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METHANE TRANSPORT AND DEGRADATION AT NATURAL GAS VENTING PILOT SITES

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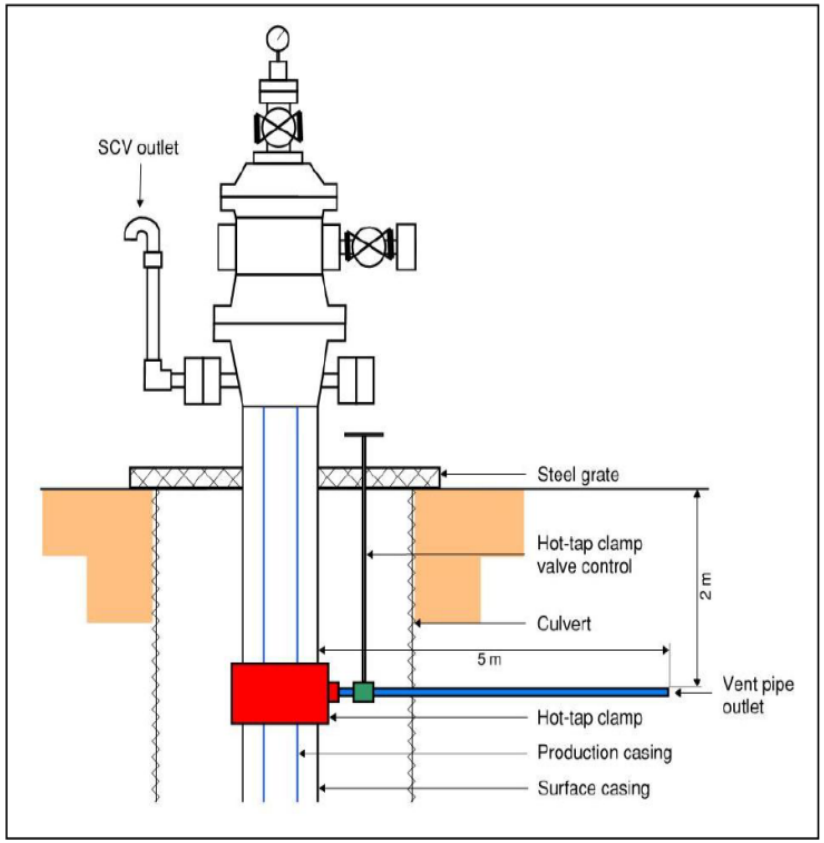
Purpose

- Compromised well casings leaking natural gas
  - Upward migration of methane, in some cases to atmosphere
  - Potential explosion risk
  - Groundwater composition effects
- Build case for risk-based approach to address abandoned wells with minor gas leakages

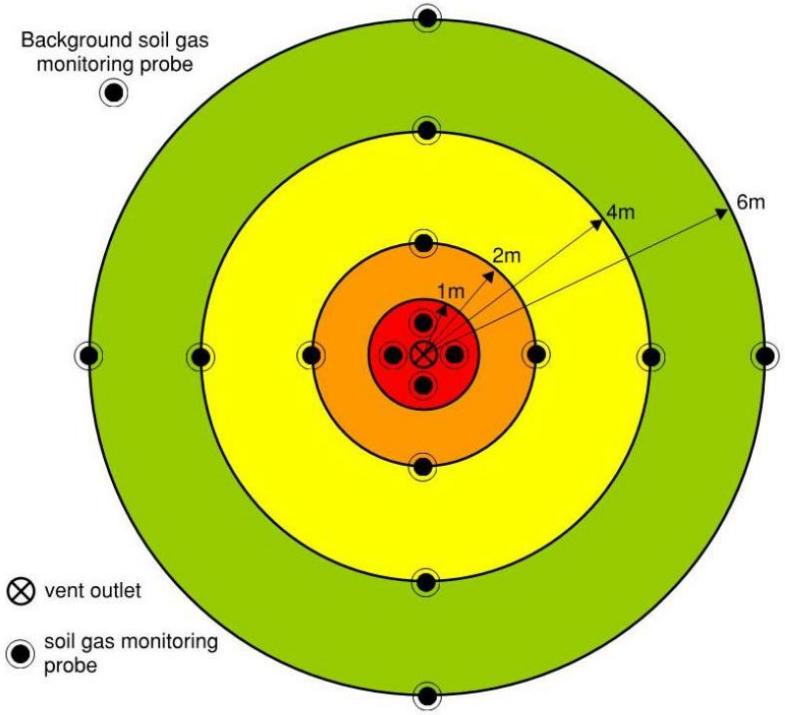
Approach

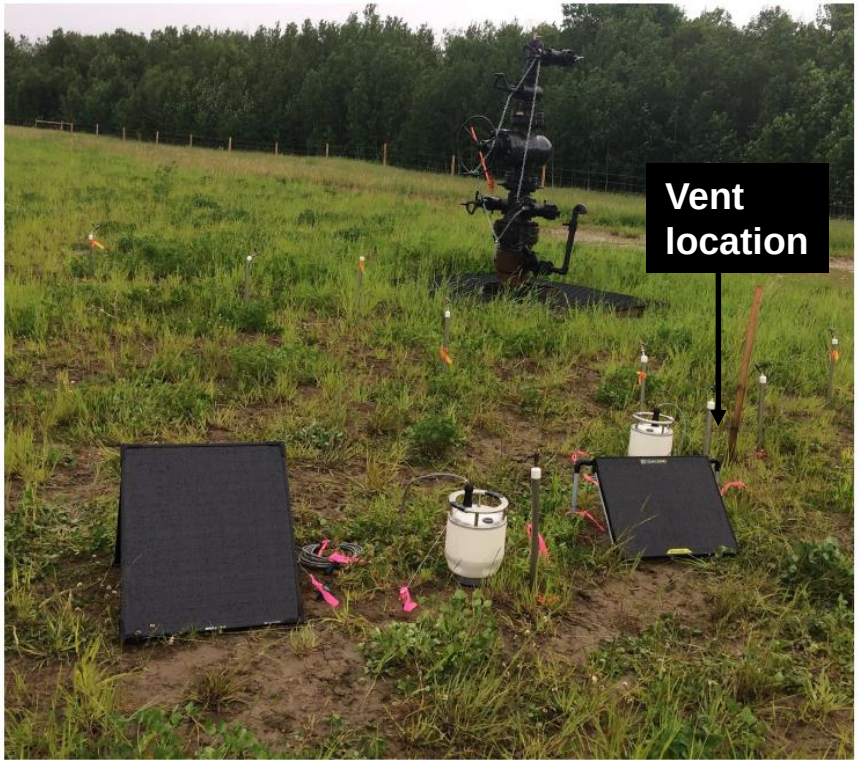
- Seven Well Sites
  - Well heads added (allow measurement of vent rates)
  - Vented gas below grade away from well



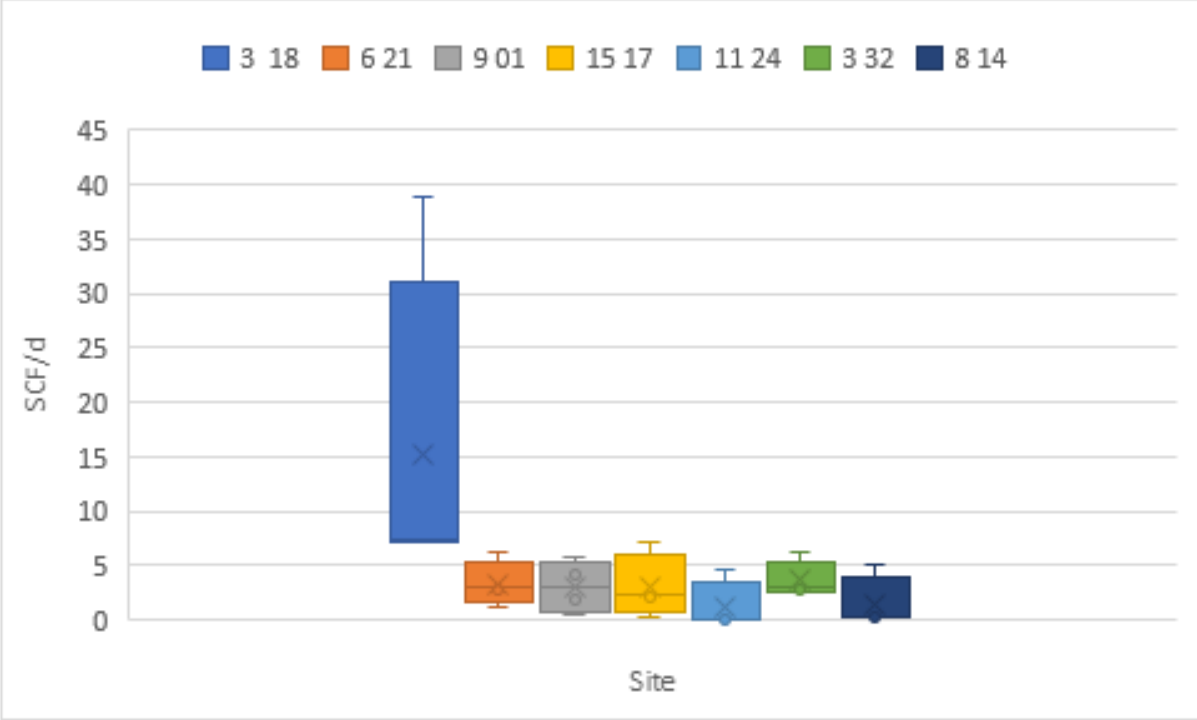
Approach Continued

- Soil gas monitoring 0.3 m (CH_4,CO_2,O_2, $\delta^{13}C$-CH_4, $\delta^{13}C$-CO_2)
- Surface CH_4 (LEL meter)
- Surface CH_4 and CO_2 flux measurements (less frequent)





Vent Flow Rates



- 1-30 SCF/day
- Higher average rates at site 3-18 (Focus of presentation)

Methane Biodegradation Background

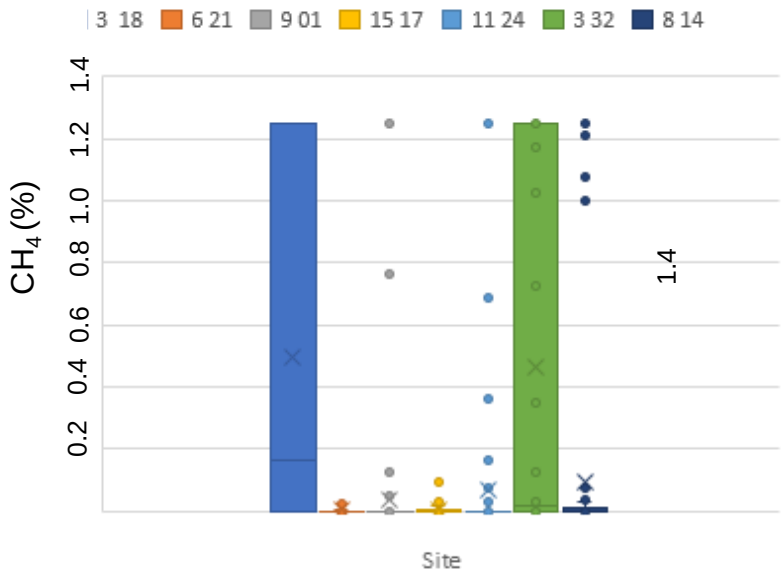
- Aerobic and anaerobic (environment dependent)
- Aerobic methanotrophs widely distributed

  $CH_4 + O_2 \rightarrow CO_2$

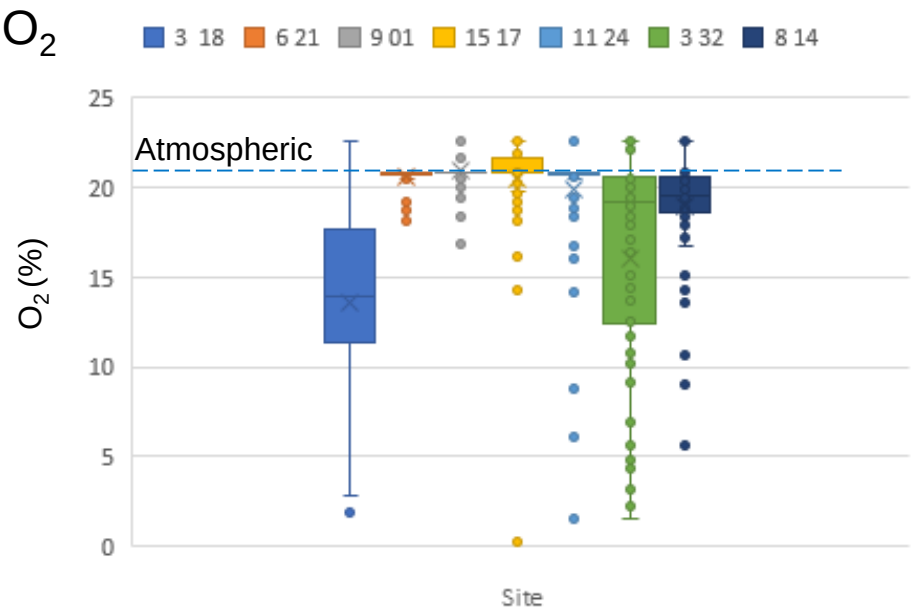
- Example environments
  - Methane seeps (terrestrial and marine)
  - Groundwater
  - Shallow soil above petroleum impacted soils
- Can be accelerated
  - Landfill bio-covers

2018 Soil Gas Results (All 7 Sites)

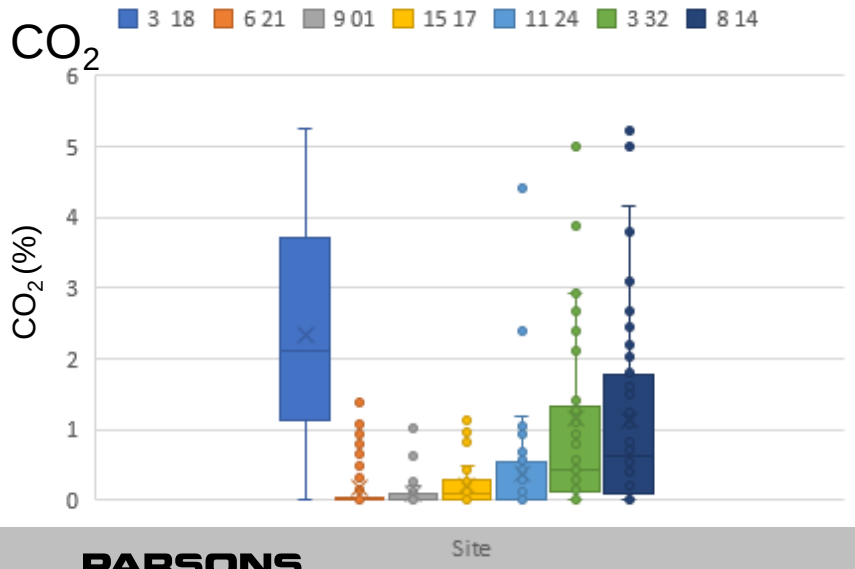
CH_4



O_2



CO_2



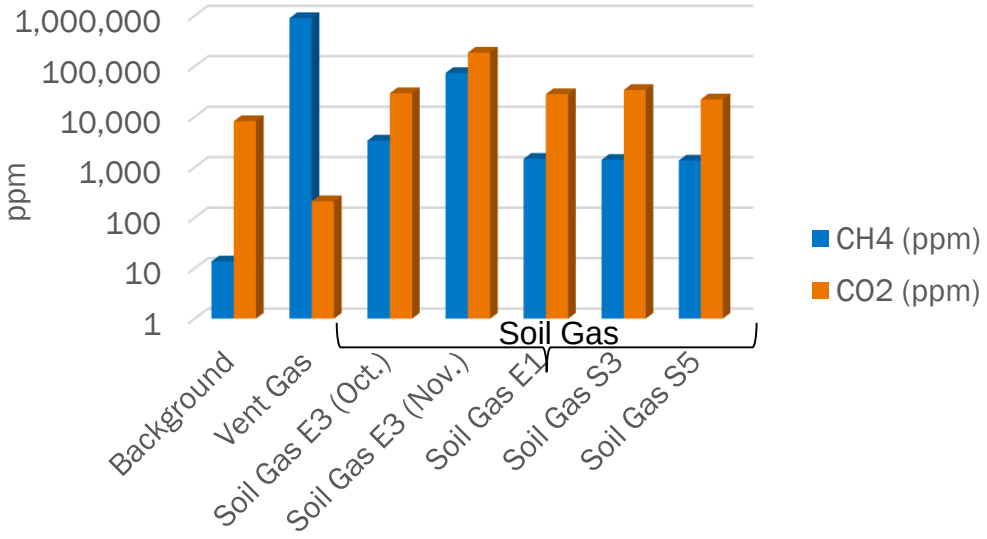
- General trends
  - Significantly higher CO_2 than CH_4
  - Sites with higher vent rates show higher CH_4, higher CO_2, and lower O_2 in soil gas.
- Consistent with aerobic methane biodegradation

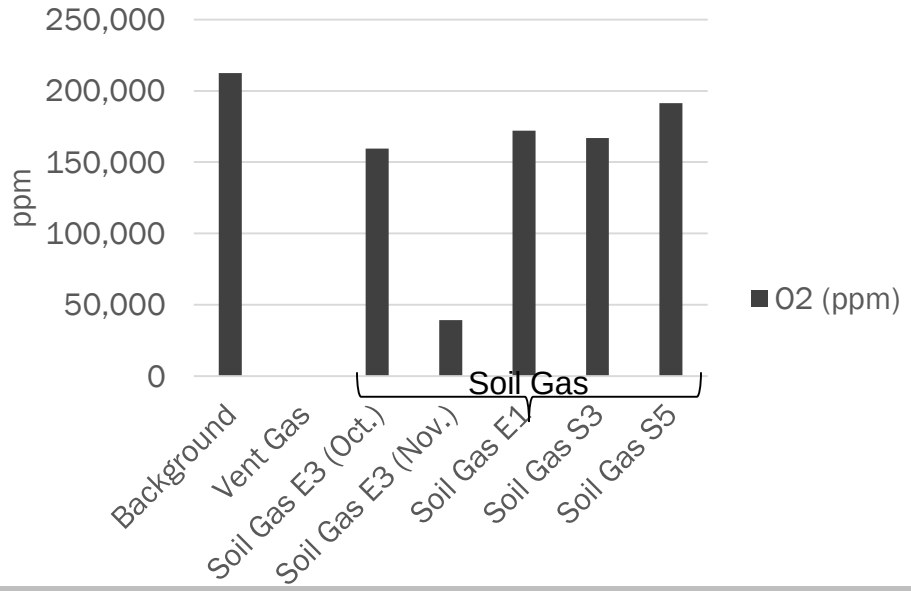
Site 3-18

Facing North - July

Facing North - September

Site 3-18 Gas Composition Indicating Methane Biodegradation





- Higher CO_2 in soil gas samples relative to background soil gas and vent gas

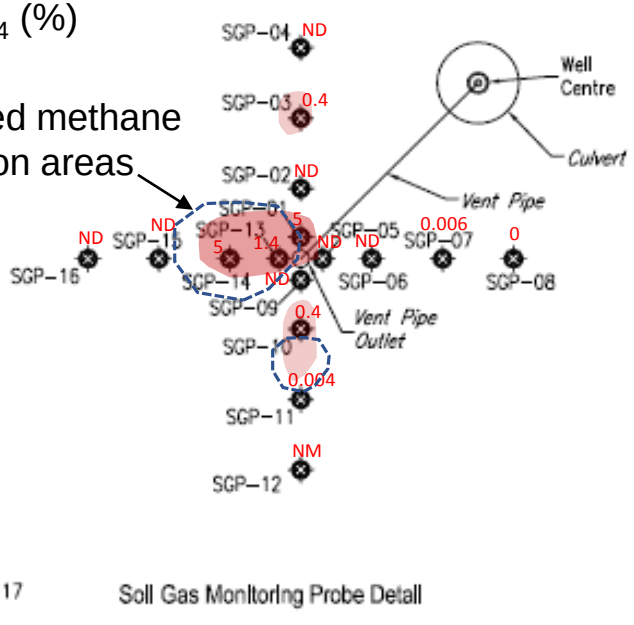
  Aerobic CH_4 Biodegradation
  $CH_4 + O_2 \rightarrow CO_2$

- Depressed oxygen in soil gas

Site 3-18 Soil Gas Distribution June 7, 2017

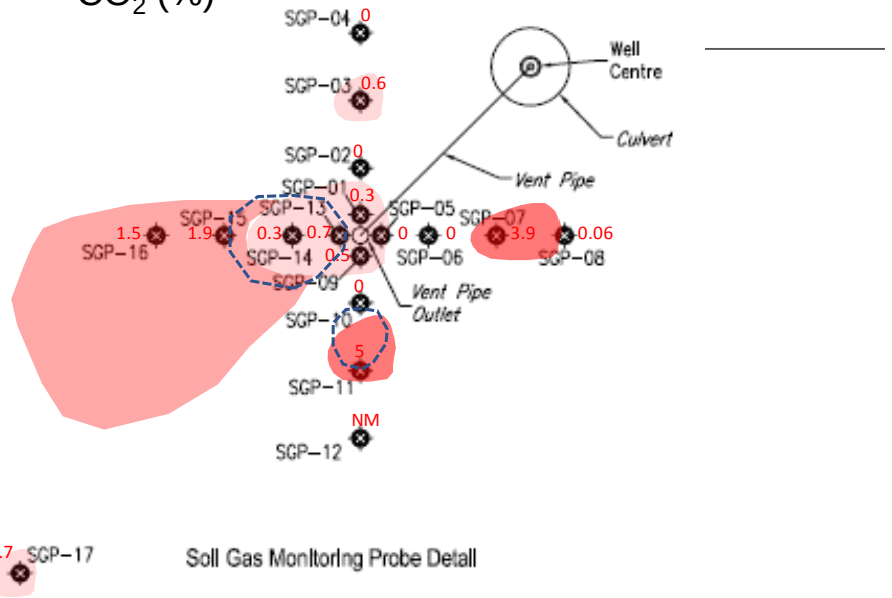
CH_4 (%)

Elevated methane oxidation areas



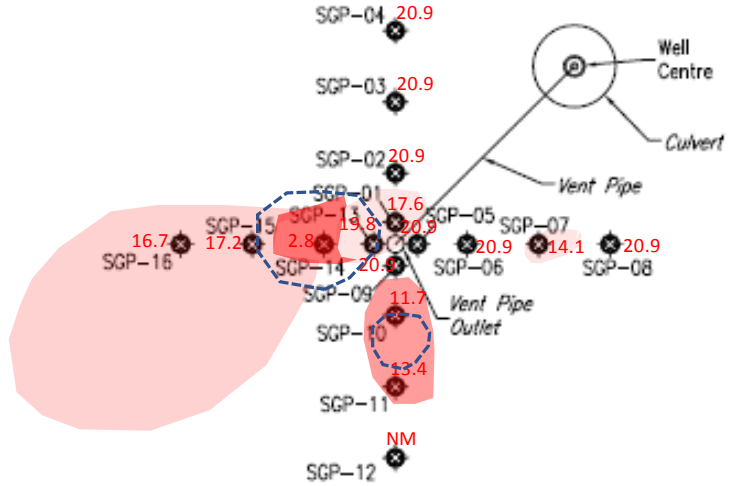
ND SGP-17 Soil Gas Monitoring Probe Detail

CO_2 (%)



0.7 SGP-17 Soil Gas Monitoring Probe Detail

O_2 (%) - Depletion shown in red



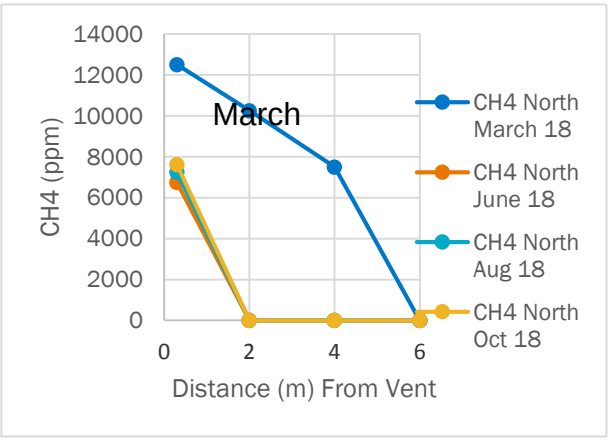
16.9 SGP-17 Soil Gas Monitoring Probe Detail

- Preferential gas migration pathways
- CO_2 production (not CO_2 in vent gas)
- Aerobic methane biodegradation limited methane migration

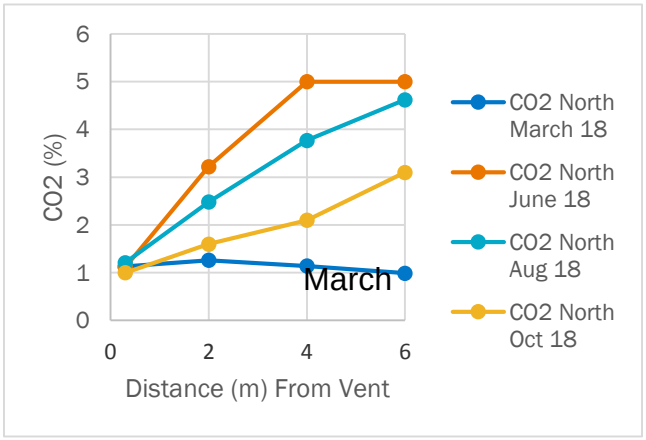
$$CH_4 + O_2 \rightarrow CO_2$$

2018 Signature of Methane Oxidation at Site 3-18 - North Transect

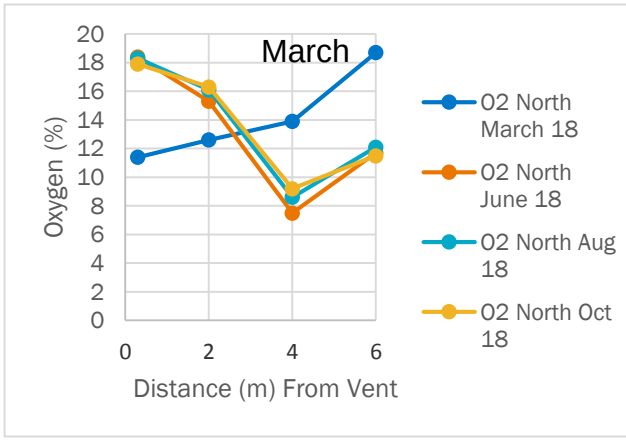
CH_4



CO_2

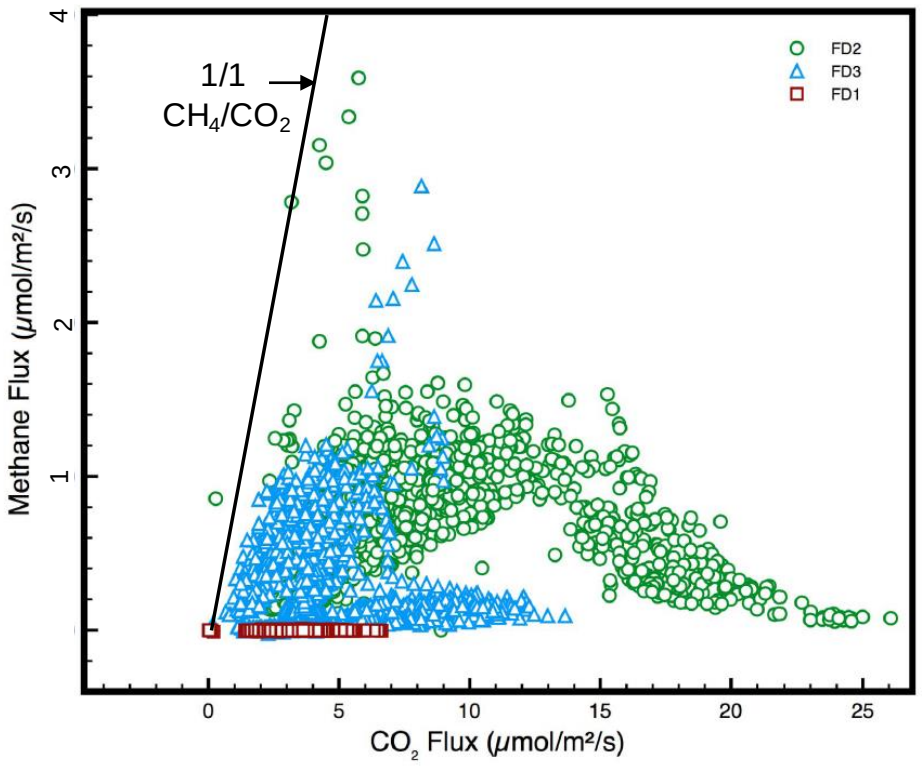


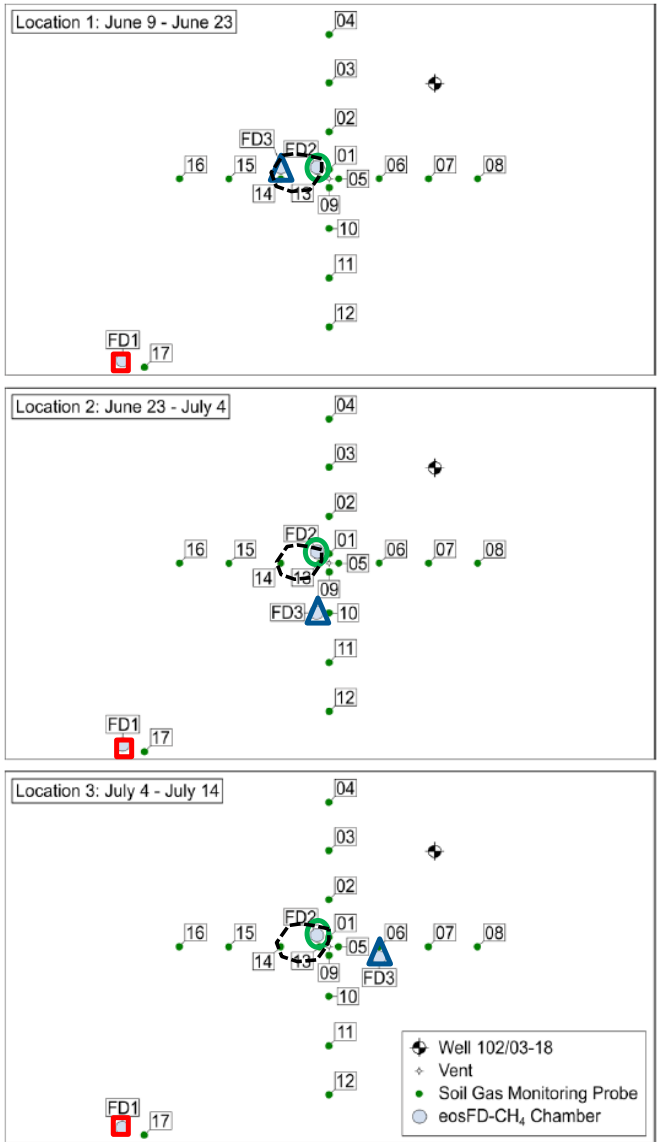
O_2



- June, August, October
  - Rapid methane oxidation per $CH_4/CO_2/O_2$ distribution
- March (cold)
  - Increased methane migration

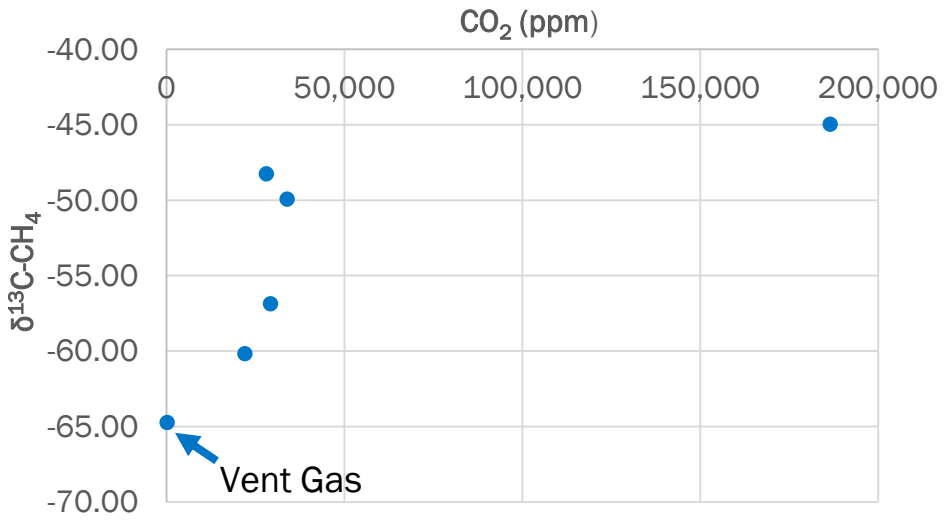
Site 3-18 Surface Gas Flux Results

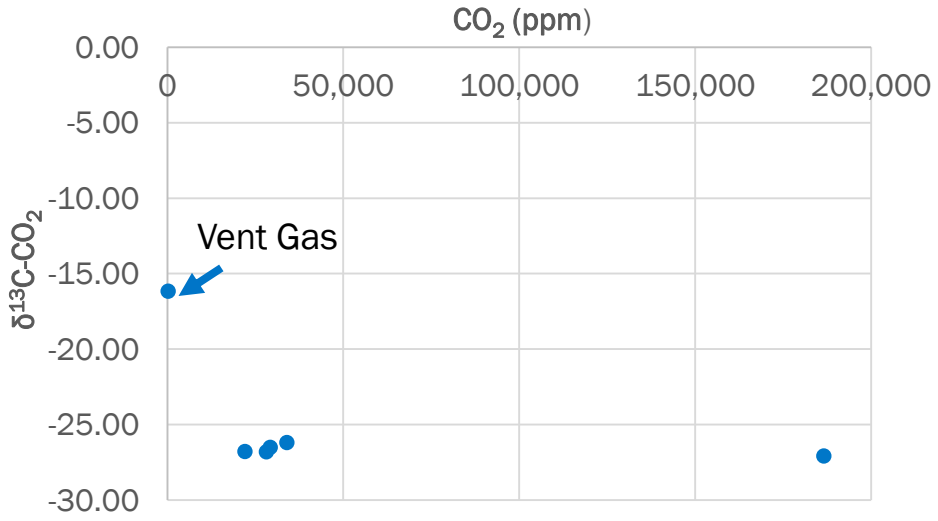




- Substantially higher CO_2 flux (generally > 10X) than CH_4 flux due to methane biodegradation
- Decreased CH_4 flux to atmosphere

Site 3-18. Gas Isotopic Composition Evidence for Methane Biodegradation





- Preferential loss of $^{12}CH_4$ (remaining CH_4 heavier)
  - Sample with the highest CO_2 and lowest O_2 contains the heaviest methane
- Generation of $^{12}CO_2$

Conclusions

- Multiple lines of evidence for significant aerobic methane biodegradation
  - Spatial patterns in CH_4, CO_2, and O_2 indicate methanotrophy at all sites
  - High CO_2 in soil gas and flux chambers
  - Stable isotopes
- Aerobic methanotrophy decreases lateral and upward methane migration
- Opportunity for low cost natural and enhanced methane attenuation (bio-filters)