CH_4 / ΣC_{2+} vs. $\delta^{13}C$ CH_4. Thermogenic methane or methane generated by abiotic processes such as the thermal degradation of organic matter at high temperature and pressure (thermogenesis) contains enriched (less negative) $\delta^{13}C$ values ranging from -50 to -20‰ VPDB and methane relative to C_{2+} gas contents (gas wetness) less than 100. Methane gas may be generated by biotic processes such as the degradation of organic matter via CO_2 reduction or fermentation reactions generating biogenic methane. It should be noted that as a normal part of soil respiration, methane may be generated or destroyed by variable biotic pathways. Biogenic methane gas may be oxidized by bacteria resulting in an 'isotopic enriching effect' (i.e. $\delta^{13}C$ values become less negative as a result of oxidizing bacteria in soils that preferentially consume ^{12}C over ^{13}C, leaving the remaining gas enriched in ^{13}C). Since biogenic oxidization decreases the ratio between ^{12}C and ^{13}C, it may result in enriched $\delta^{13}C$ CH_4 values that overlap with the MIXING or THERMOGENIC-GAS TREND. Biogenic methane may therefore contain $\delta^{13}C$ values greater than -50‰ VPDB (GCHEM, in prep).

Figure-6 NG-GC #3 Comments

Gas samples from SVP E 2.0m and the FLUX chamber (at 35 minutes and the RED line after 18.5 hours) are consistent with the 'methane oxidation trend' of biogenic gases and suggest that CH_4 gas has undergone extensive secondary biological alteration.



*Modified after Whiticar 1993

Figure-7. Natural Gas-Genetic Characterization #4 $\delta^{13}C$ CO_2 vs. $\delta^{13}C$ CH_4. Thermogenic methane or methane generated by abiotic processes such as the degradation of organic matter at high temperature and pressure contains enriched (less negative) $\delta^{13}C$ values ranging from -50 to -20‰ VPDB (or higher) and $\delta^{13}C$ CO_2 values in the range of -18 to -4‰ VPDB. Methane gas may be generated by biotic processes such as the degradation of organic matter via CO_2 reduction or fermentation reactions generating biogenic methane. Biogenic methane may contain $\delta^{13}C$ values greater than -40‰ VPDB due to biogenic oxidation processes (GCHEM, in prep).

Figure-7 NG-GC #4 Comments

$\delta^{13}C$ CH_4 and CO_2 compositions of gases obtained from SVP E 2.0m and the FLUX chamber (at 35-minutes and the RED line after 18.5-hours) are consistent and follow the methane oxidation trend and suggest that the CH_4 gas has undergone extensive secondary biogenic alteration (biogenic alteration effects) in the soils near the buried well stub.

Soil gas collected from SVP E 2.0m is consistent with gas originating from a biogenic source (i.e. normal soil respiration processes) that has been altered by secondary biogenic oxidization processes (GCHEM, in prep).

Soil gases collected during the FLUX test at 35-min are similar to the soil gases collected in SVP E 2.0m and are consistent with gases originating from a biogenic source that has undergone secondary biological alteration-oxidization processes (GCHEM, in prep). Gases collected from the FLUX chamber inlet (Red Line) and outlet (Green Line) lines after 18.5 hours contain nitrogen, oxygen, carbon dioxide, and methane levels similar to baseline/background. Low, slightly elevated above BKG levels of C_2+ light alkanes in soils may be the result of thermogenic natural gases that had previously leaked to surface pre SCVF repair operations (February-2016) and were liberated during the excavation process.

6.4 Constraints of the Vapour Intrusion Assessment

One major constraint on interpretation of the geochemical data for this project is that the lease was very wet and soils below the surface in muskeg were water saturated. Alternative and advanced vapour intrusion testing and sampling methodologies should be employed to obtain higher quality gas samples for laboratory analysis and definitive vapour intrusion assessments.

7.0 Conclusions and Recommendations

On August 15 & 16-2016, a Vapour Intrusion Assessment (VIA) was conducted by GCHEM Ltd. at COPRC Mirror Lake N-20 65-00 126-45. The well is cut, capped, and abandoned and the lease is in the process of being reclaimed. COPRC Mirror Lake was previously impacted with surface casing vent flow (SCVF) and soils outside of casing (AGM) were not investigated for natural gas leakage prior to the down hole abandonment. During the VIA, CH_4 (methane) levels were measured in soils at surface on a 12m x 12m grid pattern around well center. CH_4 levels were established at 8 locations ~25m from the well center in four directions to establish baseline natural gas concentrations. No anomalies (readings above background) were detected.

Soil vapour test holes were hand augered to a depth of ~1.5m at 13-locations in a strategic pattern around the well center. Soil Vapour Probes (SVPs) were immediately installed. Due to the wet soil conditions at the site, only 1 soil gas sample (SVP E 2.0m) was collected near the well stub as water invaded the gas sample ports at depth prior to soil vapour collection. Of the four background SVPs installed, water invaded gas samples ports at depth at three and soil vapours were collected from one dry SVP (BKG-N).

Soils above the buried well stub were hand excavated to a depth of ~1.5 meters below ground level. A FLUX chamber was installed and a 35-minute FLUX test conducted in the excavation. CH_4 gas levels increased from 29 ppmv to 288 ppmv over the duration of the test (Figure 3). A gas flow rate of 0.07 m^3/m^2/year (volumetric) and 43.63 g/m^2/year (gravimetric) was calculated.

The FLUX chamber was left on-site overnight for sample collection the following day. The FLUX chamber gas samples from the RED and GREEN lines after 18.5-hours contain elevated, above background, ΣC_2+ gas contents. Typical natural gas light alkane compositions of thermogenic natural gases follow their order of molecular abundance ($C_1 >> C_2 > C_3 > n\text{-}C_4 > n\text{-}C_5$). Gases obtained from the FLUX chamber after 18.5 hrs do not follow their order of molecular abundance ($C_1 >> C_2 < C_3 < n\text{-}C_4 > n\text{-}C_5$) and suggests that C_2+ gases have undergone extensive primary and secondary biogenic oxidization.

$\delta^{13}C$ CH_4 and CO_2 compositions of gases obtained from the SVP and the FLUX chamber (at 35-min and the RED line after 18.5 hours) are consistent with biotic gases that have undergone extensive biogenic oxidization (biogenic enriching effects).

Low levels of ΣC_2+ gas contents and methane gas that has undergone primary and secondary oxidation processes and elevated CO_2 gas found in soils above the buried well stub suggests biotic origins for the majority of methane and carbon dioxide gas and suggest normal soil respiration processes. Low levels of ΣC_2+ gas contents are consistent with possibly trapped leaking gas pre SCVF repair and natural movement of light hydrocarbons, upward through subsurface fractures and micro-fractures to surface.

At the time of this investigation and with information available to date, the buried well stub at CROPC Mirror Lake N-20 65-00 126-45 would be classified as BASELINE or NON-IMPACTED with leaking deep sourced thermogenic natural gases.

Wet soil conditions and a high water table affects VIA assessment protocol. Advanced Diffusion-Membrane Soil Vapour Probes (DM-SVPs) could be installed to confirm results in this investigation. DM-SVPs can be installed in wet or high moisture environments where gases will diffuse through a permeable membrane into an accumulation chamber allowing representative gas collection for high resolution chemical and isotopic measurements and classification and characterization of LHG contents.

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Szatkowski, B.J., Johnston, B.G., Banerjee, S., Mclasky, B.R., and Schroh, T.A. Chemical and stable isotopes to acurately characterize and classify condensed steam, leaking natural gas and sulphur contents in leaking surface casing vents in thermal enhanced oil recovery projects (GCHEM, in prep).

Szatkowski, B.J., Johnston, B.G., Banerjee, S., Mclasky, B.R., and Schroh, T.A. Exsolved mud gas chemical and stable carbon and hydrogen isotopic compositions of natural gas in the subsurface – advanced high resolution gas sampling and analytical techniques (GCHEM, in prep).

ATTACHMENT-1

Gas Migration Testing Program
Forwarded to GCHEM Ltd. by ConocoPhillips Canada

GAS MIGRATION TESTING PROGRAM

COPRC MIRROR LAKE 300/N-20 65-00 126-45

COPRC LOON CREEK 300/O-06 65-10 127-00

1. Using a pin finder identify well centre.
2. Establish a 1m x 1m grid pattern extending 6m in each direction from well centre.
3. Using a Sensit Personal Methane Detector (PMD) conduct a surface combustible gas scan at the 1m intervals around the wellbore (144 sample points). Record Sensit methane readings.
4. Obtain background levels from three locations taken a minimum of 25m from well centre. Record methane levels.
5. Auger holes to a minimum depth of 50 cm as follows:
    - above well centre.
    - Four within 30 cm of wellbore on opposite sides.
    - At 2m intervals from the wellbore every 90 degrees.
    - Three background test holes each a minimum of 25m from well centre.
    - At any point within 75m of wellbore where there is apparent vegetation stress.

If hydrocarbon contamination is present in any of the auger return soils, collect samples for analysis.

6. Install Soil Vapor Probes (SVPs) in all holes and using the attached GM diagram, record the combustible gas levels from each hole. If zeros are recorded then samples will not be required - go to step 12. If combustible gas levels are recorded proceed with step 7.
7. Remove SVPs and place ~0.5l of frac sand into the augered hole.
8. Install Soil Vapor Monitoring Probes (SVMPs) into each hole.
9. Place bentonite in hole (~1 liner foot of material).
10. Allow SVMPs to stabilize overnight with valve closed - soil gas samples will be collected the following day for isotope analyses.
11. Using a syringe, extract the soil gas from the SVMP and insert the gas into glass serum vials. Record the test hole number on the vial. Send vials to GChem for high resolution geochemical analysis.
12. Remove all SVPs/SVMPs and any other debris found on lease.

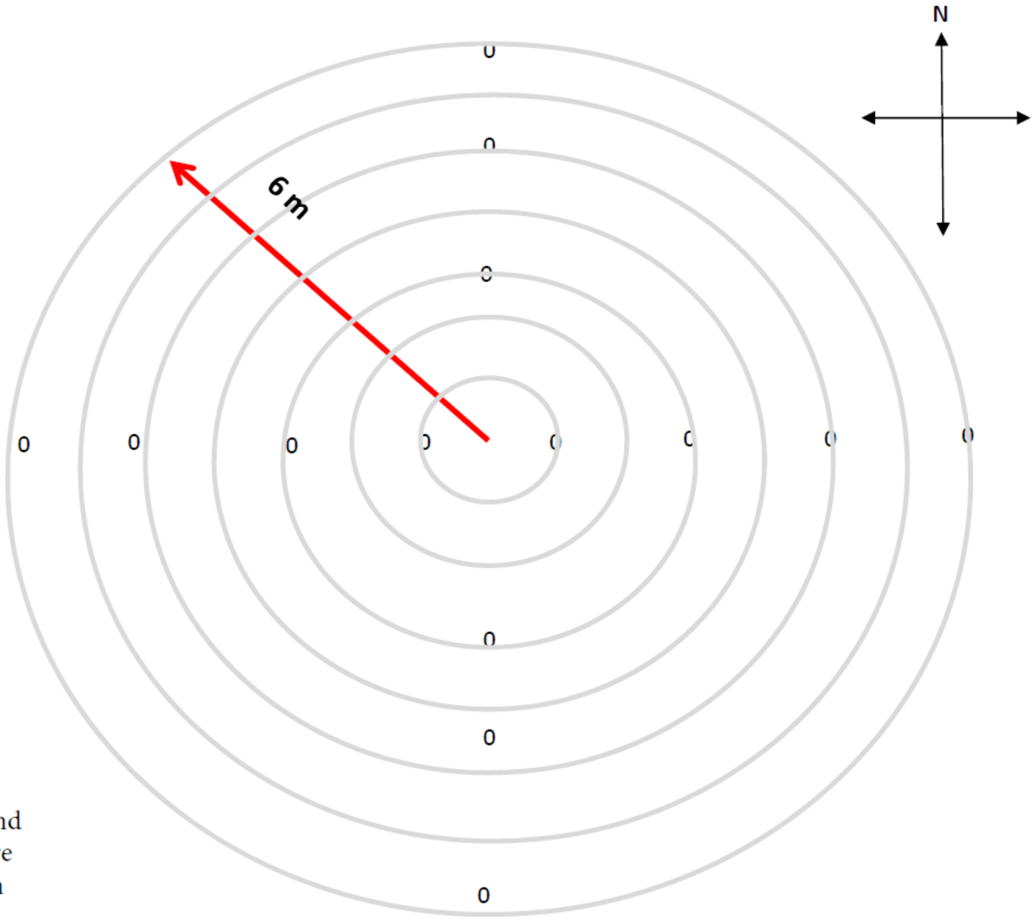
EXAMPLE GAS MIGRATION TEST PATTERN. (PATTERN MAY CHANGE DUE TO LEASE CONDITIONS.

GAS MIGRATION

Company Contact Information

Company Name:
Office: **Contacts**
UWI: ____________________
Surface Location: ____________________
Test Date: ____________________
Field: ____________________
License: ____________________
Engineering: ____________________
Technician: ____________________

Test Information



Background somewhere away from wellbore.

~ Not to Scale ~

On the diagram, indicate the location of sample points and record percentage LEL readings
Briefly describe test results and the condition of the area around the wellbore and on lease, e.g., vegetation growth, bare spots, contaminated soil, etc. Smallest circle radius is 30 cm then, 1 m, 2m to largest radius of 6 m. as per Directive 20.

All numbers above represent % of LEL readings.

____
____
____
____

ATTACHMENT-2

Surface Casing Vent Flow/Gas Migration Data Sheet

Surface Casing Vent Flow/Gas Migration Data Sheet Attachment-2

The licensee certifies that the information on this sheet is correct and that the vent flow or gas migration repairs will be done according to regulatory requirements or as directed by the AEUB / SIR.

Day	Month	Year	Your File Number
15	08	2016	16082

1 GENERAL INFORMATION AND CERTIFICATION

LICENSEE GCHEM Ltd — Licensee Code
AGENT N/A ☒ — Agent Code
CONSULTANT N/A ☐ — Consultant Code
CONTACT PERSON Brad Johnston
TELEPHONE **Business** (780) 871-4668 **Fax**

2 WELL TEST INFORMATION

LICENCE NUMBER
UNIQUE IDENTIFIER CPC Mirror Lake N-20 65-00 126-45
DATE TESTED Aug. 15-16-2016

3 SURFACE CASING VENT FLOW TEST DATA

3.1 Vent Flow Exists Yes ☐ No ☐ **No SCV available to test**
If yes Complete the rest of this section
Serious ☐ Non-Serious ☐

3.2 Test Type (e.g., bubble test, others):

3.3 Type of Flow: Gas ☐ Oil ☐ Salt Water ☐ Others (Please specify)
The flow is: Sweet ☐ Sour ☐

3.4 Casing Information:
Surface Casing Depth: m Size: mm Grade: Weight: Kg/m^3
Production Casing Depth: m Size: mm Grade: Weight: Kg/m^3

3.5 Cementing Details:
Cement Tops m Logged Yes ☐ No ☐ Estimated (from logs, tour books)
Describe cementing details (e.g., types, blends, specifications)

3.6 Vent Flow Data:
Leak-off Pressure Gradient: kPa/m Flow Rate: **m^3/d** **(If flow not measured, fill in TSTM, (too small to measure))**
Stabilized Build-up Pressure: kPa Duration: Hrs
Source of Flow: m (depth)
Determined by (log type, Carbon Isotope, etc)

3.7 Ground Water Information:
Depth of Usable Water Aquifers: m
Nearest Water Well: km

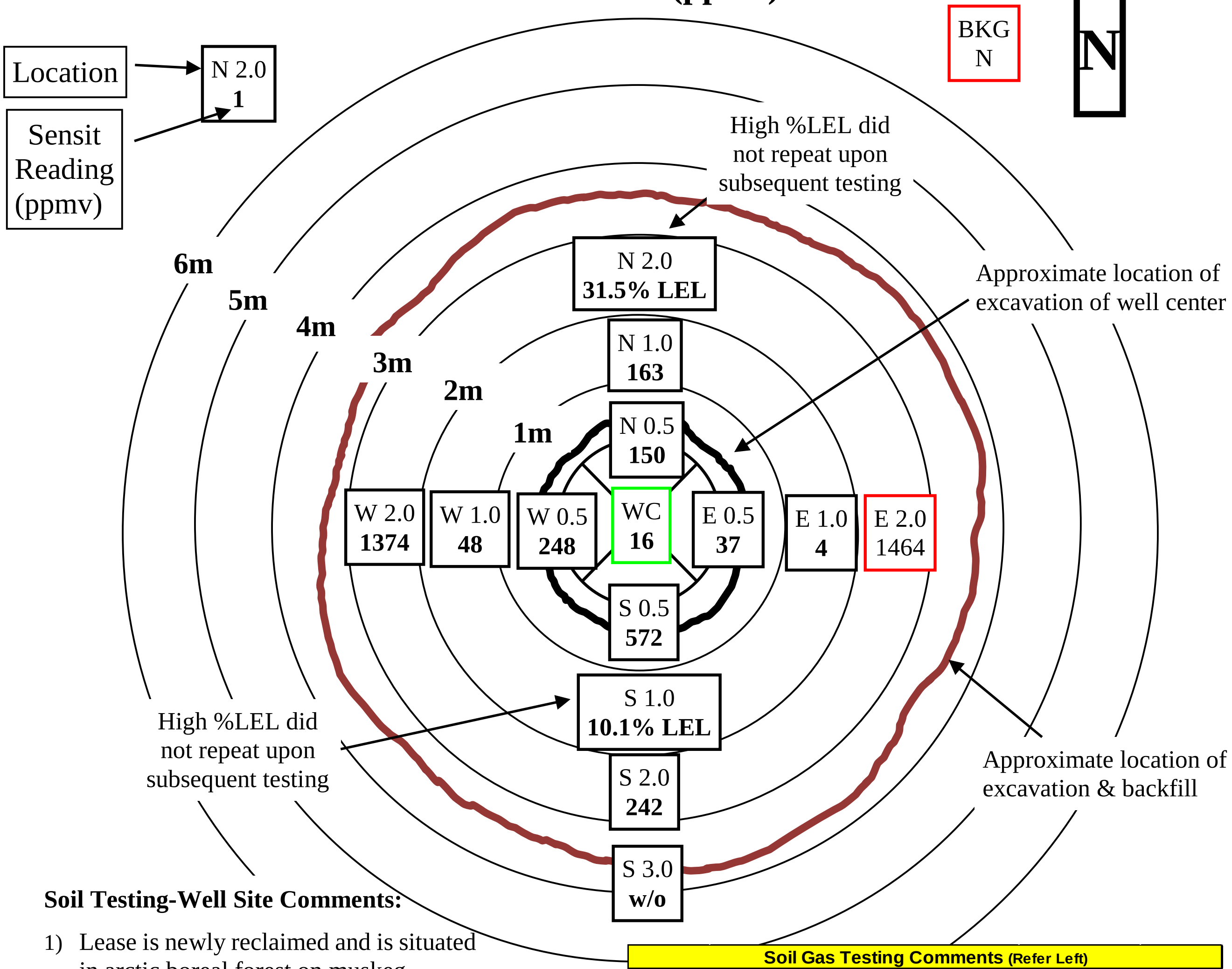
Tested By: **Bryan Szatkowski / Walker Duriez**
Please Print Name Signature

ATTACHMENT-3

SGMT-Well Site Diagram
&
Field Test Data Summary

Well Test Information				ATTACHMENT-3	
Licence No.:		**Unique Identifier:**	CPC Mirror Lake N-20 65-00 126-45	**Date Tested:**	August 15-16, 2016

AGM: SVP Location & PMD CH_4 Levels (ppmv)



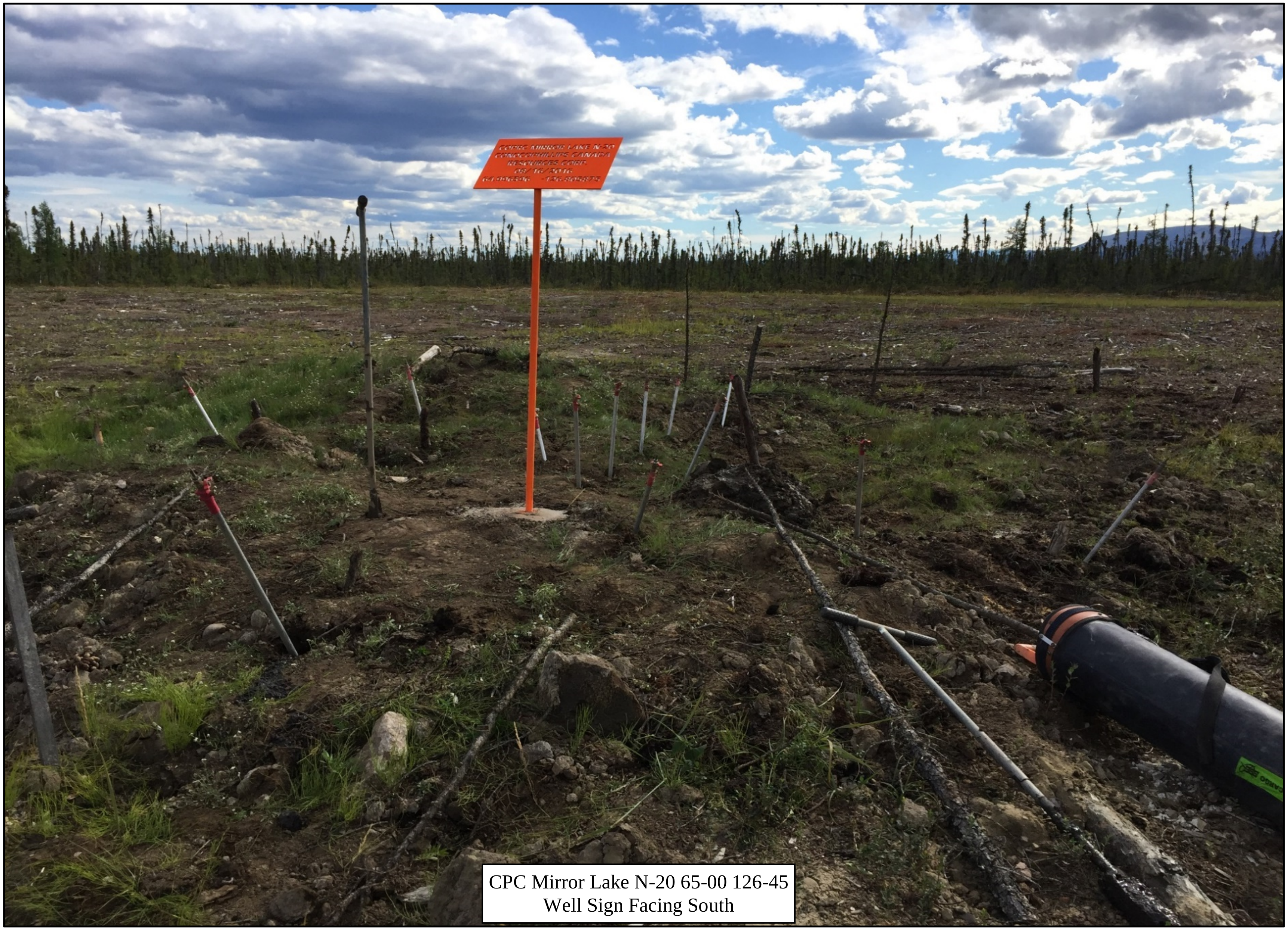
Soil Testing-Well Site Comments:

1) Lease is newly reclaimed and is situated in arctic boreal forest on muskeg.
2) Water table is at 0.3m BGL.
3) Sporadic grass and weeds cover with muskeg soil cover, high organic matter (peat).
4) Well stub was staked and located using a magnetic metal detector.
5) No equipment on site, well head sign was approximately 1m N of well stub.
6) The red boxes indicate location of the SVPs where gas samples were collected. The green box indicates the location of the Flux Chamber where 3 gas samples were collected.
7) SVP S 3.0m watered out immediately after installation. No combustible gas readings could be measured.

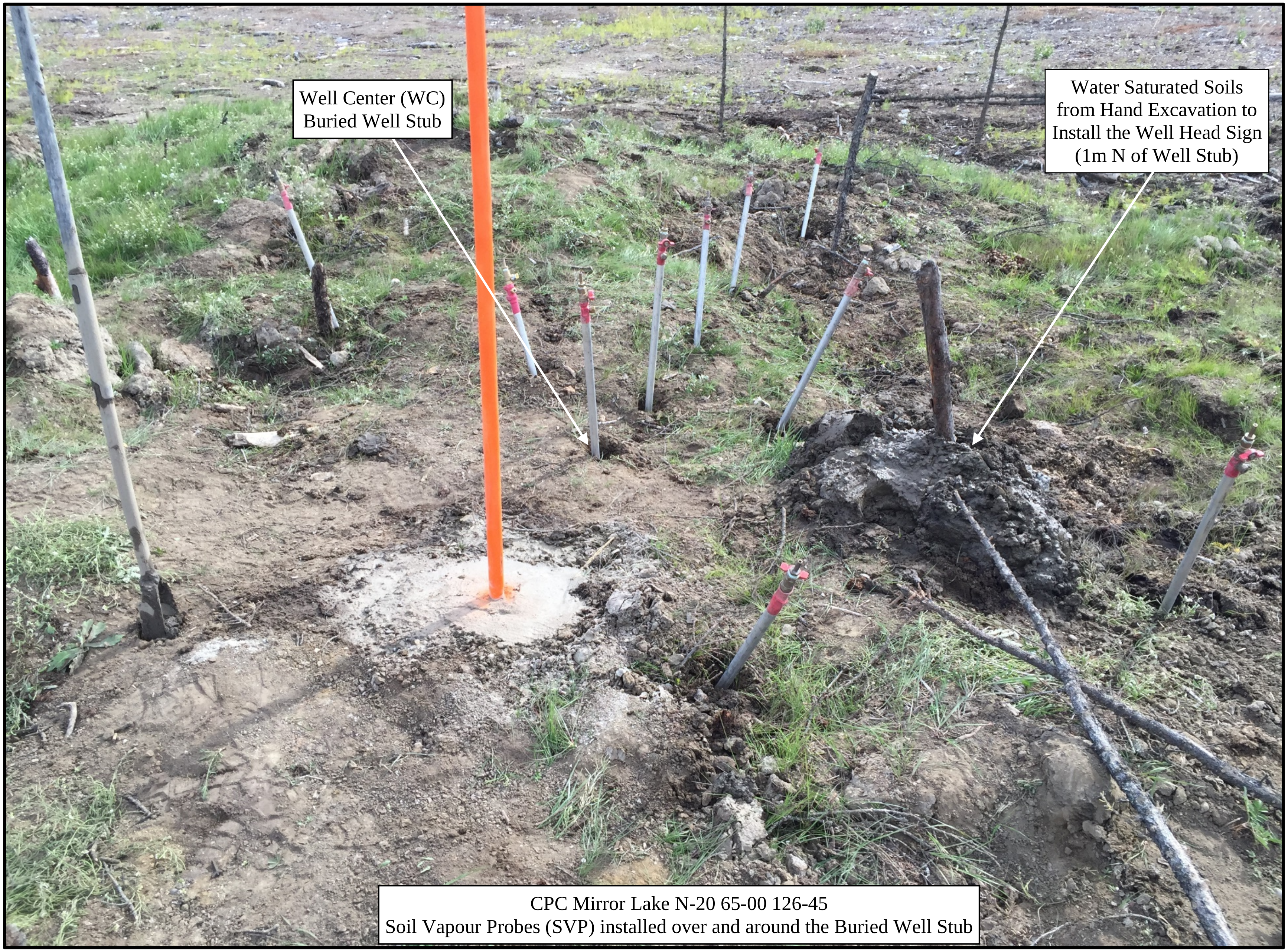
Soil Gas Testing Comments (Refer Left)			
Soil Gas Test-Site	**Soil Type**	**Moisture (1-dry 5-wet)**	**HC / Oil Contam.**
WC	md-dk bwn silty clay	5	Clean
N0.5	md-dk bwn silty clay	5	Clean
E0.5	md-dk bwn silty clay	5	Clean
S0.5	md-dk bwn silty clay	5	Clean
W0.5	md-dk bwn silty clay	5	Clean
N1.0	md-dk bwn silty clay	5	Clean
E1.0	md-dk bwn silty clay	5	Clean
S1.0	md-dk bwn silty clay	5	Clean
W1.0	md-dk bwn silty clay	5	Clean
E2.0	md-dk bwn silty clay	5	Clean
S2.0	md-dk bwn silty clay	5	Clean
W2.0	md-dk bwn silty clay	5	Clean
N2.0	md-dk bwn silty clay	5	Clean
S3.0	md-dk bwn silty clay	5	Clean
BKG-SE	0.3m peat/ overlying water-saturated muskeg	5	Clean
BKG-SW	0.3m peat/ overlying water-saturated muskeg	5	Clean
BKG-NE	0.3m peat/ overlying water-saturated muskeg	5	Clean

ATTACHMENT-4

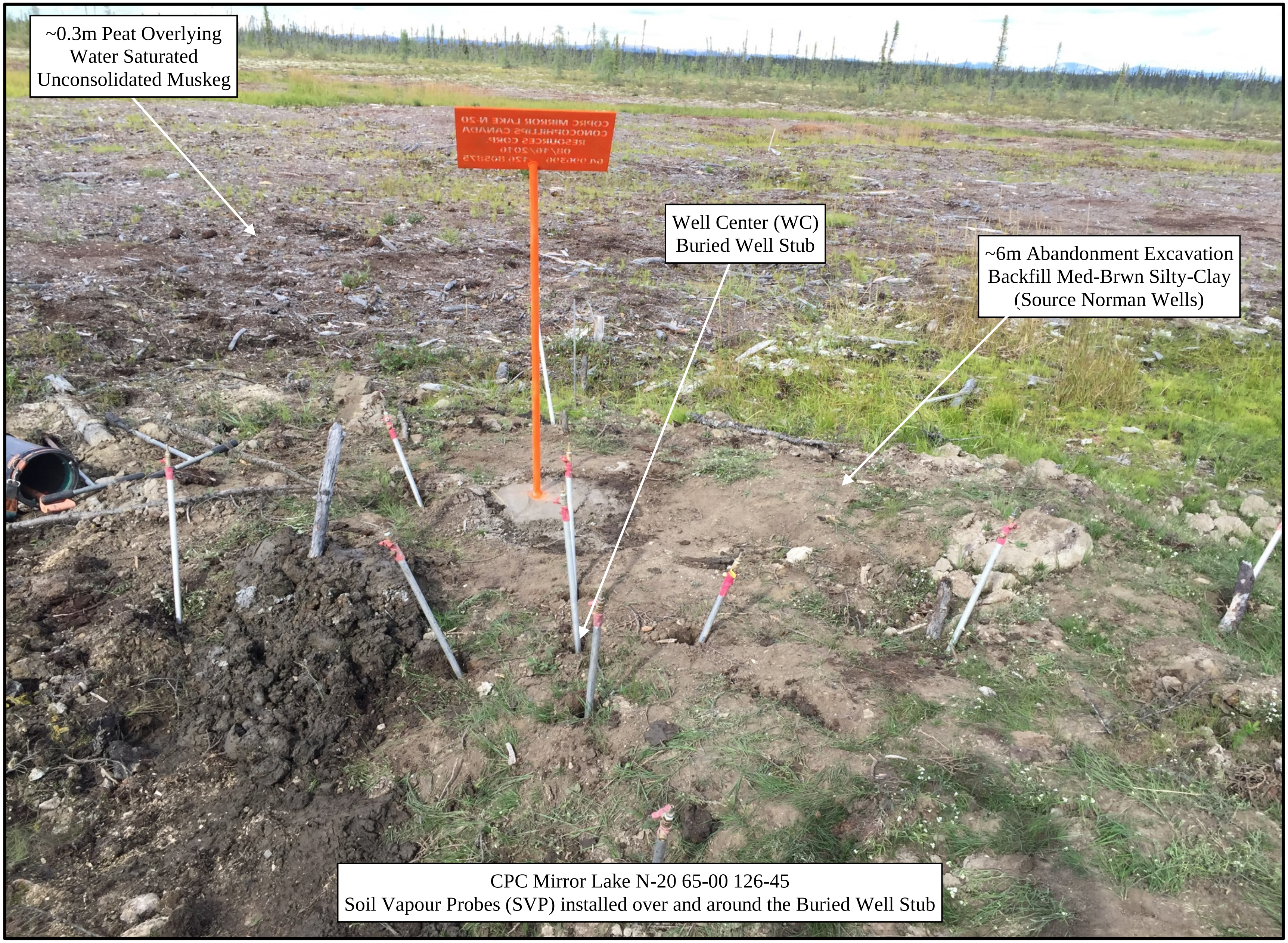
Site Photographs



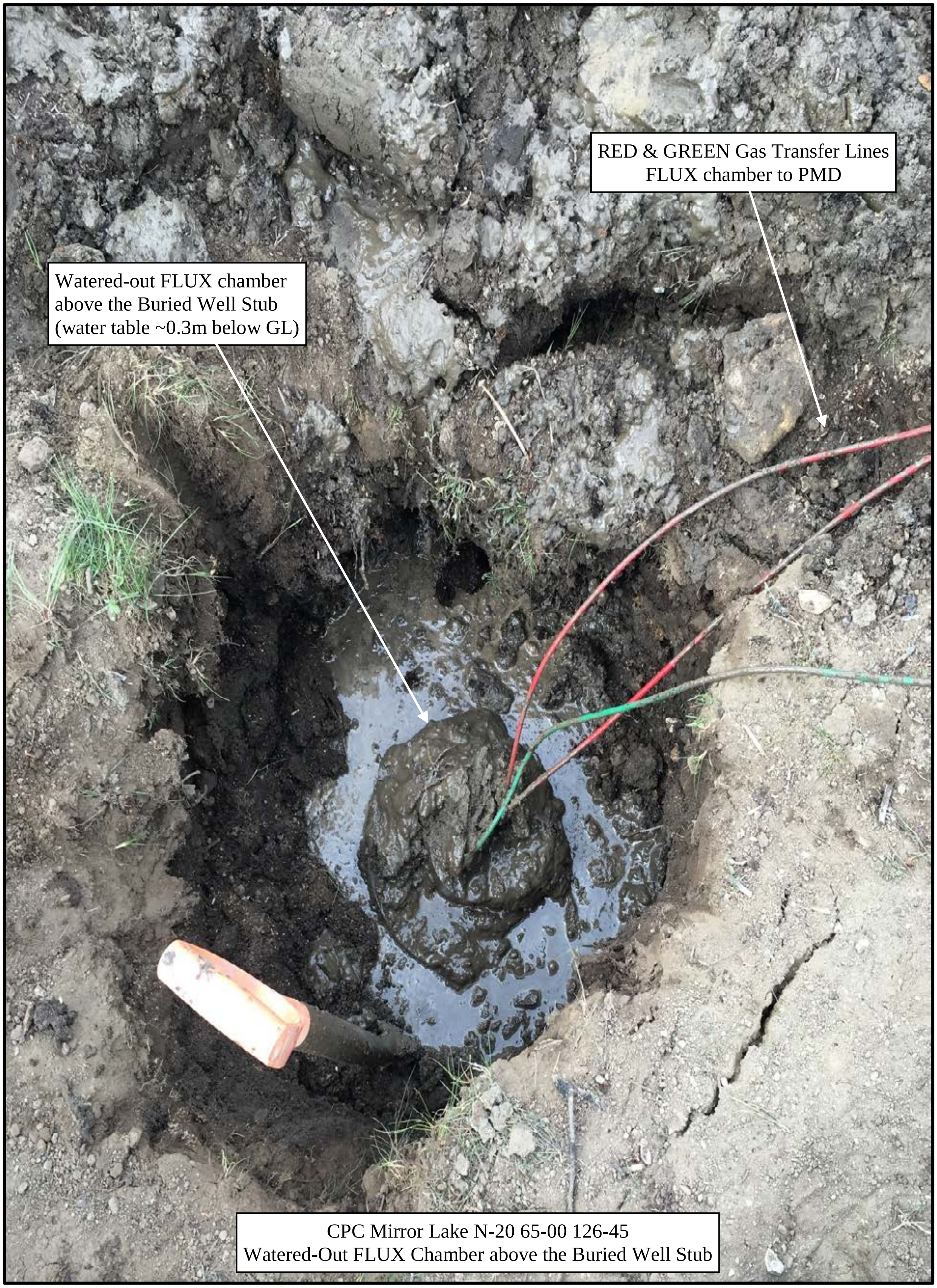
CPC Mirror Lake N-20 65-00 126-45
Well Sign Facing South



CPC Mirror Lake N-20 65-00 126-45
Soil Vapour Probes (SVP) installed over and around the Buried Well Stub



CPC Mirror Lake N-20 65-00 126-45
Soil Vapour Probes (SVP) installed over and around the Buried Well Stub



CPC Mirror Lake N-20 65-00 126-45
Watered-Out FLUX Chamber above the Buried Well Stub

After 20-minutes, no gas bubbling was observed in standing water in the excavation above the buried well stub

CPC Mirror Lake N-20 65-00 126-45
Excavation above the Buried Well Stub after removal of the FLUX Chamber