Long Term Progression of Natural Attenuation of Petroleum LNAPLs

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With Contributions from:

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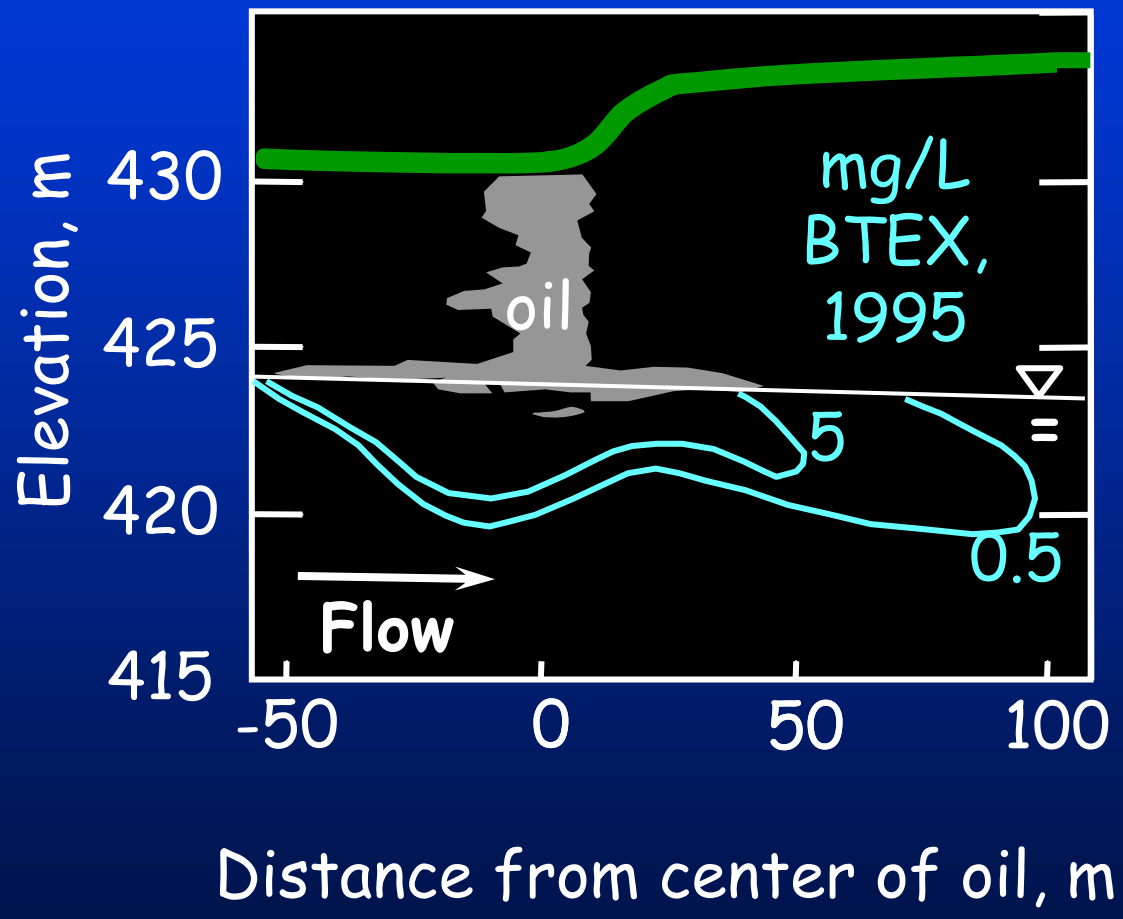
U. S. Geological Survey

USGS

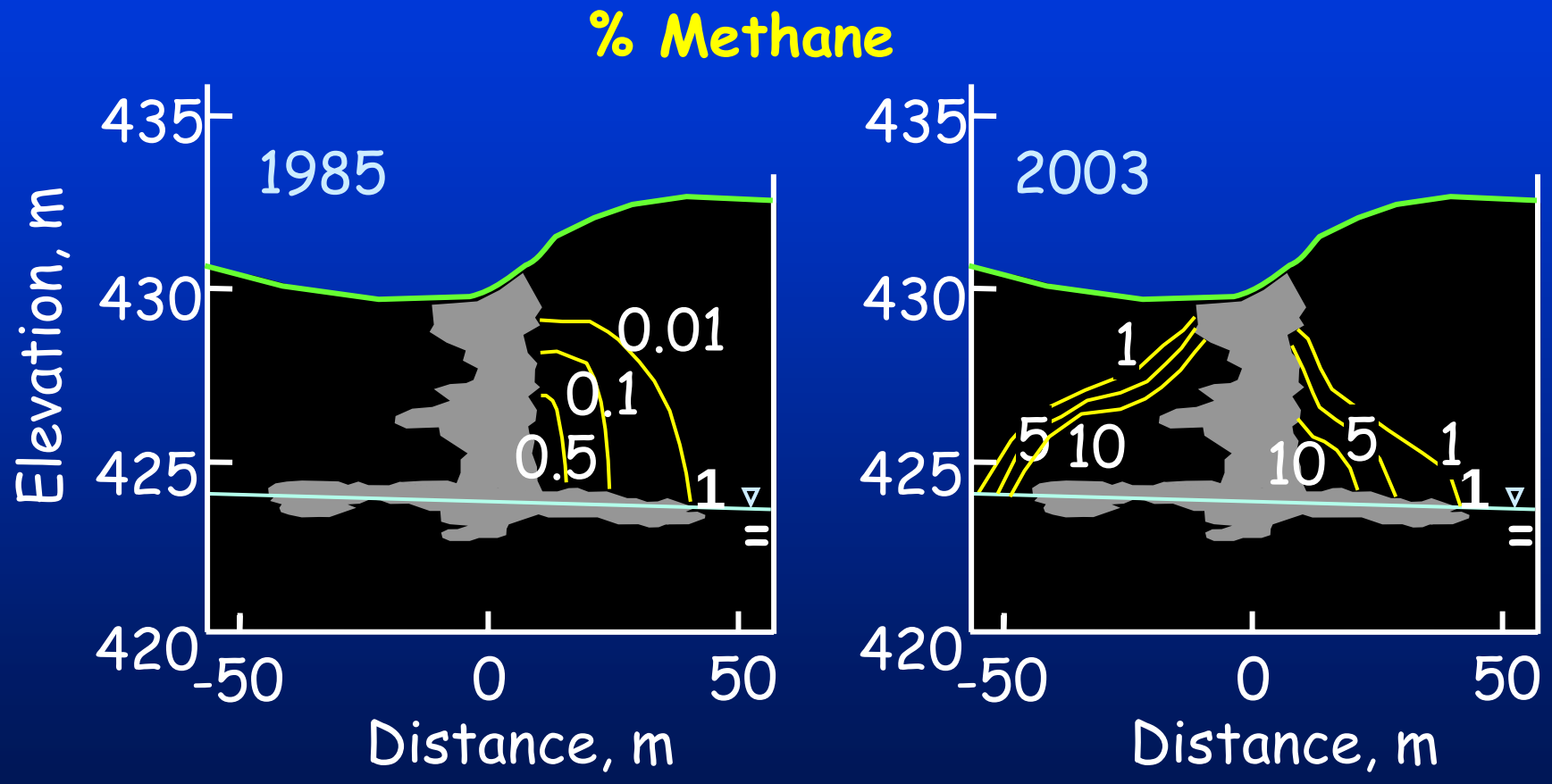
Observations of 30 years of anaerobic degradation at Bemidji

- Controls on LNAPL degradation
- Changes over time in plume
- Rate of aromatic loss from LNAPL



USGS

Methane data indicate methanogenesis has occurred in the oil body since 1985

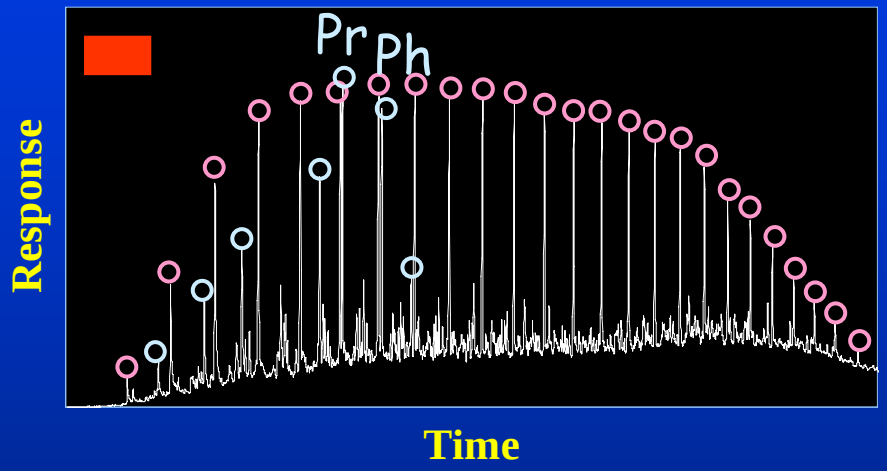


USGS

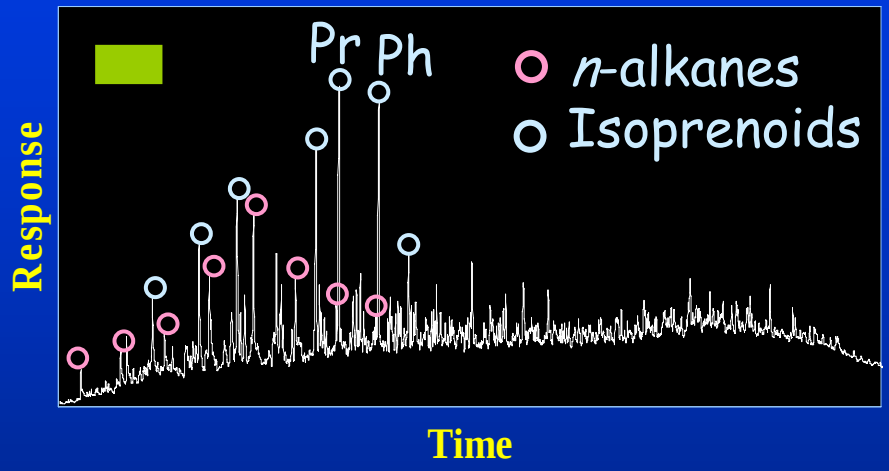
Amos et al., 2003

The oil shows a range of degradation states

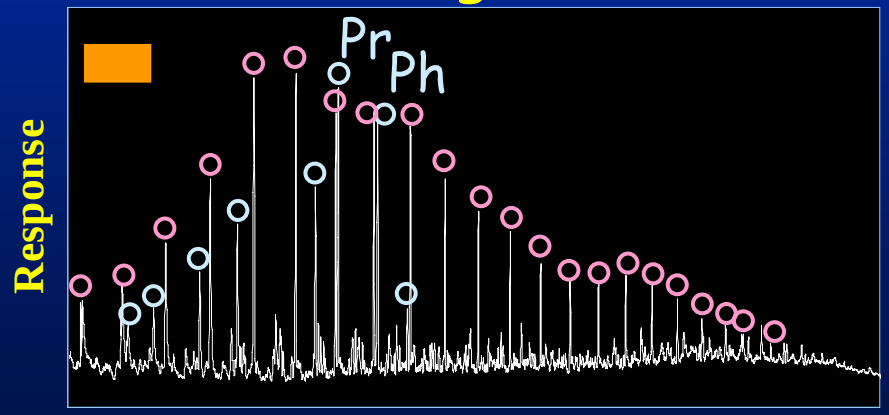
Least degraded



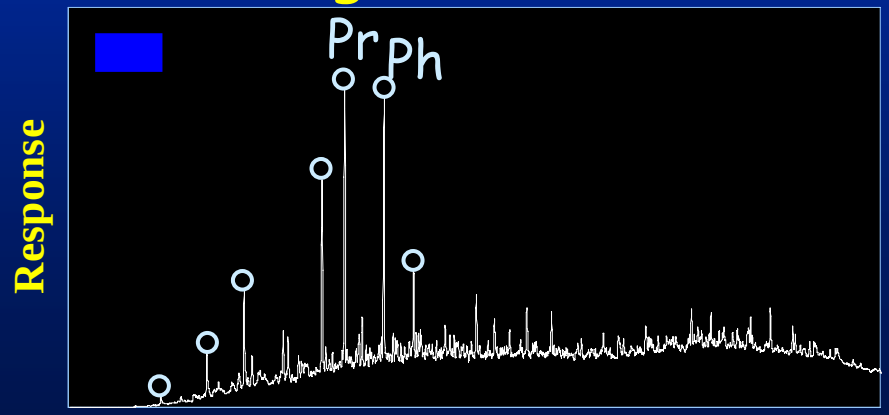
More degraded



Somewhat degraded



Most degraded



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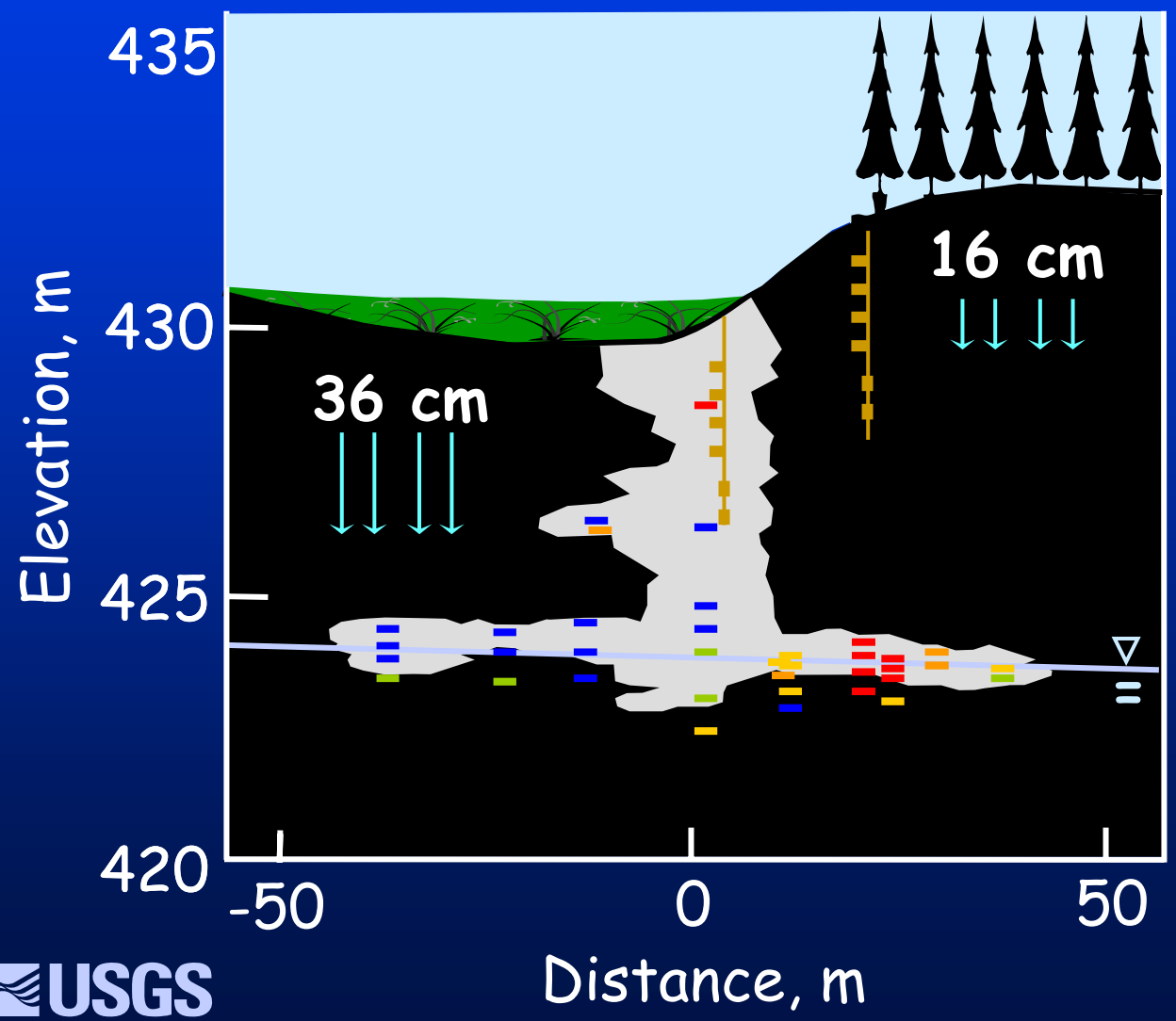
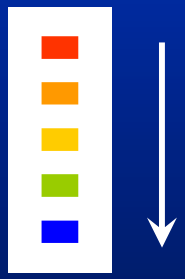
Degradation is greater where recharge is higher



2002 Precipitation 60.1 cm

Least degraded

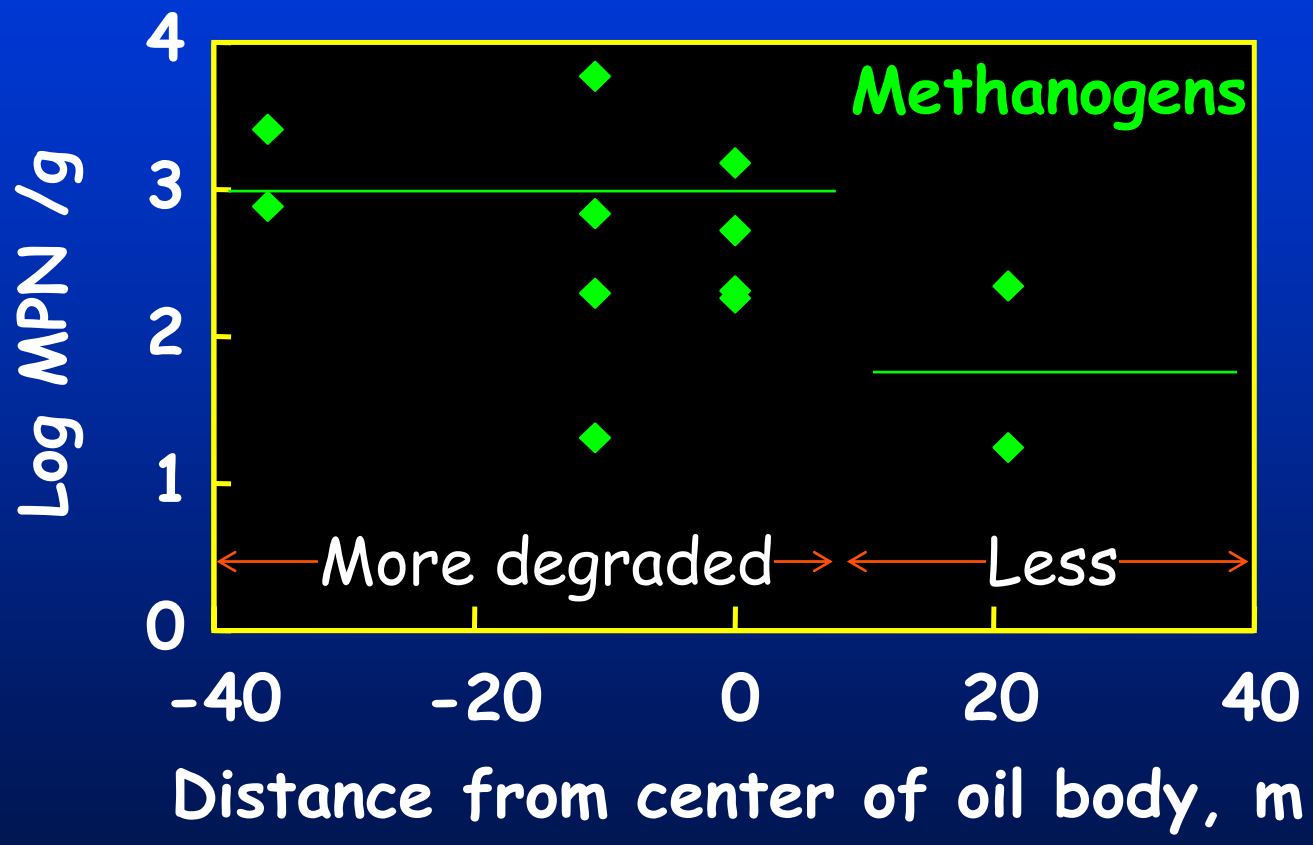


Most degraded

USGS

Bekins et al., 2005

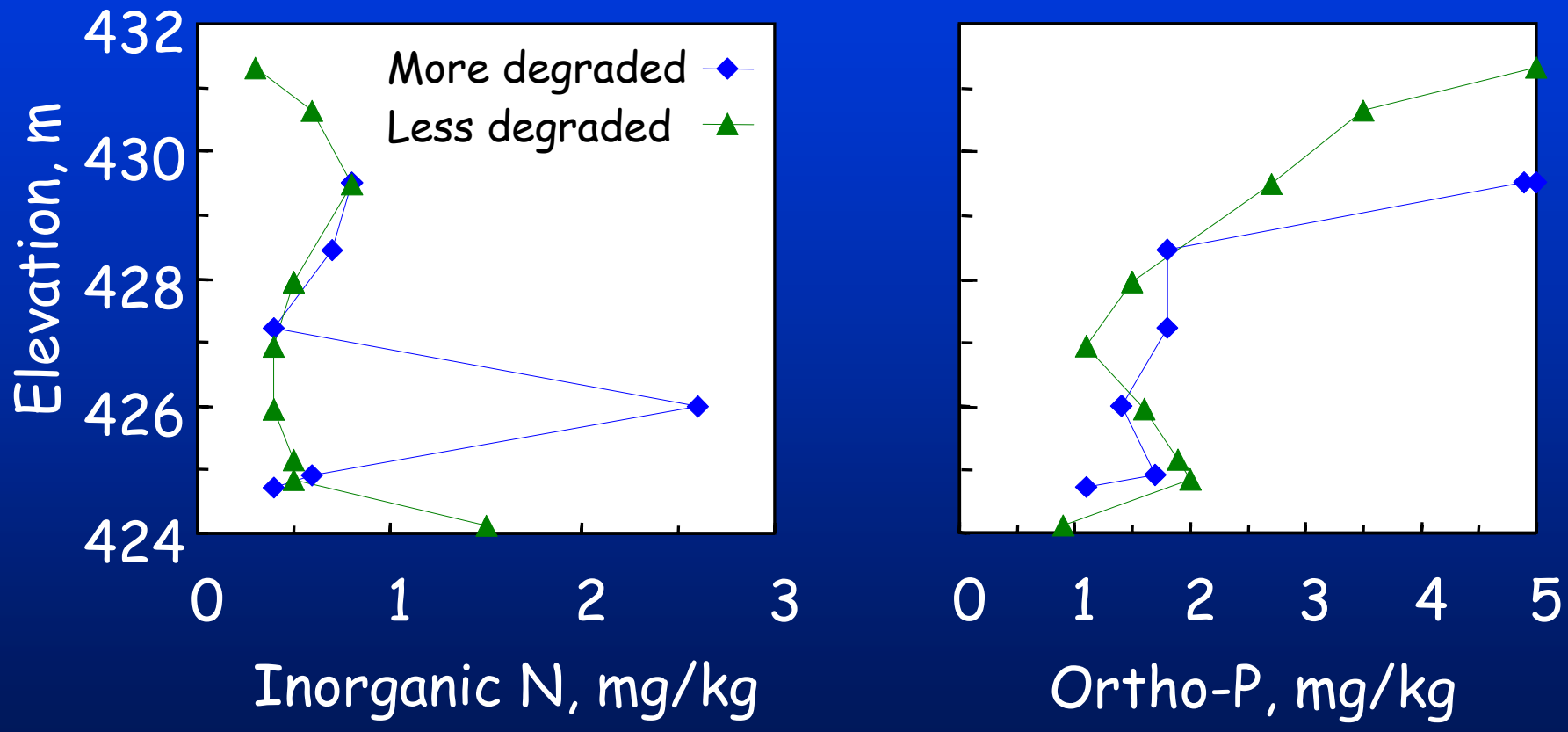
The more degraded oil has more methanogens



USGS

Bekins et al., 2005

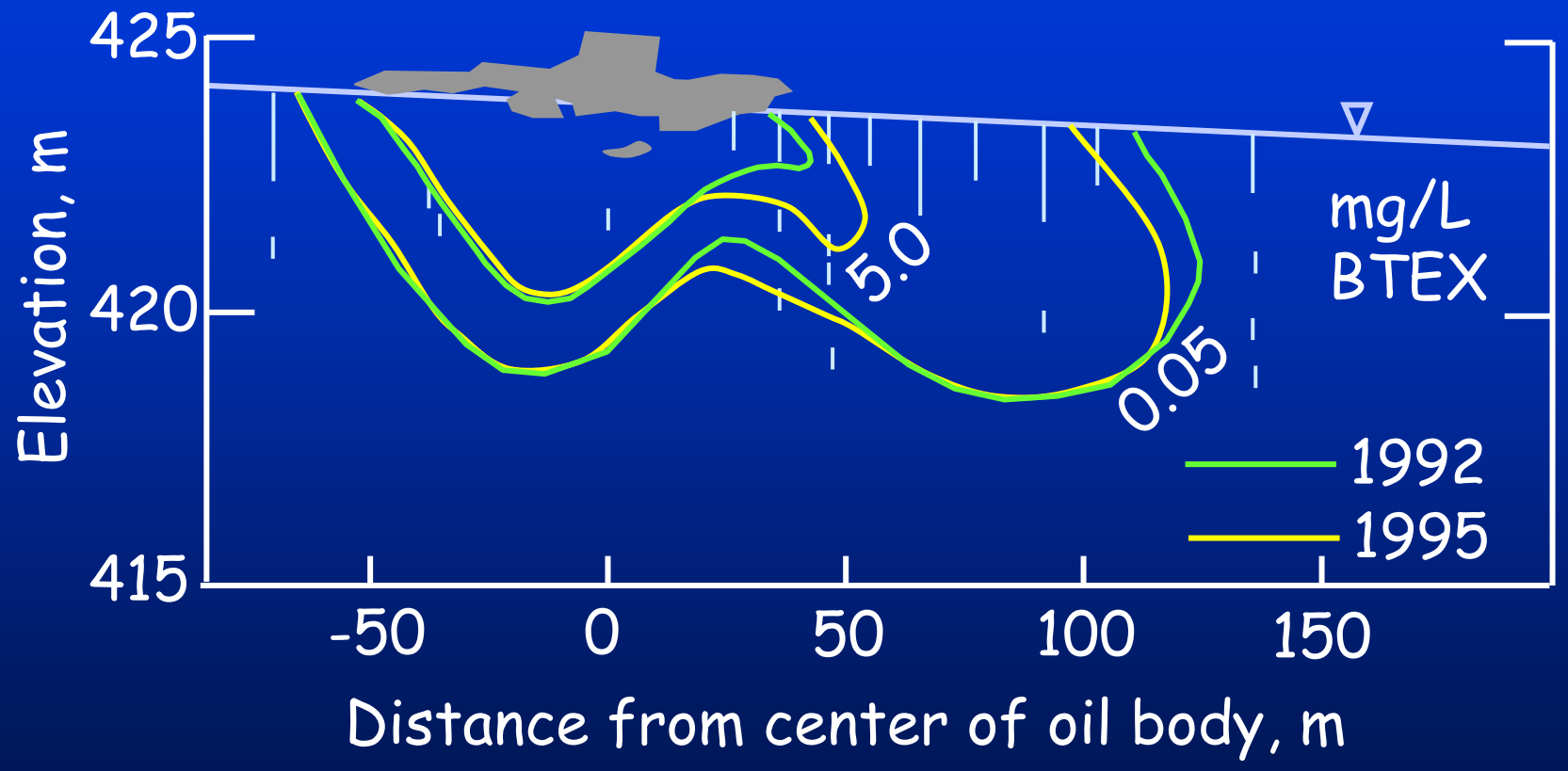
The strong decrease in P with depth indicates it may be limiting



USGS

Bekins et al., 2005

In 1995 the 5 mg/L BTEX contour was expanding at ~2.5 m/yr As Fe(III) was depleted



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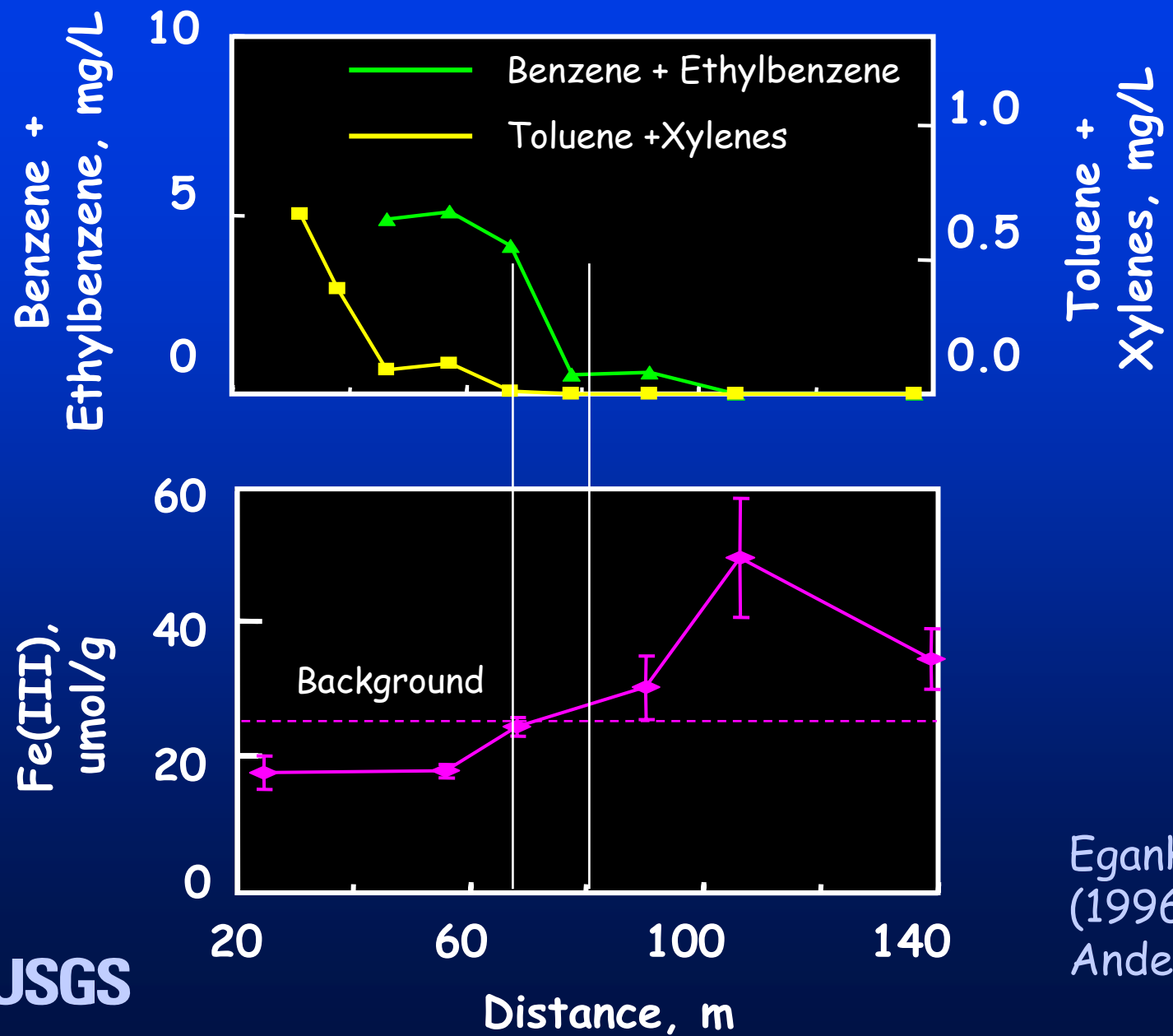
Cozzarelli et al. (2001)

Benzene degraded where Fe(III) was still high



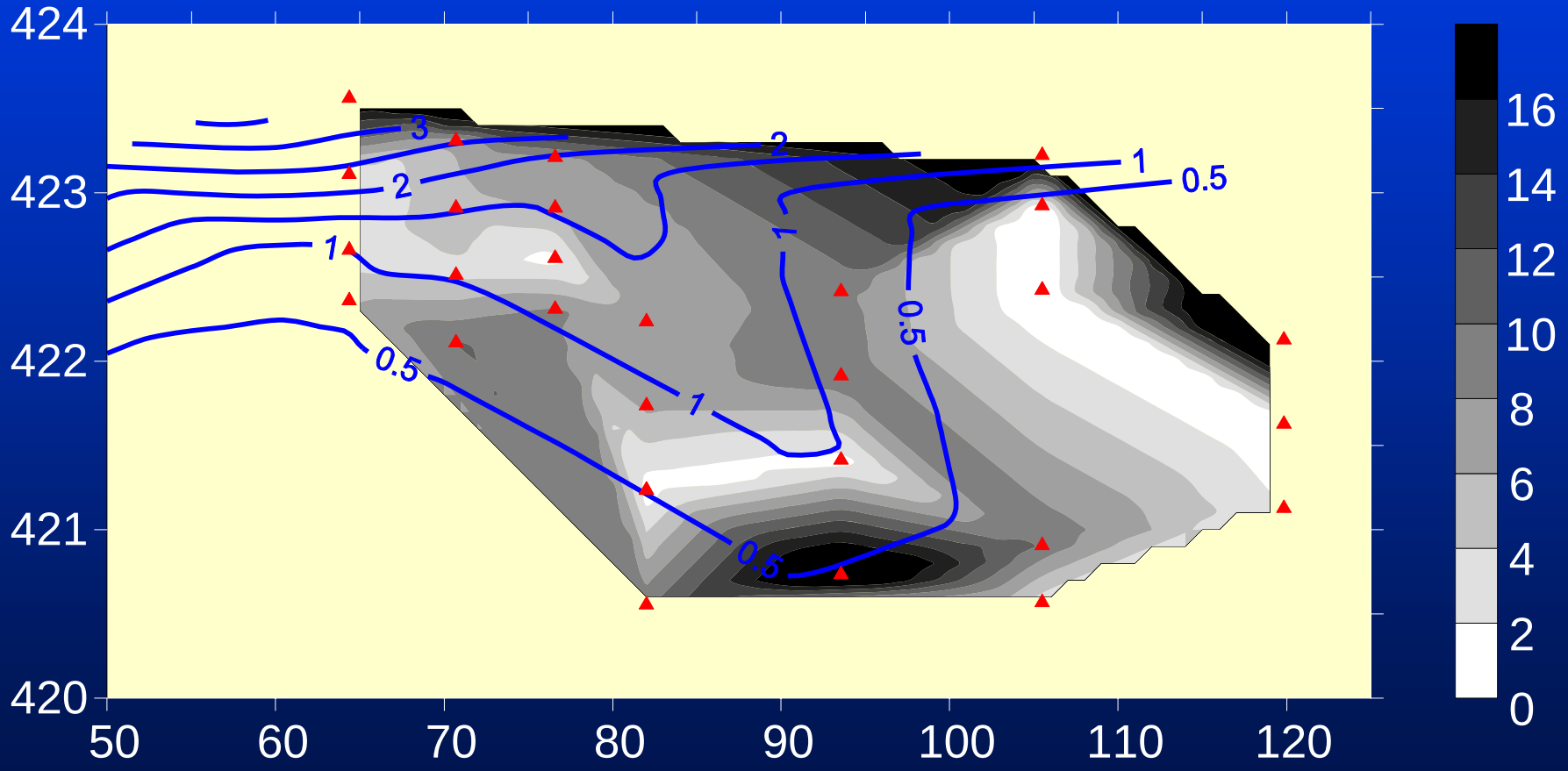
Eganhouse et al. (1996); Lovley and Anderson (2000)

USGS

In 2007 benzene loss occurs where Fe^{3+} is low perhaps by methanogenic degradation

2007 BTEX (mg/L) blue contours

Fe(III) (μmol/g) grey shaded contours



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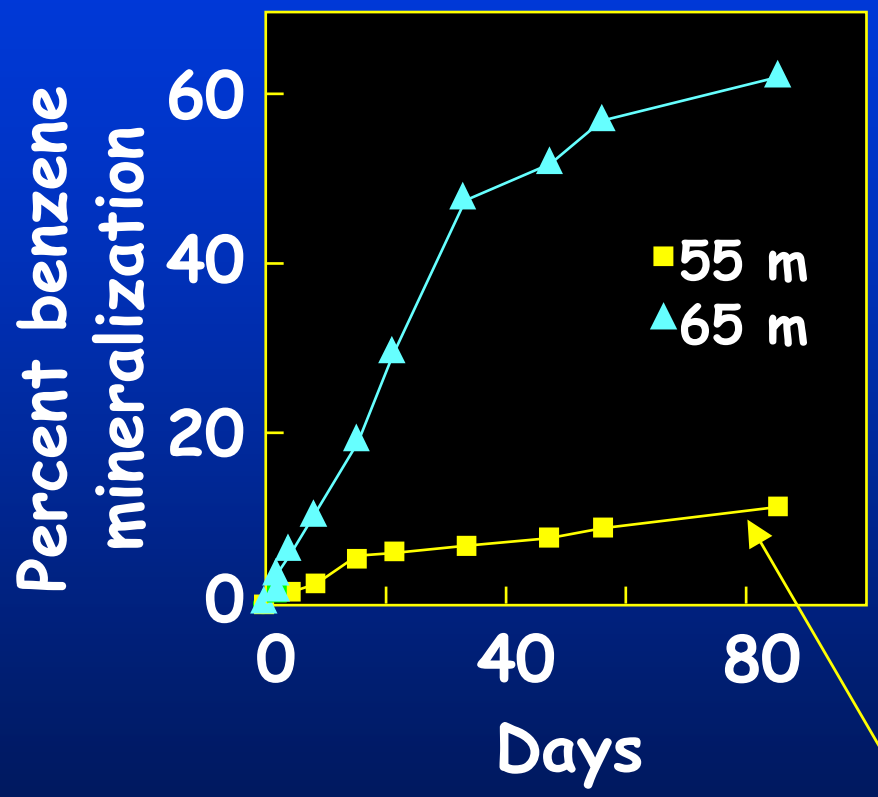
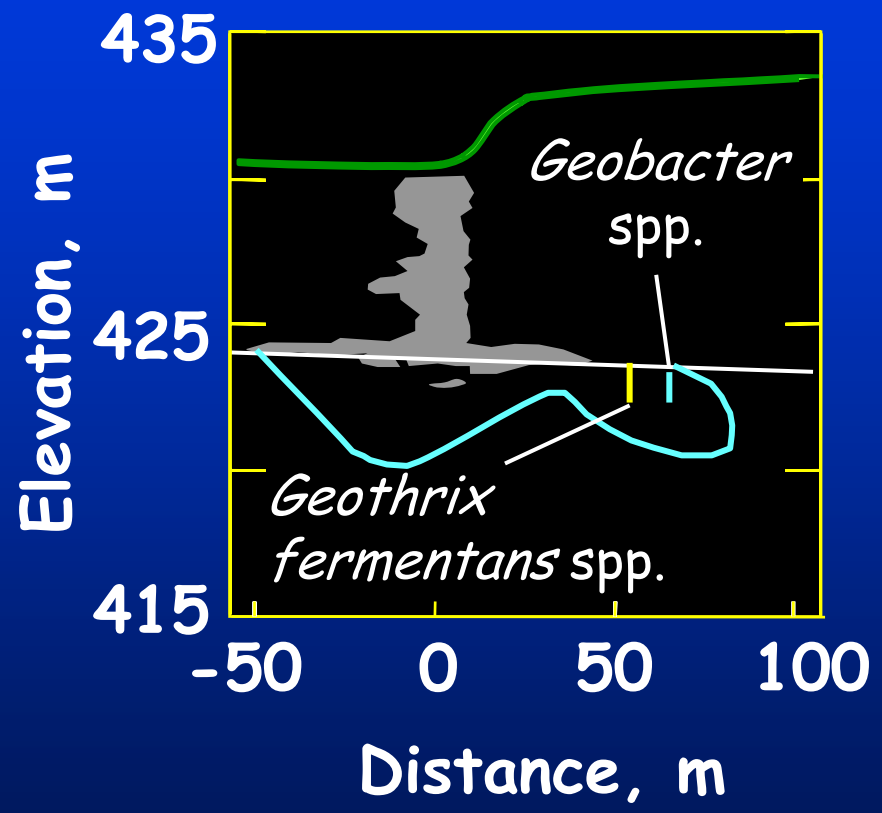
Degradation was rapid where *Geobacter* spp. were found, slow where Fe(III) was depleted





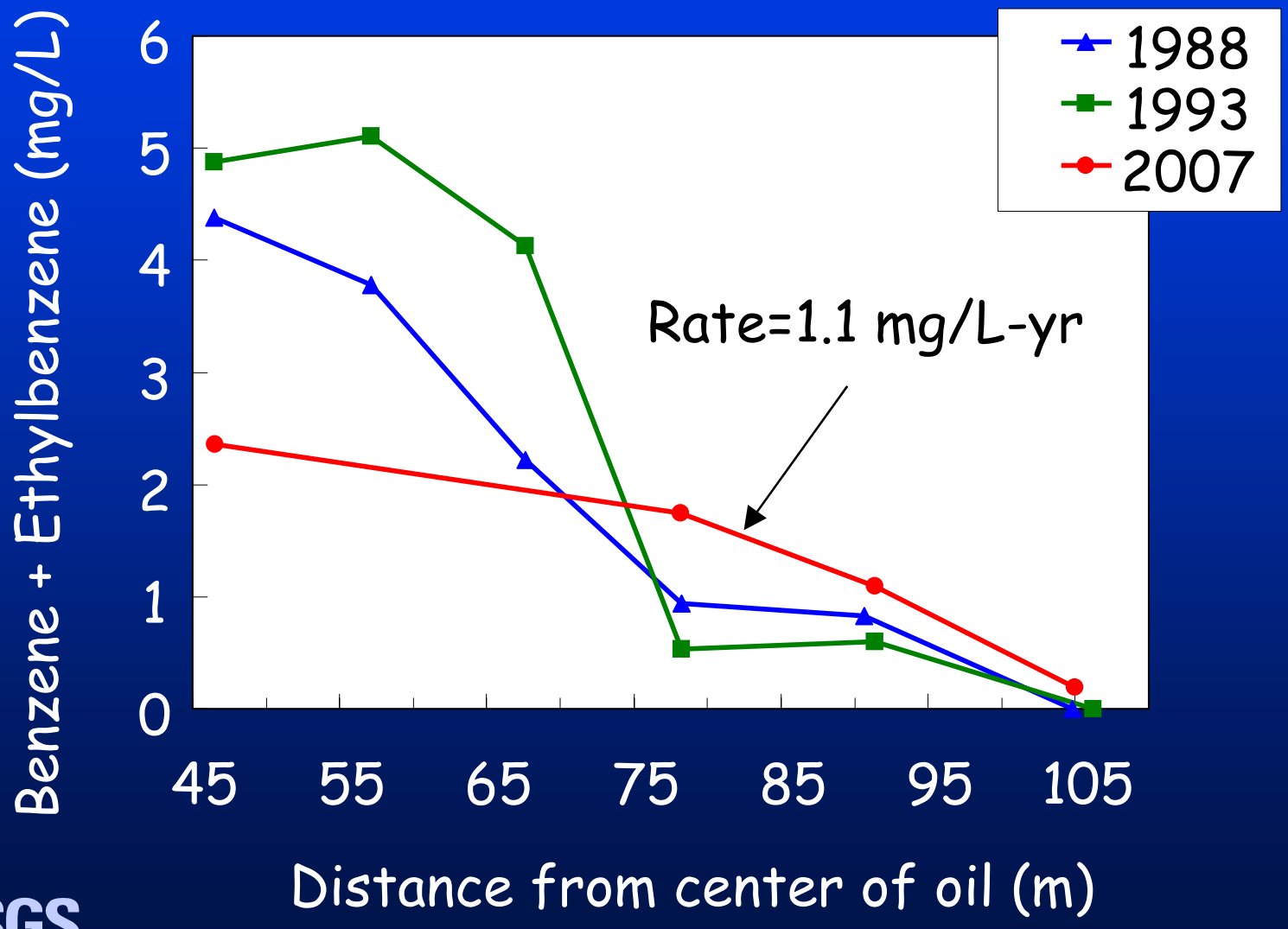
Rate=1.1 mg/L-yr

USGS

Anderson et al. (1998)

Rooney-Varga et al. (1999)

2007 data show lower benzene supply from the oil and a different degradation profile



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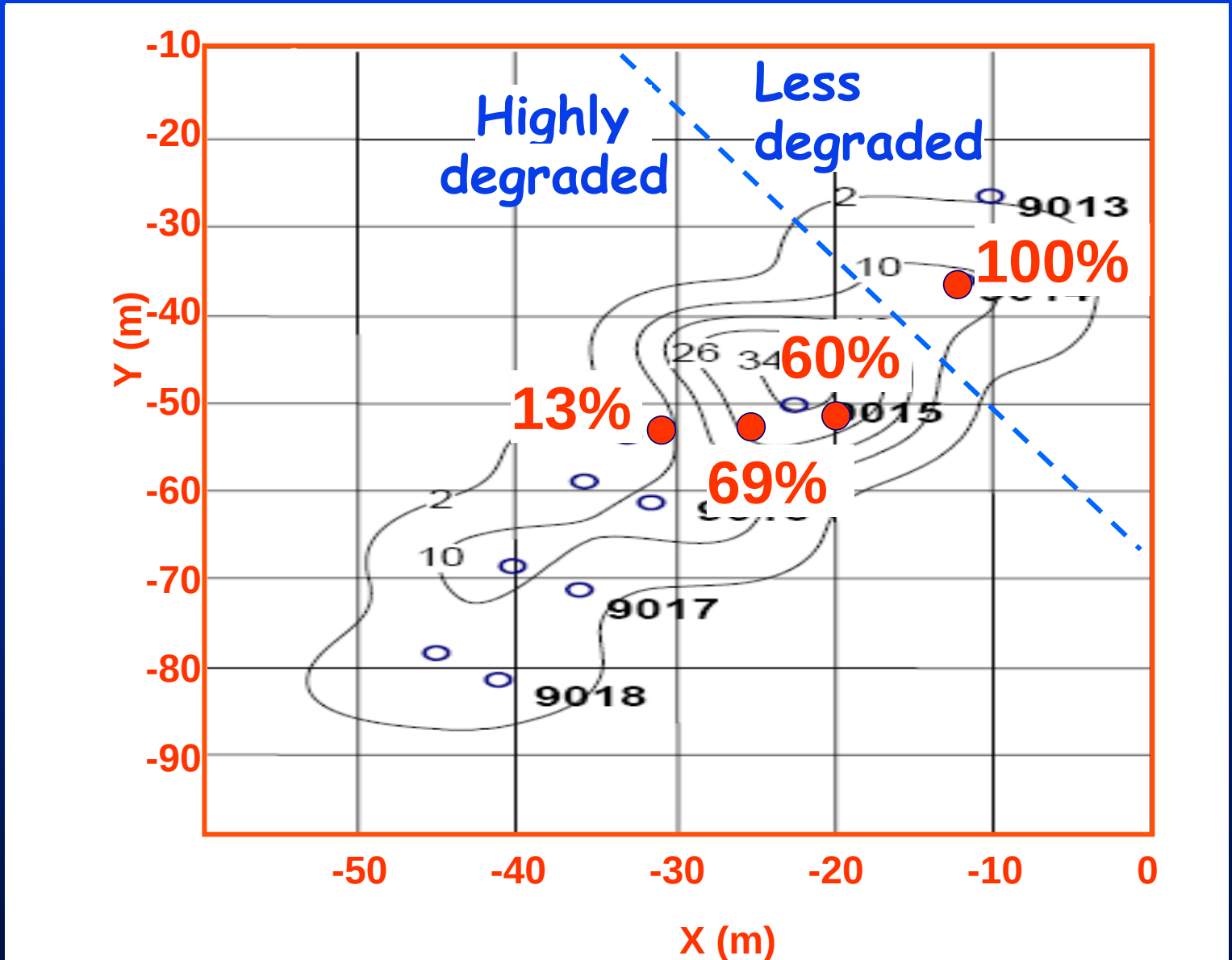
New data show significant variation in the benzene remaining in the oil



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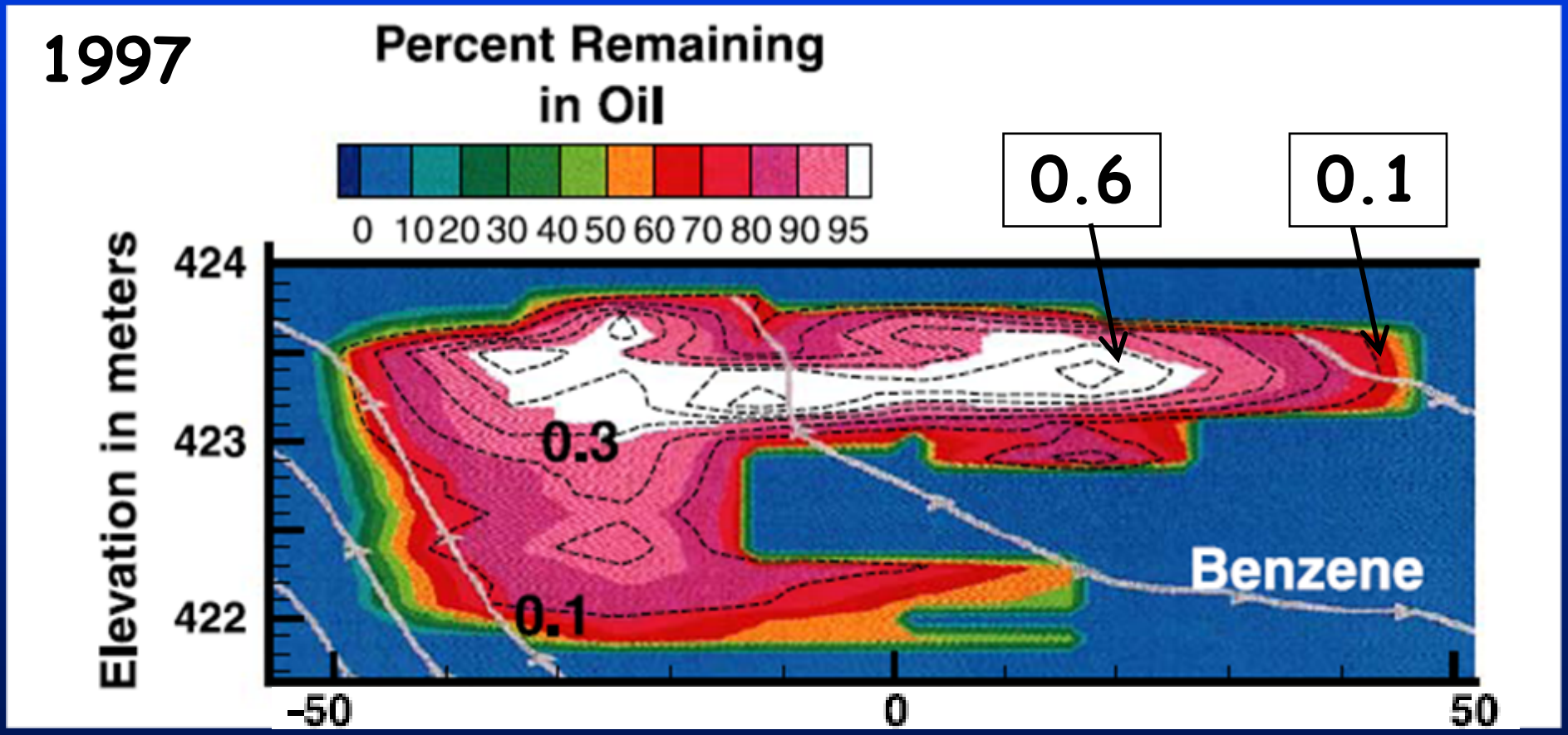
Modeling predicts depletion of benzene varies with saturation



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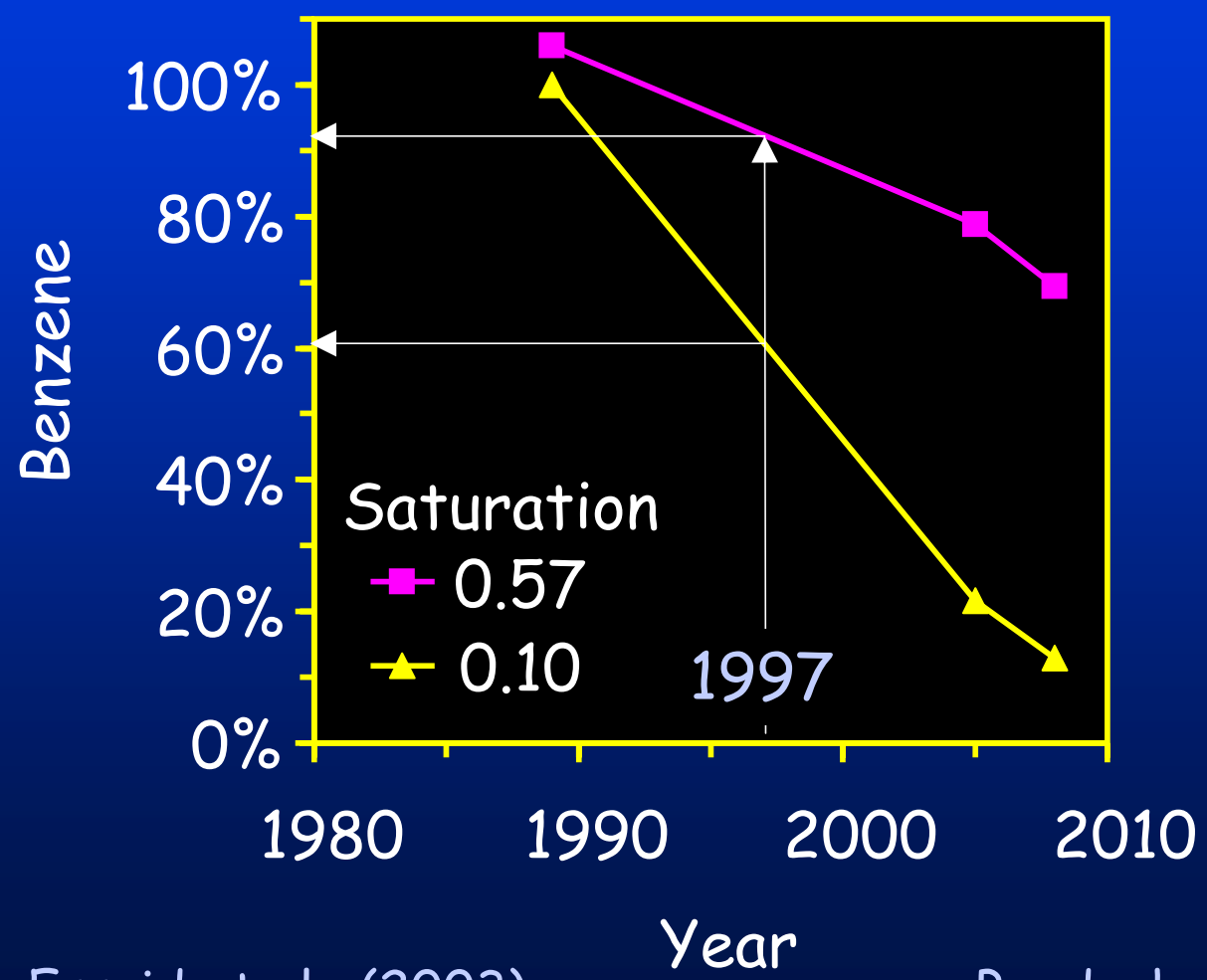
Essaid et al. (2003)

The data indicate the percent remaining in 1997 was consistent with the model

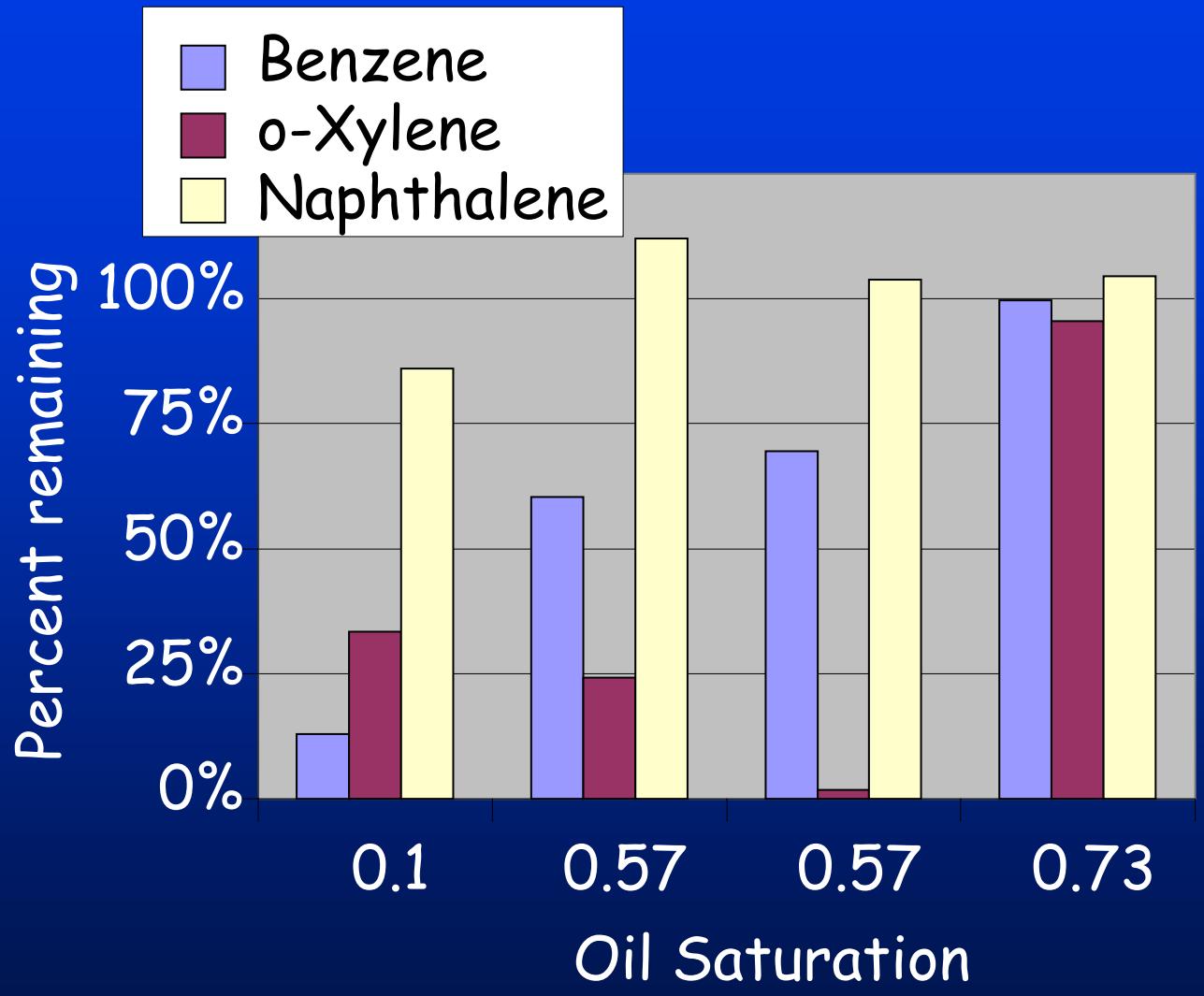


USGS

Essaid et al. (2003)

Baedecker et al. poster

Dissolution varies with saturation and solubility and is enhanced by degradation



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Baedecker et al. poster

Summary and Conclusions

Fate of oil

- Methanogenic degradation is substantial
- Rates vary depending on nutrient supplies
- Benzene depletion depends mainly on oil saturation

Ground-water plume

- Benzene supply from oil is decreasing
- Redox switching from Fe-reducing to methanogenic
- Methanogenic rate is slower but sustainable

USGS

Future work

Fate of LNAPL source

- Determine if degradation rate can be accelerated by addition of nutrients
- Extend model forward in time to project lifetime of source

Ground-water plume

- Determine if benzene is degrading under methanogenic conditions
- Determine naphthalene degradation rate

USGS