Permafrost Geotechnical Data: Thaw Consolidation Test Results and Their Application in Settlement Estimation

PermafrostNet AGM 2023

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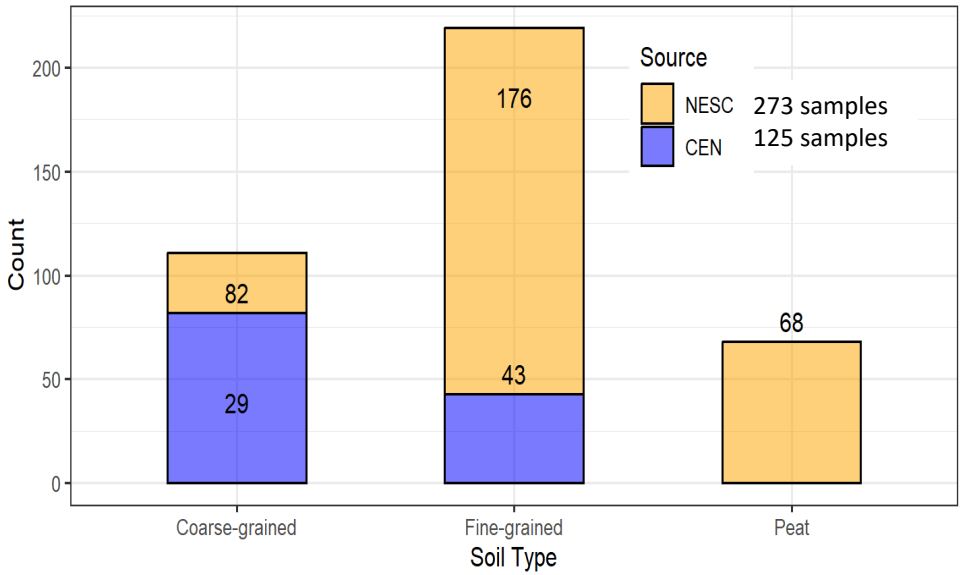
Data Integration and Objectives

- Collected, homogenized, and integrated existing thaw consolidation data into a unified database.
- Insights into distinct thaw consolidation behavior of:
  - Fine-grained
  - Coarse-grained
  - Peat
- Characterization and parameterization
- Thaw settlement estimation tool/method development

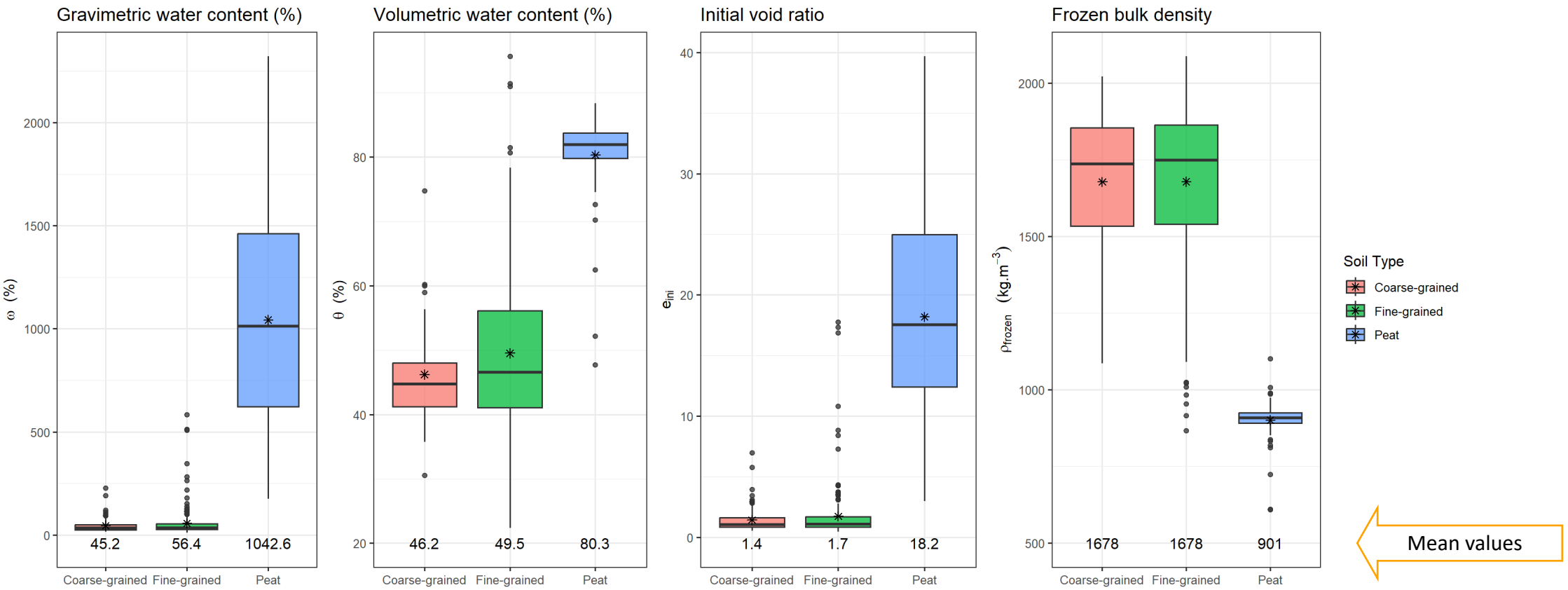
- Contributing to building geotechnical database

Existing data



Total of 398 samples

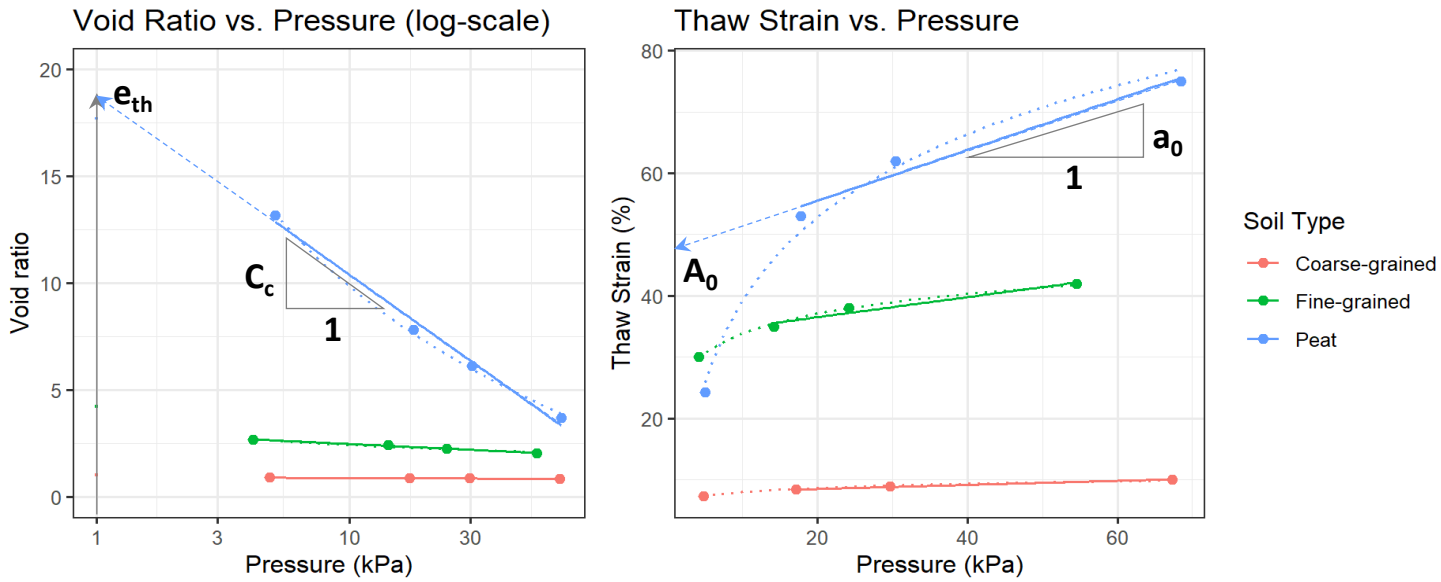
Index properties (initial condition)



Note: The reporting of properties is not consistent across all samples.

Thaw consolidation test results

- Thaw consolidation test:
  - thawing permafrost samples under an initial load
  - additional load application
- Lack of standardized procedure
- Need for comparative parameters
- Non-linear (semi-log) minimizes errors for fine-grained and peat samples



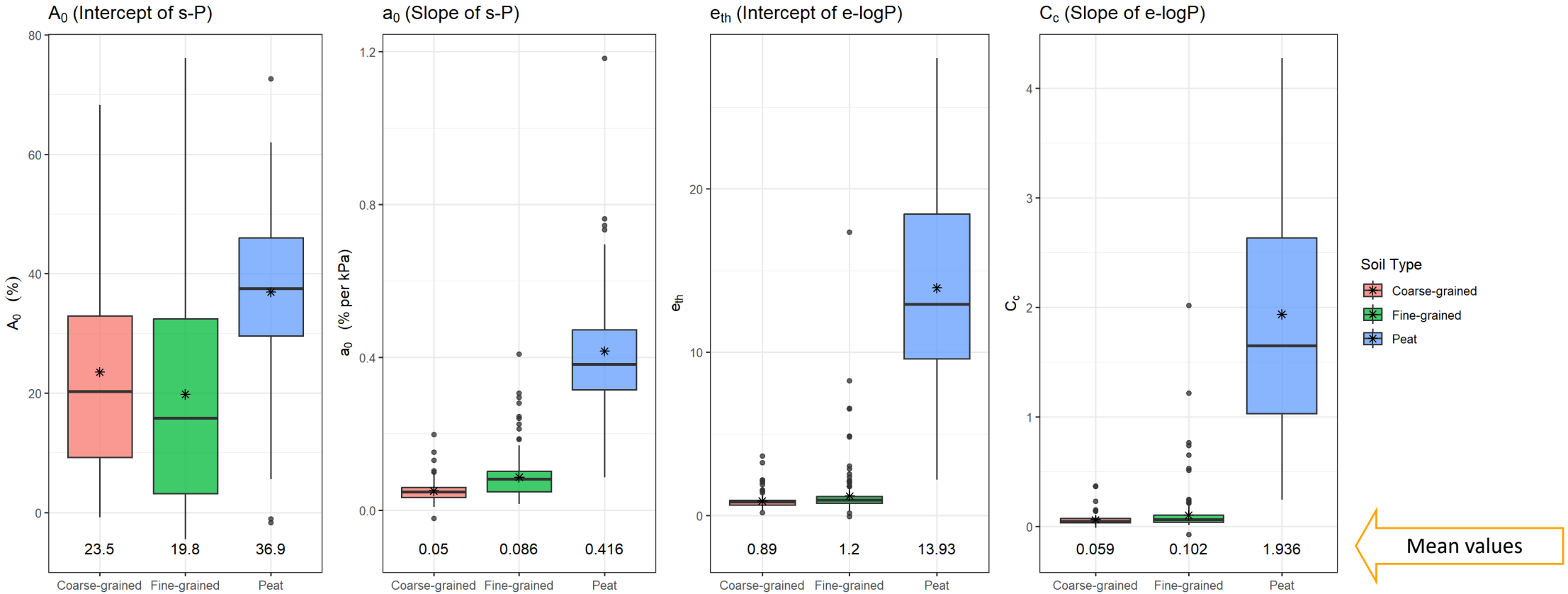
e_{th}= Initial thawed void ratio

C_c = compression index of the thawed soil

A_0=thaw settlement parameter

a_0= coefficient of compressibility

Comparative parameters



Correlation analysis for predicting variable identification

Coarse-grained

	s – P		e – log(P)	
	A_0	a_0	e_{th}	C_c
ω	0.70	0.26	0.67	0.70
θ	**0.79**	0.51	**0.77**	**0.77**
ρ_{frozen}	-0.75	-0.11	-0.61	-0.53

Fine-grained

	s – P		e – log(P)	
	A_0	a_0	e_{th}	C_c
ω	0.56	0.45	**0.88**	**0.88**
θ	0.81	0.37	0.46	0.49
ρ_{frozen}	**-0.84**	-0.43	-0.57	-0.60

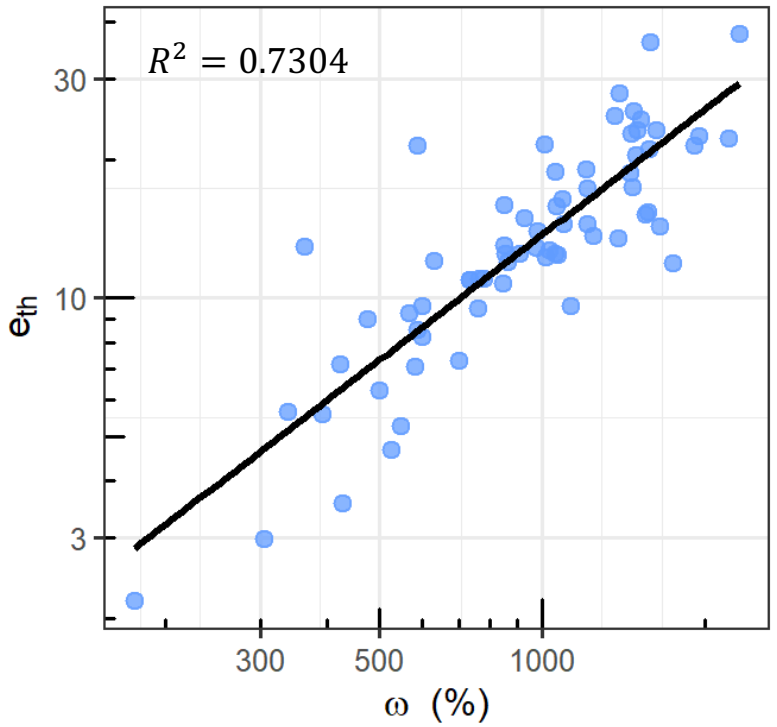
Peat

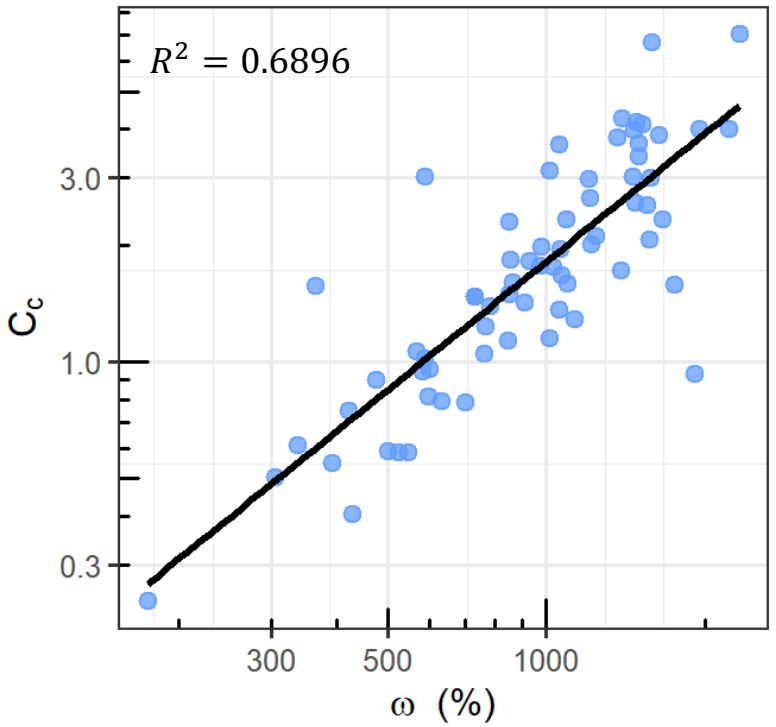
	s – P		e – log(P)	
	A_0	a_0	e_{th}	C_c
ω	0.43	0.22	**0.80**	**0.76**
θ	0.44	0.02	0.27	0.32
ρ_{frozen}	0.22	-0.26	-0.32	-0.21

ω: Gravimetric water content
θ: Volumetric water content
P_{frozen} : Frozen bulk density

Correlation coefficient > 0.75

Developed correlations (peat)

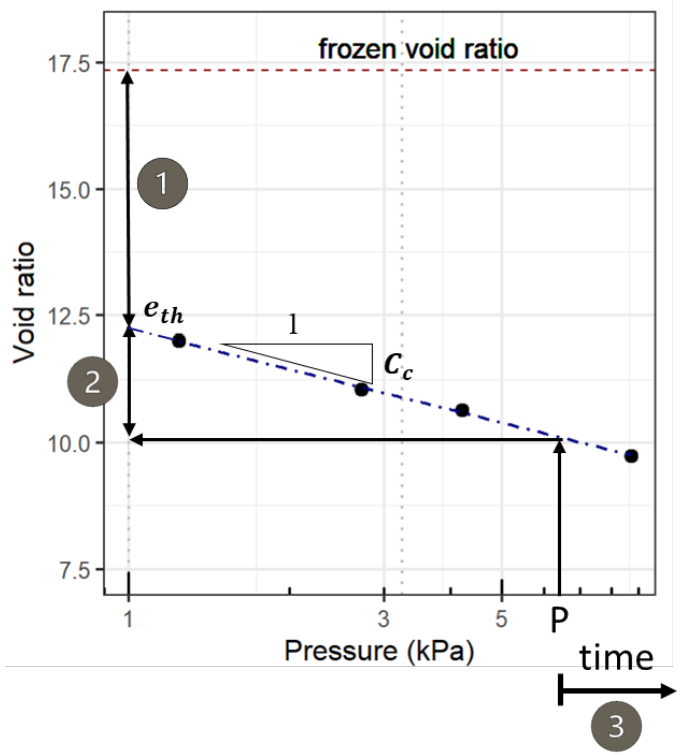


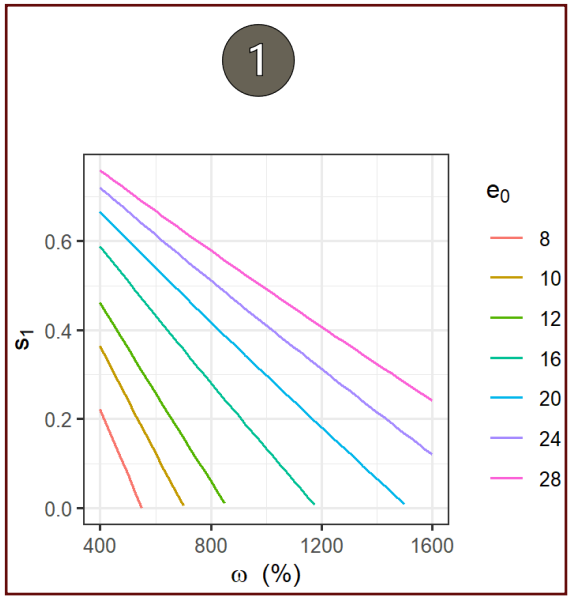


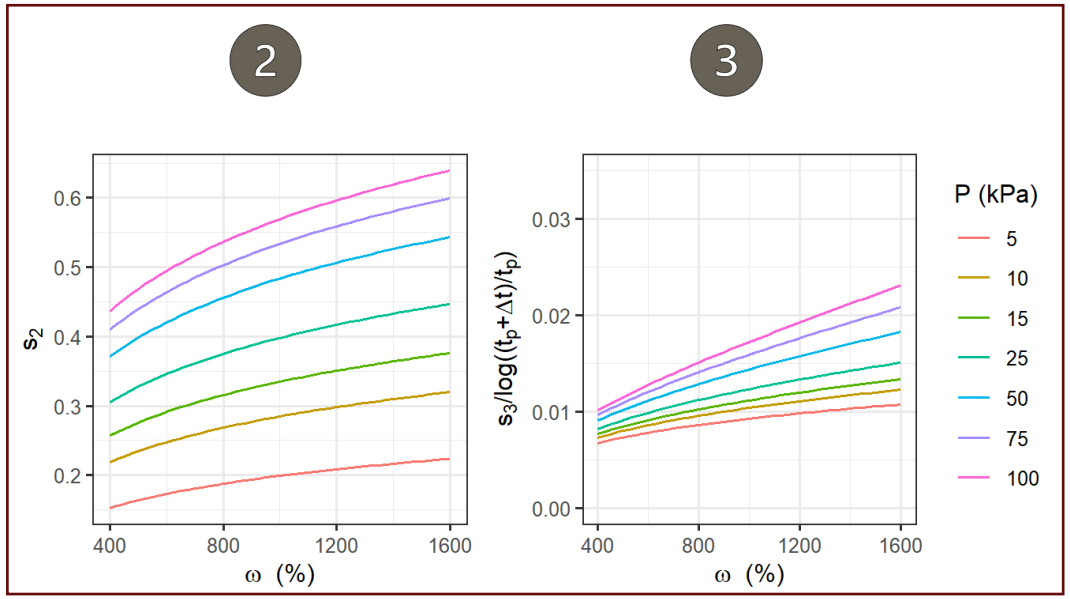
$$e_{th} = exp(-3.626 + 0.904 \ln \omega))$$

$$C_c = exp(-7.008 + 1.101 \ln \omega))$$

Estimating thaw strain for peat samples





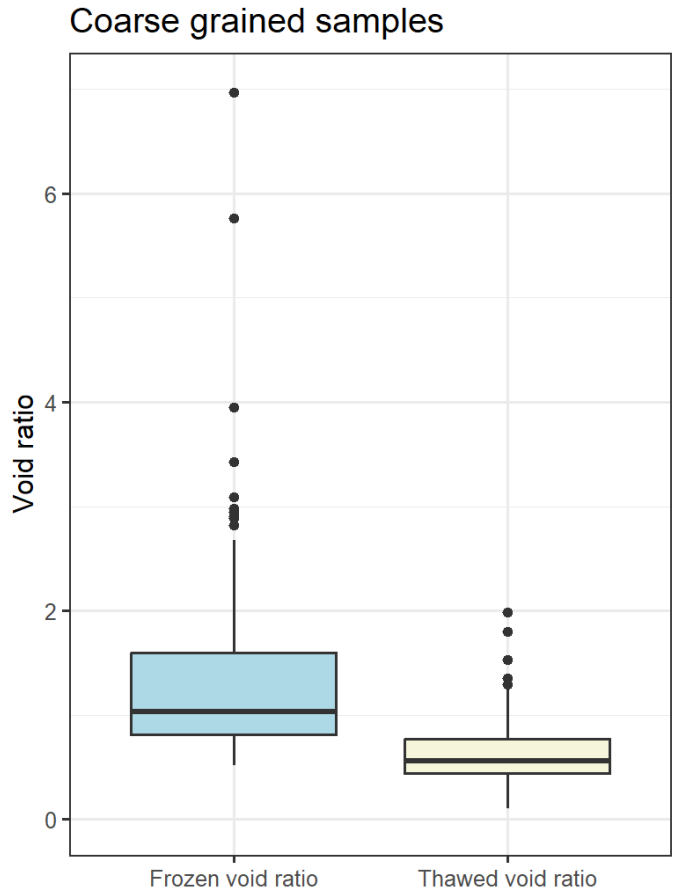


$$thaw\ strain = f(\omega, P, t)$$
$$Total\ strain = s_1 + s_2(1 - s_1) + s_3(1 - s_1)(1 - s_2)$$

$C_\alpha/C_c = 0.06 \pm 0.01$
(Mesri et al., 1997)

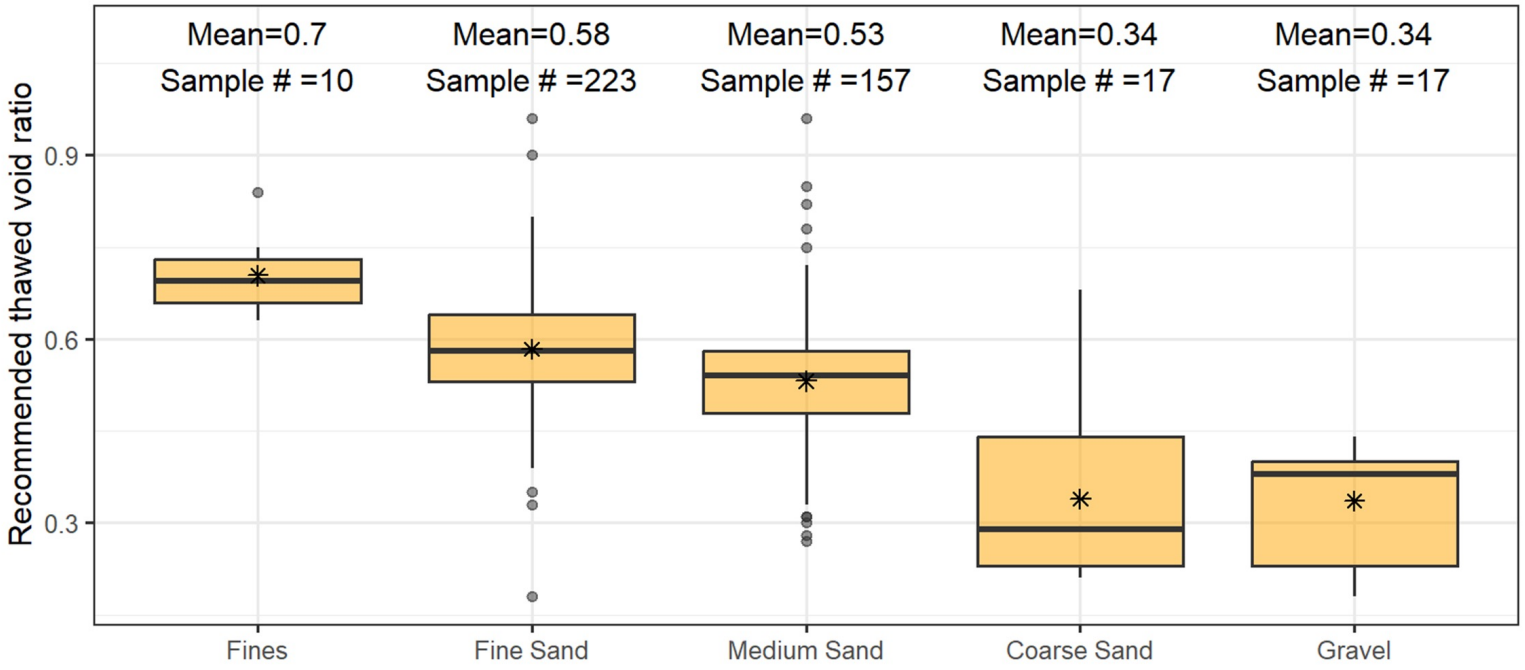
Example of using the data for estimating thaw settlement in coarse-grained sediments

- Unfrozen granular material shows a narrower void ratio range compared to frozen sediments (due to excess ice)
- Laboratory-measured minimum void ratios can be used to prescribe a conservative thawed void ratio for various types of cohesionless sediments
- Minimum void ratio depends on the particle size distribution and morphology



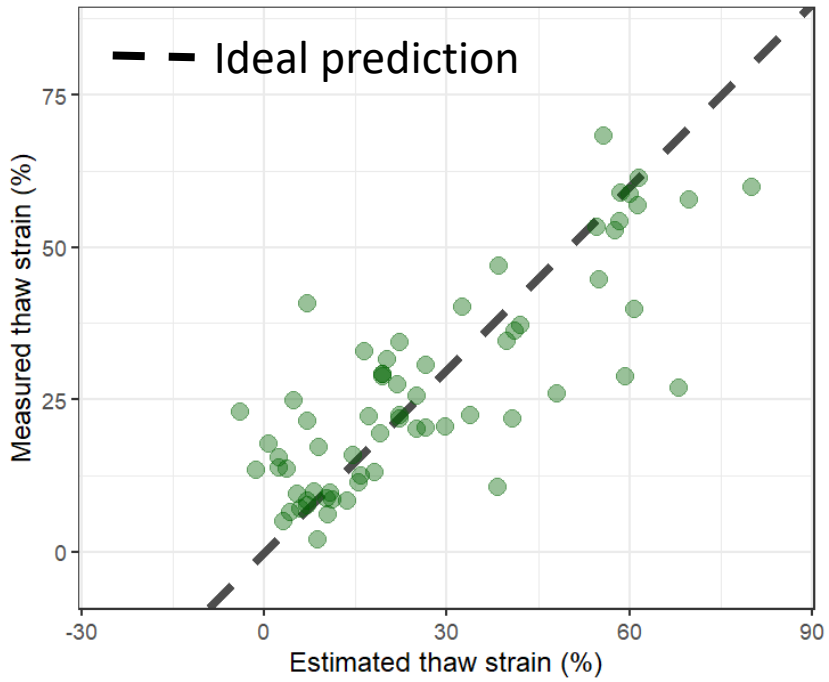
Recommended thawed void ratios

- A dataset of minimum void ratio (e_{min}) and median particle size (D_{50}) with 637 observations
- Data on the grain size distribution of cohesionless sediments



Validations

- Comparing the thaw strain estimated using recommended void ratios with the measured thaw strain



Method	Bias (%)	Error (%)	R^2
Ladanyi (1994)	5.3	13.11	0.51
Nixon and Ladanyi (1978)	8.3	15.61	0.47
Speer et al. (1973)	5.4	12.70	0.57
This study	**-0.1**	**12.66**	**0.65**

- Improved accuracy
- Reduced bias

Closing remarks

- Unified and homogenized data
  - Enhances accessibility and applicability
  - Creating / contributing to a permafrost geotechnical database.
- Distinct thaw-settlement behavior identified in three soil groups.
- Key parameters, like C_c and e_{th}, are crucial for thaw consolidation assessment.
- Improved thaw settlement prediction yields:
  - Optimized engineering designs.
  - Informed decision-making.
- Thaw strain insights offer a valuable understanding of ground ice conditions..

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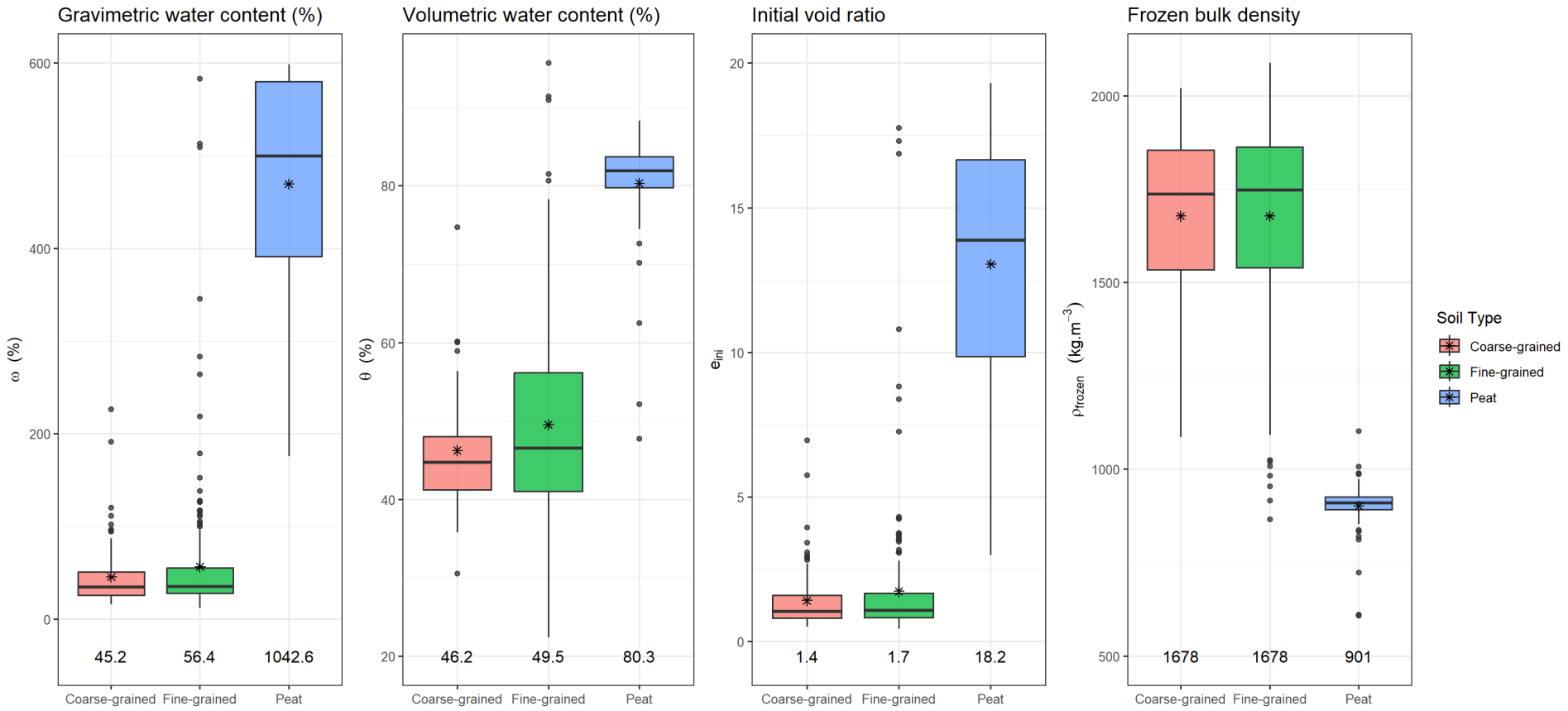
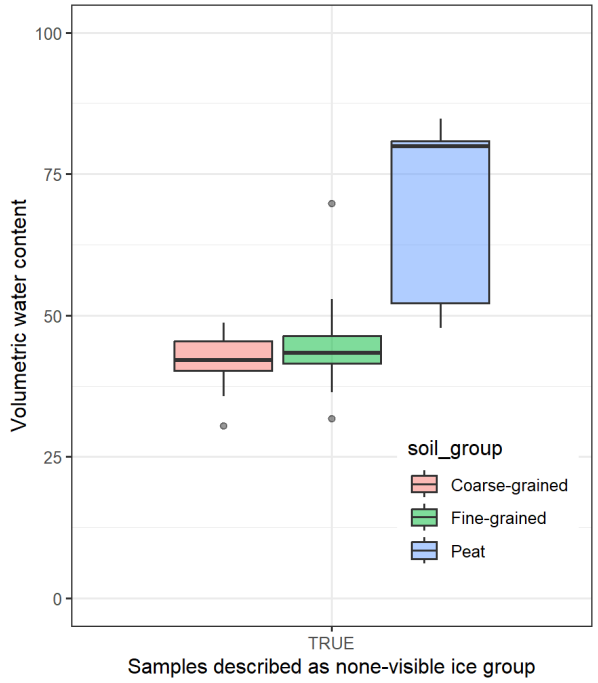
Thank you!
Any question…?

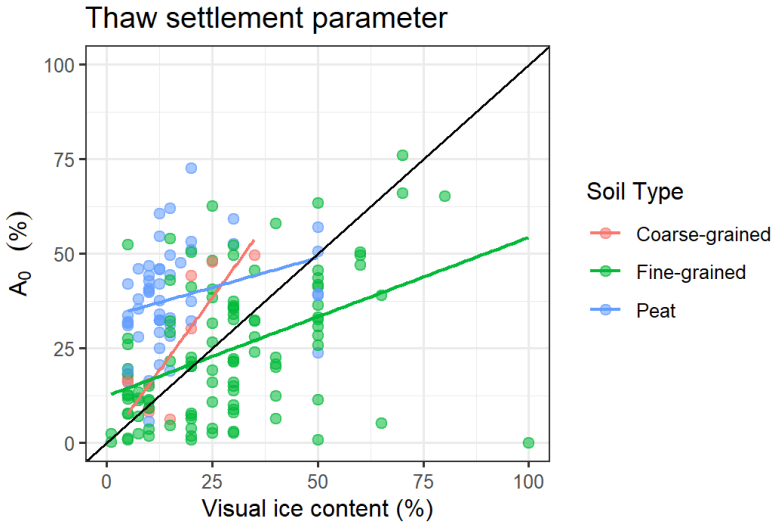
Fine-grained vs. coarse-grained (index properties)

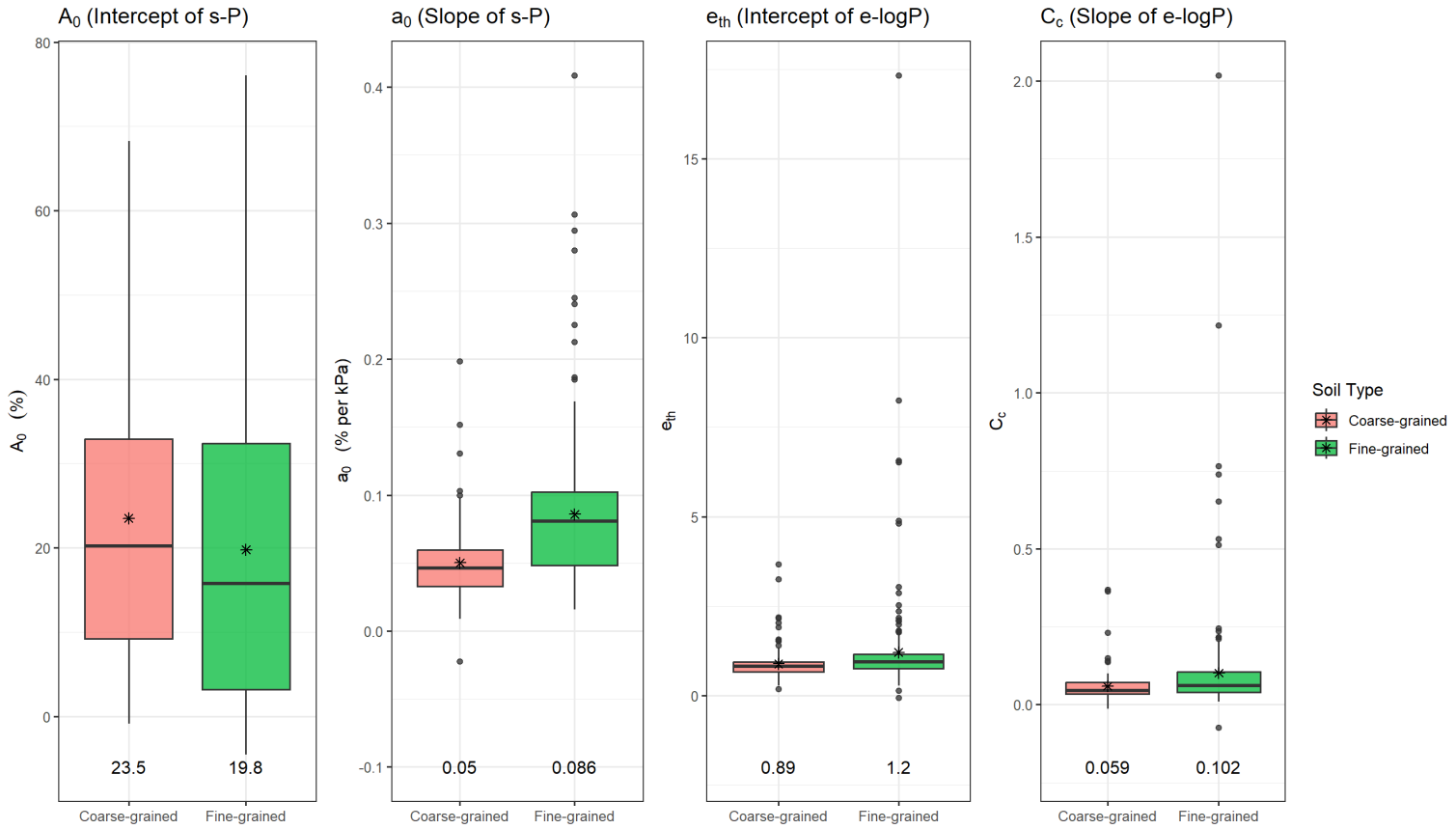


Correlation between visible ice content and A_0

- More scatter data for the peat group
- Scatter data
- A_0 and visual ice content are more comparable than volumetric water content.



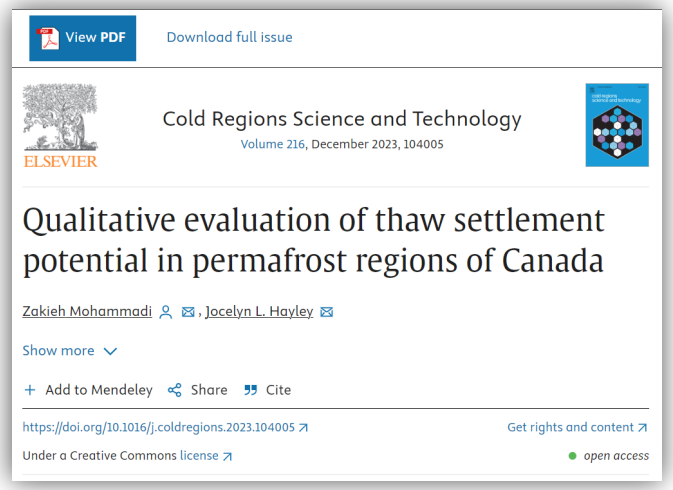



A_0 (Intercept of s-P)
a_0 (Slope of s-P)
e_{th} (Intercept of e-logP)
C_c (Slope of e-logP)
A_0 (%)
a_0 (% per kPa)
e_{th}
C_c
23.5
19.8
0.05
0.086
0.89
1.2
0.059
0.102
Coarse-grained
Fine-grained
Soil Type
Coarse-grained
Fine-grained

Overview of my PhD project

- **Objective:** To develop a framework for predicting thaw settlement in permafrost regions

Regional scale assessment → **Local-scale assessment** → **Creating the Framework**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Qualitative evaluation of thaw settlement potential in permafrost regions of Canada

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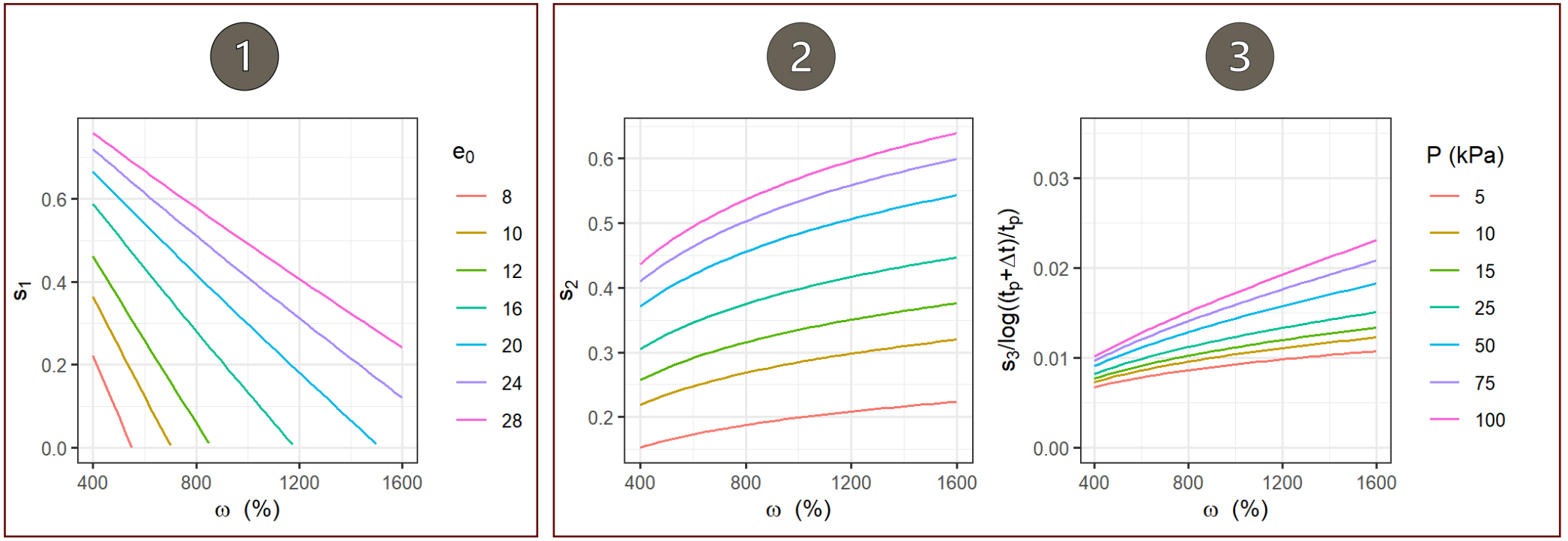
Creating predictive tools/methods for thaw settlement by accounting for the unique characteristics of fine-grained, coarse-grained, and highly organic soils.

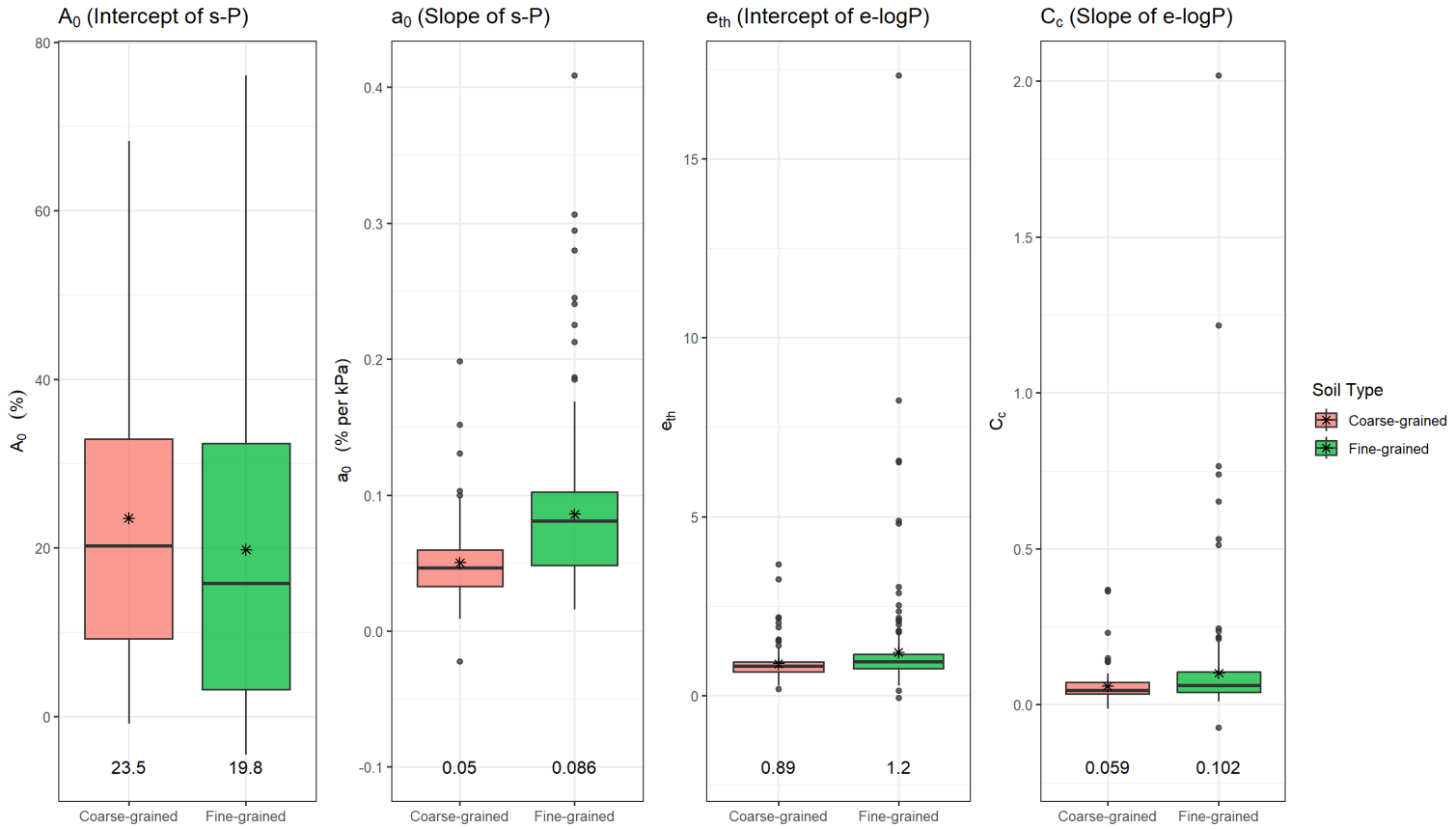
Integrating diverse components to establish a framework for assessing thaw settlement across various scales.

Design charts to calculate the total strain of peat



$$Total\ strain = \frac{\Delta H_1 + \Delta H_2 + \Delta H_3}{H_0} = s_1 + s_2(1 - s_1) + s_3(1 - s_1)(1 - s_2)$$

Comparative parameters



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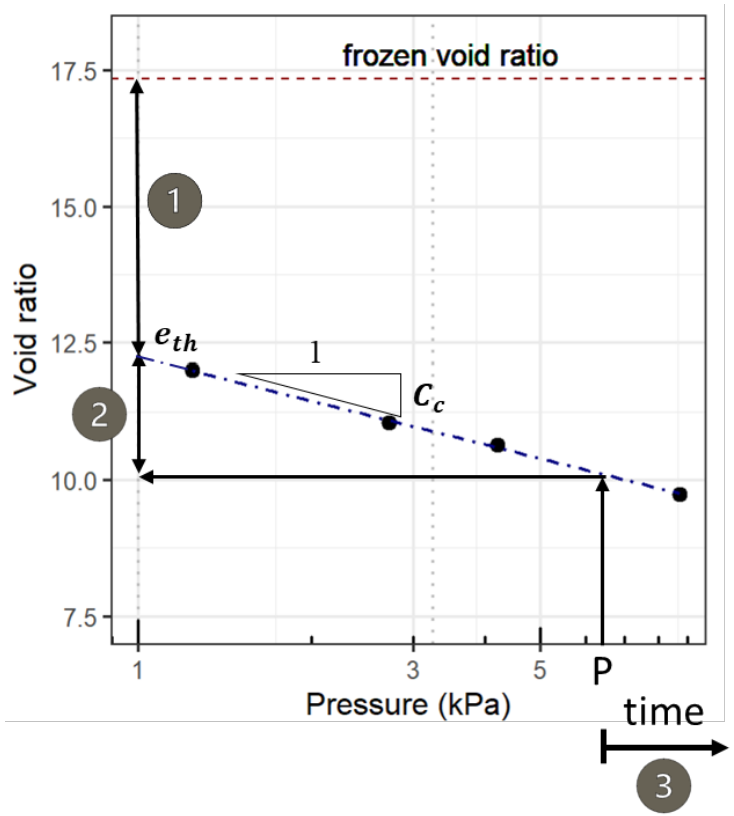

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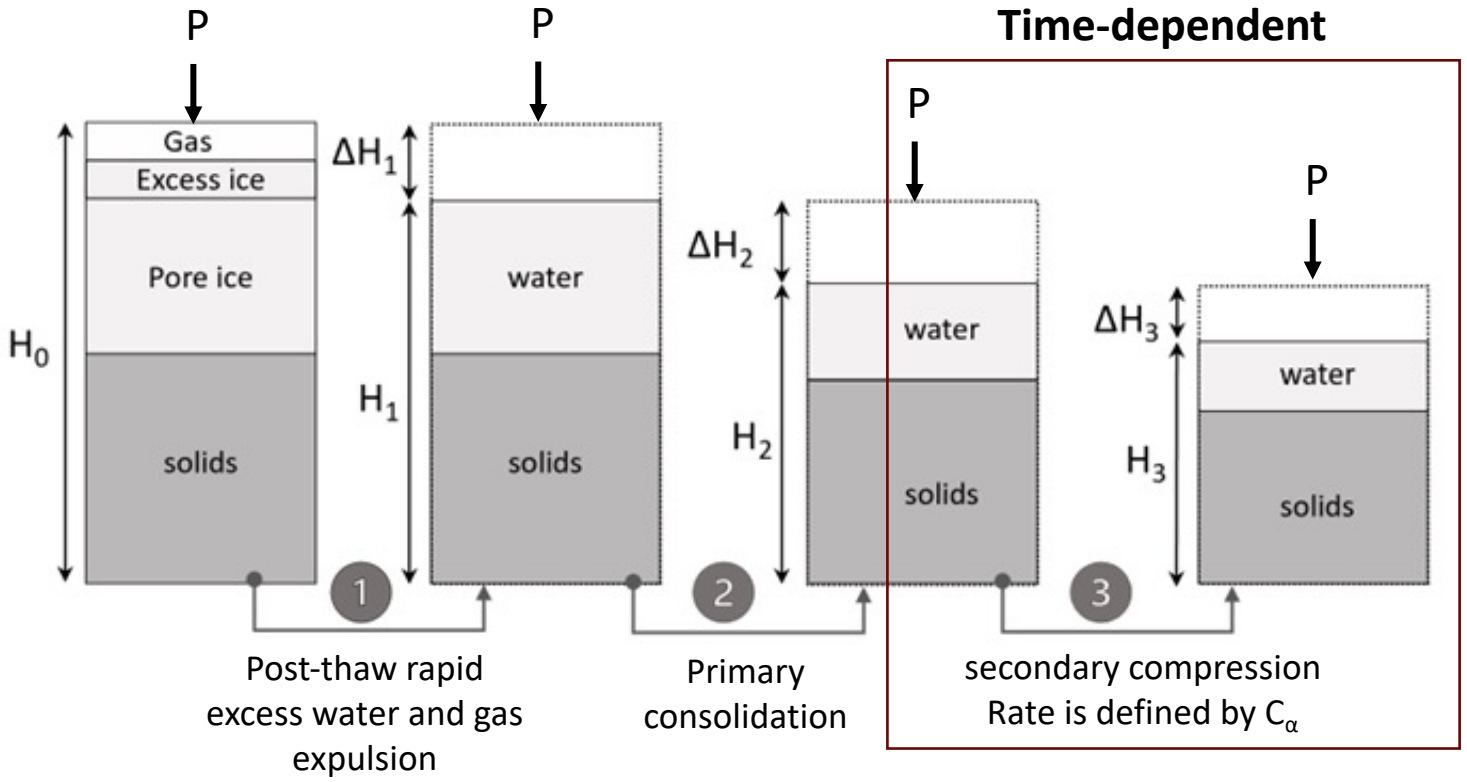
(Mesri et al., 1997)



$$Total\ strain = \frac{\Delta H_1 + \Delta H_2 + \Delta H_3}{H_0}$$

$$thaw\ strain = f(\omega, P, t)$$