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Pollen and Vertebrates of the Early Neogene Haughton Formation, Devon Island, Arctic Canada

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ABSTRACT. The Haughton Formation of northern Devon Island, arctic Canada, consists of sediments deposited in a lake that filled a large impact crater, which has been dated as early Miocene. The fossiliferous sediments contain a rich assemblage of pollen, some plant megafossils, and the only known early Neogene arctic vertebrates. Common pollen types are *Pinus*, Ericales, *Corylus*-type, *Betula*, and *Alnus*. *Picea*, *Larix*, Cupressaceae, and *Ulmus/Zelkova* also occur. These taxa, rarer hardwoods, and spores allow a vegetational reconstruction of a mixed conifer-hardwood forest. Climatic conditions were cool temperate with maritime influences. Vertebrates, including trout, smelt, swan, and four mammal genera, lend support to the climatic interpretation, and they also suggest considerable endemism for the mammals. The Haughton flora appears to be bracketed temporally by floras from various parts of the widely distributed Beaufort Formation.

Key words: Haughton Formation, Devon Island, Neogene pollen and vertebrates, early Miocene vegetational history, Beaufort Formation

RÉSUMÉ. La Formation de Haughton dans le nord de l'île Devon, dans l'Arctique canadien, est composée de sédiments déposés dans un lac qui remplissait un grand cratère d'impact datant du Miocène ancien. Les sédiments fossilifères contiennent une riche assemblage de pollen, quelques mégafossiles de plantes et les seuls vertébrés arctiques connus du Néogène ancien. Les types courants de pollen sont *Pinus*, les éricales, type *Corylus*, *Betula* et *Alnus*. Il y a aussi *Picea*, *Laryx*, les cupressacées et *Ulmus/Zelkova*. Ces taxons, bois durs plus rares et spores permettent la reconstruction d'une végétation constituée d'une forêt mixte de conifères et de feuillus. Le climat était tempéré et frais avec des influences maritimes. Les vertébrés, notamment la truite, l'éperlan, le cygne et quatre denres de mammifères, corroborent l'interprétation climatique et dénotent aussi un important endémisme chez les mammifères. La flore de Haughton semble s'inscrire chronologiquement dans des flores des diverses parties de la Formation très dispersée de Beaufort.

Mots clés: Formation de Haughton, île Devon, pollen et vertébrés du Néogène, histoire de la végétation du Miocène ancien, Formation de Beaufort

РЕФЕРАТ. Формация Хотон в северной части острова Девон Канадского Арктического архипелага состоит из осадков, отложившихся в озере, заполнявшем крупный ударный кратер, датируемый ранним миоценом. В осадках формации содержится богатый комплекс пыльцы, макроскопические остатки растений и нигде больше не обнаруженные представители арктических позвоночных раннего неогена. Чаще всего встречается пыльца таких пород, как *Pinus*, *Ericales*, *Corylus*-подобных, *Betula* и *Alnus*. Также попадается пыльца *Picea*, *Larix*, *Cupresaceae* и *Ulmus/Zelkova*. Эти таксоны, более редкие лиственные породы и споры позволяют восстановить картину смешанного хвойно-лиственного леса, росшего в условиях прохладного умеренного климата, подверженного морским влияниям. Данное определение климата подтверждается присутствием остатков позвоночных, в том числе форели, корюшки, лебедя и четырех родов млекопитающих. Эти остатки указывают также на значительный эндемизм млекопитающих. Во временно́м отношении флора формации Хотон ограничивается сверху и снизу флорой из различных частей широко распространенной формации Бофорта.

Ключевые слова: формация Хотон, остров Девон, неогеновая пыльца и позвоночные, история растительности раннего миоцена, формация Бофорта

INTRODUCTION

Haughton Astrobleme is a nearly circular meteoritic impact structure (Robertson and Mason, 1975) located at 75°22′N latitude, 89°40′W longitude, near the north-central coast of Devon Island, Northwest Territories, Canada (Fig. 1). The impact that formed the Haughton crater has been dated by two radiometric methods: the fission-track method, using apatite grains in impact-shocked gneiss (Omar *et al.*, 1987), yielded 22.4 ± 1.4 million years ago (ma); ^{40}Ar-^{39}Ar analysis on gneiss clasts provided a date of 23.4 ± 1.0 ma (Jessberger, 1988). These dates fall within the early Miocene or Aquitanian and provide a maximum age on the formation of a lake that developed within the crater.

Remnants of the sediments deposited in the lake (Figs. 2 and 3) cover about 7 km^2 in the west-central part of the astrobleme and occur as scattered outliers (Frisch and Thorsteinsson, 1978). The sediments, which are up to about 48 m in thickness, have been designated the Haughton Formation (Table 1). Field relationships suggest that deposition of the Haughton Formation took place well within the time span representing the limits of error of the dates for the impact event (Hickey *et al.*, 1988).

The Haughton Formation contains a radiometrically dated record of early Neogene arctic plant remains and thus provides a frame of reference for other vegetational studies in the arctic Neogene. Pollen and spores permit reconstruction of regional vegetation and climate. These interpretations are supplemented by the identification of macrofloral remains (currently under study by A. Kelly, Duke University, and B. Tiffney, University of California, Santa Barbara). The formation also contains the only known vertebrate fossils from the beginning of the Neogene in the High Arctic. The seven vertebrate taxa recognized from the Haughton Formation provide additional information on the climate, paleobiogeography, and biostratigraphy of the site.

A preliminary list of pollen and spores from the Haughton section was presented in Omar *et al.* (1987) and Hickey *et al.* (1988). In addition, A.R. Sweet discussed palynomorphs from two samples collected from the Haughton Formation (in Frisch and Thorsteinsson, 1978). This report updates previous information with a pollen stratigraphy from the type section and a listing of pollen from four other localities. The macroflora from the "Woodsand" of Unit 13 of the type section includes lignitized cones and needles of *Larix*, *Picea*, and a five-needle pine; fruits and seeds of

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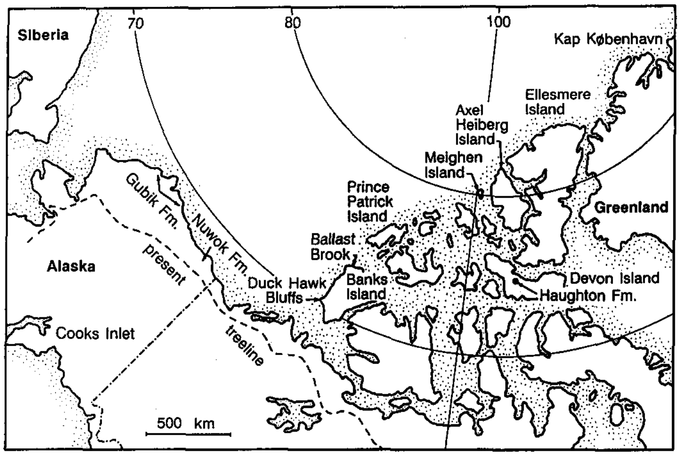

FIG 1. Location of Haughton Formation and other sites mentioned in the text.

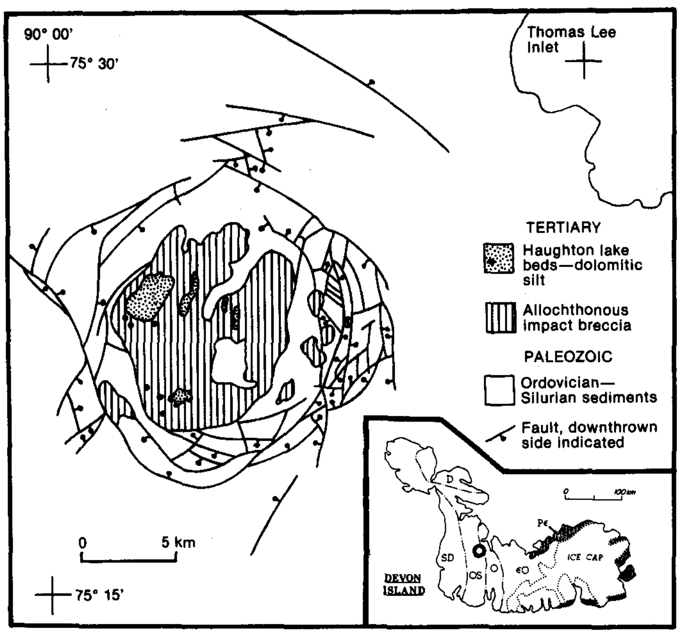

FIG 2. Location and generalized geology of Haughton crater. Stippled areas indicate exposures of the Haughton Formation (from Hickey *et al.* 1988).

Betula and Ericales; and megaspores of *Isoetes* (Hickey *et al.*, 1988).

METHODS OF POLLEN ANALYSIS

Samples of 10-20 g were prepared for pollen analysis. Sediment samples were cleaned thoroughly and broken into pea-size pieces. These sediments were disaggregated further with hot 5% KOH and sieved through a 150-mμ mesh screen to remove large rock fragments. The residue was treated with 5% HCl until there was no reaction and then with 40% HF for 24 hours. Clay was removed by washing with 5% sodium pyrophosphate and sieving through a 7 mμ Nitex screen. Material from the type section was mounted in glycerine jelly. Samples from Sections 8451, 8454, 8455, and 8456 were mounted in silicone oil.

Twelve units from the Haughton type section contained pollen and spores in sufficient number to be tallied. The palynomorphs were recovered from mudstone and siltstone and their state of preservation ranged from poor to good. The coarser sediments were barren of pollen (see Table 1 for a listing of pollen-bearing sediments). Between 87 and 1016 palynomorphs were counted per sample.

TABLE 1. Type section of the Haughton Formation, 75°4′4″N, 89°49′25″W, Haughton Astrobleme, N.W.T., Canada[1]

Unit no.	Thickness (m)	Pollen sample	Description
26	1.7		Sand, fine-grained, silty, well-sorted, massive, upper contact mantled by a rubble cap, limonite stained at base.
25	1.2		Silt, coarse, sandy, pebbly, dolomitic.
24	0.8		Mud, medium tan, grading upward to a light tan siltstone above 60 cm.
23	0.9		Silt, coarse, sub-angular (s.a.) to angular (a.), light tan.
22	0.8	8512v	Interbedded tan silt and medium grey mud, silt predominates, limonite stained.
21	1.8	8512u	Same as unit 22, except mud predominates, interbeds are 1-3 cm thick and extend from base to 130 cm. Unit contains limonite cemented, dark red-weathering concretions that form a prominent band on the slope as well as the rhinoceros locality (84-01) of Dawson.
20	0.7		Silt with medium grey clay stringers and limonite-stained layers in the basal 30 cm.
19	0.9	8512s	Mud, chippy, slightly silty, yellowish-brown with limonite staining and grey and brown interbeds.
18	2.6		Silt, coarse, slightly granular, s.a. to a., massive, bluff-forming, light tan, slightly reddish at base. "Cliff sand" unit.
17	2.9	8512q	Interbedded brownish-grey mud and tan silt with scattered red-weathering concretions.
16	1.7		Silt, s.a. to a., tan.
15	2.0	8512o	Interbedded medium brownish-grey mud and tan silt with scattered red-weathering concretions.
14	1.9		Silt, orange-yellow with mud lenses at base but becoming cleaner upward as it becomes orange and parallel-laminated. Brownish-red, flattened, iron oxide-cemented siltstone or very fine grained (v.f.g.) sandstone concretions occur at the top of the unit. This is equivalent to the artiodactyl level (84-02) and to the rabbit and shrew level.
13	2.6		Silt, coarse, slightly granular, s.a. to a., light tan, with lignitized wood fragments, twigs, roots, stems, cones, and seeds occurring in carbonaceous clay lenses. Top of unit is a mudstone. "Wood silt" unit.
12	0.6		Silt, laminated, yellowish-tan with abundant limonite nodules forming a distinctive layer, interbedded mudstones increase upward. Unit grades into 13, above.
11	1.6	8512k	Mud, medium, yellowish-brown, weathering to light yellowish-brown. Limonite nodules at 150, 90, and 60 cm.
10	0.4		Silt, coarse, s.a. to a. light yellowish-grey and apparent yellow and grey alternating laminae.
9	1.2	8512i	Mud, plastic, medium yellowish-grey. Brown silt interbeds near top, some limonite lag on the slope.
8	1.2	8512h	Silt, coarse, sandy, poorly sorted, massive, tan-weathering, reddish-brown in the basal 5 cm. Some evidence of cm-scale bedding.
7	2.4	8512g	Interbedded medium yellowish-brown mud and light yellowish-brown silt; interbeds often separated by thin limonite crusts.
6	1.0		Silt, coarse, s.a. to a., weathers to light yellowish-tan.
5	1.0	8512e	Mud, yellowish-grey, with brown laminae at base.
4	1.0		Silt, coarse, s.a. to a., light tan, with brown clay laminae.
3	1.0	8512c	Silt, fine, slightly granular, massive, yellowish-grey massive mud interbeds.
2	1.3		Silt, coarse, sandy, poorly sorted, light tan, with medium grey massive mud interbeds.
1	1.0	8512a	Sand, v.f.g., s.a. clayey, massive, medium yellowish-brown, with grey and brown clay lenses. Base of the section. Below this point the slope is extensively slumped to the stream channel but appears to be derived from light yellowish-grey silt, probably equivalent to one of the beds at the top of section 8455.

[1]From Hickey *et al.* (1988).

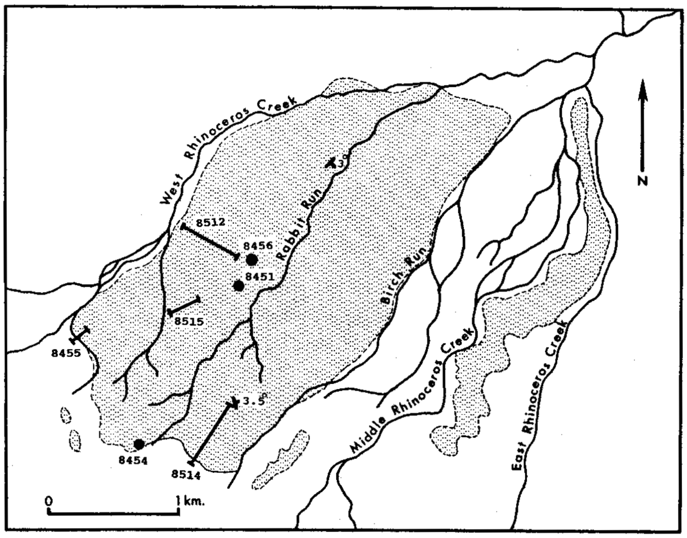

FIG. 3. Map of the main exposures of Haughton Formation showing type locality and other exposures discussed in text and strike and dip measurements (from Hickey *et al.*, 1988).

Most of the pollen and spores could be assigned to modern orders, families, and genera of plants on the basis of similar morphology. Although this similarity does not necessarily imply that ecologic or climatic requirements were the same as modern counterparts, it is interesting that the fossil assemblages have fairly good analogues in the modern pollen rain of eastern North America. These modern analogues provide a first approximation of the paleoenvironment, which can be tested by independent proxy data.

A second group of pollen and spores was badly deteriorated and not comparable to modern types. They are probably rebedded older palynomorphs from the Eureka Sound Formation (Cretaceous to Eocene) (Choi, 1983), which may have been as thick as 200 m on western Devon Island at the time of the Haughton impact (Hickey *et al.*, 1988). On the pollen diagram these types are listed as pre-Haughton taxa.

A third group of palynomorphs was too deteriorated and corroded to be identified. They are listed as indeterminate and probably represent a combination of reworked older forms and Haughton taxa that were poorly preserved. Taxa designated as unknown could not be identified from published atlases or with available reference material at the Carnegie Museum of Natural History.

For the type section, the sum of the modern, indeterminate, and unknown types was the denominator to calculate percentages of taxa assumed to date to Haughton time. The sum of all palynomorphs was used to calculate percentages of pre-Haughton taxa. At the other localities, total pollen and spores was the denominator for calculating percentages (Table 2). Common names for the important pollen taxa are shown on Table 2.

POLLEN RESULTS

Figure 4 presents the pollen and spore percentages through the type section. *Pinus* pollen is the most abundant pollen type for most units and was present in values of 3-62%. Other common taxa are Ericales (0-23%), *Corylus*-type (2-26%), *Betula* (0-7%), and *Alnus* (0-13%). *Picea* reaches values of 16% near the top of the section at 8512s, but at other levels it is present in values <2%. *Larix*, Cupressaceae, and *Ulmus*/*Zelkova* occur in small percentages (<2%) at most levels. Hardwood taxa, including *Liquidambar*, *Juglans*, *Pterocarya*, *Fagus*, *Carya*, *Castanea*, *Ilex*, and *Acer*, appear as single specimens in the type section and other sections. Spores, including *Selaginella*, *Lycopodium*, and *Sphagnum*, are present in moderate amounts, and *Osmunda* and *Botrychium* are less abundant. The amount of indeterminate pollen varies, reaching values >25% at the base and at intermediate levels 8512g, 8512h, 8512i, and 8512k. Among the pre-Haughton taxa are *Gleichenia* and *Cicatricosisporites* of Cretaceous age. A.R. Sweet (reported in Frisch and Thorsteinsson, 1978) found *Laevigatosporites*, *Paraalnipollenites*, and *Orbiculapollis* of Maestrichtian to Paleocene age. Sweet also reported *Engelhardia* and *Tilia* pollen from Haughton sediments, but neither was identified in this study. Reworked pollen from the underlying Eureka Sound Group is commonly reported from Neogene pollen assemblages in the Arctic.

In pollen samples from the other Haughton localities, the flora is generally the same (Table 2). *Pinus* is the dominant pollen type at 8451, 8455, and 8456, accounting for 54%, 43%, and 26% of the assemblages. At 8456, two specimens of haploxylon-type *Pinus* were identified. *Picea* is present in amounts ranging from 1 to 4%. *Abies*, Cupressaceae, and *Tsuga* are present in 8451, and *Abies* is present in 8455 and 8456 as single grains. *Alnus* pollen is the most common type in 8454 (22%) and is well represented in 8456 (14%). *Corylus*-

TABLE 2. Percentages of pollen and spores from other localities of the Haughton Formation[1]

Taxon	Locality 8451	8454	8455	8456
Pinus (pine)	54.1	12.5	42.9	26.4
P. strobus-type (white pine)	—	—	—	0.9
Picea (spruce)	4.3	1.4	0.8	2.3
Abies (fir)	2.1	—	—	—
Cupressaceae	0.8	—	—	—
Tsuga (hemlock)	0.5	—	—	—
Ericales	1.9	—	3.9	5.1
Salix (willow)	—	—	—	0.4
cf. *Fraxinus* (ash)	1.3	—	0.6	—
cf. *Fagus* (beech)	0.3	—	0.4	0.4
Quercus (oak)	—	—	—	0.4
Ulmus/*Zelkova* (elm/keaki)	0.8	9.7	1.9	3.7
Juglans (walnut)	—	—	1.1	0.4
Pterocarya (wing nut)	—	—	2.2	0.4
Carya (hickory)	—	4.2	7.5	1.9
Corylus-type (hazel)	3.6	10.5	12.5	6.3
Betula (birch)	2.1	13.2	8.0	4.2
Alnus (alder)	2.1	22.2	3.0	14.4
Acer (maple)	—	—	0.6	—
Liquidambar (sweetgum)	—	—	—	0.4
Castanea (chestnut)	—	—	—	0.9
TOTAL ARBOREAL POLLEN	73.9	73.7	85.4	68.5
Cyperaceae	0.3	0.6	0.3	—
Chenopodiineae	0.3	—	—	—
Cruciferae	0.3	—	—	—
Pteridium-type	—	0.6	0.8	—
Dryopteris-type	0.5			
Lycopodium-type	0.5	0.6	0.3	0.4
Osmunda-type	1.1	0.6	2.2	2.8
Sphagnum-type	1.6	0.6	4.4	8.3
pre-Haughton spores	6.9	1.2	—	—
Unknown	1.9	2.1	0.6	0.9
Indeterminate	13.6	19.4	6.0	19.1
TOTAL POLLEN (number)	375	144	361	216

[1]Total pollen is denominator used to calculate percentages.

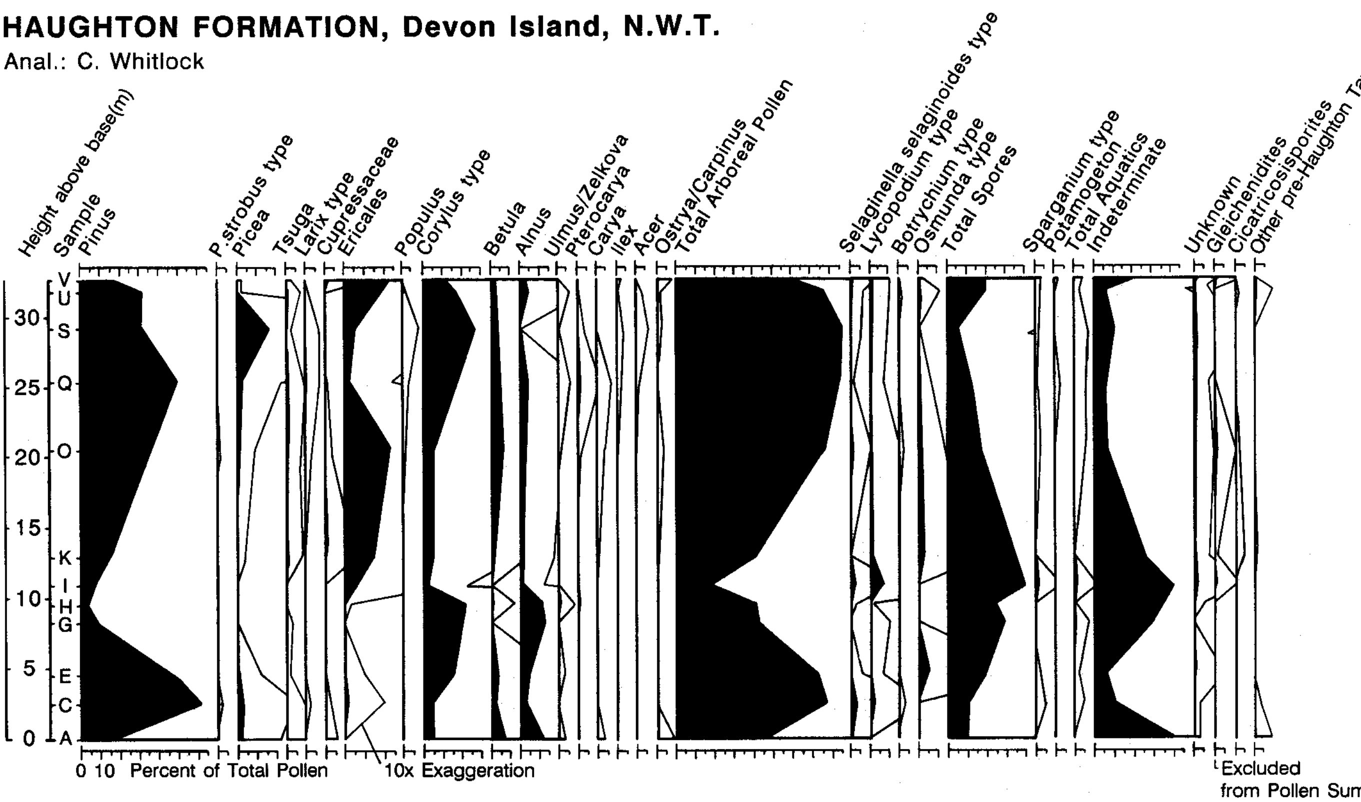

FIG. 4. Pollen percentage diagram, Haughton type section.

type is present in moderate amounts in all samples (2-12%). Many of *Corylus*-type grains were poorly preserved and it is possible that this category includes deteriorated *Myrica*, *Engelhardia*, and other *Triporopollenites*, as well as *Corylus*. *Betula* (2-13%) and Ericales (2-5%) are present in moderate amounts. *Ulmus/Zelkova* is common in 8454 (10%) and present in the other localities. Pollen of temperate hardwoods (*Acer*, *Liquidambar*, *Fagus*, *Quercus*, *Juglans*, *Pterocarya*, and *Carya*) occur as single specimens.

The pollen taxa from the type section exhibit some stratigraphical trends. *Pinus*, *Tsuga*, and *Betula* percentages are high at the base of the section in levels 8512a, 8512c, 8512e, drop to their lowest values at intermediate levels 8512g, 8512h, 8512i, and then return to high values at the top of the section in levels 8512o, 8512q, 8512s, 8512u, 8512v. *Pinus strobus*-type (haploxylon-type pine) is present in 8512c and 8512o. *Picea*, *Larix*, and Ericales are highest at the top of the section. *Populus* is present at the top of the section. *Corylus* and *Alnus* are present in 8512e, 8512g, 8512h, and also at the top of the section. Single grains of *Juglans*, *Carya*, *Acer*, *Ilex*, and *Liquidambar* were found at the top of the section.

A vegetational reconstruction for the Haughton assemblage rests on several assumptions. First, it is assumed that a significant component of the palynoflora is reworked from older sediments and therefore not useful in reconstructing the vegetation at the time of Haughton deposition. The poor preservation of the pre-Haughton forms is consistent with this postulate. Second, in the case of indeterminate forms, the deterioration is presumed to be unbiased towards any particular type, a situation that is probably not true. Third, by matching the Haughton assemblages to modern pollen spectra, an assumption is made that the ecological requirements of the Miocene taxa were similar to modern taxa at the level of genus. In the case of particular taxa, this assumption may not be valid. Matthews (1987), for example, suggests that *Epipremnum* found in the Beaufort Formation may have had boreal affinities very different from the modern tropical genera. For the dominant Haughton taxa, however, the ecological requirements are probably comparable at the taxonomic level of the pollen identifications. A final assumption is that latitudinal gradients in the early Miocene separated boreal forest, mixed conifer/hardwood forest, and hardwood forest. A somewhat different vegetational mixture from that of today might have existed, however, for warmer ocean temperatures in the Arctic during the Miocene necessarily altered the latitudinal lapse rate.

On the basis of comparison with modern pollen distributions, the vegetation during deposition of the Haughton Formation is inferred to be mixed conifer-hardwood forest dominated by *Pinus*, *Picea*, *Tsuga*, *Larix*, *Betula*, *Alnus*, and *Corylus*. The Haughton assemblage accords most closely with present-day pollen spectra from the transition between the boreal forest and the conifer-hardwood forest in eastern coastal North America (Davis and Webb, 1975; Delcourt *et al.*, 1984). The analogue, however, is by no means perfect. *Quercus* typically accounts for 10% of the pollen in modern pollen-rain samples from the present-day forest, while at Haughton it is not present in the type section and occurs in trace amounts only at locality 8456. A herbaceous component in modern spectra is attributable to anthropogenic disturbance (agriculture and forest clearance); in the Haughton section, herbaceous taxa are nearly absent. Gramineae pollen is not found, Cyperaceae pollen is uncommon, and Rosaceae, Chenopodiineae, and Cruciferae are present as single grains. Ericales pollen, however, occurs in values that exceed the modern average percentages presented by Davis and Webb (1975) and Delcourt *et al.* (1984) but that are most typical of samples from maritime heath. Ericales tree and shrub genera are generally poor pollen producers. The increase in ericaceous pollen towards the top of the section suggests instead an expansion of boreal heath at the end of Haughton time. These wetland communities may have supported *Larix* and *Picea*, just as they do today, as well as various ferns, *Sphagnum* and *Selaginella*. *Corylus* is better represented at Haughton than in the modern pollen rain from the conifer-hardwood forest, and in general *Picea* is underrepresented compared to present-day values. The occurrence in the type section of *Picea* cones, still unidentified at the species level, attests, however, to the local presence of the tree even at stratigraphic levels where spruce pollen percentages are low. Pollen of southern hardwood trees and shrubs is present in low amounts and matches modern values in the southern boreal and mixed conifer-hardwood forest attributed to distant sources. This comparison suggests that *Liquidambar*, *Castanea*, *Platanus*, and *Ilex* may not have been growing in the Haughton region.

On the Köppen Scale, the climate during Haughton time would be placed in the zone of humid, cool-temperate climate with severe winters (Daf to Dbf). This designation implies some snow accumulation and a lake that was seasonally frozen. Hickey *et al.* (1988) have estimated that mean annual temperature was between 0 and 11°C. The coldest monthly mean lay somewhere between −17 and +1°C. Climatic data assembled by Ritchie (1987) circumscribe the range of monthly mean temperatures more precisely. Vegetation supporting *Pinus*, *Picea*, *Larix*, *Tsuga*, *Abies*, Ericales, *Alnus*, *Betula*, *Populus*, *Acer*, *Ostrya/Carpinus*, and *Tilia* fall within a mean annual temperature range of 15-20°C. Modern distributions of *Tsuga*, *Ulmus*, and temperate *Betula* (for example, *B. alleghaniensis*) suggest a mean January temperature of −15°C and an absolute minimum January temperature of −40°C. The number of frost-free days reconstructed depends on whether temperate hardwoods are assumed to have been present. If *Acer*, *Ulmus*, *Juglans*, and tree *Betula* grew locally, more than 120 days with above-freezing temperatures are implied. The boreal taxa imply a growing season of less than 180 days. The maritime aspect of the flora, suggested by the abundant Ericales pollen, is reminiscent of the southern Maritime provinces of Canada, where the climate has uniformly distributed precipitation (ca. 1000 mm/yr) and cool summers with ca. 18°C July temperatures.

Comparison to Other High Arctic Pollen Data

In his study of the Haughton pollen, Sweet (in Frisch and Thorsteinsson, 1978) noted two distinct microfloras. A sample collected 30 m above the base of the lake deposits in a place where they overlie Paleozoic limestone contained *Alnus*, *Corylus*, *Sphagnum*, *Lepidodiumsporites*, and a few specimens of *Acer*, Gramineae (?), ?*Castanea*, Ericaceae, tricolpate pollen, *Tilia*, and *Engelhardia*. Nine metres higher in the section, palynomorphs were less abundant and included a few specimens of *Alnus*, *Corylus*, Gramineae, *Engelhardia*, *Lycopodiumsporites*, and *Sphagnum*. Missing from this list is any conifer pollen, the most abundant form in the type section and in other localities described here. Based on the possible presence of Gramineae pollen, Sweet suggested that the sample is younger than Oligocene in age. *Tilia* pollen was used to infer an age of Eocene or younger; the occurrence of *Acer* argued for an age no younger than Pliocene. On these lines of evidence, an age of Miocene to Pliocene was assigned.

A comparison of the Haughton flora to other late Tertiary fossils from the Arctic is not straightforward. Differences in latitude and altitude and their effect on temperature surely led to gradients in the vegetation, just as today. Differences in proximity to the coast and thus maritime conditions, orographic modification of precipitation and wind patterns, and ocean temperatures and circulation would also impose environmental variability across the Canadian arctic archipelago. The best-known, best-studied, and best-dated northern Tertiary floras lie in the Yukon Territory and around Cook Inlet in southern Alaska (Matthews and Ovenden, 1990-this issue; Wolfe *et al.*, 1966; Wolfe and Tanai, 1980), but the much more southerly location of these floras limits their usefulness for comparison.

The Beaufort Formation of the arctic islands contains many floras that encompass a considerable range of ages. Many of the sections from which floras were recovered may not be correlative with the type section on Prince Patrick Island. Localities referred to the Beaufort Formation are found on the eastern fringe of the Beaufort Sea on Prince Patrick Island, Banks Island, and Meighen Island (Matthews and Ovenden, 1990-this issue), as well as on eastern Axel Heiberg Island (Hills, 1987) and Ellesmere Island. Pollen and spores, macrofossils, and insect remains from several of these localities have been well studied, but the age and correlation of the different sections is imprecise (Matthews *et al.*, 1986; Matthews, 1987; Matthews and Ovenden, 1990-this issue).

Hills (1987) suggests that the Beaufort Formation ranges in age from Oligocene on Axel Heiberg Island to middle and late Miocene on Banks and Meighen islands, and thus some similarity with the Haughton Formation is not surprising. Hills's arguments for the age assignments are as follows: the Axel Heiberg sections contain *Metasequoia occidentalis*, *Osmunda*, *Picea banksii*, *Pinus* (two needle), and *Carya*. Presence of *Metasequoia* is the primary criterion for an Oligocene age; however, in the Cook Inlet sequence *Metasequoia* persists into the Homerian, thus until approximately 10 Ma (Wolfe and Tanai, 1980).

On Banks Island, the lower Ballast Brook locality contains macrofossils of *Pinus* (two and five needle), *Picea banksii*, *Glyptostrobus*, *Tsuga*, and *Epipremnum crassum* and pollen of *Juglans*, *Tilia*, *Carya*, and *Osmunda*. At Duck Hawk Bluffs, *Juglans-eocinerea* and *Metasequoia* were found in the lower section, along with pollen of *Alnus rugosa*-type, *Picea*, *Pinus* (some haploxylon-type), *Betula*, *Carya*, and *Tilia* (Matthews *et al.*, 1986). An age of late early Miocene to early middle Miocene, or possibly even late Oligocene is inferred from the taxodiaceous taxa, *Liriodendron*, *Phyllanthus*, and *Actinidia*, which are not found in other Neogene deposits (Matthews, 1989). The upper sections at Ballast Brook are thought to be middle to late Miocene in age (Matthews and Ovenden, 1990-this issue). It should be noted that their flora of *Pinus* (two and five needle), *Picea*, *Larix*, *Thuja*, *Juglans*, *Tilia*, and *Carya*, and ericaceous taxa matches the Haughton floral assemblage reasonably well. The Beaufort sections, however, contain more nonarboreal taxa than at Haughton, including small percentages of Gramineae, *Artemisia*, and other herbs. This nonarboreal component implies an age younger than 22 Ma for the upper Ballast Brook section.

Tundra elements are present in Beaufort sections on Meighen Island, suggesting the appearance of a cool forest-tundra environment by the end of Beaufort time. The tundra aspect of the vegetation probably reflects its location near a cool Arctic Ocean. The Meighen Island flora is different from the forest-tundra vegetation described from late Pliocene/early Pleistocene (Matuyama age) floras in the Kap København Formation of northern Greenland (Funder *et al.*, 1985; Bennike and Böcher, 1990-this issue), the Worth Point Formation of Banks Island, and the Gubik Formation of northern Alaska (Barendregt and Vincent, 1990), in that it contains a significant number of extinct conifer species (Matthews, 1987). Its inferred older age is supported by strontium isotope analysis of *Arctica* shells from associated marine sediments, which yielded a late Miocene age (Matthews, 1989). A pollen assemblage from the Beaufort Formation on Ellesmere Island (Riediger *et al.*, 1984), mixed with marine dinocysts indicative of an early Miocene age, resembles the Haughton assemblage in the presence of *Picea*, *Pinus*, *Alnus*, *Corylus/Carpinus*, *Betula*, *Myrica*, *Quercus*, and *Liquidambar*.

The Nuwok Formation on the North Slope of Alaska features a pollen flora that is also similar to that at Haughton. Wolfe and Tanai (1980) assigned the unit a late early Miocene to early middle Miocene age (Upper Seldovian) on the basis of *Pterocarya* pollen. Foraminifera suggest a late Oligocene age, as does strontium isotope analysis on *Arctica* shells, but ostracodes imply a Pliocene age (see Matthews, 1989). Ager (1987) describes a conifer-dominated pollen assemblage of *Pinus*, *Picea*, *Larix*, and Cupressaceae, as well as *Betula*, *Alnus*, and small amounts of *Pterocarya*, *Liquidambar*, *Tilia*, *Ilex*, and *Ulmus/Zelkova*. Since the Nuwok Formation is located south and west of the Haughton Formation, its age may well be younger despite the floristic similarities. Matthews (1989), however, argues for an age older than the Beaufort marine unit on Meighen Island.

FAUNAL RESULTS

Most of the vertebrate remains from the Haughton Formation occur in two layers. The more productive layer is unit 14, 16.3 m above the base of the formation, where fossils occur mostly in and weathered out of dolomitic concretions. Remains of rabbits, family Leporidae, are most common where this layer occurs. A second fossiliferous level, 10.8 m higher in unit 21, has produced a nearly complete skull and skeleton of a rhinoceros. Fish remains are largely concentrated in the southern exposures of the main outcrop area, slightly lower than the rabbit layer.

Numerous concretions contain fragmentary fish remains. Although most of these are incomplete, two salmoniform fishes have been identified, a trout, *Eosalmo* sp., and a smelt-like fish, cf. *Osmerus* sp. One bird, a swan, Tribe Cygnini, genus and species indeterminate, is represented by four phalanges. Four kinds of mammals currently recognized are: a shrew, family Soricidae, subfamily Heterosoricinae, cf. *Domnina*, known by skull and jaws; a rabbit, family Leporidae, resembling some North American species referred to *Desmatolagus*, represented by numerous complete and partial skulls, jaws, and postcranial elements; a rhinoceros, family Rhinocerotidae, known by a nearly complete, though broken, skull and skeleton; and an artiodactyl of uncertain affinities, known by several upper teeth, fragmentary jaws, and postcranial elements.

This assemblage contains some information of environmental significance. For example, trout and smelt are distinctive northern cool-water fishes and here provide some evidence for a cool temperate climate. Today North American species of swan, family Anatidae, inhabit marshy lakes and ponds but do not occur as far north as Devon Island. Presence of the swan suggests less severe climatic conditions for the area than today. The mammals are less indicative of environment, although the closest fossil relatives of the shrew and the leporid are northern in distribution: heterosoricine shrews occur in North America and Europe in the middle Tertiary; and *Desmatolagus*-like leporids are known from North America and northern Asia.

An age assessment based solely on this fauna would be relatively imprecise. Some swan-like anatids have been described from the Rupelian and Aquitanian of Europe, but otherwise the fossil record of swans is Pliocene and younger. *Domnina* ranges through the Oligocene and Miocene, as do *Desmatolagus*-like leporids. The rhinoceros has primitive dental features, resembling some Oligocene genera, but shows derived features in the skeleton. The artiodactyl has a uniquely derived tooth pattern. Fortunately, the date of the impact that allowed formation of the lake sets the fauna into a reasonable temporal context as Aquitanian.

None of the members of the vertebrate fauna shows close affinities with the Eocene Eureka Sound fauna of the arctic islands (West and Dawson, 1977), but this would not be expected in light of temporal distance and environmental differences. It is possible, however, that the highly distinctive morphologies of the rhinoceros and artiodactyl indicate that some environmental or geographic isolating mechanisms separated the Devon Island fauna from others and have done so for some time. Perhaps Lancaster Sound (Kerr, 1981) was already an effective open-water barrier to north and south movements of terrestrial vertebrates.

CONCLUSIONS

The Aquitanian flora and fauna from the Haughton Formation provide a radiometrically dated point to which other High Arctic assemblages can be compared. Plant and vertebrate evidence indicates that the habitat on northern Devon Island had a humid, cool temperate climate with severe winters but a maritime coastal effect.

Paleobotanical data from the Haughton Formation, with its temporal assignment, combined with those from other Neogene sites across the Arctic permit tracing vegetational changes from temperate forest to tundra during the last 22 Ma. Some Beaufort localities on Banks Island appear to be older than Haughton, and some on Axel Heiberg are possibly Oligocene. Many exposures of the Beaufort Formation on Prince Patrick, Banks, and Meighen islands appear to be younger than Haughton, ranging in age from middle Miocene to early Pliocene. The Nuwok Formation on the eastern North Slope of Alaska contains a flora similar to that at Haughton and has been tentatively assigned to the middle Miocene (upper Seldovian). New dates, however, suggest possibly a late Oligocene age for the Nuwok Formation. Younger still are the floras from the Kap København Formation on Greenland, believed to be late Pliocene-early Pleistocene (Funder *et al.*, 1985), and the Worth Point Formation on

Banks Island, believed to be late Pliocene-middle Pleistocene in age (Barendregt and Vincent, 1990).

The Haughton fauna shows no close affinity to the Eocene arctic Eureka Sound faunas. It provides the first insight into faunal developments at high latitudes during the early Neogene and suggests endemism for the terrestrial vertebrates.

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