Trophic Status and Methanogenesis in Peatlands

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Path of CH$_4$ Formation

**Polymers**

**Monomers**

- **Fermentation**

- **Other LMW acids/alcohols**

- **Acetate**

- **H$_2$ + CO$_2$**

- **Acetogenesis**

- **Terminal step**

**Acetate**

**CO$_2$, CH$_4$**

**Terminal step**

**2$^o$ Fermentation Acetogenesis**
Which Pathway Matters?

In typical anaerobic systems e.g., freshwater and marine muds, sewage sludge, intestinal tracts

2/3 of CH$_4$ is derived from acetate

1/3 from H$_2$/CO$_2$

Ideal conditions: Ratio of CO$_2$:CH$_4$ = ~1

In some marine systems, C-one compounds can be quite important
Turnover of *in situ* Intermediates

**Typical**
Monomer $\rightarrow$ acetate $\xrightarrow{X}$ CO$_2$ + CH$_4$

**Uncoupled**
Monomer $\rightarrow$ acetate $\xrightarrow{X}$ CO$_2$ + CH$_4$

*Inhibition*
Trophic Status Affects Pathway

acetate $\rightarrow$ CO$_2$ + CH$_4$

acetate $\times$

Bog

Acetate (µM)

0 2 4 6 8 10

CH$_4$ (µM)

0 0.25 0.50 0.75 1.00

CO$_2$ (µM)

0 40 80 120

Days

Days

Poor Fen

Acetate-C:CH$_4$ ~1000:1

Rich Fen

acetate $\rightarrow$ CO$_2$ + CH$_4$

1,300

700

250

50

1.25

160

200
Questions

- How ubiquitous?
- Are acetotrophs not present, or not active?
- Does it vary seasonally?
- What happens with alternate electron acceptors?
- What about other organic acids (or alcohols)?
- How might climate change affect decomposition path?
- Is elevation a surrogate for latitude?
- Do other compounds behave like acetate?
Alaskan Study Sites

Grouped sites by trophic status (vegetation cover)
CH$_4$ production increases with trophic status, but total C flow does not vary greatly (acetate remains important)
Stable C Isotopes and CH$_4$ Production Path

**Sphagnum → Carex**

Vegetation Class
- Poor Fen
- Intermed.
- Rich Fen

\[ \alpha = \frac{\delta^{13}\text{CO}_2 + 1000}{\delta^{13}\text{CH}_4 + 1000} \]
Temperature Affects Pathway

Temperature increases CH$_4$ and CO$_2$, but acetate production is highest at low temperature.

*Incubation temperature similar to in situ temperature*

$p < 0.05$
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In Temperate Bogs, Acetate Becomes a Source of CH$_4$ After a Spring Lag (“Acetotrophic Switch”)
Acetate in Bog Pore Water at Turnagain Bog

Depth (cm) vs. Acetate (µM)

Peat Surface and Water Table

MONTHS: JUNE, JULY, AUGUST, SEPTEMBER
Controlled by hydrology without a temporal shift
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What About Other Terminal Electron Acceptors?

Polymers

Monomers

Fermentation

H₂ + CO₂

Acetogenesis

Acetate

Other LMW acids/alcohols

Acetate

H₂ + CO₂

NO₃⁻, Fe(III), SO₄²⁻

CO₂

Terminal step
What happens to acetate that is produced in anaerobic environments?

Acetate is consumed by all other processes (Uncoupling only during CH$_4$ production)

Acetate C destined for CH$_4$ in methanogenic habitats is converted to CO$_2$
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Polymers

Monomers

Fermentation

Other LMW acids/alcohols

$H_2 + CO_2$

Acetogenesis

Acetate

Terminal step

$CO_2, CH_4$

Terminal step

What About Other Organic Acids?
Other Organic Acids

Propionate $\rightarrow$ Acetate + CO$_2$ + H$_2$

Butyrate $\rightarrow$ 2 Acetate + 2 H$_2$
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Replacement of mosses by vascular plants may lead to severe increases in CH$_4$ production

“Sites with small increases in sedges use much more acetate”
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In Temperate Bogs, Acetate Becomes a Source of CH₄ After a Spring Lag ("Acetotrophic Switch")

Since higher latitude sites often accumulate acetate all season, this suggests that temperature may influence whether a shift occurs and when
Poor fen at 1000 m experienced an acetotrophic shift in May, but at ~1900 m, this had not occurred, even in September.
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Uncoupling of Methanogenesis Affects Other Compounds

1° & 2° Fermentation, Acetogenesis

- Pectin
  - Methanol
- S Methylation
  - DMS
- Hg Methylation
  - MeHg

- Acetate
- CO₂, CH₄
Implications

- The uncoupling of methanogenesis is a common phenomenon in the north that is linked to trophic status and temperature.
- Temperature seems to create a latitude and elevation gradient, in which seasonal effects observed in temperate bogs are postponed, sometimes indefinitely, as active seasons become colder and shorter.
- Uncoupling only occurs during methanogenesis, i.e., intermediates are consumed during respiration of other electron acceptors.
- Compounds similar to acetate are also not degraded to methane.
- Uncoupling appears to be an inhibition in which acetate use is more sensitive than $\text{CO}_2$ reduction.
Implications, con’t

- Local consequences of uncoupling of decomposition:
  1) enhanced importance of fermentation and acetogenesis; 2) C flow to acetate that is degraded to CO$_2$ (fuels stream and other bacteria); 3) unique microbial population; 4) “recycling of C to mosses”

- Global consequences of decoupling:
  1) slight increases in vascular plants (sedges) may lead to sharp increases in methane formation

- Worst case scenario: Climate warming leads to methanogenic use of acetate at current production rates (temp alone: $2^\circ \uparrow \rightarrow \sim 15\% \uparrow$; path change: 100x)
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