The National Crude Oil Spill Fate and Natural Attenuation Research Site: Bemidji, MN

Barbara Bekins
Research Coordinator
USGS, Menlo Park, CA

Jared Trost
Site Coordinator
USGS, Mounds View, MN

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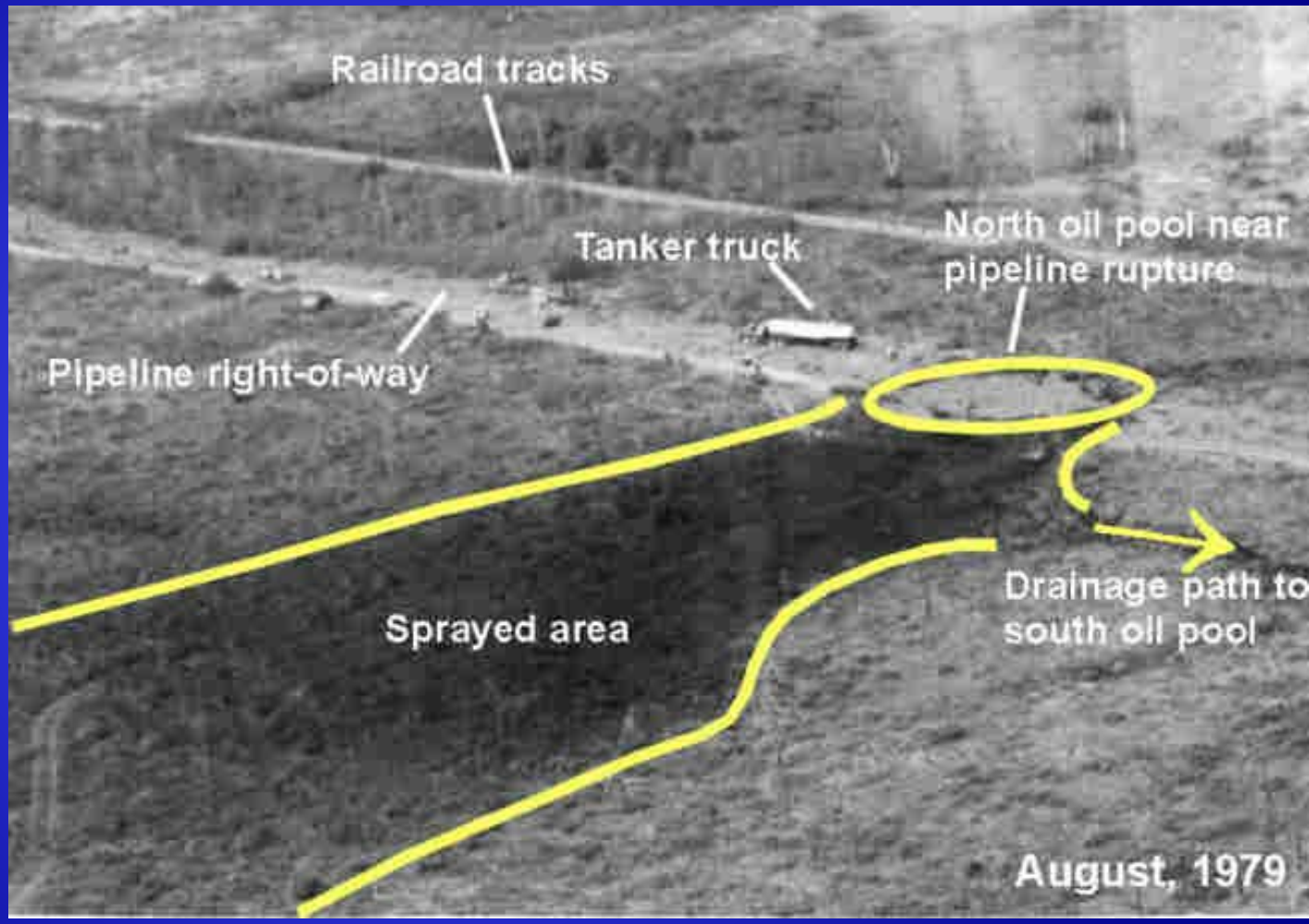
Crude-oil pipeline broke in August, 1979

High pressure (3.5 MPa or ~500 psi)
86 cm (34-inch) buried line
Spilled 1.7 million L (441,000 gallons) light crude oil



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What did we once think we knew that isn't so?

When the 1979 Bemidji spill occurred it was believed:

That biodegradation of BTEX requires oxygen

That oxygen is plentiful in shallow aquifers

That plumes mix readily with oxygen in background water

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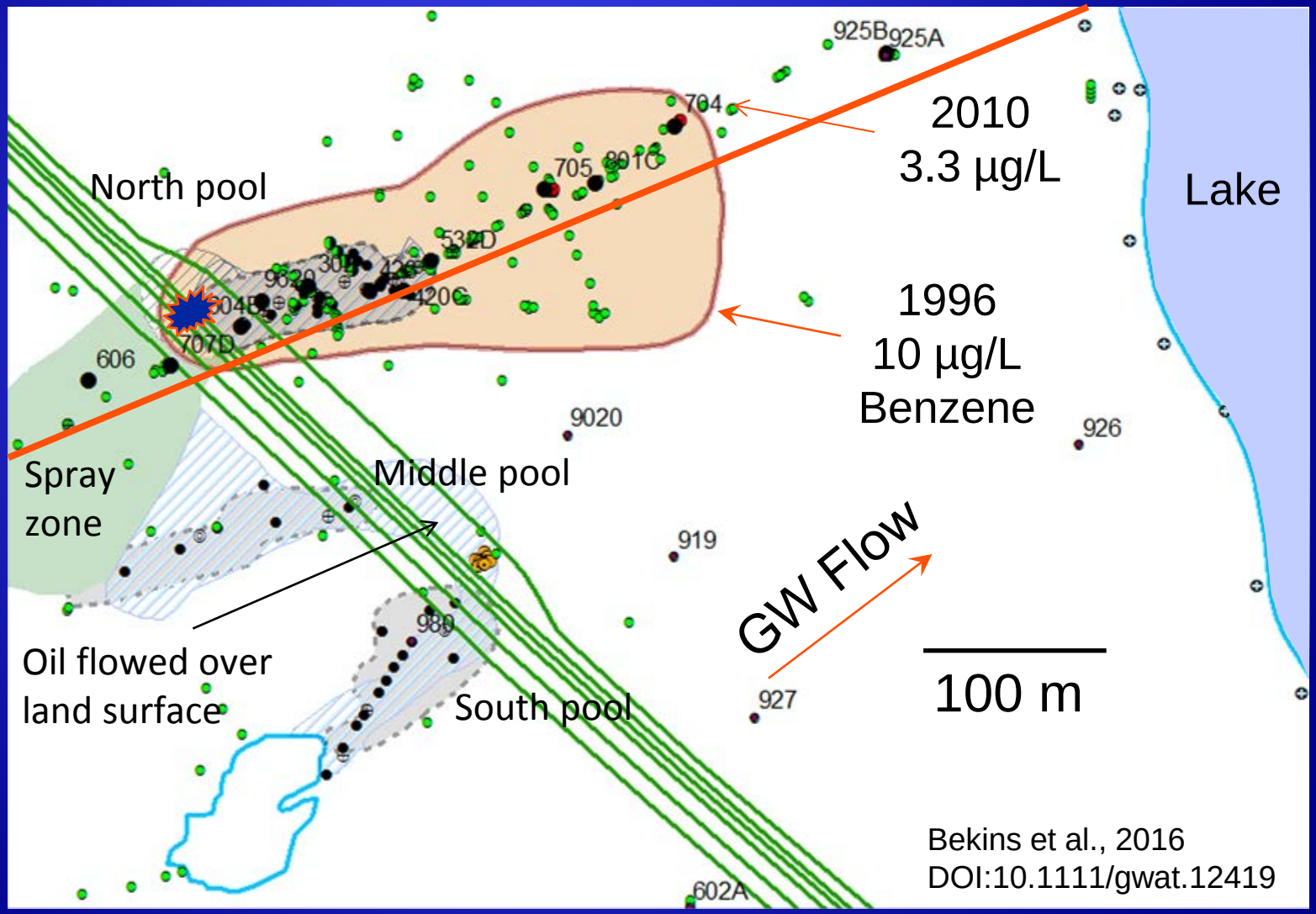
Most research is on the North oil pool and plume

Cross section line



Bekins et al., 2016
DOI:10.1111/gwat.12419

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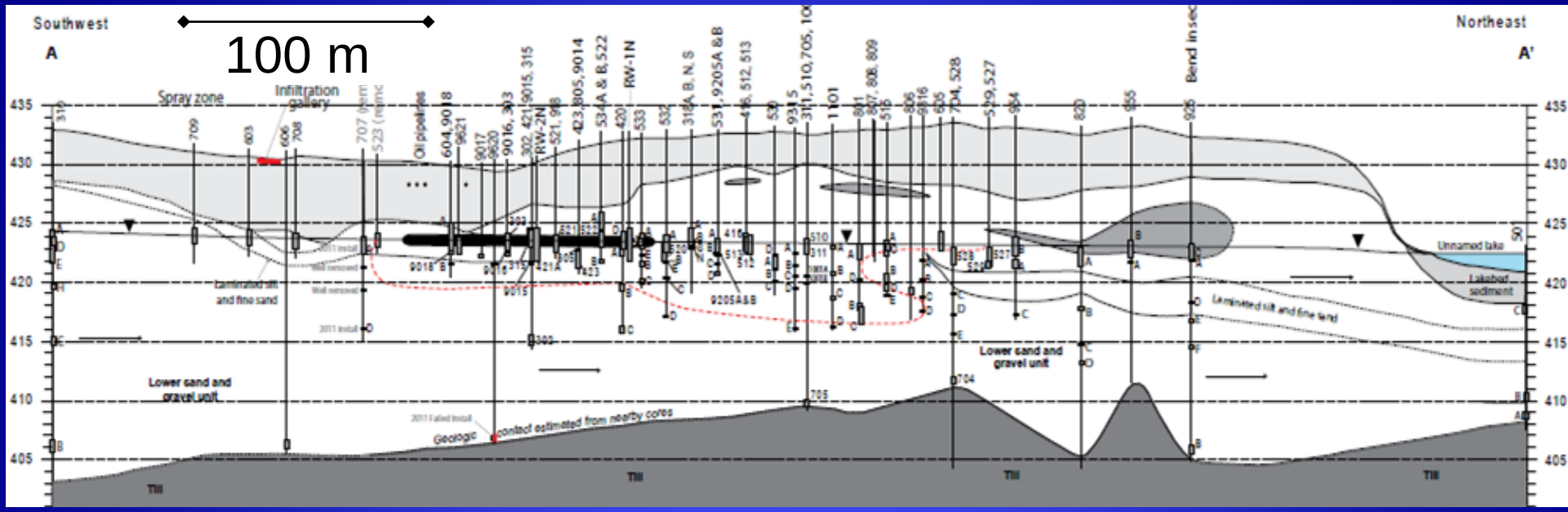
North Pool Well Transect



http://mn.water.usgs.gov/projects/bemidji/spatial/Current/xsection.pdf

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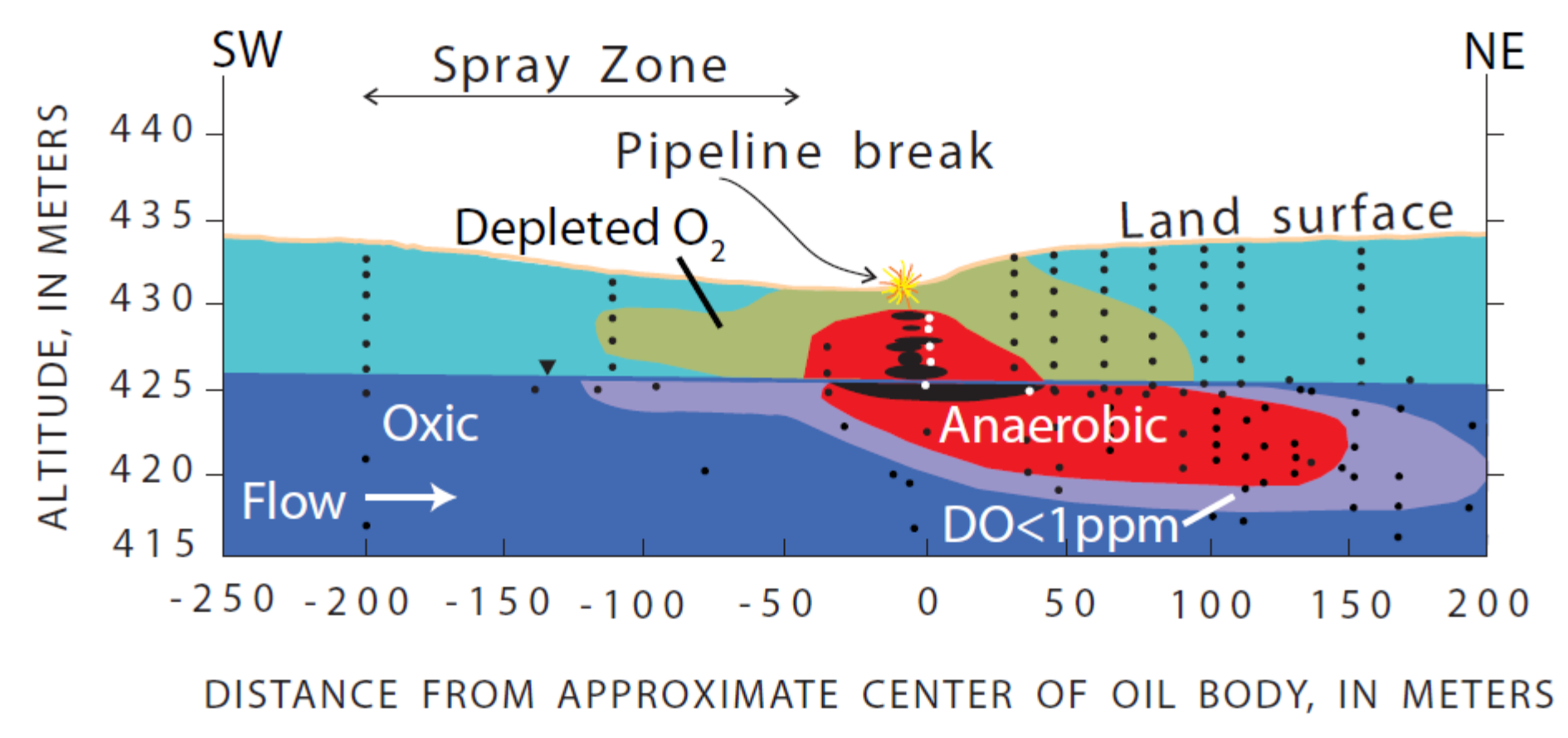
Anaerobic conditions are present above the water table and for 150 m in the plume



Groundwater from: Cozzarelli et al., 2015, Arsenic Cycling in Hydrocarbon Plumes: Secondary Effects of Natural Attenuation, Groundwater, doi: 10.1111/gwat.12316

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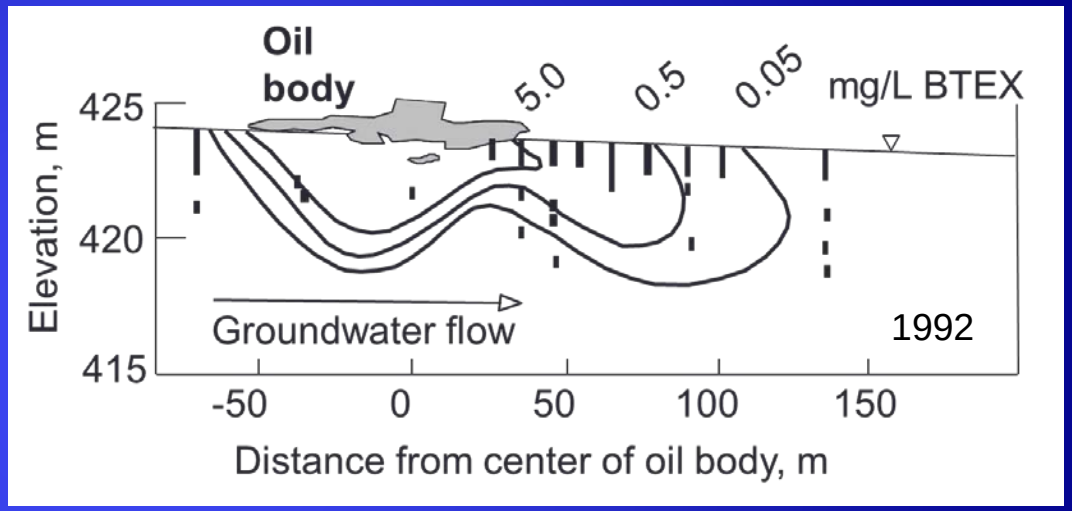
1992 results indicated the BTEX plume was at steady state or shrinking

- Observations helped establish natural attenuation as a remedial strategy*
- First demonstration of BTEX degradation coupled to iron reduction ‡‡
- Demonstrated the presence of anaerobic metabolites ‡
- Modeling showed 60% of degradation was anaerobic**



* Bennett et al. (1993); Eganhouse et al.(1993); Baedecker et al. (1993)

‡‡ Lovely et al. Nature (1989)

‡ Cozzarelli et al. (1994)

**Essaid et al. (1995)

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Progress since 2000

Oil

- Quantified total oil mass loss
- Quantified the degraded oil that exits as carbon dioxide at the surface

Plume

- Shrinking of some compound plumes, expansion of others
- Changes reflect oil composition

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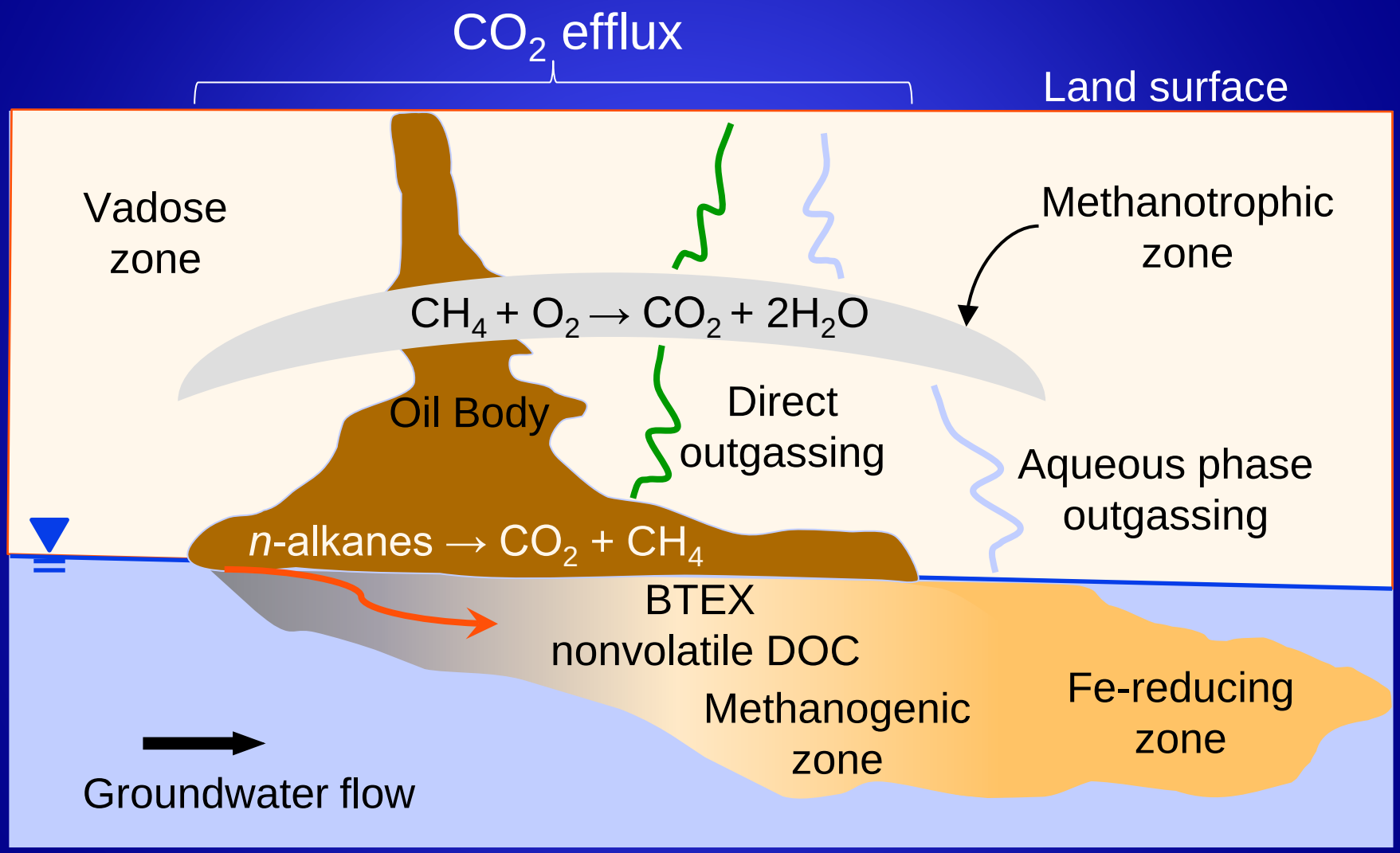
Overview of site processes



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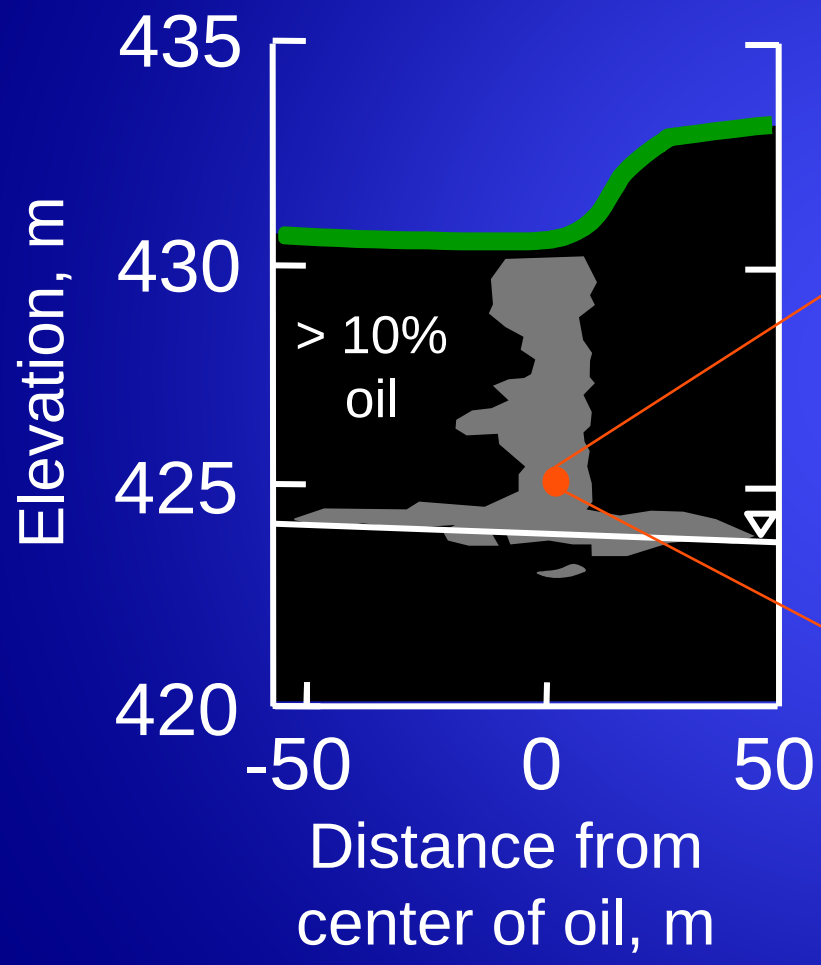
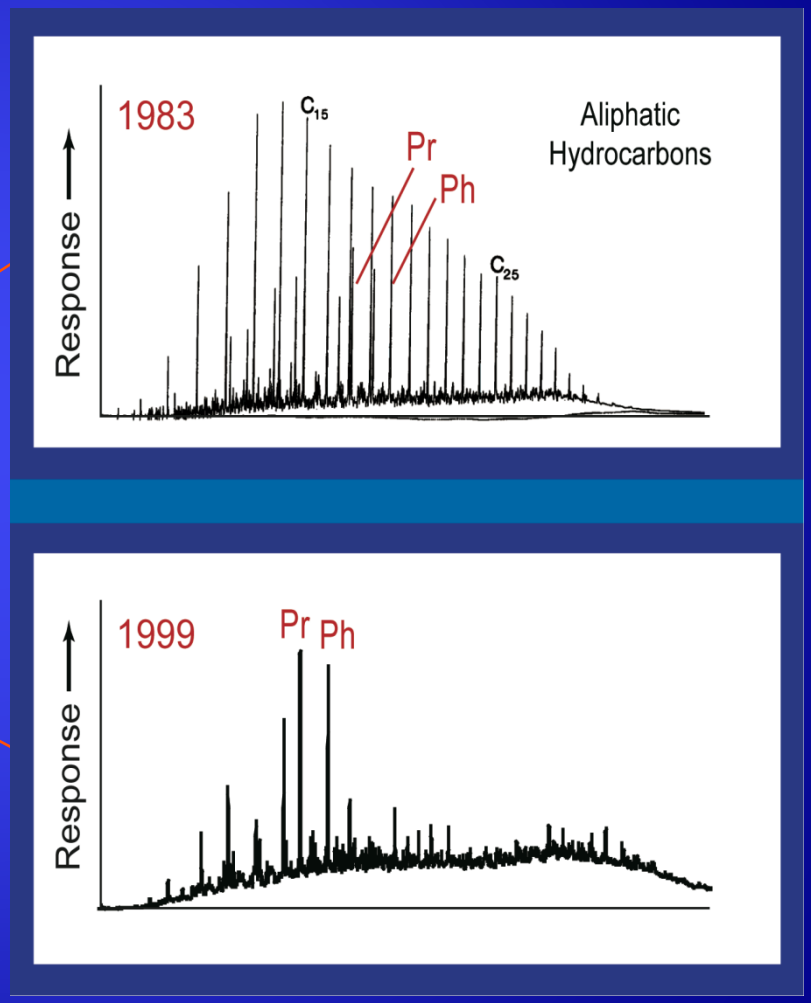
Ng et al. , 2015, DOI: 10.1002/2015WR016964

Oil -- Adjacent samples show significant degradation of *n*-alkanes from 1983 to 1999





Hostettler et al, 2008,
DOI:10.1080/15275920802115738

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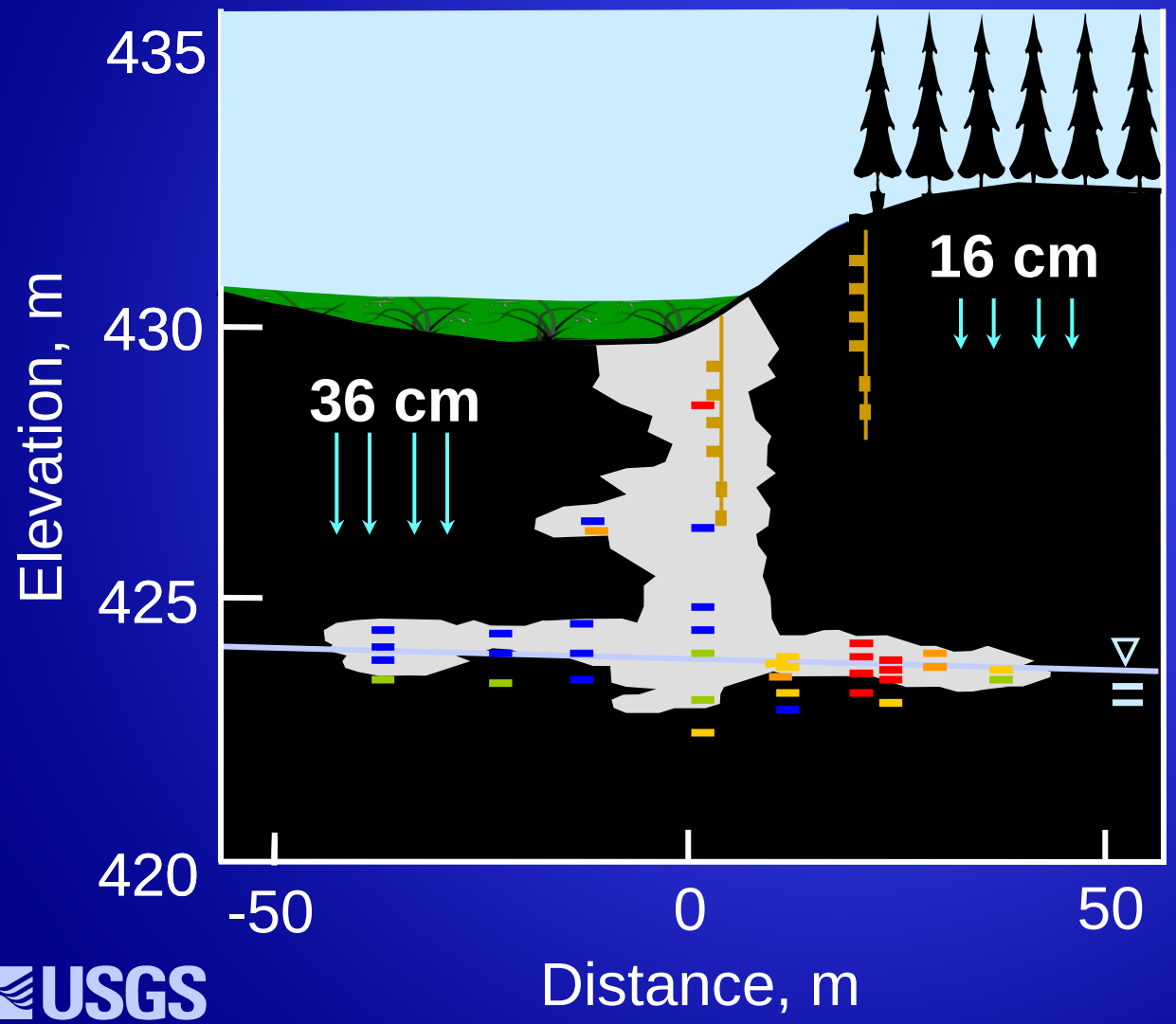
Uneven degradation rates invalidate forensic spill timing estimates 2003



Precipitation 60.1 cm

Least degraded

Most degraded

Bekins et al, 2011, DOI:10.1306/eg.11160404036

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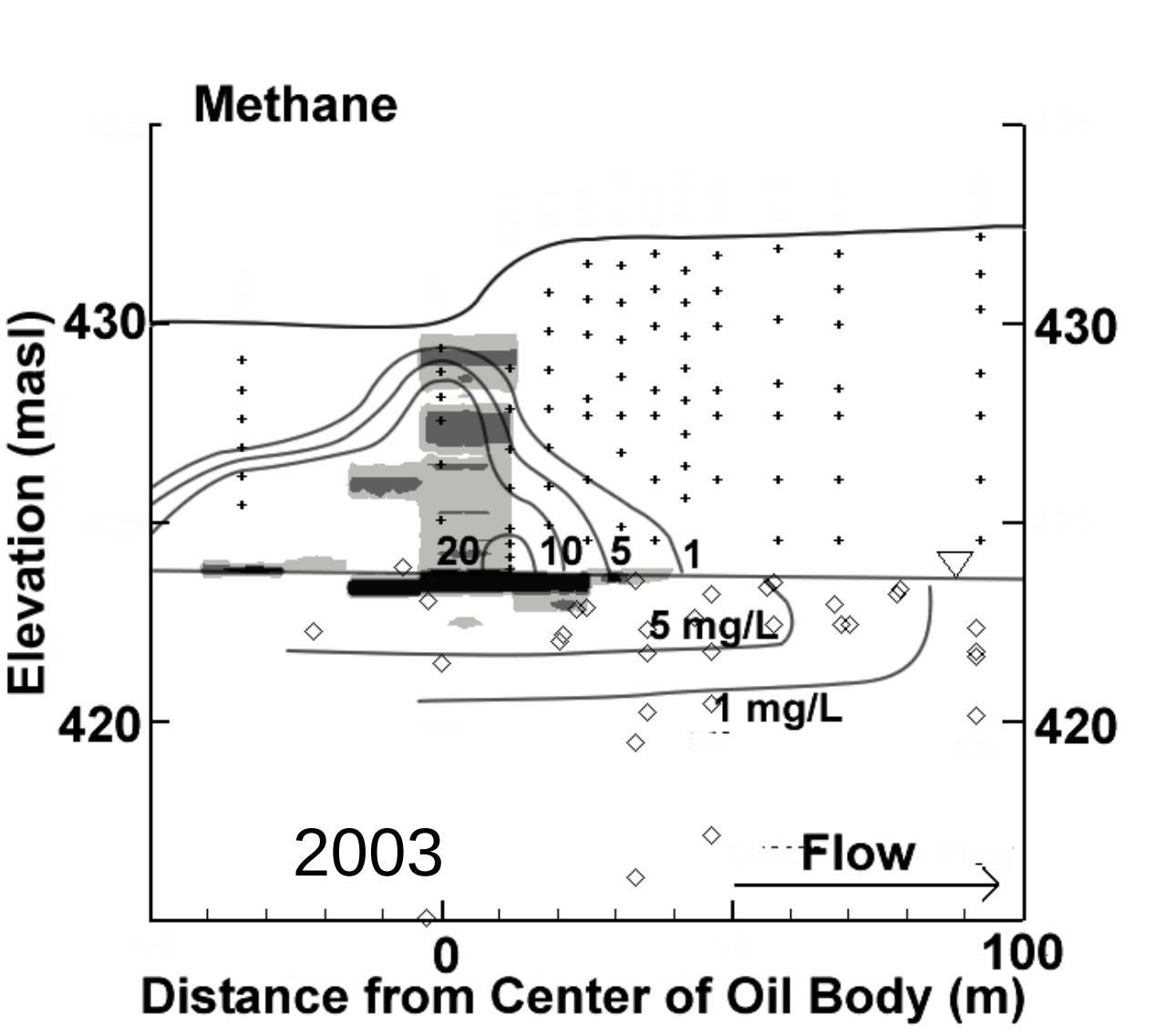
Degradation of the *n*-alkanes produces methane



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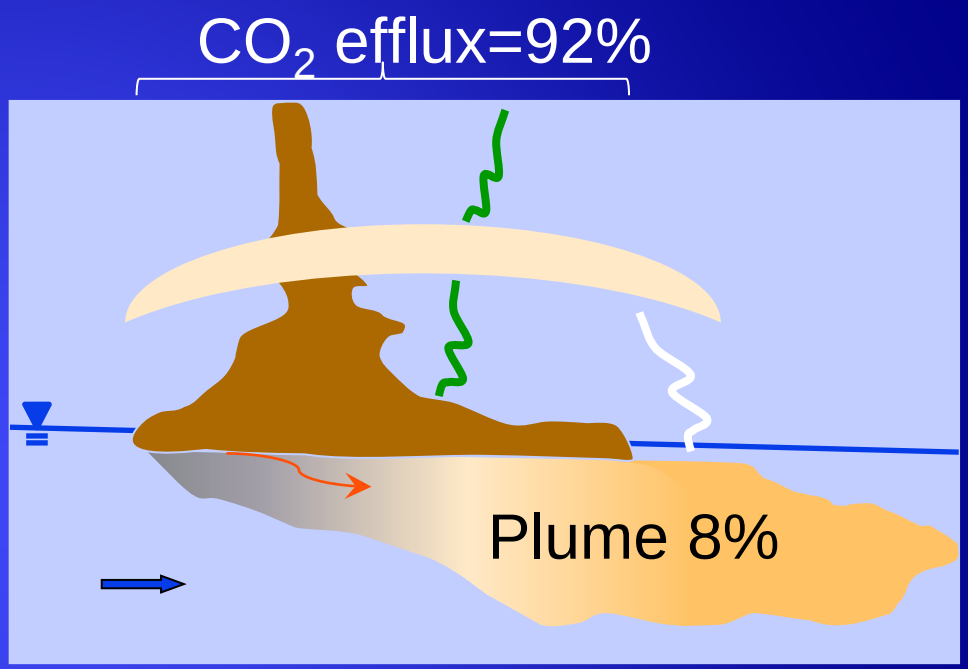
Amos et al, 2005, DOI:10.1029/2004WR003433

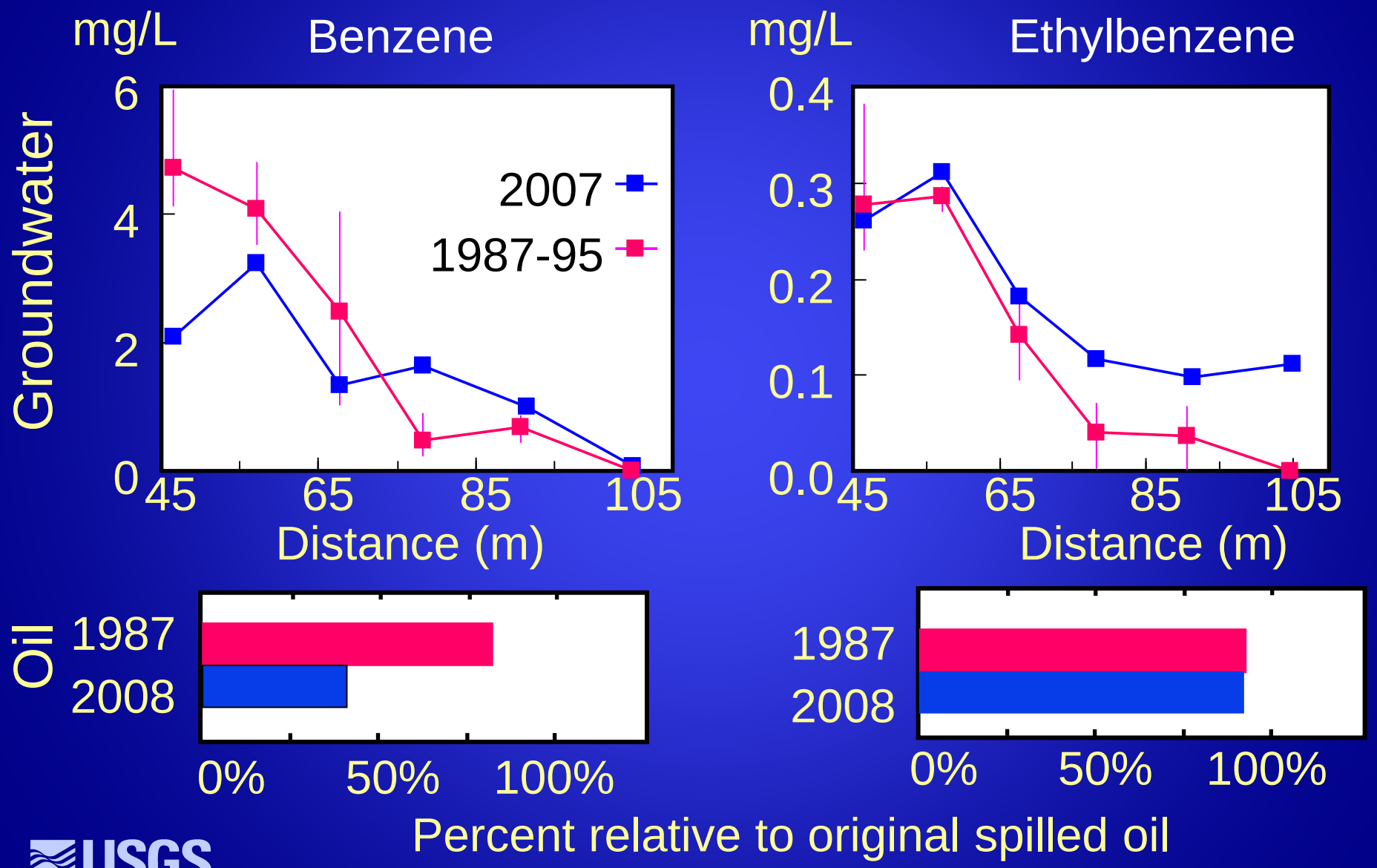
Surface CO_2 efflux

- 92% of the degraded oil C exits as surface efflux**
- 15% oil degraded in 37 years**
- Surface efflux of CO_2 varies seasonally‡



Sihota et al. (2011); Sihota and Mayer (2012)
**Ng et al. , 2015, DOI: 10.1002/2015WR016964
‡Sihota et al., 2016, DOI: 10.2136/vzj2015.09.0125

Groundwater changes reflect oil composition



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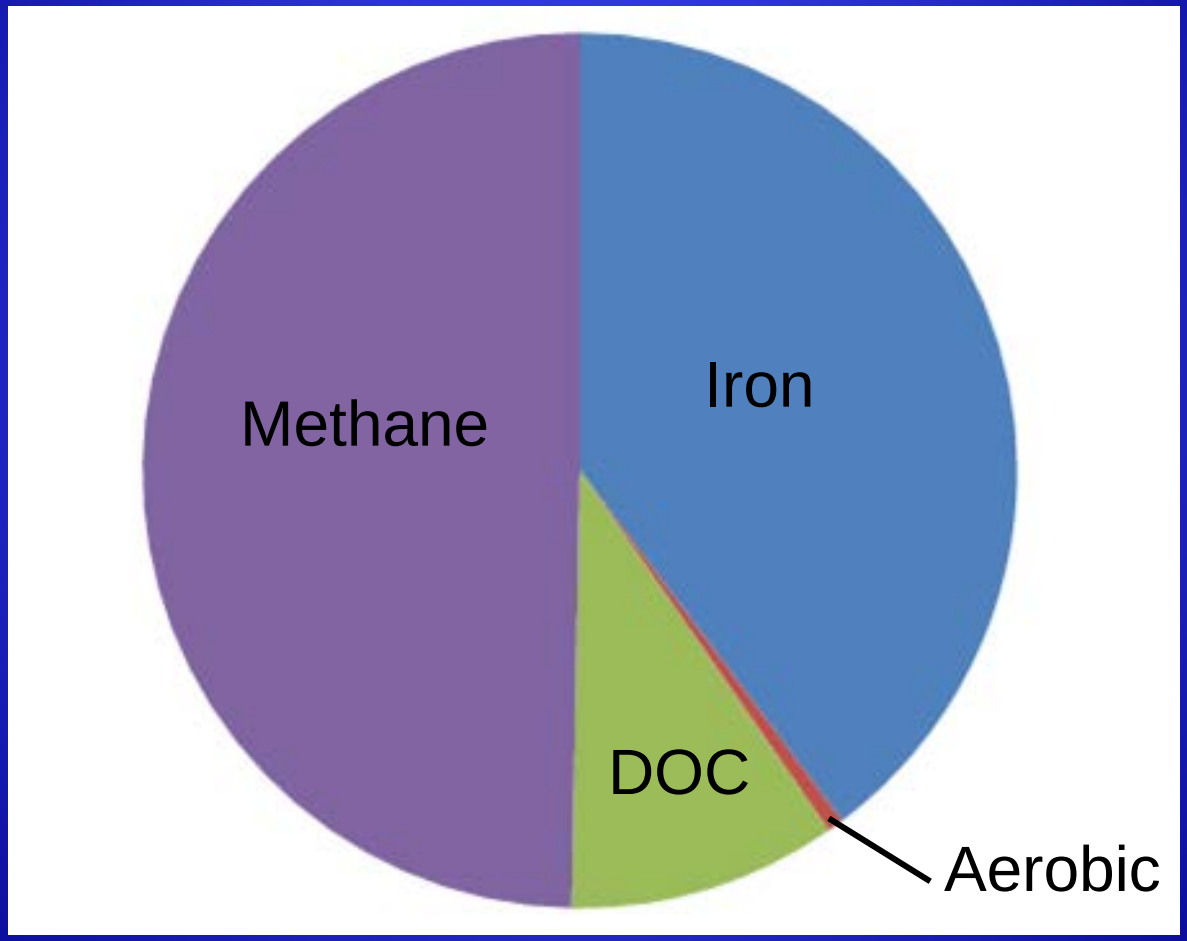
Bekins et al., 2011

Fate of the 8% of the carbon entering the plume from the oil



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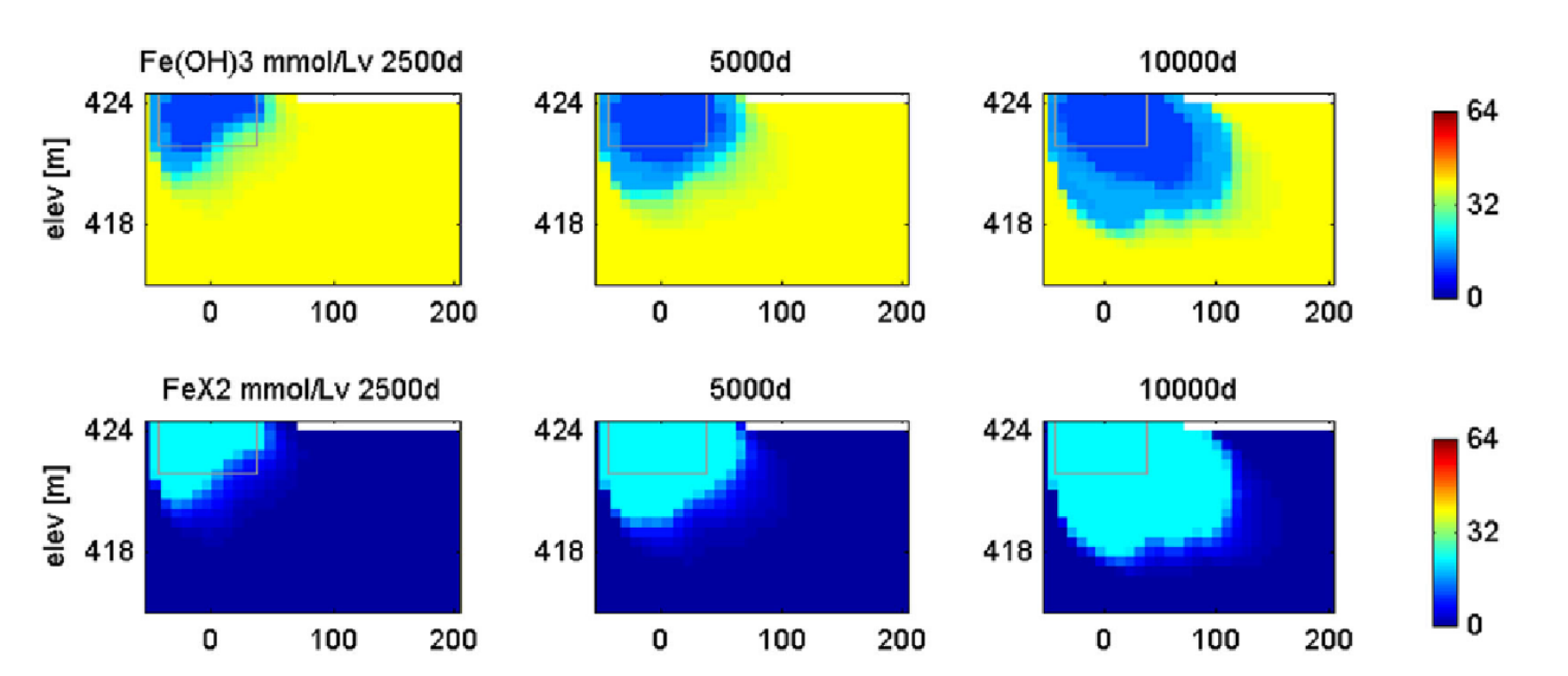
Ng et al. , 2015, DOI: 10.1002/2015WR016964

The electron acceptor Fe^{3+} is decreasing on the aquifer sediments and 99% redeposited as Fe^{2+}

7 years | 14 years | 28 years



Ng et al. , 2015, DOI: 10.1002/2015WR016964

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Summary and Conclusions

Oil

- 92% of the degraded carbon from the oil exits as surface CO_2 efflux
- Estimated total oil loss by biodegradation ~15%

Plume

- Iron reduction and methanogenesis dominate, aerobic degradation is minor
- Depletion of iron oxy-hydroxides on the aquifer sediments leads to slow growth of the plume

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Methods development ongoing projects

- Biogeophysics
- Freezing drive shoe
- Colloidal boroscope flowmeter
- Optical fluoresence probe
- Hydraulic conductivity profiling
- Low cost ^{14}C analysis

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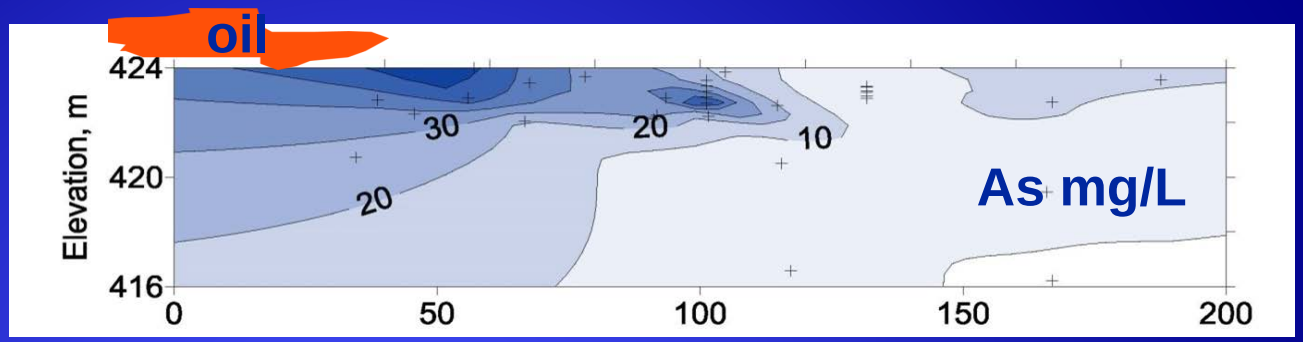
Plume ongoing projects



- Arsenic immobilization*
- Heat generated from biodegradation
- Fate of oil metabolites**
- Mixed BTEX ethanol plume experiments

*Cozzarelli et al., 2015, Arsenic Cycling in Hydrocarbon Plumes: Secondary Effects of Natural Attenuation, Groundwater, doi: 10.1111/gwat.12316

**Bekins et al., 2016, Crude Oil Metabolites in Groundwater at Two Spill Sites, Groundwater, doi: 10.1111/gwat.12419

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Oil – ongoing projects

Hydrophobic soils:

- Mapped areas of hydrophobic soils*
- Pilot remediation plots

Water ponded on hydrophobic soil

Source Zone

- Seasonal gas efflux cause
- Oil composition changes

Hydrophobicity inhibits plant growth

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*Nieber, J.L., 2013, Water repellency of soil at the Bemidji Oil Spill Site: Unsaturated Zone Interest Group Newsletter, no. 14, Spring 2013, p. 4-5.

Collaborative Agreement

- Maintain the research site
- Promote/advance science, research, education related to the fate, transport, and natural attenuation of crude oil contamination in the subsurface
- Make results widely available to researchers, industry, consultants, regulators, teachers, and students

USGS science for a changing world

Minnesota Pollution Control Agency

Beltrami County, Minnesota

ENBRIDGE

http://mn.water.usgs.gov/projects/bemidji/policy.html

Looking to the future: The site's capabilities can be used to develop new methods and understanding

Groundwater
- 255 Monitoring wells

Oil
- 35 Oil monitoring wells

Gases
- 22 Vapor wells
- Surface CO_2 efflux
- 14 continuous CO_2 and O_2

Recharge
- 4 Moisture probe arrays
- 4 Suction lysimeter arrays
- 6 Temperature profile arrays

Geophysics
- Self potential
- Magnetic susceptibility
- Electrical resistivity

Spatially referenced database
- DO, pH, SpCond
- Water levels
- Oil thicknesses

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How to get involved

Check out the website and existing data

Contact USGS or the PCA with your research ideas

Develop a project proposal

- Evaluated by Steering Committee
- Ideally include a USGS collaborator

Research Steps:

- Participate in planning
- Collect data from the site
- Provide semi-annual reports on progress

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Field Season Timeline

2016 August 1 - 12.

- Typically 20-30 people participate in the 2-week session.

April:

- Request for field project descriptions

May:

- Planning call for researchers.

June-July:

- Ongoing detailed planning as needed.

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Contacts

USGS

Jared Trost
jtrost@usgs.gov

Barbara Bekins
babekins@usgs.gov

MN Pollution Control Agency

Mark Toso
Mark.Toso@state.mn.us

Jim McCann
Jim.McCann@state.mn.us

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