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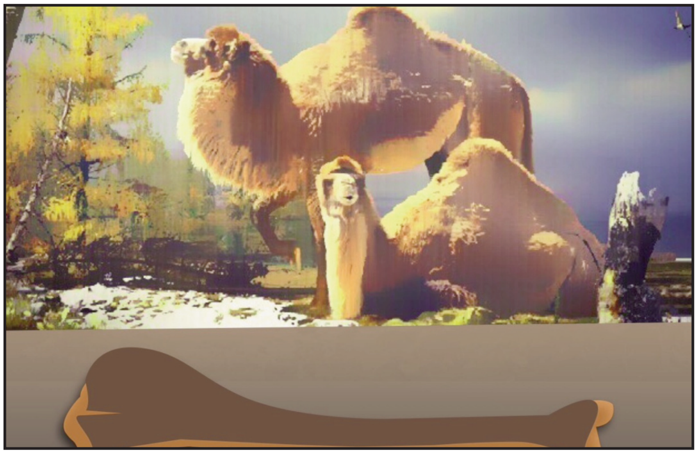

PoLAR-FIT: Pliocene Landscapes and Arctic Remains—Frozen in Time

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SUMMARY

This short summary presents selected results of an ongoing investigation into the feedbacks that contribute to amplified Arctic warming. The consequences of warming for Arctic biodiversity and landscape response to global warmth are currently being interpreted. Arctic North American records of large-scale landscape and paleoenvironmental change during the Pliocene are exquisitely preserved and locked in permafrost, providing an opportunity for paleoenvironmental and faunal reconstruction with unprecedented quality and resolution. During a period of mean global temperatures only ~2.5°C above modern, the Pliocene molecular, isotopic, tree-ring, paleofaunal, and paleofloral records indicate that the High Arctic mean annual temperature was 11–19°C above modern values, pointing to a much shallower latitudinal temperature gradient than exists today. It appears that the intense Neogene warming caused thawing and weathering to liberate sediment and create a continuous and thick (>2.5 km in places) clastic wedge, from at least Banks Island to Meighen Island, to form a coastal plain that provided a highway for camels and other mammals to migrate and evolve in the High Arctic. In this summary, we highlight the opportunities that exist for research on these and related topics with the *PoLAR-FIT* community.

RÉSUMÉ

Ce bref résumé présente les résultats choisis d'une enquête en cours sur les déclencheurs qui contribuent à l'amplification du réchauffement de l'Arctique. Les conséquences du réchauffement sur la biodiversité arctique et de la réponse du paysage au réchauffement climatique sont en cours d'être interprété. Des dossiers nord-américains de paysage à grande échelle et le changement paléoenvironnementales durant le Pliocène sont exceptionnellement préservés et scellées dans un état de congélation qui fournissant une occasion pour la reconstruction paléoenvironnementale et faunistique avec une qualité et une résolution sans précédent. Pendent une période de réchauffement global seulement ~2,5°C au-dessus de moderne les dossiers, moléculaire, isotopique, annaux de croissance, paléofaunistique et paléovégétation indiquent que l'Arctique a connu une augmentation de la température annuelle moyenne de 11–19°C au-dessus de moderne, en montrant un inferieur gradient de température latitudinal qu'aujourd'hui. Il semble que le réchauffement intense pendent le Néogène a provoqué la décongélation et erosion pour libérer les sédiments et créer une plaine côtière continuel et épaisse (> 2,5 km dans lieux) qui a fourni une route pour les chameaux et autres mam-

Geoscience Canada, v. 44, https://doi.org/10.12789/geocanj.2017.44.116 pages 47–54

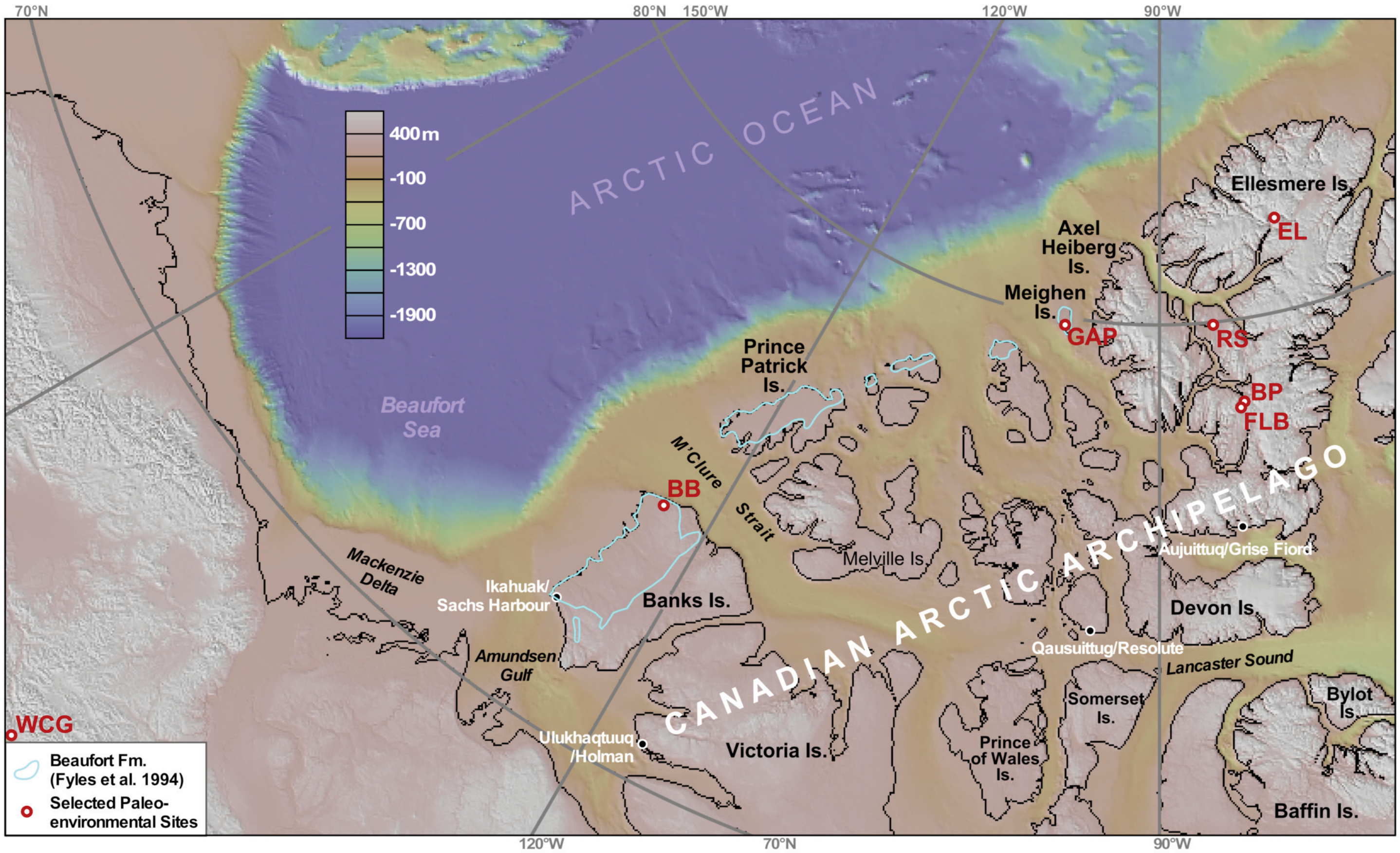

Figure 1. Map of Arctic North America with geographic features described in the text. Previous '*Pliocene Landscape and Arctic Remains—Frozen In Time*', (*PoLAR-FIT*) sites include: BP –Beaver Pond, BB –Ballast Brook, EL –Ekblaw Lake, FLB –Fyles Leaf Bed, GAP –'The Gap' on Meighen Island, RS –Remus Section, WCG –White Channel Gravel in the Klondike District, Yukon. The blue outline represents the modern onshore distribution of Beaufort Formation (Fyles et al. 1994). The original Beaufort Formation has been interpreted by others to have formed a continuous Arctic Coastal Plain from Banks Island to Meighen Island, and possibly from the Mackenzie Delta to beyond Axel Heiberg Island. North Polar Projection DEM constructed with GEOMAPAPP v 3.6.4 using International Bathymetric Chart of the Arctic Ocean v 3, 30 arc-second resolution.

mifères pour migrer et évoluer dans l'Haut-Arctique. Dans ce résumé, nous soulignons les opportunités qui existent pour la recherche sur ces sujets et les sujets connexes avec la communauté *PoLAR-FIT*.

INTRODUCTION

Today's thawing of permanently frozen Pliocene clastic sediments and organic layers in Arctic Canada and Alaska (Fig. 1) provides access to exquisitely preserved, sub-fossilized floral, faunal, molecular, and isotopic records. These records document amplification of temperature change in polar regions (e.g. Ballantyne et al. 2013) during periods of global warmth on the magnitude predicted for our next century (Masson-Delmotte et al. 2013). The Pliocene sediments exposed onshore, including the Beaufort Formation, span a variety of depositional environments (marine, lacustrine, paludal, alluvial, fluvial, and possibly glacial) over a wide temporal range (ca. 3.8 to 2.6 Ma; see later discussion of Geochronology), including varves and possible annual couplets of sand and leaf layers spanning a millennium. Until recently (e.g. Feng et al. 2017) numerical models of Pliocene climate were unable to reproduce the high paleo-temperatures in the High Arctic while reliably replicating low-latitude temperature proxies (Salzmann et al. 2013). The collective record suggests that there may be feedbacks that are not adequately represented by the models. Temperature, humidity, CO_2, and continentality may be controlled by factors such as different forest types and densities, sea-ice cover, the effects of forest fires, and the possibility that ocean circulation through the High Arctic was limited until the Beaufort Formation was incised and the Northwest Passages were opened. Despite the discovery of well-preserved wood by explorers on Banks Island 150 years ago (Heer 1868), the paleoenvironmental and paleoclimate research is still in its infancy and the biochronostratigraphy is too imprecise to test synchroneity and reconcile the disparities among the sites. Furthermore, accelerated processes such as retrogressive thaw slumping is rapidly removing or exposing previously entombed sedimentary, macrofossil, and biochemical records before they can be examined within their stratigraphic context.

To tackle these challenges, an international multidisciplinary team has assembled with the shared objective of studying these systems in an integrated way. The represented disciplines include paleoclimatology, geomorphology, geochronology, biogeochemistry, dendroclimatology, floral and faunal paleontology, evolutionary biology, and landscape ecology. Members of the '*Pliocene Landscape and Arctic Remains—Frozen In Time*', or *PoLAR-FIT* working group span from early-career to senior scientists, some of whom have worked on the Pliocene records over the past four decades (Table 1 lists the founding members, but we hope that others will join).

The initial goals of *PoLAR-FIT* are to maximize synergy, minimize the prohibitive costs of fieldwork in the Arctic, and expedite progress toward common research objectives that will have the immediate and broadest impact on the global community. This article provides a short review and outline of past and planned *PoLAR-FIT* research and highlights the many opportunities for other scientists to contribute and join.

Table 1. Founding *PoLAR-FIT* members.

Ballantyne, A.	University of Montana
Barendregt, R.	Lethbridge University
Barker, J.	Byrd Polar and Climate Research Centre
Braschi, L.	Dalhousie University
Brigham-Grette, J.	University of Massachusetts
Csank, A.	University Nevada, Reno
Fletcher, T.	University of Montana
Fortier, D.	University of Montreal
Froese, D.	University of Alberta
Gilbert, M.	Canadian Museum of Nature
Gosse, J.	Dalhousie University
Grant, G.	Byrd Polar and Climate Research Centre
Greenwood, D.	Brandon University
Harington, C.R.	Canadian Museum of Nature (Emeritus)
Lakeman, T.	Norwegian Geological Survey
Manion, P.	Dalhousie University
Matthews, J.	Geological Survey of Canada (Retired)
McPhee, R.	American Museum of Natural History
Rybczynski, N.	Canadian Museum of Nature; Carleton University
Smith, R.	University of Calgary
Telka, A.	Paleotec Services
West, C.	University of Saskatchewan
Zazula, G.	Yukon Geological Survey

PROGRESS IN PLIOCENE ARCTIC PALEO-ENVIRONMENTAL RESEARCH

The Floral Record

The Pliocene Arctic and sub-Arctic were characterized by both a more northerly position of the tree line compared to today (e.g. the limit was ~80°N on Meighen Island, compared to ~69–61°N in the western Arctic or 56°N in Labrador [e.g. Tozer and Thorsteinsson 1964; Hills 1975; Matthews 1987; Fyles et al. 1991]) and, consequently, a broader latitudinal extent of the Boreal zone. Based on pollen and plant macrofossils a flora more diverse than a modern boreal forest was found for the Pliocene units, including 80–90 species of nonvascular plants and 90 different species of vascular plants. The taxonomic and comparative studies of these flora represent a substantial legacy inherited by the group (e.g. Matthews and Ovenden 1990; Matthews and Fyles 2000; Fletcher et al. 2017). Included in this list are 12 different tree taxa identified from leaves or reproductive parts including, larch (*Larix*), birch (*Betula*), spruce (*Picea*), hemlock (*Tsuga*), pine (*Pinus*), alder (*Alnus*), poplar (*Populus*), and fir (*Abies*) (e.g. Matthews and Ovenden 1990; Ballantyne et al. 2010). Wood found in many of the fossil forest sites has been identified as larch (*Larix*), spruce (*Picea*), pine (*Pinus*) and birch (*Betula*) (e.g. Matthews and Ovenden 1990; Csank et al. 2011a). Based on plant abundances Matthews and Ovenden (1990) concluded that the flora is closely similar to modern Asian forests rather than to a typical North American boreal forest, and more recent workers support this conclusion (Ballantyne et al. 2010; Csank et al. 2011a). Elements of modern-character tundra communities were also already in place both within boreal communities, and potentially at higher latitudes (Matthews and Ovenden 1990; Matthews and Fyles 2000). The woody elements of the flora are conspicuously well preserved in some areas (Devaney 1991; Davies et al. 2013) (Fig. 2) and present a rare but significant opportunity to construct overlapping annual sequences with tree ring records (e.g. Csank et al. 2013). Extensive peat deposits (Mitchell et al. 2016) record long, environmentally sensitive floral sequences from pollen, seeds, needles, cones, leaves (Fig. 3), flowers, and mosses. The flora can often be identified to modern genera and in some cases species, permitting precise climate and vegetation reconstructions (e.g. Ballantyne et al. 2010). In addition, these same deposits preserve faunal remains ranging from terrestrial (e.g. beetles) and aquatic invertebrates (e.g. Fyles et al. 1991; Elias and Matthews 2002) to the vertebrate inhabitants of these Arctic forests (e.g. Rybczynski et al. 2013).

Vertebrate Paleontology

Currently, the record of Pliocene vertebrates from the High Arctic is known almost entirely from sites on Ellesmere Island, notably the Beaver Pond site (Fig. 1) near the head of Strathcona Fiord. Elsewhere, isolated bone fragments of possible Pliocene age have been found on Banks Island (by the co-authors in 2013) and Meighen Island (by the co-authors in 2010) but remain under investigation (Fig. 1). Decades of field excavations from Beaver Pond have yielded a boreal forest community with no modern analogue. The assemblage is more diverse than modern treeline communities and includes fossil bear, horse, deerlet, rabbit, various small carnivores, shrew, beaver, fish, scaup duck and frog (Tedford and Harington 2003; Mitchell et al. 2016). Many fossils from the site represent new taxa, including the fish (*Sander teneri*), badger (*Arctomeles sotnikovae*), shrew (*Arctisorex polaris*), and deerlet (*Boreameryx braskerudi*) (Hutchison and Harington 2002; Tedford and Harington 2003; Dawson and Harington 2007; Murray et al. 2009). The deerlet is notable because it appears to be derived from an early branch of the deer lineage; however, its dentition is highly specialized, suggesting high latitude endemism.

Owing to the geographical remoteness of Ellesmere Island (Fig. 1) and its Pliocene fossils, the closest fossil communities of similar age available for comparisons are in Northeastern China and Idaho. Most taxa, such as the badger and horse (*Plesiohipparion*) show closest affinities to Pliocene fossil vertebrates of the Yushe Basin, China, whereas the rabbit (*Hypolagus*) and dog (*Eucyon*) represent lineages that originated in

https://doi.org/10.12789/geocanj.2017.44.116

Figure 2. A sub-fossil stick, long held in permafrost, exposes at its end the characteristic cut-marks made by the lower front teeth of the Pliocene beaver *Dipoides sp.* (photo credit: M. Lipman).

Figure 3. An ancient leaf protrudes from the slope where the enclosing sands have eroded as the permafrost face thaws (photo credit: M. Lipman).

North America. The Beaver Pond bear represents a species ("*Ursus" abstrusus*) also collected in Idaho, although the lineage originates in Eurasia (Tedford and Harington 2003). In recent years, fragments of fossil bone (Fig. 4) collected from the nearby Fyles Leaf Bed site belong to a giant camel, possibly *Paracamelus*, of North American lineage (Rybczynski et al. 2013) (Fig. 5). Significantly, taxonomic identification of the bone fragments as camel was aided by collagen fingerprinting. The discovery that these ~3.5 Ma fossils preserve collagen, a structural protein that makes up about 80% of the organic fraction of mammal bones is remarkable, providing a foundation for future ecological and taxonomic investigations.

Sedimentary Records of Landscape Responses to Climate Change

The Pliocene records described above were recovered from onshore exposures of the Beaufort Formation (from Banks

Figure 4. Fossil remains of an Arctic giant camel – lateral view of right tibia specimen (NUFV 210), from Fyles Leaf Bed (FLB) site, Strathcona Fiord (Ellesmere Island), shown within the tibia of a modern camel (*Camelus dromedaries*, ROM MAM 94191). The modern *Camelus* tibia has been scaled up 30% to match the size of the fossil tibia. Scale bar, 10 cm. (From Rybczynski et al. 2013: figure 3).

Figure 5. Mid-Pliocene camels prepare for the long dark winter along a shallow river channel in a beaver-cut larch and birch-dominated taiga forest, 100 km southeast of what is now the Eureka weather station, Ellesmere Island (digital image, J. Csotonyi).

Island to Meighen Island) or correlative deposits (e.g. on Ellesmere Island). Previous and ongoing efforts have focused on characterizing the depositional environments that contain the organic remains. The Beaufort Formation was originally described by Tozer (1956) but most recently defined by Fyles et al. (1994) as outcrops along the western Canadian Arctic Archipelago (Fig. 1). The Beaufort Formation formed the Arctic Coastal Plain (e.g. Devaney 1991) which is the uppermost unit of the Arctic Continental Terrace Wedge (Trettin 1989). The braided-stream deposit extends into a thick (up to 3 km) clastic wedge offshore. The marine extension of the clastic wedge is the Iperk Formation and estuarine sediments are recognized onshore in the Beaufort Formation (England 1987; Fyles 1990; McNeil et al. 2001). Fyles et al. (1994) and others before documented sites at other locations, such as high terraces and alluvial fans throughout Ellesmere Island, which have a similar age and faunal and floral record, but a different depositional environment from the braided stream coastal plain Beaufort Formation sediments. The various depositional environments inform the paleoenvironmental reconstruction and the sedimentary architectural elements provide a sense of duration at single exposures. For instance, at the base of the Fyles Leaf Bed section (Fig. 1), varved lake sediments containing dropstones underlie hundreds of rhythmic beds of sand–leaf layer couplets interpreted to represent shallow overbank and crevasse splay deposits adjacent to a distributary sandy braided-stream system. The possible annularity of those beds is being investigated and could potentially be exploited to reveal the frequency of forest fires and other climatogenic events. Cross-bedded woody detritus (Davies et al. 2013) is an example of a sedimentary structure apparently unique to a Pliocene forested fluvial environment with long dark and subzero winters. The emerging chronostratigraphy seems to indicate that much of the Beaufort Formation, and perhaps regional correlatives (e.g. parts of the offshore Iperk Formation, the White Channel Gravel in Yukon (Fig. 1), and various high terraces and alluvial fans on Axel Heiberg and Ellesmere Islands), were deposited over a very short time period between about 3.8 to 2.6 Ma, spanning the Pliocene–Pleistocene climate transition.

If the mapped units of Beaufort Formation on each western island of the archipelago were part of a continuous coastal plain, then the Northwest Passages (e.g. M'Clure Strait, Fig. 1) may not have existed in the Pliocene. The absence of the Northwest Passages prior to the Quaternary has been considered since Tozer (1956) but not proven. However, ongoing research to evaluate the regional lithospheric flexural response to their excavation reveals that the topography of the islands is consistent with post-Beaufort Formation (i.e. Quaternary) excavation (Manion 2017). The subsequent drop in relative sea level with Pleistocene cooling likely caused fluvial incision initially, followed by glacial deepening under the Innuitian and Laurentide Ice Sheets. It also appears that lithospheric flexure by loading of the Neogene clastic wedge may have partly controlled the ribbon-like distribution of the mapped Beaufort Formation by providing accommodation space with (albeit low amplitude) flexural bulge parallel but inland of the western coast line (Manion 2017). Acquisition and interpretation of high resolution seismic reflection data throughout the Northwest Passages is needed to fully address the timing and evolution of the Northwest Passages.

We now are attempting to quantify the rates of sedimentation throughout the Beaufort Formation and correlative units such as the White Channel Gravel of the Klondike Gold District. Abundances of cosmogenic nuclides in quartz grains reflect duration of their exposure to cosmic radiation, decay duration during burial, and erosion rate of the exposed surface. In every sample, hundreds of thousands of quartz sand grains record the erosion rate from different locations throughout a Pliocene catchment and allow us to evaluate the spatial and temporal variability in catchment average paleoerosion rates. The results allow us to test landscape responses to climate change, such as the possibility that weathering before and during the mid-Pliocene warm period may have provided an easily accessed source of quartz-rich sand to form the Beaufort Formation clastic wedge (up to 3 km thick in places) during the Pliocene-Pleistocene transition.

Paleoclimate Indices

There is broad interest in the Pliocene as a deep-time laboratory for understanding near-future climate. The ages of the localities studied by this workgroup span 3.8–2.6 Ma covering a large portion of the Pliocene. These sediments would have recorded paleoclimate during the warm periods of the Pliocene, and the transition into cooler climates involving large-scale Northern Hemisphere glaciation. Overlain on this trend are damped periodicities which have been detected and are linked to obliquity and processional cycles (e.g. Draut et al. 2003) and variability in atmospheric CO_2 (Seki et al. 2010; Pagani et al. 2010; Martínez-Botí et al. 2015). Nested within the broader period considered by *PoLAR-FIT*, the mid-Pliocene warm period (*mPWP*; 3.29–2.97 Ma), has received the greatest attention in the literature as the time slice for the long-running Pliocene Research Interpretation and Synoptic Mapping (PRISM) project. The *mPWP* was defined on the basis of a recognizably high global temperature and the convenience of magnetostratigraphic boundaries (Haywood et al. 2009). Shorter time slices (e.g. 3.264–3.025 Ma) provide foci for the other studies (e.g. Pliocene Model Intercomparison Projects (PlioMIP), Haywood et al. 2009). The time recorded at our terrestrial localities is much broader, as are our uncertainties (see Geochronology) and thus precise correlation with the *mPWP* is not yet possible. Improving the precision and quantity of terrestrial observations of climate is currently a critical goal for providing data against which climate models may be verified.

The high-quality preservation of multiple proxies available from the sites currently investigated by *PoLAR-FIT* allows for the simultaneous reconstruction of paleoclimate and paleoenvironment from a single site. For example, we can determine atmospheric CO_2, air temperature, and water temperature all at the same locality. Terrestrial climate proxies used at the High Arctic sites so far include mutual range methods on the beetle fauna (Elias and Matthews 2002) and flora (Ballantyne et al. 2010), dendroclimatologic and isotopic approaches using tree rings (Ballantyne et al. 2006, 2010; Csank et al. 2011a), 'clumped isotopes' (i.e. using molecules of similar chemical composition but different isotopic composition) analysis of freshwater molluscs (Csank et al. 2011b), and bacterial tetraether analysis (Ballantyne et al. 2010) (Fig. 6). There is also potential for investigation using foliar physiognomic methods (e.g. variation in leaf margin attributes, cf. CLAMP: Yang et al. 2011), mutual climatic range methods with improvements to the statistical framework (e.g. CRACLE; Harbert and Nixon 2015), leaf stomatal methods to determine coeval CO_2 (Roth-Nebelsick 2005), and biogeochemical potential via functional

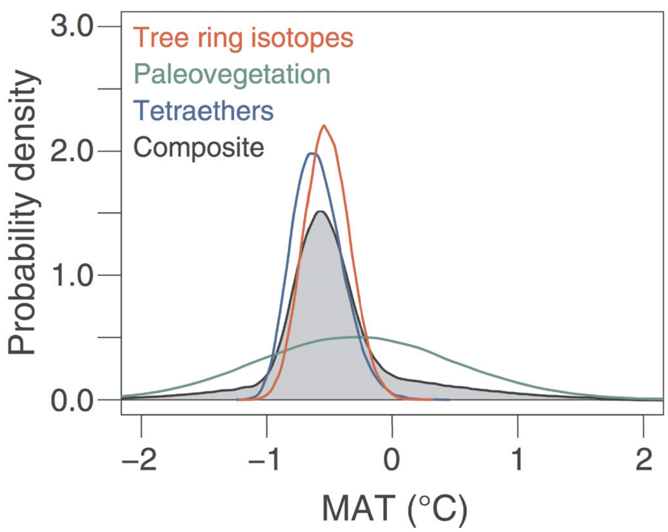

Figure 6. Using multiple proxies for paleoclimate analysis. Probability density functions of mean annual temperature (MAT) estimates for the Arctic during the Pliocene based on three independent proxies. Plotted are the three bootstrapped estimates of MAT derived from our three proxies (coloured lines) and the density function for the composite estimate of MAT derived from resampling the joint distribution across all three independent proxies (grey-filled; from Ballantyne et al. 2010: figure 2).

microbial genes (Xue et al. 2016). The group also is attempting to crossdate multiple *in situ* logs containing one or more burn scars to assist in the assessment of fire frequency. Some logs have over 200 tree rings.

Geochronology

The fossil-rich Beaufort Formation and correlative sediments have been dated with a combination of biostratigraphy, magnetostratigraphy, and numerical methods including cosmogenic $^{26}Al/^{10}Be$ burial and isochron methods on quartz sand, and amino acid racemization (AAR) and Sr isotope dating of marine shells (*Mya truncata* and *Hiatella arctica*). At Meighen Island (Fig. 1), AAR (>2.4 ± 0.5 Ma) and Sr (2.8–5.1 Ma) results (Brigham-Grette and Carter 1992) support the marine and terrestrial biostratigraphy. In the Klondike Gold District of Yukon, cosmogenic nuclide burial ages (Hidy et al. 2013) have confirmed the interpretation of magneto- and biostratigraphy pinned with tephrochronology using fission track dating of volcanic glass (Preece et al. 2011). Their burial age 2.64 +0.20/–0.18 Ma (1σ total external error; now 2.84 Ma adjusted for updates in cosmogenic nuclide production rates) for the top portion of the Upper White Channel Gravel dates the first Cordilleran Ice Sheet and provides a maximum age for the top of the White Channel Gravel (Fig. 1). As in the Yukon, the goal is to anchor paleomagnetic stratigraphy at sites throughout the Beaufort Formation to utilize the precision of the timing of polar reversals. Cosmogenic nuclide burial dating at the Beaver Pond Site (Fig. 1) yielding 3.4 +0.6/–0.4 Ma was interpreted as a minimum age for the Beaver Pond owing to the possibility of post-depositional production of the isotopes by deeply penetrating muons (Rybczynski et al. 2013). Twenty kilometres from the Beaver Pond, minimum burial ages of 3.8 +1.0/–0.7 Ma were reported for the Fyles Leaf Bed site (Fig. 1; Rybczynski et al. 2013). Additional samples have since been collected to improve on the precision of these sites, and unpublished and tentative ages have been measured at Meighen Island, Banks Island, and the Remus site on Ellesmere Island. Moving forward, *PoLAR-FIT* will use the $^{26}Al/^{10}Be$ burial and isochron methods at sites with key fossil or environmental records, where sediments are sufficiently thick to minimize the effect of post-depositional production by cosmic ray secondaries. However, to improve on the cosmogenic nuclide burial dating we will continue to further develop magnetostratigraphy where possible (e.g. Fyles et al. 1991). *PoLAR-FIT* will continue to collaborate with other researchers (including the Geological Survey of Canada and international groups) to build on this Arctic chronostratigraphy. The cosmogenic nuclide results also yield paleo-erosion rates, which provide insight into the variation in sedimentation rates during the climate transition.

EXAMPLES OF HYPOTHESES

The *PoLAR-FIT* workgroup has prioritized topics and hypotheses for testing initially, as follows:

(i) That Arctic forest processes, including forest fires, may be important feedbacks to polar amplification of temperature.
(ii) The 'regolith hypothesis,' that a thick saprolite or regolith was generated during the mid-Pliocene and stripped rapidly during the Pliocene–Pleistocene transition.
(iii) That the Northwest Passages were last opened after 2.7 Ma ago, beginning with fluvial incision in response to Pleistocene sea-level fall, and continuing with glacial erosion which widened and deepened the straits and sounds.
(iv) Consequently, we also hypothesize that the terrestrial distribution of the Beaufort Formation is tied to loading-induced lithospheric flexure and that unloading during excavation of the Northwest Passages may have caused strata and topography to experience uplift along the coasts of the straits.
(v) That records of summer temperature may provide insight into the nature of sea ice cover during the Pliocene.
(vi) The closest fossil relatives of the known High Arctic Pliocene flora and fauna are in mid-continental western North America and the Yushe Basin, China.
(vii) We hypothesize from biogeographical and phylogenetic evidence that an extensive, diverse polar Neogene forest biome existed in the warm part of the Pliocene, spanning Eurasia and northern North America. We will test this by searching for additional confirmatory fossil evidence in future field seasons.

PoLAR-FIT RESEARCH OBJECTIVES

The long-term research objectives of *PoLAR-FIT* are:

1. To understand the interaction of climate and landscape change and how this has affected the evolution and migration of organisms through the Western Arctic during the Pliocene.
2. To understand factors underlying Pliocene floral and faunal

diversity, and the role of the Neogene Arctic in patterning modern biodiversity.
3. Identify and quantify proxies of climatic and environmental conditions in the Pliocene Arctic that improve our understanding of ecological processes and climate interactions at high latitudes during periods of global warmth.
4. To develop a conceptual model, supported by sedimentology and stratigraphy, lithospheric flexure modelling, paleoecology, and paleoclimatology that captures the landscape evolution of the Canadian Arctic Archipelago since the middle Pliocene.

The short-term (5–10 year) research goals are:
1. To identify additional Pliocene sites, with well-constrained ages, to improve data-model comparisons for warm period climate modelling.
2. To build a Pliocene annual time series by crossdating fossil wood and to investigate whether multiple proxies derived from fossil tree rings can be used to characterize the annual and seasonal climate of the Arctic and understand its impacts on ecosystem dynamics.
3. To investigate the impact of currently hypothesized terrestrial feedbacks to polar amplification through climate and atmospheric proxies, and environmental and paleoecological reconstruction at key sites, and integration with current climate modelling.
4. To discover and describe Pliocene High Arctic vertebrate species, using morphological and proteomic techniques.
5. To enrich the faunal, floral, and paleoenvironmental proxy interpretations with improved chronostratigraphy and to investigate the archipelago-scale landscape evolution during the Pliocene-Pleistocene transition.

Targeted Sites

The Beaufort Formation has been recognized on all western Arctic Canada islands, from Banks Island to Meighen Island (Fig. 1). Correlative records have been studied at multiple sites throughout Ellesmere Island, and mid- to late-Pliocene fossil tree fragments on Axel Heiberg and Bylot Island (Fig. 1) have been studied (e.g. Csank et al. 2013), although the stratigraphy there needs further analysis and improved confidence for dating. Offshore, seismic and well data, and core samples from the Iperk Formation are being analyzed to help establish the timing of the post-Miocene transgression and other unconformities, and to separate Pleistocene and Holocene deposits from the Pliocene (Lakeman et al. 2014). With new tools, we are improving the bio- and chrono-stratigraphic correlation of new and existing Pliocene sections such as the White Channel Gravel (Fig. 1) and other well-studied records in western Yukon and northern Alaska. Unlike older and more resilient lithified records, most of these Pliocene beds may have survived only because of permafrost. While retrogressive thaw slumps, solifluction, and other gravitational erosion continue to rejuvenate and expose new records in unconsolidated sands—motivating revisits—key records at some locations are unlikely to survive decades. The next major target, planned for 2017, will be dozens of sections exposed on Prince Patrick Island, where the Beaufort Formation was first described by Tozer (1956).

ACKNOWLEDGEMENTS

PoLAR-FIT is grateful for the outstanding logistic support provided throughout the Canadian Arctic by the Polar Continental Shelf Program and in-kind support for accessing these sites. Without their professionalism and efficiency, our discoveries and knowledge growth could not be possible. We also thank the Canadian Museum of Nature for the past and recent support of critical research and meeting space, field equipment, and funding for research by members of their Arctic program. *PoLAR-FIT* members have benefited from financial support from Natural Science and Engineering Research Council of Canada Discovery Grant Program and NSERC-Northern Research Supplement Program, and the USA National Science Foundation. Special thanks to W. Garfield Weston Foundation for funding NR, a Post-doctoral Fellowship to TL, and a Graduate Student Fellowship to a past student; the National Geographic Society, who have provided field funding for NR and TF; and Byrd Polar and Climate Research Centre, Ohio State University Office of International Affairs, Geologic Society of America, the Columbus Rock and Mineral Society and the individual donors for their field funding for GG. Most significantly, we thank the northern hamlets of Resolute Bay (Qausuittuq), Grise Fiord (Aujuittuq), Sachs Harbour (Ikahuak), and Holman (Ulukhaqtuuq) and their Hunting and Trapping Committees for supporting our research over the past two decades. We hope past and future *PoLAR-FIT* landscape and climate research will be directly useful to their communities. We thank D. Froese for comments that improved an earlier version of this manuscript, and T. Bell, J. England, and A. Kerr for reviews which significantly improved its readability.

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Received November 2016
Accepted as revised March 2017