

Beaufort Formation (Late Tertiary) as Seen from Prince Patrick Island, Arctic Canada¹

JOHN G. FYLES²

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ABSTRACT. The Beaufort Formation, in its type area on Prince Patrick Island, is a single lithostratigraphic unit, a few tens of metres thick, consisting of unlithified sandy deposits of braided rivers. Organic beds in the sand have yielded more than 200 species of plants and insects and probably originated during the Pliocene, when the area supported coniferous forest. This Beaufort unit forms the thin eastern edge of a northwest-thickening wedge of sand and gravel beneath the western part of the island. These largely unexposed beds, up to several hundred metres thick, include the Beaufort unit and perhaps other older or younger deposits. On the islands northeast and southwest of Prince Patrick Island (Meighen Island to Banks Island), the name Beaufort Formation has been applied to similar deposits of late Tertiary age. Most recorded Beaufort beds on these islands are stratigraphically and paleontologically equivalent to the "type" Beaufort, but a few sites that have been called Beaufort (such as Duck Hawk Bluffs and the lower unit at Ballast Brook, on Banks Island) differ stratigraphically and paleontologically from the "type" Beaufort. This paper recommends that these deposits (probably middle Miocene) and others like them be assigned new stratigraphic names and not be included in the Beaufort Formation as now defined. Informal names Mary Sachs gravel (Duck Hawk Bluffs) and Ballast Brook beds are proposed as an initial step. Formal use of the name Beaufort Formation should be restricted to the western Arctic Islands.

Key words: Beaufort Formation, Prince Patrick Island, arctic Canada, late Tertiary, Pliocene, plant fossils, paleo-environment, fluvial sediments, stratigraphic nomenclature

RÉSUMÉ. La formation de Beaufort, dans sa région type de l'île Prince Patrick, est une unité lithostratigraphique unique, de quelques dizaines de mètres d'épaisseur, composée de sédiments sableux non lithifiés de cours d'eau anastomosés. Les couches organiques dans le sable ont produit plus de 200 espèces de plantes et d'insectes datant probablement du Pliocène lorsque la région supportait une forêt de conifères. Cette unité de Beaufort forme la mince extrémité orientale d'un coin de sable et de gravier s'épaississant vers le nord-ouest au-dessous de la partie occidentale de l'île. Ces couches qui affleurent très peu et qui mesurent jusqu'à plusieurs centaines de mètres d'épaisseur, comprennent l'unité de Beaufort et peut-être d'autres dépôts plus anciens ou plus récents. Dans les îles au nord-est et au sud-ouest de l'île Prince Patrick (de l'île Meighen à l'île Banks), le nom formation de Beaufort a été attribué à des dépôts semblables du Tertiaire tardif. La plupart des couches de Beaufort relevés dans ces îles sont stratigraphiquement et paléontologiquement équivalents au "type" Beaufort, mais quelques sites que l'on a appelés Beaufort (comme les falaises Duck Hawk et l'unité inférieure au ruisseau Ballast dans l'île Banks) diffèrent par leur stratigraphie et leur paléontologie due "type" Beaufort. Il est recommandé dans le présent document que ces dépôts et d'autres semblables changent d'appellations stratigraphiques et soient exclues de la formation de Beaufort. En première étape, il est proposé d'adopter comme appellations non officielles gravier de Mary Sachs (falaises Duck Hawk) et couches du ruisseau Ballast. L'emploi officiel de formation de Beaufort devrait être limité aux îles arctiques occidentales.

Mots clés: Formation de Beaufort, île Prince Patrick, Arctique canadien, Tertiaire tardif, Pliocène, plantes fossiles, paléo-environnement, sédiments fluviaux, nomenclature stratigraphique

РЕФЕРАТ. Формация Бофорта образует в своей типовой области на острове Принс Патрик единое литостратиграфическое подразделение мощностью несколько десятков метров, состоящее из нелигнифицированных песчаных отложений разветвленных рек. Во входящих в состав этих отложений слоев органических остатков обнаружено более 200 видов растений и насекомых. Эти слои сформировались, очевидно, в плиоцене, когда в этом районе произрастали хвойные леса. Формация Бофорта образует тонкий восточный край утолщающегося в северо-западном направлении клина песка и гравия, залегающего под западной частью острова. Эти почти нигде не выходящие на поверхность пласты, мощность которых достигает нескольких сот метров, включают в себя формацию Бофорта и, возможно, другие более древние или более поздние отложения. На островах, лежащих к северо-востоку и к юго-западу от острова Принс Патрик (от острова Миен до острова Банкс), название "формация Бофорта" применяется по отношению к сходным отложениям конца третичного периода. Большая часть выявленных бофортских слоев на этих островах стратиграфически и палеонтологически соответствуют бофортскому "типу", однако стратиграфические и палеонтологические характеристики нескольких толщ, получивших название бофортских (например, утес Дак Хок Блаффс и нижнее подразделение в разрезе ручья Балласт Брук на острове Банкс), отличаются от бофортского "типа". Мы предлагаем дать этим и другим подобным отложениям новые стратиграфические названия и не включать их в формацию Бофорта при ее нынешнем определении. В качестве первого шага предлагается принятие таких неофициальных названий, как "гравий Мэри Сакс" (утес Дак Хок Блаффс) и "слои Балласт Брук". Применение названия "формация Бофорта" следует официально ограничить западными островами Канадского Арктического архипелага.

Ключевые слова: формация Бофорта, остров Принс-Патрик, Канадская Арктика, конец третичного периода, пли-оцен, растительные остатки, палеосреда, речные осадки, стратиграфическая номенклатура.

INTRODUCTION

The Beaufort Formation is of current interest as a source of information on the climate and environment of arctic North America shortly before the onset of the "arctic" conditions that now characterize the region. The presence of these sands and gravels, containing abundant evidence of former forest conditions, was recognized by explorers in the mid-19th century. The deposits were formally named the Beaufort Formation by Tozer (1956) in the Mould Bay area of Prince

Patrick Island. From his original description, it is clear that Tozer intended the name Beaufort Formation to apply also to comparable deposits on other islands.

During the succeeding decade, largely as a result of reconnaissance surveys by Tozer and Thorsteinsson, the name Beaufort Formation was indeed applied to generally similar strata on all the islands facing the Arctic Ocean (Fig. 1) from Meighen Island at Latitude 80°N to the southwestern tip of Banks Island at Latitude 72°N (Thorsteinsson, 1961; Thorsteinsson and Tozer, 1959, 1962; Tozer and Thorsteinsson,

¹Geological Survey of Canada Contribution 17090

²Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8
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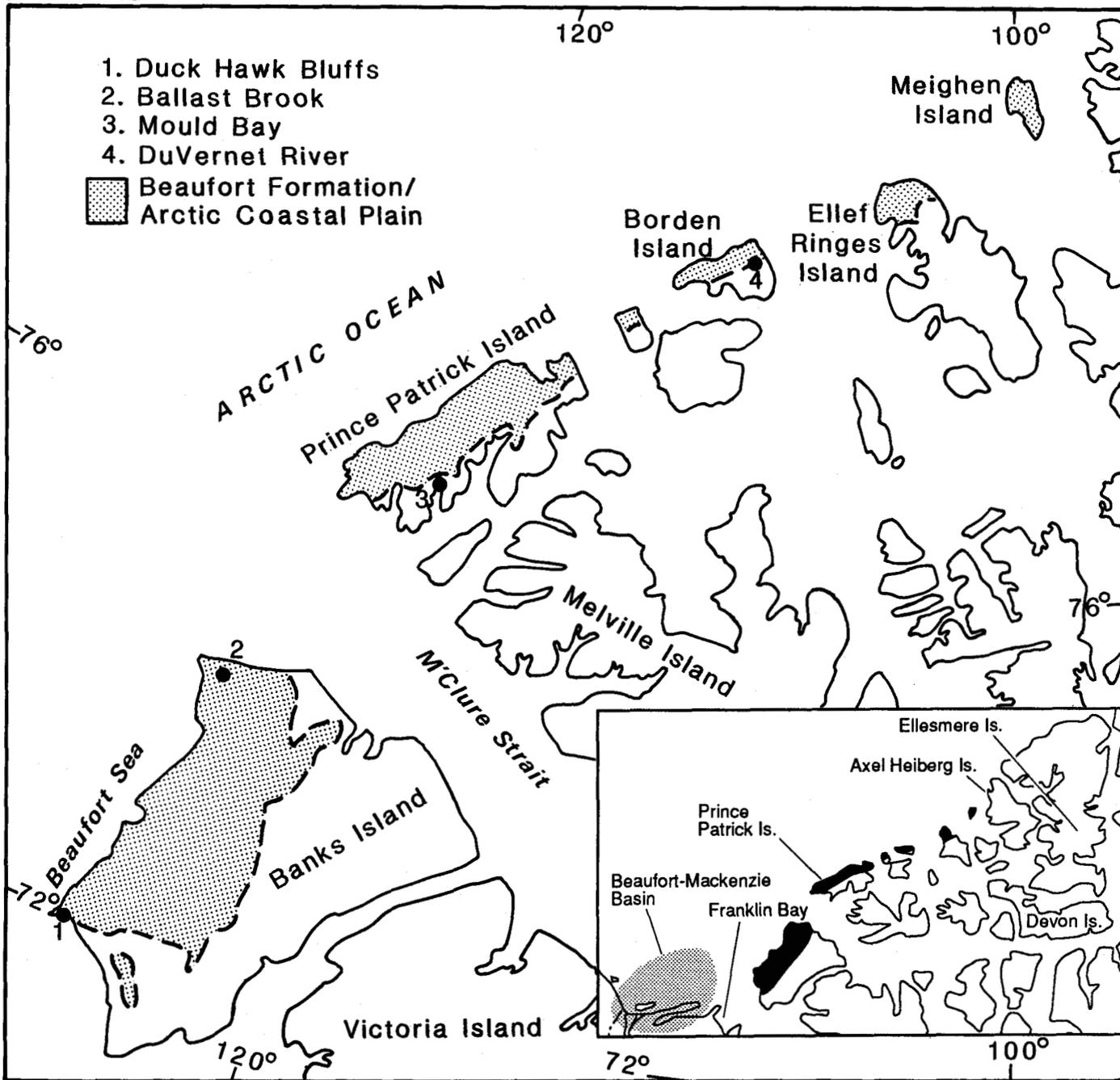


FIG. 1. Regional setting and distribution of Beaufort Formation and related strata, arctic Canada.

1964). More recently, following paleobotanical assignment of the Beaufort deposits on Banks Island to the Miocene (Hills and Ogilvie, 1970; Hills *et al.*, 1974), the name Beaufort Formation has been extended to Miocene or Neogene sediments in and around the Mackenzie-Beaufort basin southwest of the original belt and on Ellesmere and Axel Heiberg islands to the northeast. In the Mackenzie-Beaufort region, the term Beaufort has been applied by various authors to largely deltaic (marine) sediments of Miocene to Pliocene age. In a stratigraphic report on that region, Dietrich *et al.* (1985: 617) point out that "use of this term [i.e., Beaufort Formation] is fraught with many problems," that "unfortunately no definitive ages have ever been determined at the type section" and that "the relationship between the Banks Island Beaufort and the type section remains obscure."

Against this background, the present paper reports on results of investigations designed to improve knowledge of the Beaufort Formation in its type area on Prince Patrick Island and makes preliminary comments on correlation.

As a consequence of this focus on the type area, where the Beaufort Formation is a single distinctive stratigraphic unit, this paper takes a position on use of the name Beaufort Formation that is more restricted than that taken in some earlier publications. Thus, this paper recommends that the name Beaufort Formation should not be used for late Tertiary deposits that are not stratigraphically equivalent to the "type" Beaufort and that other names be used instead. I recognize that this proposal is only a first step in rationalizing the nomenclature and that there are different concepts of "the Beaufort" as seen from other islands (distant from the type section).

GENERAL CHARACTER OF THE BEAUFORT DEPOSITS

The deposits to which Tozer and Thorsteinsson and other early workers applied the name Beaufort Formation in the western Arctic Islands consist typically of unlithified, flat-lying quartz-rich sand and gravel and are characterized by the presence of abundant unaltered wood. They occur in a belt coinciding in a general way with the Arctic Coastal Plain and extending along the western part of all the low islands bordering the Arctic Ocean from Meighen Island to southern Banks Island. This belt (Fig. 1), 1200 km long and averaging 50 km wide (onshore), is broken by the NW-SE straits between the islands but is not significantly displaced either laterally or vertically across these valleys.

In typical exposures, the deposits are a few metres to a few tens of metres thick. They apparently increase in thickness across the belt towards the west or northwest and are presumed to extend beyond the present coastline beneath the Arctic Ocean, although direct information on this subject is not yet available. Characteristically, a major unconformity separates the Beaufort strata from a variety of underlying bedrock units of Paleozoic to Tertiary age.

BEAUFORT FORMATION ON PRINCE PATRICK ISLAND

The information presented below is based largely upon field investigations on Prince Patrick Island in 1964 by J.G. Fyles and in 1987 by Fyles, J. Devaney, and D.A. Hodgson. Figure 2 shows the extent of the formation on the island and the location of sites visited on the ground in 1964 and 1987, including the 12 sites at which Devaney prepared detailed sedimentological sections. The sites visited include several in the Mould Bay area where Tozer originally described the Beaufort Formation.

As is evident from Figure 2, the Beaufort Formation occurs as an elongated belt underlying the western two-thirds of Prince Patrick Island. This belt is largely within the part of the island described as the Arctic Coastal Plain. Surface exposures of Beaufort strata are confined almost entirely to the southeast margin of the belt, where the Beaufort deposits are thin and are dissected by valleys of numerous short streams draining towards the adjacent bays and inlets. Most of the data points on Figure 2 occur in this thin, marginal part of the Beaufort; principal exceptions are three of the petroleum exploration wells and the three coastal exposures in the south-western extremity of the island.

Stratigraphy and Sedimentology

In the exposures examined, the Beaufort strata are a few metres to more than 60 m thick, near-horizontal, and completely unlithified. The dominant material is quartz-rich, medium to coarse sand, and sandy pebble gravel. Gravel clasts are sub-round to round and consist dominantly of sandstone, quartzite, chert, and resistant fine clastic rocks. Metamorphic and igneous rock types are absent or exceedingly rare. Remarkably fresh unmineralized and uncompressed wood is a common constituent, scattered through the section or concentrated in lenticular layers. Devaney recognized the following facies:

- 1, clast-supported gravel (channel floor lags, bars); 2, abundant cross-bedded sand (channel floor dunes, linguoid bars); 3, rippled sand; 4, plane-laminated sand (minor); 5, horizontally bedded fines . . . mixes of sand, mud, and

woody detritus; 6, clay-rich mud (overbank suspension deposits); and 7, woody plant detritus, beds of flat-lying logs, sticks, twigs, wood chips, bark, leaves, moss, seeds, rare cones, insects (overbank deposits). The facies are interpreted to be sandy braided-river deposits. Facies 1 to 4 represent bar and channel deposits, with facies 2 the most abundant. Facies 3 to 7, relatively minor in amount, are interpreted as low-stage (and) overbank deposits. Rapid facies changes are the norm. Well defined fining upward sequences 1.2 to 2.5 m thick are uncommon [Devaney and Fyles, 1988].

These facies recur throughout the observed stratigraphic sections on Prince Patrick Island. Clearly defined marker beds or laterally traceable sub-units have not been recognized. Thus, from the information presently available, the Beaufort Formation in exposed sections on Prince Patrick Island is considered to form a single stratigraphic unit. The exposure illustrated in Figure 3 (15 km west of Mould Bay weather station and at 76°15'N, 119°55'W) is typical and is here designated as Reference Section 1 for the Beaufort Formation. Matthews *et al.* (1990) refer to this exposure as Devaney section 1: it is within the area originally described by Tozer as typical of the Beaufort Formation.

The Beaufort Formation on Prince Patrick Island lies on bedrock of Devonian to Cretaceous age, and at some sites the lowermost Beaufort strata are conspicuously gravelly. At one locality, for instance, a basal gravel, about 1.5 m thick and containing angular to sub-rounded cobble- to boulder-sized clasts from nearby bedrock units, lies between Beaufort sand and the underlying sandstone. The eroded top surface of the sandstone has relief of several metres in a distance

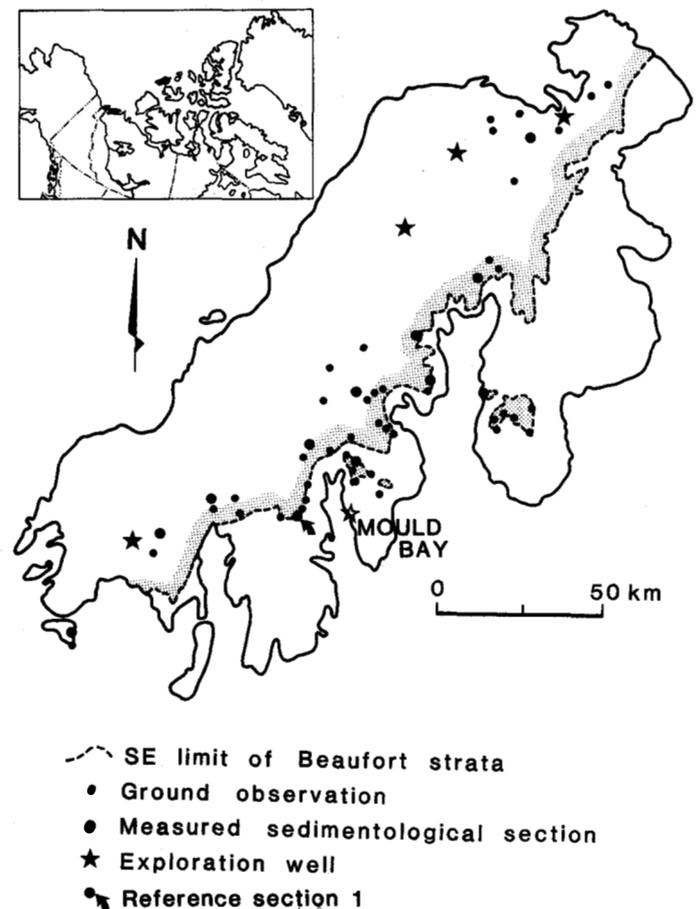


FIG. 2. Data locations, Beaufort Formation, Prince Patrick Island.

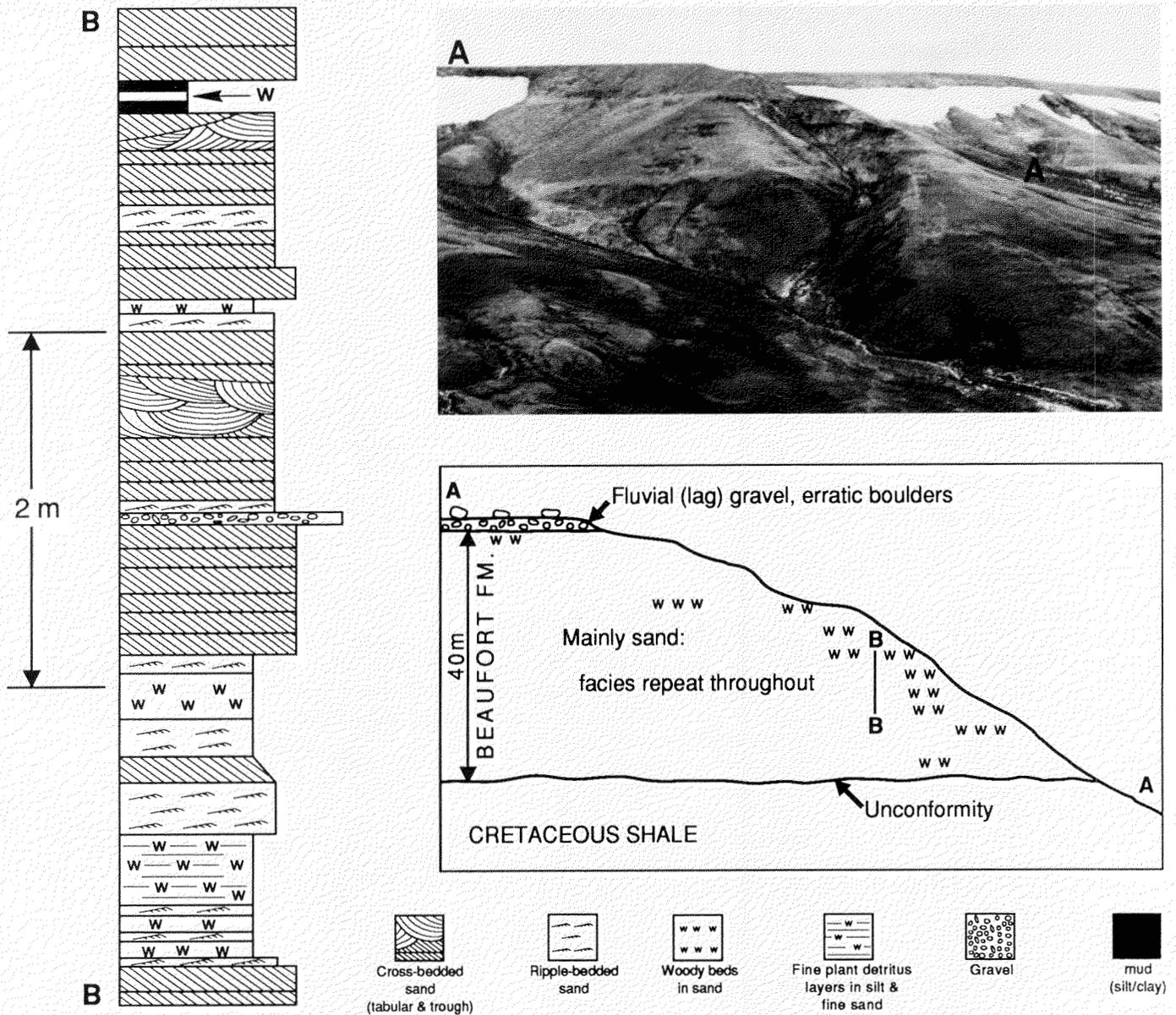


FIG. 3. Reference Section 1 for the Beaufort Formation, 15 km west of Mould Bay weather station (see Fig. 2). Facies diagram and photograph courtesy of J.R. Devaney, Department of Geology, University of Ottawa.

of about 100 m. On a regional scale, the sub-Beaufort surface decreases in altitude from east to west, although at some sites local relief on the basal surface obscures this general trend.

Commonly, the Beaufort sands are capped by 1-2 m of pebbly sandy gravel containing boulders. This gravel differs from that in the Beaufort Formation in the size of the boulders present (0.5-1 m common; exceptionally 2+ m), and the presence of clasts of diabase, granite, gneiss, limestone, etc., that are absent from (or exceptionally rare in) the Beaufort strata. This gravel cap or lag coincides with a summit-level plain that, on a regional scale, slopes gently down to the northwest, towards the coast of the Arctic Ocean. The profile of this plain across north-central Prince Patrick Island is shown on section B-B' (Figs. 4 and 5).

Figure 5 also shows the approximate position of the eroded upper surface of the Beaufort beds, the steeper profile of the bottom of the Beaufort unit, and northwestward thickening of the unit itself. In the southeastern half of the

profile, the Beaufort strata are only a few metres to a few tens of metres thick, increasing generally from southeast to northwest. This "thin zone" includes the entire outcrop belt of the Beaufort Formation in this part of the island. In contrast, the Beaufort unit thickens substantially northwestward along the northwest half of the profile, attaining a thickness of approximately 350 m beneath the arctic coast. This inference is based on petroleum industry subsurface data, as noted in Figure 4.

In southeastern Prince Patrick Island, both northeast and southwest of Mould Bay, ridges of Paleozoic and Mesozoic bedrock rise a few tens of metres above the high eastern margin of the supra-Beaufort plain; these rock ridges show no evidence of ever having been covered by Beaufort strata (Hodgson, 1990). This relationship is shown on Figure 5, section A-A', which also illustrates the northwestward decrease in altitude of the eroded upper surface of the Beaufort strata and their thickening in the same direction beneath the western part of the island.

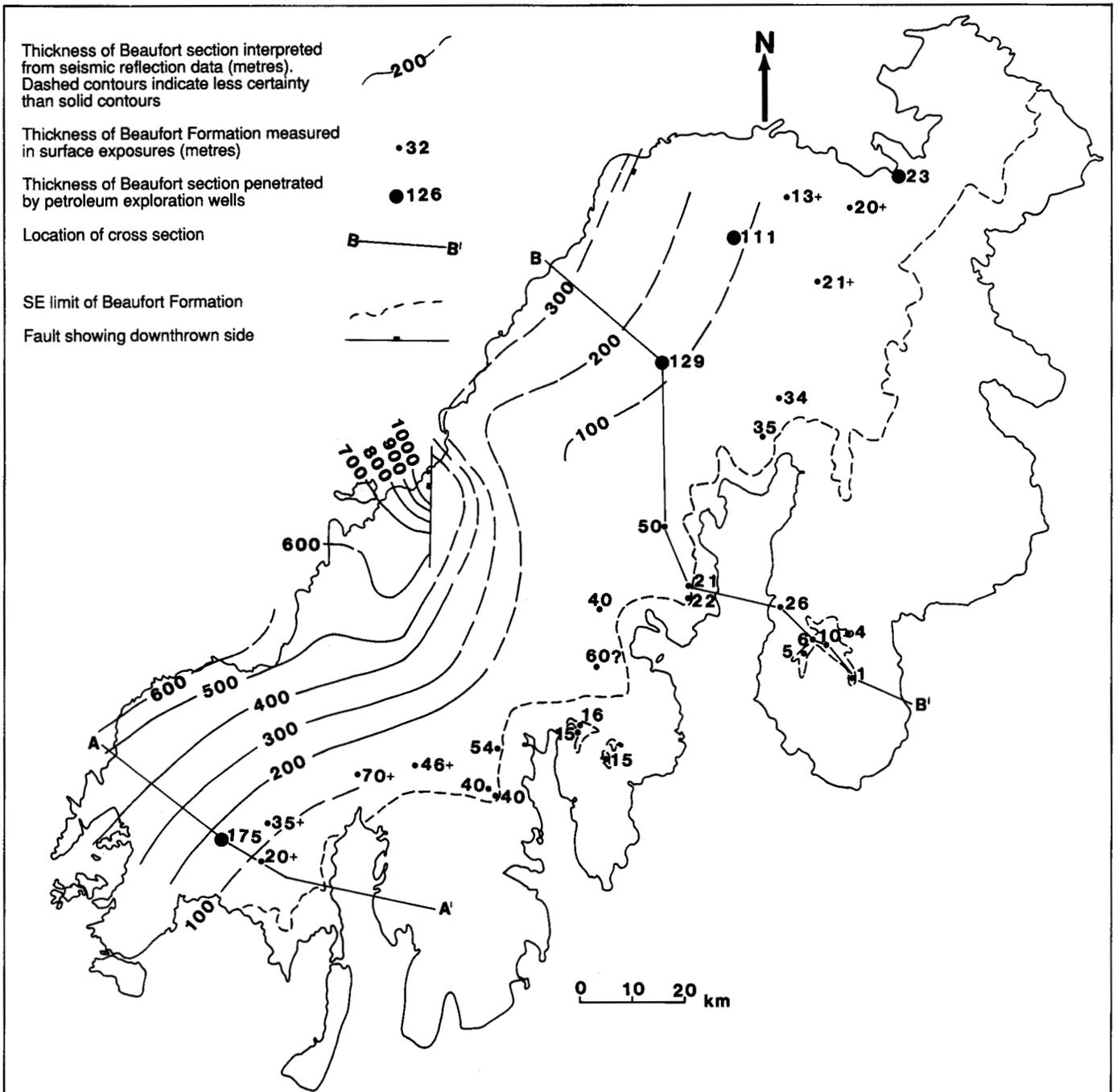


FIG. 4. Thickness of the Beaufort Formation and related strata, Prince Patrick Island. Isopach contours by T. Brent, Geological Survey of Canada, Calgary, from interpretation of petroleum industry reflection seismic data.

The "type" Beaufort Formation, as originally named by Tozer, is located in the thin, exposed part of the wedge of sediment described already. The information presented above concerning stratigraphy and sedimentology is drawn almost entirely from surface exposures in the "thin zone," as is the paleontological information presented in the following pages. In contrast, little information is available concerning the nature of the thick deposits west of the main belt of exposures. Presumably, this wedge includes strata belonging to the same unit and of the same age as the exposed "type" Beaufort Formation, but it may also include deposits representing

stratigraphically higher and/or lower levels of different sedimentary character or age.

As noted above, the Beaufort Formation in its type area on Prince Patrick Island consists of braided river deposits (Devaney and Fyles, 1988). In view of the surface and subsurface configuration of the belt of Beaufort sediments on the island, they probably originated as coalescing deposits of a number of such streams flowing northwest across a lowland along the margin of the continent. Cross-bedding directions are suggestive of currents flowing generally west or northwest (statistical study not done), and clasts in the

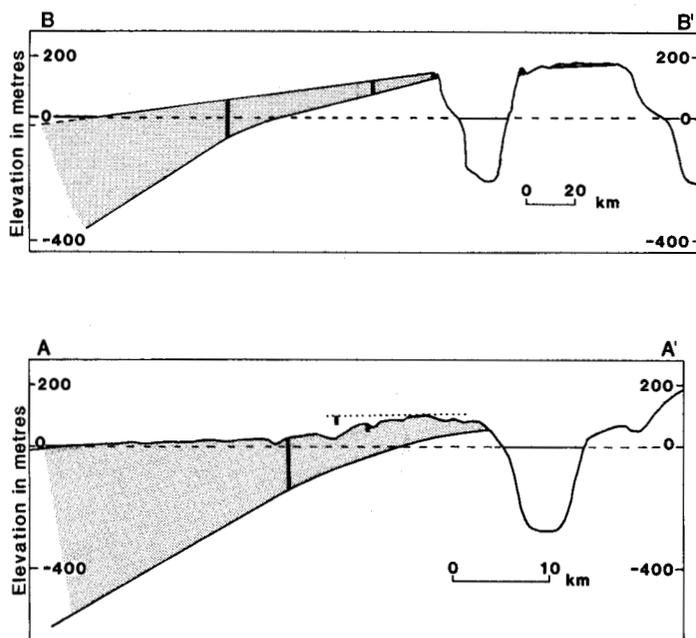


FIG. 5. Diagrammatic cross sections illustrating northwest thickening of the Beaufort Formation and related strata beneath Prince Patrick Island. Location of sections marked on Figure 4.

Beaufort include lithologies similar to rock types occurring on eastern Prince Patrick Island, Melville Island, and northeast Banks Island. The size of the drainage basins involved and the original extent of the deposits upstream from the present outcrop belt remain unknown.

Plant Materials and Other Fossils

Plant materials make up a substantial component of the Beaufort sediments on Prince Patrick Island. In exposed faces, layers rich in wood and other plant remains are common and concentrated at particular stratigraphic levels. Traced laterally, individual plant-rich layers "pinch out" and are replaced by others at different levels. Wood is detrital, waterworn, and generally lacks bark. Sticks and logs up to 50 cm in diameter and several metres in length occur individually on bedding planes in medium to coarse sand or gravel. Woody mats forming lenticular beds can be more than 0.5 m thick and several metres long and may enclose isolated clasts, mud balls, blocks of peat, and rare cones.

Fine plant materials mixed with fine sand or silty mud occur as horizontal beds darker than most other strata in the Beaufort Formation. In some of these beds, the plant material is dominantly water-worn fragments of wood; others contain needles, leaves, moss, and integrated branching twigs with or without bark. In some layers the dominant material is moss, and beds of mossy peat up to 30 cm thick have been observed. On the other hand, tree stumps, soils, root zones, or other evidence of plants in growth position have yet to be found on the island.

Investigation of the fossil materials contained in the Beaufort Formation began in the 19th century with identification of wood specimens from Prince Patrick Island. Thus, wood collected by Mecham (1855) was described by Heer (1868) as having microscopic structure similar to the living species *Pinus strobus*, although he suggested that the enclosing strata are Miocene. In recent years, much information has been published on fossils extracted from Beaufort

and related strata on Banks Island and Meighen Island (Hills, 1975; Hills *et al.*, 1974; Hills and Matthews, 1974; Matthews, 1987; Matthews *et al.*, 1986), but little paleontological information was available for the Beaufort Formation on Prince Patrick Island prior to the present investigations. The only significant earlier comment is by Hills (1975:I-65): "cones of *Picea banksii* and a single *Carya* nut were the only macrofossils recovered. The pollen assemblage is dominated by *Picea* and *Pinus*. *Tsuga* is rare as well as pollen assignable to deciduous species except *Alnus*, *Betula*, and *Carya*." Hence, a major objective of the 1987 field work was to obtain samples for paleontological study from the plant beds of the Beaufort Formation on this island, which includes the type area of the formation.

Initial paleontological study of these samples has now been undertaken by the following specialists in the Geological Survey of Canada: D. McIntyre (palynology), R.J. Mott (palynology), J.V. Matthews, Jr. (plant macrofossils, fossil insects), and L. Ovenden (fossil mosses). Twenty-three wood specimens, selected at random from seven sites on the island, have been identified (in order of decreasing abundance) as *Abies*, *Pinus* (both *P. strobus* type and *P. banksiana* type), *Larix*, *Picea*, and *Populus* (Mott, 1968). Pollen analyses (Mott, 1987a,b) for three samples are reproduced as Table 1.

A report on initial findings (Matthews *et al.*, 1990) tabulates 96 species of vascular plants, 49 of bryophytes, and 80 of arthropods. The macroscopic fossils of vascular plants include seeds and other parts of the following conifers: *Abies*, *Larix*, *Picea*, *Pinus* (2 and 5 needle), and *Thuja*. In addition, the Prince Patrick samples have yielded macrofossils of a number of shrubs and herbs, including *Cleome*, *Decadon*, *Hypericum*, *Physocarpus*, *Weigela*, and *Epipremnum crassum*. Insect fossils from the Prince Patrick Beaufort samples are mostly from beetles. Of these, the majority are "typical of active floodplain sites near the river . . . or live in proximal wetland biotopes. Many of them can be found in Quaternary age assemblages from the northern boreal zone. What sets the Beaufort Formation assemblages apart from Quaternary samples is the presence of a few fossils of extinct species and others . . . that now live well south of northern Canada" (Matthews *et al.*, 1990:122).

Most moss species contained in the Beaufort samples from Prince Patrick Island live today in both the arctic and boreal zones; a few species are now restricted to the Arctic; and a few now occur principally in the northern boreal region. Although the moss beds look like peat that has grown in place, Ovenden (Matthews *et al.*, 1990) has shown that the moss assemblages in all Beaufort samples include species that do not grow together in the same environment. Therefore, all the Beaufort moss samples studied to date are considered to be allochthonous. On the other hand, the large volume of moss contained in the Beaufort peat beds and its excellent state of preservation are suggestive of growth sites nearby. For instance, in describing one sample, Ovenden states: "The felted appearance indicates it formed as a detrital accumulation, perhaps by water moving slowly through a fen and also carrying fragments more characteristic of streambanks" (Ovenden, 1988:2).

In summary, the fossil materials in the Beaufort sediments on Prince Patrick Island have obviously been transported by rivers and include some materials that have originated in different environmental settings. Plant materials reworked from older formations are present (e.g., coal and amber from

TABLE 1. Pollen analyses of samples from exposed sections of the Beaufort Formation on Prince Patrick Island

Taxa	1	2	3
Included in pollen sum			
<i>Picea</i>	6.9	9.3	4.8
<i>Pinus</i>	30.6	33.7	28.8
<i>Larix</i>	—	0.7	—
<i>Betula</i>	30.9	12.3	26.5
<i>Alnus</i>	15.3	13.0	12.3
<i>Salix</i>	3.3	2.7	0.6
<i>Myrica</i>	0.6	0.3	0.6
Ericaceae	1.8	2.0	1.6
Gramineae	8.1	17.3	19.7
Tubuliflorae	0.3	1.0	—
Ambrosiaceae	—	0.3	—
<i>Artemisia</i>	—	0.7	0.6
Rosaceae	0.3	—	—
Caryophyllaceae	—	0.3	0.6
Ranunculaceae	—	0.3	—
Polygonaceae	—	—	0.3
Unidentified	2.7	6.0	3.2
Excluded from pollen sum			
<i>Lycopodium annotinum</i>	—	0.3	—
Pteridophyta	0.3	5.3	1.6
Polypodiaceae	3.3	3.0	1.3
Cyperaceae	4.5	14.0	12.0
<i>Sphagnum</i>	7.8	6.3	14.9

Numbers in each column represent percentage of the pollen sum for each sample. Between 200 and 300 pollen grains were counted for each sample. #1 — sample FG-87-1e: 76°15'N, 119°55'W. #2 — sample FG-87-10b: 76°33.5'N, 119°23'W. #3 — sample FG-64-145d: 76°15'N, 121°00'W. Pollen identifications by R.J. Mott (GSC Palynological Reports 87-11 and 87-14).

the Eureka Sound Group; Cretaceous pollen). Nonetheless, the principal elements of the assemblage taken together seem to characterize this stratigraphic unit and set it apart from others in the region. Thus, the unit contains a striking quantity of woody material in an unaltered state. Moss is abundant and in a number of places occurs as beds of mossy peat. Remains of vascular plants are abundant. Most of the plant and insect fossils are hardly distinguishable from extant taxa, though some plants and insects are extinct. Many of the plants are typical of floodplain areas or poorly drained sites. Conifers are a common constituent, but remains of temperate hardwood tree species are rare or absent. The overall assemblage seems to represent coniferous (boreal?) forested conditions, but includes shrubs presently found in temperate regions.

Age

The "type" Beaufort Formation on Prince Patrick Island is inferred to be Pliocene in age based upon correlation with the Beaufort occurrences on Meighen Island (Matthews *et al.*, 1990). The assemblage of plant macrofossils described above for Prince Patrick Island is very similar to that present in the Beaufort sand exposed on Meighen Island (Matthews, 1987). Further, marine clay associated with the plant beds on Meighen Island has yielded the foraminifer *Cibicides grossus* (McNeil, 1988, 1990), the presence of which is a clear indication of Pliocene age.

Although the Beaufort fossil floras from the two islands are very similar, they are not identical. Thus the Prince Patrick Island assemblage represents coniferous forest, while that from Meighen Island suggests forest-tundra boundary conditions; these differences presumably result from slight

differences in latitude and/or age (Hills, 1975; Matthews *et al.*, 1990).

INTER-ISLAND COMPARISONS AND NOMENCLATURE

In the original reference to the Beaufort Formation, Tozer (1956:25) states: "These beds are named the Beaufort formation as sediments of this type are apparently widely distributed on the northeast side of the Arctic Archipelago, facing the Beaufort Sea and Arctic Ocean. The best exposures seen are west and northwest of Mould Bay, and the beds in this area may be considered as typical."

In their report on Banks Island, Thorsteinsson and Tozer (1962:69) state:

The type section of the Beaufort Formation is on Prince Patrick Island. There, the formation was defined by Tozer (1956:25) to accommodate about 250 feet of unconsolidated sand and gravel that form about three-quarters of the island. The Beaufort Formation is now known to form a belt of sediments fringing the northwestern islands of the Arctic Archipelago. Beside Prince Patrick Island, regions of the Arctic Islands now known to be underlain by the Beaufort Formation include: all of Meighen Island —; Isachsen Peninsula of Ellef Ringnes Island —; north Borden Island and northwest Brock Island —; and western Banks Island.

This application of the name Beaufort Formation to "a belt of sediments fringing the northwestern islands of the Arctic Archipelago" was based on general similarity in sedimentological character and stratigraphic setting and on geological continuity rather than any rigorous extrapolation from the type area on Prince Patrick Island. At that time, it was not known whether the deposits included in the Beaufort Formation were late Tertiary or Quaternary. Subsequent investigations of paleontology and stratigraphy (e.g., Hills, 1975, and earlier) have led to agreement that all the deposits in the belt are indeed late Tertiary in age, and current estimates range from early Miocene to Pliocene. As noted previously in this paper, the whole section of Beaufort strata in the type area on Prince Patrick Island is now inferred to be Pliocene — a conclusion leading to questions about use of the name Beaufort Formation for deposits that are distinctly older.

The following paragraphs compare the principal occurrences in the belt of western islands with one another, and particularly with the "type" Beaufort Formation on Prince Patrick Island, and make suggestions about correlation and nomenclature. The discussion is intended to set the stage for future designation of formally named formations and/or members and for decision on future use of the name Beaufort: either restricted as a formation (as recommended in this paper) or, perhaps, broadened as a group (of formations). For the present, following the existing definition, it is recommended that the Beaufort Formation be restricted to deposits that are stratigraphically equivalent to the "type" Beaufort on Prince Patrick Island. Informal stratigraphic names are proposed for a few occurrences that do not seem to be stratigraphically equivalent to the Beaufort Formation in its type area.

Northern Banks Island

Fluvial sand and gravel containing wood, and generally similar to the Beaufort Formation on Prince Patrick Island, are widely distributed in the western half of Banks Island

(Craig and Fyles, 1960; Thorsteinsson and Tozer, 1962; Vincent, 1983; Miall, 1979). Although these strata are exposed in a number of localities, substantial stratigraphic and paleontological investigations in the northern part of the island have been undertaken only in the vicinity of Ballast Brook (Fig. 1). At this locality, Fyles recorded that "a 100-metre Beaufort section consists of sand and gravel with much wood underlain by a 3-metre peat bed followed by sand and silt containing fine plant detritus" (Craig and Fyles, 1965:4). Hills (1969) further subdivided the stratigraphic section at Ballast Brook and recorded an unconformity separating the lower unit X (including the peat bed and underlying strata) from the upper unit Y. Subsequent publications by Hills and associates and by Matthews (1987) maintain this "upper" and "lower" designation. Vincent (1983:13) comments that in most places on Banks Island sand and gravel of the upper Beaufort unit at Ballast Brook rest directly on the Eureka Sound Formation and that the lower Beaufort unit described by Hills and Fyles is generally absent.

Similarity of the upper unit at Ballast Brook to the Beaufort strata exposed on Prince Patrick Island has been noted in a number of papers (e.g., Hills, 1969, 1970; Hills and Matthews, 1974; Matthews *et al.*, 1990). Both localities display similar sedimentological characteristics and lithology and contain abundant unaltered wood and plant detritus. General paleontological similarity, indicative of coniferous forest, is evident from the pollen data of Hills (1975) and from plant macrofossils at both localities (Matthews *et al.*, 1990). Hence, it is appropriate to use the name Beaufort Formation for the upper unit at Ballast Brook.

Hills has suggested that this upper unit at Ballast Brook correlates with the Homeric Stage of Alaska (Hills *et al.*, 1974), which is classified by Wolfe (1981) as Middle to Upper Miocene. Now that the Beaufort Formation in its type area on Prince Patrick Island seems to be Pliocene in age (this report; Matthews *et al.*, 1990), the upper strata on northern Banks Island probably are also Pliocene. On the other hand, Matthews has recognized slight differences in plant microfossil assemblage between Ballast Brook and Prince Patrick Island and between Ballast Brook and Meighen Island (Matthews *et al.*, 1990). These differences perhaps record slight differences in age rather than in latitude, leaving open the possibility of a Pliocene and/or latest Miocene age for the upper beds at Ballast Brook.

The lower unit at Ballast Brook, tentatively assigned by Fyles (Craig and Fyles, 1965) to the Beaufort Formation, consists of sub-units of clay, silt, sand, and gravel and includes a prominent bed of compressed woody peat. These strata, together comprising Hills's unit X, differ in appearance from the overlying upper unit (Hills's unit Y), and "the contrast between the compressed and altered wood from unit X and the unaltered and uncompressed wood from unit Y and the angular discordance between the two units suggest that a considerable time interval may be represented by the unconformity" (Hills, 1969:207).

Plant fossils identified in the lower unit at Ballast Brook include forms not characteristic of either the upper unit at Ballast Brook or the Beaufort Formation exposed on Prince Patrick Island. Thus, Hills (1975:1-65) reports that "The lower 40 m has yielded a rich palynoflora dominated by such deciduous genera as . . . *Carya*, *Corylus*, *Juglans*, and *Tilia*" (in addition to conifers), and Matthews (1987) has recorded macrofossils of *Glyptostrobus*. On the basis of fossil content

and stratigraphic setting, Hills (1975) considers the lower unit at Ballast Brook to be Early to Middle Miocene in age.

Although much remains to be learned about the strata exposed in the Ballast Brook section, it is evident that the lower unit is distinct and separate from the upper unit, is more altered than the upper unit, and seems not to be stratigraphically equivalent to the "type" Beaufort Formation on Prince Patrick Island. Hence, use of the terms lower and upper Beaufort should be discontinued and use of the term Beaufort Formation at Ballast Brook should be restricted to the upper unit. Further, I propose that the term Ballast Brook beds be used informally for the lower unit until enough information is available to define and name it as a formal stratigraphic unit.

Southern Banks Island

Wood-bearing gravel and sand, conspicuously exposed in the coastal Duck Hawk Bluffs adjacent to the southwest tip of Banks Island (Fig. 1), have long been considered to belong to the Beaufort Formation (Craig and Fyles, 1960; Hills *et al.*, 1974; Vincent *et al.*, 1983). This occurrence, and its graphic fossil record (Hills *et al.*, 1974; Matthews *et al.*, 1986; Matthews, 1989) are well documented in the literature, conveying the message that the Beaufort Formation at this locality is Early to Middle Miocene in age. Thus, the strata at Duck Hawk Bluffs have yielded macrofossils of *Metasequoia*, *Glyptostrobus*, *Juglans*, *Liriodendron*, *Phyllanthus*, *Actinidia*, and other plants absent from, or rare in, fossil collections from the type area of the Beaufort Formation on Prince Patrick Island and from the Beaufort (upper) unit at Ballast Brook. Further, the sediments themselves and enclosed plant material are more altered than those in the type area of the Beaufort Formation.

This occurrence, lying unconformably on shale of the late Cretaceous Kanguk Formation and overlain by sand of the Worth Point Formation (early Quaternary?; Vincent *et al.*, 1983), has not been tied through physical stratigraphy to Beaufort strata exposed elsewhere on southern Banks Island. Recognizing the isolated occurrence of these deposits and that they are not stratigraphically equivalent to the type Beaufort Formation on Prince Patrick Island, they should be given a local lithostratigraphic name. I recommend that they be referred to informally as the Mary Sachs gravel (Mary Sachs Creek reaches the shore a few hundred metres east of the principal outcrops of these strata). I also recommend that a formal name be established as soon as practicable. Some of the plant taxa listed above for the Mary Sachs gravel also occur in samples from the Ballast Brook beds 250 km to the north, but available data are insufficient to infer that the two occurrences belong to the same stratigraphic unit.

Ellef Ringnes and Borden Islands

Sandy, wood-bearing, unlithified sediments assigned to the Beaufort Formation lie beneath the Arctic Coastal Plain (Fig. 1) on western Borden Island and on the northern peninsula of Ellef Ringnes Island (Craig and Fyles, 1960; St-Onge, 1965; Tozer and Thorsteinsson, 1964). On northern Ellef Ringnes Island, petroleum industry subsurface data (Meneley *et al.*, 1975) document Beaufort Formation underlain by the Eureka Sound Group. These formations constitute an undeformed clastic wedge that thickens northward from a few metres to more than 1000 m in a distance of about 50 km. Along their

dissected southern margin, these deposits are less than 100 m thick, over Mesozoic rocks, and consist of two distinct stratigraphic units (Fyles, 1965). The upper unit, like Beaufort deposits elsewhere, consists of unlithified, commonly cross-bedded quartzose sand and subsidiary chert-pebble gravel locally containing abundant wood. However, the wood is more altered than that in the Beaufort strata of Prince Patrick Island, mossy beds are absent, and thin beds of dark brown and black silt and clay are common. The lower unit is dark brown, semi-consolidated silt, silty sand, and silty pebble gravel containing altered wood and fine plant material that in places is almost coaly. Much of the sediment is poorly sorted; some is cross-bedded. Yellow chemical alteration is common. On Borden Island the same two units are present and are particularly well exposed in a 30 m high undercut bank of the DuVernet River (Fig. 1), where they lie unconformably on rocks of Triassic age.

Clay and silt beds in the sandy upper unit on Ellef Ringnes Island have yielded a "rich palynoflora" (Hills, 1975:1-65) in which "the high *Picea* pollen characteristic of more southerly localities is markedly decreased and replaced by pollen of *Alnus*, *Betula*, *Ledum* and ericaceous plants." Hills notes similarity between this plant assemblage and that in the Meighen Island Beaufort (representing forest/tundra boundary). In contrast, samples from the lower unit on both Ellef Ringnes Island (St-Onge, 1965) and Borden Island (Tozer and Thorsteinsson, 1964) contain abundant tree pollen, principally from a variety of conifers, but including a small (but consistent) amount of pollen from deciduous "hardwoods" such as *Corylus*, *Carpinus*, *Quercus*, *Juglans* type, and *Castanea* type (Terasmae, 1961).

Hence, it is apparent from information at hand that two distinct units underlie the coastal plain on Ellef Ringnes and Borden islands. The upper sandy unit is physically and (apparently) paleontologically similar to the Beaufort Formation on Prince Patrick Island. In contrast, the lower brown silty unit is physically and (apparently) paleontologically different from the Beaufort on Prince Patrick Island; perhaps it is part of the Eureka Sound Group, or perhaps the equivalent of the Ballast Brook beds or Mary Sachs gravel (Middle or Early Miocene) on Banks Island. Initial investigation of samples collected in 1989 from both units on both Ellef Ringnes and Borden islands has not revealed stratigraphically significant plant macrofossils (J.V. Matthews, pers. comm. 1990).

Meighen Island

All of Meighen Island is underlain by sandy, wood-bearing strata that were assigned to the Beaufort Formation by Thorsteinsson (1961). These deposits and the contained plant and insect fossils are similar to the "type" Beaufort Formation on Prince Patrick Island (Matthews *et al.*, 1989). Clayey beds in the lower part of the exposed sandy section have yielded marine molluscan shells and the Pliocene age foraminifer *Cibicides grossus* (McNeil, 1988). Implications of the occurrence of these datable marine beds are noted in the section of this report on the age of the Beaufort Formation. The presence of marine strata in the Beaufort section on Meighen Island sets this locality apart from all other known Beaufort occurrences on the western Arctic Islands.

Unlike the "type" Beaufort Formation, which is the thin southeast edge of the late Tertiary sedimentary wedge on

Prince Patrick Island, the exposed Beaufort beds on Meighen Island (200 m thickness exposed above sea level) form the uppermost part of approximately 3000 m of Tertiary clastic strata penetrated by a petroleum exploration well beneath the island (Asudeh *et al.*, 1989). The upper part of the well log indicates that sand and gravel similar to the Beaufort Formation extend several hundred metres below sea level. These strata, lying beneath the Beaufort strata visible on the island, need not be all of the same age as the exposed Pliocene-age marine clay and plant-bearing sand.

Other Arctic Islands and the Western Arctic Mainland

Late Tertiary deposits are present on a number of islands east of the Arctic Coastal Plain belt, which is the focus of this paper. On Ellesmere and Axel Heiberg islands to the northeast (Fig. 1), "high terrace" sediments (Fyles, 1989) include deposits formed under boreal and tree-line conditions probably during the Pliocene. Some uppermost beds of the thick continental sequence generally included in the Eureka Sound Group have been described as Miocene (Bustin, 1982; Riediger *et al.*, 1984). On Devon Island, the lacustrine Houghton Formation is Miocene (Hickey *et al.*, 1988). On several of the central islands (particularly Melville Island), gravel apparently forming remnants of a thin fluvial cover, locally containing wood, may be as old as late Tertiary (Hodgson *et al.*, 1984).

In describing such occurrences, it has been easy to informally use the name Beaufort. Further, the name Beaufort Formation has been applied formally to some of them on Ellesmere and Axel Heiberg islands (Riediger *et al.*, 1984; Bustin, 1982; Wilson, 1976). Nonetheless, it is preferable to restrict use of the name Beaufort to the late Tertiary belt along the northwest margin of the archipelago, where it was originally used, and to refrain from extending the name to other parts of the archipelago, regardless of similarities of age, fossils, and stratigraphic character (see also De Paor *et al.*, 1989). An exception may perhaps be made for the thin, gravelly "outliers" on Melville and adjacent islands, if and when they have been demonstrated to be the thin upstream extension of the Beaufort deposits.

In keeping with the foregoing, it seems appropriate to discontinue use of the term Beaufort Formation southwest of the Arctic Archipelago on the northern continental mainland (Fig. 1) near Franklin Bay (Yorath *et al.*, 1975; Matthews *et al.*, 1989; Vincent, 1990-this issue) and in the Beaufort/Mackenzie basin (Dietrich *et al.*, 1985).

CONCLUSIONS

1. The Beaufort Formation, in its type area on Prince Patrick Island, is a single stratigraphic unit a few tens of metres thick, consisting of unlithified sandy sediments containing abundant unaltered plant material.

2. Sedimentary structures characteristic of the Beaufort sands indicate deposition by braided rivers. These rivers appear to have flowed northwest.

3. Plant and insect fossils contained in the Beaufort Formation on Prince Patrick Island are indicative of coniferous forest. Based on paleontological comparison with Meighen Island, the "type" Beaufort is considered to be Pliocene.

4. The exposed Beaufort on Prince Patrick Island is the thin southeastern edge of a largely unexposed, northwest-

thickening wedge of sandy sediments beneath the western part of the island. These sediments include strata equivalent to the Beaufort Formation but may also include deposits of different sedimentary character and age.

5. Many of the deposits that have been called Beaufort Formation on the islands north and south of Prince Patrick Island appear to be stratigraphically equivalent to the "type" Beaufort Formation. On the other hand, a few late Tertiary sites that have previously been called Beaufort differ stratigraphically and paleontologically from the "type" Beaufort Formation. Particular examples are the deposits at Duck Hawk Bluffs and the lower unit at Ballast Brook, on Banks Island. This paper suggests that these and other such units should not be included in the Beaufort Formation as presently defined, but rather should be assigned new formation (and/or member) names. In the future, combination of such units as a group may be appropriate.

6. On a broader scale, use of the name Beaufort Formation should be restricted to the belt of sediments, discussed above, along the northwest margin of the archipelago. I recommend that the name should not be used formally elsewhere on the Arctic Islands or on the mainland or in the Beaufort/Mackenzie basin southwest of the archipelago.

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