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Paleoclimatological Assessment of the Southern Northwest Territories and Implications for the Long-Term Viability of the Tibbitt to Contwoyto Winter Road, Part I: Core Collection

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SUMMARY

This pilot program is part of a larger, on-going research program that will provide data obtained from biological and chemical analyses of lake sediments and tree rings to track climate change over the past ca. 4000 years in the southern Northwest Territories. The primary data will be complemented by traditional accounts of past climate variability. The goals of the larger project will be to increase the current understanding of natural climate variability in the southern Northwest Territories in general, and the Tibbitt to Contwoyto Winter Road in particular, to increase the knowledge base required for better predictions as to how current and forecasted climates may affect the ecosystems of this region. The pilot program represents the first attempt to collect freeze cores from lakes in the southern Northwest Territories. Three freeze cores and associated water quality measurements were collected from Tibbitt Lake, Waite Lake, and Dome Lake, located along the Tibbitt to Contwoyto Winter Road between March 19th and March 22nd, 2009. All cores are primarily composed of mud and range in colour from black to brown. Freeze coring captured the unconsolidated sediment-water interface in two cores and it is concluded that freeze coring is an appropriate method for sediment core collection in northern lakes. Radiocarbon ages on bulk sediment samples from ROAD09-WAITE01 indicate that post-glacial sedimentation rates in Waite Lake are high relative to more northerly sites and confirms that high-resolution (mm scale) sub-sampling of the core will permit decadal to sub-decadal analyses of late Holocene climate change. The pilot program has also been successful in obtaining sediment samples from the sediment-water interface of lakes near Yellowknife. These samples were collected to develop a thecamoebian-based training set for the quantitative inference of climate parameters from fossil communities preserved in the sediments of lakes along the Tibbitt to Contwoyto Winter Road.

ACKNOWLEDGEMENTS

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BACKGROUND

The diamond industry is an essential component of the economy of the Northwest Territories (NWT); it accounted for 50% of the territorial real domestic product in 2006. Transportation of goods and services to and from mines and projects in the NWT and

Nunavut (NU) is essential for industry success and growth, but represents a major challenge due to a lack of infrastructure in Canada's territories and the remoteness of many industrial properties. A 568 km long winter road, called the Tibbitt to Contwoyto Winter Road (TCWR), is the only ground transportation route that services major mines in the NWT, including the Ekati Diamond Mine (BHP Billiton Diamonds Inc.), Diavik Diamond Mines Inc. (Rio Tinto Group), the Snap Lake Mine (De Beers Canada Inc.), and the proposed Gahcho Kué Project (De Beers Canada Inc.). The road was first constructed in 1982 and since 1999 it has been licensed and operated by the Tibbitt to Contwoyto Winter Road Joint Venture (TCWRJV), a partnership currently between Echo BHP Billiton Diamonds Inc, Diavik Diamond Mines Inc. (Rio Tinto Group), and DeBeers Canada Inc. The TCWR is the world's longest heavy haul winter road and is critical to the economy of the NWT ($500 million of goods per year transported). Use of the winter road has increased substantially since its construction in the early 1980s, and an all-time maximum of 10,922 truck-loads traveled north on the route in 2007 (7,387 loads traveled north in 2008). The winter road is a significant component of the development of new diamond wealth in the NWT, and has allowed for the continued exploration for other commodities such as gold and base metals in the mineral-rich Slave Geological Province. The road has also serviced various outfitters located throughout the region.

Cold winter temperatures are critical to the viability of the TCWR as most of the road (495 km; 87%) is built over frozen lakes with only 73 km traversing 64 land portages between lakes. Changing ice stability, thickness, and duration of cover associated with recent climate variability can have dramatic impacts on the use of the road. For example, an unusually mild and stormy winter in 2006 associated with the El Niño/Southern Oscillation (ENSO) resulted in a substantially shortened winter road operation (26 days below average) and significant industry financial losses.

The Intergovernmental Panel on Climate Change Fourth Assessment Report (2007) reports that global average surface temperatures have increased by 0.6-0.8°C over the past century and some climate General Circulation Models predict that global temperatures will increase by as much as 3.6°C by the end of the 21st century. Meteorological data show that northern regions continue to warm at a rate twice as fast as the rest of the world (IPCC, 2001, 2007; ACIA, 2004) and climate models predict that the southern NWT will become 2-3°C warmer over the next 50 years (Schlesinger and Mitchell, 1987; ACIA, 2004). Historical data sets of ice cover in the Northern Hemisphere show that over the past 150 years, water bodies have frozen progressively later and ice breakup dates have occurred increasingly early (Magnuson et al., 2000). These trends are expected to continue in the future as global temperatures continue to rise. Based on studies of lakes in Scotland and northern Europe, a 3°C temperature increase could result in a decrease, by as much as 100 to 130 days, in annual ice cover duration (Burn and Hag Elnur, 2002; Thompson et al., 2005). If these scenarios become reality, climate-related changes in ice cover duration and stability might thus have a drastic impact on winter road transportation, and in turn, the industries of the NWT. High transportation costs for alternative routes (e.g. air) will have a major negative influence on the feasibility of any new mining operations, so it is critical for policy makers, planners and mine developers to understand how future climate variability will impact the TCWR.

The climate of the NWT has changed substantially and rapidly in the past, although instrumental records are sparse; systematic monitoring of temperature only began in the 1940s. This brief data set is inadequate for analyzing the characteristics of climate change on decadal and longer time scales. Therefore, a more complete understanding of medium and long-term climate oscillations and their correlation to short-term variations can only be achieved through the analysis of proxies of climate and environment preserved in the geological record.

Lake sediments contain continuous archives of recent and paleo- limnological conditions and are arguably the most complete records available of aquatic and terrestrial environments through time. The high quality paleoenvironmental data that can be derived from lacustrine environments explain why paleolimnological research has undergone a surge in interest and application through the last decade. Paleolimnology is now a multidisciplinary science that is playing a key role in many fields of environmental science, including baseline environment assessments (Smol, 2008).

Thecamoebians are benthic protists that are abundant in lacustrine habitats and have tests that fossilize well in Holocene sediments (Patterson et al., 1985). Research on this group has shown that they have great potential for paleolimnological and paleoecological study because they respond to changes in aquatic environments that can be linked to climate (e.g. lake trophic status, pH, temperature, and oxygen levels; Booth, 2001). Consequently, they have been successfully used in paleoclimate reconstructions throughout North America (e.g. McCarthy et al., 1995; Booth, 2001), including at high latitudes in Canada (Kliza and Schröeder-Adams, 1999; Dallimore et al., 2000). Recently, Roe et al. (in press) developed the first training sets utilizing lacustrine thecamoebians for lakes in southern Ontario.

Previous limnological and paleoecological research in the NWT has mainly focused on surface sediments, single indicators of past change, and has used a low spatial and temporal resolution (centennial-scale) (Figure 1; Pienitz et al., 1997; Rühland et al., 2003; Huang et al., 2004; Rühland and Smol, 2005). Exceptions include the recent work of MacDonald et al. (2009) at Lake S41 where a temporal resolution of 90 years (including dating error) was achieved and the comprehensive studies conducted at Queen's (MacDonald et al., 1993; Wolfe et al., 1996; Pienitz et al., 1999) and Toronto Lakes (Moser and MacDonald, 1990; MacDonald et al., 1993; Pienitz et al., 1999).

OBJECTIVES

The objectives of this preliminary study are to collect, date, and describe sediment cores from lakes along the southern portion of the TCWR that will be used for paleolimnological study. The cores will be sub-sampled at a fine resolution (mm scale) for microfossil analysis during the summer and fall of 2009. One graduate student has already been recruited to the project. Andrew Macumber, a Master's student at Carleton University, will analyze fossil thecamoebians (arcellaceans) under the supervision of Dr. R. Timothy Patterson. His study will represent the first analysis of fossil and modern assemblages of testate amoebae in the southern NWT and is only the second investigation involving thecamoebians, after Dallimore et al. (2000), to take place in the territory. We will attempt to develop a thecamoebian-based transfer function for the southern NWT by

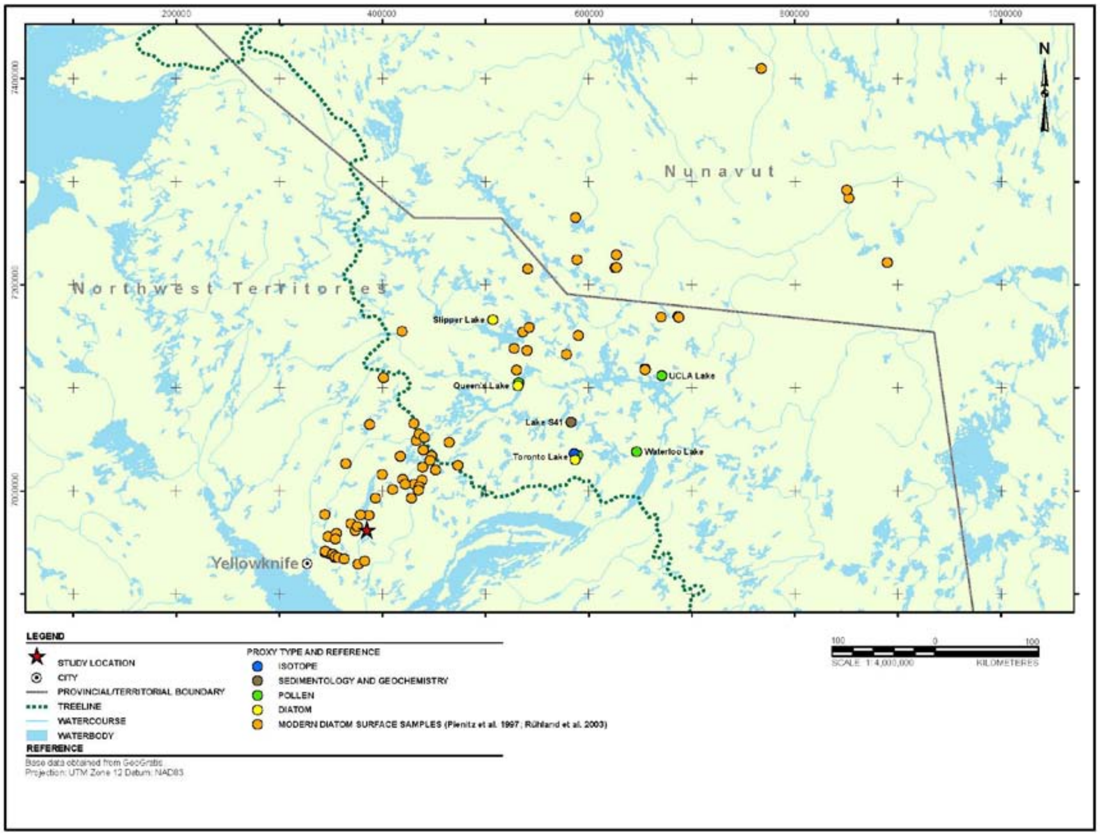

Figure 1: Map of the southern Northwest Territories showing the locations of previous paleolimnological and paleoclimatological research and the location of the study area. Orange circles denote surface diatom studies at informally named lakes (Pienitz et al., 1997; Rühland et al., 2003). The locations of Lake S41 (MacDonald et al., 2009), Queen's Lake (Moser and MacDonald, 1990; MacDonald et al., 1993; Pienitz et al., 1999), Slipper Lake (Rühland and Smol, 2005), Toronto Lake (MacDonald et al., 1993; Wolfe et al., 1996; Pienitz et al., 1999), and UCLA Lake (Huang et al., 2004) are shown.

analyzing extant communities in sediment-water interface samples from lakes located near Yellowknife (collected in July 2009) and from lakes spanning a latitudinal gradient from the southern to northern portions of the TCWR (to be collected in March 2010), then statistically relating community composition to measured environmental variables. If successful, the transfer function will be applied to the sediment cores collected from the TCWR to quantitatively reconstruct paleoclimate parameters.

STUDY SITE

The study area for this preliminary work is the southern portion of the TCWR (Figure 2). This region is located within the Taiga Shield Ecozone (Lands Directorate, 1986). West of Hudson Bay, this ecozone spans northern Manitoba and Saskatchewan, southern portions of NU, and the south central area of NWT. The climate of the study area is subarctic and continental, and is characterized by short summers and long, cold winters. Annual precipitation is low (175-200 mm) and mean daily January temperatures range

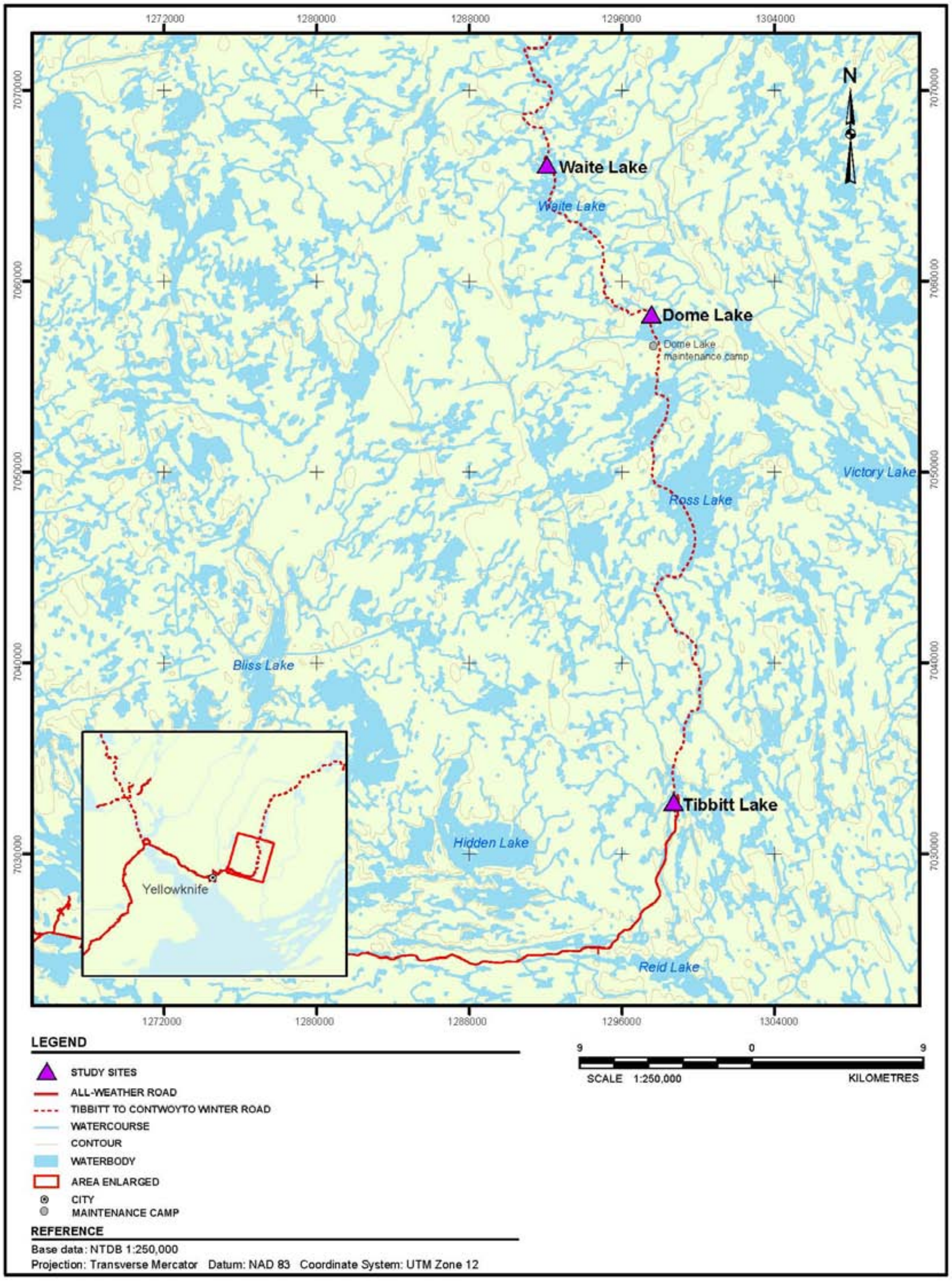

Figure 2: Map of the southern Northwest Territories showing the southern portion of the Tibbitt to Contwoyto Winter Road and the location of study lakes.

from -17.5ºC to -27.5ºC while mean daily July temperatures range from 7.5ºC to 17.5ºC. Boreal forests make up most of the groundcover of this ecozone and are dominated by coniferous stands of black spruce (*Picea mariana* (Mill.) BSP.) and white spruce (*Picea glauca* (Moench) Voss), along with tamarack (*Larix laricina* (Du Roi) K. Koch) and pine (*Pinus* L.). Deciduous trees including birch (*Betula* L.), trembling aspen (*Populus tremuloides* Michx.), alder (*Alnus* Mill.), and willow (*Salix* L.) grow in moist habitats. Along the northern limits of the ecozone, the boreal tree line is reached where forest stands are open and lichen woodlands merge into areas of shrub tundra. The vegetation surrounding the study lakes includes black spruce and white spruce with mixed deciduous species, including birch and willow. The presence of charred trees provides evidence for a recent fire.

METHODS

Freeze Coring

Lake selection

Numerous lakes were targeted for study based on the availability of sub-bottom seismic profiling and bathymetry data provided by the TCWRJV. Three lakes - Dome Lake, Waite Lake, and Tibbitt Lake - were selected based on anecdotal evidence provided by the staff of the Joint Venture Management Committee and the Dome Lake Maintenance Camp that suggested that these basins contained conformable sedimentary sequences (Figure 2). Descriptions of lakes provided by Dome Lake Maintenance Camp staff members included sediment substrate type, bathymetry, and whether ice froze to the bottom, thus disturbing the lakebed. Additionally, Waite Lake was selected because it was identified by the TCWRJV as being a problem lake for the operation of the TCWR. Small lakes, ponds, and bogs located adjacent to the TCWR were not targeted for coring for two reasons, despite their superior suitability for paleolimnological study: 1) the truck equipped with a rear-mounted auger of adequate width for freeze coring was unable to leave the TCWR; and 2) there is specific interest in how climate change may impact lakes currently traversed by winter road traffic. We anticipate collecting cores from multiple locations and selecting the most suitable cores based on sedimentology, chronology, and location for detailed study.

Coring location

Water depth of the coring location was a selection criterion established using a sounding line, a fish finder, and bathymetry data provided by the TCWRJV. We targeted relatively shallow sites (less than 8 m) to reduce the incidence of capturing sediments exposed to bottom water anoxia during summer temperature stratification of the water column. This criterion is especially important for the study of thecamoebians because these benthic organisms thrive in oxygenated conditions. Distance from shoreline was another selection criterion. We targeted sites that were more than 3 metres away from the shoreline to reduce shore effects (e.g. erosion) on thecamoebian assemblages.

Water quality characterization

Winter water quality characteristics (pH, dissolved oxygen, temperature) were recorded per metre depth at each core location using a YSI multi-metre probe. This type of data helps to characterize the limnology of the basin and can be used to develop quantitative transfer functions that link the distribution of biological organisms during the winter months to environmental variables.

Coring

A freeze corer with 12 cm wide faces was used to collect sediment cores (Swain, 1973). This method was chosen because sediments are disturbed less than coring with a gravity corer or a Livingstone corer that can displace sediments as it is lowered. With a freeze corer, sediments are frozen *in situ*. This is an advantage over other types of coring methods because the unconsolidated sediment-water interface is not disturbed by compaction during and after core collection. The freezing of sediments *in situ* also prevents disturbance to the stratigraphy because there is no release of dissolved gases resulting from pressure and temperature changes upon bringing sediment to the surface, a problem of open tube corers (Crusius and Anderson, 1991). This study represents the first time a freeze core has been collected in the southern NWT and the second known case of freeze coring in the territory (McAndrews, 1975).

The freeze corer is a 1.9 m rectangular box that has wood panels on three sides and an aluminum metal face on one side. The freeze core was filled with a slurry of dry ice (solidified carbon dioxide) and ethanol. The core was lowered at a steady pace (with the assistance of a coring frame equipped with a winch and wire attached to the core) onto the sediment-water interface. The core was then pushed with metal core rods into the sediment as far as it could go or to a calculated depth that would not overshoot the sediment-water interface. The freeze core was left *in situ* for 15-25 minutes to allow lake sediments to freeze to the metal face of the corer. d The corer was then pulled up and lain on the ice with the metal side up to allow sediments to continue freezing before transport to the Dome Lake Maintenance Camp. At the maintenance camp, the core was emptied of its internal contents of dry ice and ethanol and filled with hot water. Sediments were then gently chiseled off the corer. The 2-3 cm thick slabs of frozen lake sediments were labeled and secured to wooded slats with plastic shrink wrap and tape for transportation to Yellowknife.

Sedimentological description

The sediment cores were unwrapped in Yellowknife for sedimentological description. The upper surface (1 mm or less) of the cores was thawed using a hairdryer. The remainder of the sediment was kept frozen during this process because melting water from ice inclusions could distort sedimentary sequences. Sediment colour and grain size was determined using Munsell soil colour charts. Sediment cores were shipped frozen to

Carleton University on March 25th, 2009. Close interval sampling with a microtome device was completed during the fall of 2009 for the Waite Lake sediment core.

Radioisotope dating

Five bulk sediment samples were submitted for radiocarbon dating by atomic mass spectrometry to Beta Analytic Inc.

Development of a Thecamoebian-based Transfer Function

Transfer Function

A transfer function is a mathematical representation of the relationship between an input (e.g. temperature, dissolved oxygen, nutrients) and an output of a system (e.g. biological community composition). If the modern relationship between a biological community and an environmental variable or variables is statistically quantified, the information can be extrapolated quantitatively to infer past environmental conditions based on sub-fossil and fossil communities.

Lake and location selection for surface sediment sampling

Small lakes that could be accessed with a canoe from the Ingraham Trail, the all-weather gravel road east of Yellowknife, were targeted for surface sediment collection to develop the thecamoebian-based transfer function (Figures 1 and 2). Within targeted lakes, the following criteria were used to select suitable locations for sampling:

- Sampling in small bays was preferred because thecamoebians thrive in sheltered environments;
- Samples were collected at least 3 metres from the shore to reduce shore effects on community structure; and
- Samples were collected as far as possible from the road to reduce the effects of contaminant (e.g. dust) input from the road.

One to three sites within each lake were sampled to assess intra-lake variability of thecamoebian populations.

The sampling of lakes along the Ingraham Trail represents the development of an initial dataset that will be expanded to include the entire length of the TCWR.

Water quality measurements

Water quality parameters (dissolved oxygen, temperature, and conductivity) were measured at one metre intervals using a YSI multi-metre probe. Surface water pH was measured with a hand-held pH metre. All equipment was calibrated according to manufacturer's instructions. Ambient weather conditions (cloudiness, air temperature) were recorded for each day.

Surface sediment collection

The global position of the sampling location was recorded. Surface sediments were collected using an Ekman grab (a spring-loaded rectangular box that is lowered to the bottom of the lake where its mechanical jaws are triggered remotely with a weighted ‘messenger’). The top 5 cm of the Ekman grab sample were collected with a wooden spoon and placed into sterile containers for thecamoebian identification and enumeration; geochemical analysis of total phosphorus, total nitrate and nitrite; and total trace metals by inductively coupled plasma mass spectrometry. All samples were stored at 4 °C and geochemical samples were shipped cold within 5 days of collection to Caduceon Environmental Laboratories in Ottawa.

RESULTS

Sediment Cores

Metadata associated with sediment cores

Three continuous sediment cores were retrieved from lakes along the Tibbitt to Contwoyto Winter Road (Table 1).

The sediment-water interface, which can be unconsolidated in northern lakes, was successfully captured at Tibbitt and Dome Lakes. The sediments at Waite Lake were exceptionally unconsolidated and the sediment-water interface was not captured. Depth sounding and subsequent over-penetration of the core (indicated by the expulsion of sediment-laden water from the top of exposed core rods) revealed that the depth determined by bathymetry data and a sounding line was an overestimate. However, we do believe we retrieved sediments near the interface because the upper sediments of core ROAD09-WAITE01-A appear to have particles suspended in ice.

Water Quality Data

Water quality data was collected at each coring location (Table 2).

Sedimentological Description

Cores were described sedimentologically, following Schnurrenberger et al. (2003) (Table 3).

Table 1: Core site and sediment core information

Lake	Date cored	UTM	Elevation above mean sea level (m)	Depth at core site (m)	Core name	Core length (m)
Dome Lake	March 19th, 2009	12V 0384603, 6962007	Not recorded	1.74	ROAD09-DOME01	0.76
Tibbitt Lake	March 21st, 2009	12V 0378690, 6937301	225	6.72	ROAD09-TIBBITT01	1.285
Waite Lake	March 22nd, 2009	12V 0381526, 6970997	296	1.80	ROAD09-WAITE01	2.055

Notes: m – metres

Table 2: Water quality associated with each coring location

Lake	Depth (m)	Temperature (°C)	Dissolved Oxygen		pH	pH mV	Conductivity (µS/cm)
			%	mg/L			
Dome Lake	0.23	0.63	60.9	8.56	6.12	75.4	46
	1.04	0.71	43.8	6.26	6.10	71.8	40
	1.74	1.33	25.4	3.6	6.31	65.2	38
Tibbitt Lake	0.15	0.00	110.5	16.03	7.14	22.4	-
	1.01	0.01	101.9	14.85	7.17	21.0	-
	2.31	0.02	96.1	14.01	7.19	20.0	-
	3.18	0.02	92.5	13.50	7.20	19.2	-
	4.24	0.02	89.1	13.00	7.24	17.0	-
	5.27	0.02	86.0	12.55	7.28	14.9	-
	6.36	0.02	84.1	12.28	7.30	14.1	-
	6.72	0.02	82.9	12.11	7.28	15.1	-
Waite Lake	0.09	0.07	127.2	18.47	7.40	9.2	80
	1.4	0.07	119.4	17.34	7.39	9.7	82
	1.8	0.07	114.6	16.61	7.38	9.9	83

Notes: m – metres; °C – degrees Celsius; % - percent; mg – milligrams; L – litres; µS – microsiemens; cm – centimetres ; mV – millivolts; - conductivity port on probe had a film of ice over it and could not read

Table 3: Sedimentological description of the lake sediment cores

Core	Section	Length (cm)	Grain size	Conclusions (Munsell code)
ROAD09-DOME01	A	27	Mud	Very dark grey (7.5 yr 3/1) massive mud with organic debris
	B	49	Mud	Very dark grey (7.5 yr 3/1) massive mud with organic debris. Indistinct transition to very dark grayish brown (10 yr 3/2) at 34 cm with less organic debris
ROAD09-TIBBITT-01	A	88	Mud	Black (7.5 yr 2.5/1) massive mud with dark red (2.5 yr 3/4) particles. Diffuse transition to very dark grey (7.5 yr 3/1) massive mud at 2.5 cm
	B	55.5	Mud	Very dark grey (7.5 yr 3/1) massive mud. Indistinct transition to very dark grayish brown (10 yr 3/2) massive mud at 27 cm
ROAD09-WAITE01	A	73	Mud	Very dark grayish brown (10 yr 3.2) massive mud
	B	89	Mud	Very dark grayish brown (10 yr 3.2) massive mud. Indistinct transition to very dark brown (10 yr 2/2) massive mud at 60 cm
	C	43	Mud	Very dark brown (7.5 yr 2.5/3) massive mud

Notes: cm – centimeters

ROAD09-DOME01 (Figure 3):

Core ROAD09-DOME01 was retrieved in two sections: ROAD09-DOME01-A and ROAD09-DOME01-B. ROAD09-DOME01-A is 27 cm in length and has an ice lens that occupies the upper 6 cm of the core. The sediment collected in the upper 11 cm of the core is approximately 4 cm thick. Between 11 cm and the base of the section at 27 cm, the thickness of the core is approximately 8 cm. Organic debris, including grasses, sticks, and leaves, is abundant on the surface of the core. The grain size of ROAD09-DOME01-A is mud.

Overall, ROAD09-DOME01-A is described as: very dark grey (7.5 yr 3/1) massive mud with organic debris.

ROAD09-DOME01-B is a continuation of ROAD09-DOME01-A and is 49 cm in length. The core is 8 cm thick. Organic debris is present but in less abundance than section A. Of note is a 12 cm long leafy plant fragment between 0-12 cm. The grain size of ROAD09-DOME01-B is mud.

Overall, ROAD09-DOME01-B is described as: very dark grey (7.5 yr 3/1) massive mud with organic debris. An indistinct transition to very dark greyish brown (10 yr 3.2) occurs at 34 cm. Less organic debris is present after 34 cm.

Anecdotal evidence, primarily from Martin Janssen, suggested that core ROAD09-DOME01 may not be a conformable sedimentary sequence. Mr. Janssen, who has worked in the area for 20 years, described a recent shoreline transgression near the coring site and postulated that an under-ice wave caused by loaded northbound trucks may have pushed sediment toward the north end of the lake where it is piling up. An apparent shoreline transgression could also be due to receding water levels. The abundance of

Figure 3: Core ROAD09-DOME01-B has abundant macrofossils.

organic matter in the upper portions of core ROAD09-DOME01 and the transition to less organic debris down-core may indicate redeposition of sediment or frequent disturbance of upper sediments. This core is therefore not recommended for detailed stratigraphic study but is appropriate for a top-bottom study design.

ROAD09-TIBBITT01 (Figure 4):

Core ROAD09-TIBBITT01 was retrieved in two sections: ROAD09-TIBBITT01-A and ROAD09-TIBBITT01-B. ROAD09-TIBBITT01-A is 88 cm in length, and its thickness is ~2 cm. The grain size is mud. There is a colour change at 2.5 cm of the core. The upper 2.5 cm are interpreted to represent the unconsolidated sediment-water interface.

Overall, ROAD09-TIBBITT01-A is described as: black (7.5 yr 2.5/1) massive mud with dark red (2.5 yr 3/4) particles contained in the upper 2.5 cm of the core. A diffuse transition to very dark grey (7.5 yr 3/1) mud occurs at 2.5 cm.

ROAD09-TIBBITT01-B is 55.5 cm in length. This section of the core is about 2 cm thick. The grain size is mud.

Overall, ROAD09-TIBBITT01-B is described as: very dark grey (7.5 yr 3/1) massive mud. An indistinct transition to very dark greyish brown (10 yr 3/2) occurs at 27 cm.

Figure 4: Core ROAD09-TIBBITT01-A has a distinct transition in colour from black (7.5 yr 2.5/1) with dark red (2.5 yr 3/4) particles to very dark grey (7.5 yr 3/1) mud at 2.5 cm. This transition is interpreted to represent the transition from the unconsolidated sediments of the sediment-water interface to more consolidated underlying sediments.

ROAD09-WAITE01 (Figures 5a and 5b):

Core ROAD09-WAITE01 was retrieved in three sections: ROAD09-WAITE01-A, ROAD09-WAITE01-B, and ROAD09-WAITE01-C. ROAD09-WAITE01-A is 73 cm in length. The core is about 2 cm thick with a 0.5 cm thick ice layer under the sediments. The grain size is mud.

Overall, ROAD09-WAITE01-A is described as: very dark greyish brown (10 yr 3/2) massive mud.

ROAD09-WAITE01-B is 89.5 cm long. The core is about 2 cm thick with a 0.5 cm thick ice layer under the sediments. The grain size is mud.

Overall, ROAD09-WAITE01-B is described as: very dark greyish brown (10 yr 3/2) massive mud. An indistinct transition to very dark brown (10 yr 2/2) massive mud occurs at 60 cm.

ROAD09-WAITE-C is 43 cm long. The core is about 2 cm thick with a 0.5 cm thick ice layer under the sediments. The grain size is mud.

Overall, ROAD09-WAITE01-C is described as: Very dark brown (7.5 yr/2) massive mud.

Figure 5a: Core ROAD09-WAITE01-B. Note the frothy texture of upper (to the right of the photograph) sediments.

Figure 5b: Core ROAD09-WAITE01-C in cross section. Note the layer of ice underlying the sediments.

Radioisotope dating

Five sediment sub-samples were collected from two cores on March 23rd, 2009 (Table 4) and submitted to Beta Analytic Inc. for AMS radiocarbon dating. Four samples were taken from cores ROAD09-WAITE01-A,B, and C at regular intervals, including from the base of the core. One sample was taken from core ROAD09-TIBBITT01-C. Bulk sediment samples were selected from these cores due to a paucity of macrofossils. It is not expected that hardwater effects will contaminate bulk sediment samples due to the igneous and metamorphic geology of the basins of Waite and Tibbitt Lakes. No samples were submitted for radiocarbon dating from core ROAD09-DOME01 because thawing of the exceptionally thick sediment package retrieved from Dome Lake may have caused disruption of the stratigraphy. In addition, this core was not targeted for detailed study.

An age-depth model was generated for Waite Lake using calibrated radiocarbon ages (Figure 6). Calibrated ages remove the ‘wiggle’ in radiocarbon chronologies produced form variable ^{14}C production through time.

The x-intercept of the age-depth model suggests that the upper ~300 years of sedimentation were not retrieved. The slope of the line reconstructs an average sedimentation rate of ~0.06 cm/year and the high r^2 value suggests that sedimentation rates have not changed substantially in the past ca. 4000 years of deposition. The sedimentation rate reconstructed for Waite Lake is relatively high for a northern basin. For comparison, the sedimentation rate at Lake S41, located just south of Aylmer Lake, averaged 0.012 cm/year over the past ca. 2850 years (MacDonald et al., 2009).

Surface Sediment Sampling for the Development of a Thecamoebian-based Transfer Function

Fifty surface sediment samples were collected from nineteen lakes near Yellowknife for thecamoebian and geochemical analyses. Study sites ranged from N 62º33.124 to N 62º28.007 in latitude and from W 113º21.522 to W 114º43.603 in longitude. Field information and water quality measurements are presented in Table 5 and Table 6, respectively. All lakes were near neutral in pH, ranging from 6.55 to 8.65. Qualitative water clarity ranged from very good to very poor. Lake depth at the sampling site ranged from 2 m to less than 0.3 m. Few lakes appeared to be thermally stratified and surface water temperatures ranged from 15 ˚C to 22.7 ˚C.

CONCLUSIONS

Three sediment cores were collected in March 2009 from the Tibbitt to Contwoyto Winter Road with a freeze corer. The corer successfully captured the unconsolidated sediment-water interface at Tibbitt Lake. This interface was over-penetrated at Waite Lake but coring at this site did retrieve what appeared to be unconsolidated sediments. Sediment cores were sedimentologically described and radiocarbon dated. The chronology for Waite Lake indicates that lakes in the southern portions of the Tibbitt to Contwoyto Winter Road have sedimentation rates that are sufficiently high to achieve a decadal to subdecadal reconstruction of paleoclimate.

Table 4: Radiocarbon dates from Waite and Dome Lake sediments

Lake	Sample (and Lab Number)	Absolute core depth (cm)	$^{12}C/^{13}C$ ratio (‰)	Conventional ^{14}C age (yr BP)	Calibrated age 95% CI (cal. yr BP)[a]	Median calibrated age (cal. yr BP)
Waite	ROAD09-WAITE01-A 65-67.5 cm	65-67.5	-18.6	1520 ± 40	1333-1520	1426.5 ± 93.5
Waite	ROAD09-WAITE01-B 79-81 cm	152-154	-18.3	2580 ± 40	2691-2769	2730 ± 39
Waite	ROAD09-WAITE01-C 22-23 cm	184.5-185.5	-18	2920 ± 40	2955-3210	3082.5 ± 127.5
Waite	ROAD09-WAITE01-C 43-43.75 cm	204.75-205.5	-17.2	3460 ± 40	3633-3838	3735.5 ± 102.5
Tibbitt	ROAD09-TIBBITT01-A 55-55.5 cm	55-55.5	-22.6	2390 ± 40	2338-2503	2420.5 ± 82.5

Notes: cm – centimeters; ‰ – parts per thousand; CI – confidence interval; $^{12}C/^{13}C$ ratio provides information on the source of carbon; yr BP – years before the 1950 standard; cal. yr BP – calendar years before present; a – calibrated using the INTCAL04 dataset (Reimer et al., 2004) and the CALIB 5.0.2 computer program (Stuiver et al., 2005).

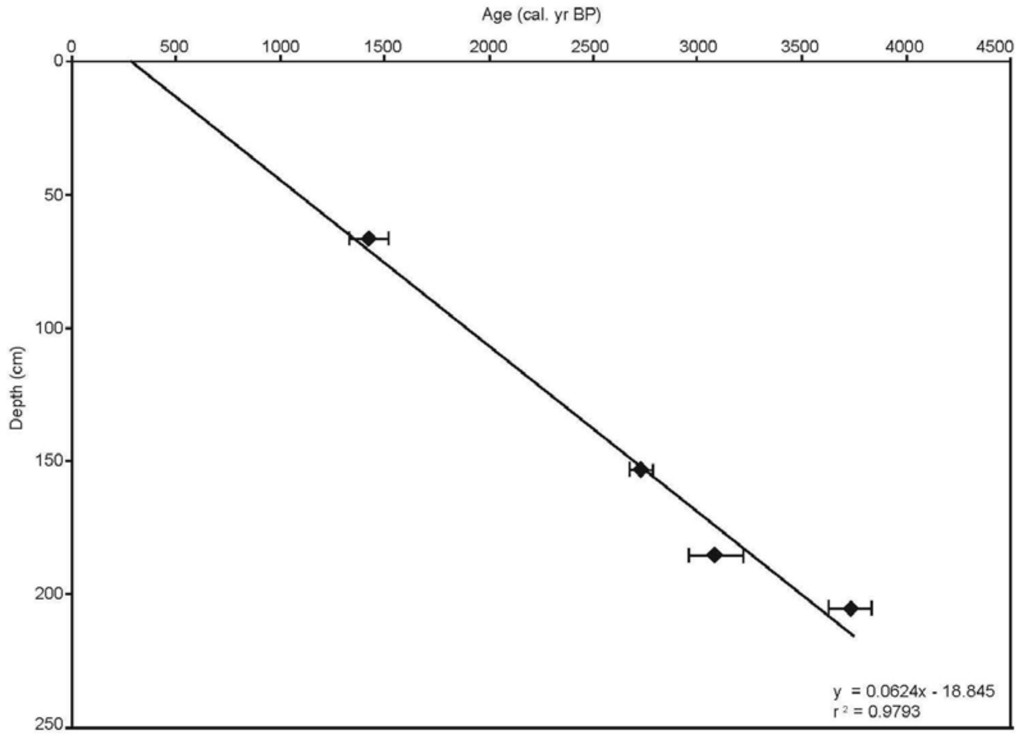

Figure 6: Age-depth model for core ROAD09-WAITE01 based on the linear regression of median calibrated radiocarbon dates against sediment depth (cm – centimeters, cal. yr BP – calibrated radiocarbon years before present; error bars represent 95% confidence intervals). The age-depth model is not forced through zero and suggests that the upper ~300 years of deposition was not retrieved.

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