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USING FOSSIL TREES TO ESTIMATE PALEOCLIMATE OF BANKS ISLAND, ARCTIC CANADA AND THE EFFECTS OF MODERN CLIMATE CHANGE ON THE ARCTIC

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INTRODUCTION

At latitude 74°N, Banks Island is 6° north of present-day treeline and devoid of much vegetation. However, peat, woody debris, and well-preserved trees from the Miocene and Pliocene are exposed in the hillsides (Fyles et al. 1994). The presence of genera including *Pinus*, *Picea*, *Metasequoia*, and *Glyptostrobus* (Miocene) and *Pinus*, *Picea*, and *Larix* (Pliocene) represents a climate that was considerably warmer than that of the modern Arctic. Samples of the fossil trees were collected to study their wood anatomy and annual productivity. This information is essential to accurately estimate the paleoclimate of the Canadian Arctic and identify the role of the polar trees in regulating the global carbon cycle. With the current rate of global warming expected to cause worldwide temperatures to increase 1.4-4.3°C (4-10°C at high northern latitudes) by 2100, the Arctic environment could change significantly (Chernicoff and Whitney 2002; Hassol 2004). Understanding the changes caused by past climatic warming can help to predict how Arctic vegetation will respond to future fluctuations in climate.

Stratigraphy

Sand, silt, and clay strata of the Ballast Brook Formation (Miocene) are indicative of a fluvial/floodplain depositional environment. Near the top of the formation is a layer of peat, traceable for 15 km, consisting of cones, leaves, needles, twigs, and logs ("Unit 4" of Fyles et al. 1994). At the top of the 3-meter-thick peat layer, *in situ* stumps are exposed. Logs are scattered throughout the peat but lie adjacent to their corresponding stumps.

The Beaufort Formation (Pliocene) is separated from the Ballast Brook Formation by an angular unconformity that represents at least 1.7 Ma (McNeil et al. 2001). After the area underwent uplift and erosion in the Late Miocene/Early Pliocene, a braided river deposited the Beaufort sediment (Fyles et al. 1994). In this unit of sand, silt, and gravel, unaltered, uncompressed logs and woody debris were deposited (see Murphy 2006, this volume). Unlike the *in situ* stumps of the Miocene peat, the Pliocene wood was transported prior to burial. The presence of intact roots, branches and treetops indicates the wood was deposited close to the source.

Banks Island Today

The current vegetation of northwestern Banks Island gives no indication of the diverse coniferous forests that once existed. With a MAT (mean annual temperature) of -14°C and less than 100 mm of precipitation per year, Banks Island is within the prostrate shrub zone with mosses, herbs, and low growing shrubs comprising the vegetation (Good and Bryant 1985).

METHODS

Wood samples were collected from the Ballast Brook peat layer (in the middle and top of the unit) and from wood deposits scattered throughout the Beaufort Formation. Samples collected from the Beaufort Formation were better preserved than the compressed Miocene wood in the Ballast Brook Formation. In both cases the samples were unmineralized and in good condition for analysis and identification. Fossil wood was thin-sectioned for microscopic identification. Since it was not possible to distinguish among species, wood was classified according to genus. We measured the ring widths of 68 Miocene (26 from the middle peat unit and 42 from the top of the peat unit) and 34 Pliocene wood samples. After the samples were identified, ring widths of the same genus were averaged to compare with modern tree ring data.

RESULTS AND DISCUSSION

Tree Identification

Three coniferous genera were identified from wood gathered in the Beaufort Formation; *Picea* (spruce), *Larix* (larch), and *Pinus* (pine). *Picea* and *Larix* dominate the flora of the formation. Of the 32 Pliocene samples collected, 24 were either spruce or larch (Fig. 1).

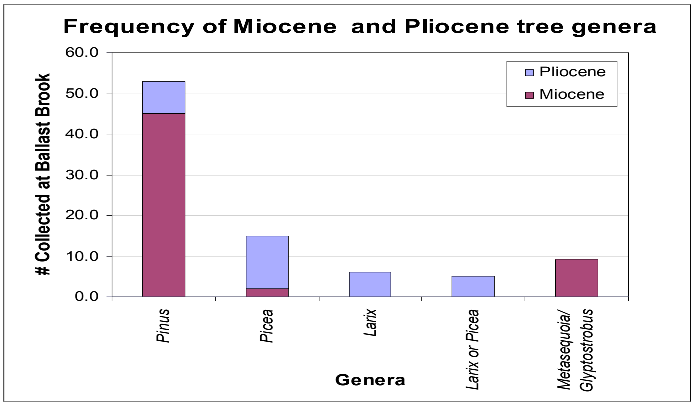

Figure 1. Number of samples of each genus collected at Ballast Brook. Pinus dominated the Miocene forest, while Picea and Larix were most common in the Pliocene.

In thin section, these two members of the Pinaceae family are characterized by piceoid cross-field pits, grouped resin canals and 1-2 simple pits (Fig. 2). Their features are sometimes indistinguishable from each other and were therefore occasionally grouped into a "*Larix* or *Picea*" category.

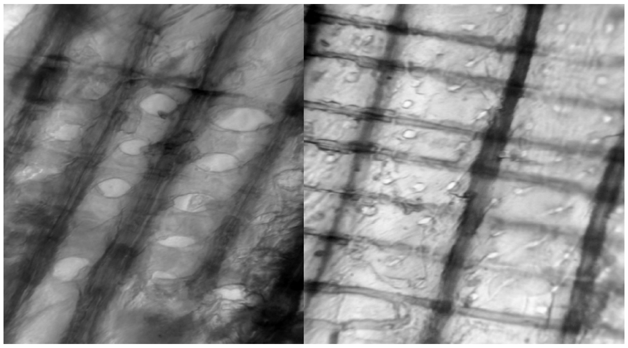

Figure 2. Pinus crossfield pits (left) compared to those found in Picea and Larix (right).

Pinus (pine) was the dominant constituent of the Miocene forest. Of the 56 samples identified from the Ballast Brook Formation, 45 were *Pinus*. Comparatively, the genus constituted only 8 of the 32 Beaufort Formation samples. In thin section, *Pinus* was identified by large, independent resin canals, fenestriform or pinoid cross-field pits, and ray tracheids (Fig. 2).

Metasequoia and *Glyptostrobus* were found only at the top of the Ballast Brook Formation peat layer. Together, they comprise about 6% of the sampled Miocene wood. The wood is less dense than both *Pinus* and *Picea* samples and was identified in thin section by simple pitting (up to 4 per tracheid), longitudinal parenchyma, and taxodiod cross-field pits (Figs. 3, 4).

Previous research involving identification of the Banks Island flora has produced similar findings. H. Jetté identified wood from the Ballast Brook Formation. Of the 11 wood samples studied, Jetté identified *Pinus* (comprising over half of the samples), *Picea*, and *Sequoia/Metasequoia* (Fyles et al. 1994). In addition to the genera identified in our study of the Beaufort Formation flora (*Picea, Larix,* and *Pinus*), Roy and Hills (1972) cited the existence of *Abies* (fir) and Eraeagnaceae (a family of small trees and shrubs).

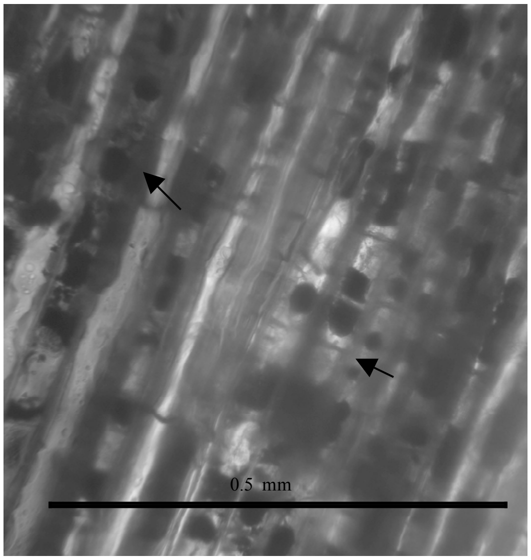

Figure 3. Abundant longitudinal parenchyma in Glyptostrobus.

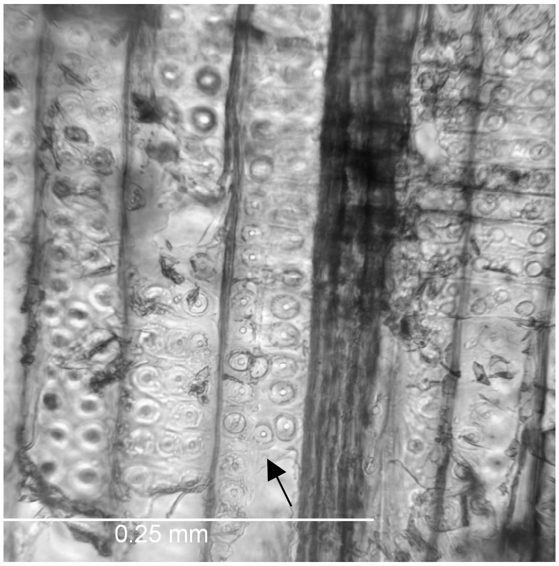

Figure 4. Triserate tracheid pits characteristic of Metasequoia and Glyptostrobus.

Ring Widths

Pinus collected from the Ballast Brook Formation had an average ring width of 1.3 mm. *Metasequoia* and *Glyptostrobus* were partly distinguishable by their much smaller rings, averaging 0.2 mm. In the Beaufort Formation, mean ring width of *Picea* and *Larix* was 0.7 mm. *Pinus* rings from the Pliocene formation (average=0.8 mm) were thinner than those of the same genus in the Ballast Brook Formation.

Current Distribution

Picea currently grows in regions where mean July temperatures reach 4-16°C, although 12-16°C is most favorable for growth, and annual precipitation ranges from 500-1000 mm (Kerwin et al. 2004). Spruces that grew on Banks Island are distinct from modern *Picea* and have been assigned the name *P. banksii*, a now-extinct species (Jackson and Weng 1999).

Considered a mesothermal genus, modern *Metasequoia* distribution is limited. The only living species, *M. glyptostroboides*, is native to the Sichuan-Hubei region of central China where it remained unidentified until the 1940s. The region annually receives 1000-2000 mm of precipitation and records a MAT of 19°C (Chu and Cooper 1950). Although its native range is restricted, *Metasequoia* can tolerate a wide variety of climates under cultivation (Williams 2004).

Miocene Climate

The presence of *Metasequoia*- and *Glyptostrobus*- bearing peat in the Ballast Brook Formation indicates a warm, wet climate on Banks Island. Although *Metasequoia* was an important constituent of Northern Hemisphere Tertiary forests (Williams et al. 2003) it is now extinct in North America and Europe (LePage et al. 2003; Visscher and Jagels 2003). Because it is a relict taxon, modern distribution patterns do not accurately predict its range in the past. *Metasequoia* is classified as mesothermal, a category that defines a MAT of 13-24°C as necessary to support the greatest diversity and productivity of the genus (Greenwood et al. 2005). This classification, however, does not necessarily restrict the growth of *Metasequoia* to climates with the specified MAT. In a more equable climate, such as the Miocene, *Metasequoia* might have been able to survive at a much lower MAT than that of its current range. (Greenwood et al. 2005).

Our research supports a previous study by McNeil et al. (2001) that proposes a MAT of 9°C at Banks Island during the Miocene. The *Metasequoia*/*Glyptostrobus* wood collected on Banks Island had strikingly thin rings (average=0.2 mm). Tree ring thicknesses have been shown to respond to temperature fluctuations, thus making them good indicators of paleoclimate (Graumlich 1991). As long as precipitation is sufficient, trees grow faster (and therefore have larger rings) at higher temperatures. As mesothermal genera are normally associated with average temperatures above 9°C, the small ring widths evident in our samples would be expected in a climate that was too cool to support optimal growth.

Pliocene Climate

Our tree ring measurements were compared to those of associated modern genera using data collected from the World Center for Paleoclimatology. The annual diameter growth (ring width x 2) of *Picea* averaged 1.4 mm, suggesting a MAT in the Pliocene of -4 to -6°C (Fig. 5). *Pinus* do not exhibit a strong trend between ring width and temperature. Therefore, widths measured from *Pinus* samples in the Ballast Brook and Beaufort Formations were not considered reliable indicators of past climate.

Although it is tempting to constrain the Banks Island flora in terms of a modern analog, an exact reconstruction of the Miocene and Pliocene forests does not presently exist (Fyles et al. 1994). Certain characteristics of the ancient Arctic forests, however, are comparable to modern environments. The assemblage of trees and width of *Picea* rings in the Beaufort Formation is suggestive of a Pliocene environment that resembled modern boreal forest conditions. The disappearance of *Metasequoia* and *Glyptostrobus* and dominance of microthermal taxa (MAT<13°C) represent a cooling trend from the Miocene to the Pliocene. In Inuvik, Northwest Territories, Canada (68°13’N, 135°00’W), the treeline forest is dominated by *Picea glauca* and *P. mariana*, although *Larix, Pinus*, and *Abies* (fir) are important constituents. *Betula* (birch), *Alnus* (alder), and *Populus* (poplar) are also present (Edlund and Garneau 2000). Radial ring widths of *P. glauca* range from 0.23-0.72 mm and average 0.5 mm (Wein et al. 2001). These values are within the range of most of the Pliocene trees we sampled. The comparability of Inuvik forest composition and *Picea* ring widths with the Beaufort Formation flora is suggestive of a Pliocene climate that resembled the modern Arctic treeline environment.

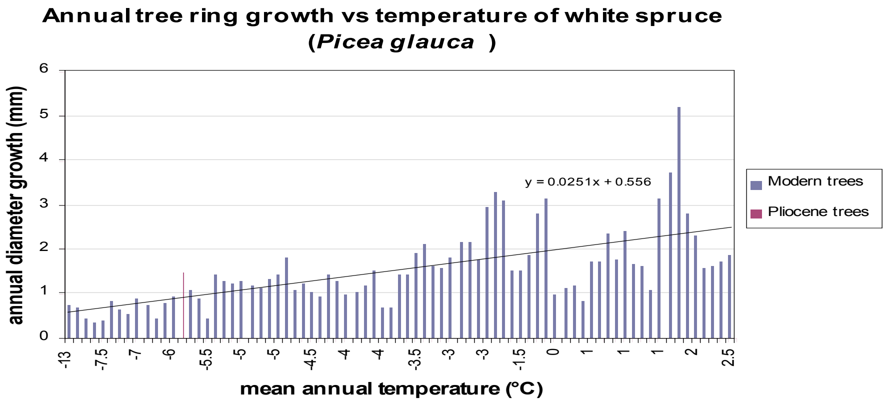

Figure 5. Ring width data of P. glauca compiled from World Center for Paleoclimatology. Red bar represents Picea average from Beaufort Formation. Elias and Matthews (2002) estimate a MAT of 10°C greater than present (-5°C) during the Pliocene maximum (~3 Ma). Our ring width data fall within the values to be expected at this temperature.

Limitations

Differences in the variables responsible for climate change and the environmental and biophysical conditions prior to the warmings must be considered before relying too heavily on the predictive power of past environments (Hebda 1996). Unlike Miocene and Pliocene warming, when equatorial and southern latitudes were minutely affected, the earth's climate is currently experiencing an overall increase in temperature that exceeds natural variability (Chandler 1997; Graumlich 1991). An increase in atmospheric CO_2 is attributed as the primary cause of this instantaneous (geologically speaking) change in global climate (Matthews and Fyles 2000). The ancient forests on Banks Island were a product of gradual climate change that was less a function of atmospheric CO_2 concentration and more exhibitive of fluctuations in ocean circulation patterns; thus it is uncertain if modern vegetation will respond analogously. The Tertiary forests can, however, illustrate the likely 'final state' of tundra-invading forests and give insight into the forests' role in the carbon cycle (Hebda 1996).

SIGNIFICANCE

The presence of diverse coniferous forests on Banks Island during past periods of climate maximums reveals the likelihood that modern climate change will result in the northward migration of treeline. How similarly the encroaching forests will mirror their ancient counterparts remains uncertain. If Arctic temperatures do increase by the predicted 10°C from doubled atmospheric CO_2 (Hassol 2004), the Pliocene forest composition provides a reasonable estimate of warming-induced forest succession in the now-treeless Arctic.

REFERENCES CITED

Chandler, M.A., 1997, The Climate of the Pliocene: Simulating Earth's last great warm Period: NASA website, http://www.giss.nasa.gov/research/features/pliocene, accessed 2/7/06.

Chernicoff, S. and Whitney, D., 2002, Geology:Haughton Mifflin Company, Boston. 648 p.

Chu, K.L. and Cooper, W.S., 1950, An Ecological Reconnaissance in the Native Home of Metasequoia Glyptostroboides: Ecology, 31(2): 260-278.

Edlund, S.A. and Garneau, M., 2000, Overview of Vegetation Zonation in the Arctic. In Garneau, M. and Alt, B.T. (eds.), Environmental Response to Climate Change in the Canadian High Arctic: Geological Survey of Canada Bulletin, 529: 113-127.

Fyles, J.G, Hills, L.V, Matthew, J.V., Barendregt, R., Baker, F., Irving, E. and Jette, H., 1994, Ballast Brook and Beaufort Formations (Late Tertiary) on Northern Banks Island, Arctic Canada: Quaternary International, 22(23): 141-171.

Good, T.R. and Bryant, I.D., 1985, Fluvial-aeolian sedimentation-an example from Banks Island, N.W.T., Canada: Geografiska Annaler, 67A(1-2): 33-46.

Graumlick, L.J., 1991, High Latitude Tree Ring Data: Records of climatic change and ecological response. In Weller, G., Wilson, C.L. and Severin, B.A.B (eds.), International Conference on the Role of the Polar Regions in Global Climate Change. Vol. II: Geophysical Institute, University of Alaska Fairbanks. 565-569.

Greenwood, D.R., Archibald, S.B., Mathewes, R.W. and Moss, P.T., 2005, Fossil biotas from the Okanagan Highlands, southern British Columbia and northeastern Washington State: climates and ecosystems across an Eocene landscape: Canadian Journal of Earth Sciences, 42: 167-185.

Jackson, S.T. and Weng, C., 1999, Late Quaternary extinction of a tree species in eastern North America: Ecology, 96(24): 13847-13852.

Hassol, S.J., 2004, Impacts of a Warming Arctic. Arctic Climate Impact Assessment: Cambridge University Press, U.K.

Hebda, R., 1996, Atmospheric change, forestry and biodiversity. Environmental Monitoring and Assessment: on Royal BC Museum website, http://

www.royalbcmuseum.bc.ca/nh_papers/atmospheric.html, accessed 2/13/06.

Kerwin, M.W., Overpeck, J.T., Webb, R.S. and Anderson, K.H., 2004, Pollen-based summer temperature reconstructions for the eastern Canadian boreal forest, subarctic and Arctic: Quaternary Science Reviews, 23: 1901-1924.

LePage, B.A., 2001, New species of Picea (Pinaceae) from the middle Eocene of Axel Heiberg Island, Arctic Canada: Bot. J. Linn. Soc., 135: 137-167.

Matthews, J.V. and Fyles, J.G., 2000, Late Tertiary plants and arthropod fossils from the high-terrace sediments of Fosheim Peninsula, Ellesmere Island, Nunavut. In Garneau, M. and Alt, B.T. (eds.), Environmental Response to Climate Change in the Canadian High Arctic: Geological Survey of Canada Bulletin, 529: 295-317.

McNeil, D.H, Duk-Rodkin, J.D., Dietrick, J.R., White, J.M., Miller, K.G. and Issler, D.R., 2001, Sequence Stratigraphy, biotic change, 87Sr/86Sr record, paleoclimatic history, and sedimentation rate change across a regional late Cenozoic unconformity in Arctic Canada: Canadian Journal of Earth Sciences, 38: 309-331.

Roy, S.K., and Hills, L.V., 1972, Fossil woods from the Beaufort Formation (Tertiary), northwestern Banks Island, Canada: Can. J. Bot., 50: 2637-2648.

Visscher, G.E., Jagels, R., 2003, Separation of Metasequoia and Glyptostrobus (Cupressaceae) based on wood anatomy: IAWA, 24(4): 439-450.

Wein, R.W., Landhausser, S.M., Salomons, M.J., Sander, B., Schoplick, J. and Truscott, J., 2001, Productivity of White Spruce in the Mackenzie Delta Region. In Sustainable Forestry in the Gwich'in Settlement Area: Biological Perspectives: Sustainable Forest Management Network Project Report 2001, 31.

Williams C.J., Johnson A.H., LePage, B.A., Vann D.R., and Sweda, T., 2003, Reconstruction of Tertiary Metasequoia Forests II. Structure, Biomass and Productivity of Eocene Floodplain Forests in the Canadian Arctic: Paleobiology, 29(2): 238-274.