GAS SEEPAGE ON EARTH

Experience with microseepage measurements, flux detection and indirect indicators

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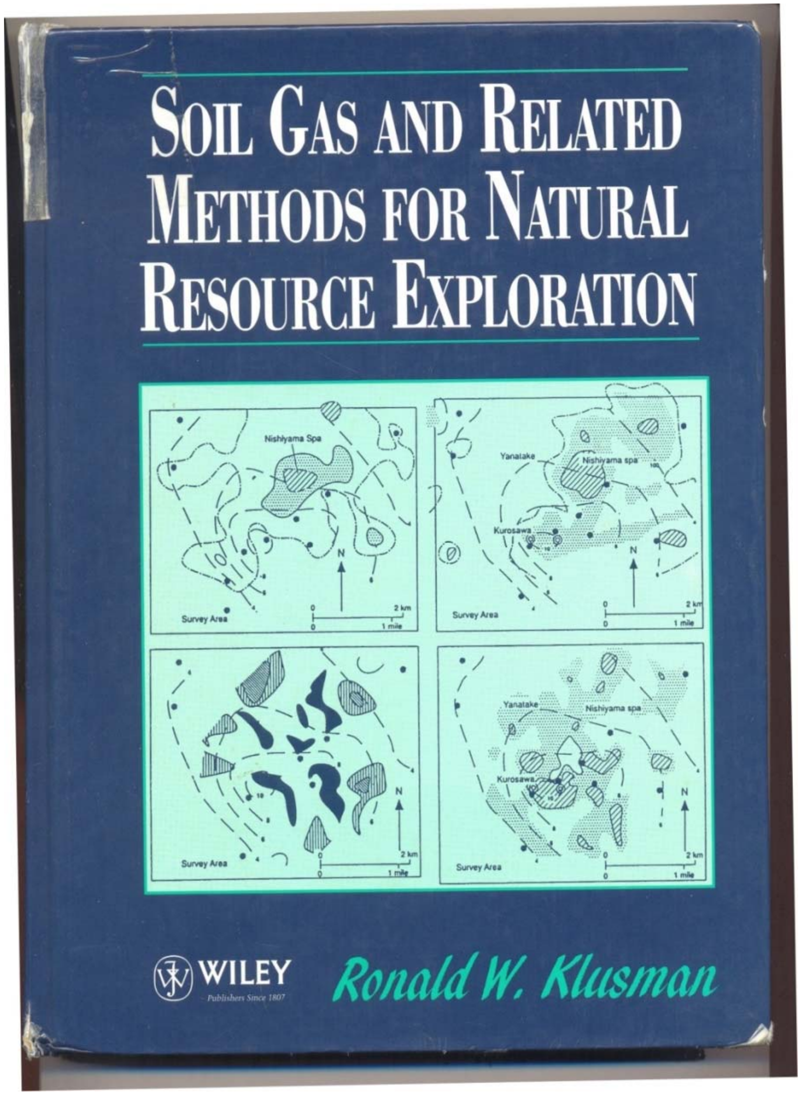
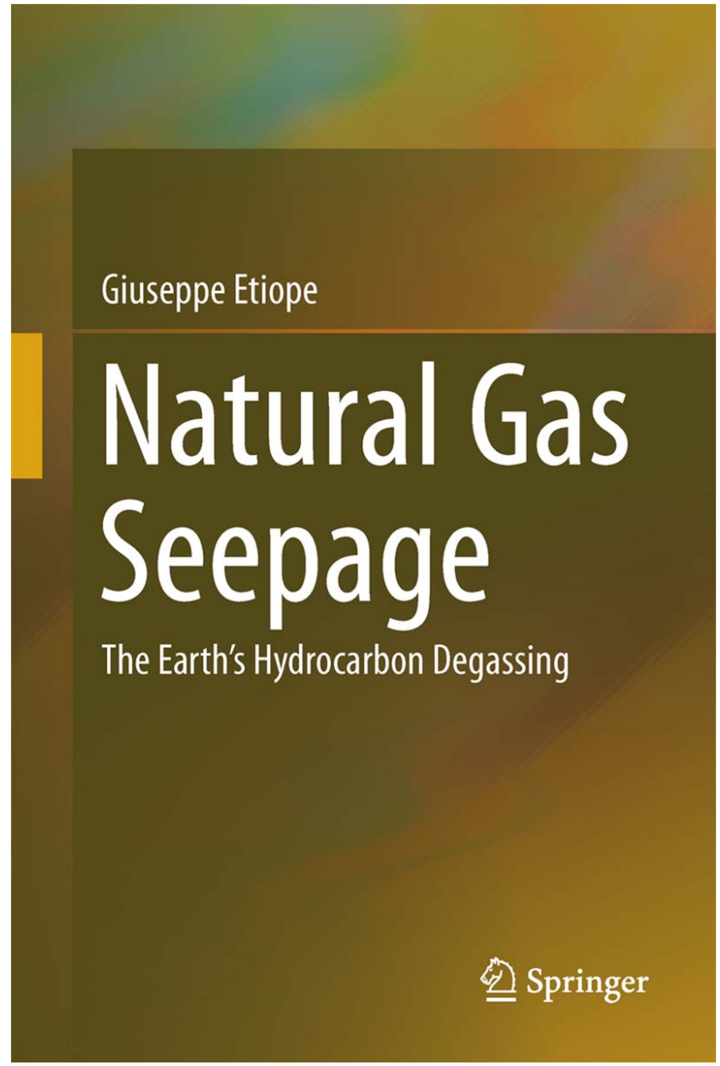
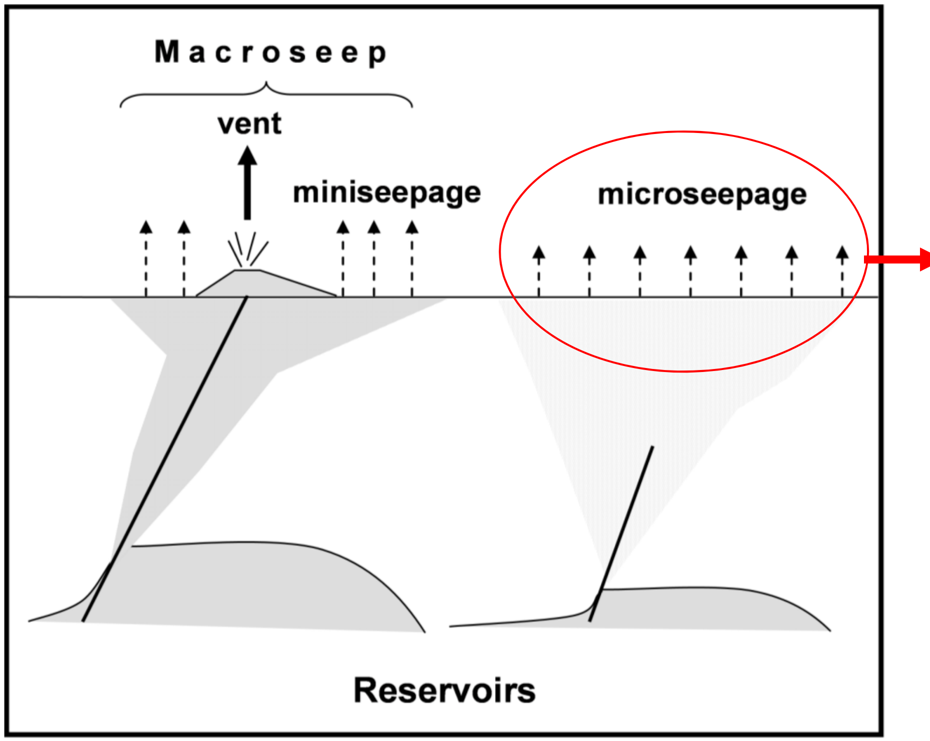
Klusman, 1993

Etiope, 2015

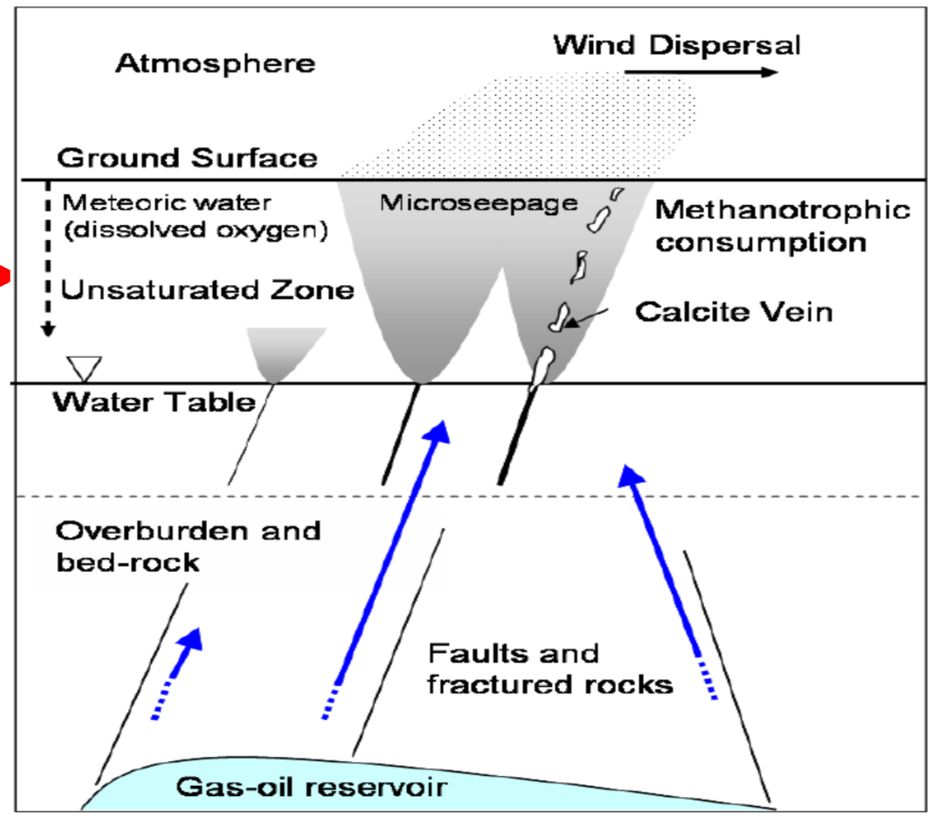




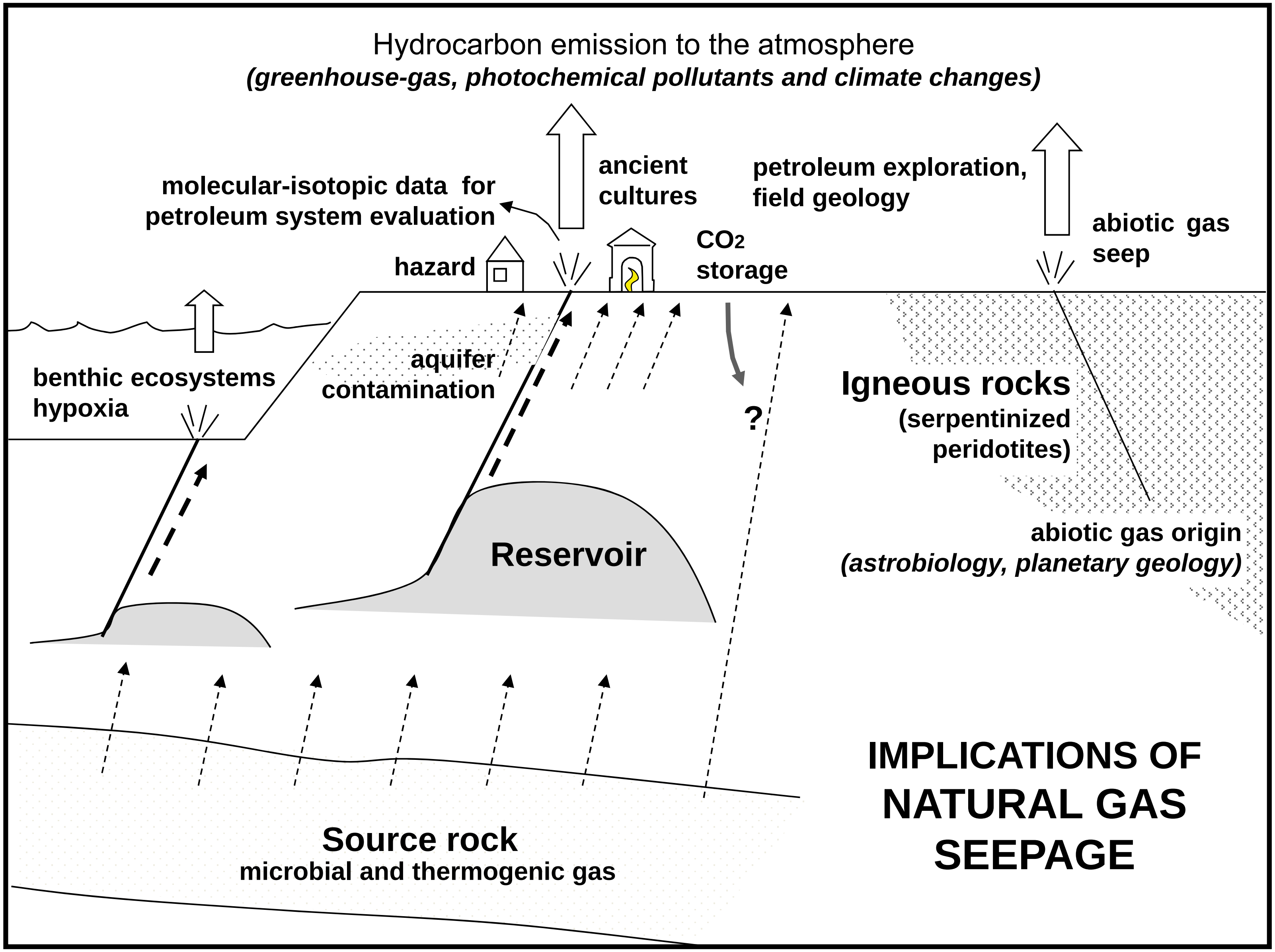
What is gas seepage



microseepage



Importance of gas seepage on Earth

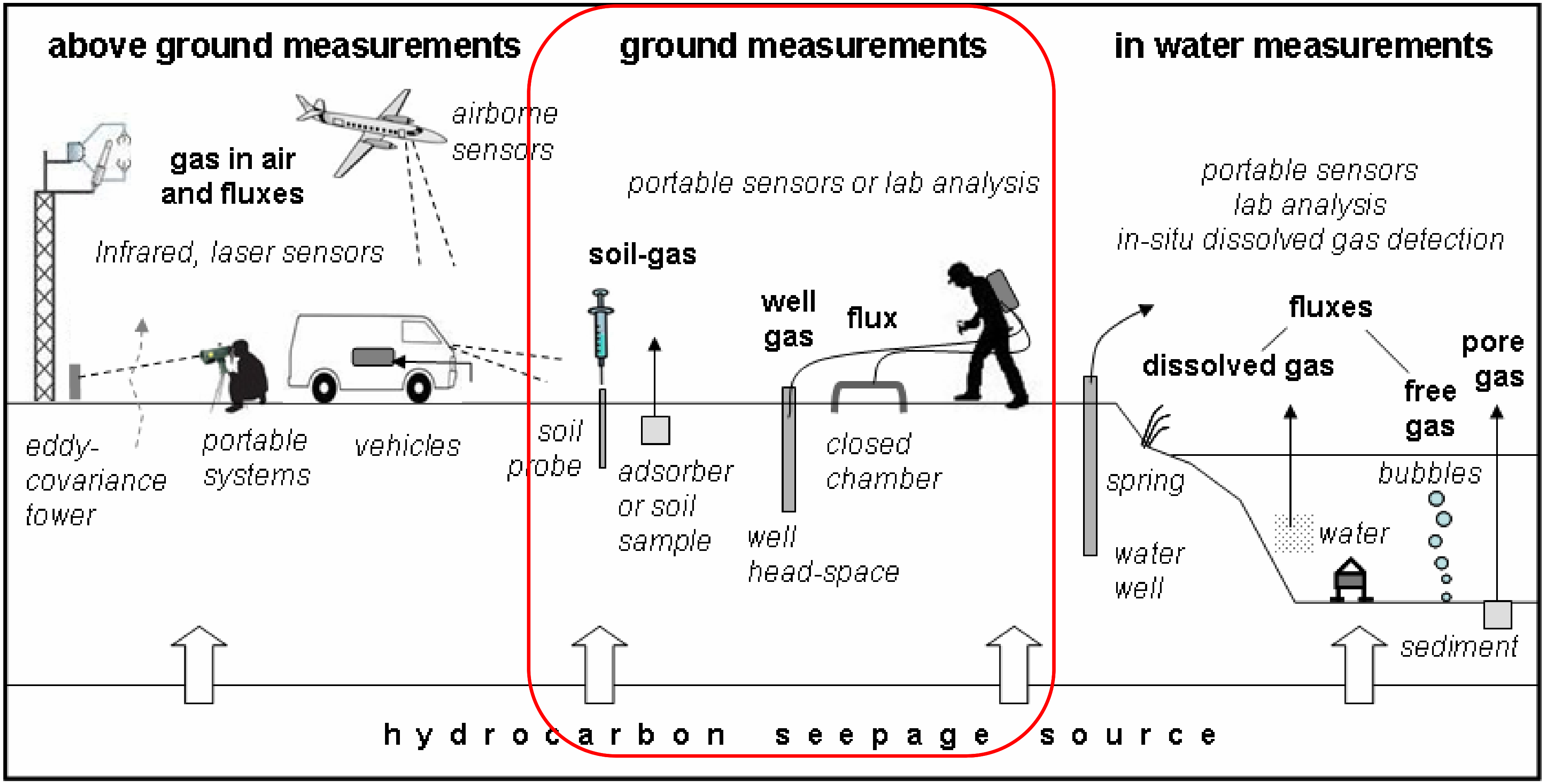


Etiope (2015)

How to detect and measure gas seepage

Effective only for significant seepage

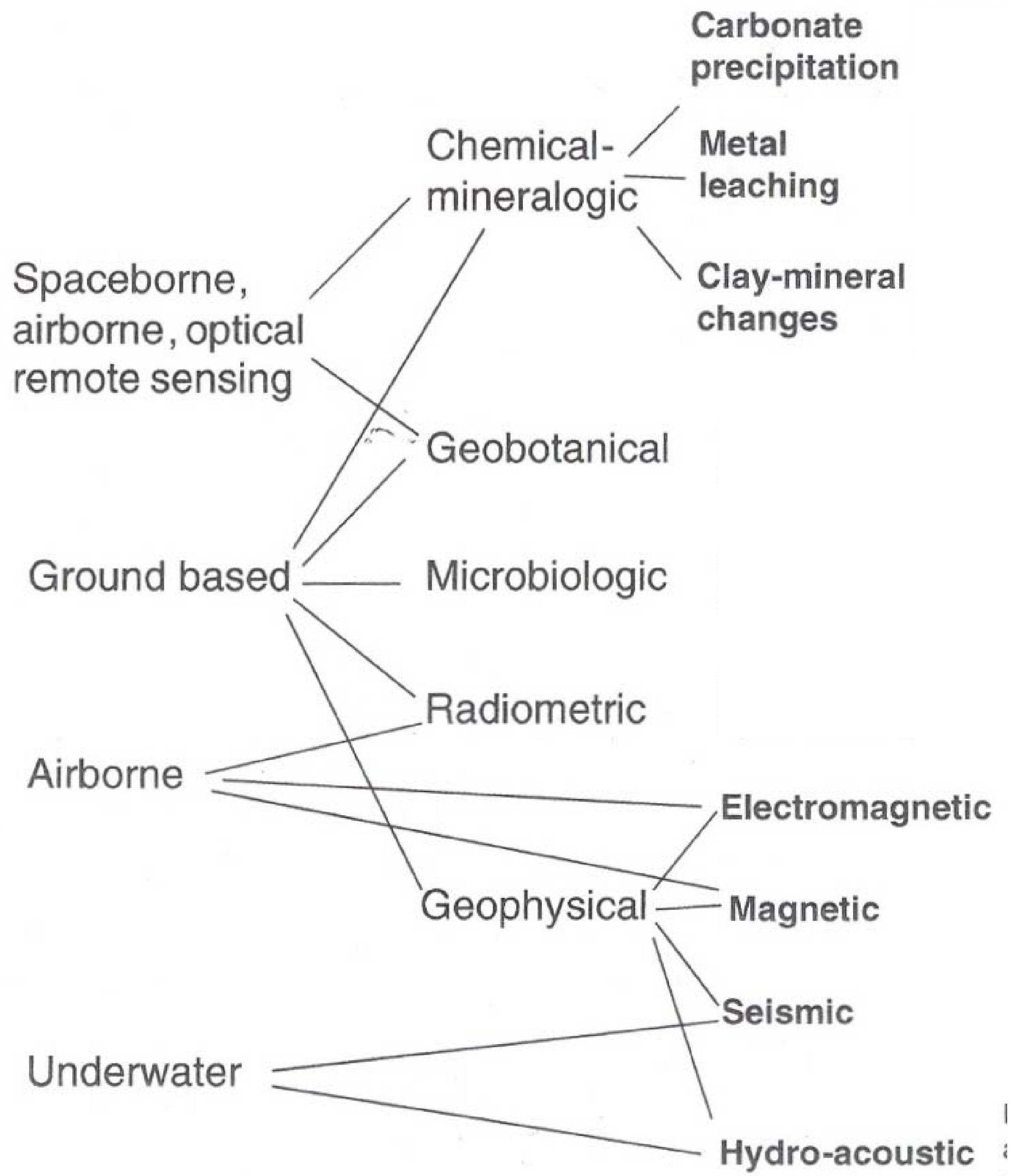
Effective also for very low seepage



approach to be adopted for Mars

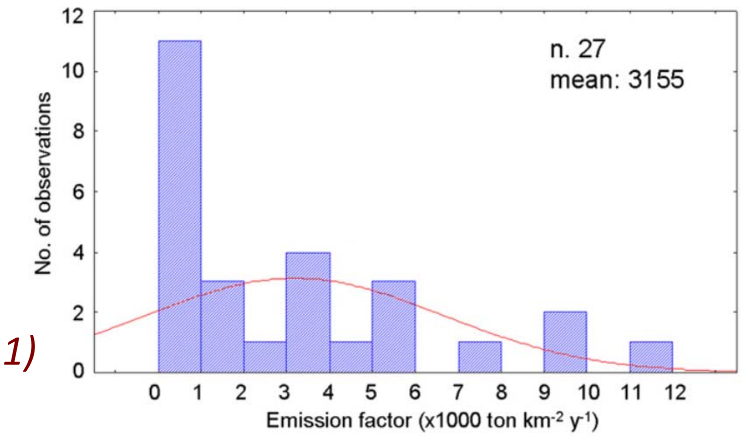
Etiope (2015)

Indirect Methods for Detection of Gas Seepage
(Modified from Etiope , 2015, Figure 4.5)



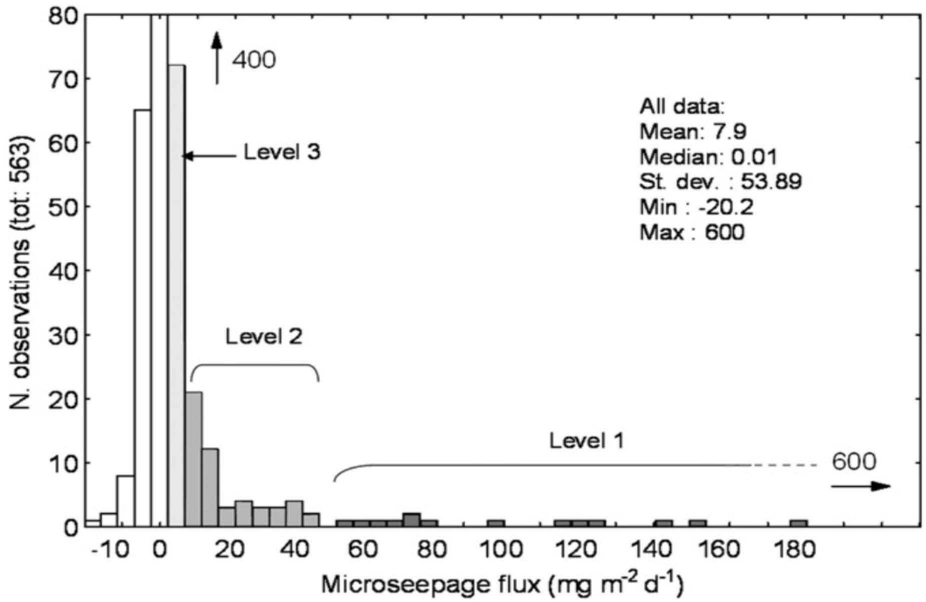
Typical methane fluxes from seepage on Earth

Gas seeps 0.1 – 100 ton/year (10^3 ton/year in large seeps)



Mud volcanoes *mean* 3100 ton km^{-2} y^{-1}

Etiope et al (2011)

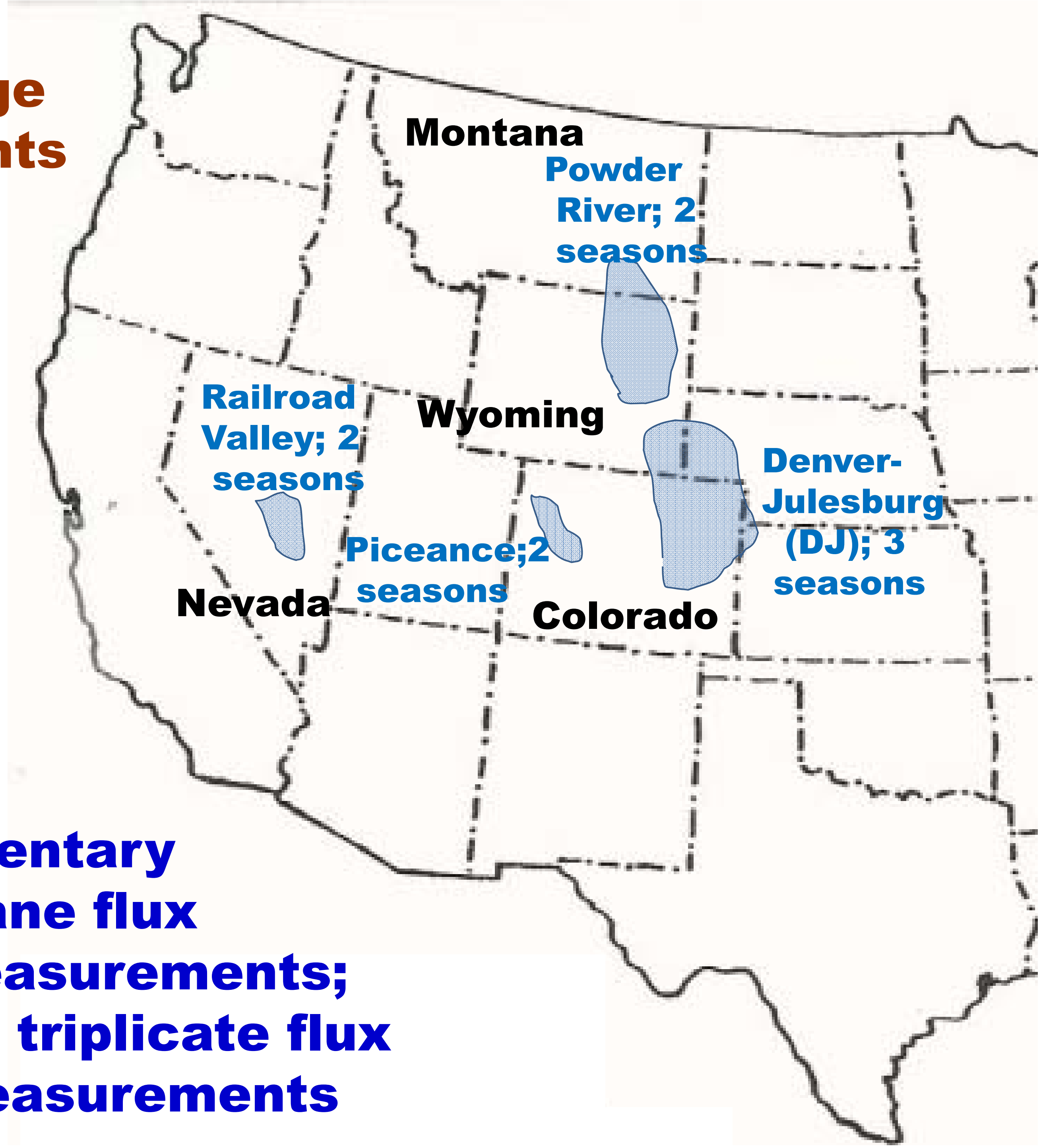


Microseepage
by definition >0 mg m^{-2} day^{-1}

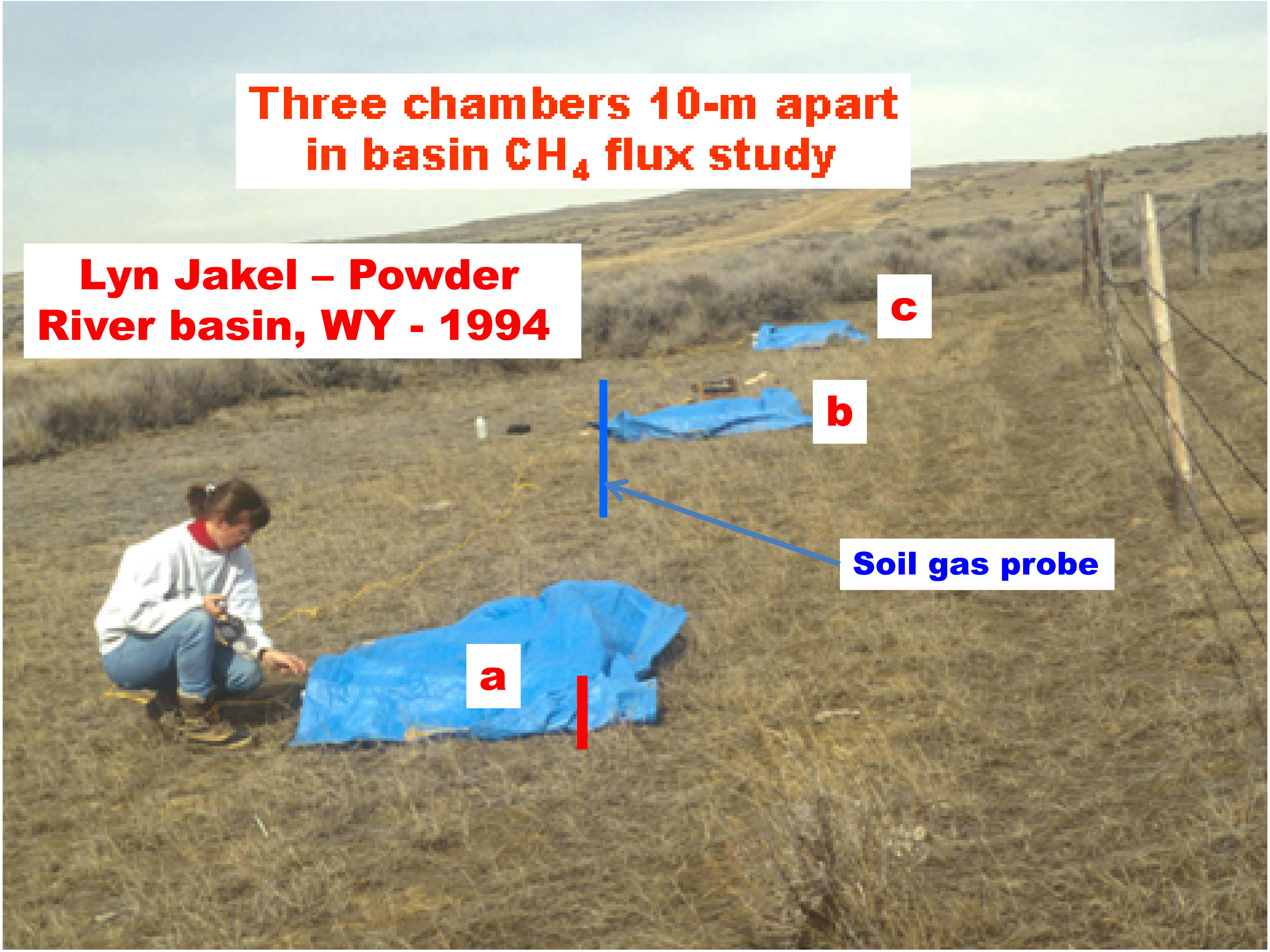
Methanotrophy
"negative" (downward flux)
drawing CH_4 from atm.

Etiope and Klusman (2010)

Microseepage measurements in USA



Early sedimentary basin methane flux baseline measurements; Total of 342 triplicate flux chamber measurements

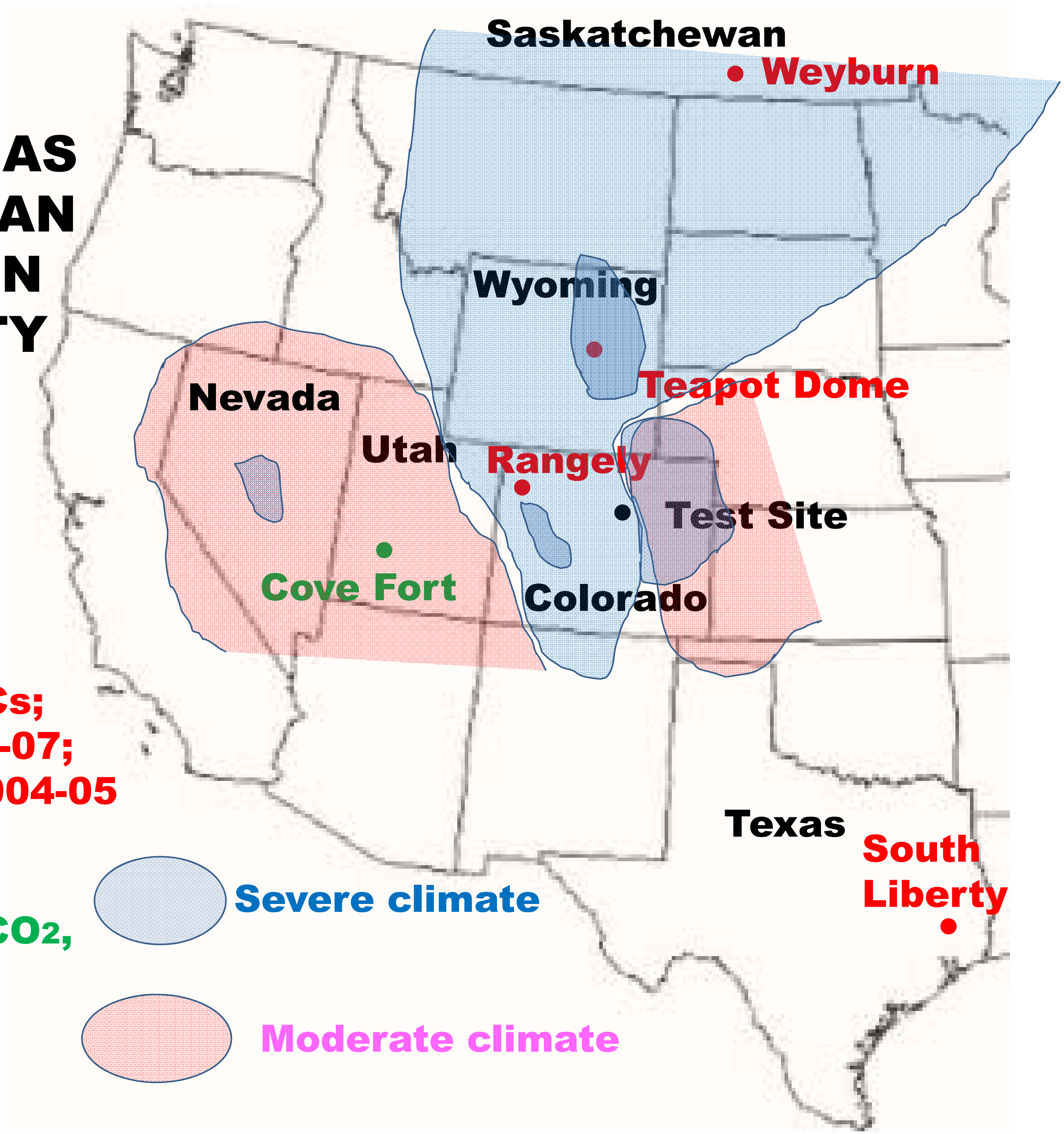

Three chambers 10-m apart in basin CH_4 flux study
Lyn Jakel – Powder River basin, WY - 1994
c
b
Soil gas probe
a

FLUX, SOIL GAS SITES WITH AN EMPHASIS ON SEASONALITY

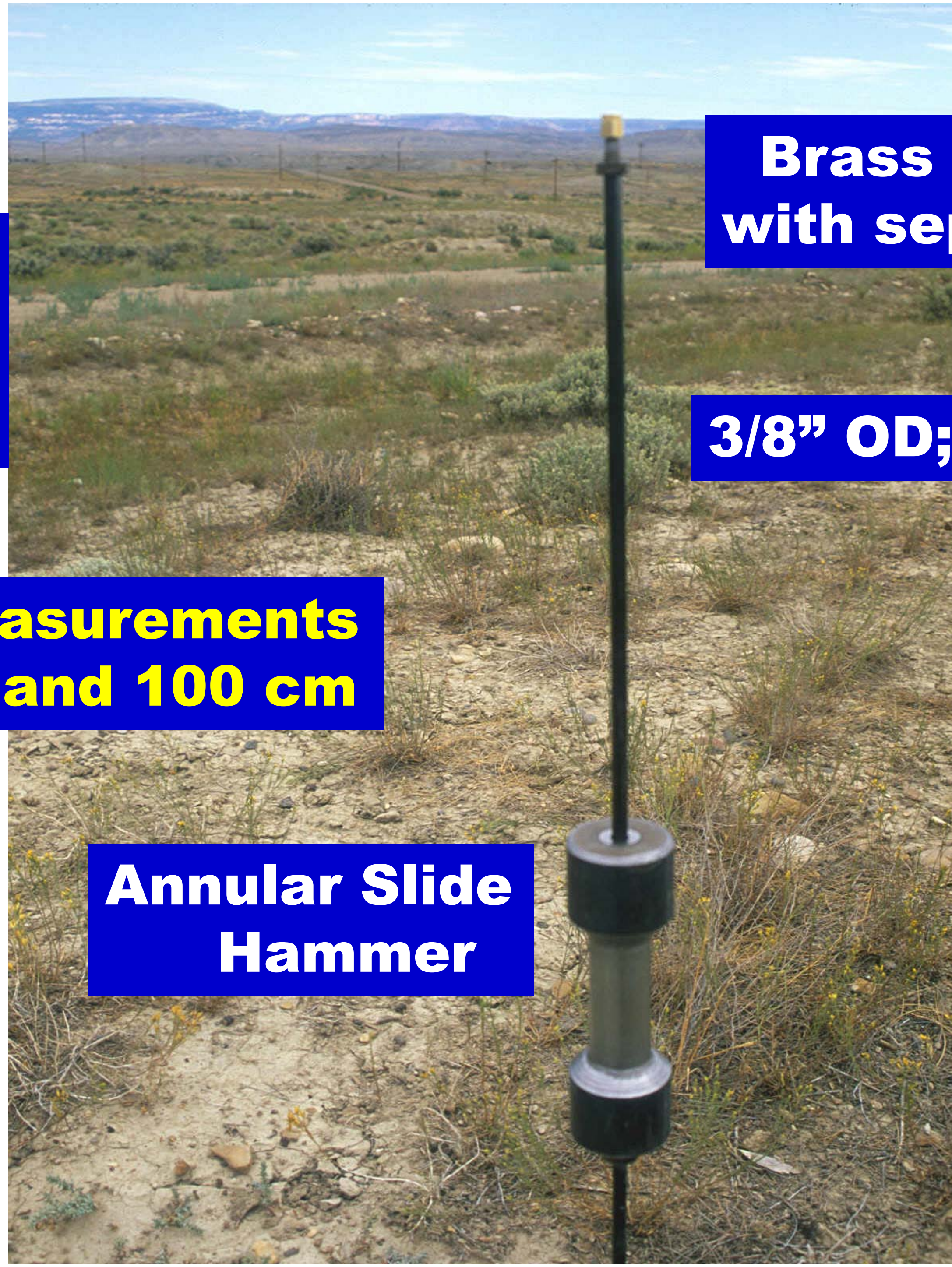
Test site – early measurements of a variety of gases

CO_2-EOR sites;
CH_4, CO_2, light HCs;
Inert Gases -2000-07;
South Liberty – 2004-05
Weyburn -2011

Geothermal CH_4, CO_2, N_2O -1998-99



GENERIC SOIL GAS PROBE

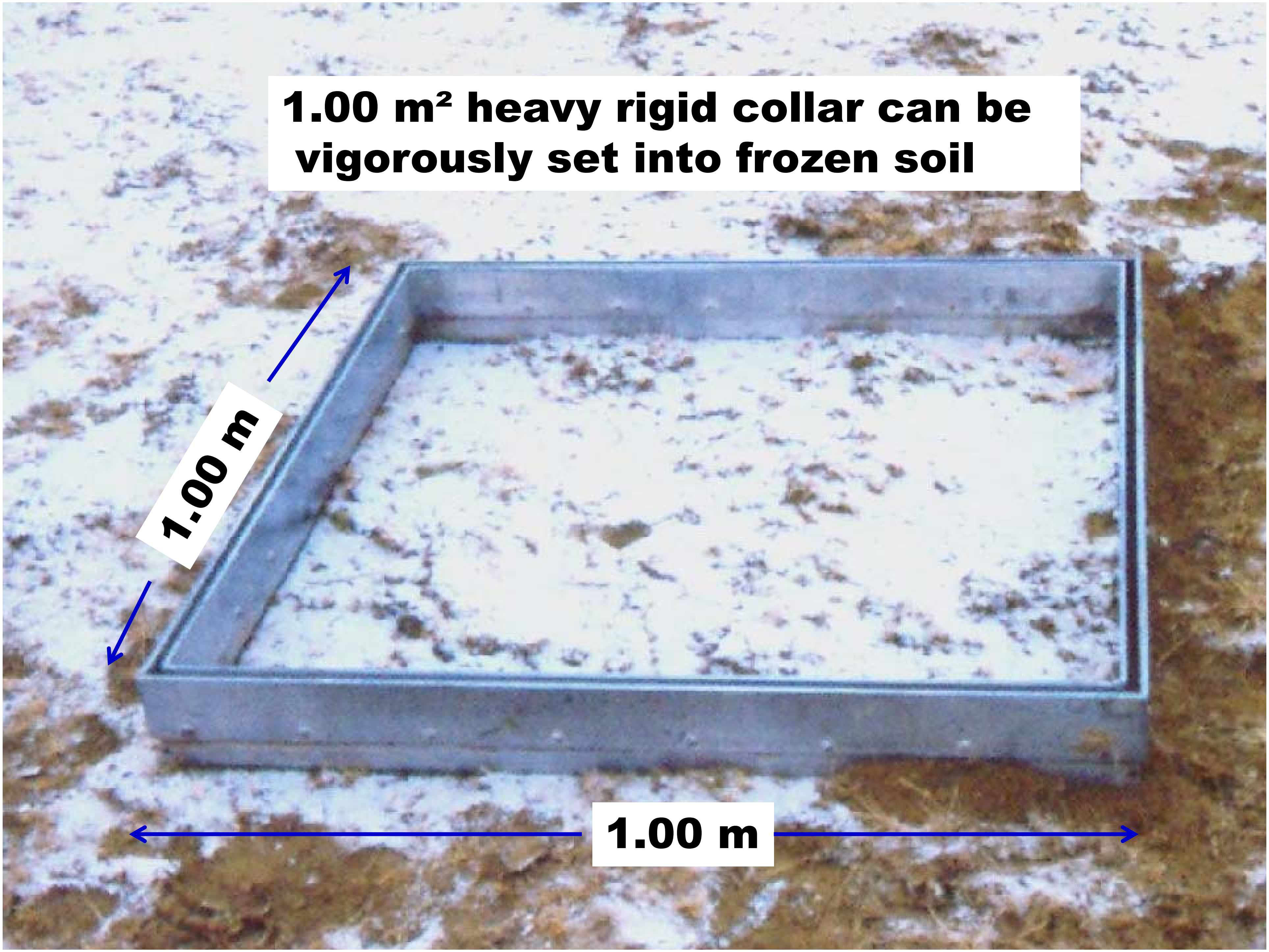


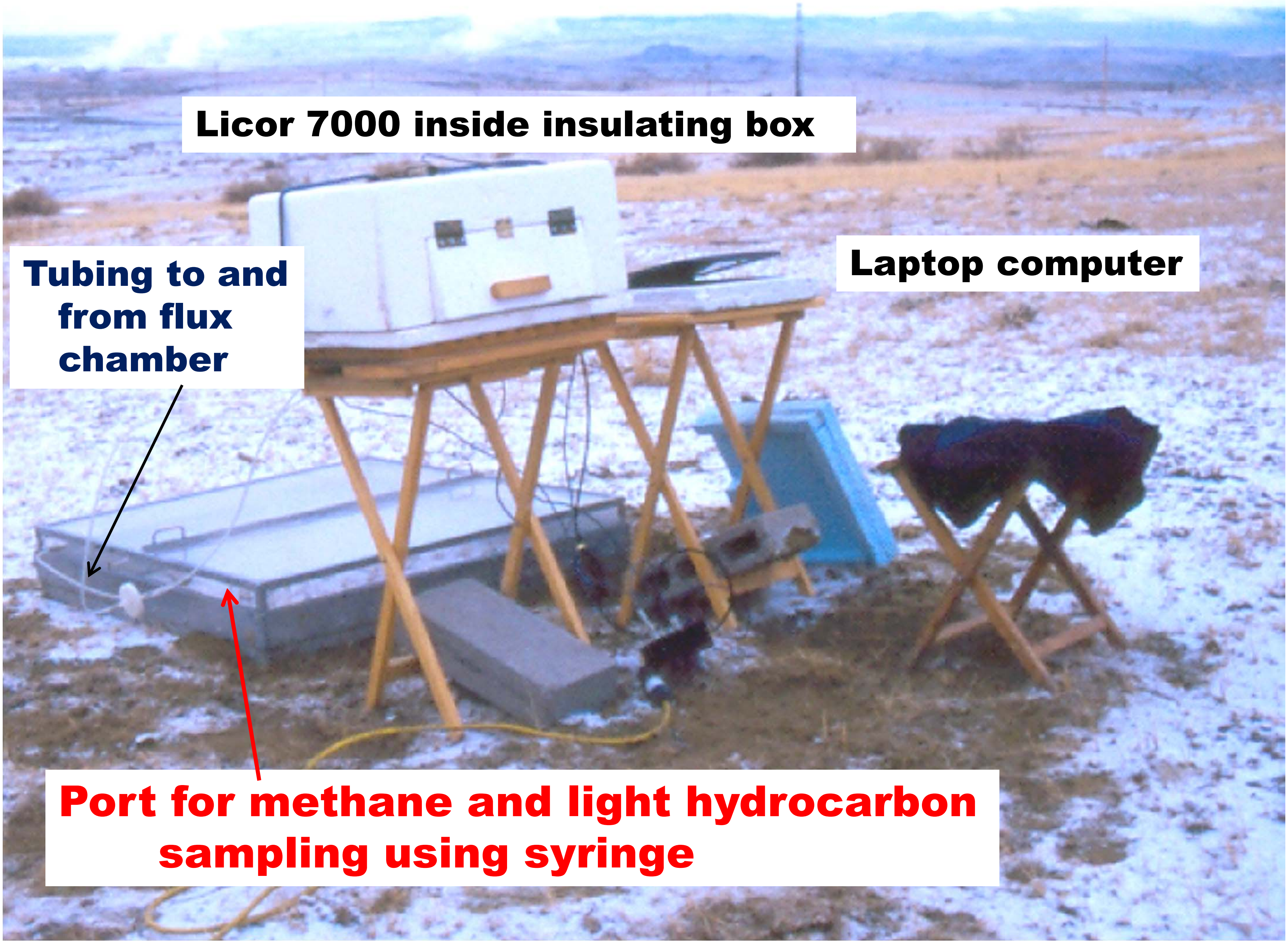
Soil gas measurements at 30-, 60-, and 100 cm

IMPROVEMENTS NEEDED FOR MONITORING, VERIFICATION AND ACCOUNTING (MVA) FOR APPLICATION IN CARBON CAPTURE AND GEOLOGIC STORAGE OF CO_2

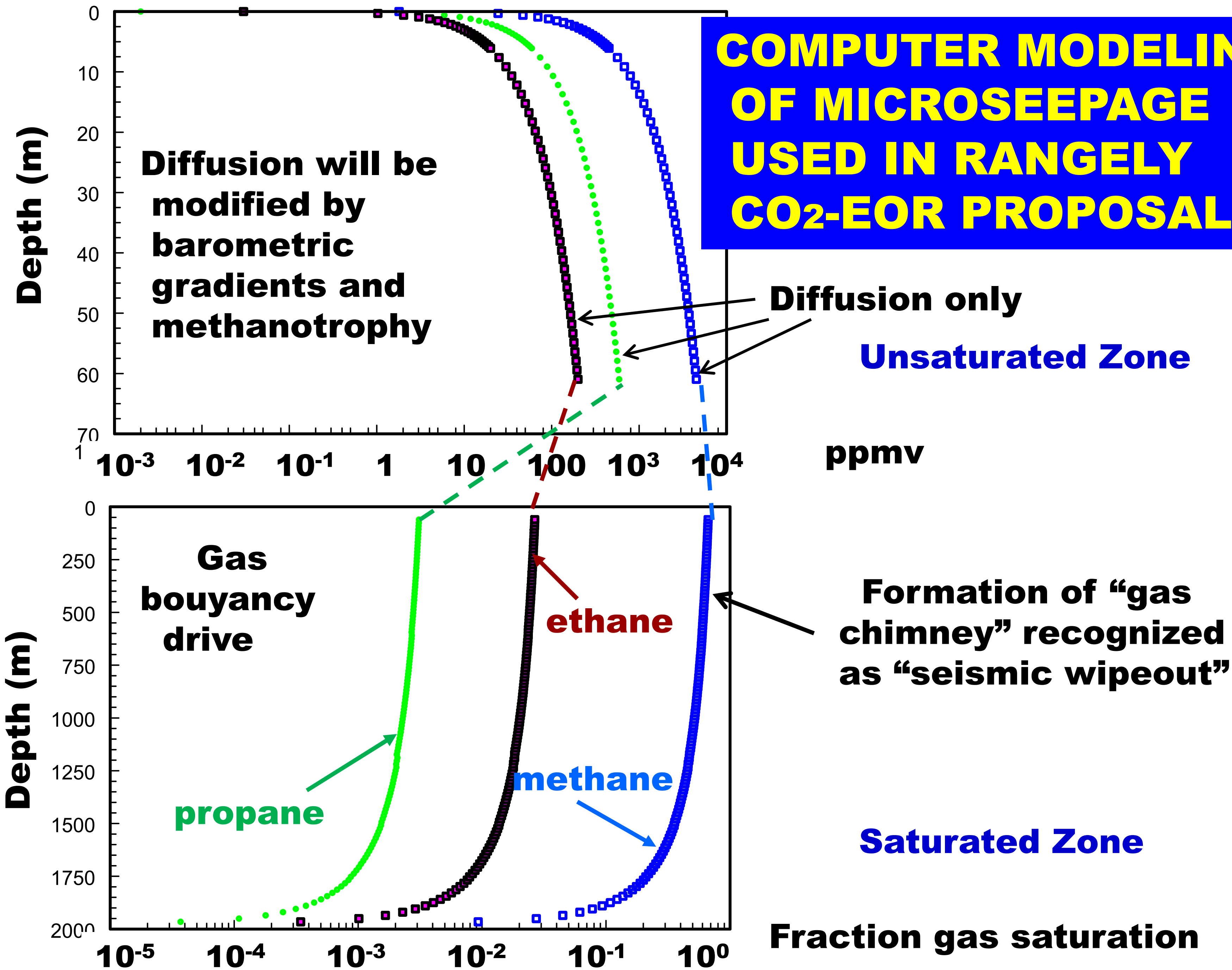
- Full seasonality needed in gas flux and soil gas measurements,
- Improved IR-based measurement of CO_2 in the 300-1000 ppmv range,
- More isotopic measurements of both CO_2 and CH_4 for evaluation of the role of methanotrophy,
- Focus measurements on faults and potential role as conduits for buoyant fluids,

- Seasonality, isotopic measurements, and faults as conduits will be particularly important on Mars. Large declining barometric gradients will draw gases upward.


1.00 m² heavy rigid collar can be vigorously set into frozen soil
1.00 m
1.00 m

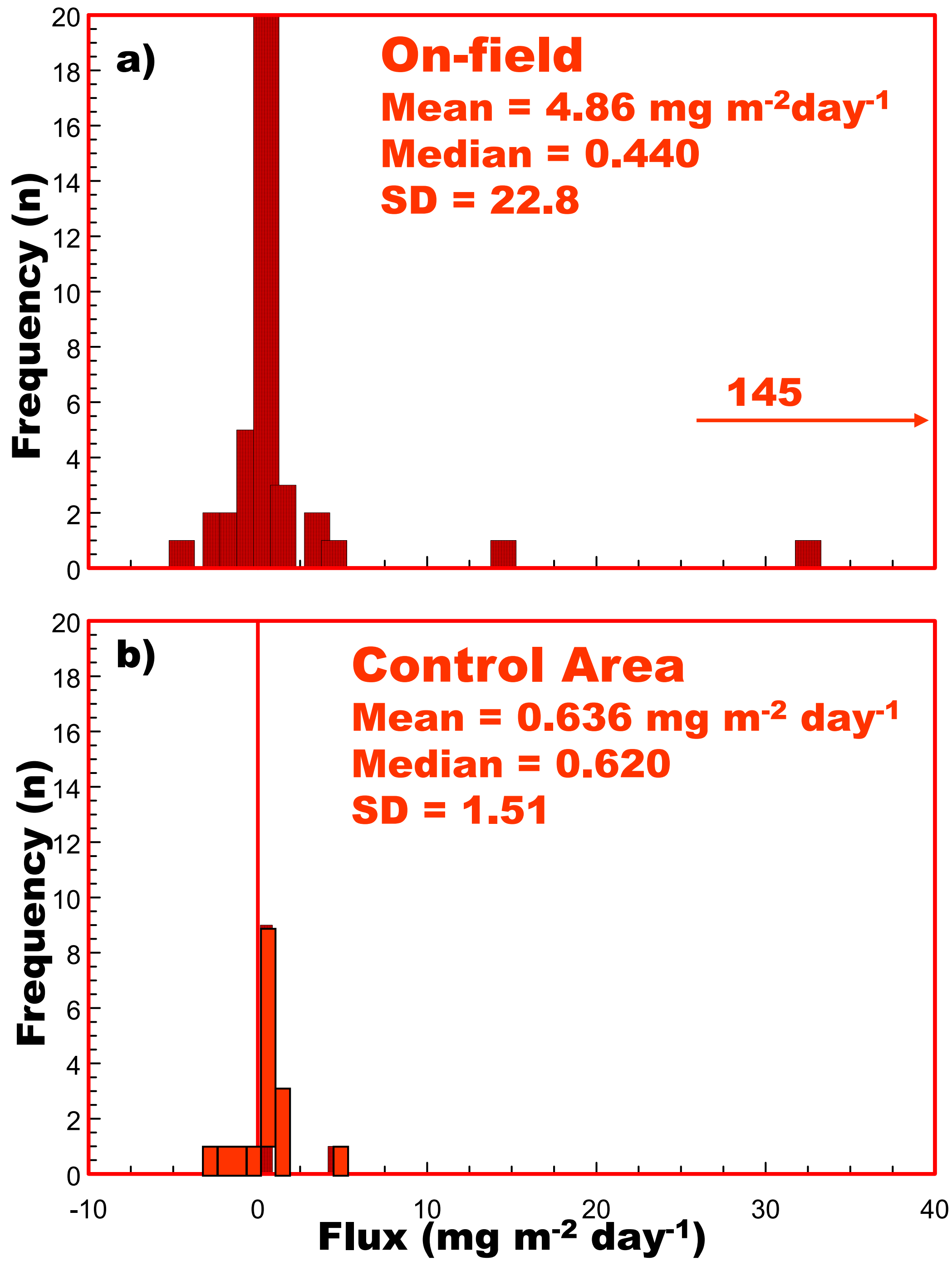

Licor 7000 inside insulating box
Laptop computer
Tubing to and from flux chamber
Port for methane and light hydrocarbon sampling using syringe

COMPUTER MODELING OF MICROSEEPAGE USED IN RANGELY CO_2-EOR PROPOSAL



Rangely CH_4 Flux

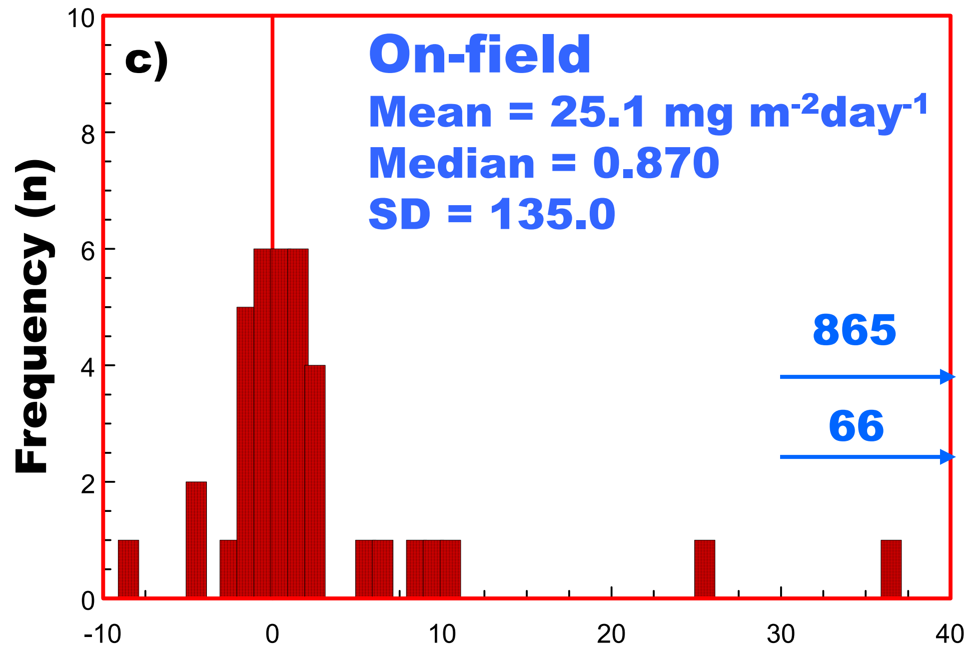
Summer, 2001

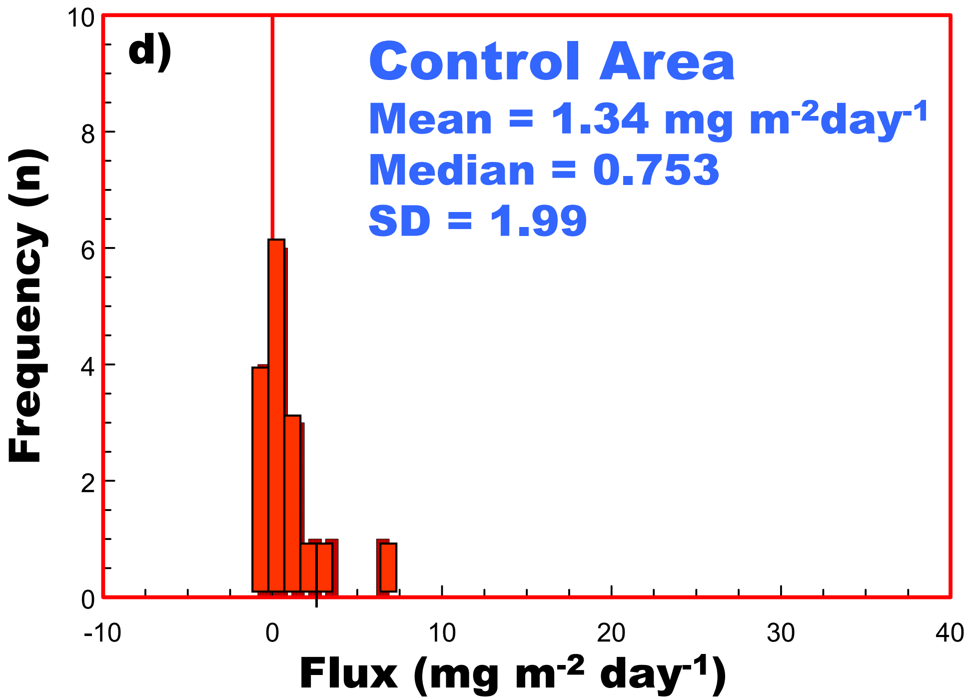


Rangely CH_4 Flux

Winter 2001/02

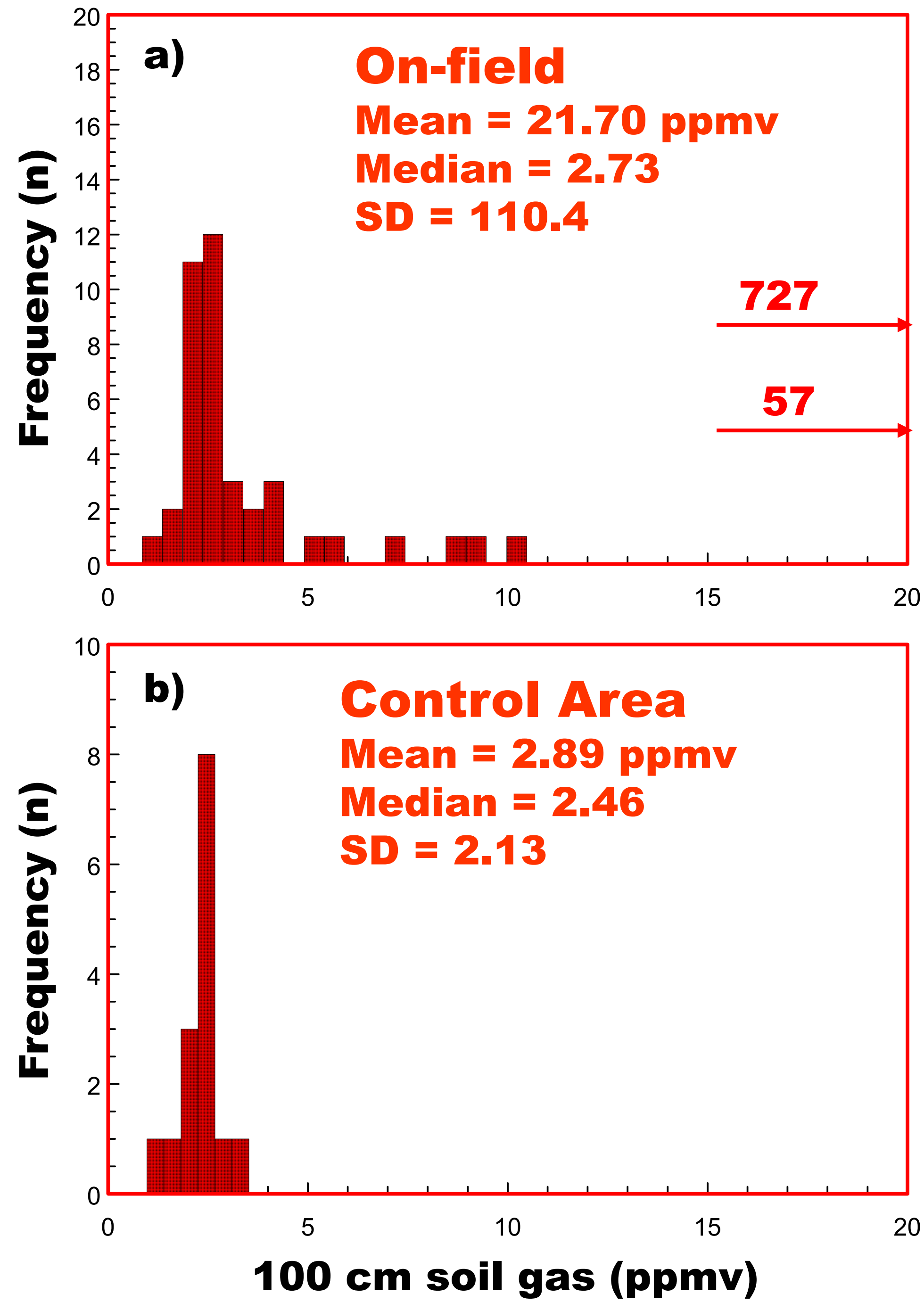
Note that some negative fluxes still occur in winter





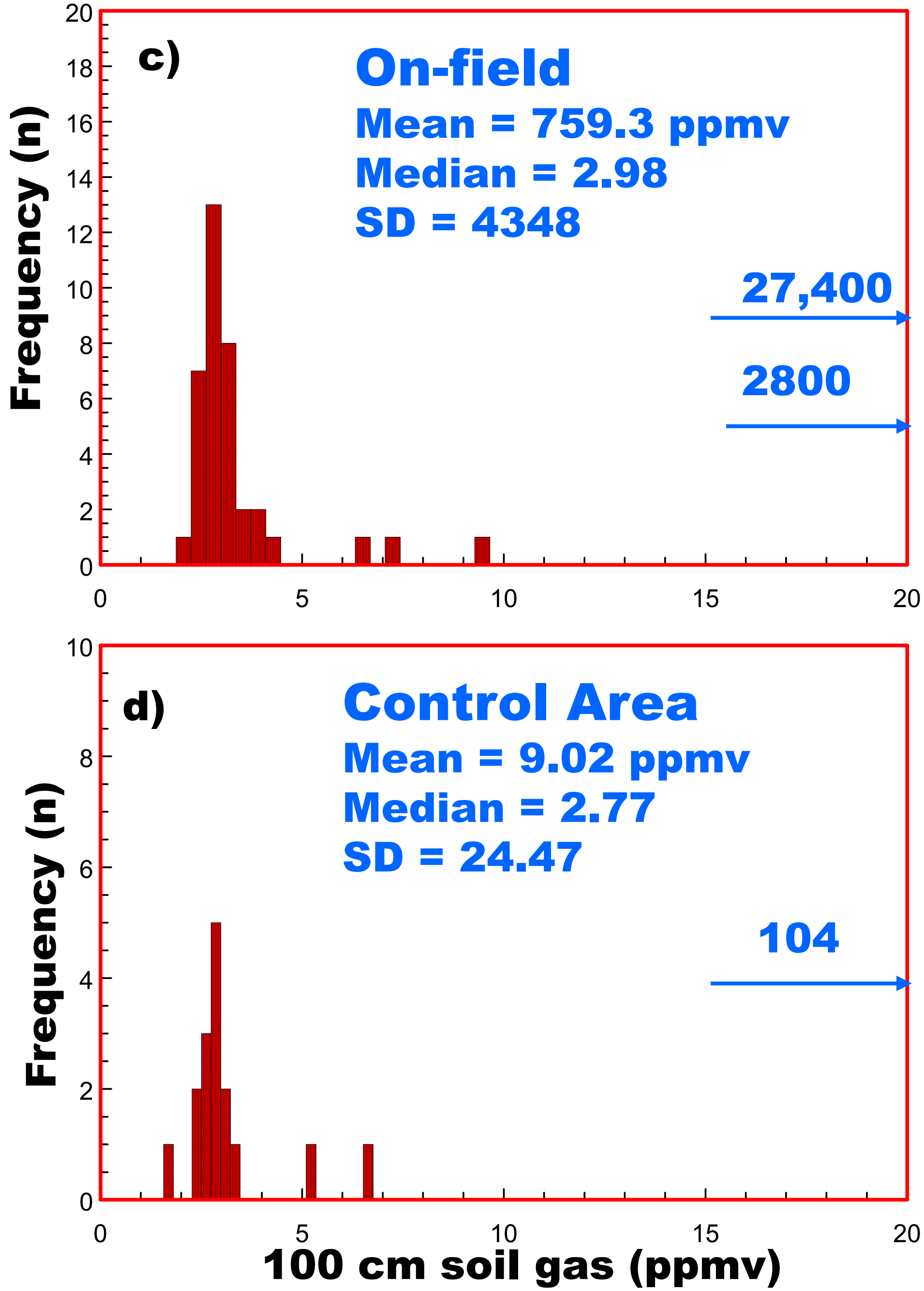
Rangely 100 cm soil gas CH_4

Summer 2001



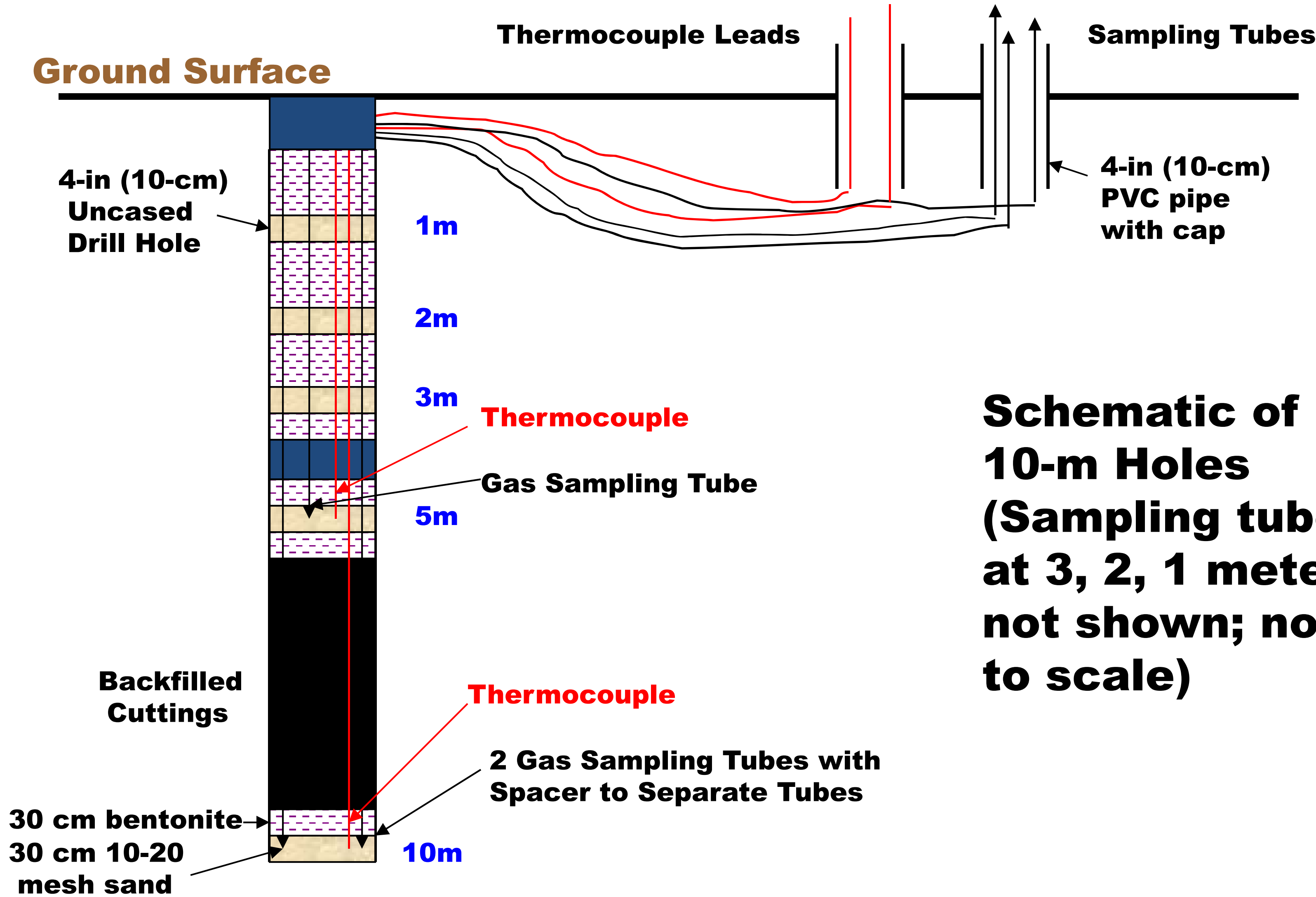
Rangely 100 cm soil gas CH_4

Winter 2001/02

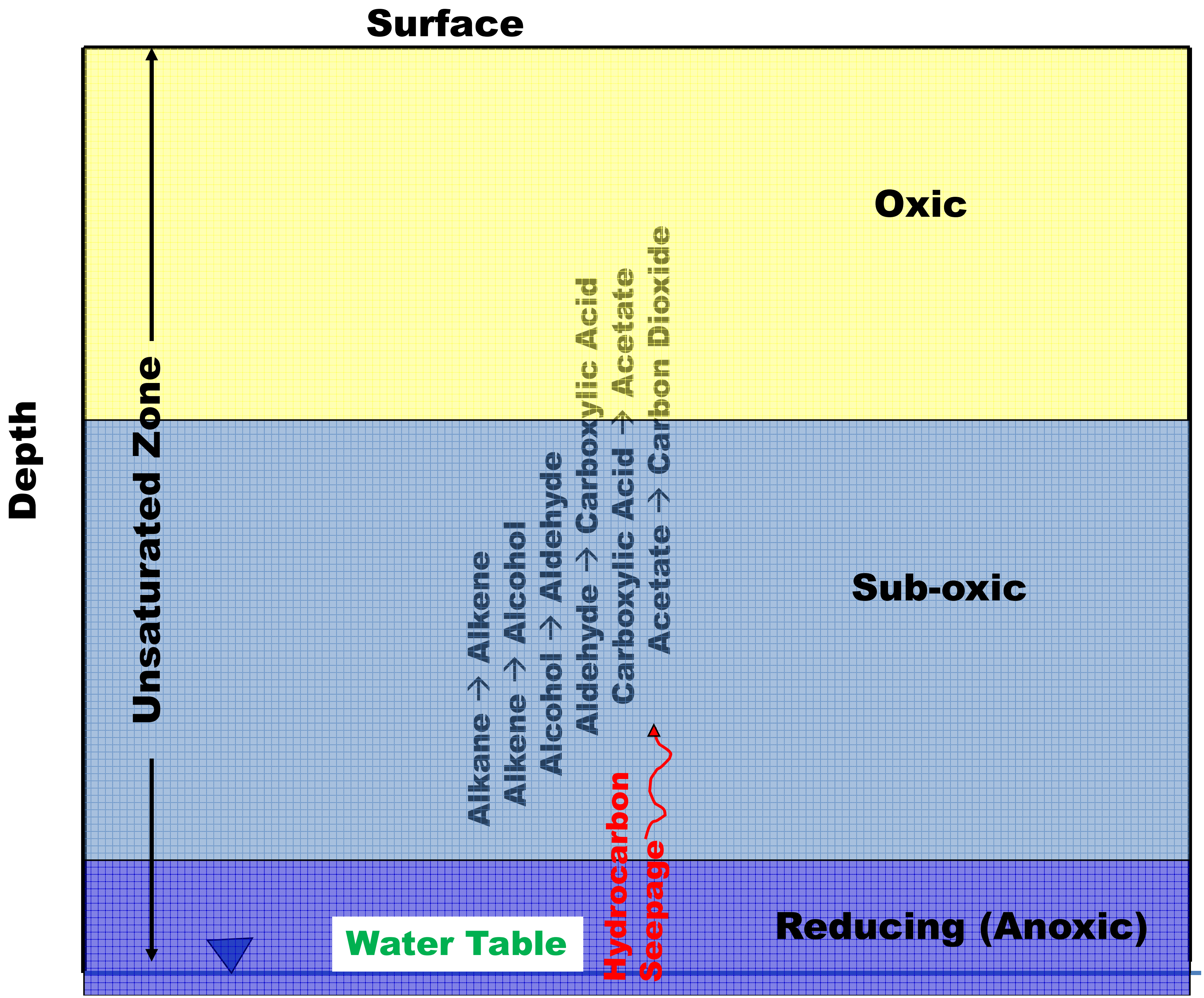


SELECTION OF "INTERESTING" LOCATIONS FOR 10-M HOLES

- Magnitude and direction of both CO_2 and CH_4 fluxes,
- Magnitude and gradient of both CO_2 and CH_4 concentrations in soil gas profiles,
- Isotopic shift in 60-, and 100 cm soil gas CO_2 relative to atmospheric CO_2,
- Selected locations with microseepage evident, and with microseepage absent; soil gas contributes more to the selection process than fluxes; shallow concentration gradients will be useful on Mars.

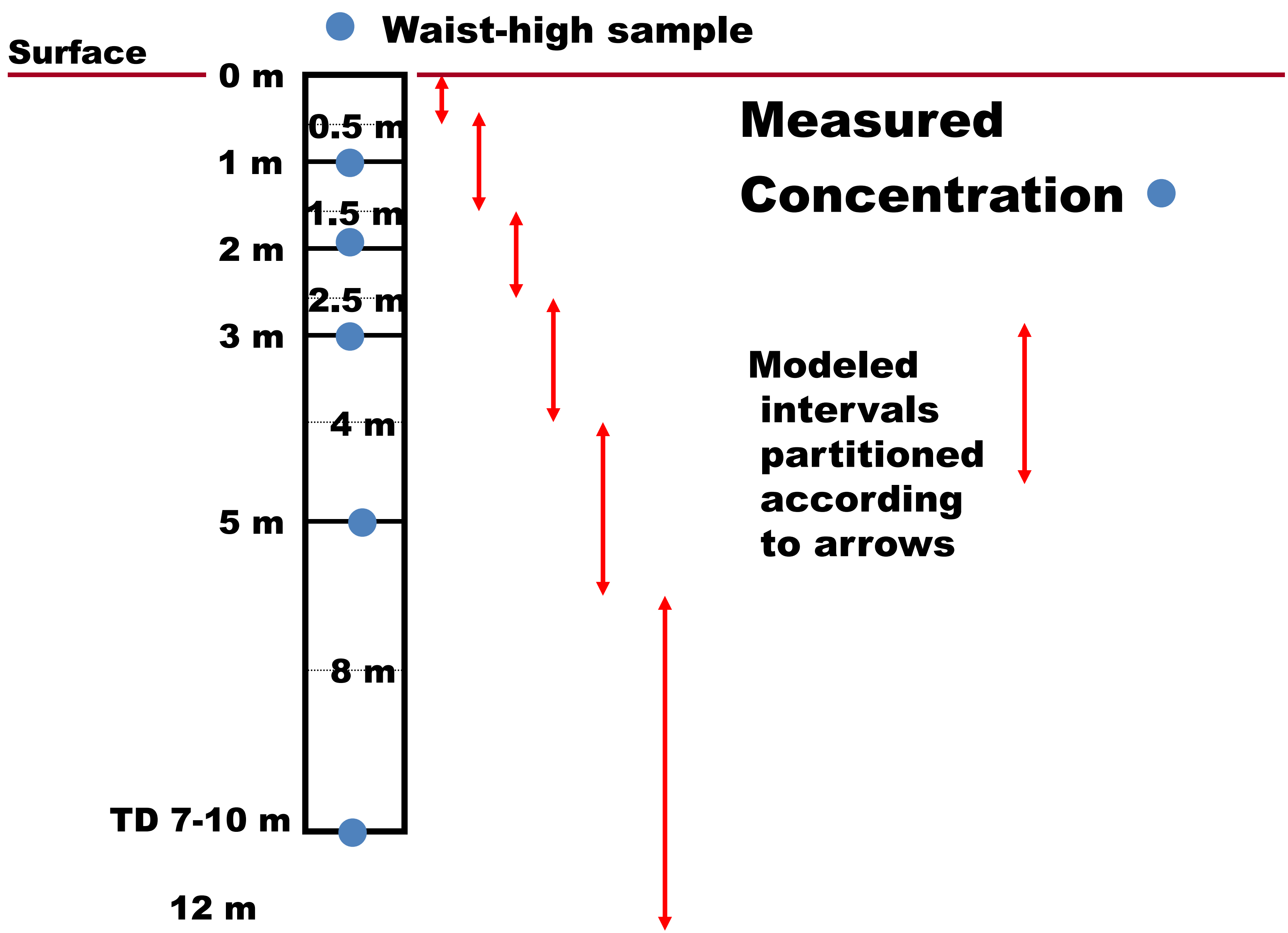


Schematic of 10-m Holes (Sampling tubes at 3, 2, 1 meters not shown; not to scale)



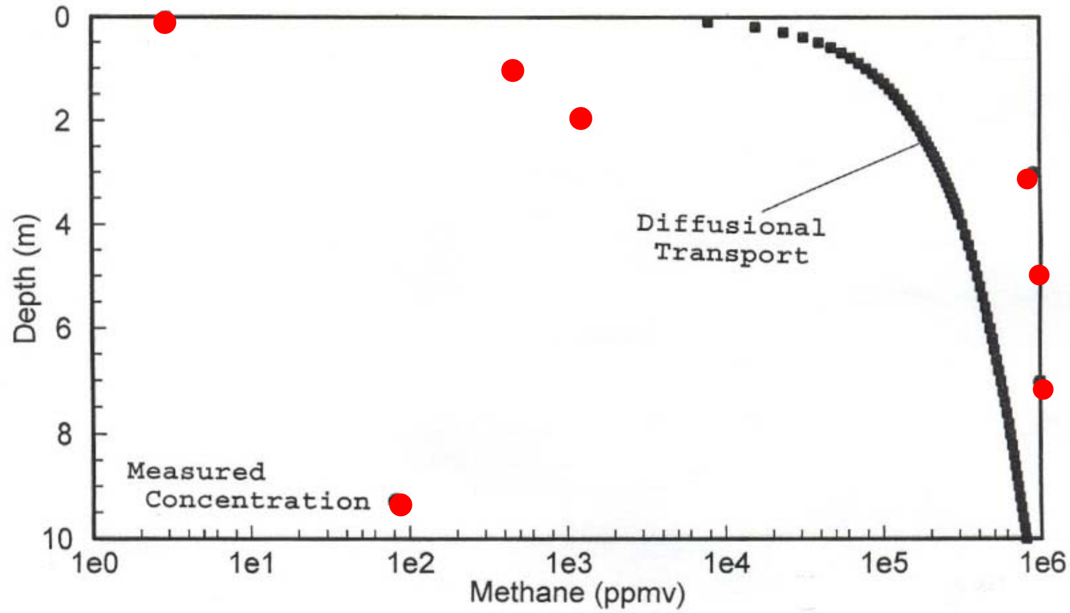
Surface
Oxic
Sub-oxic
Reducing (Anoxic)
Depth
Unsaturated Zone
Water Table
Hydrocarbon Seepage
Alkane → Alkene
Alkene → Alcohol
Alcohol → Aldehyde
Aldehyde → Carboxylic Acid
Carboxylic Acid → Acetate
Acetate → Carbon Dioxide

MODELING INTERVALS FOR "DEEP" (10-meter) HOLES

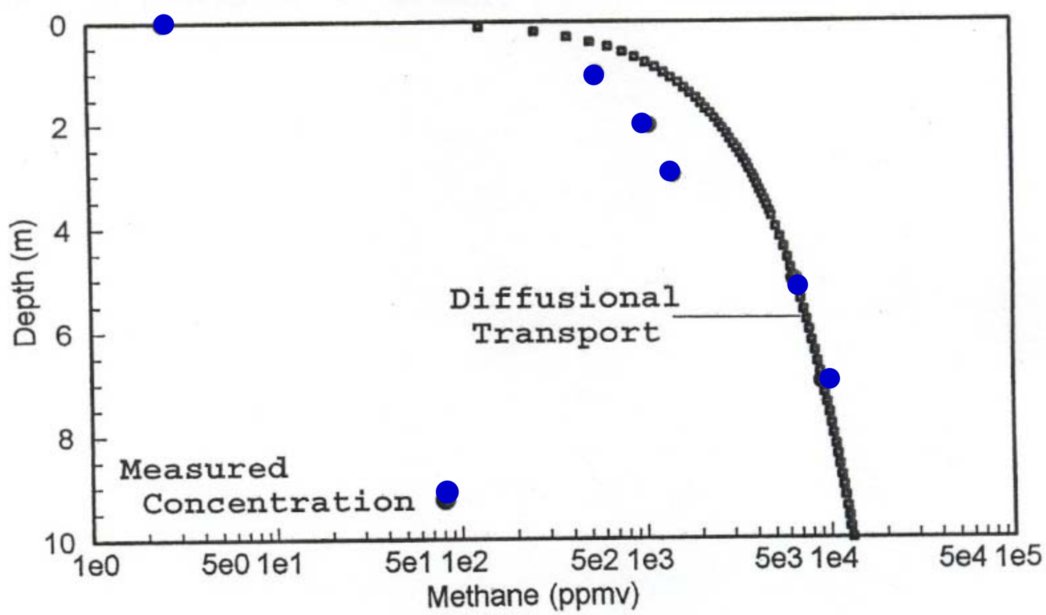


Rangley Measured and Modeled CH_4 Profile for 10-m Hole 01; Diffusion Only

Summer, 2002

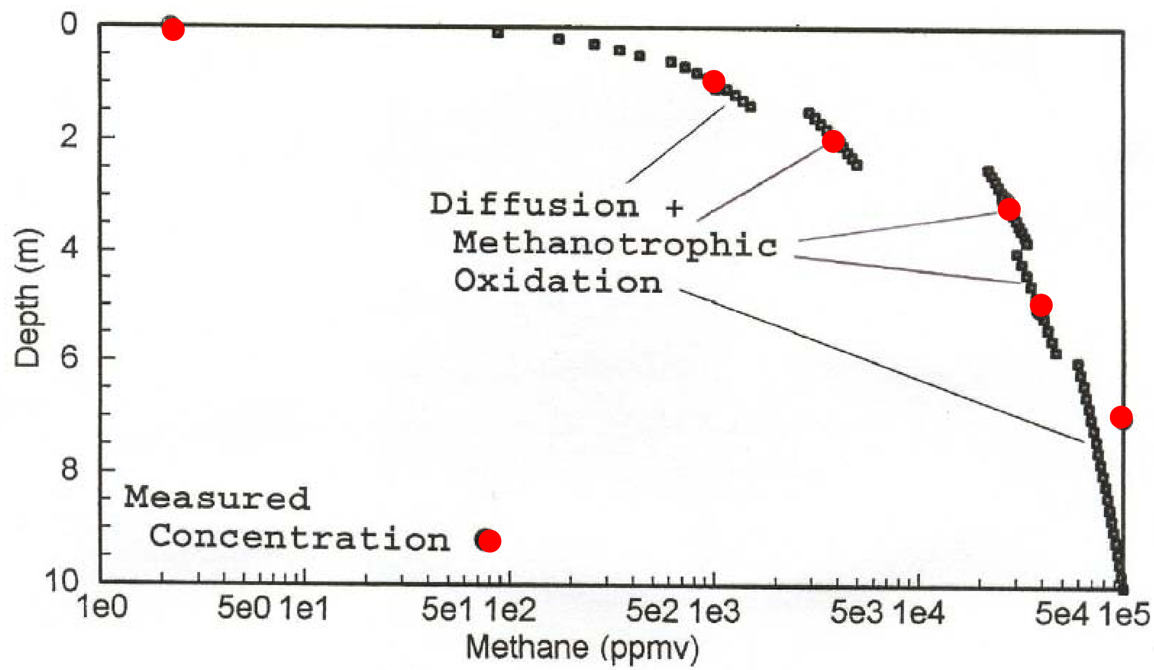


Winter, 2001/02

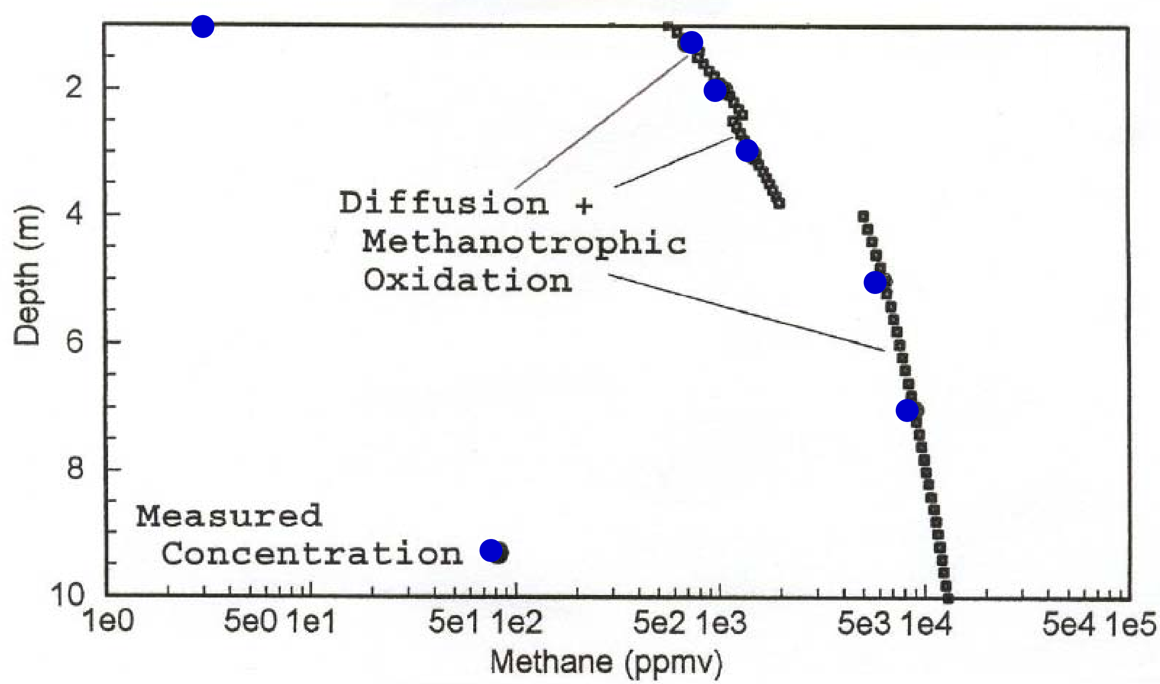


Rangely Measured and Modeled CH_4 Profile for 10-m Hole 01 Diffusion and Methanotrophic Oxidation

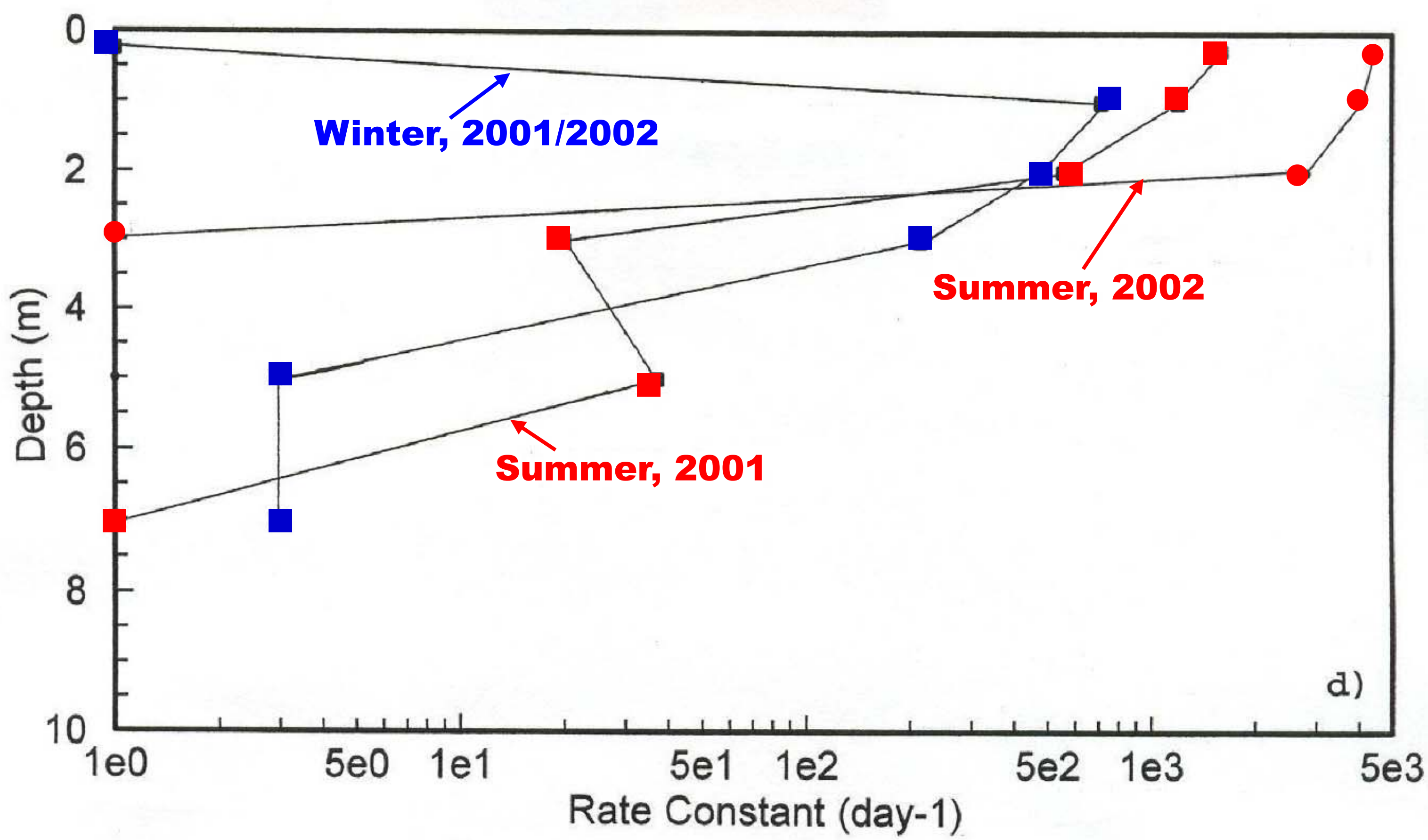
Summer, 2001



Winter, 2001/02

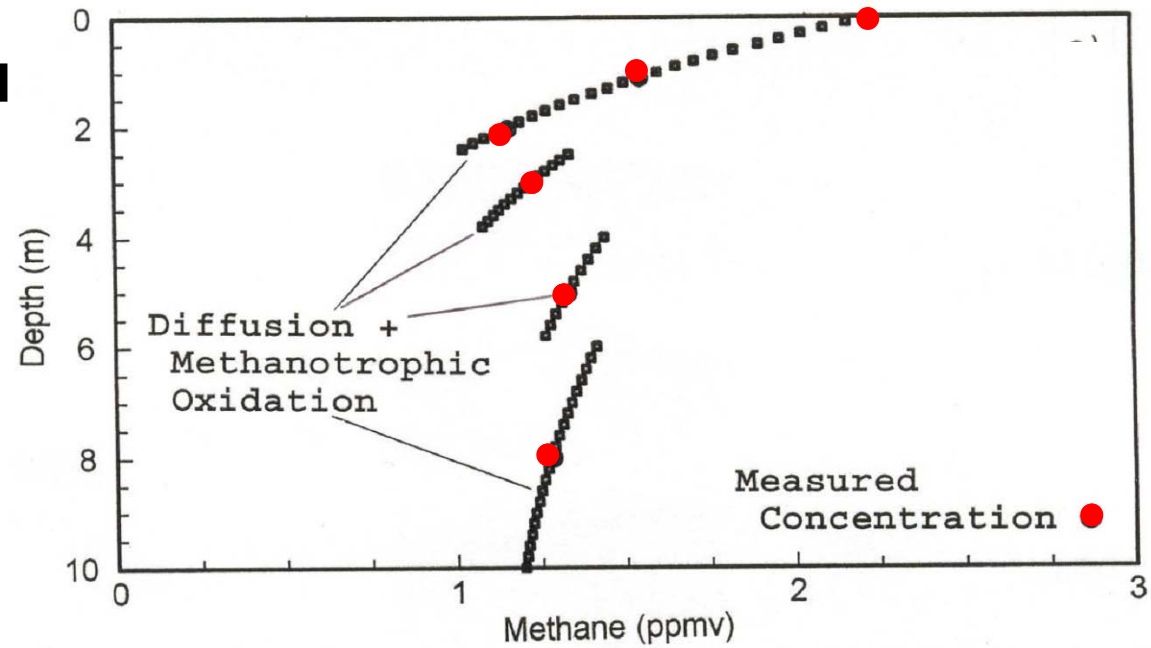


First-order Degradation (Methanotrophy) Rate Constants for CH_4; "Deep" Hole 01

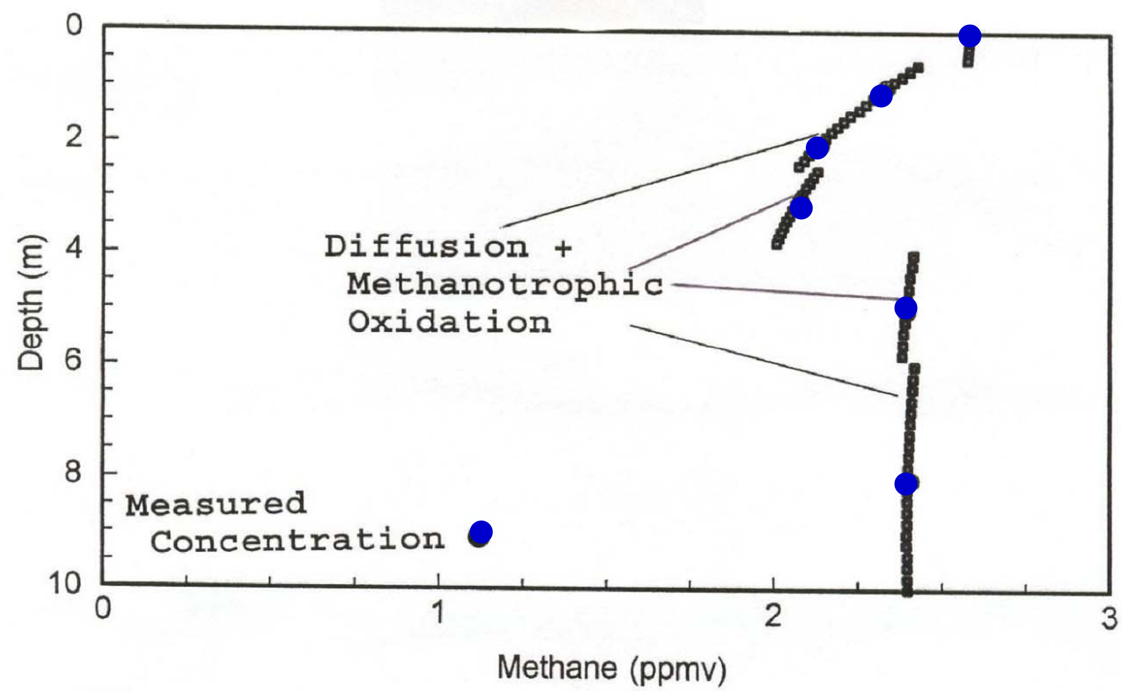


Rangely Measured and Modeled CH_4 for 10-m Hole 28; Diffusion and Methanotrophic Oxidation

Summer, 2001



Winter, 2001/02

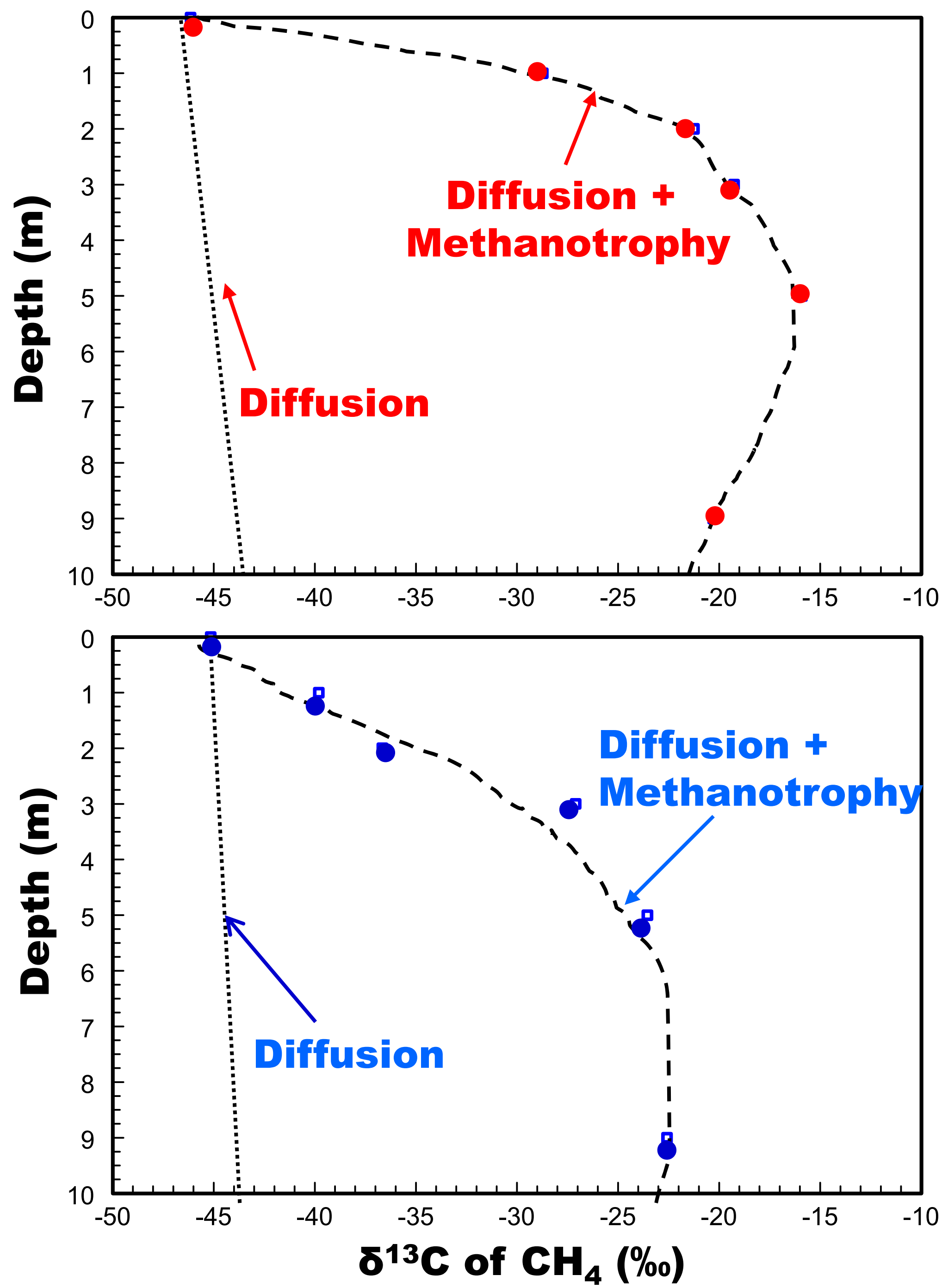


Note sub-atmospheric concentration of CH_4. A lower limit for methanotrophy not observed.

Isotopic shift in $\delta^{13}C$ of CH_4 in anomalous 10-m Hole 03 at Rangely; Reservoir = -40.71‰

Summer, 2002

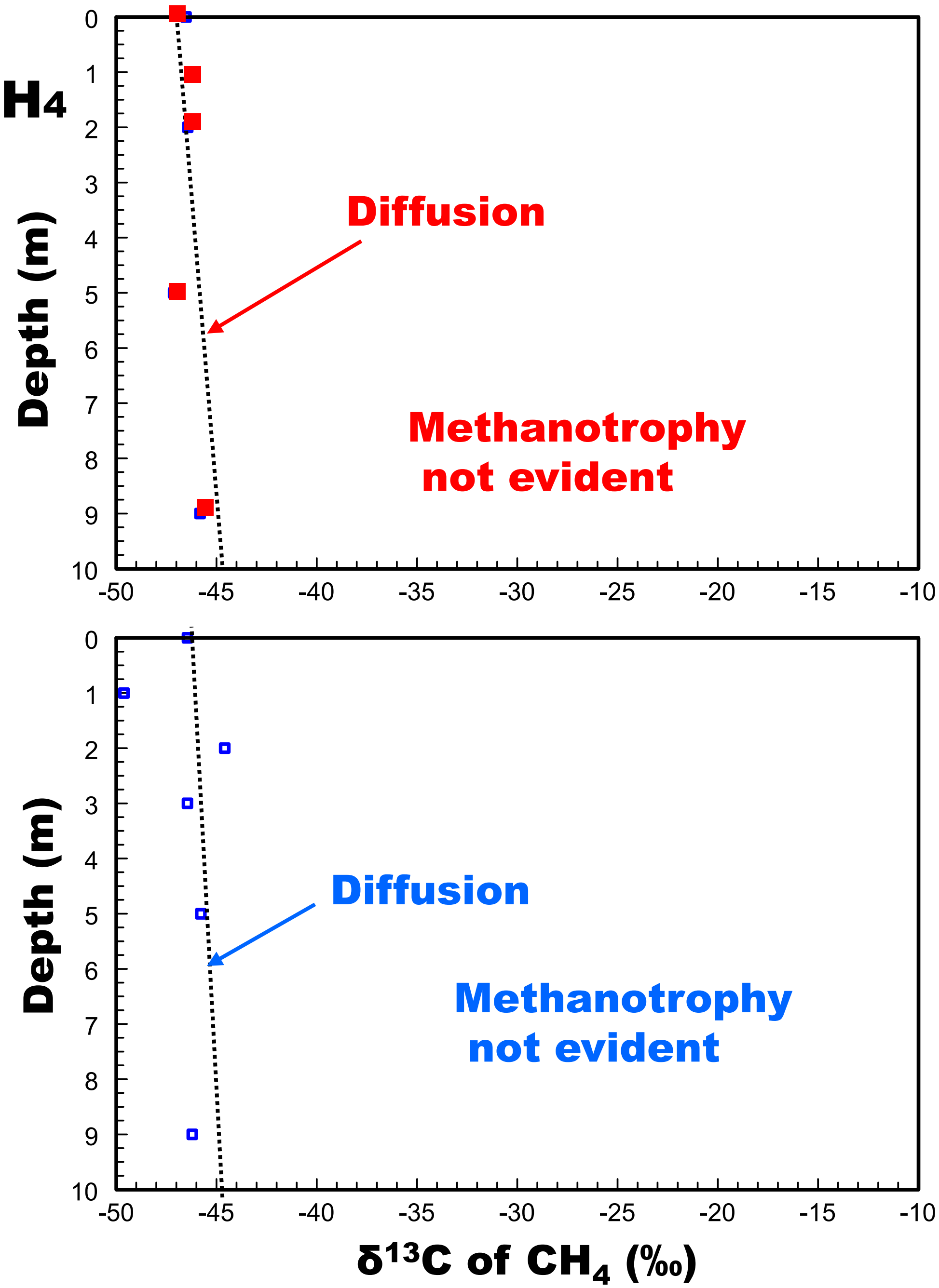
Winter, 2001/02



Isotopic shift in δ¹³C of CH_4 in non-anomalous 10-m Hole 34 at Rangely Reservoir = -40.71‰

Summer, 2002

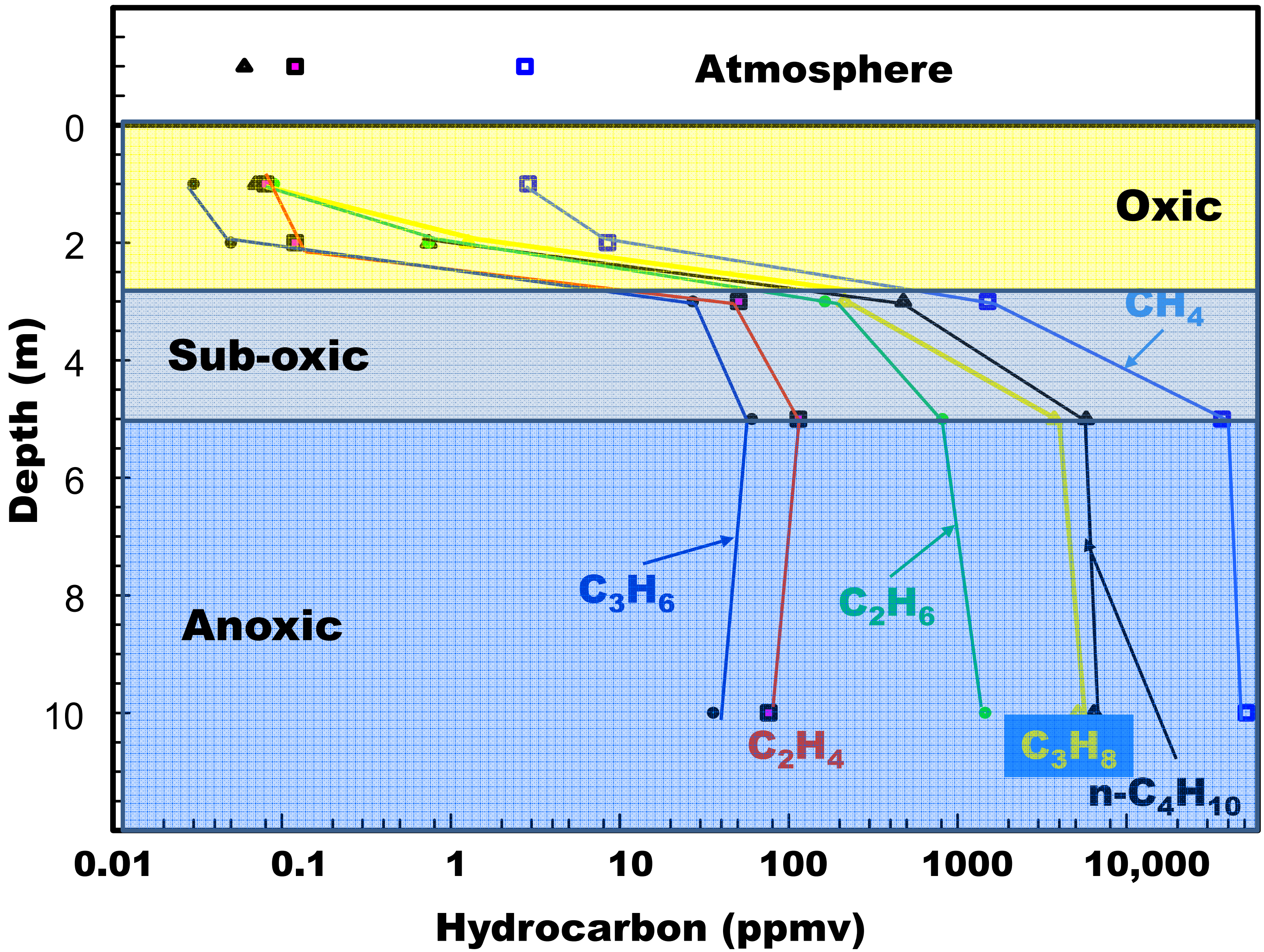
Winter, 2001/02



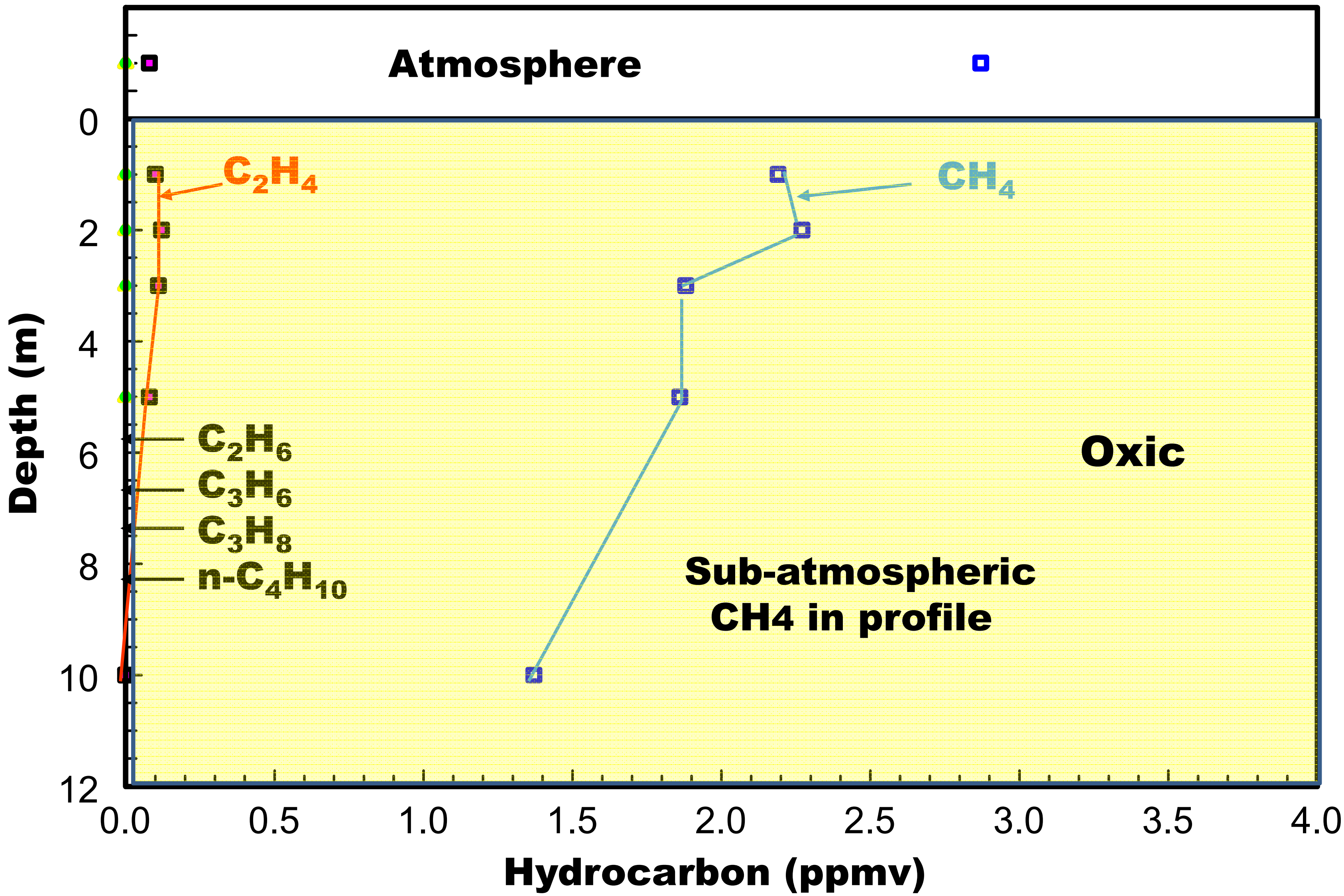
ESTIMATION OF CH_4 MICROSEEPAGE INTO THE ATMOSPHERE AT RANGELY (a start on Accounting)

- **The gross CH_4 microseepage into the atmosphere over 78 km^2 is 700±1200 tonnes $year^{-1}$ using the winter rate***
- **The net CH_4 microseepage into the atmosphere is 400 metric tonnes $year^{-1}$ ±?, subtracting the control area from the on-field data.**
- ***non-parametric estimated rate is positive with $\alpha = 0.015$.**

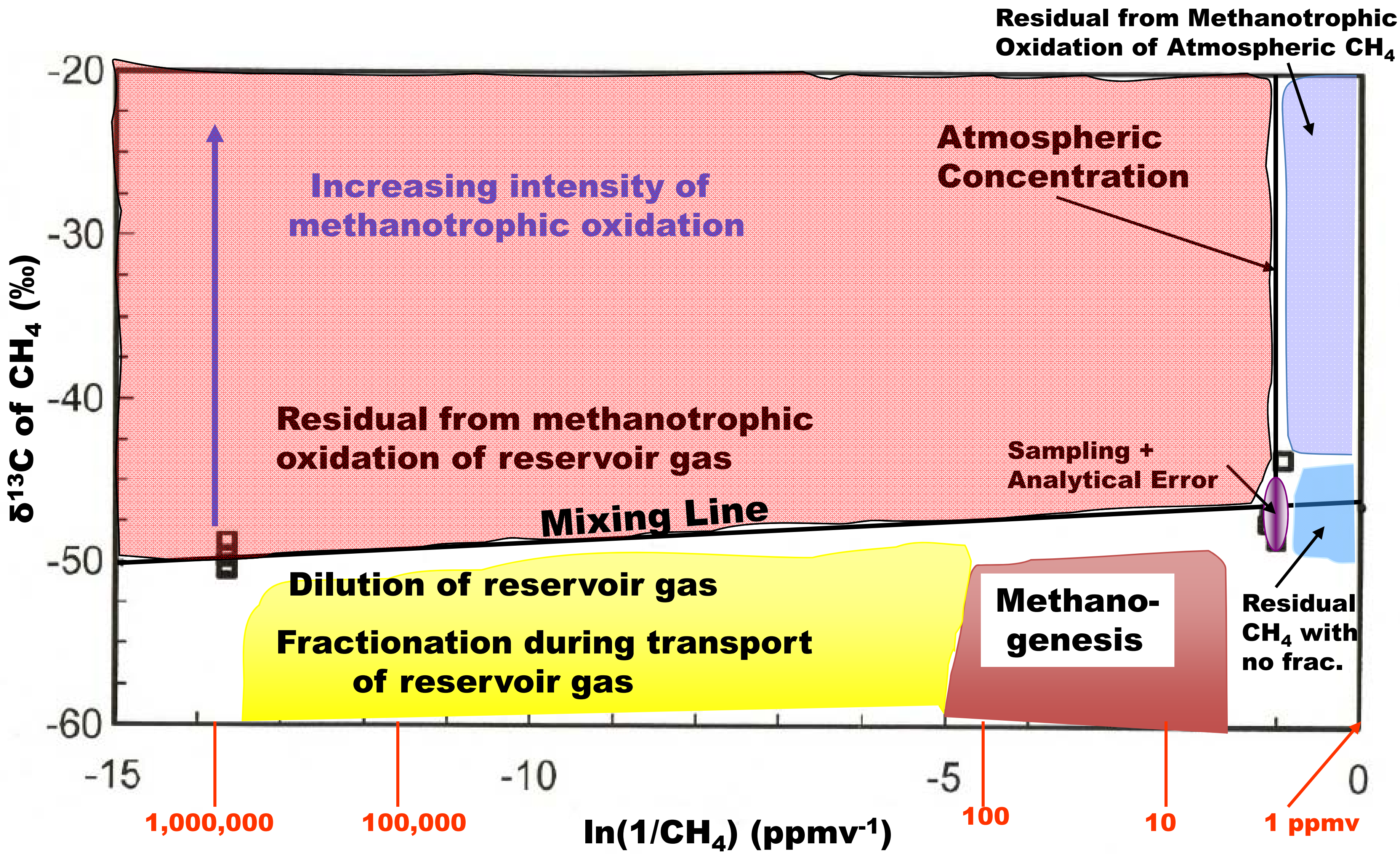
TEAPOT DOME – LIGHT HYDROCARBONS IN ANOMALOUS 10-m HOLE 17; JANUARY, 2005



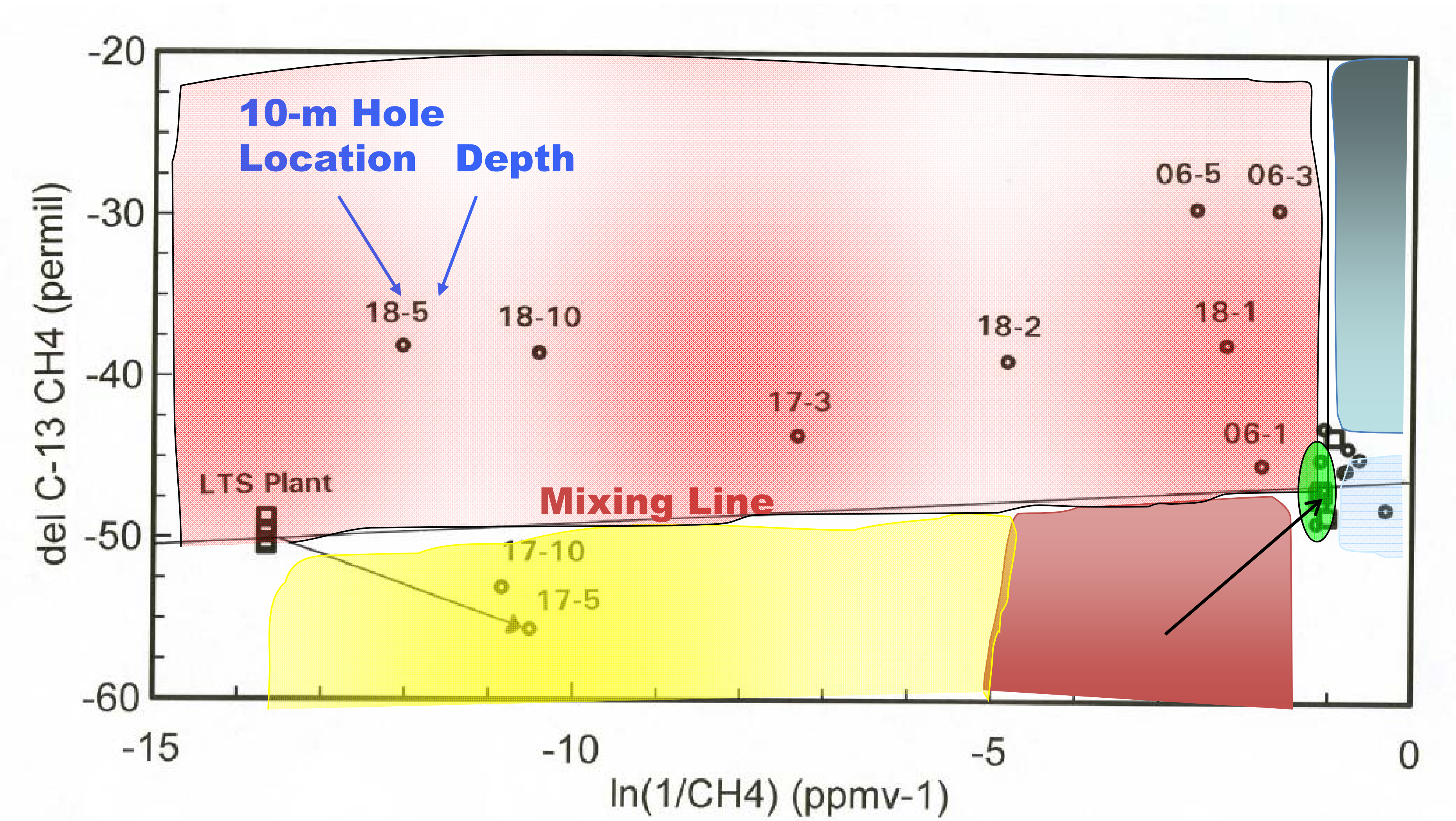
TEAPOT DOME – LIGHT HYDROCARBONS IN NON-ANOM.10-m HOLE 02; JANUARY, 2005



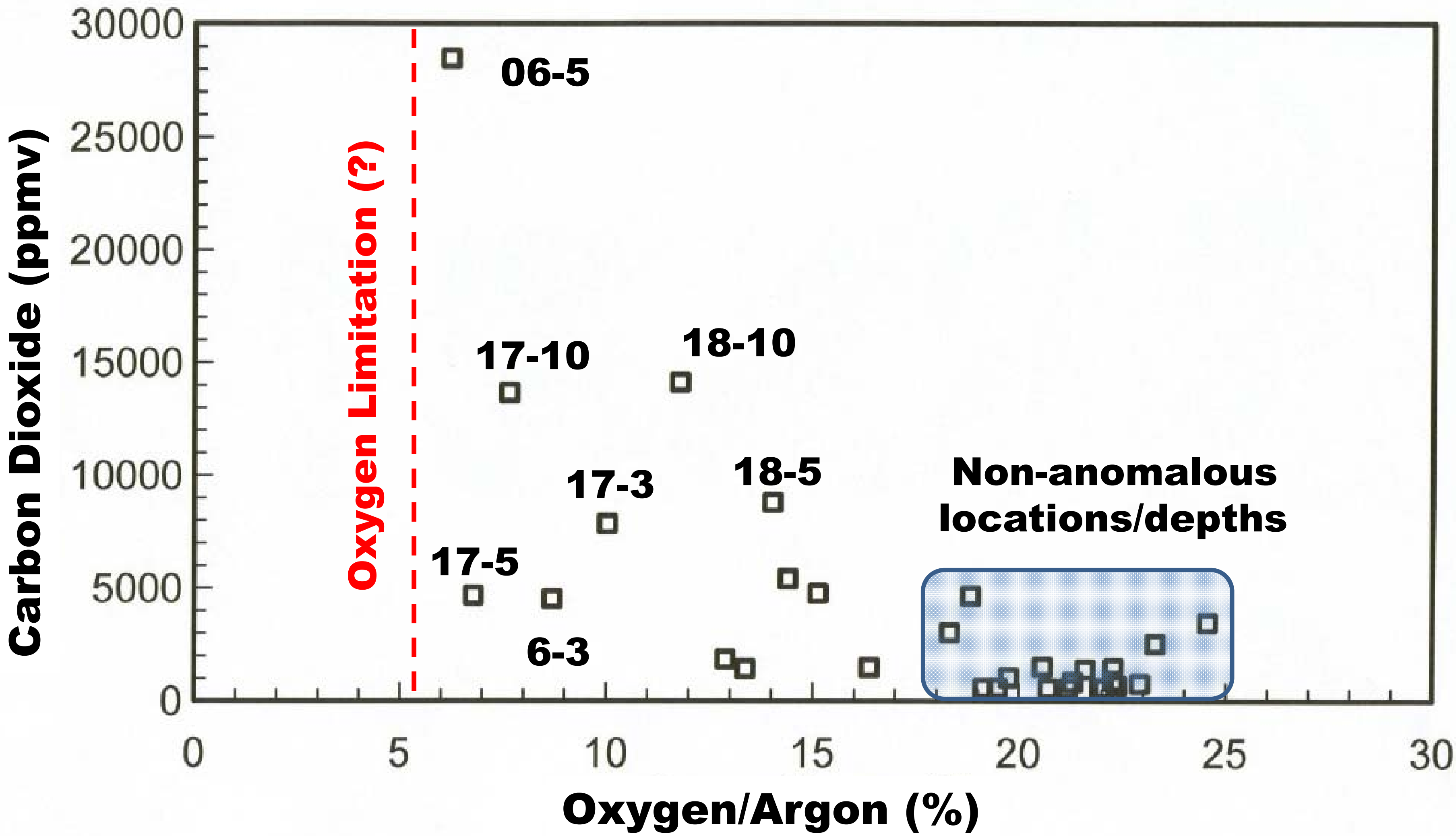
Generic δ^{13}C of CH_4 vs. ln(1/CH_4) Diagram

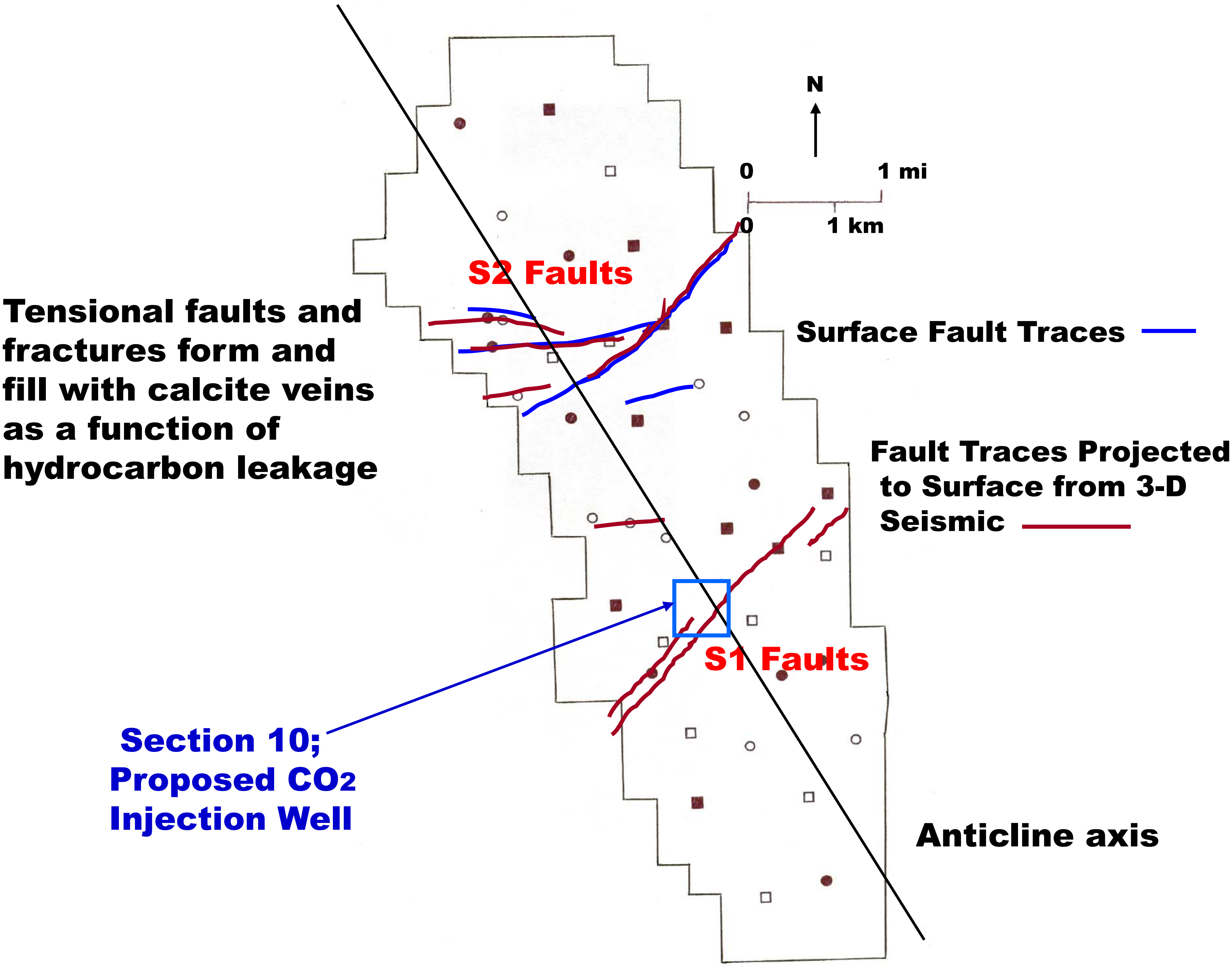


TEAPOT DOME – 10-m HOLES JANUARY, 2005



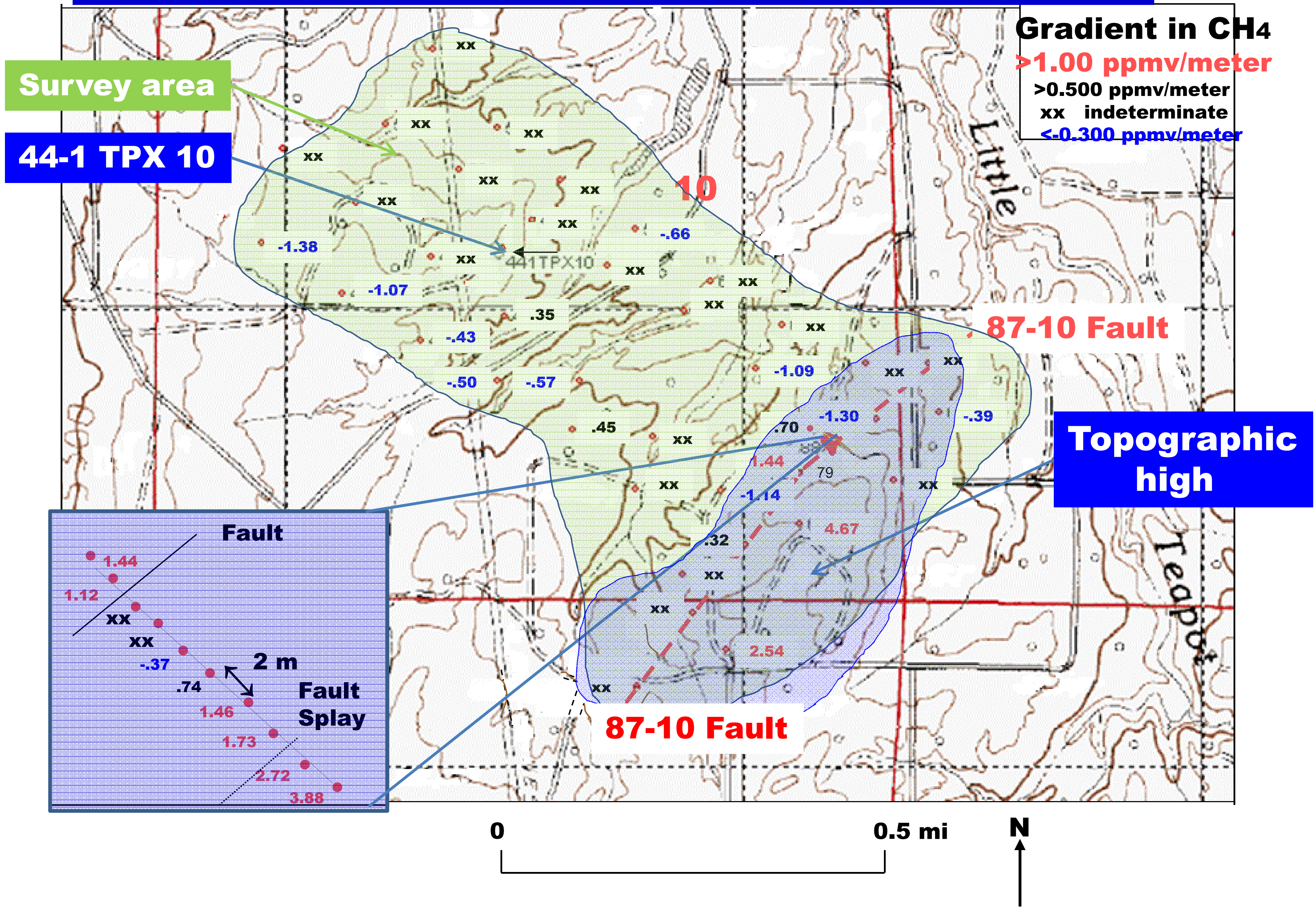
Teapot Dome – Winter, 2005
10-m Holes



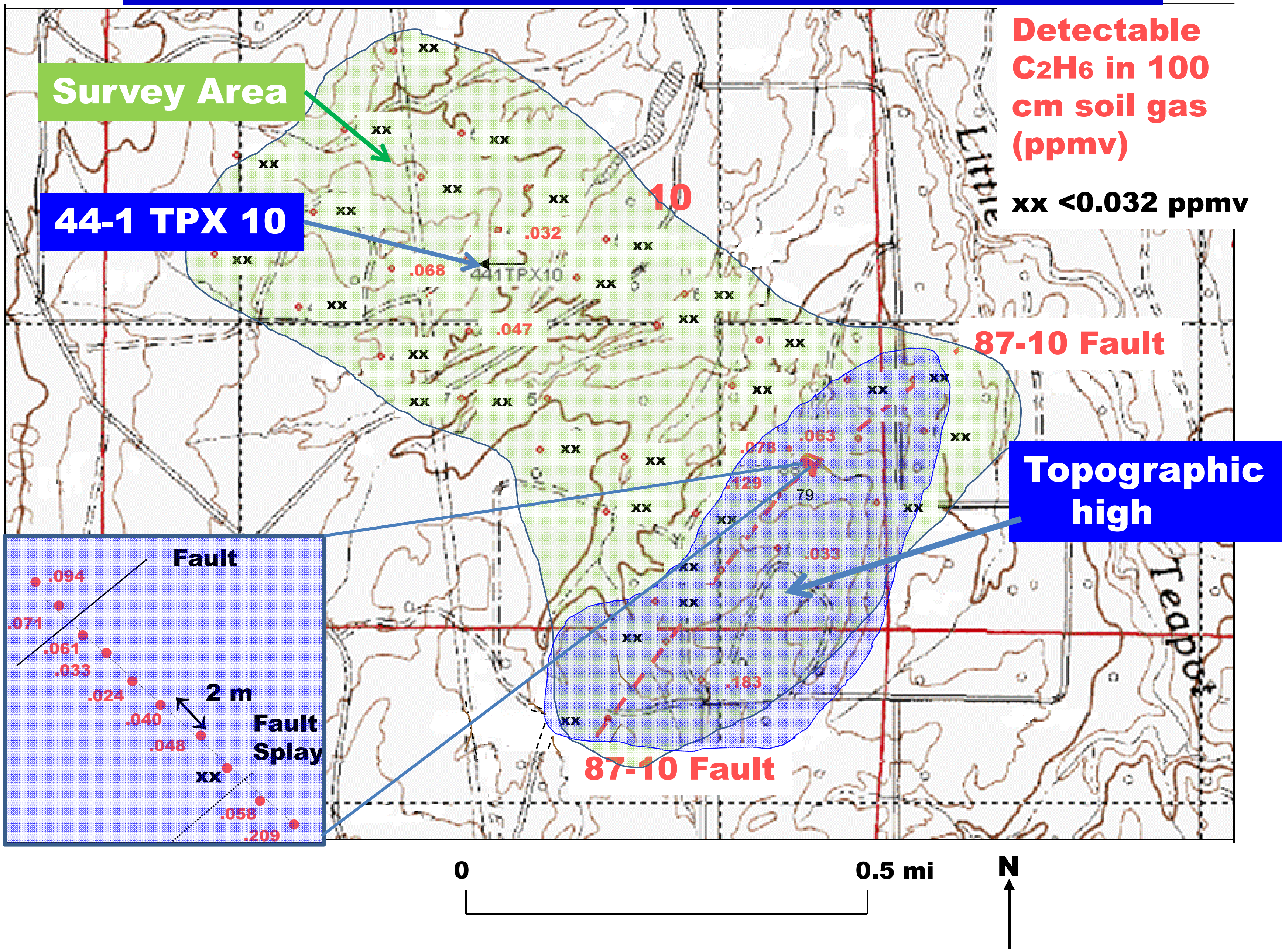


Tensional faults and fractures form and fill with calcite veins as a function of hydrocarbon leakage
S2 Faults
N
0
1 mi
0
1 km
Surface Fault Traces
Fault Traces Projected to Surface from 3-D Seismic
S1 Faults
Section 10; Proposed CO_2 Injection Well
Anticline axis

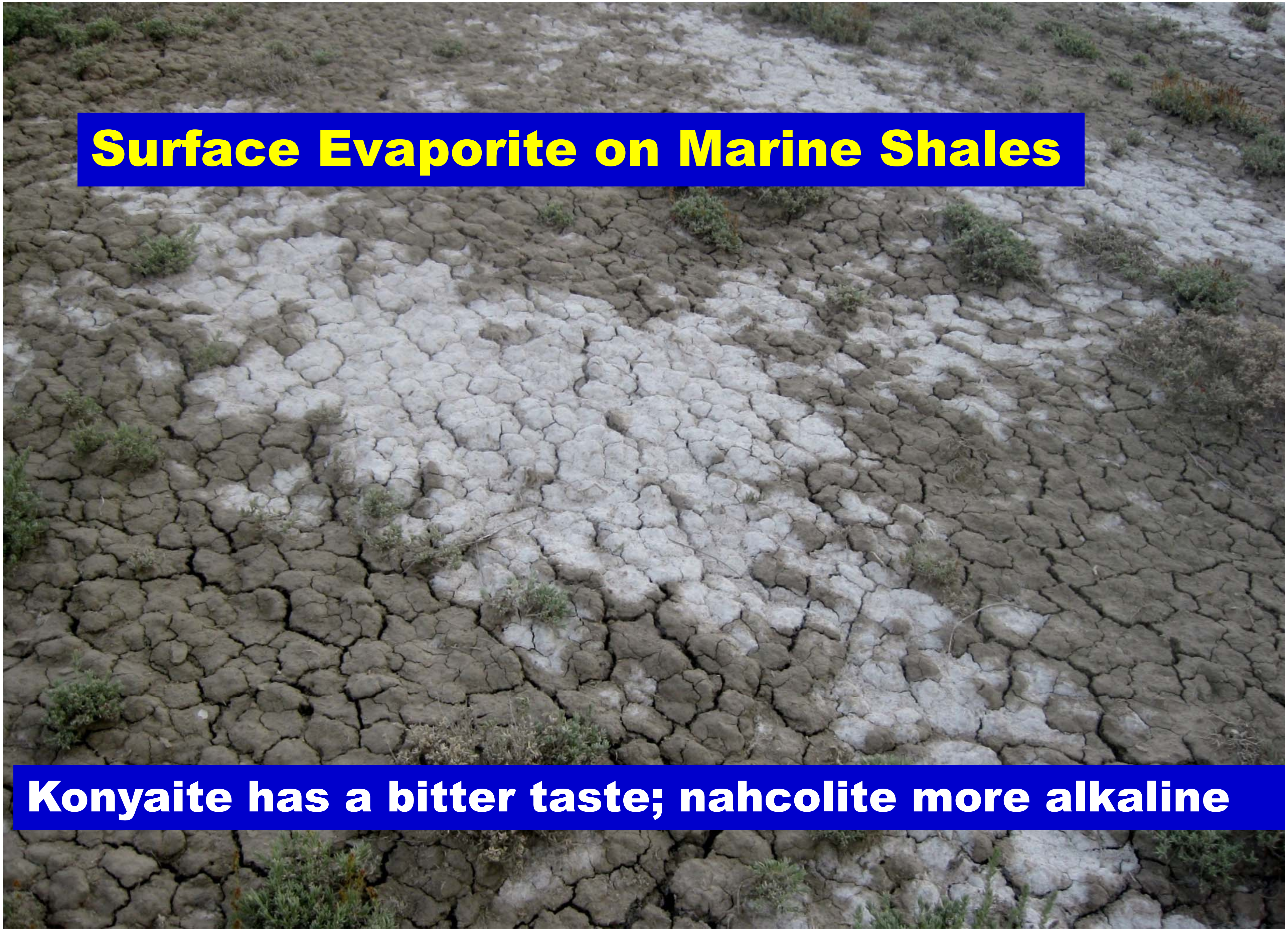
Teapot Dome – Section 10 Soil Gas Survey



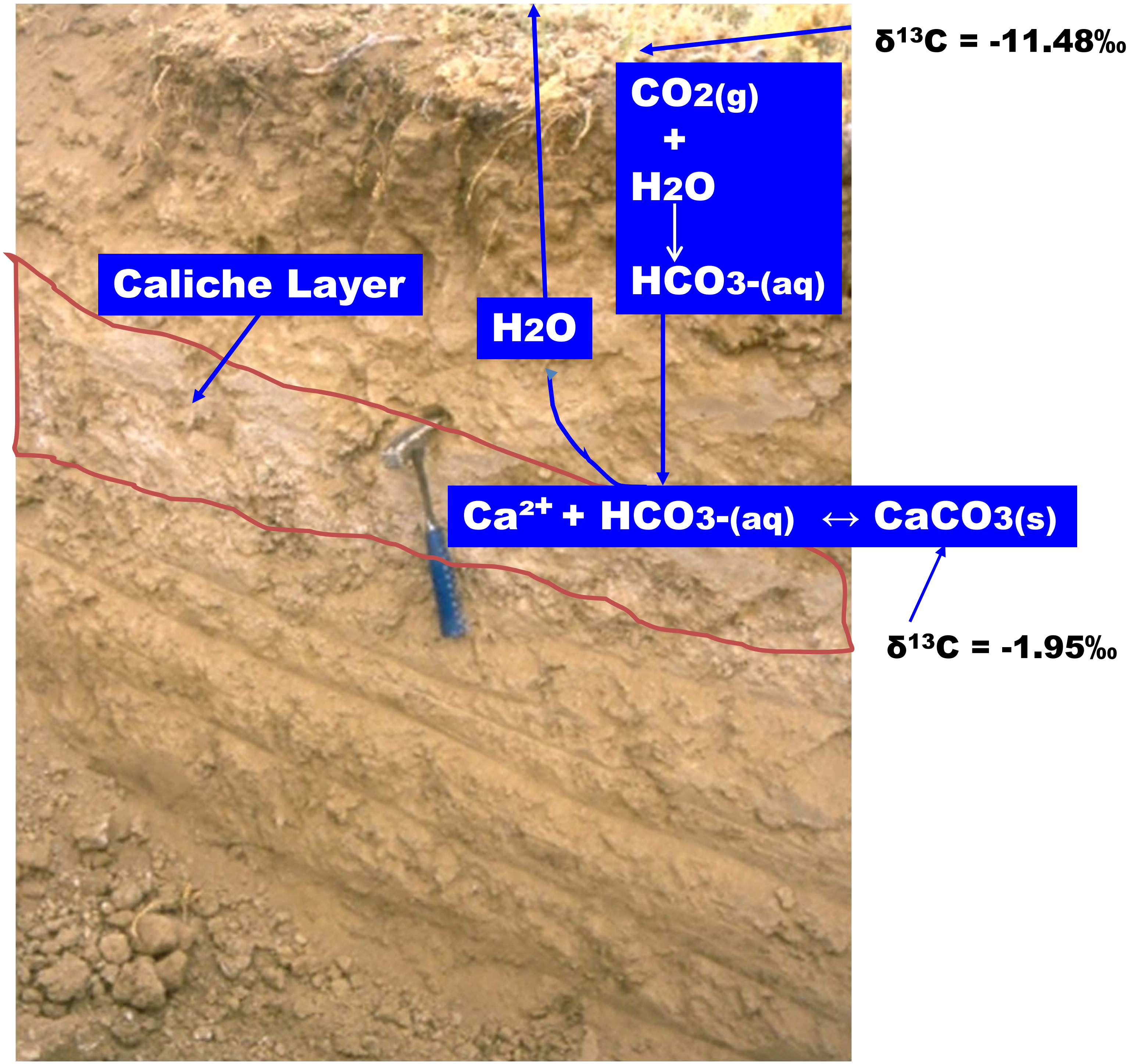
Teapot Dome – Section 10 Survey Area




TRENCH 87-10W
Bentonite-rich “soil”
Konyaite bloom forms overnight; Na2Mg(SO4)2·5H2O
Sussex sandstone chips with CaCO3 in partings

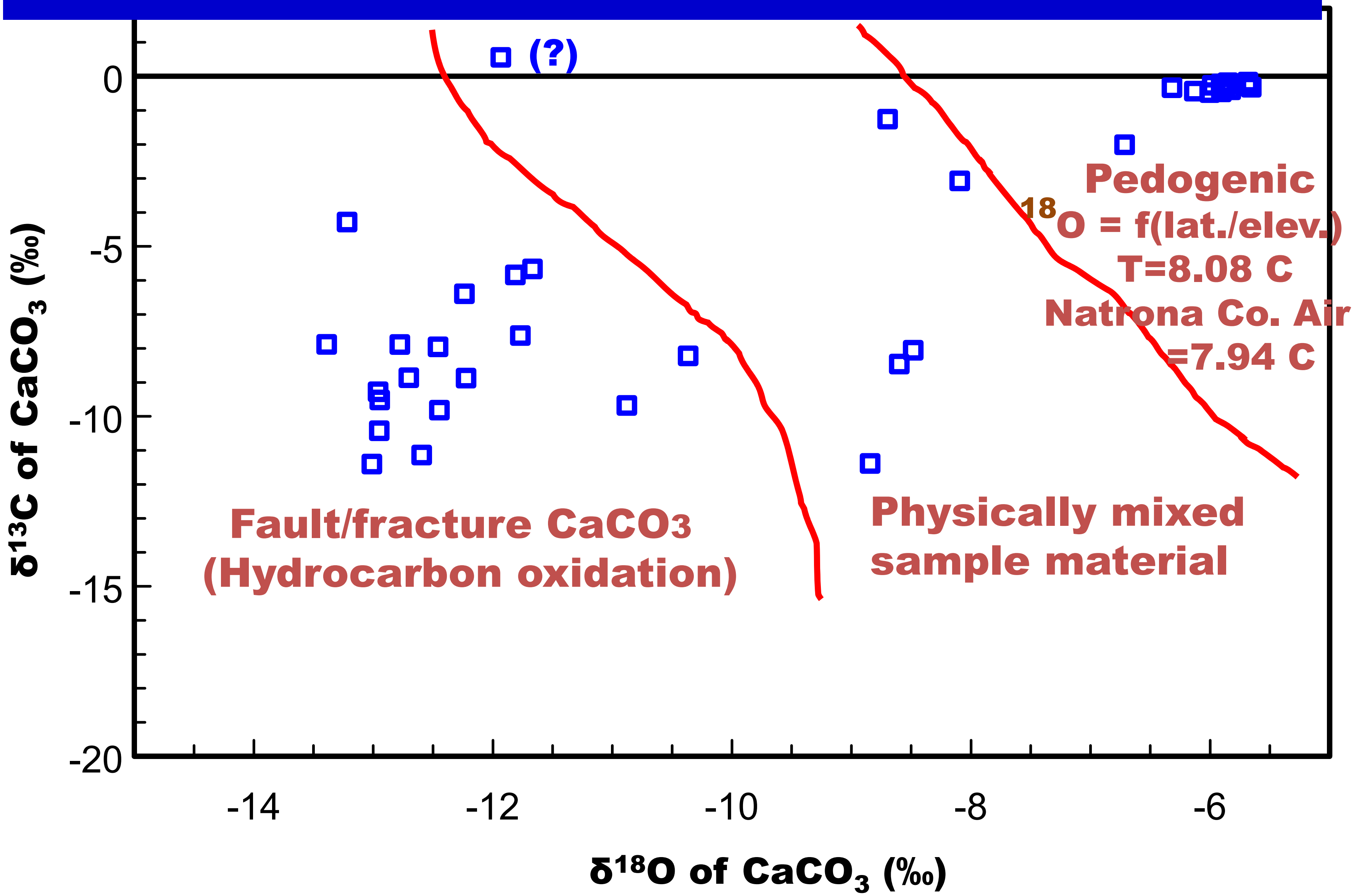

Surface Evaporite on Marine Shales
Konyaite has a bitter taste; nahcolite more alkaline


Coarse-grained calcite
in Trench 87-10E
Estwing
Grip



$\delta^{13}C$ = -11.48‰
$CO_{2(g)}$
+
H_2O
$HCO_3^-{}_{(aq)}$
Caliche Layer
H_2O
Ca^{2+} + $HCO_3^-{}_{(aq)}$ ↔ $CaCO_{3(s)}$
$\delta^{13}C$ = -1.95‰

TEAPOT DOME - SECTION 10 – TRENCHES 87-10W and 87-10E



INDIRECT INDICATORS OF GAS SEEPAGE

(from Klusman, 1993, Chapter 7)

Applicability to Mars

Yes Satellite imagery – Linear and circular features, topographic highs, color shifts indicative of alteration

Yes Secondary carbonate and sulphate minerals

Yes $\delta^{13}C$ and $\delta^{18}O$ of cements and vein materials

Yes Electrical resistivity of shallow subsurface

Yes Horizontal gradient magnetic intensity indicative of iron reduction producing magnetite and sulphides

Yes Radiometric – redox processes inhibiting migration of uranium and potassium-40 in near-surface

Yes Gradients in temperature with depth – Heat flow related to mass flow because of poor thermal conductivity of rocks

? Selected trace elements in soils – iodine, strontium, ratioed to iron as indicators of redox conditions

INDIRECT INDICATORS OF GAS SEEPAGE

Applicability to Mars

? Gradients in inert gases with depth – variable results because of high mobility of helium, high concentrations of neon and argon in the Earth atmosphere overwhelming a signal from depth

? UV fluorescence of organics extracted from soil indicative of multi-ring structures

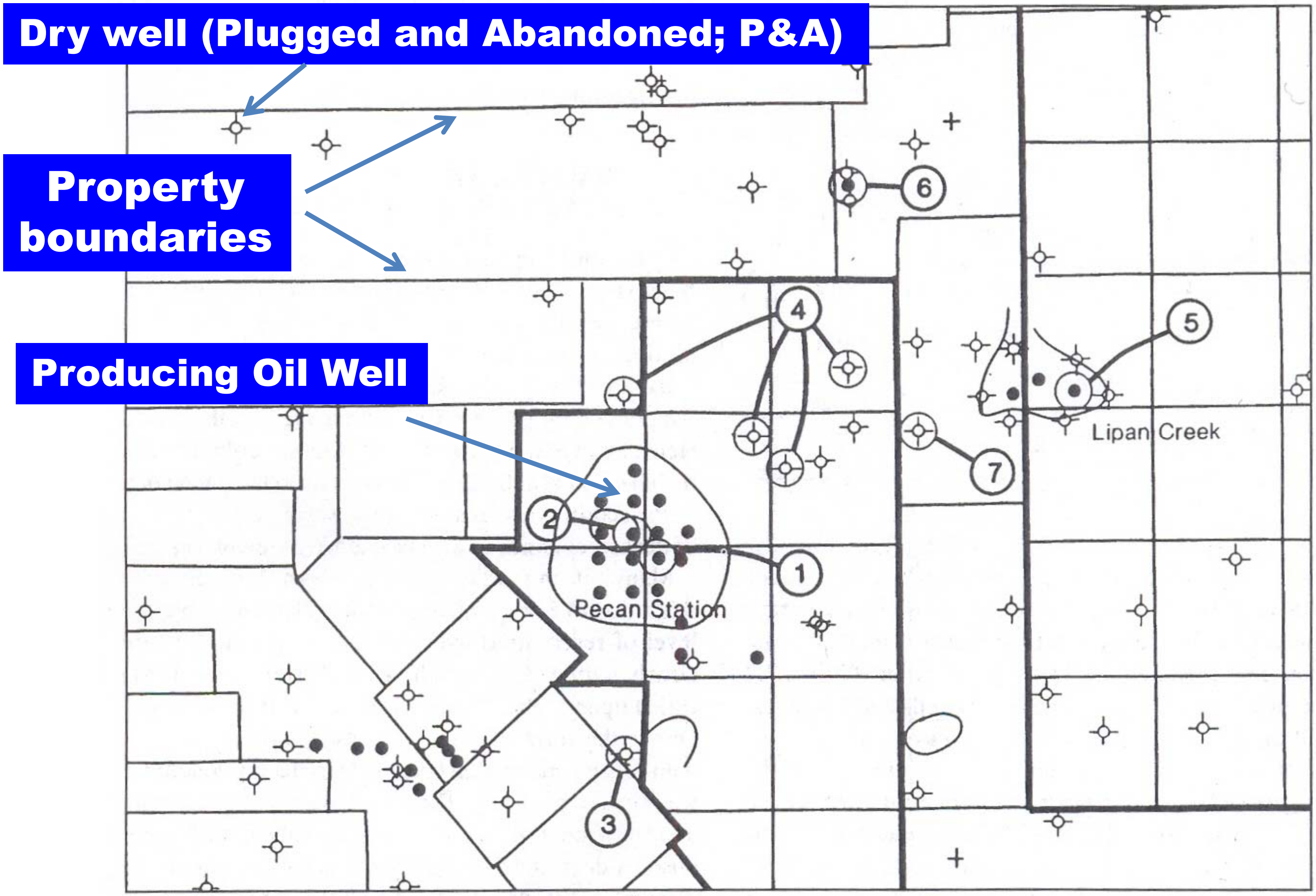
No Geobotany and biogeochemistry – Natural selection processes indicative of unusual soil chemistry

No Satellite radar – detection of oil film on sea surface

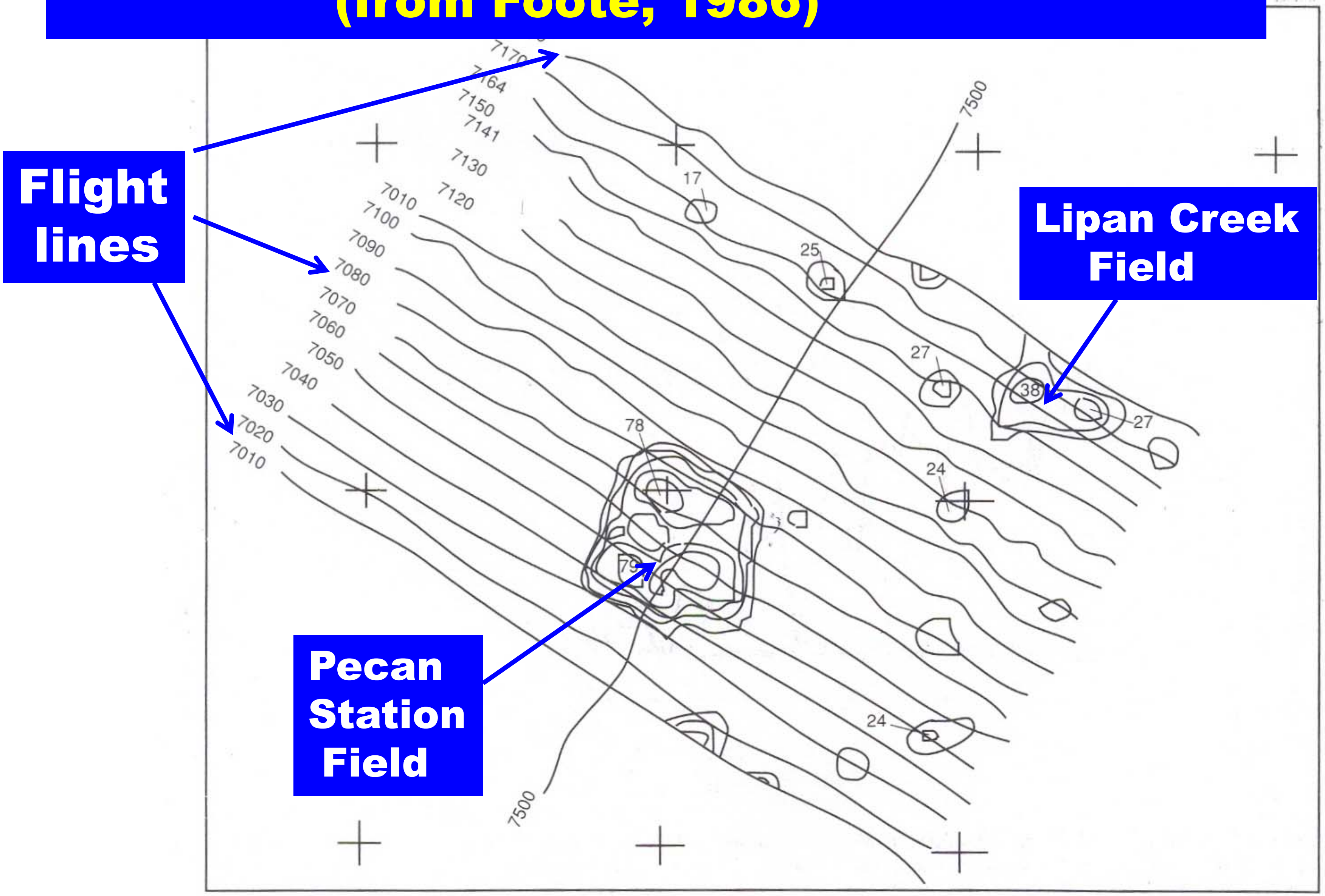
No Microbiological – Specific organisms tolerant of alcohols produced by stepwise oxidation

No Ground radar – indicative of polar molecules; water vapor as a "carrier gas."

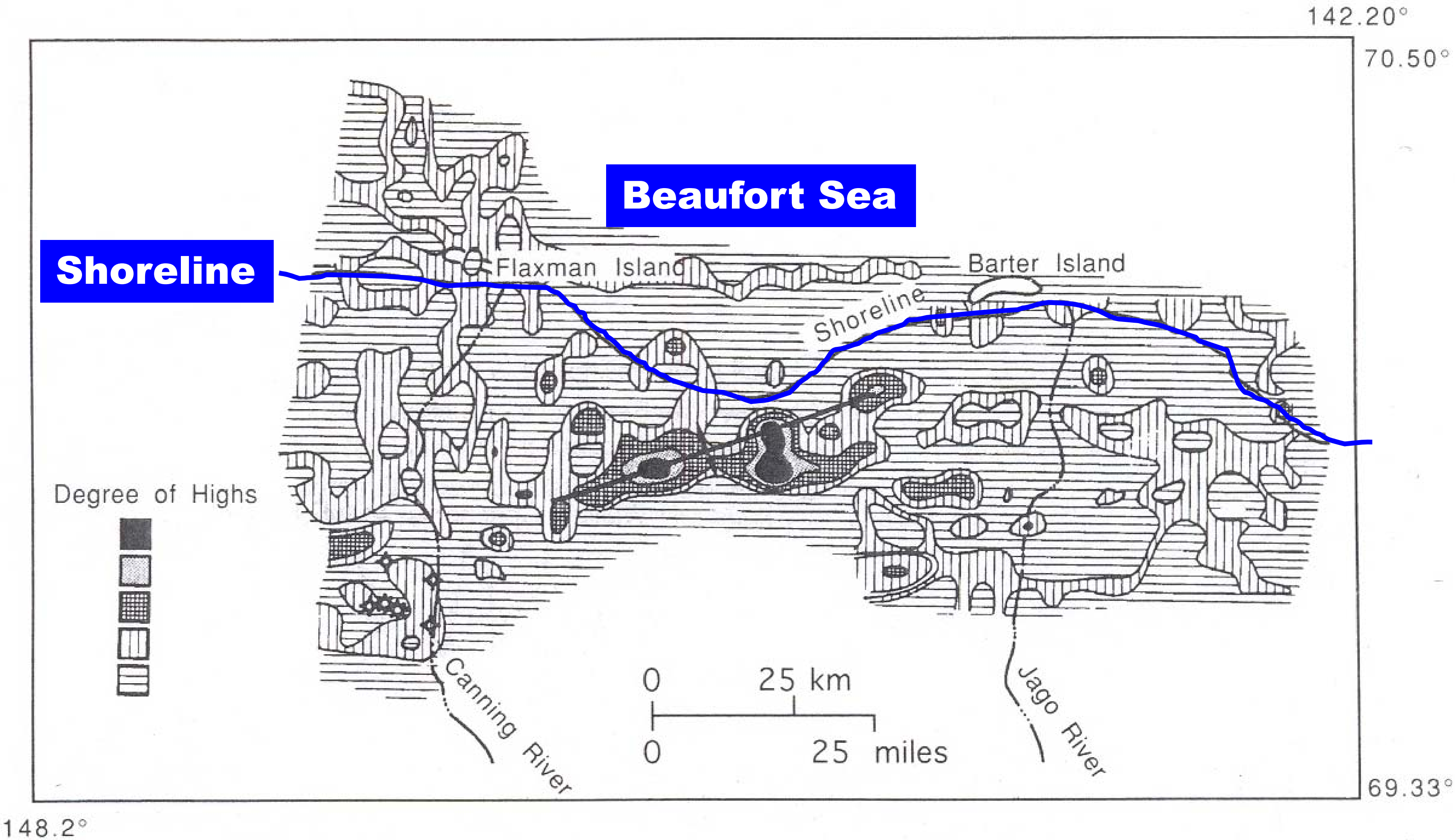
Oil Production in Tom Green County, Texas (from Foote, 1986)



Horizontal Gradient Magnetometer Survey in Tom Green County, Texas (from Foote, 1986)



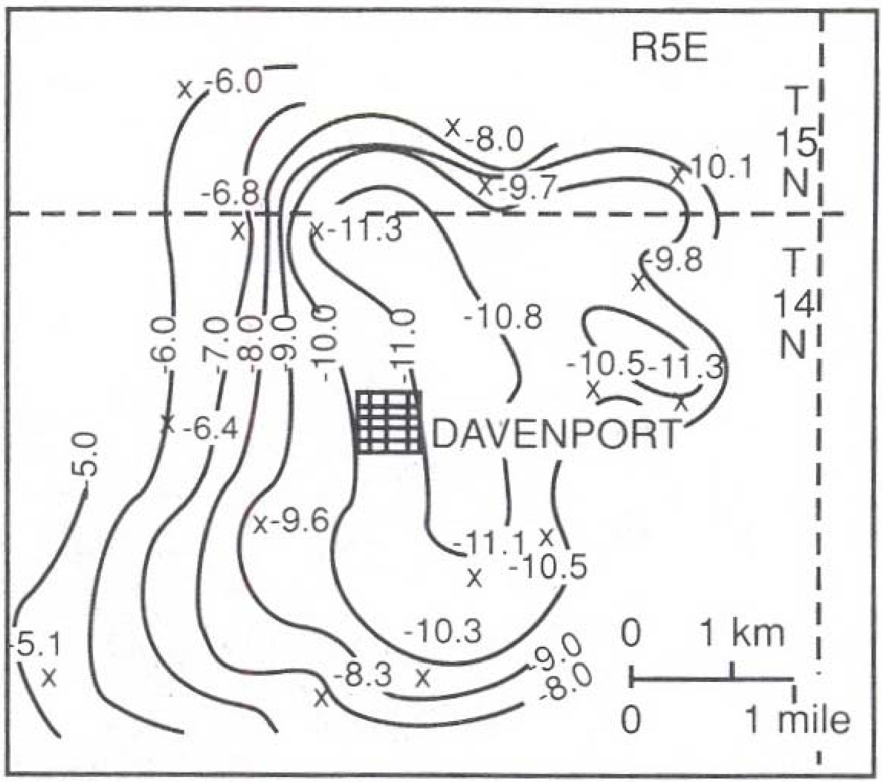
Magnetic Anomalies over Marsh Creek Anticline in Arctic National Wildlife Refuge, Alaska (from Donovan et al., 1984)



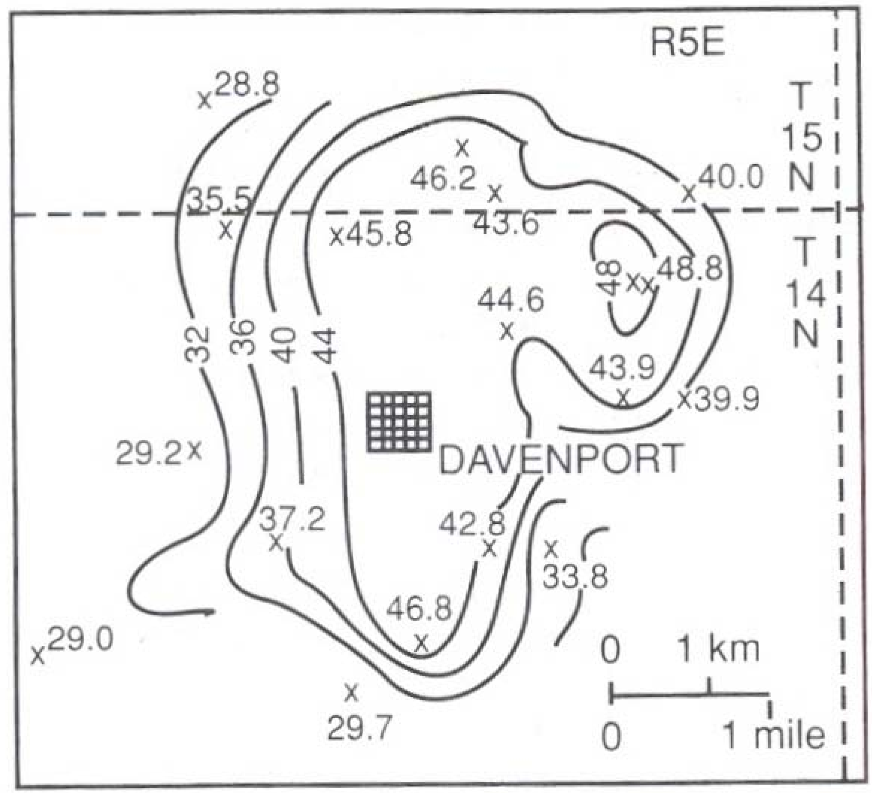
Isotopic Shift of Carbonate Cement Above Seepage at Davenport Field, OK (from Donovan et al., 1979)

≈ 210 shallow dolomite cement samples on a grid

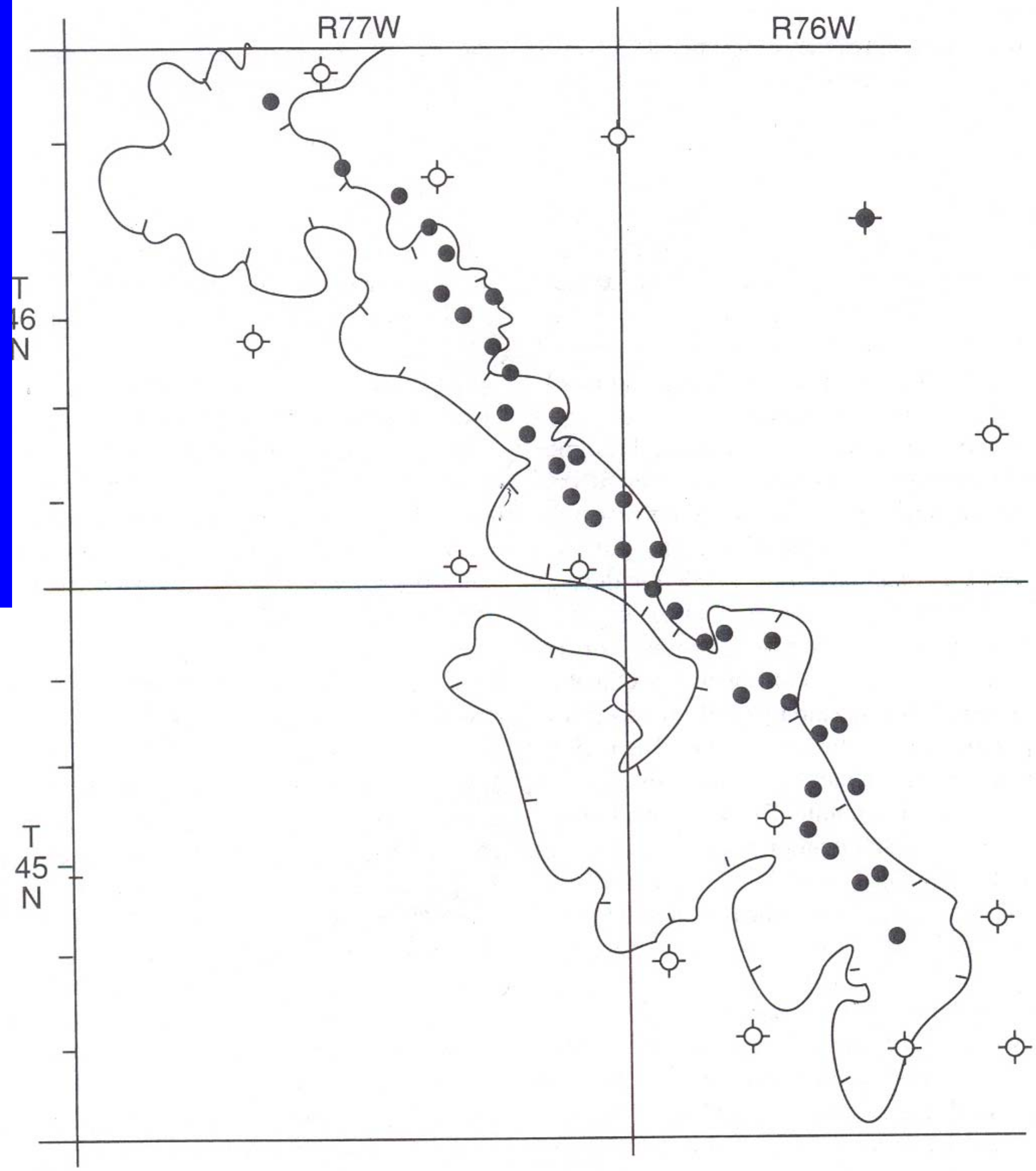
$\delta^{13}C$ of $(Ca,Mg)(CO_3)_2$



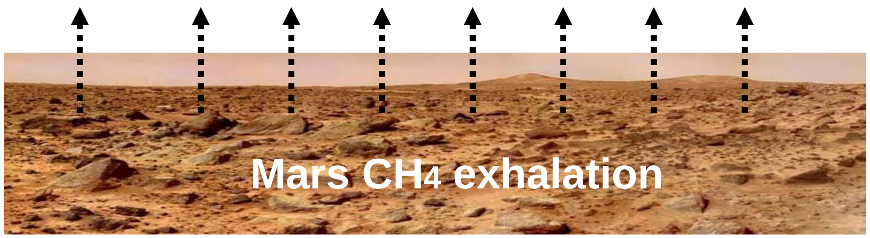
$\delta^{18}O$ of $(Ca, Mg)(CO_3)_2$



In-fill Drilling by December, 1981 Superimposed Over 1974 Gamma Radiation Survey at Heldt Draw Oil Field, Powder River, WY (from Curry, 1984)



A FEW MARTIAN SEEPS or WEAK MICROSEEPAGE CAN SUSTAIN THE ATMOSPHERIC CH_4 LEVEL (and the Mumma's plume)



the CH_4 plume on Mars reflects an episodic emission of ~19,000 t CH4 yr−1 (Mischna et al., 2011) or ~150,000 t CH4 yr−1 (Lefevre and Forget, 2009)

equivalent to a diffuse microseepage of ~10-100 mg $m^{-2}d^{-1}$ from an area of 500 to 5000 km^2

If the whole 30000 km^2 olivine outcrop at the Nili Fossae (Hoefen et al., 2003) is assumed to exhale, a microseepage of 2 mg $m^{-2}d^{-1}$ (the lowest level detected in terrestrial peridotites) would be sufficient to support the plume

If a global Martian CH_4 source of around 100-300 t yr^{-1} is required to maintain the 10 ppb atmospheric level (Atreya et al, 2007), one large mud volcano or a few small mud volcanoes, or just a very weak microseepage, sparse in different zones of Mars, would be sufficient.

Etiope, Oehler, Allen (2011)
Etiope, Ehlmann, Schoell (2013)

SPECULATIONS ABOUT EXPERIMENTS ON MARS

- Slim coring device needed on rover
- Locations for coring visually selected based on surface geology
- Cores drilled to practical depth and inserted into incubation chamber that can subsequently be sealed and warmed to slightly above freezing
- Spike chamber with minor hydrogen and trace of water, CO_2 indigenous in atmosphere
- Monitor pressure and atmospheric composition and isotopy daily with TLS; two weeks enough(?); can be done while traveling, DETECTION OF METHANOGENESIS (?)
- Pressure can detect adsorption/desorption and/or leakage
- Purge gas from chamber, spike chamber with minor oxygen and a trace of water, methane, CO_2 indigenous in atmosphere
- Monitor pressure and atmospheric composition and isotopy; two weeks enough(?); can be done while moving, DETECTION OF METHANOTROPHY (?)
- Expel core from chamber; drill next core.

Main final messages

Observations of terrestrial gas seepage can be used to infer forms and magnitude of potential seepage on Mars, and perhaps where to look

Seasonality on Earth is important

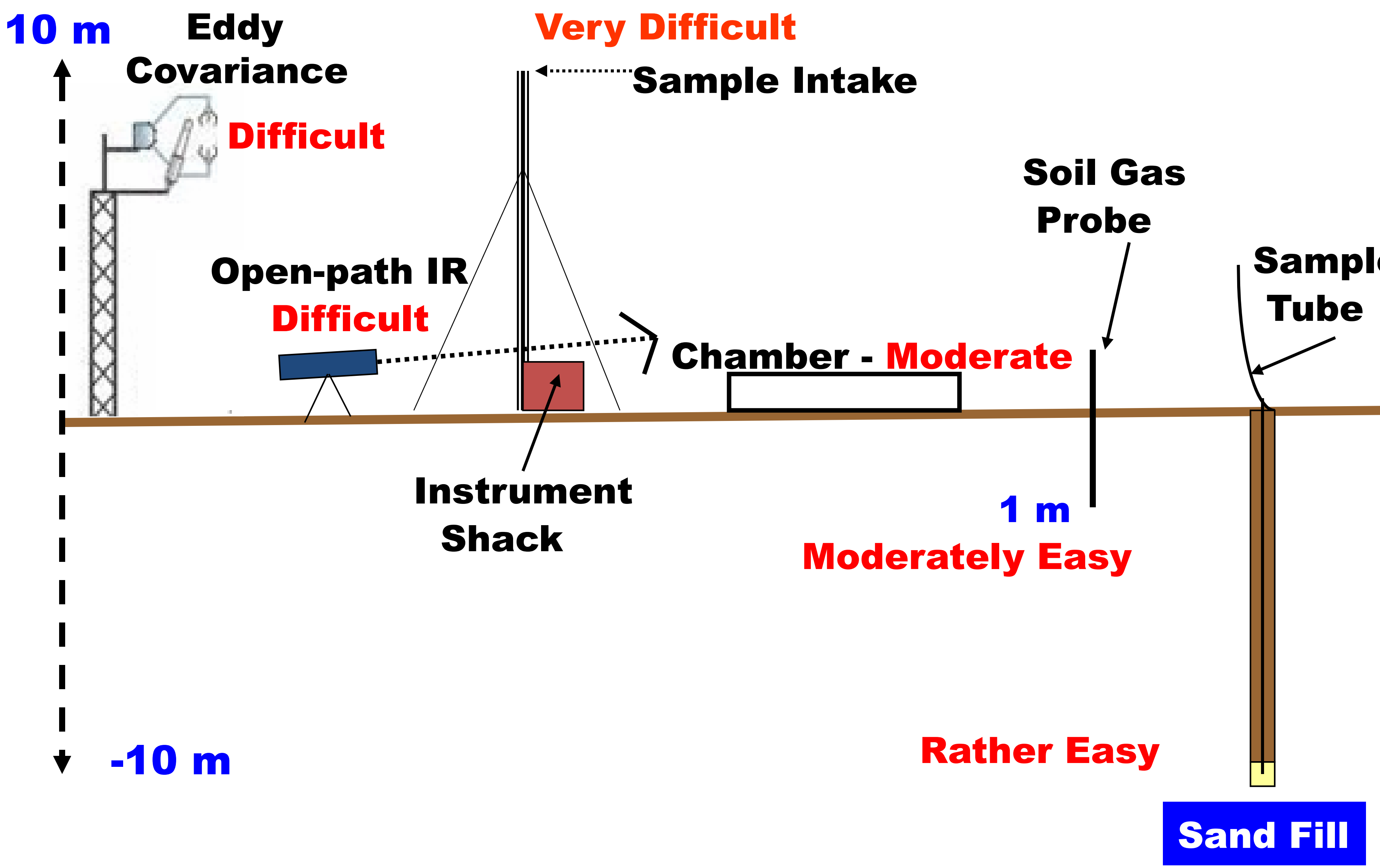
Low microseepage, sparse in different zones of Mars, would be sufficient to sustain methane observed in the atmosphere

BUT, as on Earth, CH_4 microseeping on Mars cannot be detected a few cm above the soil, because of winds and dilution of the leaking gas

Recommendation

Geologic CH_4 on Mars should be searched preferably above or near faults or at apparent mud volcanoes, by drilling into the soil or using accumulation chambers on the ground

DETECTION OF MICROSEEPAGE



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