# MORPHOLOGICAL ANALYSIS OF LATE TERTIARY *PICEA* AND *PINUS* CONES IN THE WESTERN CANADIAN ARCTIC

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## INTRODUCTION

The Miocene Ballast Brook and Pliocene Beaufort Formations are well exposed on the valley walls of Ballast Brook, northwestern Banks Island Canada. These deposits and the plant fossils they contain record important information about high-latitude forest environments for which there are no present-day analogs. Fossils recovered at scattered locations throughout the Beaufort and Ballast Brook Formations have been described and interpreted by others as the remains of a relatively diverse swamp and riparian forests (Heer 1868; Hills and Ogilvie 1970; Fyles et al. 1994). However, plant macrofossils from one of the most prominent features of the Ballast Brook Formation, the massive "Unit 4" peat, have received little study. During the summer of 2005, I collected well preserved *Picea* and *Pinus* cones from this layer. My objectives were to classify these cones by taking cone length and width, scale length and width, and bract length measurements in order to better understand the paleoecology of the Miocene.

## SITE GEOLOGY

Hills (1970) subdivided the previously named Beaufort Formation into the current boundary distinctions, naming the underlying sediments the Ballast Brook and the overlying facies the Beaufort. The Ballast Brook Formation presently consists of five individual units as reported by Fyles et al. (1994), the entire formation being approximately thirty-nine meters thick. The bottom three units (units 1, 2, and 3) are composed of back swamp sediments, meandering fluvial sediments, and splay deposits, respectively. The fourth unit consists of a three meter-thick layer of autochthonous peat; this layer, known as the Ballast Brook peat, is exposed for more than fifteen kilometers as a result of the current braided river system. Organic constituents of the peat include wood, needles, roots, twigs, and cones, all of which are flattened as a result of vertical compression. The fifth unit is composed primarily of massive amounts of clay and silt, and was probably deposited as a result of a lacustrine environment (Fyles & Hills et al. 1994). The Miocene plant fossils described in this paper occur in the upper and middle portion of Unit-4 peat layer. The Pliocene plant fossils occur in woody debris lenses scattered throughout the Beaufort Formation.

## METHODS

The samples were transported from the field embedded in plastic containers with damp, dense sand surrounding them to prevent damage in transit. Upon arrival, each sample was hand- and airbrushed, and sprinkled with water in order to remove adhered mineral grains. I measured the following morphological attributes of each fossil cone: cone length and width, cone scale length and width, and scale bract length. At least two scale and bract measurements were taken from each sample in order to provide a

more complete representation of the data.

# RESULTS

## *Picea*

Preliminary analysis of the collected cones indicated the presence of the genus *Picea* in addition to that of *Pinus*. It was determined that *Picea* was represented in these cones as a result of the absence of an umbo (common to *Pinus*). Additionally, the presence of relatively thin, round deltoid scales helped to separate the *Picea* specimens.

The cone length data and cone scale size suggest that two general cone morphotypes exist among the cones I analyzed (Fig. 1). Numbers in parentheses represent averages.

*Morphotype 1* (M1): **cone** ovate to sometimes oblong-cylindrical, moderate taper, up to 66 (51.0) mm long and 26 (22.2) mm wide, thin woody cone scales; **scales** round deltoid to circular, moderate to wide obovate, up to 15.5 (12.7) mm long and 13.3 (11.2) mm wide, apical margin entire, apex rounded, abaxial surface glabrous; **bract** denate to entire, lanceolate, up to 7.2 (5.2) mm long and 2.5 (2.0) mm wide, basally adnate but medially and apically unattached, single protruding apical tooth.

*Morphotype 2* (M2): **cone** slightly ovate to oblong-cylindrical, moderate to low taper, up to 71 (62.5) mm long and 29.5 (25.2) mm wide, thin woody cone scales; **scales** round deltoid, narrow to wide obovate, up to 17.6 (14.5) mm long and 15.0 (12.8) mm wide, apical margin erose to entire, apex rounded, abaxial surface glabrous; **bract** dentate to entire, lanceolate, up to 6.7 (5.2) mm long and 2.5 (2.0) mm wide, basally adnate but medially and apically unattached, single protruding apical tooth.

Table 1 presents the averages of cone scale measurements for the two morphotypes. The cone and scale length/width ratios of these two morphologies are similar to each in suggesting a single species. Specifically, although the cone length and width and scale length and width measurements differ between the two morphotypes, the ratios of length to width are very similar to each other. Additionally, the fact that the scale morphologies of the two morphotypes are similar provides further support to the single species claim. Finally, since the most distinctive data usually come from bracts, the similarity in bract length and in morphology (the presence in both morphotypes of a dentate border and a protruding apical tooth) helps to prove beyond doubt that the two *Picea* morphotypes are a single species.

| Morph | CONES | | | SCALES | | | BRACTS | |
|---|---|---|---|---|---|---|---|---|
| | Length (mm) | Width (mm) | L/W | Length (mm) | Width (mm) | L/W | Length (mm) | Bract length / scale length |
| **M1** | 51.1 | 22.2 | 2.3 | 12.7 | 11.2 | 1.1 | 5.2 | 2.4 |
| | 43.0 – 66.0 | 18.5 – 26.0 | 1.9 – 2.7 | 10.2 – 15.6 | 9.2 – 13.3 | 0.9 – 1.2 | 4.2 – 7.2 | 2.1 – 3.4 |
| **M2** | 62.5 | 25.2 | 2.4 | 14.5 | 12.8 | 1.1 | 5.2 | 2.8 |
| | 58.0 – 71.0 | 21.5 – 29.5 | 2.0 – 3.0 | 11.7 – 17.6 | 9.7 – 15.0 | 0.9 – 1.3 | 3.9 – 6.7 | 2.2 – 3.4 |
| **N1** | 70.0 | 24.4 | 2.8 | 25.1 | 14.7 | 1.8 | 4.1 | 5.9 |
| | 60.0 – 89.5 | 23.2 – 25.3 | 2.6 – 3.5 | 18.5 – 30.8 | 10.0 – 17.9 | 1.5 – 2.2 | 3.5 – 5.0 | 5.7 – 6.2 |
| **N2** | 39.1 | 24.1 | 1.6 | 16.6 | 8.7 | 1.9 | 3.8 | 4.7 |
| | 28.2 – 55.4 | 18.9 – 28.2 | 1.3 – 2.1 | 13.7 – 18.9 | 7.1 – 10.2 | 1.6 – 2.3 | 3.3 – 4.5 | 4.1 – 5.4 |

**Table 1. Cone, scale, and bract measurements of each *Picea* (M) and *Pinus* (N) morphotype.**

### *Pinus*

The measurements collected from the *Pinus* cones show two distinct groupings (Fig. 2). Unlike the *Picea* samples, each grouping is quite distinct from the other despite the fact that one grouping is extremely compressed, whereas the other is not.

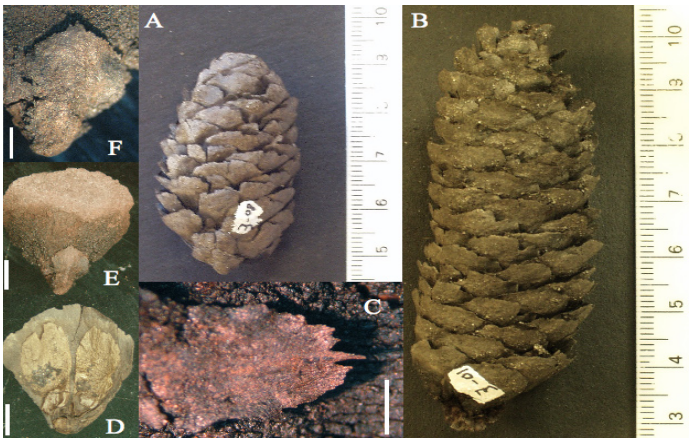


**Figure 1. (A, B) Two morphotypes of Fossil *Picea* recovered from the Ballast Brook Formation, Banks Island, Canada. (C) Cone scale bract (scale bar = 1 mm). (D) Proximal surface of cone scale with seeds still attached (scale bar = 3 mm). (E) Distal surface of cone scale with bract (scale bar = 3 mm). (E) close up view of bract (scale bar = 1 mm).**

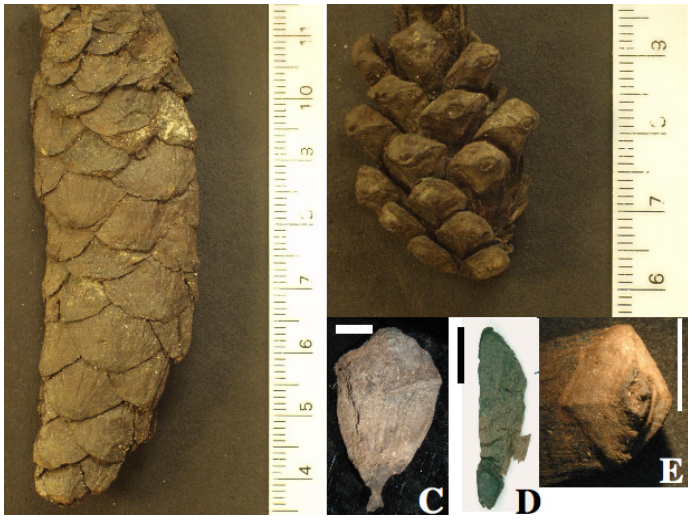


**Figure 2. Two types of fossil *Pinus* recovered from the Ballast Brook Formation, Banks Island Canada. (A) Pinus (Hapoxylon) ovuliferous cone. (B) Pinus (Diploxylon) ovuliferous cone. (C) Distal surface of Hapoxylon pine cone scale and (D) Hapoxylon seed with seed wing (scale bars = 5 mm). (E) Dipoxylon pine cone scale displaying a prominent dorsal umbo and transverse keel (scale bar = 4 mm).**

*Pinus morphology 1* (N1): **cone** oblong compressed, slightly ovate, low taper, up to 89.5 (70.0) mm long and 25.3 (24.4) mm wide, thin/papery to thick/woody scales; **scales** somewhat lanceolate, wide obovate, up to 30.8 (25.1) mm long and 17.9 (14.7) mm wide, apical margin entire, axial surface lineated, abaxial surface glabrous; **bract** round circular, up to 5.0 (4.1) mm long, basally to medially adnate; **umbo** terminal, faint.

*Pinus morphology 2 (N2)*: **cone** ovate, moderate to high taper, up to 55.4 (39.1) mm long and 28.2 (24.1) mm wide, thick woody scales; **scales** tabular to slightly obovate, up to 18.9 (16.6) mm long and 10.2 (8.7) mm wide, apical margin entire, axial and abaxial surfaces smooth and glabrous; **bract** round circular, basally to medially adnate; **umbo** dorsal, pronounced, diamond-shaped.

## DISCUSSION & CONCLUSIONS

Our analysis of plant fossils from the Ballast Brook Formation indicates that that both spruce and pine coexisted in the Miocene lowland swamp forests. Although initial measurements suggested at least two distinct species of spruce, detailed morphological measurements suggest that the spruce cones we recovered were most likely from a single species. The lack of variation in relevant diagnostic criteria supports this interpretation. For example, the bract morphology of both morphotypes is very similar in terms of length (5.2 mm) and morphology (Fig. 1). Furthermore, although the cone and scale lengths of each morphotype are quite distinct, their length to width ratios are nearly identical. This is suggestive of a single species.

The fossil cones that we recovered share morphological similarities with both extinct and extant species of spruce. By comparing our fossils to the morphology of extant spruce cones it was determined that the fossil species of *Picea*

found in the Ballast Brook peat is most closely related to the extant *Picea glauca* (Table 2; Hills and Ogilvie 1970).
Our fossils were most similar to *P. glauca* in terms of cone and scale morphology. Specifically, the slight to moderate taper of the cone and the round deltoid shape of the scales are similar to *P. glauca*; the bract morphology, however, does not suggest a relationship.

Bract morphology has been deemed a taxonomically useful indicator at the species level. Hills and Ogilvie (1970) used bract morphology to conclude that fossil spruce cones recovered from the Pliocene Beaufort Formation sediments were distinct from extant *P. glauca* (white spruce) and representative of an extinct species (*Picea banksii*). Specifically, *P. banksii* has a lanceolate bract with a prominent apical tooth whereas *P. glauca* has a more spatulate bract with no apical tooth. The bract morphology of the majority of the cones we recovered was more like those of *P. banksii* rather than *P. glauca*. Interestingly, bract morphology was also similar to those of the extinct Eocene spruce, *P. nansenii* described by LePage (2001), although bracts of *P. nansenii* are much shorter than that of *P. banksii*.

The fossils recovered from the Ballast Brook peat share similarities to both and extant and an extinct *Picea,* thus placing the *Picea* species in the "middle ground" between *P. banksii* and *P. glauca*. Hills and Ogilvie (1970) state that the major difference between these two species is the cone length. Further support for this notion comes from the bract morphology.

Although the fossil scale and cone morphologies are very similar to *P. glauca* (LePage 2001), the bract morphology is similar to that of *P. banksii*. Interestingly, the fossil cones have relatively variable bract morphologies (Fig. 1). Specifically, while the lanceolate nature of the bract is relatively constant, the length of the protruding apical tooth and the "toothiness" of the bract vary considerably. Unfortunately, Hills and Ogilvie (1970) do not provide a systematic description of the amount of bract morphology variation within *P. banksii*. As a result, it cannot presently be determined if the Miocene cones belong to *P. banksii* or to a different species.

The modern genus *Picea* A. Dietrich is composed of approximately 30 – 40 species, many of which are common to the North American continent. Spruces generally prefer relatively cool climates, but can exist as far south as the tropic of Cancer, provided that an alpine to sub-alpine environment exists (Farjon 1990). Specifically, *P. glauca* and *P. mariana* (black spruce) are common to areas with poor drainage, and thus to the backswamp ecological setting that probably existed during the Miocene on northwestern Banks Island. While *P. glauca* can occur in swamps, the species is more common to fluvial soils. Conversely, *P. mariana* is very common to swamp and/or permafrost sites. Both species occur at relatively low elevations in high-latitude environments, and generally grow in similar climatic and precipitation conditions (Farhon 1990).

| Morphology | CONES | | SCALES | | BRACTS |
|---|---|---|---|---|---|
| | Length (mm) | Width (mm) | Length (mm) | Width (mm) | Length (mm) |
| **M1, M2 (combined)** | 57.8 | 24.2 | 14.1 | 12.4 | 5.2 |
| | 43.0 – 71.0 | 18.5 – 29.5 | 10.2 – 17.6 | 9.2 – 15.0 | 3.9 – 7.2 |
| ***Picea glauca* (Cyp. Hills, Alb.)** | 52.9 | 27.9 | 15.3 | 12.2 | 5.5 |
| | 43.2 – 67.0 | 23.3 – 33.7 | 12.5 – 18.0 | 11.2 – 13.4 | 4.7 – 7.3 |
| ***Picea banksii* (Banks Island)** | 85.0 | 34.0 | 18.0 | 15.0 | 5.5 |
| | 63.0 – 110 | 25.0 – 45.0 | 11.0 – 24.0 | 11.0 – 19.0 | 4.0 – 7.0 |

**Table 2. *Picea* morphology compared with that of *Picea glauca* (Cypress Hills, Alberta)and *Picea banksii* (Hills 1969).**

The distinction between the two *Pinus* morphologies was not nearly as difficult as was that of *Picea*. The extremely large, broad, and relatively flat scales characteristic of N1, as well as the terminal umbo on the cone scales, suggest that this fossil species most closely resembles that of *Pinus strobus* (Fig. 2). To our knowledge, these are the first cones of a soft pine species to be recovered and described from a high-latitude fossil locality. This would be consistent with the fossil pine needles described by Fyles et al. (1994) and fossil wood described by Roy and Hills (1972) that were assigned to *Pinus strobus*. Indeed, the habitat of the eastern white pine is one that exists both at sea level and within close proximity of an abundant water supply, both of which are present on northwestern Banks Island.

The narrow, thick scales of N2 with a transverse keel and prominent dorsal umbo on the apophysis are consistent with cones produced by members of the hard pine subgroup (haploxylon pines; Farjon 2005; Fig. 2). Assignment to a particular species, however, is problematic. Hills (1975) recovered similar cones and described them as an extinct pine (*Pinus paleodensiflora*). The cones we recovered are consistent with this interpretation and are very similar to the extant species *Pinus densiflora* and suggest that this morphology is most closely related to *Pinus rigida*, or the hard pine. Most interestingly, we are unaware of any modern lowland forest that is composed of members of the hard pine, soft pine, and spruces due to the varying physiological tolerances of the different taxa.

# FUTURE WORK

Hills and Ogilvie (1970) noted that *P. glauca* (from Cypress Hills, Alberta) and *Picea banksii* are exceedingly similar in all respects except that of the greater cone length of the latter species. It has been suggested that *P. banksii* dominated the Pliocene forests of Banks Island (Hills and Ogilvie 1970; Fyles et al. 1994) and it is possible that the fossils we recovered from the Ballast Brook peat are *P. banksii*. However, the variation in bract morphology we observed suggests that our cones may in fact be a sub-species of *P. banksii* and an ancestral *P. glauca*. An analysis of the bract morphological variation in the *P. banksii* type specimens may shed light on these relationships. These questions and more may be answered as research on Banks Island continues in the near future.

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# REFERENCES

Farjon, Aljos. 1990. Pinaceae: drawings and descriptions of the genera. Koeltz Scientific Books

.

Farjon, Aljos. 2005. Pines: drawings and descriptions of the genus *Pinus*, second edition. Brill.

Fyles, J. G.; Hills, L. V.; Matthews, J. V.; Barendregt, R.; Bakers, J.; Irving, E.; Jetté, H. 1994. *Ballast Brook and Beaufort Formations (Late Tertiary) on northern Banks Island, Arctic Canada*. Quaternary International, 22-23: 141–171.

Heer, O. 1868. *Die Fossile Flora der Polarländeer*. 192 pp. Druck und Verlag von Zürich

Hills, L.V. 1970. Stratigraphy of the Beaufort Formation along the western margin of Canadian Arctic Islands. Bulletin of American Association of Petroleum Geologists. 54: 2486.

Hills, L.V. 1975. Late Tertiary floras Arctic Canada: An interpretation. Proceedings of Circumpolar Conference on Northern Ecology. 1(65)-2(71). National Research Council of Canada.

Hills, L.V.; Ogilvie, R. T. 1970. Picea banksii *n. sp. Beaufort Formation (Tertiary), northwestern Banks Island, Arctic Canada*. Canadian Journal of Botany, 48: 457–464.

LePage, Ben A. 2001. *New species of* Picea *A. Dietrich (Pinaceae) from the middle Eocene of Axel Heiberg Island, Arctic Canada*. Botanical Journal of the Linnean Society, 135, 137 – 167.

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