

GEOCHEMICAL SOIL GAS SURVEY
A Site Investigation of SW30-5-13-W2M
Weyburn Field, SASKATCHEWAN

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Date: August 27, 2010

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1. Summary

A geochemical soil gas survey of the Kerr property, which is situated in the Weyburn Field currently undergoing Enhance Oil Recovery (EOR), showed high concentrations of CO₂ that averaged about 23,000 ppm (2.3%) over most of the property and a major anomaly with concentrations as high as 110,607 ppm (11%) in the north central part of the property.

The provenance or source of the high concentrations of CO₂ in soils of the Kerr property is clearly the anthropogenic CO₂ injected into the Weyburn reservoir. Source of the CO₂ is clearly established by: (a) a stable carbon isotope ratio approximating the known ratio of the injected anthropogenic gas received by pipeline from North Dakota; (b) a major shift from baseline values; and (c) a much heavier carbon isotope ratio than for biogenic CO₂.

The Weyburn-Midale EOR project reportedly injects into the Weyburn and Midale reservoirs about 8,000 tonnes a day of anthropogenic CO₂ pipelined in liquid form from the Great Plains Synfuels Plant in North Dakota. Enhanced oil recovery as practiced at the Weyburn field has two main objectives: to enhance oil recovery and to sequester CO₂ permanently in the subsurface.

Near the potable water well NW of the abandoned residence the CO₂ concentration is about 4,300 ppm, but at 2-300 meters to the NW of the house it is 110,607 ppm (at the epicenter of the major anomaly), and within a radius of 100 meters it is 17,000 ppm, a concentration that far exceeds the threshold level for health concerns.

CO₂ could enter the home in dangerous concentrations through the crawl space due to negative pressures caused by a natural gas heating furnace. Further soil gas could be drawn into the home from warmer air rising and other mechanical exhausts such as bath fans, clothes dryers, range hoods and

water heaters. It should be noted that the concentration of CO₂ in soils near the Kerr residence could change rapidly on a daily basis because of the dynamic movement of CO₂ in the EOR operations.

To mitigate the effects of near-surface production of biogenic CO₂ and barometric pumping, samples were taken by a probe at a depth of three feet or well below the biologically active A-and B-horizon of the soil profile. The dry conditions of the well-drained till and the barren nature of the soil were also conducive to low biogenic CO₂ concentrations at the near-surface.

It can be concluded that given the lack of EOR infrastructure, only deep-seated fractures/faults can provide the means for fast-flow migration of CO₂ horizontally into the Kerr property from EOR operations in adjacent areas. Empirical data shows that CO₂ moves horizontally very quickly. Following injection of CO₂ over one month, the injected CO₂ was detected at two producing wells 100 meters and 500 meters from the injection well.

A number of fractures/faults are indicated by lineaments that crisscross the Kerr property (NTS topographic map-Goodwater). Although fault/fractures are indicated by the contours of CO₂, methane and C₂+ (Figure 6, 7 and 8), a geochemical survey of a larger area contingent to the Kerr Property could shed more light on the structural analysis and fast-flow paths affecting the flow of CO₂ into the Kerr property. Contours show that both open and closed fractures/faults exist.

The geochemical soil gas survey showed very high concentrations of methane (max 24.27 ppm) and C₂+ (max 5.94 ppm). The methane is mainly thermogenic. A high C₂+ content, a ratio of 11.64 for C₁/C₂ and a ratio of 78% for methane/total hydrocarbons all indicate three as yet undiscovered light oil reservoirs with some liquids on the Kerr property.

No leakages of light hydrocarbons or CO₂ were found around any well location including the producing oil well in the SW corner, the abandoned oil well in the SE corner and the salt water injection well NW of the Kerr home.

The survey clearly shows the usefulness of geochemical soil gas surveys in assessing EOR projects for leakage of CO₂ and light hydrocarbons and exploring for oil and gas in mature oil fields. The survey also demonstrates that the overlying thick cap rock of anhydrite over the Weyburn reservoir is

not an impermeable barrier to the upward movement of light hydrocarbons and CO₂ as is generally thought.

Petro-Find conducted a reconnaissance survey to determine the presence of petroleum at the surface. This is important from the environmental point of view and to ascertain the existence of fracture/faults that have intersected oil reservoirs at depth. Petroleum seepage and its link with major onshore and offshore oilfields all over the world are well documented.

The reconnaissance found evidence of surface leakages of liquid petroleum in the form of a blue silvery sheen around the entire circumference of the pond/pit north of the Kerr residence. It is our experience from oil exploration projects that surface oil seepages correlate with open fractures/faults that have intersected oil reservoirs. It is also possible that the oil could have entered the water table from leaking wells, improperly plugged wells, pipelines etc. either on or outside the property.

The ponds in the gravel pit north of the Kerr residence clearly exhibit anoxic conditions with heavy growth of weeds, bulrush and scum.

To establish the provenance of the observed macroseeps, five samples were taken of the sludge containing small amounts of the blue sheen. The analysis proved inconclusive - only one sample had significant petroleum C₁₆-C₃₄ hydrocarbons (34 ug/L - Tab 2). Low concentrations were expected from the analysis because the thin film of silvery blue sheen of only 1/1000 mm in thickness constitutes a very small portion of the entire sample.

2. Introduction

On May 4, Petro-Find Geochem Ltd received a Request for a Proposal from Barry Robinson, Staff Lawyer for ***Ecojustice***, a law firm representing Cameron and Jane Kerr, to conduct a geochemical soil gas survey on their property (SW 1/4 30-5-13-W2M) near Weyburn, Saskatchewan (Figure 1). The Kerr property is within the confines of the huge Weyburn Field currently operated by Cenovus Energy (Figure 2).

Petro-Find replied with a proposal May 12 that was accepted by the Kerrs around June 6. The Kerrs also agreed to go ahead with the analysis of water samples to identify petroleum in water as well as isotopic analysis of CO₂ to show the provenance of any CO₂ discovered.

Cam and Jane Kerr, owners of the property, initiated this study because they are deeply concerned about air and water pollution, which they feel has been the result of the oil activity on and in the vicinity of their property. These concerns have impacted their ability to mine an extensive deposit of sand and gravel in the NE portion of their property and have forced them to vacate the property because of health concerns.

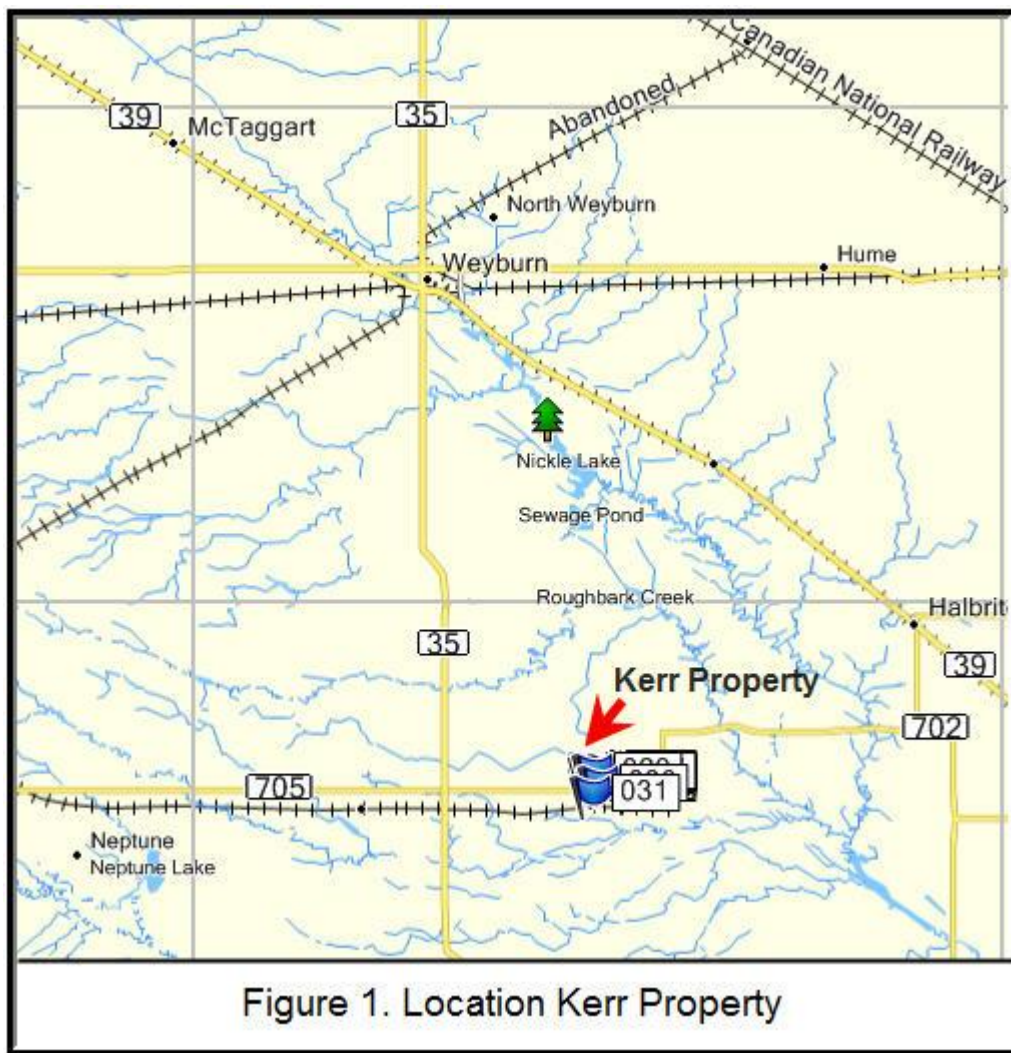
The objectives of the geochemical soil gas survey were to:

- (a) Determine the nature and source of the environmental phenomena the Kerrs have observed on their property (SW 30-5-13-W2M);
- (b) Establish conclusively if such phenomena are related to the injection of water or CO₂ utilized in the Weyburn Enhanced Oil Recovery project of the Weyburn Field; and
- (c) Determine the source of these phenomena if they are not related to the EOR/water flooding project.

Discovered in 1954, the Weyburn Field underwent primary production until 1964 when it was water injected to enhance oil recovery. Multi-leg horizontal drilling beginning in 1991 further increased oil recovery. Since 2000, oil production of the Weyburn Field has been further enhanced by a massive Enhanced Oil Recovery (EOR). The CO₂, pipelined in liquid form from a lignite gasification project in North Dakota, is injected into the reservoir at a reported rate of 8,000 tons a day (total for Weyburn and adjacent Midale fields) to reduce the oil viscosity. Water also injected into the oil reservoir sweeps the low-viscosity oil to horizontal and vertical production wells. CO₂ is separated from the produced oil and re-injected. The EOR project is currently operated by **Cenovus** (formerly **Encana**); the adjacent EOR project at Midale is operated by Apache Canada.

As part of the IEA GHG Weyburn CO₂ Monitoring and Storage Project, a consortium of companies and organizations under the management of the Petroleum Technology Research Center (PTRC) conducted five soil gas surveys (2001-2005) of a six-Section area some 2 miles north of the Kerr property. The area comprises only about 8% of the total field size of 70 square miles and only 5% of the total Weyburn and Midale fields.

One of the primary objectives of the IEA verification and monitoring study was to ascertain whether CO₂ and other gases had migrated to the surface as a result of the EOR operation. It was concluded in its final report that the



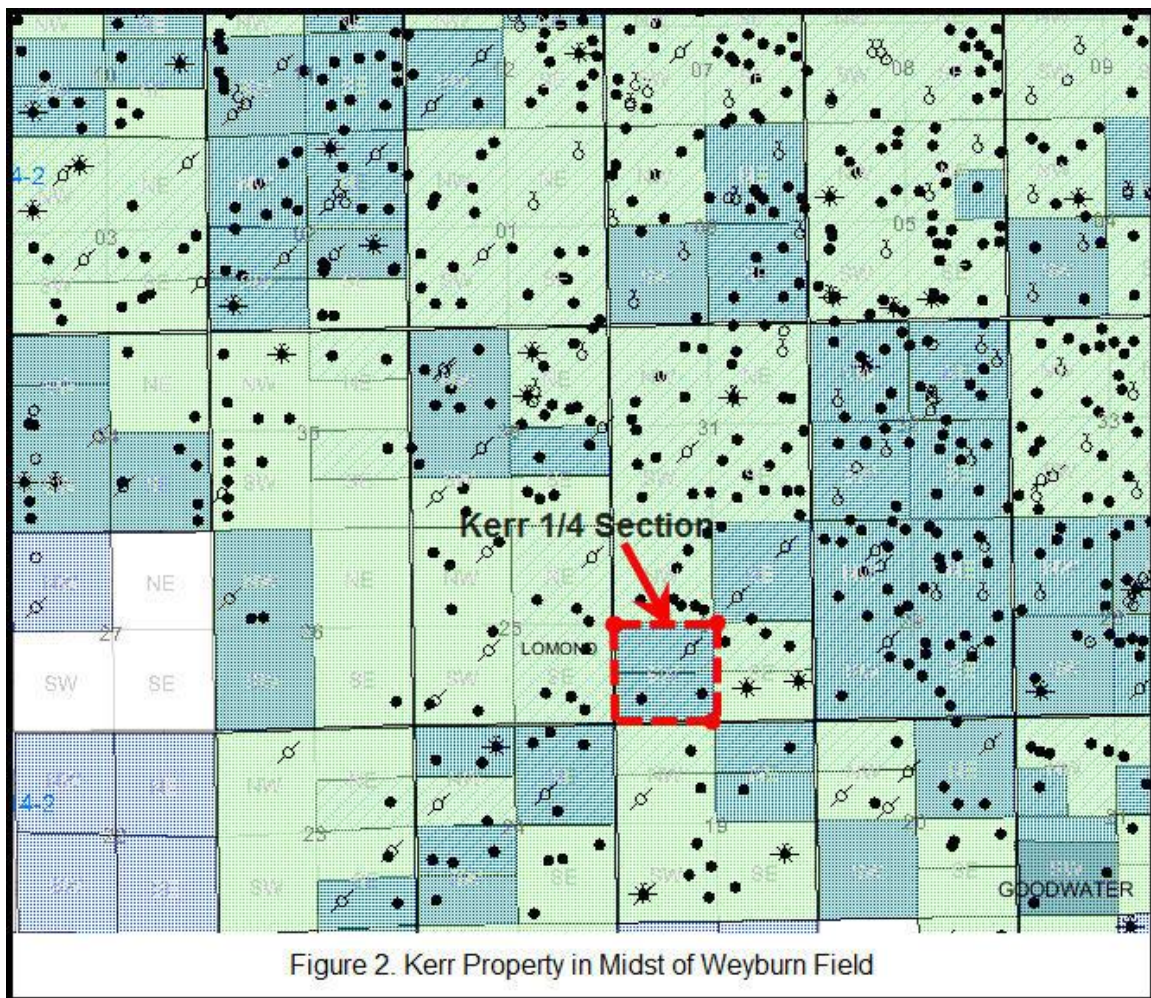
CO₂ found in soil gas was produced biogenically and there were no indications of any significant leakage of gas from depth. To the author's knowledge no geochemical surveys for monitoring purposes have been conducted in either field since 2005.

The field work was conducted by Paul Lafleur and Rudy Willick on July 29. All soil gas analysis for hydrocarbons and CO₂ was conducted in Petro-Find's laboratory by Rudy Willick (Chemical Technologist) and completed on August 6. Rudy Willick is a graduate of the Saskatchewan Institute of Applied Science and Technology in Chemical Technology. Analysis of water/sludge/blue sheen samples was completed by the **Saskatchewan Research Council** on August 18. Carbon Isotope analysis of CO₂ in vials by the **University of Saskatchewan** was completed on August 27. This report,

including the contouring of data and interpretation, was drafted by Paul Lafleur PEng, President of Petro-Find Geochem Ltd.

3. Property Description and Location

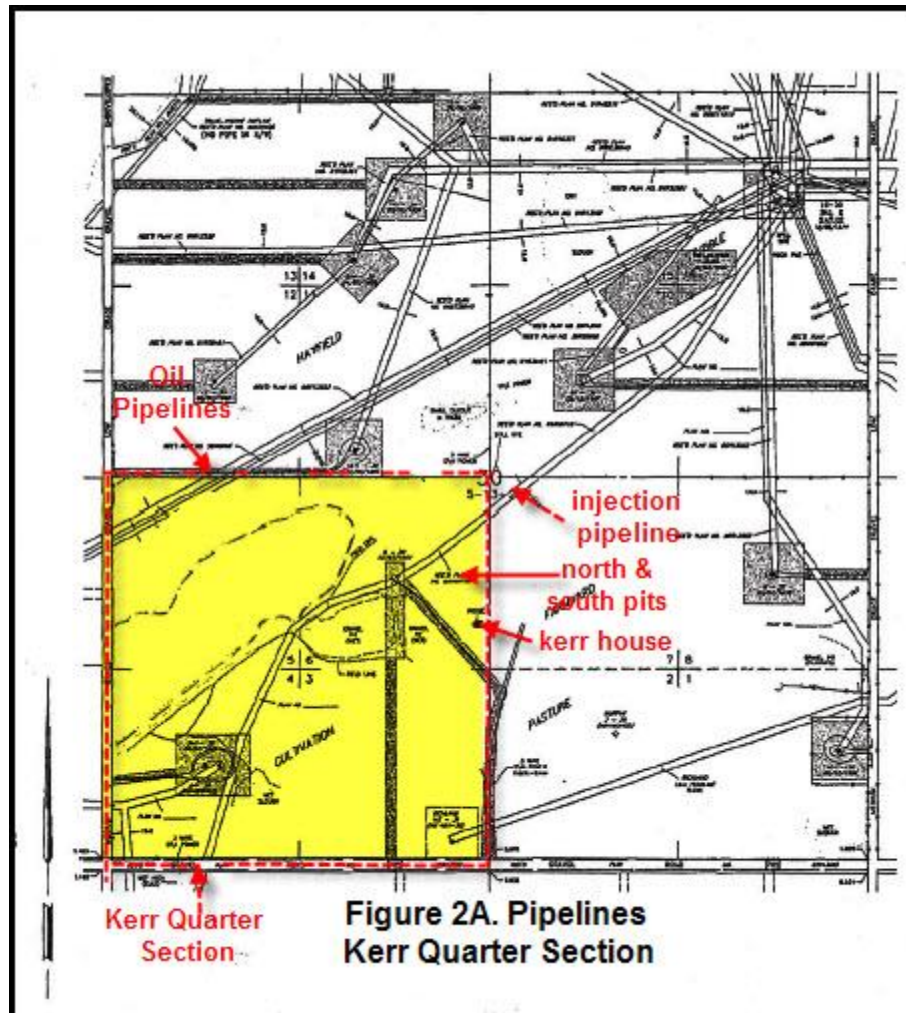
The property (SW 30-5-13-W2M) is located some 22 miles S-SE of the City of Weyburn in south Saskatchewan (Figure 1). It is enclosed on two sides – south and west - by gravel roads (Figures 2A, 2B). The property is essentially a flat till plain with an outwash of sand and gravel covering some 40 acres in the NE portion of the property.



Prominent features are two pits excavated for gravel, a large one immediately west of the Kerr house and one about one-hectare in size just north of the residence. The Kerrs commenced the excavation of the latter in July 2003. Originally there were two pits that became filled with water up to

the water table – called the North and South Ponds. The two ponds have become one pond as a result of the heavy rains that raised the water table earlier this year. This pit has progressively changed over the years and has now been overgrown with vegetation (Figures 9 and 10). The property is either pasture or under cultivation (hay) except for a major slough that traverses the property in a NE-SW direction some 200-300 meters NW of the farmhouse.

The property has: one production well with horizontal leg (in SW corner, currently operating); an oil pipeline traversing the northwest corner; one saltwater injection pipeline traversing the property from the NE to SW corners; one abandoned salt water injection well 150 meters NW of the Kerr abandoned home; two abandoned oil wells (one in the SW corner near the



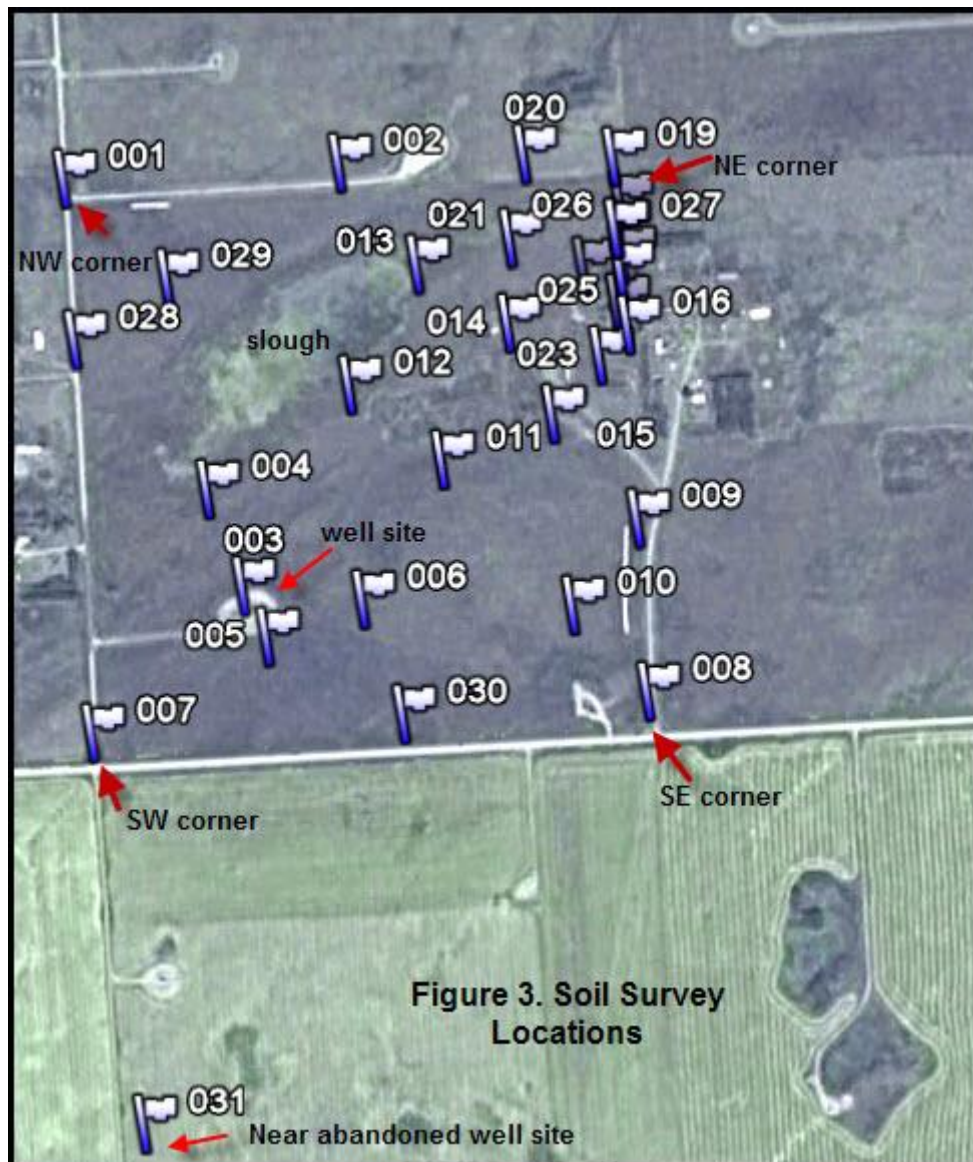
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the basement but went dry and the existing well was dug in 1981. Gas heating replaced oil heating about 25 years ago. Gas bubbles were observed in the well and sinks in the house, but SaskEnergy were unable to find any leaks (of natural gas). A multiple gas monitor was unsuccessful in identifying the gas bubbles in the well or sinks. No CO2 or CO detectors were ever used; only one for radon.

4. Methodology

The surface of the property was sampled by a proprietary probe using a cordless drill. Depth of sampling was about three feet, well below the A-zone to avoid contamination by biogenic CO₂ and methane.

A syringe was used to purge the probe of ambient air and extract a 24 cc sample, which was injected into a previously evacuated vial (to 1/5 torr or 0.0003 bar). The evacuation system is of Petro-Find's own design. To avoid any breakage in transit to Petro-Find's laboratory in Saskatoon, the vials were inserted into holes cut into Styrofoam and placed in firm boxes.



A GPS (Garmin CSX) was used to record the coordinates of each sampling point as well as various locations including the oil seep areas surrounding the pit. The GPS was loaded with a Garmin Topo Canada map for guidance in the field.

All analysis of light hydrocarbons and CO₂ was performed in Petro-Find's state-of-the-art lab at Innovation Place, Saskatoon. In the lab the septum was pierced with a syringe and 2cc was withdrawn for injection into a gas chromatograph equipped with FID and TCD detectors. The analytes were the C₁-C₅ Alkanes, C₂-C₄ Alkenes and the fixed gas, CO₂. Analysis was performed by a qualified chemical analyst using a high-end gas chromatograph. To obtain a high linear dynamic the gas chromatograph was calibrated each day with all the individual gases expected to be measured

The coordinates and analytical data were downloaded to a computer and saved as an EXCEL file. Petro-Find's state-of-the-art software program was used to produce contour maps of CO₂, methane and C₂+ (sum total of all the C₂-C₅ analytes) concentrations (Tab 4 and Exhibits 1 and 2). The scattered data points were contoured by a triangular, non-gridded computer program. All printing was done in-house to maintain confidentiality. Contours were printed on clear film for overlay on a previously prepared georeferenced base map.

Samples were taken (using special bottles provided by SRC) of the water and mud containing the blue iridescence around the edges of the gravel pit north of the Kerr residence (now abandoned). Blue iridescence, which is indicative of oil seeps from whatever source, contains BTEX which fluoresces when exposed to UV radiation at 254nm. As the survey was conducted during daylight, the mud samples were not scanned by a UV portable detector to detect petroleum. It has been well documented that BTEX compounds are highly volatile and subject to intense microbial degradation in surface environments. This factor plus their tendency to evaporate quickly suggest that their existence is short-lived once a seep has reached the surface.

The soil gas was first extracted from the vials for analysis of hydrocarbons and CO₂. Then some of the vials were sent to the University of Saskatchewan for analysis of the stable carbon isotopes C₁₂ and C₁₃ in CO₂. All mud and water samples were sent to the Saskatchewan Research Council (SRC) for analysis of hydrocarbons.

5. Geochemical Soil Gas Survey for Hydrocarbons

Geochemical soil gas surveys are ideal for the monitoring of CO₂ sequestration and EOR projects at the near-surface. The Petro-Find method is based on the sampling and analysis of light hydrocarbons and fixed gases such as CO₂ in soils that have migrated in mostly a vertical direction from underlying hydrocarbon reservoirs. The concentration patterns or surface anomalies of these microseeps can be reliably related to a petroleum or gas accumulation at depth as well as hydrocarbons/CO₂ leakages that have migrated along fractures/faults from EOR or sequestration projects.

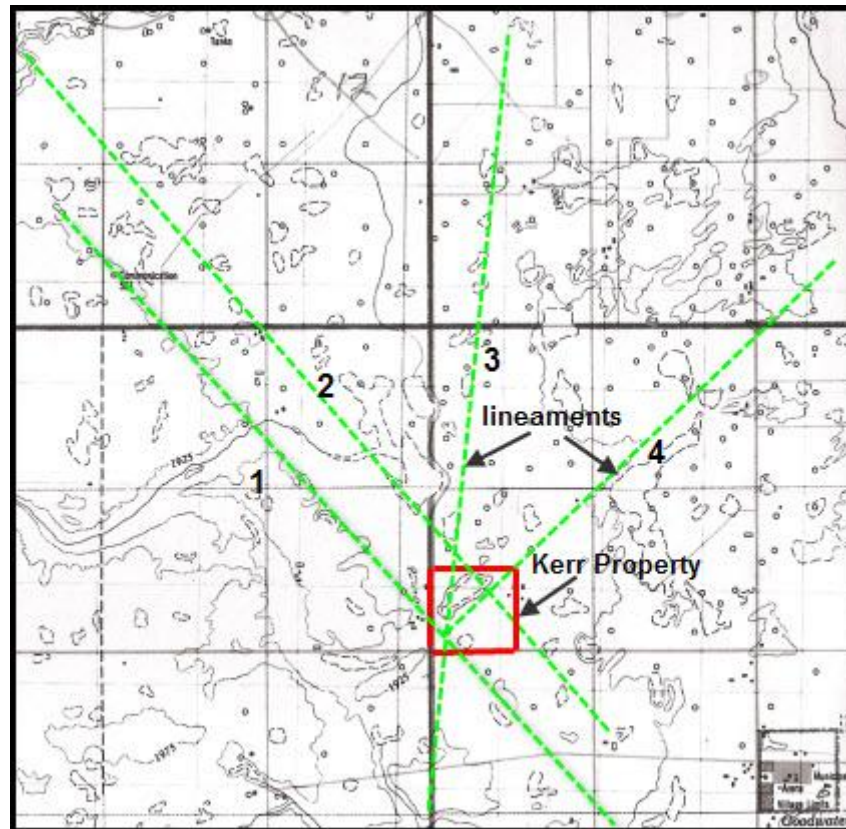


Figure 4. Lineaments- Kerr Property

The Weyburn Oil Field is, according to all reports, highly fractured with orthogonal fractures and faults running generally in a NE and NW directions. From an NTS topographic map (Goodwater) at least 4 lineaments are apparent in the Kerr property area (Figure 4). A thick cap rock of anhydrite is thought to act as a permeable barrier to the upward mobility of reservoir gases and CO₂. However, any open fractures can act as conduits for light hydrocarbons and CO₂ as well as the heavier hydrocarbons in the

form of oil to the surface. Alternatively, closed fractures act as barriers to the sweeping action of water and CO₂ flooding in EOR projects and the contours of light hydrocarbons/CO₂ in soil gas exhibit a damming effect. For example, lineament 3 (Figure 4) is a closed fracture as expressed by the contours for CO₂, methane and C₂+ (see Figures 6, 7 and 8).

The fact that the relative amount of light alkanes and alkenes in soil gas has about the same relative composition as the gas in the underlying reservoir provides a reliable indicator of the type of reservoir the anomaly represents. Some principal indicators of reservoir content are: percentage of methane (C₁) in total light hydrocarbons (C₁-C₅); ratio of methane to ethane; and ethane+ or the sum of the ethane to pentane concentrations.

In general, the near-surface anomaly or surface expression of a hydrocarbon reservoir decreases in intensity once the reservoir undergoes production because of declines in pressure.

6. Sampling and Analysis of Oil Macroseeps

Any hydrocarbon exploration of a property must take into account any signs of petroleum at the surface. These seepages or macroseeps indicate oil migration up fracture/faults that have intersected oil reservoirs at depth. Petroleum seepage and its link with major onshore and offshore oilfields all over the world are well documented.

Macroseeps are often observed as thin translucent and iridescent films on ponds, lakes, streams and muskeg. Macroseeps can easily be detected with fluorescent lamps because of their high concentration of lighter BTEX compounds. On the other hand, microseeps that have migrated from oil and gas reservoirs to the surface by diffusion and buoyancy mechanisms are microscopic and can be detected only by specialized instruments such as the gas chromatograph. Both macroseeps and microseeps rapidly disappear at the surface because of evaporation and biodegradation.

The Request for Proposal outlined various environmental phenomena observed by the Kerr family. Photographs submitted clearly showed a silvery blue sheen or iridescence on surface waters of the North and South Gravel Pits. A blue sheen, an iridescent sheen and brown color indicate a thin film of oil that is one micron, 2-3 microns and 3+ microns in thickness, respectively.

Samples containing the blue sheen are usually sent to a specialized laboratory for analysis to verify the existence of petroleum. Scanning with ultraviolet at 254nm of the blue sheen at night gives a green-yellow fluorescence, a sure indicator of petroleum. The blue sheen on water includes BTEX compounds, which do not accumulate because they rapidly disappear by evaporation and microbial degradation

7. Geochemical Soil Gas Survey for CO₂

The geochemical soil gas method using a probe is the most cost-effective tool for the surface monitoring of CO₂ leakages from EOR and other sequestration sites. Surface monitoring of CO₂ is complicated by the fact that the detection of such leakages can be masked by the relatively high concentrations of this gas in the near-surface environment. The major contributors of CO₂ in soils are microbial activity and root respiration, which fluctuate widely depending on such factors as temperature and moisture. Barometric pumping also causes wide variations in CO₂ concentrations at the near-surface (maximum 1.5 foot depth) due to an exchange of CO₂ with the atmosphere. The groundwater degassing of CO₂ derived from respiration and dissolved CO₂ from infiltrating water is also a factor. Some off-gassing of CO₂ from organic carbon in subsurface formations can also contribute to background values.

To mitigate the effects of near-surface production of CO₂, samples were taken by a probe at a depth of three feet or well below the biologically active A-and B-horizon of the soil profile. Also, barometric pumping, which causes wide swings in CO₂ concentrations at the near-surface due to an exchange of CO₂ with the atmosphere, is minimized.

The changing patterns of CO₂ and light hydrocarbon concentrations from one survey to the next are best depicted by contours. The contours are printed on clear for overlay on base maps so that they may be compared with successive surveys. A triangular, non-gridded computer program provides accurate contouring of concentrations.

Enhanced oil recovery as practiced at the Weyburn field has two main objectives: to enhance oil recovery and to sequester CO₂ permanently in the subsurface. While the enhanced oil recovery process is contributing in a major way to oil recovery, there is always a risk that this injected gas will migrate away from the primary target formation. A reliable and effective

monitoring system using geochemical soil gas surveys ensures that sequestration is a safe and acceptable method for the permanent disposal of CO₂. Repetitive surveys over a long period of time give assurances that there is no leakage to the surface.

Given ideal trapping conditions CO₂ is expected to be permanently sequestered in the subsurface. If trapping is less efficient the upward migration of CO₂ plumes can take some time to reach the surface in any concentration. In contrast, leakage can quickly reach the surface in high concentrations by means of improperly plugged wells, open fractures/faults and other fast-flow paths. If CO₂ reaches the shallow subsurface or migrates out of the ground into the ambient air, health and environmental risks can arise. A study by Mollard and Associates as part of the Weyburn study showed considerable faulting and fracturing in the area of the Weyburn reservoir (The IEA Weyburn CO₂ Monitoring and Storage Project). A lineament study of the Kerr property shows major lineaments traversing the Kerr property, an indication of fracturing and faulting (Figure 4).

The Weyburn-Midale EOR project currently injects into the Weyburn and Midale reservoirs about 8,000 tonnes a day of anthropogenic CO₂ pipelined in liquid form from the Great Plains Synfuels Plant in North Dakota. The CO₂ supply is reported to be comprised of 96% CO₂, 2.3% C₂+ hydrocarbons, 0.9% hydrogen sulphide, 0.7% methane, 0.1% carbon monoxide, and minor amounts of nitrogen, oxygen and water (Source: The IEA Weyburn CO₂ Monitoring and Storage Project; Final Report of the European Research Team; British Geological Survey; 2005).

Table 4.7 U.S. Occupational Exposure Standards (National Institute for Occupational Safety and Health, 1997).		
	CO ₂ concentration (ppm; %)	Circumstances
REL*	5,000 ppm (0.5%)	TWA*, 10-hour day, 40-hour week
STEL*	30,000 ppm (3%)	15-minute TWA
IDLH*	40,000 ppm (4%)	Immediately dangerous to life/health

NOTE: REL = recommended exposure limit; STEL = short-term exposure limit; IDLH = immediately dangerous to life and health. TWA = time-weighted average. See text for additional discussion.

Table 1. U.S. Occupational Exposure Standards for CO₂
Source: IEA GHG Weyburn CO₂ Monitoring and Storage Project

Any breakthrough to the surface can be identified by excess CO₂ in soil gas over background and by the stable carbon isotope signature, which is

different from the CO₂ found in natural gas, oil and soils (biogenic). Also, analysis of radiogenic C¹⁴ of CO₂ in soil gas that is not present in anthropogenic gas produced from lignite, can also be used to establish the provenance of the CO₂.

It is important to assess the CO₂ concentration in soils because of the possible harm to humans, flora and fauna. It is well known that human health can be impacted at very low levels. Humans can die of asphyxiation if the concentration of CO₂ in air is as little as 50,000 ppm (5%) (Source: The IEA Weyburn CO₂ Monitoring and Storage Project, Final Report of the European Research Team, 2005). This can be a major problem for homes situated over high leakage areas because of the negative pressures caused by winter heating.

In the first report of the IEA GHG Weyburn CO₂ Monitoring and Storage Project in 2004 the Recommended Exposure Limit (REL) for the workplace, based on a time-weighted average (TWA) was 5,000 ppm over a 10-hour workday during a 40-hour week (Table 1). The Short-Term Exposure Limit, a 15-minute time-weighted average of 30,000 ppm, “should not be exceeded at any time.” A 40,000 ppm concentration is regarded as “Immediately Dangerous to Life or Death”. The report further noted that more restrictive requirements might be expected for a domestic building, where people may spend a longer time indoors. For someone remaining in the home for 24 hours per day the limiting threshold is half the workday value, or 2,500 ppm.

The Minnesota Department of Health “has set workplace safety standards of 10,000 ppm for an 8-hour period and 30,000 ppm for a 15 minute period. This means the average concentration over an 8-hour period should not exceed 10,000 ppm and the average concentration over a 15 minute period should not exceed 30,000 ppm.” According to the report, the carbon dioxide itself can cause headache, dizziness, nausea and other symptoms at high levels. This could occur when exposed to levels above 5,000 ppm for many hours. At even higher levels, CO₂ can cause asphyxiation as it replaces oxygen in the blood and exposure to concentrations around 40,000 ppm is immediately dangerous to life and health.

8. Carbon Isotope Analysis of CO₂

Increased CO₂ concentration over baseline values in soils over a sequestration site is of course the primary indicator of leakage from a

reservoir undergoing EOR. The usefulness of C12 and C13 stable isotopes in determining provenance of CO₂ (i.e. whether biogenic or anthropogenic) depends largely if the isotopic ratio C12/C13 (Delta C13 or the fractional difference between a sample and a standard) of the injected CO₂ is significantly different than that of the baseline CO₂. Leakage would be indicated by a shift in this ratio.

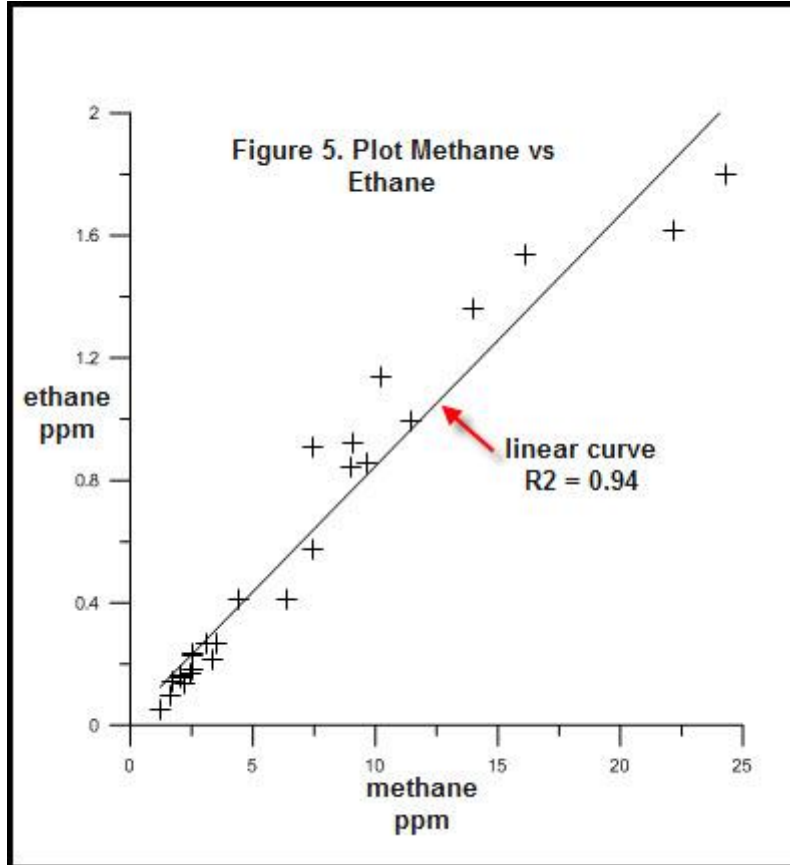
A paper – “Tracing the Fate of Injected CO₂ in the Subsurface Using Chemical and Isotopic Techniques” (Climate Change: Global Risks, Challenges and Decisions, Earth and Environmental Science 6, 2009) - is summarized as follows: “Stable isotope data can assist in successful monitoring of the fate of injected CO₂ in enhanced oil recovery and geological storage projects. This is demonstrated for the International Energy Agency Greenhouse Gas Weyburn-Midale CO₂ Monitoring and Storage Project (Saskatchewan) and the Pembina Cardium CO₂ Monitoring Project (Alberta) where **fluid** and **gas** samples from multiple wells were collected and analyzed for geochemical and isotopic compositions. In both projects, C and O isotope values of injected CO₂ were sufficiently distinct from those of background CO₂ in the reservoir. Consequently C and O isotope ratios constitute a suitable ‘fingerprint’ for tracing the fate of injected CO₂ in the respective reservoirs. The objective of this paper is to demonstrate the usefulness of isotopic tracers for geochemical monitoring of injected CO₂.”

The above referenced study went on to say: “At Weyburn baseline delta13C values of CO₂ gas (delta 13CCO₂) were between -12‰ and -14‰ The injected CO₂ at Weyburn comes from a coal gasification plant in North Dakota and has a delta 13CCO₂ value of -20.4 ‰. After CO₂ injection commenced, geochemical data revealed that CO₂ contents increased to reach 70-90 mole % at one observation well (Weyburn Well 1) after over a year of injection whilst delta13CCO₂ values steadily decreased to values near -20 ‰. In contrast, geochemical data for a second well (Weyburn Well 2) displayed only a minor increase in CO₂ concentration with time while the delta13CCO₂ values trended towards values near -20 ‰ circa one year after CO₂ injection began.”

The results at Weyburn were compared with those at the Pembina EOR project in Alberta. “At Pembina baseline delta13C values for CO₂ gas were between -16 and -18 ‰ CO₂ injected at Pembina is trucked in daily and has a mean delta13C value of -4.5 ± 2 ‰ depending on the source of the

CO₂. Geochemical data for one observation well (Pembina Well 1) revealed that CO₂ concentrations increased rapidly as CO₂ injection began to maximum values around 90% within 6 months of injection. At the same time delta13CCO₂ values increased rapidly towards values of -5 ‰. Geochemical data for a second observation well (Pembina Well 2) showed negligible changes in CO₂ concentration with time while delta13C values trended towards -8 ‰ over a period of 6 months after injection began.”

The study concluded: “Regulatory and safety issues dictate that successful CCS projects will require the ability to trace the fate of CO₂ in the reservoir... Carbon isotope ratios are an effective tool to trace the movement and reaction of injected CO₂ in mature oil fields, provided that the injection CO₂ is isotopically distinct.”



9. Results and Interpretation

A geochemical soil gas survey of the Kerr property, which is situated in the Weyburn Field currently undergoing Enhance Oil Recovery (EOR), showed

high concentrations of CO₂ that averaged about 23,000 ppm (2.3%) over most of the property and a major anomaly with concentrations as high as 110,607 ppm (11%) in the north central part of the property.

The provenance or source of the high concentrations of CO₂ in soils of the Kerr property is clearly the anthropogenic CO₂ injected into the Weyburn reservoir. Source of the CO₂ is clearly established by: (a) a high stable carbon isotope ratio approximating the known ratio of the injected anthropogenic gas received by pipeline from North Dakota; (b) a major shift from baseline values (Table 2); and (c) a much heavier carbon isotope ratio than for biogenic CO₂ (Tab 3).

Analysis of six samples of CO₂ shows Delta 13C values in the -21.6 to -22.9 range with an average of -22.0, which compares with -20.4 for the

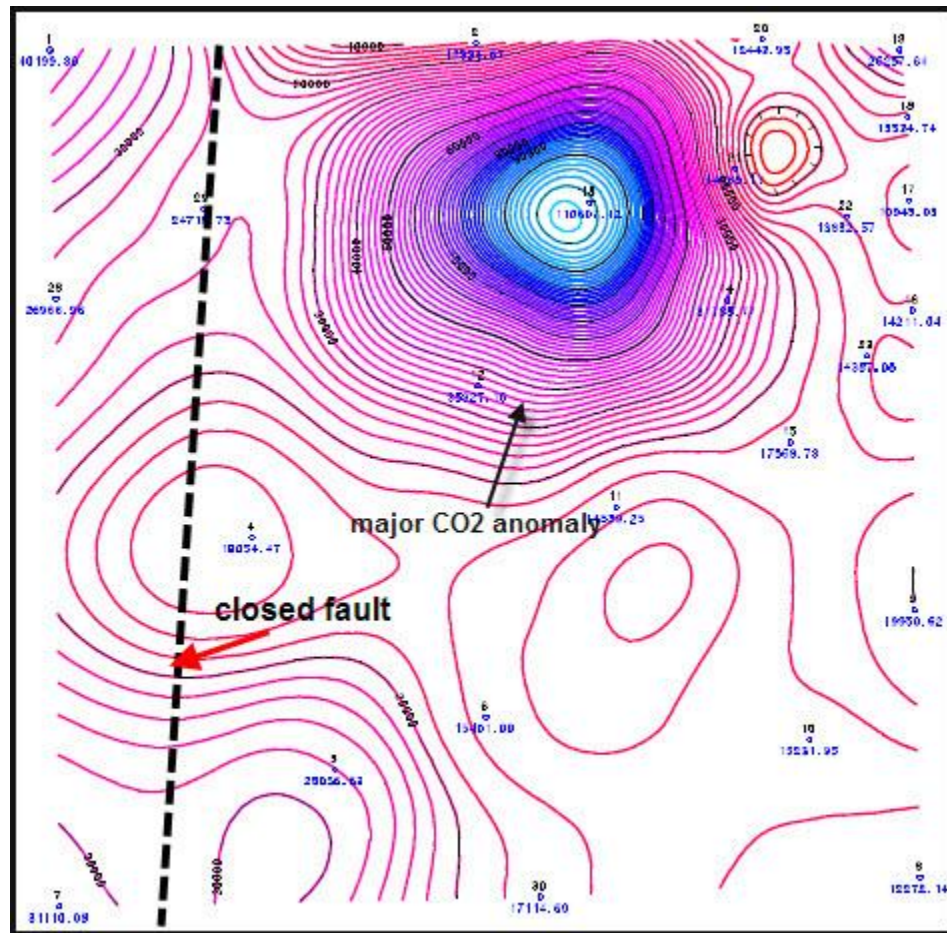


Figure 6. CO₂ Contours

injected CO₂. The average value shows a major shift from the -12 to -14 baseline values of the producing formation prior to injection of CO₂ (Table 2). An average value that is slightly lighter than that of the injected CO₂ indicates the samples contained a very small amount of biogenic CO₂ with a Delta C13 in the -27 to -28 range (University of Saskatchewan Thesis: Storage of Organic and Inorganic Carbon of Biogenic Origin in the Soil of the Parkland-Prairie Ecosystem; Dunling Wang; 1997).

To mitigate the effects of near-surface production of biogenic CO₂, soil gas samples were taken by a probe at a depth of three feet or well below the biologically active A- and B-horizon of the soil profile. Also, barometric pumping, which causes wide swings in CO₂ concentrations at the near-surface due to an exchange of CO₂ with the atmosphere, is minimized. The dry conditions of the well-drained till and the barren nature of the ground were also conducive to low CO₂ concentrations at the near-surface.

The Weyburn-Midale EOR project reportedly injects into the Weyburn and Midale reservoirs about 8,000 tonnes a day of anthropogenic CO₂ pipelined in liquid form from the Great Plains Synfuels Plant in North Dakota. Enhanced oil recovery as practiced at the Weyburn field has two main objectives: to enhance oil recovery and to sequester CO₂ permanently in the subsurface.

Near the potable water well NW of the abandoned home the CO₂ concentration is about 4,300 ppm, but at 2-300 meters to the NW of the house it is 110,607 ppm (at the epicenter of the major anomaly), and within a radius of 100 meters it is 17,000 ppm, a concentration that far exceeds the threshold level for health concerns (Table 1). The Recommended Exposure Limit (REL) for the workplace, based on a time-weighted average (TWA) is 5,000 ppm over a 10-hour workday during a 40-hour week. For someone remaining in the home for 24 hours per day, which can happen in winter, the limiting threshold is half the workday value, or 2,500 ppm.

CO₂ could enter the home in dangerous concentrations through the crawl space due to negative pressures caused by a natural gas heating furnace. Further soil gas could be drawn into the home from warmer air rising and other mechanical exhausts such as bath fans, clothes dryers, range hoods and water heaters.

It should be noted that the concentration of CO₂ in soils near the Kerr residence could change rapidly on a daily basis because of the dynamic movement of CO₂ in Weyburn EOR operations. Empirical data shows that CO₂ moves horizontally very quickly. Following injection of around 750 tonnes of CO₂ over one month, the injected CO₂ was detected at two producing wells 100 meters and 500 meters from the injection well (Source: Monitoring CO₂ During Enhanced Hydrocarbon Recovery and Geological Storage; UK Department of Trade and Industry; Issue 13, February 2007).

Table 2
Comparison Delta13C Values for CO₂ Gas between Weyburn and Pembina EOR Operations and Kerr Property

	<u>Baseline*</u>	<u>Injected CO₂</u>	<u>After Injection</u>
Weyburn SK	-12 and -14	-20.4	-20.4 (after one year)
Pembina Alta	-16 and -18	-4.5	-5, -8 (after 6 months)
Kerr Property	-12 and -14**	-20.4	-22.0 ***

Source for Weyburn and Pembina EOR data: Tracing the Fate of Injected CO₂ in the Subsurface Using Chemical and Isotopic Techniques; Climate Change: Global Risks, Challenges and Decisions, Earth and Environmental Science 6, 2009.

*Delta13C range of original formation CO₂ ** Same as baseline values for Weyburn study; *** Average analysis of six CO₂ samples from Kerr property (Source: University of Saskatchewan)

It can be concluded that given the lack of EOR infrastructure on the Kerr property, only deep-seated fractures/faults can provide the means for fast-flow migration of CO₂ horizontally into the Kerr property from EOR operations in adjacent areas. A plan of the property (Figures 2A and 2B) shows only a water injection pipeline buried four feet traversing the property in the area of the CO₂ anomaly. No CO₂ pipelines traverse the property at both the surface or reservoir levels, and the closest CO₂ injection facility is one mile away (Kerrs communication with *Cenovus*).

A number of fractures/faults are indicated by lineaments that crisscross the Kerr property (NTS topographic map-Goodwater). Although fault/fractures are indicated by the contours of CO₂, methane and C₂+ (Figures 6, 7 and 8),

a geochemical survey of a larger area contingent to the Kerr Property could shed more light on the structural analysis and fast-flow paths affecting the flow of CO₂ into the Kerr property. Contours show that both open and closed fractures/faults exist. An example of the latter is a major closed fault essentially paralleling the west road (Figures 6, 7 and 8) as evidenced by the low concentration of CO₂, methane and C₂+ along a linear pattern.

The geochemical soil gas survey showed very high concentrations of methane (max 24.27 ppm) and C₂+ (max 5.94 ppm). As the concentrations of methane correlate well with those for ethane (R²=0.94) (Figure 5), the methane is mainly thermogenic. The high-grade C₂+ anomalies suggest

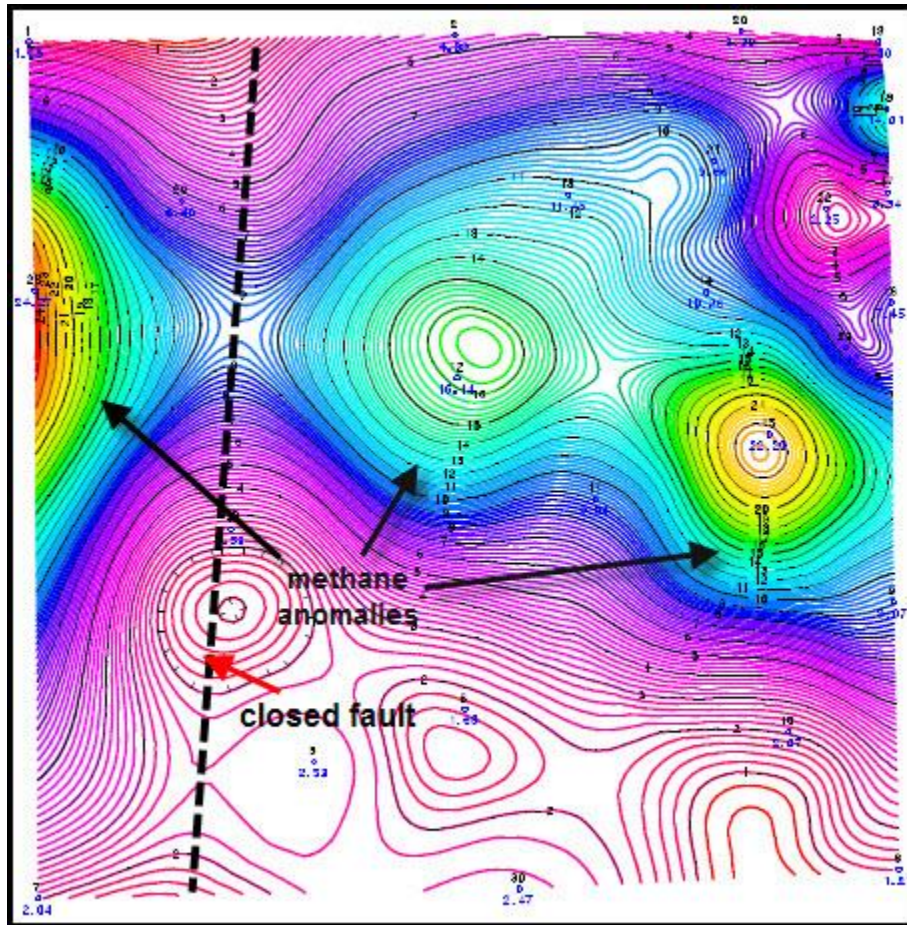


Figure 7. Methane Contours

three as yet undiscovered oil reservoirs on the Kerr property: one trending W by NW in the north (in line with an oil well just north of the Kerr property); one in the south-central area; and one on the western border (Figure 8). A high C₂+ content, a ratio of 11.64 for C₁/C₂ and a ratio of 78% for

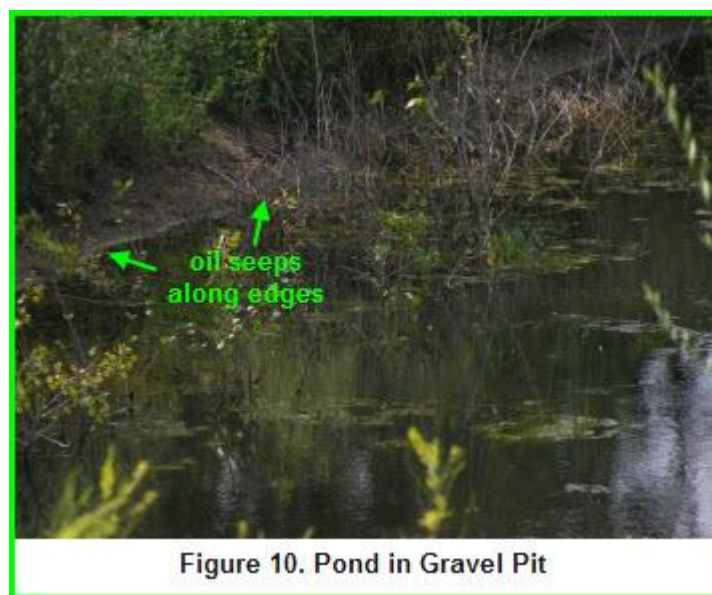
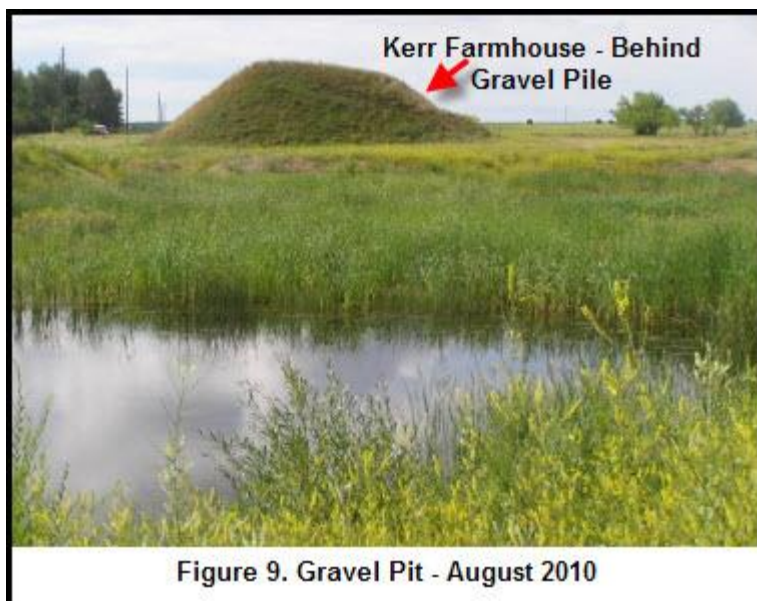
The survey clearly shows the usefulness of geochemical soil gas surveys in assessing EOR projects for leakage of CO₂/light hydrocarbons and

exploring for oil and gas in mature oil fields. The survey also demonstrates that the overlying thick cap rock of anhydrite over the Weyburn reservoir is not as an impermeable barrier to the upward movement of light hydrocarbons and CO₂ as is generally thought. The high C₂+ concentrations are consistent with known concentrations over oil reservoirs elsewhere in the Province. It can be concluded that the CO₂ and the light hydrocarbons have not only penetrated the anhydrite cap rock but have found their way to the surface in large amounts by fast-flow conduits such as faults and fractures.

Petro-Find conducted a reconnaissance survey to determine the presence of liquid petroleum at the surface. This is important from the environmental point of view and to ascertain the existence of fracture/faults that have intersected oil reservoirs at depth. Petroleum seepage and its link with major onshore and offshore oilfields all over the world are well documented.

The reconnaissance for macroseeps showed a blue silvery sheen around the entire circumference of the pond in a gravel pit just north of the Kerr residence. It is our experience from oil exploration projects that surface oil seepages correlate with open fractures/faults that have intersected oil reservoirs. In the Weyburn oil field area, which has undergone secondary (water-flooding) and tertiary (EOR) recovery for many years, it is also possible that the oil could have entered the water table from leaking wells, improperly plugged wells, pipelines etc. either on or outside the property. The ponds in the gravel pit north of the Kerr residence clearly exhibit anoxic conditions with heavy growth of weeds, bulrush and scum (Figures 9 and 10).

To establish the provenance of the observed macroseeps, five samples were taken of the sludge containing small amounts of the blue sheen. The analysis proved inconclusive - only one sample had significant C₁₆-C₃₄ hydrocarbons (34 ug/L-Tab 2). Low concentrations were expected from the analyses because the thin film of silvery blue sheen of only 1/1000 mm in thickness constitutes a very small portion of the entire sample. A UV lamp was used to ascertain if petroleum had leaked into the potable water well, but no fluorescence was observed. This experiment should be redone by lowering the UV lamp near the well water level. No other UV reconnaissance was conducted on the property because of daylight conditions.



10. Statement of Qualifications –Paul Lafleur

I, Paul Lafleur of 215 Mallin Crescent, Saskatoon, Saskatchewan, S7K7X3, phone number 306-931-3156 do hereby certify that:

I am a graduate Geological Engineer from the Colorado School of Mines and a graduate of the University of Western Ontario. I have had years of experience practicing my Profession as a geologist, engineer and mineral economist. During the last eight years I have been engaged as a Geological Engineer to conduct geochemical soil gas surveys for oil and gas. I am currently the President of Petro-Find Geochem Ltd of Saskatoon SK. Paul and Ruth Lafleur are the sole owners of the company.

I am a registered Professional Engineer with the:

Association of Professional Engineers & Geoscientists of Saskatchewan (APEGS).

Association of Professional Engineers, Geologists and Geophysicists of Alberta (APEGGA).

I have been granted permission by The Association of Professional Engineers & Geoscientists of Saskatchewan to offer my services in Saskatchewan as a Consulting Engineer/Geoscientist in the following fields:

Geological Engineering: mineral and energy economics; application of trace hydrocarbon and fixed gas analysis of soil gas to identify and characterize the presence of hydrocarbons and minerals.

The APEGS *Certificate of Authorization* for Petro-Find Geochem Ltd is ***C1406***.