Seasonal and spatial variation in soil chemistry and anaerobic processes in an Arctic ecosystem

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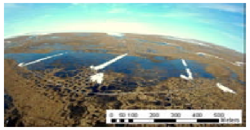
Drained thaw lake basin near Barrow in Arctic coastal plain of Northern Alaska



Study area: north, central and south boardwalks of Biocomplexity site are visible. Note extensive polygonization. These ice wedge polygons create complex microtopographic patterns that can control soil processes.

View along one of the boardwalks

Background

Our previous work showed that Fe(III) reduction is an important process in this ecosystem (Lipson et al. in review). Fe(III) reduction impacts the C cycle by providing an e- acceptor for anaerobic respiration, and an alternative metabolic pathway that competes with methanogenesis. Fe(III) reduction may be especially important in areas such as this medium-aged (~300 years old) drained lake thaw basin (DTLB) because the organic layer is thin enough that the mineral layer is included in the active layer (Hinkel et al. 2004), potentially allowing increased access to this alternative e- acceptor.

- **Primary goals**

Determine the effects of seasonal and microtopographic variation on soil chemistry and anaerobic processes

Investigate importance of Fe(III) reduction to C cycle:
Respiration
Methanogenesis

Organic layer ~15cm thick, overlying mineral layer

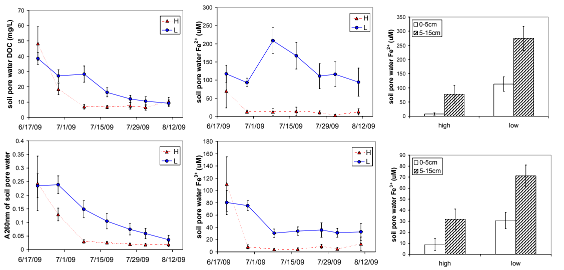
Top of mineral layer

Approach

- Soil pore water, soil samples and *in situ* electrochemical measurements collected in high (polygon rims) and low areas (polygon centers) along three transects within basin
- Additional intensive sampling of pH and ORP to correlate with elevation from DEM
- Soil and water samples analyzed in lab for chemical and biological properties
- Fe(III)-reduction experiment performed in field to measure potential Fe(III)-reduction rates and contribution to soil respiration

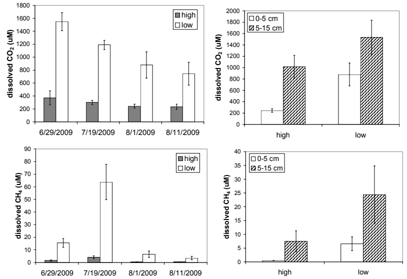
Results: Pore water Chemistry

- **Topographic trends**: lower areas higher in Fe^{2+}, Fe^{3+}, DOC, A260, dissolved CO_2 and CH_4
- **Seasonal Trends**: Most dissolved species highest soon after thaw (except CH_4 and Fe^{2+} peak later)
- **Depth trends**: Higher concentrations at 5-15cm than 0-5cm (dissolved CO_2, CH_4, Fe)
- **Relationships among dissolved species**: Fe^{3+} correlated with A260 (*organic chelators?*), CO_2 corr. w/ Fe^{3+} and DOC (*release of C and e- acceptor drive early peak in resp?*), CH_4 neg. corr. w/ Fe^{3+} (*competing anaerobic processes?*)

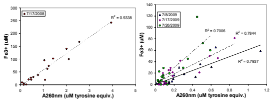


Soil pore water sampled using Rhizon soil moisture samplers into vacutainers. Seasonal data was collected from 0-5 cm horizon. Depth data comparing 0-5 and 5-15 cm horizons were collected 8/1/09-8/11/09. DOC = Dissolved organic carbon, measured by Mn(III) method (Bartlett & Ross 1988), A260 = absorbance at 260 nm. Fe(II) and (III) measured by 1,10-phenanthroline method (AMC 1978).

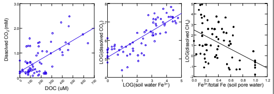
Results: Pore water Chemistry, continued



Dissolved CO_2 and CH_4 in soil pore water, measured by GC analysis of headspace. Seasonal data is from 0-5cm horizon, depth comparison made on 8/1/09



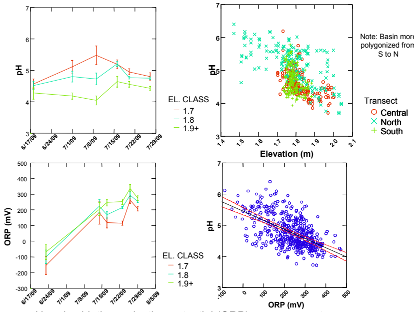
Data not shown: soil water positive for siderophores (Schwyn & Neilands 1987). Pore water contains high levels of oxalate (HPLC); Oxalate absorbs strongly in UV. So: *much of A260 may be explained by oxalate and other siderophores*.



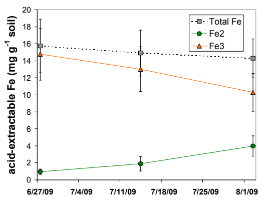
Relationships among soil water variables

Soil Chemistry

- **Topography**:
  - pH higher in low areas, ORP lower in low areas.
- **Season**:
  - pH increases after thaw in low areas, declines later. ORP lowest after thaw, increases (as water table drops).
  - Organic layer contains significant Fe-minerals (acid extractable), which become reduced over season.
- **Depth**:
  - higher total Fe at depth (mineral layer), but more Fe^{3+} at surface.
  - CH_4 production incr. w/ depth
- **Interrelationships**:
  - pH neg. correlated w/ORP (Fe reduction consumes protons).
  - CH_4 production occurs most where Fe^{3+} is rare (CH_4 at depth, Fe(III) at surface)

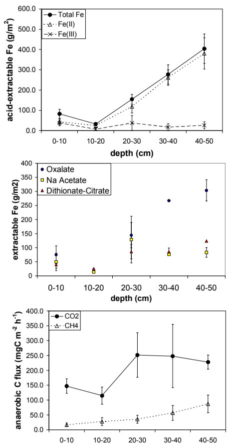


pH and oxidation-reduction potential (ORP) measurements made in field using Thermo-Orion 5-Star meter and probes.

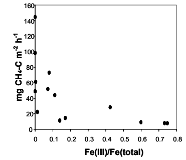


Seasonal changes in Fe^{2+} and Fe^{3+} in 1N H_2SO_4 extracts of organic soils (0-15 cm). *Note progressive reduction of Fe in mineral phase. Based on Fe fractionation data for the depth profile, the Fe(III) and Fe(II) could be from ferrihydrite and siderite, respectively. These changes are substantial, and can be used to estimate seasonal contribution of Fe reduction to ecosystem respiration (Re)*

Soil Profile Data



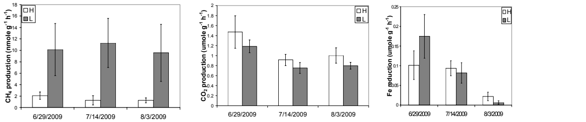
Depth series of replicate soil cores. Frozen cores collected with SIPRE corer, sliced into 10 cm horizons, which were subdivided for analyses: CO_2 and CH_4 produced in anaerobic incubation (10°C, 24h, N_2 atmosphere) and Fe extractable in various fractions (1N H_2SO_4, oxalate (ferrihydrite, lepidocrocite, magnetite), sodium acetate (siderite), dithionite-citrate (ferrihydrite, lepidocrocite, goethite, hematite).



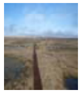
Relationship between CH_4 production and ratio of Fe(III) to total Fe in acid extracts of depth series. *CH_4 is produced where Fe(III) is rare.*

Soil Biology (anaerobic incubations in lab)

- **Topography**:
  - higher CH_4 production in soils from low areas
- **Season**:
  - CO_2 production highest early, moderate decline over time (*consistent w/ dissolved CO_2 data*)
  - Fe reduction highest early, declines sharply over time (*decline in available Fe^{3+}?*)



Field Fe-reduction Experiment



- Soil collars installed in four replicate low centered polygons
- Injections of: ferric pyrophosphate ($Fe_4(P_2O_7)_3$), sodium pyrophosphate ($Na_4P_2O_7$), EDDS (chelator), water
- Soil water monitored for Fe reduction (1, 4, 24 h)
- Soil respiration measured with portable chamber
- Experiment performed on 7/25/2009

- Fe reduction occurred in all treatments: lowest in water control, intermediate with chelators (*solubilize Fe(III)*), highest with added chelated Fe(III)
- Respiration increased with increasing Fe-reduction
- In Fe(III) addition treatment, all respiration accounted for by Fe-reduction

	Fe reduction (µmole Fe/m²/s)	Soil respiration (µmole CO_2/m²/s)	Percent of respiration by Fe-reduction*
Water	0.319 (0.138)	0.669 (0.182)	13.5 (5.8)
$Na_4P_2O_7$	1.731 (0.667)	1.196 (0.506)	37.1 (18.1)
EDDS	3.228 (0.645)	1.103 (0.214)	74.9 (15.7)
$Fe_4(P_2O_7)_3$	5.323 (0.762)	1.313 (0.242)	125.8 (23.7)

* Assumes C with oxidation state of zero is used as substrate (e.g. glucose). However, if more oxidized substrates such as organic acids (acetate, oxalate) are used, values would be higher. If more reduced compounds such as alcohols are used as substrates, values would be lower

Conclusions

- **Fe(III) reduction profoundly affects the C cycle in this ecosystem:**
  - Contributes significantly to heterotrophic respiration (R_h): up to 100% of R_h when sufficient Fe(III) is present. During July, about 30% of R_h based on rate of Fe(III) dissolution from minerals in organic layer (assuming R_h is 50% of R_e found in other studies)
  - Appears to compete with methanogenesis (at landscape, depth profile and seasonal levels)
- **Ice wedge microtopography controls patterns of oxidation-reduction processes in this landscape**
- **High CO_2 flux after thaw may be partly due to availability of DOC and Fe(III)**
- **Siderophores and organic acids solubilize Fe(III) from minerals, allowing high concentrations in soil pore water**

Acknowledgements

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