Identifying the Source of Migrating Gases in Surface Casing Vents and Soils Using Stable Carbon Isotopes, Golden Lake Pool, West-central Saskatchewan

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Abstract

Gases were collected from surface casing vents and in soils around wellbores of the Golden Lake Pool in west-central Saskatchewan to identify wells having active gas migration. The origin of gas in the samples was determined to be background, contamination, biogenic, or thermogenic. Thermogenic gases have relatively deep sources and are indicative of gas migration. A template of the geochemical characteristics of subsurface n-alkane gases was constructed using gases collected while drilling a well located close to the Golden Lake Pool. By comparing the molecular and carbon isotopic compositions of migrating gases to those of the subsurface gases, the geological source, or depth, of the gas leakage is indicated. This information can greatly assist remediation of leaking wells.

***Keywords**:* gas migration, carbon, stable isotopes, alkanes, thermogenic, Golden Lake, Mannville Group, Lloydminster.

1. Introduction

In western Canada, many oil and gas wells are leaking gas into surface casing vents and into soils around the wellhead (Jocksch *et al.*, 1993). This undesired leakage, or migration, of natural gases from deep (thermogenic) sources poses significant operational and environmental concerns (Saponja, 1995). Fugitive gases may migrate into shallower strata contaminating aquifers, soils and, ultimately, may be released to the atmosphere (Rowe, 1998). Gaseous hydrocarbons may enter a wellbore at points of poor cement bonding with wall rock, in small, and possibly gas induced, channels within the cement itself, or in microannuli at the contact between casing and cement (Figure 1; Erno and Schmitz, 1994). Where gas is detected in the vent between the production and surface casings, it is considered to be surface casing vent flow (SCVF). Where found in soils outside the casing, it is termed active gas migration (AGM). Correct identification of the origin of the gas found near the wellhead is important for determining appropriate remediation procedures. In addition to thermogenic gas associated with drilling and hydrocarbon exploitation activities, gases may be present in soils from biological activity, contamination, or natural background processes (Szatkowski *et al.*, 2001).

Identifying the geological source from which gases are migrating has proven a difficult task (Forbes and Uswak, 1992), but is essential to the successful remediation of a leaking well. Conventional methods for identifying the source of leaking gases have been variably successful and include noise, temperature, cement bond, and cement imaging logs. In this study, a technique is presented that fingerprints the geological source of leaking gases using molecular compositions and stable isotopic compositions of carbon in light n-alkane gases. Stable carbon isotopic compositions of n-alkane gases change systematically with stratigraphic depth (Rowe and Muehlenbachs, 1999) so that individual geological formations may have related gases that have unique and distinguishing carbon isotope compositions. By comparing molecular and carbon isotopic compositions of migrating gases to established compositions of subsurface gases, a source for the migrating gases can be identified. A template of the molecular and isotopic compositions of subsurface gases was developed in the immediate area and is used to identify the geological origin of gases collected from AGM and SCVF at the Golden Lake heavy oil pool of west-central Saskatchewan.

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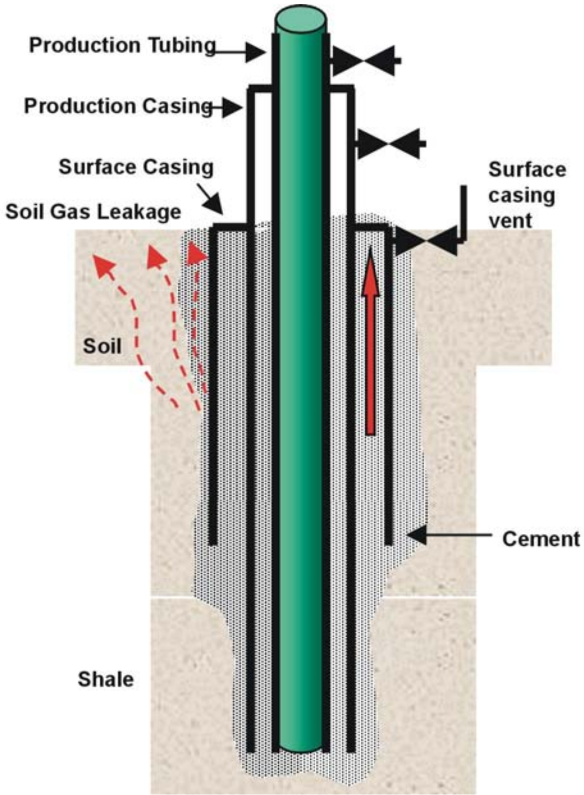

Figure 1 - Schematic diagram of typical well completion showing possible dispersion of migrating gas in soils adjacent to wellhead and leakage into surface casing (after Erno and Schmitz, 1994).

2. Study Setting

The Golden Lake Pool was discovered by Husky Oil in 1965. It is currently operated by Petrovera Resources to produce heavy oil from Cretaceous sandstones of the Mannville Group. In this area, the Mannville Group has been subdivided, in ascending order, into the Dina, Cummings, Lloydminster, Rex, General Petroleums, Sparky, Waseca, McLaren, and Colony members. Sandstone beds in the upper members are prone to hydrocarbon charging in structural highs. Above the Mannville Group are approximately 400 m of shales and siltstones of the Colorado and Montana groups which, in turn, are overlain by Quaternary glacial tills. The Mannville Group unconformably rests on Devonian carbonates of the Woodbend Group.

The Golden Lake Pool is nearing the end of its production life and many wells are scheduled for abandonment and surface reclamation. As a result of early drilling practices and poorer quality cement then available, many wells are plagued with AGM and SCVF. Surface gas migration tests were performed on 65 oil or natural gas wells in the Golden Lake Pool, mainly in sections 10 and 11 of Township 48, Range 23W3 (Figure 2).

Molecular and carbon isotopic compositions of light n-alkane molecules were measured on gases collected during surface gas-migration testing to determine the source of migrating gases. The compositions of the surface gases were compared to geochemical compositions of subsurface gases previously established. The control samples were collected during construction of a depth profile of subsurface gas compositions specifically for the Golden Lake Pool as described below.

3. Methods

a) Collection of Surface Gases

Surface casing vents were tested for positive gas pressure and flow. To identify SCVF, a bubble test is performed by immersing a hose connected to the vent 2.5 cm into a column of water. The vent is considered to have flow if one bubble is observed within 10 minutes according to the accepted industry definition. In cases where positive pressure was detected, the flow rate, expressed in m^3/day, was established. Twenty-four hour shut-in or stabilized build-up pressures were not recorded.

Soils near wellheads were investigated for the presence of combustible gases using an auger to drill 5 cm diameter holes to depths of 1.1 m to 2.5 m. AGM sampling holes were drilled successively outward from the wellhead at 1 m spacing in four directions at 90º. Specialized, stainless steel tubes designed to collect soil vapour were immediately inserted into the holes. An isolation disk is inserted at depth to prevent communication with atmospheric gases. A small vacuum was applied to the sampling tube to remove potential residual atmospheric contamination. Gases in the hole were allowed to equilibrate for 30 minutes and field readings of subsurface gases were made using a hand-held %LEL (lower explosive limit) detector at each site. Readings above 0% LEL are considered, by industry, to indicate gas migration. Gas samples were extracted from each test drill hole through a sampling port and valve system in the collection device and contained in a 140 mL gas tight syringe. Gases were injected through a septa seal into pre-evacuated 30 mL glass serum bottles for storage prior to analysis. Using identical methods, background samples were taken from soils away from the wellhead.

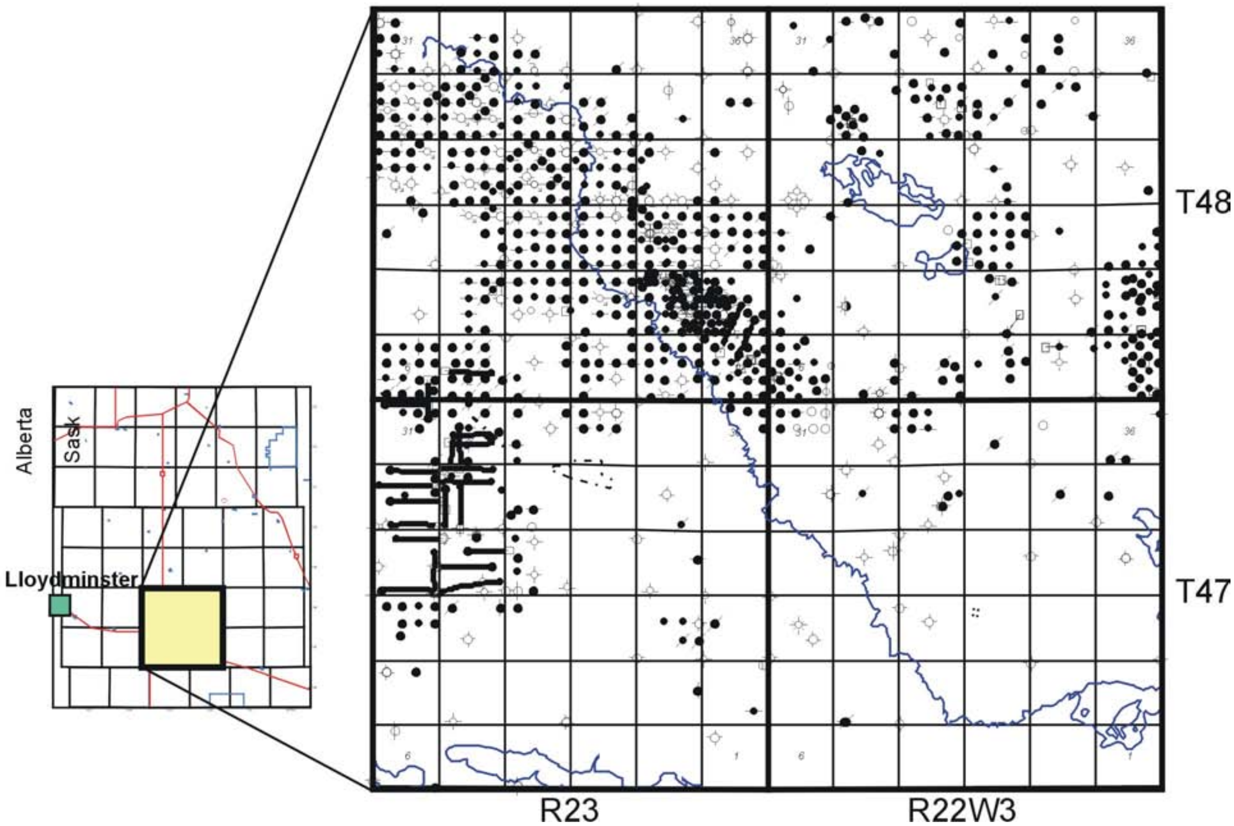

Figure 2 - Map of study area including the Golden Lake heavy oil pool in west-central Saskatchewan. The pool was discovered in 1965 and has been extensively produced. Many wells are presently scheduled for abandonment.

b) Collection of Subsurface Gases

Gas samples used to construct templates of the isotopic and molecular compositions of subsurface gases must be obtained during drilling. Ideally, the template well is located near the field to be studied. For this study, gases were collected from drilling mud every 2 to 7 m using a specialized manifold while drilling the control well, Petrovera Maidstone 1A1-4-48-22W3. Samples were lag-time corrected. Trip-gas, shut-down-gas, survey-gas and connection-gas pulses were identified, but not used, in the construction of the subsurface gas profile. For comparison, gases were similarly collected while drilling Petrovera Maidstone A8-4-48-22W3. Molecular compositions were determined for light n-alkane gases of both wells, but stable isotopic compositions were only measured on gases collected from the A1A-4-48-22W3 location. Depth profiles of the stable isotopic compositions of carbon in methane, ethane, propane, and n-butane liberated from mud-gas during drilling are shown in Figure 3.

c) Compositional and Isotopic Analyses

Molecular compositions and concentrations of alkanes, alkenes, hydrogen, and helium were measured using a Hewlett Packard 5890 Series II gas chromatograph configured for low-level detection at G-Chem Environmental Ltd. Specific molecules targeted in this study include methane, ethane, ethene, propane, propene, iso-butane, n-butane, iso-pentane, n-pentane, and C_6+ compounds. Surface and subsurface gases were analyzed using identical parameters.

Measurements of the stable carbon isotope compositions of individual n-alkane molecules were performed at the University of Alberta on a Finnigan Matt 252 Gas Chromatograph–Combustion-Continuous Flow–Isotope Ratio Mass Spectrometer (GC-C-CF-IRMS). For successful carbon isotope measurements, concentrations of at least 150 ppm v/v methane and carbon dioxide (CH_4 and CO_2), 10 ppm v/v ethane (C_2H_6), 5 ppm v/v propane (C_3H_8), and 2 ppm v/v n-butane (n-C_4H_{10}) are required. Carbon isotope values are reported in delta (δ) notation relative to PDB standard in parts per mil (‰).

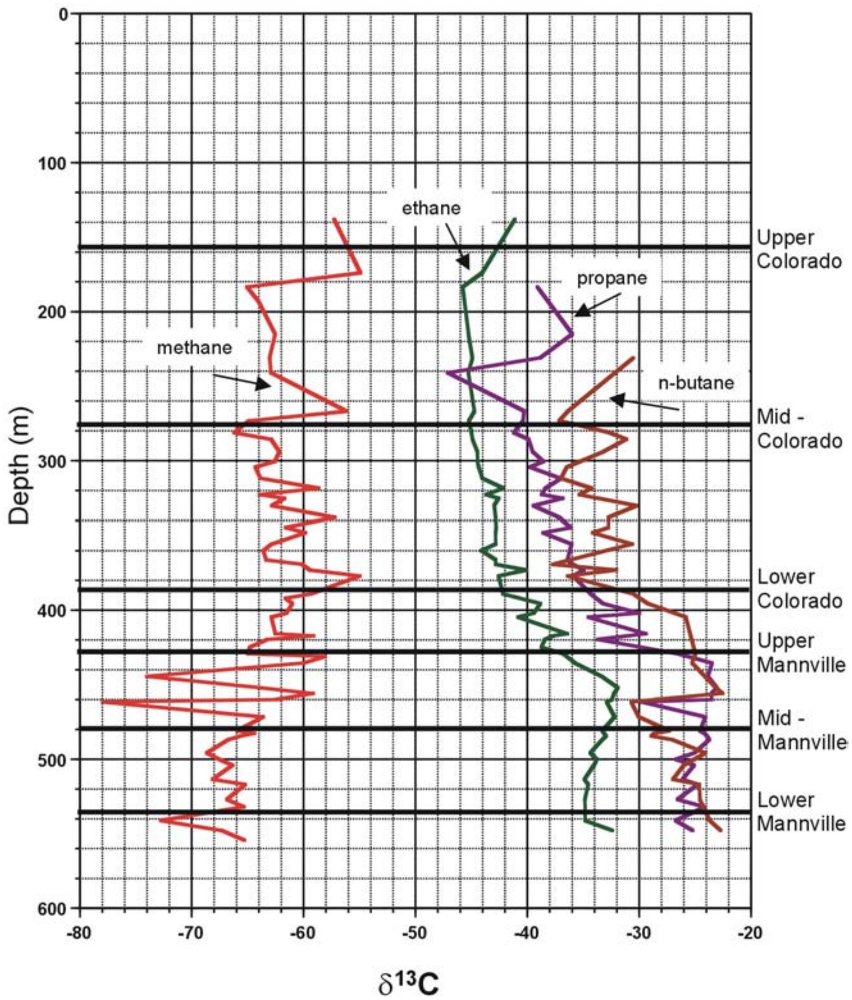

Figure 3 - Profiles of the isotopic composition of carbon in n-alkane gases collected while drilling Petrovera Maidstone 1A1-4-48-22W3.

4. Gas Classification

Gases detected in soils and surface casing vents at a wellhead may result from several origins. Biogenic gases are produced by bacteria (swamp gas) and are almost exclusively methane, although a very minor ethane component has been suggested to be present in rare instances (Whiticar, 1994). Common field practice involves using a %LEL detector that generally does not distinguish the types of hydrocarbons present so that biogenic gas could potentially be confused with active gas migration. By analyzing the molecular composition of the gas using high sensitivity gas chromatography, a biogenic source can be identified that may otherwise have been misinterpreted as being active gas migration.

Contamination by oil spills, fuels, and solvents around wellheads is present in older, established oil fields and is indicated by samples that have high contents of C_6+ compounds and greater amounts of butane and pentane relative to ethane and propane.

Natural gases associated with hydrocarbon reservoirs at depth have relative amounts of n-alkanes that decrease in the order methane, ethane, propane, n-butane, and n-pentane. Samples exhibiting this characteristic pattern of alkane contents probably have deep thermogenic sources and, where present in surface casing vents or soils around a wellhead, suggest that SCVF or AGM is occurring.

The background level of gases naturally present in soils varies according to region. The baseline level should be established for a particular area by taking samples from sites that are more than 50 m away from nearby wellheads. In this study, baseline was defined to be three standard deviation units above the average of methane and of the sum of the C_2+ n-alkanes, ethane, propane, n-butane, and n-pentane as measured in background samples. Figure 4 depicts the classification of hydrocarbon gases detected in surface casings, soils, and background at the Golden Lake Pool. Samples collected from soils around wellheads having less than baseline amounts of C_2+ components and methane are considered to be within background levels of hydrocarbons and do not exhibit AGM. Note that background samples are also included on Figure 4. Samples having high contents of methane, but low amounts of C_2+ compounds indicate a biogenic source, although none was detected during this survey. Gases collected from soils and surface casing vents that have above baseline amounts of both methane and C_2+ compounds indicate a thermogenic source, and that gas migration is occurring. Similar diagrams have been constructed to identify contamination, but are not presented in this paper.

5. Identification of Geological Source of Gas Migration

Once gases are identified as related to AGM or SCVF, the geological source must be identified to assist in downhole remediation efforts to eliminate gas migration. In the Lloydminster region, migrating gases typically do

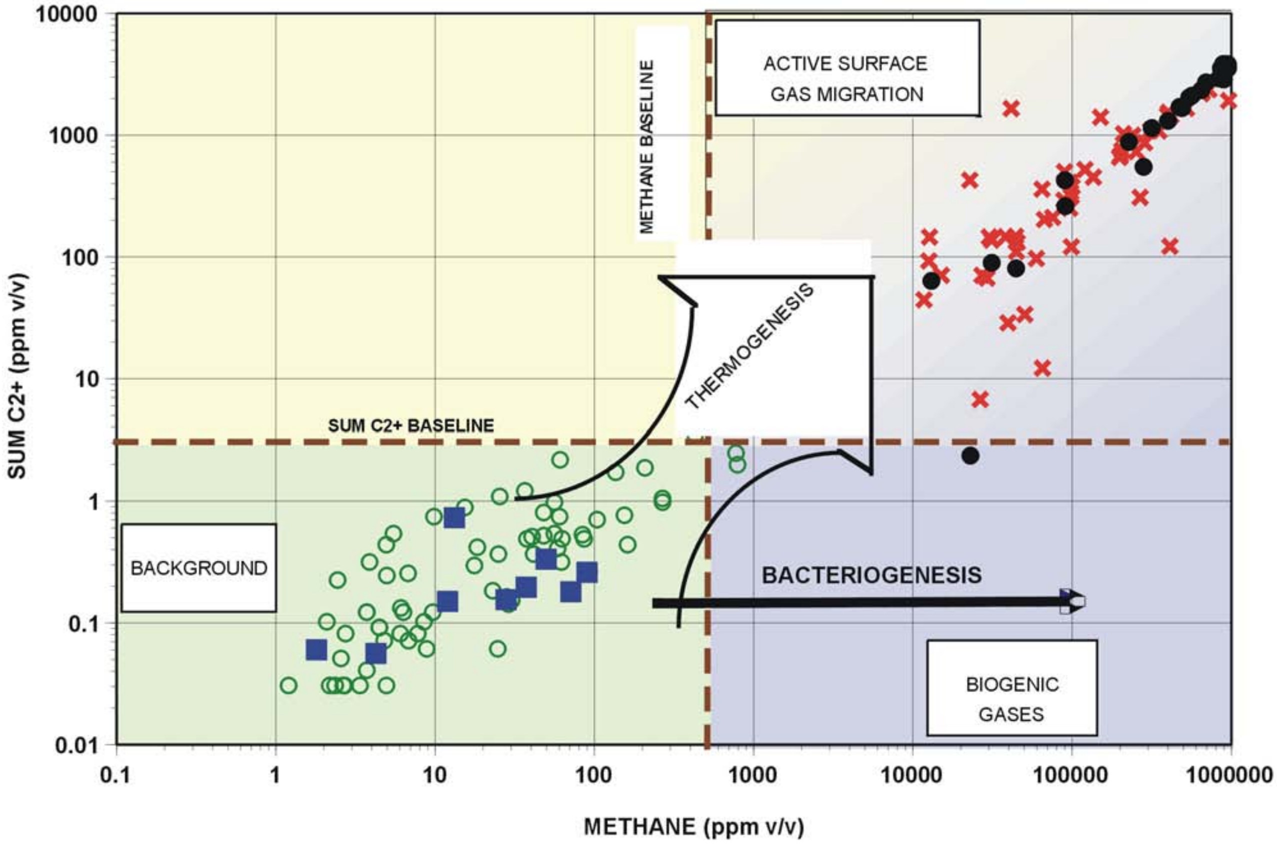

Figure 4 - Diagram showing classification of combustible gases possibly encountered in gas migration surveys. Baseline values are calculated using samples taken in undisturbed areas away from wellheads and oil field activity. Samples having high amounts of methane and heavier n-alkanes (ethane, propane, n-butane, and n-pentane) contain gas from thermogenic sources and are indicative of active gas migration. Gas samples having high methane content, but low amounts of C_2+ compounds likely result from biogenesis. Low amounts of both methane and C_2+ compounds indicate no gas migration is occurring. Open circles represent samples collected in background; solid squares are soil gas samples collected near wellbores that have no active gas migration; solid circles are surface casing samples that exhibit active gas migration; and crosses are soil gas samples near wellbores that indicate active gas migration.

not originate from the zone of production (primarily Mannville Group), but from strata at some level above this zone.

The profiles of the isotopic compositions of ethane, propane and n-butane usually show sympathetic variations with depth that may, or may not, be reflected by similar variations in the isotopic composition of methane (Figure 3). In the Lloydminster area, the heavier n-alkane molecules typically have increasing $\delta^{13}C$ values with depth through the shales of the Colorado Group and show a marked increase near the top of the Mannville Group. The distribution of isotopic compositions within alkane gases of the Mannville Group can be area specific, with $\delta^{13}C$ values remaining somewhat similar or even decreasing slightly with depth. Thus, it is demonstrated that there is a systematic variation in carbon isotopic compositions of alkane gases with stratigraphic depth.

By relating variations among isotopic and molecular compositions of n-alkane gases to the stratigraphic intervals from which the gases were collected, diagnostic geochemical signatures can be determined for individual lithological units. For example, Figure 5 shows the relation between the carbon isotopic compositions of ethane and propane and their geological formation of origin. Discrete geological intervals are shown to have unique isotopic characteristics. Thermogenic gases collected at surface in soils or surface casing vents may be compared to this template of subsurface gas compositions to identify their geological source. Other diagrams relating isotopic and molecular parameters are also used that enhance the identification of geological sources.

The isotopic composition of gases from surface casing vents of the Golden Lake Pool are displayed relative to the isotopic compositions of subsurface gases in Figure 6a. This figure indicates that the majority of leaking gases in this area are coming from beds within the mid- to upper-Lower Colorado Group, and only few are leaking from Mannville formations. Similarly, Figure 6b indicates the relation between gases collected from soils near wellheads and subsurface gas compositions. Soil gases indicate that they originate primarily from the mid to lower Colorado

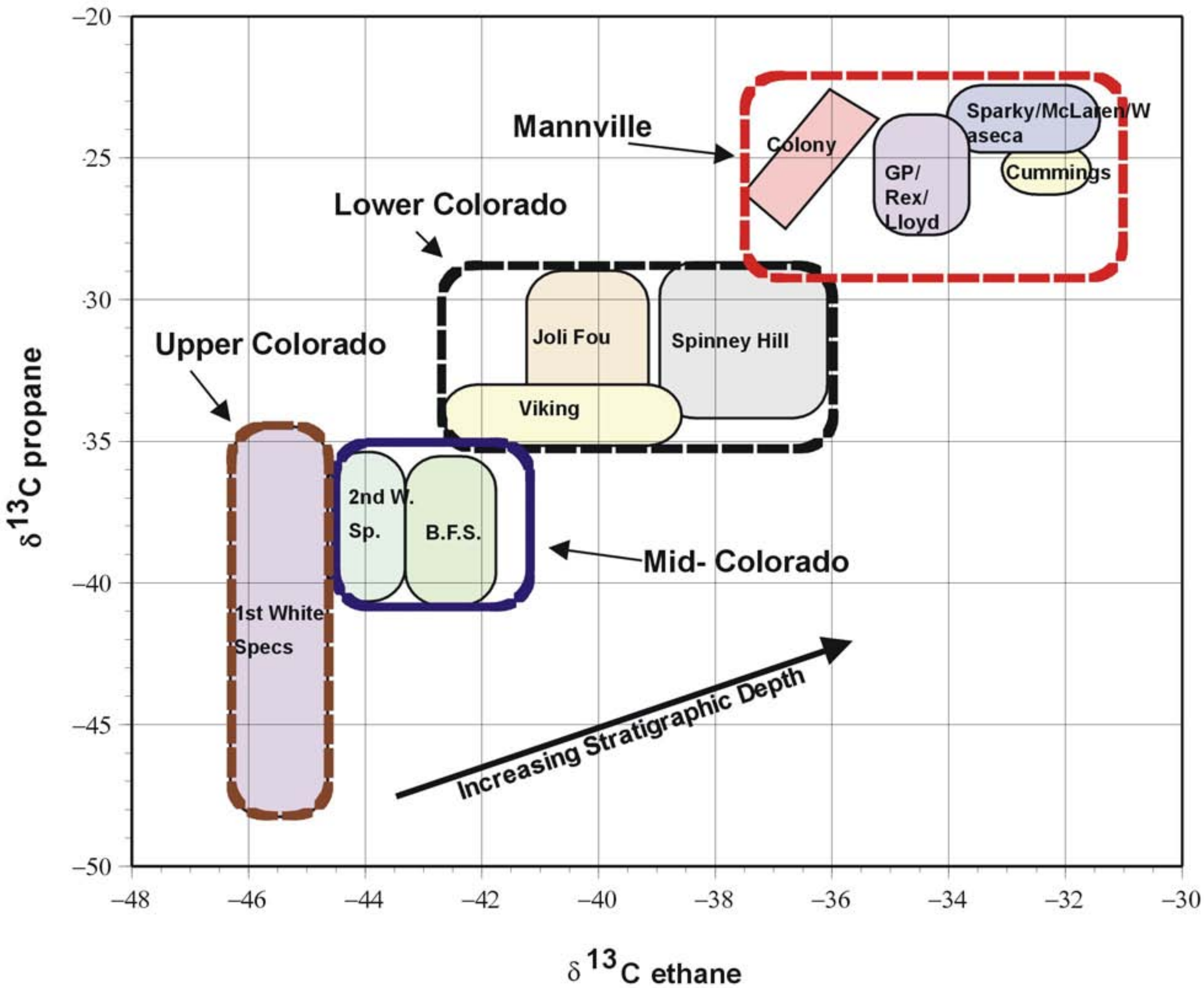

Figure 5 - The relation between the carbon isotopic compositions of ethane and propane in subsurface gases in the vicinity of the Golden Lake Pool. The geological formations from which the gas originated are shown and indicate that unique geochemical signatures exist for n-alkane gases related to their depth of origin in the subsurface. BFS, Base Fish Scales.

Group, although there is considerably more scatter observed than in gases from surface casing vents. This is because within soils is a greater likelihood for biodegradation to affect the isotopic composition of the gases (e.g. Stahl, 1980). There is also a higher potential for mixing of biogenic and thermogenic gases, and for contamination to influence isotopic compositions. The use of other distinguishing criteria not presented here can resolve some of the uncertainties exhibited in Figure 6b, although at present it is clearly preferable to use surface casing vent samples to identify the geological source of leaking gases.

Once a geological source is identified for a particular leaking well, the depth interval having the highest potential can be refined further using geophysical logs. The use of molecular and stable isotope compositions of n-alkane gases, therefore, can significantly help focus remediation efforts on the geologic interval that is the source of migrating gas.

6. Summary

Molecular and stable isotopic compositions of carbon in n-alkane gases can be used to fingerprint the geological source of migrating gases detected in surface casing vents and in soils around leaking wells. Such identification is achieved by comparing the geochemical characteristics of the surface gases to a template of the molecular and isotopic compositions of subsurface gases for the region of interest. This information can improve the success of remediating leaking wells by helping target fugitive gas sources more precisely.

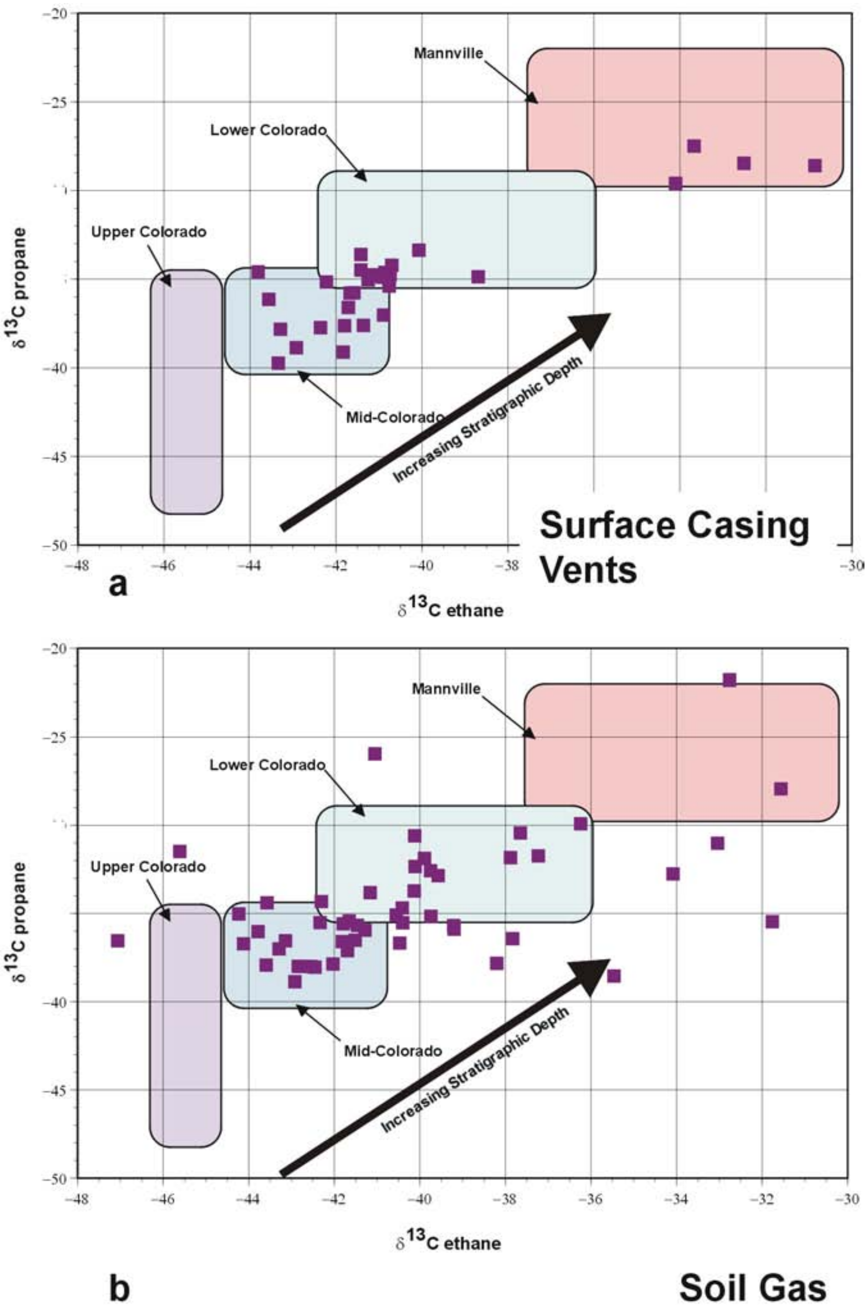

Figure 6 - a) The carbon isotopic composition of gases collected from surface casing vents in the Golden Lake Pool relative to the isotopic compositions of subsurface gases collected while drilling Petrovera Maidstone 1A1-4-48-22W3. The origins of most of the surface casing vent gases are indicated to be from mid to lower Colorado Group sources, with only minor contribution from Mannville sources. b) The isotopic compositions of gases collected from soils around wellheads in the Golden Lake Pool. These gases also suggest that they have been sourced mainly from Colorado Group rocks, although this is more uncertain than with the surface casing vent samples.

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