[PS]Integration and Evaluation of Four Geochemical Methods for Regional Onshore Petroleum Exploration in the Mackenzie Delta, Northwest Territories, Canada*

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Abstract

A regional geochemical orientation survey was conducted over the Tuk Tertiary oil field (10-25 MMBO), Tuk Cretaceous gas field (280 BCF) and the Mayogiak Devonian oil field (4 MMBO) in the Mackenzie Delta of the Northwest Territories, Canada. The orientation survey evaluated four analytical methods to determine which, if any, could provide surface expressions of the oil & gas fields through thick permafrost (100 to 600 m). The most effective method(s) could then be used to focus cost-prohibitive seismic surveys and drilling over onshore parts of the vast Mackenzie Delta. Lake sediment and soil core samples were collected at 500 to 1,000 meter intervals on 2-kilometer spaced lines over an approximate area of 150 square kilometers. Lake sediments and soil cores were analyzed for headspace- and blender-extractable C_1-C_6 alkanes by flame ionization detection gas chromatography (GC-FID). Soil cores were also analyzed for acid-extractable C_1-C_6 alkanes (GC-FID) and C_6-C_{36} aromatic hydrocarbons by Synchronous Scanned Fluorescence (SSF).

All methods tested provided surface indications of the oil and gas fields. Thermogenic (C_2-C_6) hydrocarbons are anomalous in lake sediments and soil cores over and adjacent to the oil and gas fields. Acid-extractable C_2-C_6 hydrocarbons in soil cores provide the best discrimination between background and productive areas. Headspace C_2-C_6 hydrocarbons in lake sediments show more coherent anomalies over the Tuk and Mayogiak oil and gas fields than do blender-extracted gases. Three-ring aromatic hydrocarbons are anomalous in soil cores directly over the Tuk oil and gas fields.

The main conclusion from the geochemical orientation study over the Tuk and Mayogiak fields is that hydrocarbon analysis soil cores and lake sediments provides statistically significant thermogenic hydrocarbon anomalies over oil and gas fields at wide-spaced sample intervals, despite the thick permafrost in this region. Regional geochemical surveys for similar sized fields in the Mackenzie Delta should therefore involve the collection of lake sediments at 500 to 1,000 meter intervals for headspace C_1-C_6 hydrocarbon analysis. Lake sediments are the preferred sample medium because they can be collected at greater frequency and lower cost than soil cores. Anomalous areas should be followed up with closer-spaced (~200 meter) soil core samples for acid-extractable C_1-C_6 alkanes by flame ionization gas chromatography (GC-FID) and C_6-C_{36} aromatics by SSF.

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All methods tested provided surface indications of the oil & gas fields. Thermogenic (C_2-C_6) hydrocarbons are anomalous in lake sediments and soil cores over and adjacent to the oil & gas fields. Acid-extractable hydrocarbons in soil cores and headspace hydrocarbons in lake sediments provide better anomaly distribution and discrimination between background and productive areas than blender-extractable gas in lake sediments and headspace gas in soil cores. Three-ring aromatic hydrocarbons are anomalous in soil cores over the southern part of the Tuk oil & gas fields suggesting the ascent of heavier liquid hydrocarbons along possible faults.

The main conclusion from the geochemical orientation study over the Tuk and Mayogiak fields is that hydrocarbon analysis of lake sediments and soil cores provides statistically significant thermogenic hydrocarbon anomalies over the oil and gas fields at wide-spaced sample intervals, despite the thick permafrost in this region. Regional geochemical surveys for similar sized fields in the Mackenzie Delta should therefore involve the collection of lake sediments at 500 to 1,000 meter intervals for headspace C_1-C_6 hydrocarbon analysis. Lake sediments are the preferred sample medium for regional exploration because they can be collected at greater frequency and lower cost than the soil cores. Anomalous areas could be followed up with closer-spaced (~200 meter) soil core samples for acid-extractable C_1-C_6 alkanes by flame ionization gas chromatography (GC-FID) and C_6-$C3_6$ aromatics by SSF.

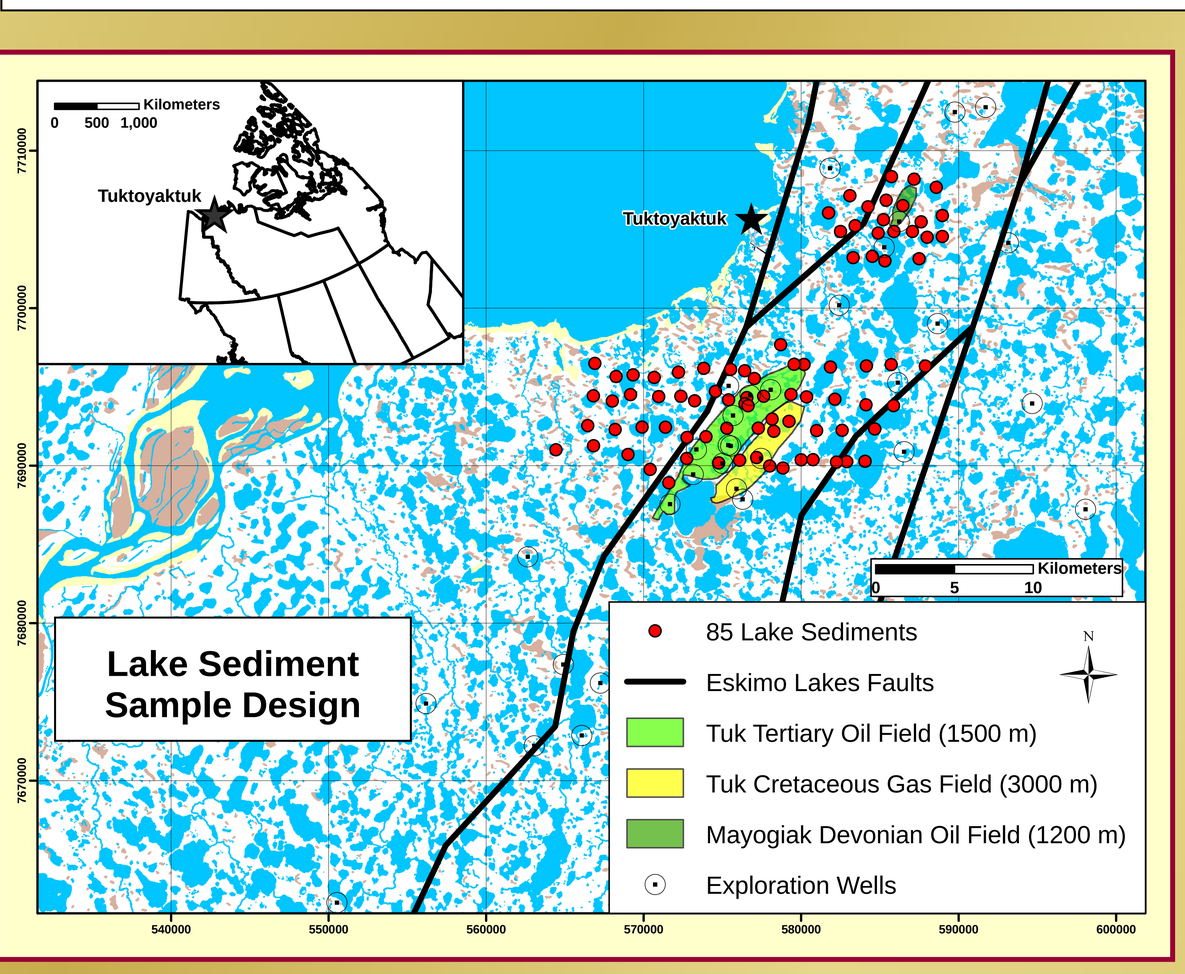
The Pleistocene glaciated terrain over the Mackenzie Delta is generally flat with a uniform distribution of periglacial lakes. Lake bottom sediments were chosen as a preferred sample medium for the study because of the uniform distribution of abundant lakes in this region. The Pingo (Eskimo name for “small hill”) shown in the photograph was formed by permafrost rise into a drained lake or river channel. Pore water is expelled in front of the rising permafrost, and the resulting pressure causes the frozen ground to rise and an ice core to form.

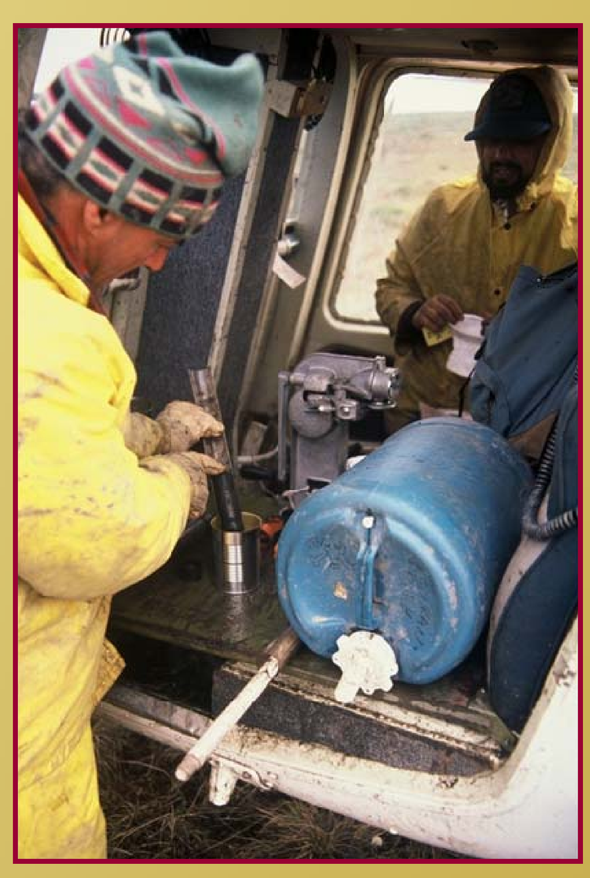
Lake Sediment and Soil Core Collection, Hydrocarbon Analysis and Interpretation and Plotting of the Data

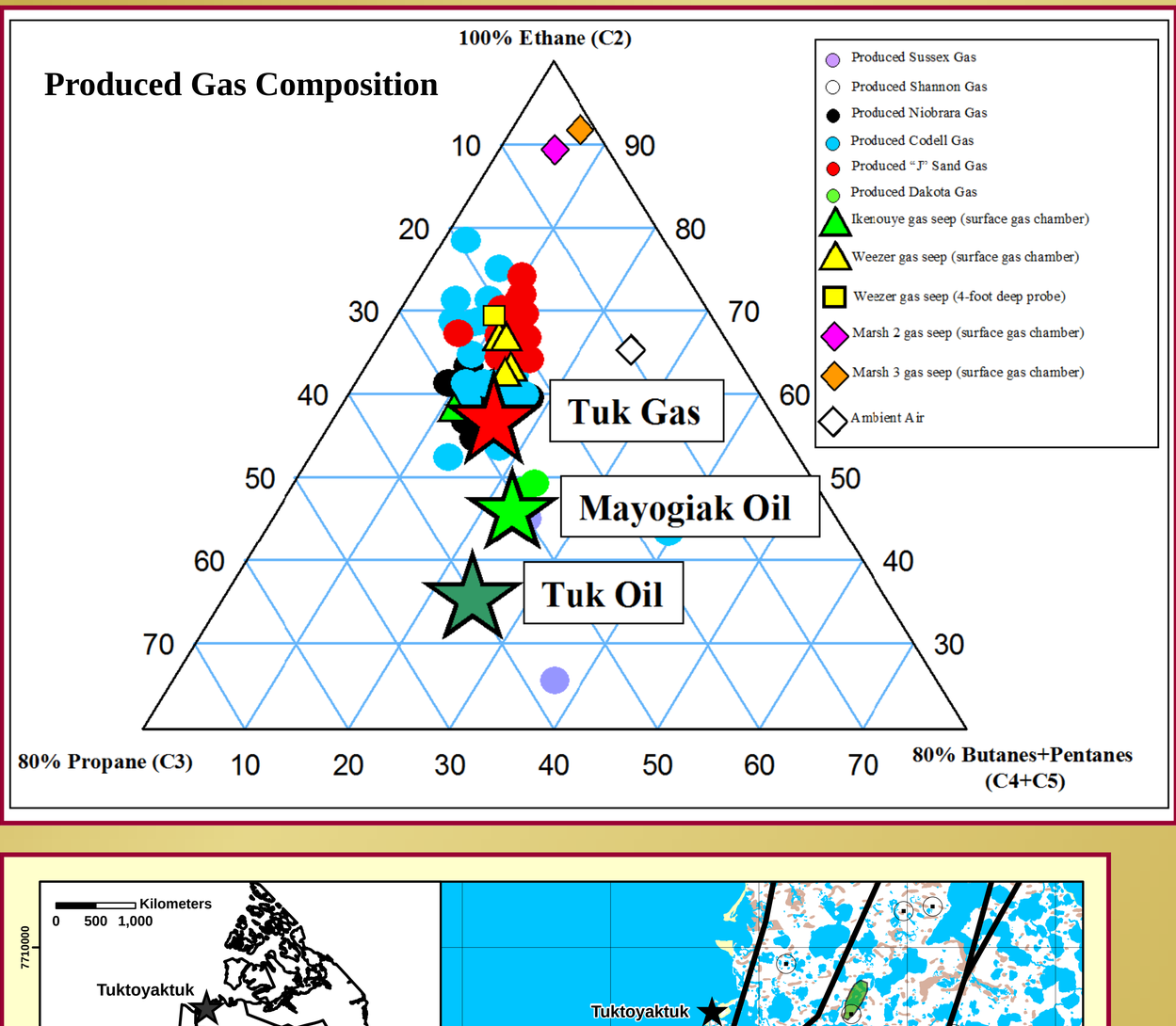
Lake bottom sediments were collected over the Tuk Tertiary oil field (1500m depth), Tuk Cretaceous gas/condensate field (3000 m depth), and the 1,200 meter deep Devonian Mayogiak oil fields in the vicinity of the town of Tuktoyaktuk, NWT Canada. A total of 85 lake bottom sediments were collected at 1-2 km intervals over approximately 150 km^2. Organic-rich lake sediment was collected from depths of 0.3 to 0.6 m below the lake floor with a 30 kg (65 lb) gravity core dropped from a helicopter equipped with pontoons. A total of 90 soil cores were taken over the Tul oil & gas fields from 1.5 meter depth by first drilling with a power auger and then a split-spoon core barrel.

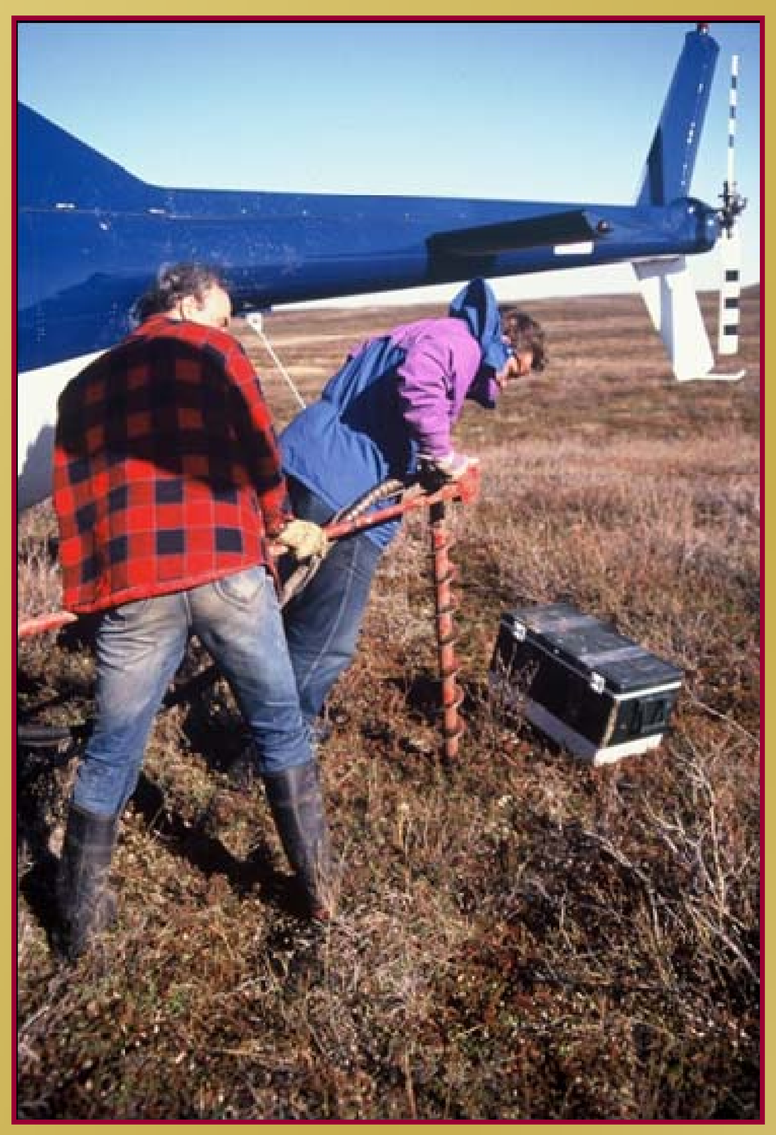
A 250 cc volume of the lake sediments and soil cores was placed in a 500cc can immediately upon removal from the core barrel. The remaining volume was filled with hydrocarbon-free distilled water and bactericide to prevent microbial degradation of the light C1-C6 hydrocarbons. The can was then sealed on-site with a canning machine, and a 100cc volume of fluid was displaced with pure nitrogen injected through a septa in the lid. The cans were frozen for storage and subsequent shipping. In the laboratory, hydrocarbons were liberated from the lake sediments and soil cores into the can’s headspace by heating (80-90 ^oC) and agitation. An aliquot of gas was then withdrawn into a syringe from the can and injected into an gas chromatograph with a flame ionization detector for the analysis of methane, ethane, ethylene, propylene, iso-butane, normal-butane, normal-pentane, and normal-hexane. After the initial headspace analysis the lake sediment and soil core samples were ground in a blender and another headspace samples was with drawn for hydrocarbon analysis. Dried and sieved splits of the soil core samples were also analyzed for acid-extractable C_1-C_6 hydrocarbons and Synchronous Scanned Fluorescence for C_6-C_{36} aromatic hydrocarbons.

The hydrocarbon data were compiled in Excel and statistically evaluated using Statistica 7.0. The thresholds between background and anomalous hydrocarbon concentrations were picked off probability plots and discriminant analysis was used to determine how well the different methods could distinguish between anomalous and background conditions over and off the oil & gas fields. Hydrocarbon concentrations were plotted as proportional symbols in ArcGIS 10.0 and canonical score plots from discriminant analysis were prepared in Statistica 7.0.









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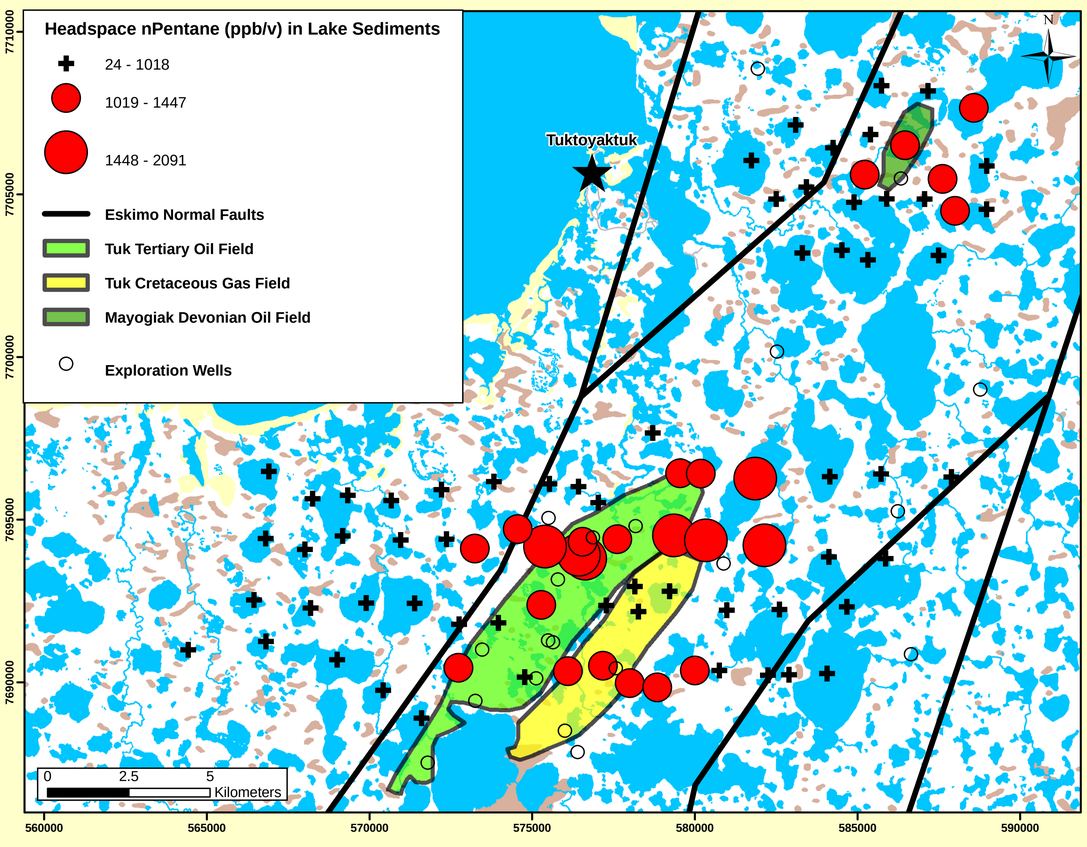
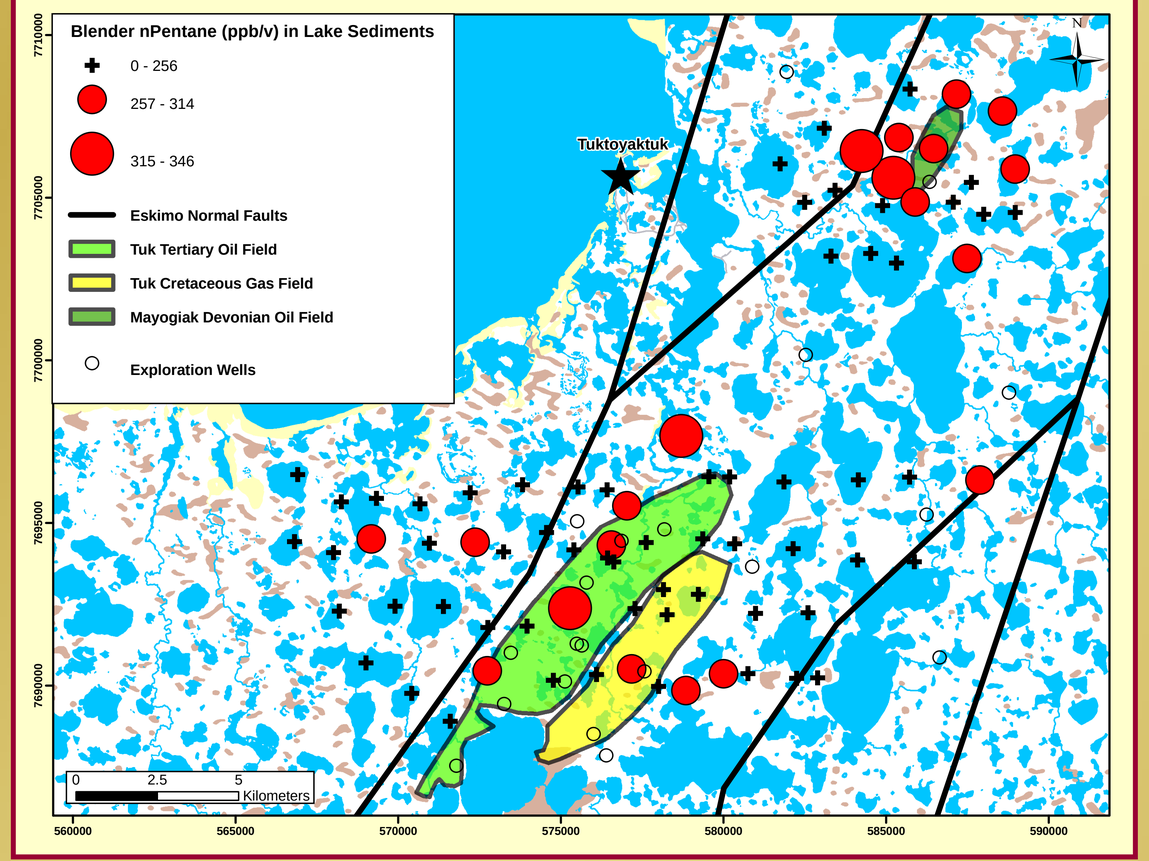
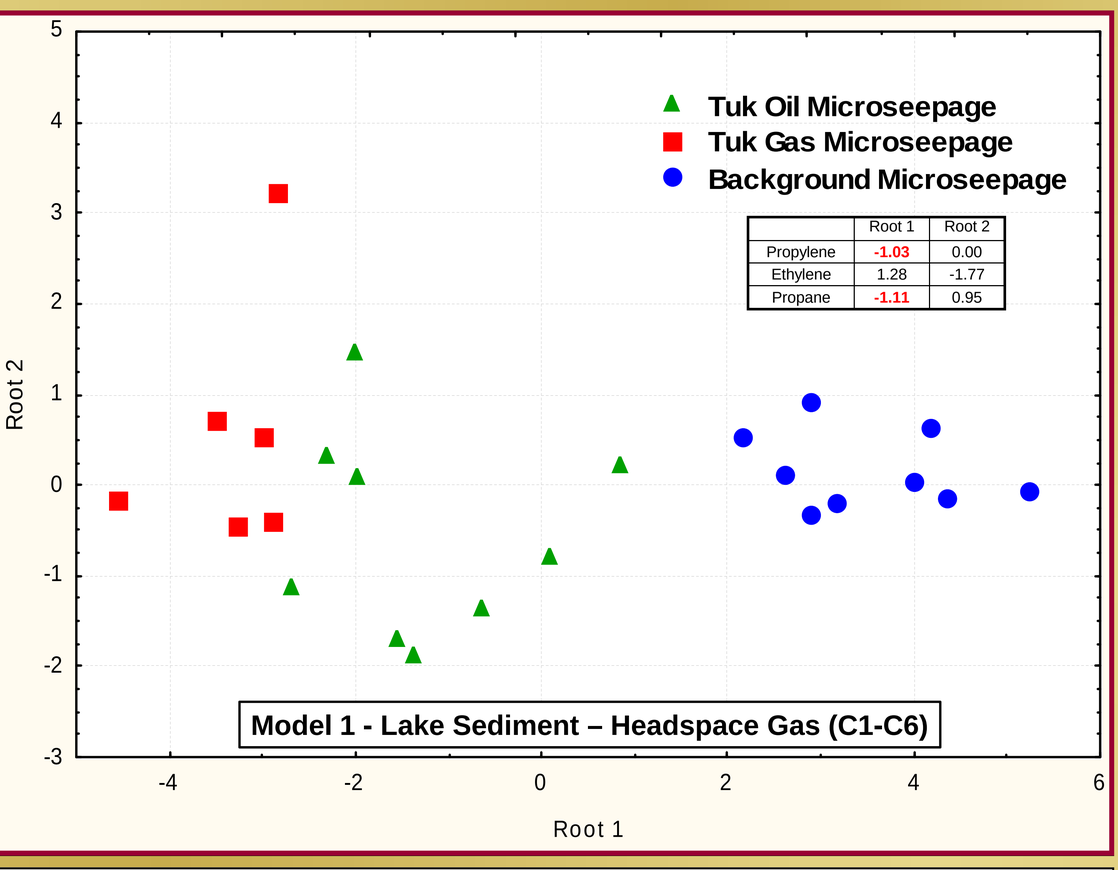


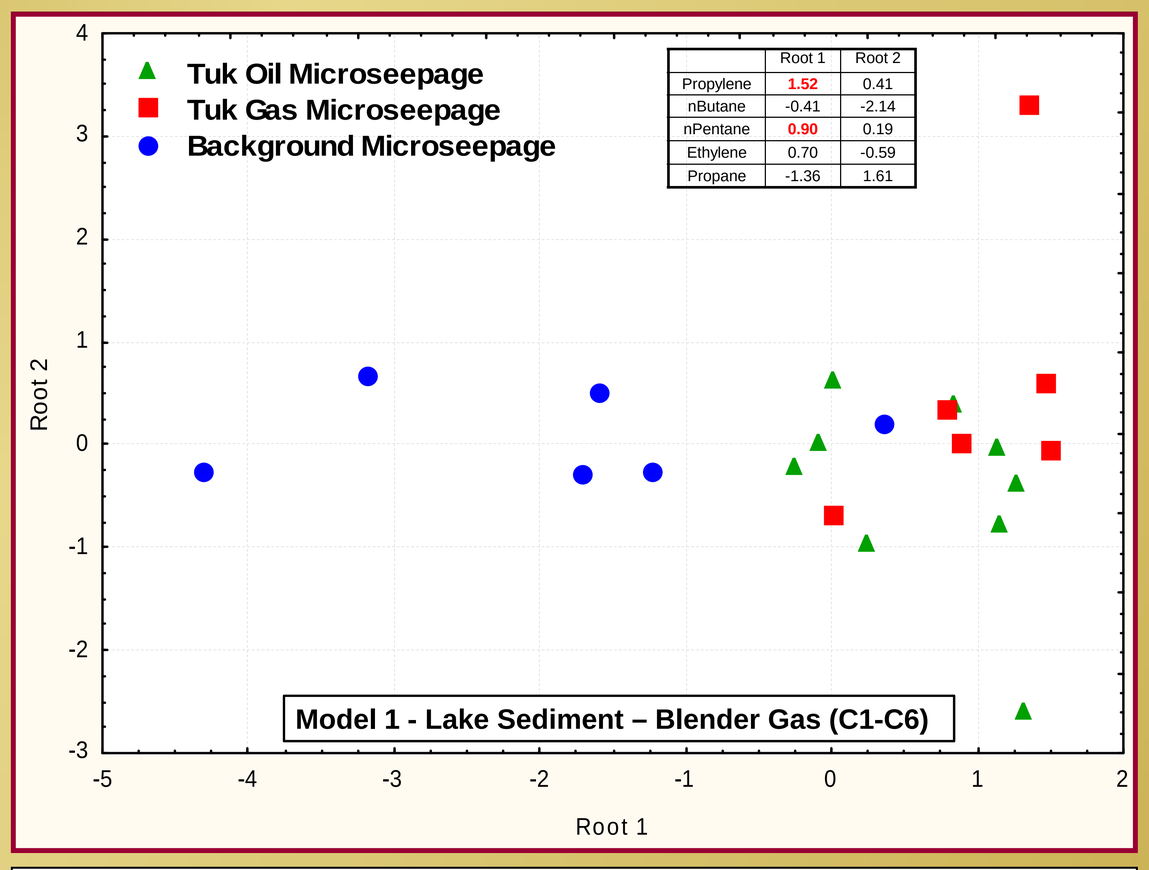
Distribution of headspace nPentane (C5) in lake sediment samples over and around the Tuk and Mayogiak oil and gas fields. There is good spatial correlation of the nPentane anomalies with the Tuk and Mayogiak oil & gas fields. Anomaly contrast is about 2.



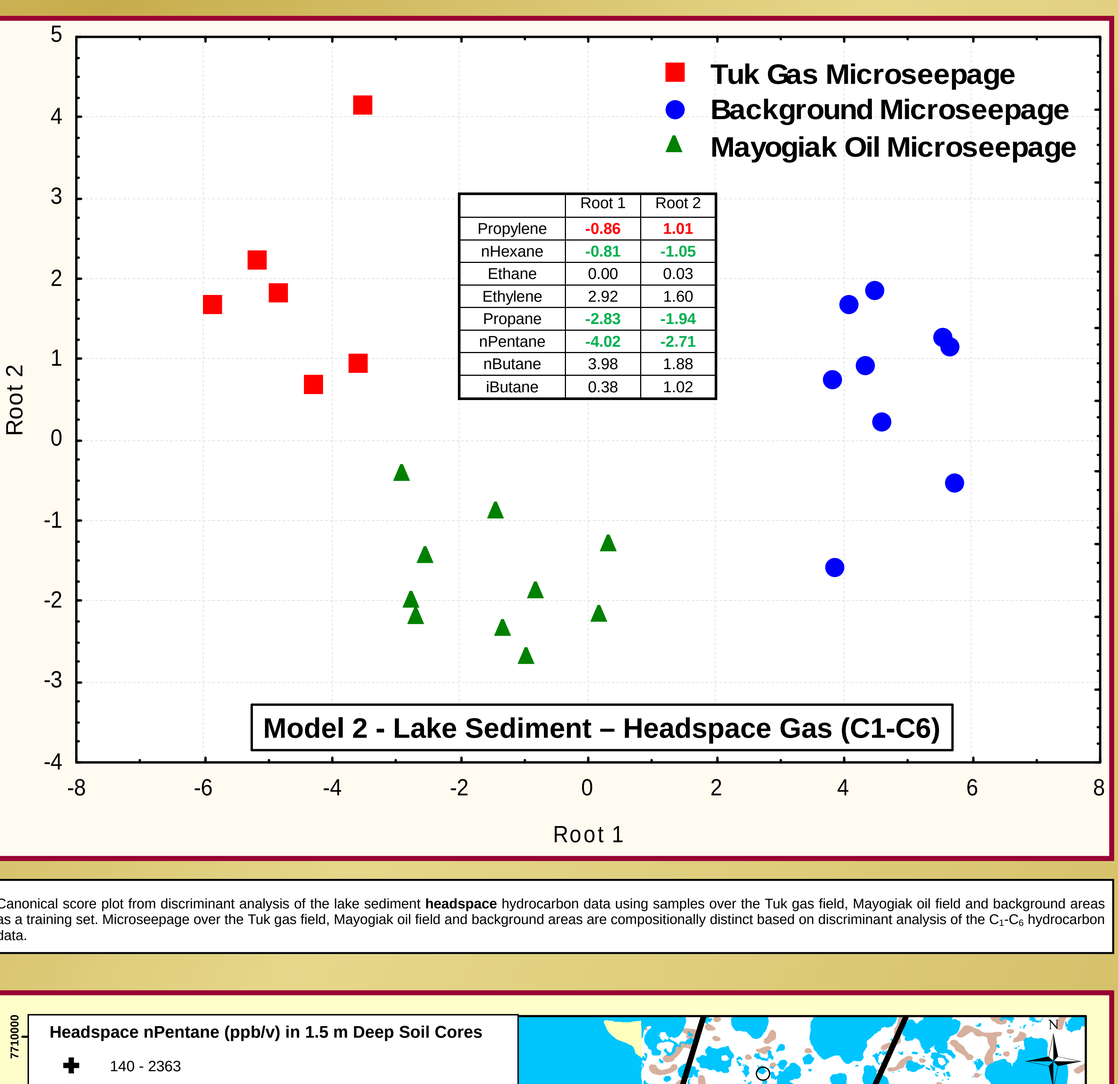
Distribution of blender-extractable nPentane (C5) in lake sediment samples. Although there is some spatial correlation of the nPentane anomalies with the oil and gas field, the anomalies are more erratic compared with the headspace nPentane results. Anomaly contrast is about 1.4.



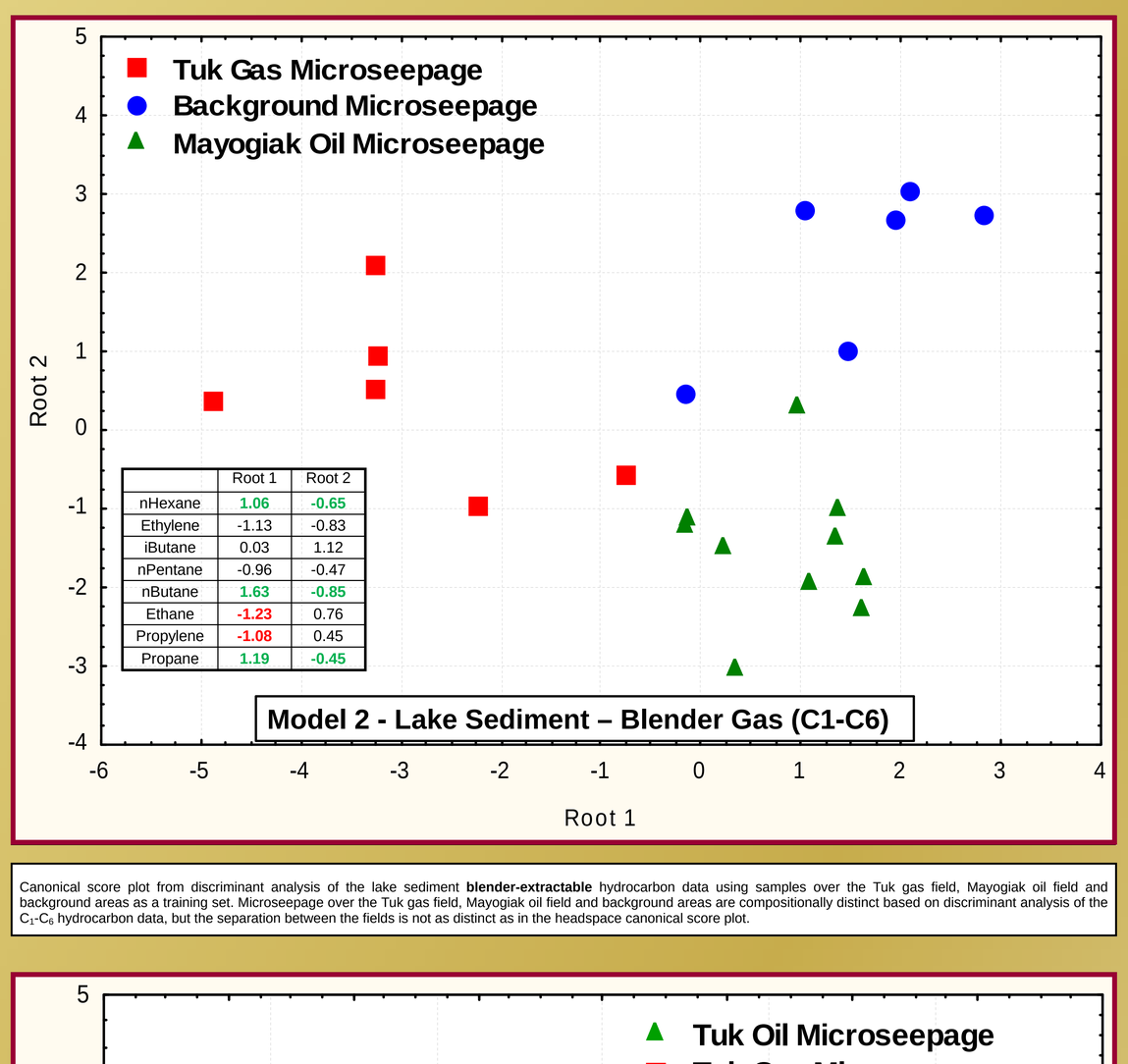
Canonical score plot from discriminant analysis of the lake sediment **headspace** hydrocarbon data using samples over the Tuk oil & gas fields and background areas as a training set. Microseepage over background and productive areas are well discriminated, but it is difficult to distinguish between the microseepage over the Tuk oil & gas fields based on the C_1-C_6 hydrocarbon data.



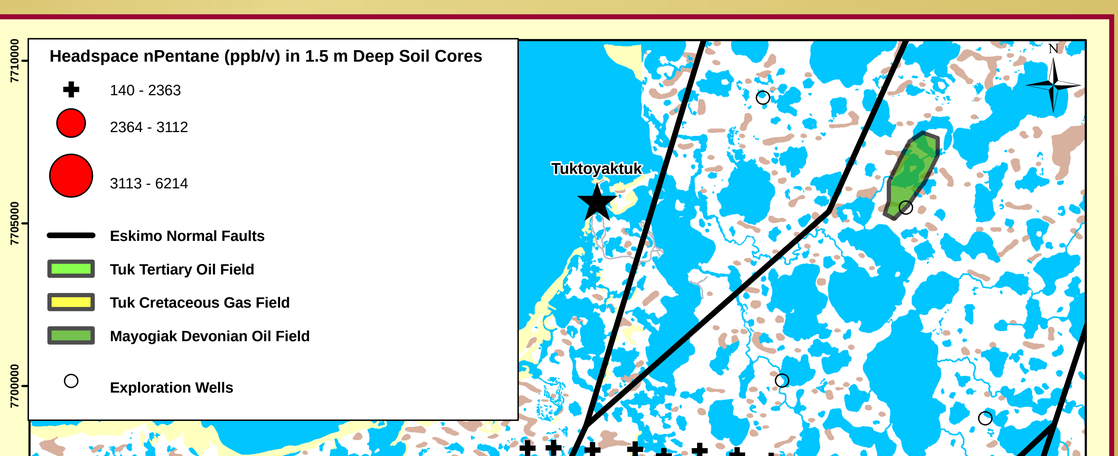
Canonical score plot from discriminant analysis of the lake sediment **blender-extractable** hydrocarbon data using samples over the Tuk oil & gas fields and background areas as a training set. Microseepage over background and productive areas are moderately discriminated, but microseepage over the Tuk oil & gas fields cannot be distinguished based on the C_1-C_6 hydrocarbon data.



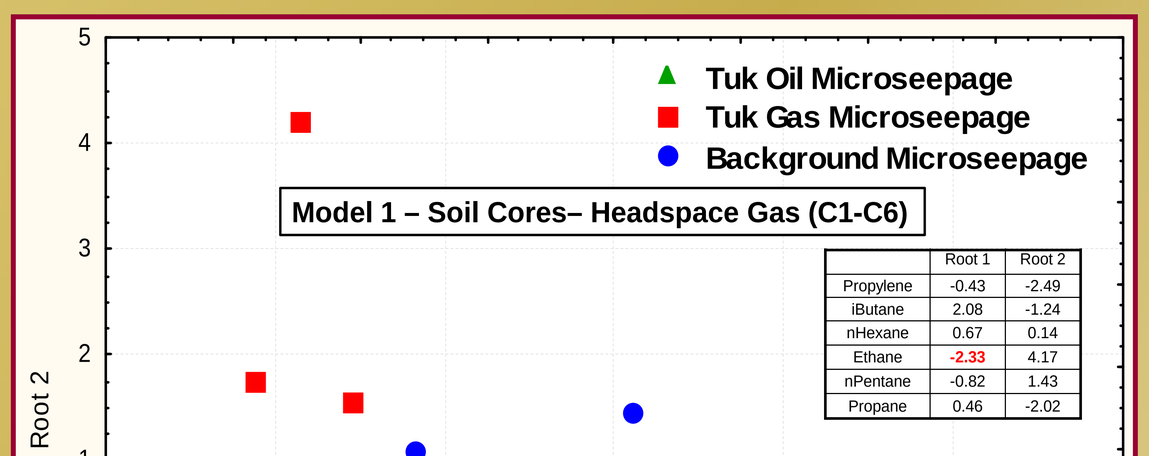
Canonical score plot from discriminant analysis of the lake sediment **headspace** hydrocarbon data using samples over the Tuk gas field, Mayogiak oil field and background areas as a training set. Microseepage over the Tuk gas field, Mayogiak oil field and background areas are compositionally distinct based on discriminant analysis of the C_1-C_6 hydrocarbon data.



Canonical score plot from discriminant analysis of the lake sediment **blender-extractable** hydrocarbon data using samples over the Tuk gas field, Mayogiak oil field and background areas as a training set. Microseepage over the Tuk gas field, Mayogiak oil field and background areas are compositionally distinct based on discriminant analysis of the C_1-C_6 hydrocarbon data, but the separation between the fields is not as distinct as in the headspace canonical score plot.



Distribution of **headspace** nPentane (C5) in soil core samples over and around the Tuk oil and gas fields. There is good spatial correlation of the nPentane anomalies particularly with the Tuk oil field and Eskimo Lake normal faults. Anomaly contrast is about 2.6.



Canonical score plot from discriminant analysis of the soil core **headspace** hydrocarbon data using samples over the Tuk oil & gas fields and background areas as a training set. Microseepage over background and productive areas are poorly discriminated, and it is difficult to distinguish between the microseepage over the Tuk oil & gas fields based on the C_1-C_6 hydrocarbon data.

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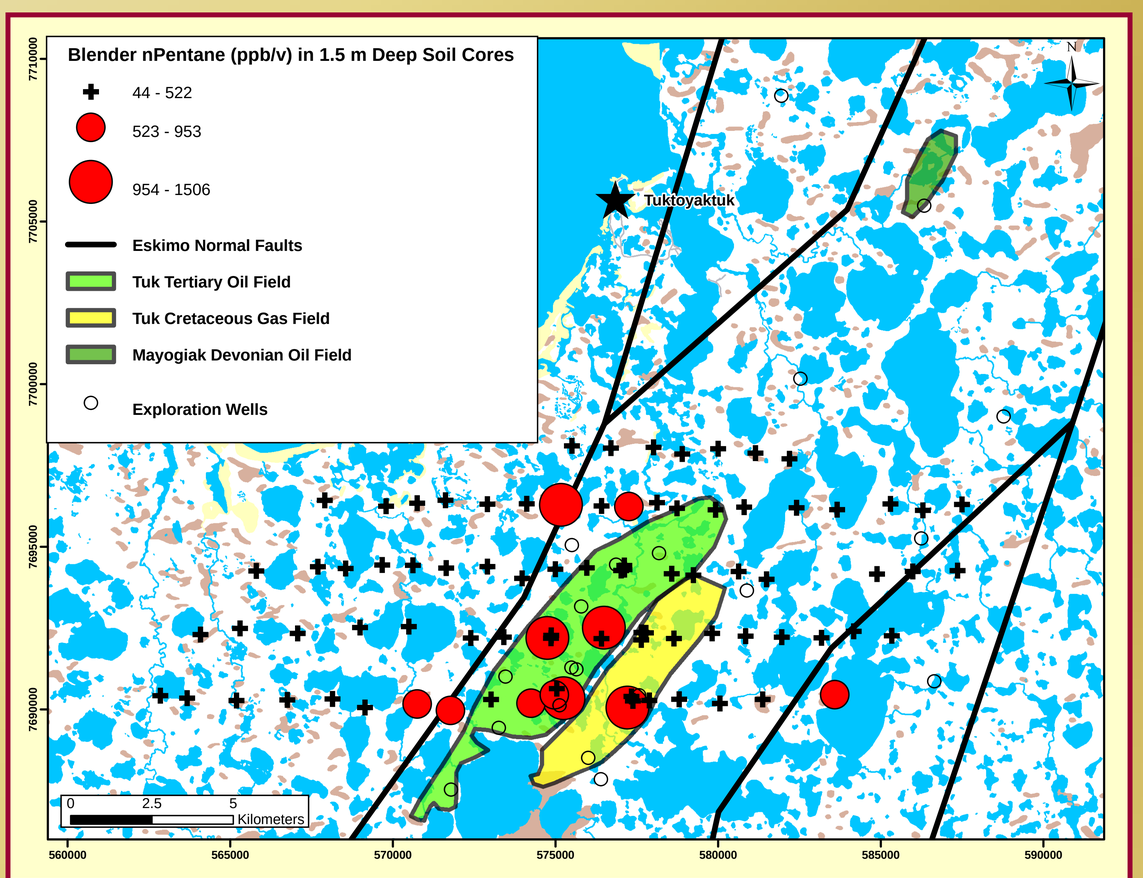
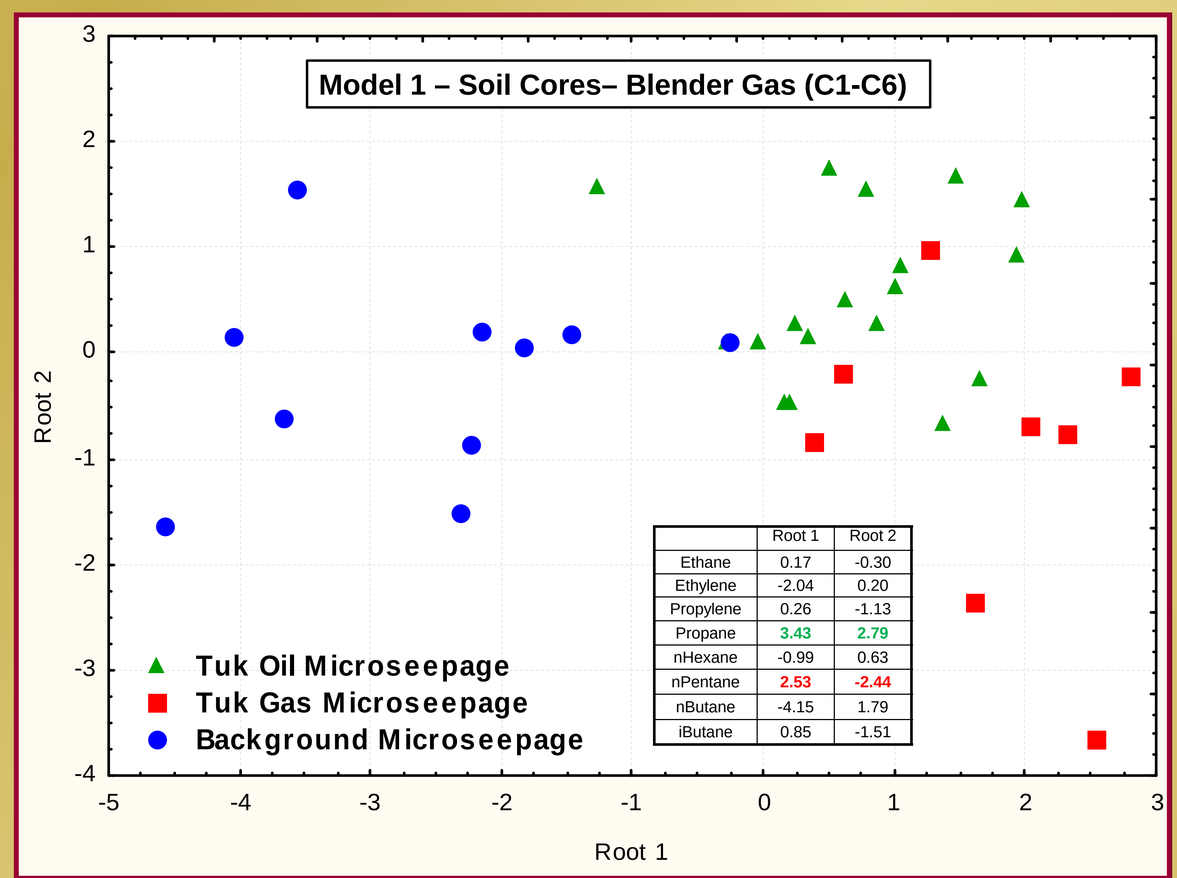
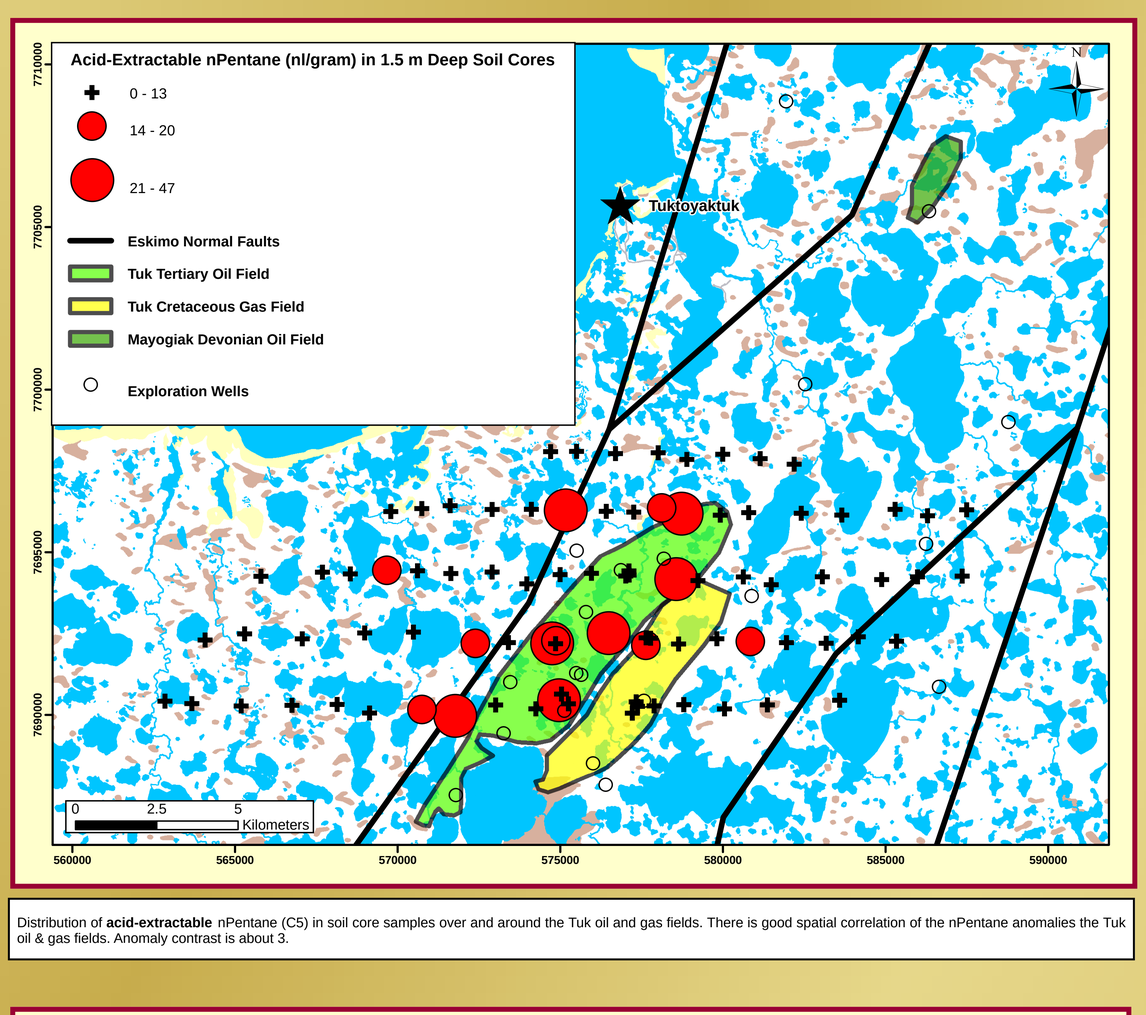


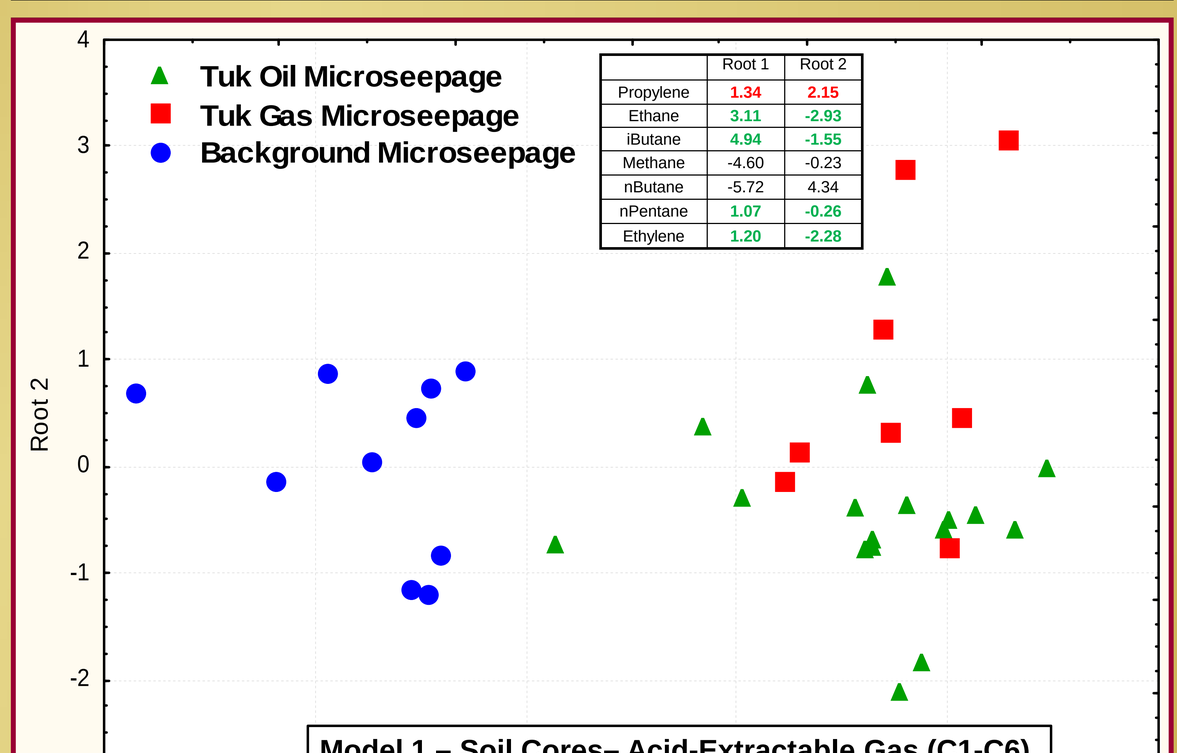
Distribution of **blender-extractable** nPentane (C5) in soil core samples over and around the Tuk oil and gas fields. There is good spatial correlation of the nPentane anomalies the Tuk oil & gas fields. Anomaly contrast is about 3.



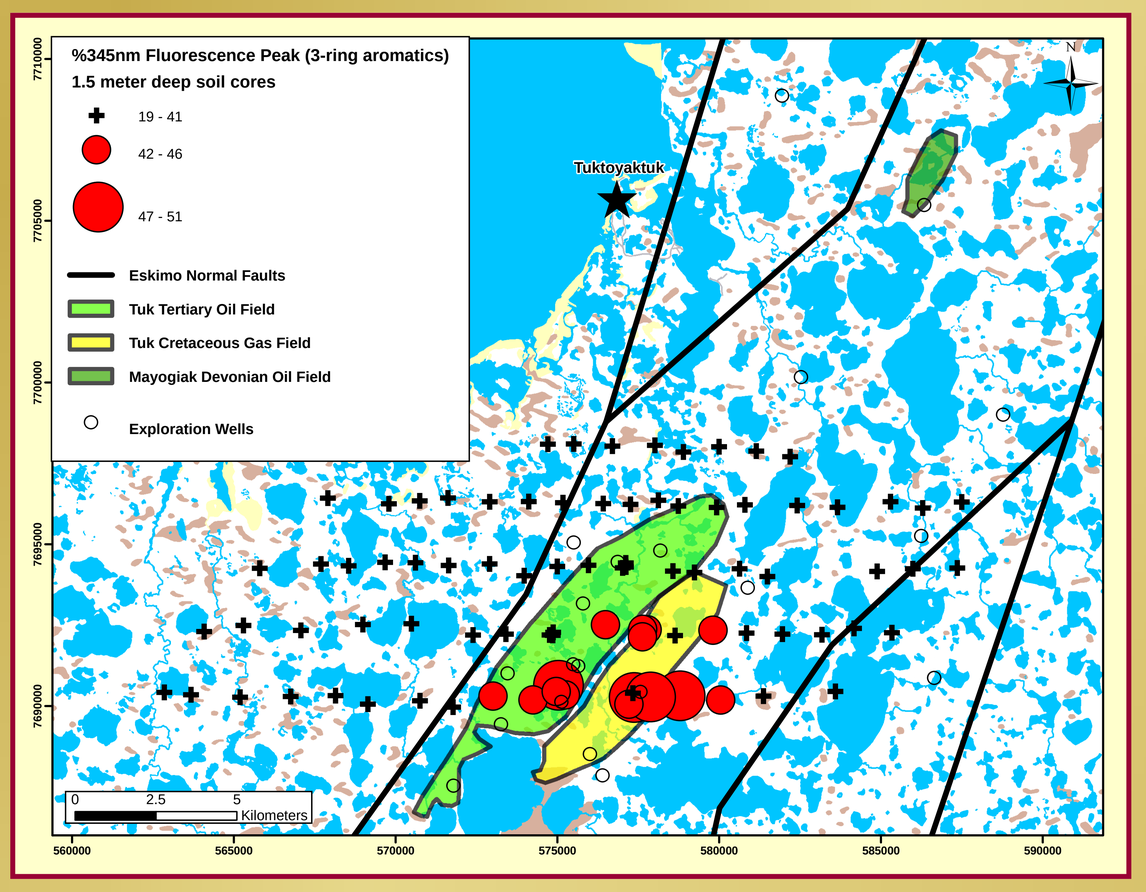
Canonical score plot from discriminant analysis of the soil core **blender-extractable** hydrocarbon data using samples over the Tuk oil & gas fields and background areas as a training set. Discrimination of the microseepage over background and productive areas is better than that shown by the headspace nPentane, but microseepage over the Tuk oil & gas fields cannot be distinguished.



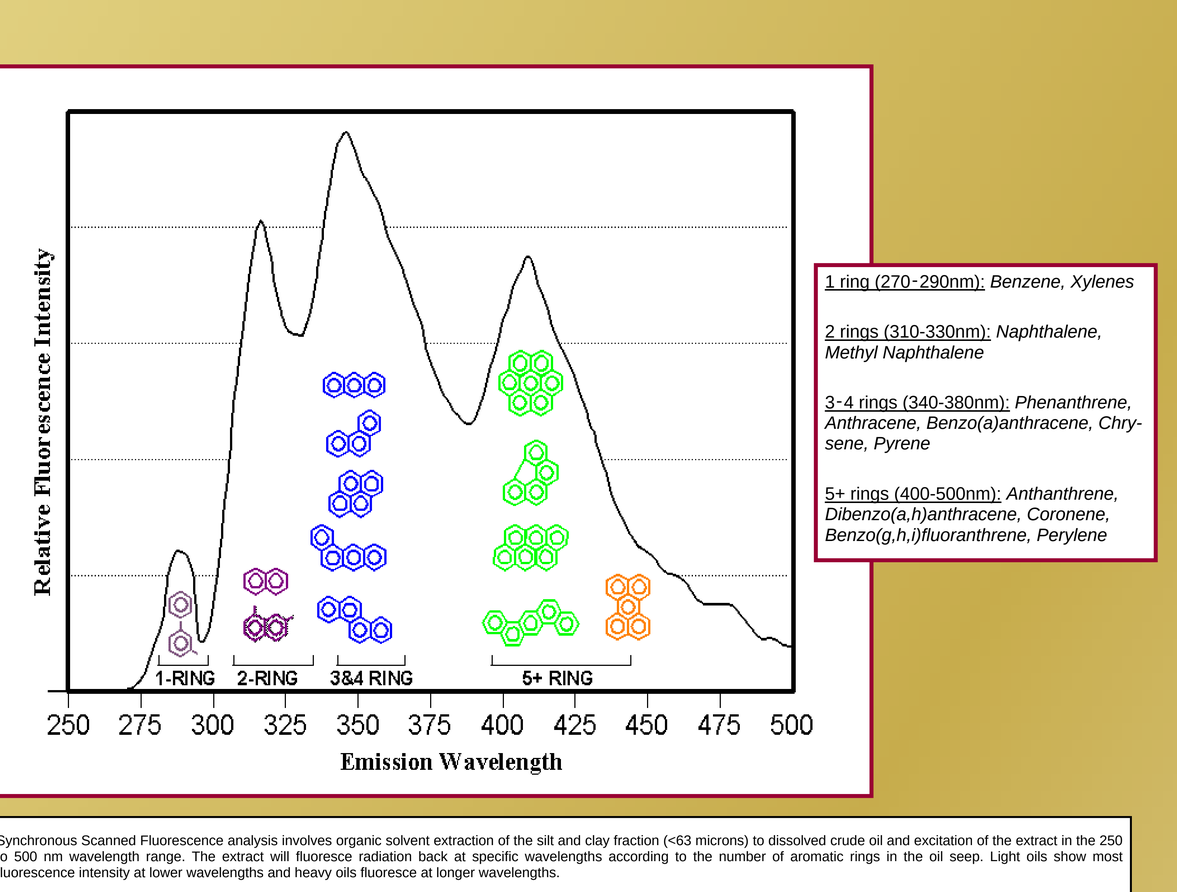
Distribution of **acid-extractable** nPentane (C5) in soil core samples over and around the Tuk oil and gas fields. There is good spatial correlation of the nPentane anomalies the Tuk oil & gas fields. Anomaly contrast is about 3.



Canonical score plot from discriminant analysis of the soil core **acid-extractable** hydrocarbon data using samples over the Tuk oil & gas fields and background areas as a training set. Discrimination of the microseepage over background and productive areas is better than that shown by the headspace nPentane, but microseepage over the Tuk oil & gas fields cannot be distinguished.



Distribution of %345 nm intensity (3-ring aromatics) soil core samples over and around the Tuk oil and gas fields. There is good spatial correlation of the 3-ring aromatic anomalies and the southern part of the Tuk oil & gas fields, possibly reflecting a fault along which heavy hydrocarbon liquids could ascend.



1 ring (270-290nm): *Benzene, Xylenes*

2 rings (310-330nm): *Naphthalene, Methyl Naphthalene*

3-4 rings (340-380nm): *Phenanthrene, Anthracene, Benzo(a)anthracene, Chrysene, Pyrene*

5+ rings (400-500nm): *Anthanthrene, Dibenzo(a,h)anthracene, Coronene, Benzo(g,h,i)fluoranthrene, Perylene*

Synchronous Scanned Fluorescence analysis involves organic solvent extraction of the silt and clay fraction (<63 microns) to dissolved crude oil and excitation of the extract in the 250 to 500 nm wavelength range. The extract will fluoresce radiation back at specific wavelengths according to the number of aromatic rings in the oil seep. Light oils show most fluorescence intensity at lower wavelengths and heavy oils fluoresce at longer wavelengths.

Conclusions

- All analytical methods tested on the lake sediment and soil core samples provide an indication of the oil & gas fields.
- The analysis of headspace gas from lake sediments provides more coherent hydrocarbon anomalies over the oil & gas fields and better discriminates between background and anomalous conditions than the blender-extractable gas. The majority of hydrocarbons in lake sediments are probably liberated from bubbles and sorption sites on organic matter, and subsequent grinding in a blender does not improve anomaly distribution or anomaly contrast.
- Acid-extractable and blender-extractable hydrocarbons in soil cores show better discrimination between background and anomalous conditions than the headspace gas method probably because the hydrocarbons are occluded in carbonates, which require release by acid-extraction or grinding.
- Regional surveys in the Mackenzie Delta and other glaciated terrains should involve the collection of lake sediments at 500 to 1,000 meter intervals for headspace hydrocarbon analysis based on:
  - ♦ The uniform anomaly distribution over the oil & gas fields.
  - ♦ Good discrimination between anomalous and background conditions.
  - ♦ More cost-effective and faster sampling method than the more labor intensive soil core sampling method.
  - ♦ Thawing permafrost under the lakes probably provides more permeability for hydrocarbon migration.
- Anomalous areas could be followed-up with soil cores taken at shorter (200 meter) intervals for fluorescence and acid-extractable hydrocarbon analysis to confirm the lake sediment anomalies.
- The sampling and analysis of lake sediments and soil cores for hydrocarbons represent cost-effective methods for pre-screening large areas within the Mackenzie Delta to focus more costly seismic surveys and drilling.