Arsenic in Soil in the Yellowknife Region

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Introduction

Legacy mining activities within and around the City of Yellowknife have resulted in significant land and water contamination. The roasting of gold-bearing arsenopyrite (FeAsS) ore at Giant Mine resulted in the release of approximately 20,000 tonnes of arsenic trioxide (As_2O_3) into the surrounding environment[1]. Previous work has demonstrated that arsenic (As) from roaster emission persists in near surface soils and can be distinguished from natural arsenic using advanced mineralogical tools[2,3,4]. A regional geochemical soil survey was implemented over the summers of 2015 and 2016 to determine the extent of impact by this past industrial activity. This regional survey hopes to better define the gradient of As concentrations in soils with respect to the distance from contaminant sources, and determine the zone of influence from past mining and processing activities.

Research Objective:

Determine the extent of arsenic contamination within a 30km radius from the City of Yellowknife.

- How is arsenic distributed throughout the study area? What might cause high degree of variability?
- How do direction, distance and elevation influence the distribution of arsenic?
- How does soil geochemistry vary between different terrain units?

Study Area & Sample Collection

During the summers of 2015 and 2016, 439 soil samples were collected from within a 30 km radius of Yellowknife. The goal of the regional soil sampling survey was to collect a large number of samples throughout the study region from a variety of terrain units. Four primary units were sampled within the study region: forested canopy outcrop soils (FCOSC), forested canopy soils (FCSC), outcrop soils (OSC), and peat (PSC).
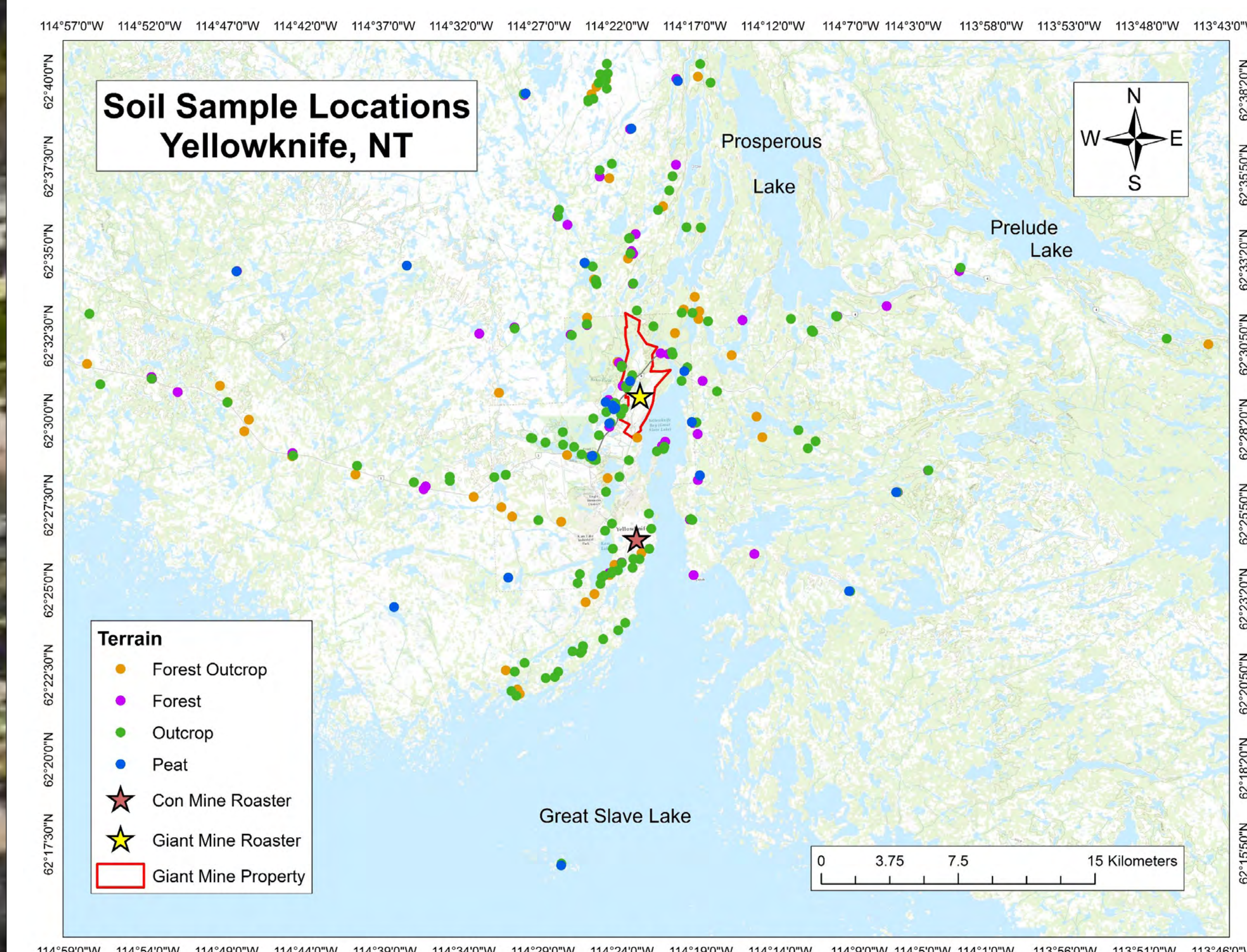

Figure 1. Map of study area and sample locations surrounding Yellowknife and the Giant Mine property.

Target areas were selected based on 1) distance from the former Giant and Con Mine roasters, 2) direction from the roasters with respect to prevailing wind direction, and 3) location with respect to past or on-going research. Within each target area soils were sampled from the four distinct terrain units. Soil cores were collected to maintain the integrity of the soil profile at depth. At some locations multiple soil samples of a similar soil unit were collected to test for variability at the site scale. Samples were collected from undisturbed locations whenever possible.

Sample Collection:

- Soil cores were retrieved with aluminum tubing that was driven into the soil surface using a drive-head and a sledgehammer, or by cutting into the peat using a saw.
- In areas where core samples were not feasible, grab samples were retrieved.
- Cores and grab samples were frozen for transport back to Queen's University and kept frozen prior to lab preparation.
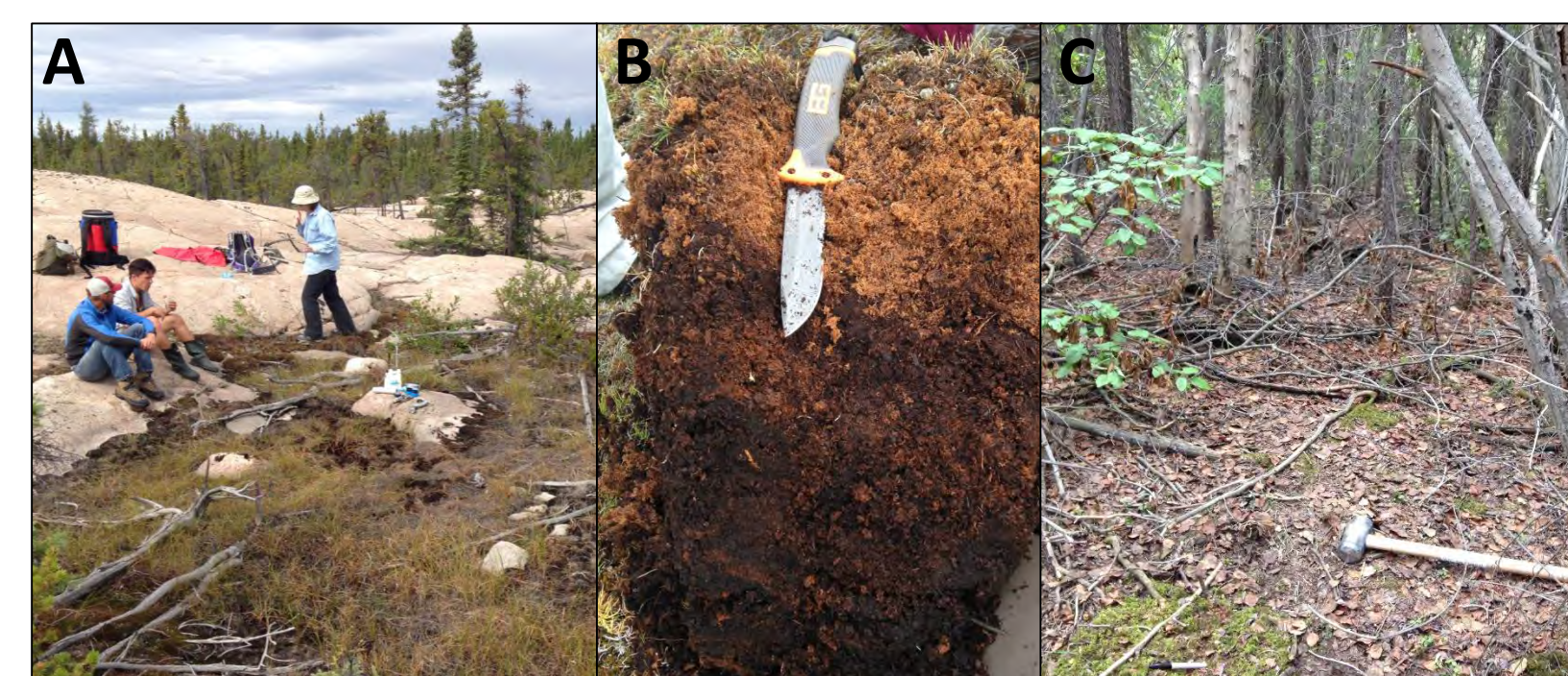

Figure 2. A) Outcrop soil pocket. B) Peat core. C) Forested canopy sample site.

Sample Preparation & Analytical Methods

The aluminum core tubes were cut lengthwise and carefully separated using a ceramic blade. Compression throughout the cores had to be calculated prior to sub-sectioning a representative public health (PH) layer (top 5cm). The PH layers were homogenized and divided into sub-samples. Grab samples were homogenized and emptied into plastic trays where they could also be separated into sub-samples. Peat samples were kept frozen prior to being sub-sectioned with a hacksaw. In addition to analyzing the PH layer at each sample site, C-horizon samples are being sub-sectioned from select cores to test for background arsenic concentrations.
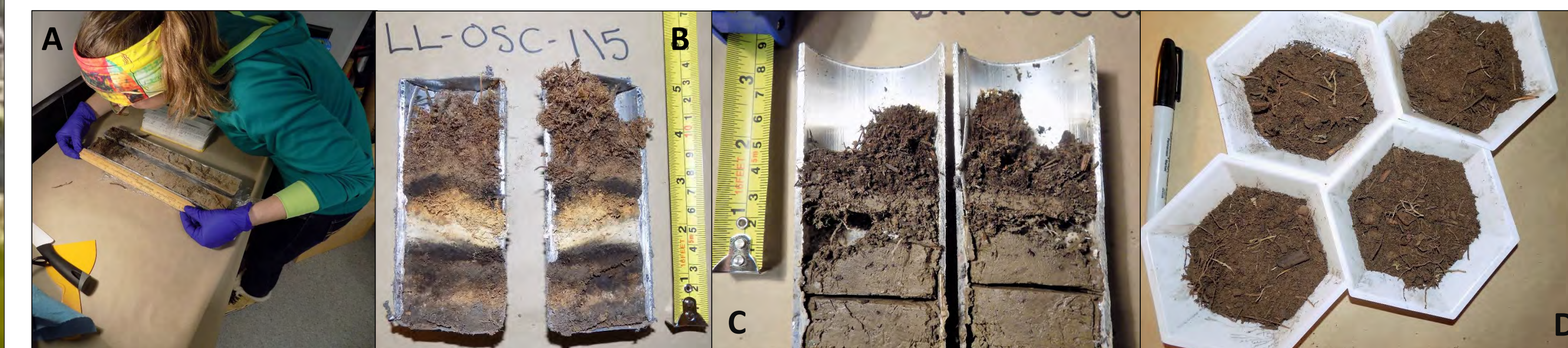

Figure 3. A) The PH layer of a soil core being measured. B) Separated outcrop soil core taken near Long Lake. C) A forested canopy soil sample with the PH layer measured and sectioned. D) Four sectioned and homogenized sub-samples.

One sub-sample from each sub-sectioned core and grab sample were submitted for total elemental analysis by ICP-MS and ICP-OES. A set of additional sub-samples were air-dried and ground before being sent away to analyze for total organic carbon content. Polished epoxy mounts are being created for select cores, which will be analyzed using scanning electron microscopy coupled with automated mineralogy to identify the solid species of arsenic present within the soil units. Anthropogenic sources of arsenic will be characterized by a presence of As_2O_3 and As-bearing iron-oxides derived from roaster stack emissions.
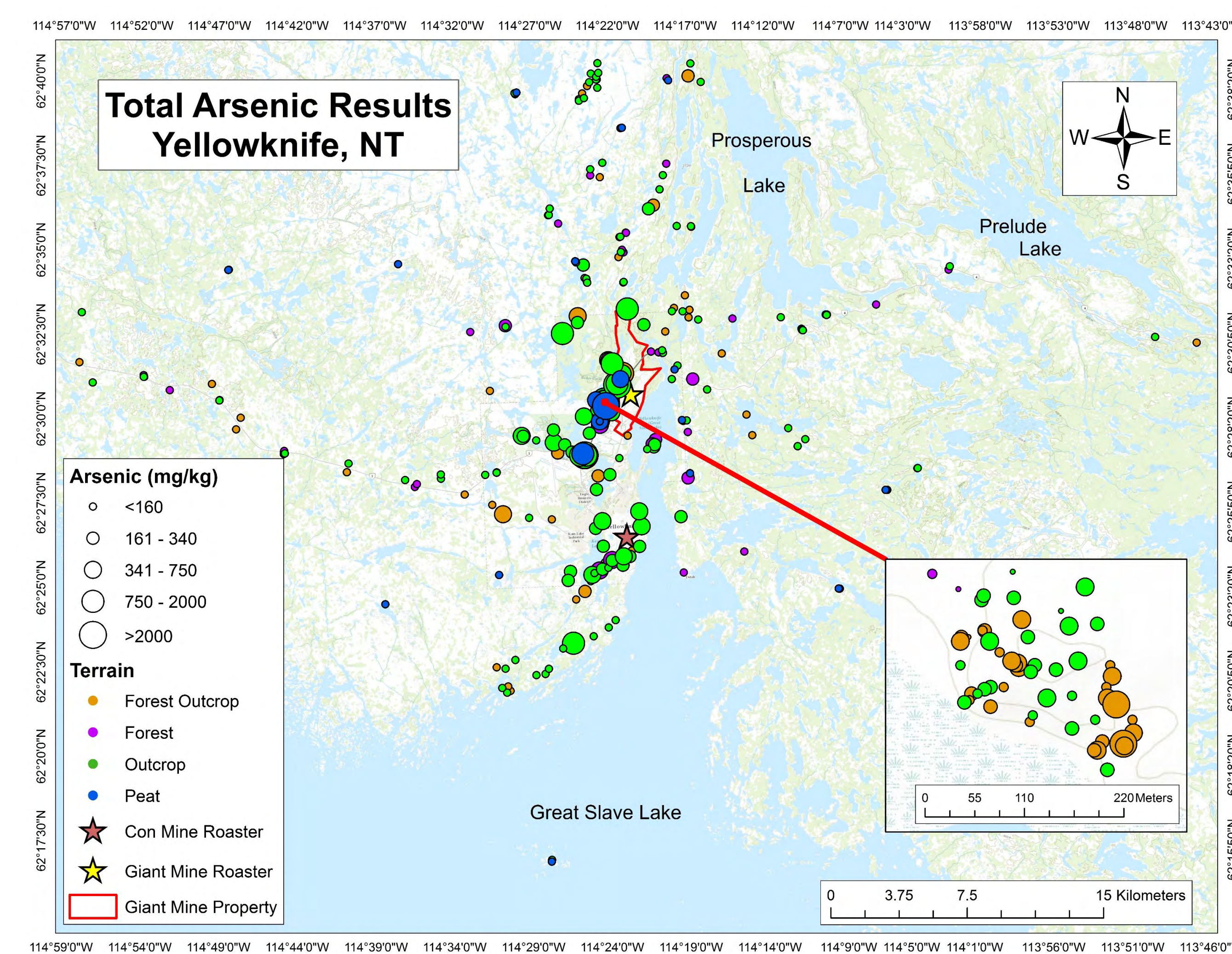
Results

Figure 4. Map indicating total arsenic concentrations measured in the PH layer within the study area.

Total arsenic results indicate that concentrations of arsenic in soils are highest to the west of the Giant Mine Property. Considerable variability was observed between proximal sample locations, suggesting a number of factors could play a role in the distribution of arsenic and soil geochemistry at the local site scale. The remediation objectives for arsenic in Yellowknife area soils are 160 ppm and 340 ppm for residential and industrial land use areas, respectively[5].

Discussion

Data were logged transformed to meet assumptions of normality for the statistical procedures used. One-way analysis of variance (ANOVA) with Tukey comparisons, and regression analyses were completed in *Minitab 17*. All tests were performed at a 95% confidence interval (α = 0.05). The letter and number groupings used to classify the factors below are in chronological order, with A and 1 representing the highest mean arsenic concentrations.
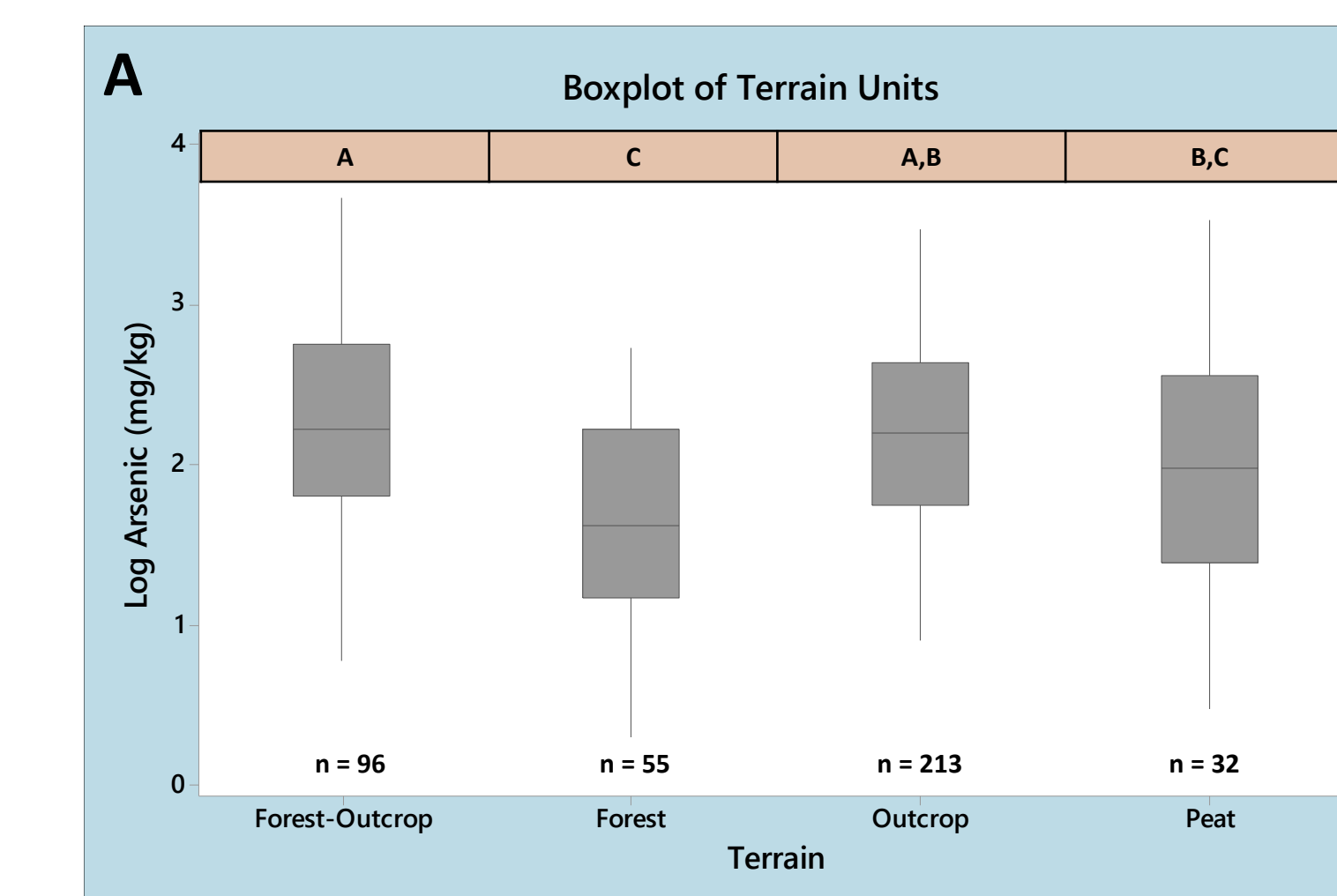

Figure 5A. The mean arsenic concentrations of FCOSC and OSC are significantly different from PSC and FCSC; OSC and PSC are significantly different from FCSC ($p < 0.001$).
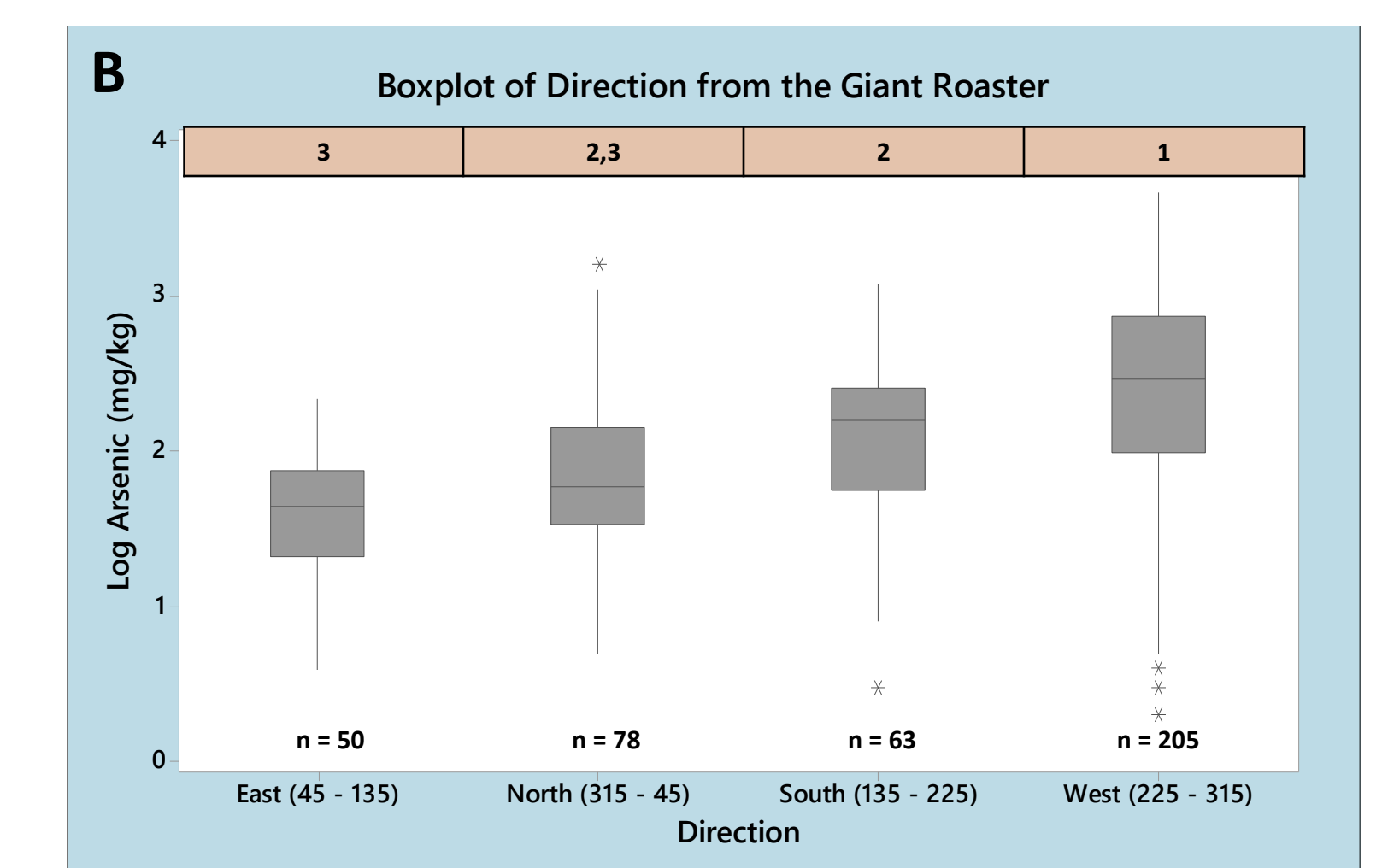
Figure 5B. Mean arsenic concentrations that do not share a letter in regards to direction, are significantly different ($p < 0.001$).
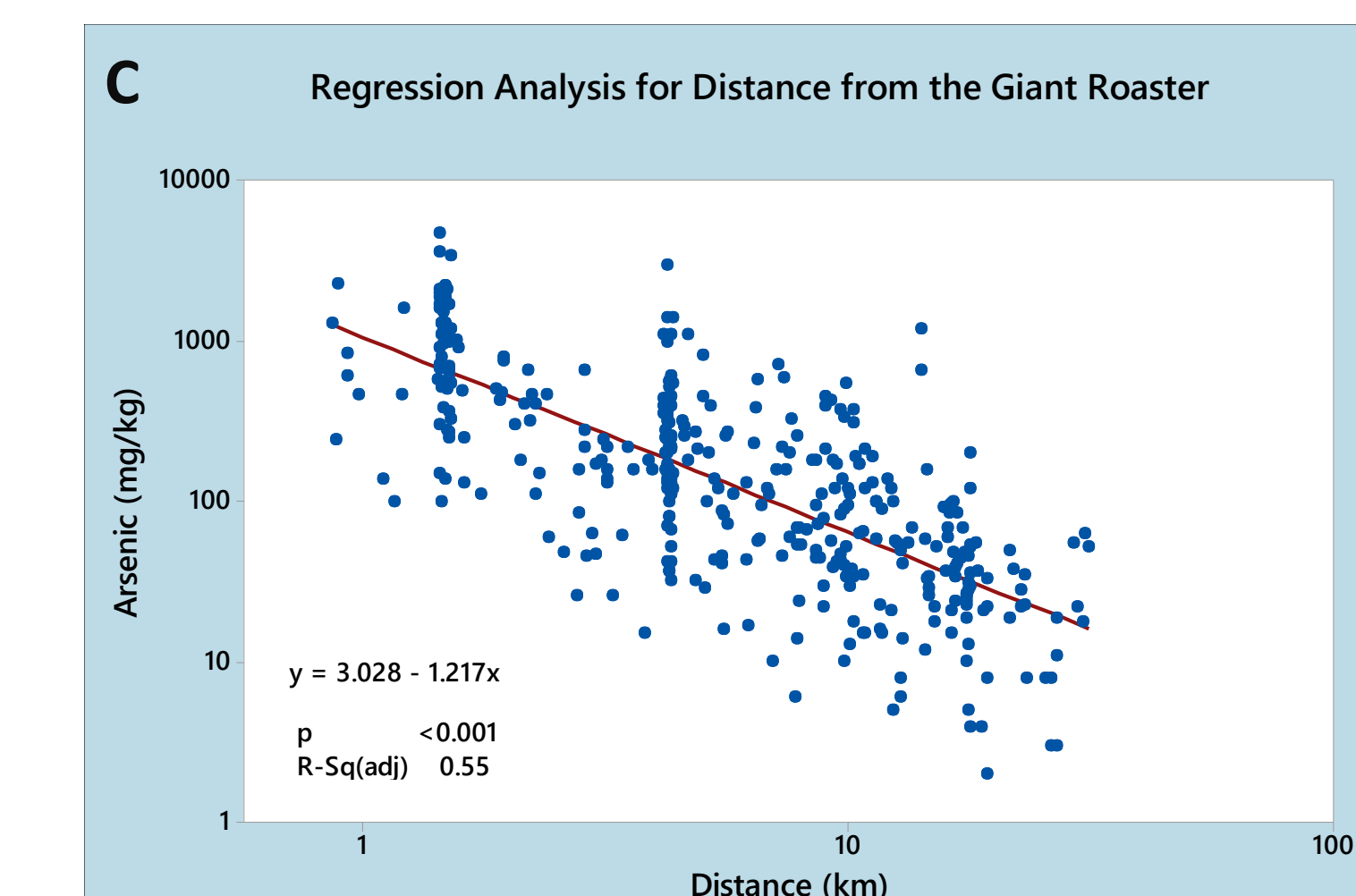
Figure 5C. The regression analysis indicates decreasing As concentrations with increasing distance from the Giant Mine roaster ($R^2_{(adj)}$ = 0.55; $p < 0.001$).
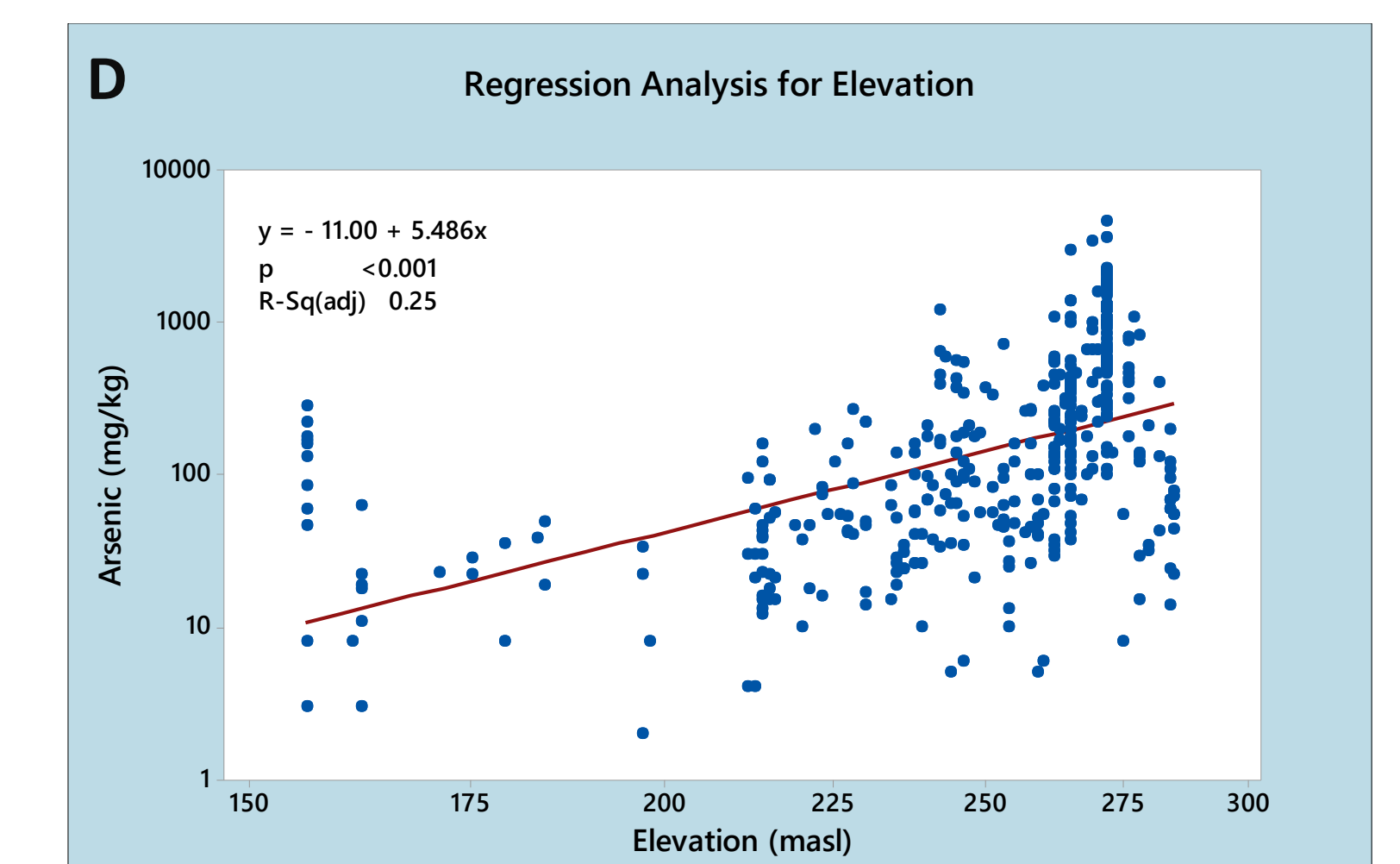
Figure 5D. The regression analysis indicates a trend of increasing As concentrations with increasing elevation ($R^2_{(adj)}$ = 0.25 ; $p < 0.001$).

Iterative modelling was completed to determine which factors best explain the distribution of As throughout the study region. Results from an analysis of covariance model demonstrated that the model of best fit included all four of the environmental variables explored. The model had an adjusted R^2 value of 0.68 ($p < 0.001$).

Future Work

Samples have been prepped and submitted for total organic carbon (TOC) analysis. The effect of this fifth factor on the distribution of arsenic throughout the study region will be examined. Select cores are being analyzed using scanning electron microscopy coupled with automated mineralogy to identify the solid species of arsenic present within the soil units. Anthropogenic sources of arsenic will be distinguished from natural sources of arsenic by the presence of As_2O_3 and distinctive arsenic-bearing iron-oxides.

Acknowledgments

References

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