ARCTIC
VOL. 43, NO. 4 (DECEMBER 1990) P. 339-363

Late Tertiary and Early Pleistocene Deposits and History of Banks Island, Southwestern Canadian Arctic Archipelago[1]

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(Received 12 January 1990; accepted in revised form 5 April 1990)

ABSTRACT. Fossil-rich sediments on Banks Island provide an excellent record of events and conditions that prevailed in arctic Canada during the late Tertiary and Early Pleistocene. In the late Tertiary, fluvial sands and gravels of the Beaufort Formation and related deposits were laid down on the coastal plain facing the Beaufort Sea. Relative sea level was lower than today. Both mixed deciduous/coniferous and coniferous forests existed on Banks Island. Mean July temperatures must have been +10°C warmer than present. The Early Pleistocene Worth Point Formation records a period during which preglacial landscapes were modified by fluvial, eolian, and colluvial processes. Continuous permafrost was likely present, sea level was lower than today, and southern Banks Island was covered by an open larch-dominated forest-tundra. Mean July temperatures were probably some 5-7°C warmer than present. Although some evidence indicates possible earlier glaciations, the best record of an early continental ice advance is provided by widespread glacial and marine sediments of the Duck Hawk Bluffs Formation laid down during the Early Pleistocene Banks Glaciation. This advance was distinctly more extensive than Middle or Late Pleistocene ones and glacio-isostatically controlled sea levels were much higher than those of today. During the Early to Middle Pleistocene Morgan Bluffs Interglaciation, climate on Banks Island was cooler than in preglacial times. Although the tree line may have extended to the southern part of the island, fossil remains in seven localities indicate typical low arctic conditions (mean July temperatures 2-5°C warmer than present). Eustatic sea level was some 30 m higher than the present and permafrost was continuous. The Banks Island record provides critical information on periods when conditions in the Arctic were significantly warmer than today. As such it can serve as a basis to understand and forecast the nature and impact of future man-induced atmospheric warming.

Key words: arctic Canada, Banks Island, late Tertiary, Early Pleistocene, glaciation, interglaciation, Beaufort Formation, Worth Point Formation, Duck Hawk Bluffs Formation, Morgan Bluffs Formation, Quaternary geology

RÉSUMÉ. Sur l'île de Banks, des sédiments, riches en matières organiques, enregistrent les événements et les conditions qui ont prévalus dans l'Arctique canadien au cours du Tertiaire supérieur et du Pléistocène inférieur. Au Tertiaire supérieur, les sables et graviers fluviatiles de la Formation de Beaufort et autres dépôts associés ont été mis en place sur la plaine côtière faisant face à la mer de Beaufort. Le niveau relatif de la mer était plus bas que celui d'aujourd'hui. Une forêt mixte de feuillus et de conifères et une forêt de conifères existaient sur l'île. La température moyenne de juillet était de 10°C plus chaude qu'actuellement. La Formation de Worth Point, du Pléistocène inférieur, témoigne d'une période au cours de laquelle les modelés préglaciaires ont été modifiés par les processus fluviaux, éoliens et de versants. Le pergélisol était probablement continu, le niveau relatif de la mer était plus bas qu'aujourd'hui et une toudra forestière dominée par les mélèzes recouvrait la partie méridionale de l'île de Banks. La température moyenne de juillet était probablement de 5 à 7°C plus élevée que présentement. Bien que de plus vieilles glaciations aient pu affecter la région, la Glaciation continentale de Banks, du Pléistocène inférieur, est la plus ancienne bien documentée. Au cours de cette glaciation, beaucoup plus étendue que celles du Pléistocène moyen et supérieur, les sédiments glaciaires et marins de la Formation de Duck Hawk Bluffs ont été mis en place et le niveau marin relatif, contrôlé par la glacio-isostasie, était plus élevé qu'à l'actuel. Au cours de l'Interglaciaire de Morgan Bluffs, au Pléistocène inférieur et moyen, le climat était plus frais qu'à l'époque préglaciaire. Bien que la limite des arbres ait peut-être atteint l'extrémité méridionale de l'île, les restes végétaux et animaux indiquent que les conditions étaient caractéristiques du bas arctique (température moyenne en juillet de 2 à 5°C plus élevée qu'à l'actuel). Le niveau de la mer était d'environ 30 m plus élevé que maintenant et le pergélisol était continu. Les données de l'île de Banks fournissent des renseignements sur des périodes antérieures beaucoup plus chaude que présentement. Celles-ci peuvent donc nous aider à mieux comprendre et prédire l'impact futur du réchauffement atmosphérique occasionné par l'activité humaine.

Mots clés: Arctique canadien, Ile de Banks, Tertiaire supérieur, Pléistocène inférieur, glaciation, interglaciation, Formation de Beaufort, Formation de Worth Point, Formation de Duck Hawk Bluffs, Formation de Morgan Bluffs, géologie du Quaternaire

РЕФЕРАТ. Изобилующие ископаемыми остатками отложения острова Банкс являют собой великолепную летопись событий и условий, преобладавших в Канадской Арктике в конце третичного периода и раннем плейстоцене. В конце третичного периода на прилегающей к морю Бофорта равнине отложились речные пески и гравий формации Бофорта. Относительный уровень моря был в эту эпоху ниже, чем в наше время. На острове Банкс росли как смешанные лиственные (широколиственные) и хвойные, так и хвойные леса. Средняя температура июля была, очевидно, на 10Ц выше, чем сегодня. В отложениях раннеплейстоценовой формации Уорт Пойнт отражается период, на протяжении которого доледниковые ландшафты изменялись под воздействием речных, ветровых и коллювиальных процессов. Это время характеризовалось, вероятно, сплошной вечной мерзлотой, более низким, чем в наши дни, уровнем моря, а также наличием редкостойной лесотундры с преобладанием лиственницы в южной части острова Банкс. Средние температуры июля были, очевидно, на 5-7Ц теплее, чем в наше время. Имеются указания на возможные более ранние оледенения, однако наиболее полную картину древнего наступления континентального льда дают широко распространенные ледниковые и морские осадки формации Дак Хок Блаффс, отложившиеся в ходе раннеплейстоценового банксковского оледенения. Продвижение льда в этом случае было существенно более значительным, чем при оледенениях среднего и позднего плейстоцена, а определявшийся гляциоизостатическими движениями земной коры уровень моря был намного выше, чем в настоящее время. В течение морган блаффского межледниковья, установившегося в раннем и среднем плейстоцене, климат на острове Банкс был холоднее, чем в доледниковые периоды. Хотя верхняя граница лесов, возможно, и достигала южной части острова, ископаемые остатки, собранные в семи разных местах, указывают на условия, типичные для низких широт Арктики (средняя температура июля на 2-5Ц теплее, чем сегодня). Эвстатический уровень моря был приблизительно на 30 метров выше, теперешнего, а многолетняя мерзлота была сплошной. Собранные на острове Банкс материалы служат источником чрезвычайно ценной информации о тех перио-дах, когда климат Арктики был значительно более теплым, чем в настоящее время. Эти материалы должны помочь нам лучше понять и предсказать характер и последствия вызванного деятельностью человека потепления атмосферы.

Ключевые слова: Канадская Арктика, остров Банкс, конец третичного периода, ранний плейстоцен, оледенение, межледниковье, формация Бофорта, формация Уорт Пойнт, формация Дак Хок Блаффс, формация Морган Блаффс, геология четвертичного периода.

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INTRODUCTION

Systematic surficial geology mapping, as well as stratigraphic and paleomagnetic investigations on Banks Island, in the southwestern Canadian Arctic Archipelago (Fig. 1), have led to the identification of well-preserved late Tertiary and Early Pleistocene deposits. These have been subdivided into four formations: 1) the Beaufort Formation and related deposits of late Tertiary age; 2) the Worth Point Formation of Early Pleistocene age; 3) the Duck Hawk Bluffs Formation of Early Pleistocene age; and 4) the Morgan Bluffs Formation of Early to Middle Pleistocene age. The purpose of this report is to provide a concise summary of new and of already available but dispersed information on these late Tertiary-Early Pleistocene deposits.

THE BEAUFORT FORMATION AND RELATED DEPOSITS OF THE COASTAL PLAIN

Definition and Past Studies

On Banks Island, the Beaufort Formation and related sediments consist of sand and gravel, with minor silt and clay, wood, peat, and organic detritus, laid down on a coastal plain by generally west- and north-flowing rivers. The Beaufort Formation was initially described and named on Prince Patrick Island by Tozer (1956), who recognized that similar deposits were likely present on the west coast of the arctic islands fronting the Beaufort Sea and Arctic Ocean. Subsequently, Beaufort Formation sediments on Banks Island were recognized and described by Craig and Fyles (1960, 1965), Thorsteinsson and Tozer (1962), Hills (1969), French (1972), Miall (1979), and Vincent (1983). Fyles (1990-this issue) has suggested that beds in the Duck Hawk Bluffs and in the lower portion of sections along Ballast Brook are lithostratigraphic units distinct from the Beaufort Formation. He termed the suite of sediments in the Duck Hawk Bluffs, the Mary Sachs gravel, and the older sediments at Ballast Brook, the Ballast Brook beds. The diverse assemblage of flora and fauna contained in beds of the Duck Hawk Bluffs in southwestern Banks Island and of the Ballast Brook area of northwestern Banks Island were also intensively studied by Hills (1975), Hills *et al.* (1974), Hills and Ogilvie (1970), Kuc (1973), Kuc and Hills (1971), Matthews (1976, 1987, 1989), Matthews *et al.* (1986) and Roy and Hills (1972). The fossil plants and

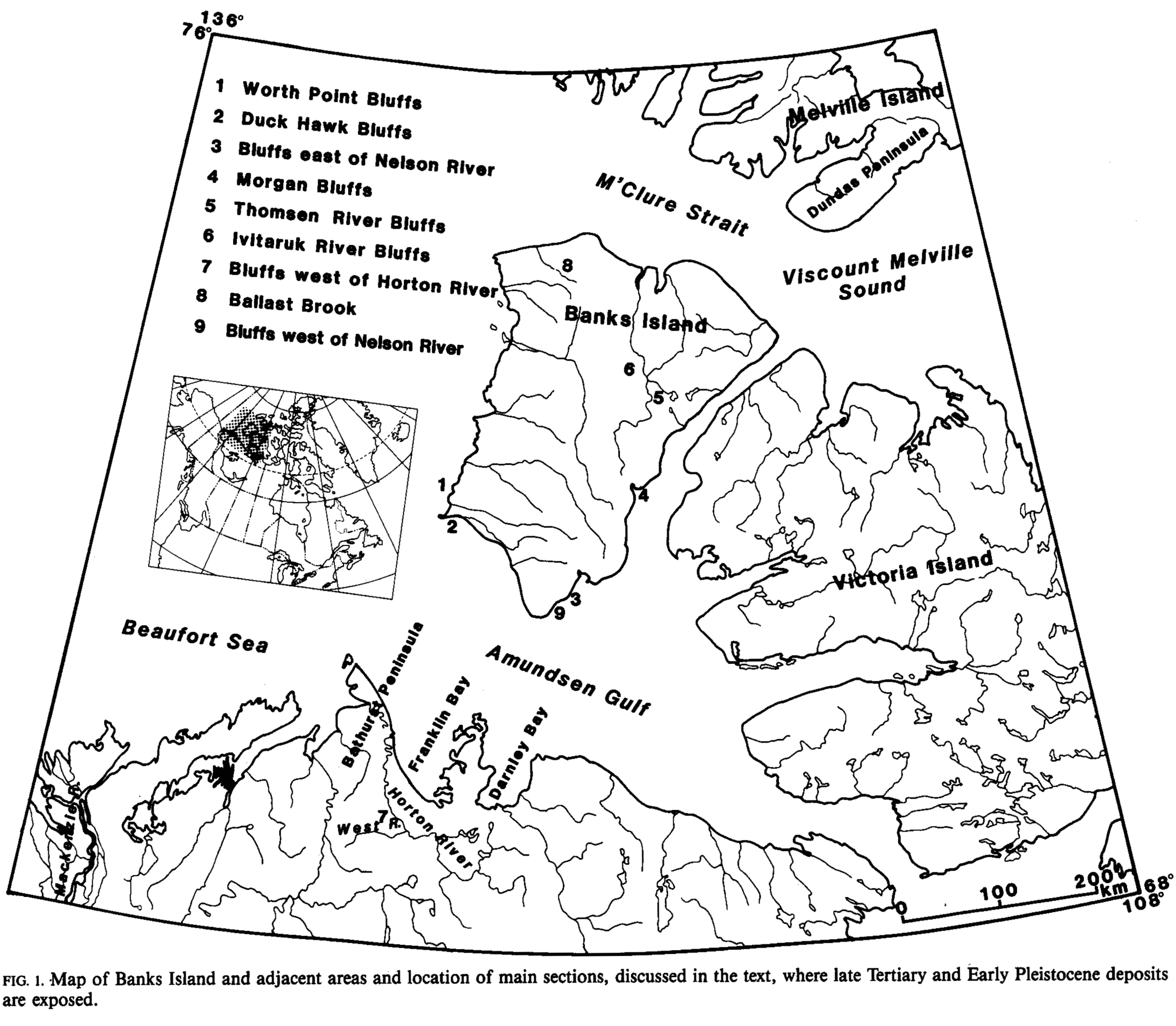

FIG. 1. Map of Banks Island and adjacent areas and location of main sections, discussed in the text, where late Tertiary and Early Pleistocene deposits are exposed.

insects recovered in the Duck Hawk Bluffs (=Mary Sachs gravel) document mixed deciduous/coniferous forests. Those recovered in older deposits at Ballast Brook (=Ballast Brook beds) may also document a mixed forest, but the younger deposits (=Beaufort Formation) there only record a coniferous forest.

In this review of late Tertiary and Early Pleistocene deposits of Banks Island, only general comments will be made on the Beaufort Formation and related sediments, but some previously unpublished information, useful for future studies, will be presented. The reader is referred to Fyles (1990-this issue) and Matthews and Ovenden (1990-this issue) for more detailed discussion on Beaufort Formation and related sediments stratigraphy and floras and faunas.

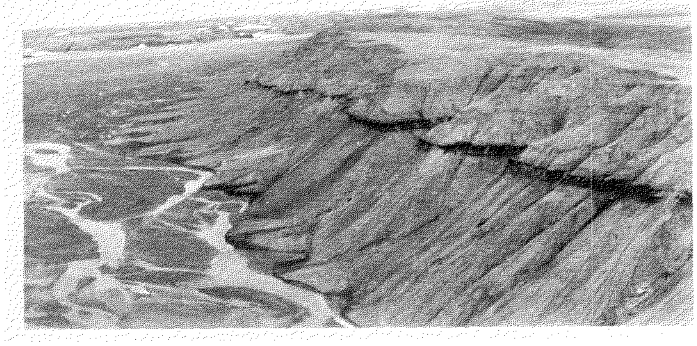

FIG. 3. Exposure of late Tertiary (=Ballast Brook beds and Beaufort *sensu stricto* of Fyles, 1990-this issue) sands and gravels with an up to 4 m thick woody lignite bed on the right bank of Ballast Brook on northwestern Banks Island (GSC photo 167399).

General Description

Beaufort Formation and related sediments on Banks Island consist mainly of horizontally and cross-bedded sand with gravel. Quartzites, multicolored cherts, and quartzitic sandstones are the dominant rock types of the gravel clasts with sandstones, dolomites, and siltstones sometimes present. Extremely rare granitic and gabbroic rocks have also been observed. Boulders of quartzite and quartzitic sandstone, 0.5–1.5 m in diameter, have been observed in sections of unquestionably unreworked Beaufort Formation (*sensu stricto*) sediments during the 1990 field season. These were likely carried by river ice or within tree stumps at the time of deposition. The best exposures of late Tertiary sediments on the island are located along the Duck Hawk Bluffs and Ballast Brook (Fig. 1). Gravel is distinctly more abundant in the former area. Redeposited but generally unaltered and uncompressed wood (Fig. 2), as well as pockets of fine organic detritus, are disseminated within the alluvial deposits. Autochthonous peats and lignites (Fig. 3) have been observed only in the Ballast Brook basin.

Extent and Thickness

The extent of surface or near surface deposits of the Beaufort Formation and related deposits on Banks Island, based on surficial geology mapping by Vincent (1980a,b, 1983), is portrayed on Figure 4. Outliers have been identified farther east and south than what is depicted on geological maps (Miall, 1979). The deposits may even underlie thick glacial sediments south of the drainage divide between Thesiger Bay and eastern Amundsen Gulf. Generally, the sediments are thick and continuous only in the coastal zone north of Bernard River. Elsewhere, numerous outliers a few tens of metres thick are present and older Paleogene or Cretaceous sediments are found underlying them in river or coastal exposures. In many instances river and glacial erosion have effectively stripped the late Tertiary cover. Some 100 m of Beaufort sediments are exposed along Ballast Brook and an oil well log (Bar Harbour E-76) indicates a total thickness of 276 m in the extreme northwest portion of the island (Miall, 1979).

FIG. 2. Exposure of Beaufort Formation sands and gravels with wood on the right bank of the upper Fawcett River on northwestern Banks Island (GSC photo 167750).

Boundaries and Postdepositional History

The Beaufort Formation and related sediments on Banks Island rest with marked unconformity on the lower Cretaceous Christopher Formation, the upper Cretaceous Kanguk Formation, and the upper Cretaceous and Paleogene Eureka Sound Group. They are overlain by preglacial deposits of the Worth Point Formation and by Pleistocene glacial, marine, and nonglacial deposits. The nature and stratigraphic setting of the preglacial deposits indicate that the Beaufort surface was modified by subaerial processes over an extended period of time. In particular, consequent streams incised the coastal plain surface, and wind acting on alluvial plains mobilized and redeposited sand and silt. Valley fills found both at the Worth Point and the Duck Hawk Bluffs exposures and relatively thick eolian deposits at the Duck Hawk Bluffs bear witness to this activity.

As shown on Figure 5, much of the surficial primary Beaufort sediments of northwestern Banks Island have been intensively reworked by fluvial, glacial, and marine processes or have been covered by younger sediments. Only the areas shown in white on Figure 5 are possible remnants of the original depositional surface. Even there, asymmetric V-shaped valleys have been cut into the deposits and Quaternary loess blankets the interfluve areas (Fig. 5). The loess was likely derived from the outwash plains of western Banks Island, as well as from the Beaufort Sea Shelf when it emerged during the multiple Quaternary glaciations. Locating the original depositional surface and recognizing the processes that have modified it is important. The preglacial sediments and fossils found on the primary Beaufort surface are the ones that will provide the clues to understanding the events that preceded

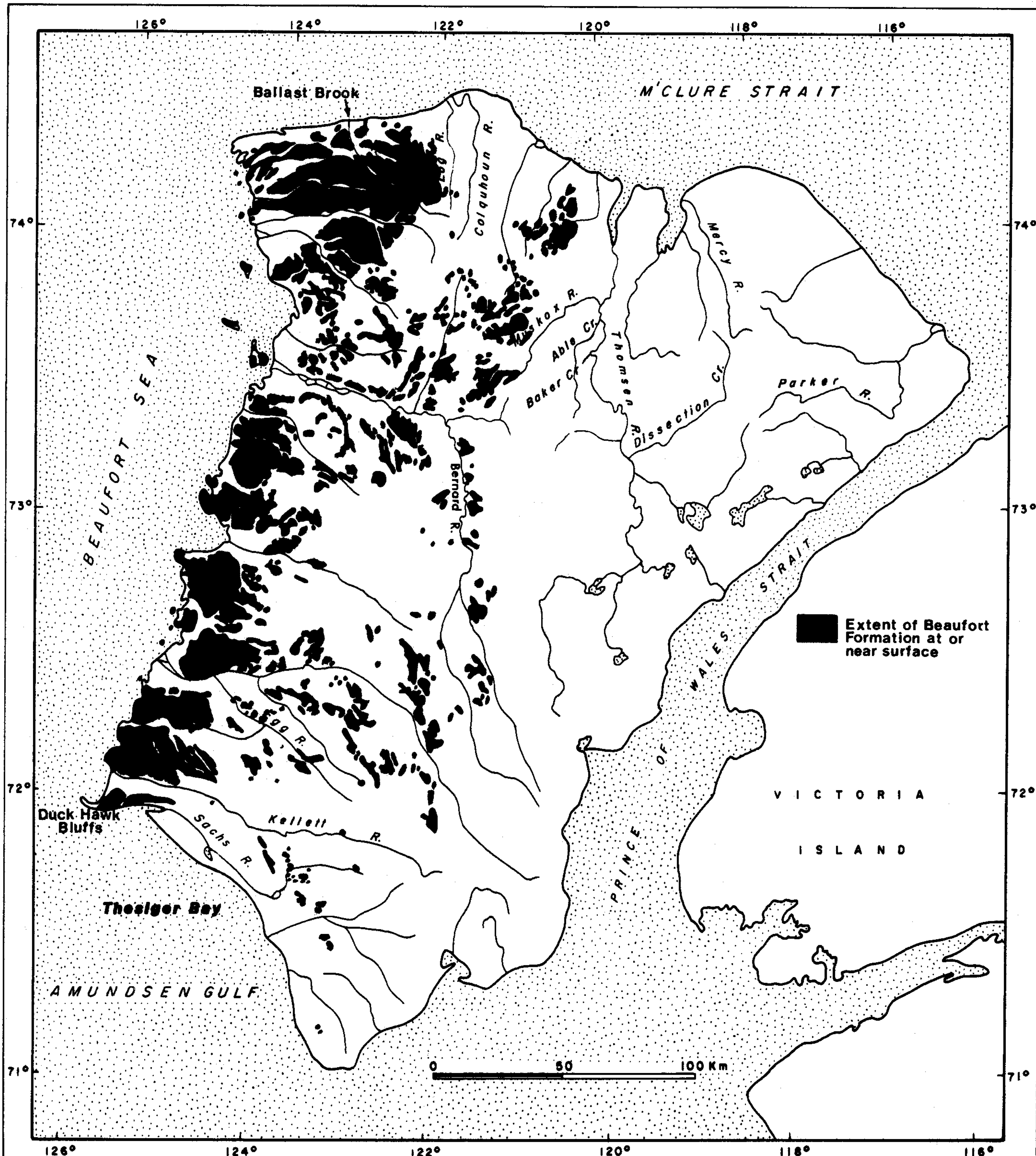

FIG. 4. Map of Banks Island showing the extent of Beaufort Formation and related sediments at or near the surface.

and led to the onset of glaciation in the Arctic. When studying sediments lying on or near the Beaufort surface in the clearly glaciated part of the island, care must be taken to ensure that the sediments are in place, since evidence for glaciotectonism acting on Beaufort deposits has been documented at the Duck Hawk Bluffs and Worth Point Bluffs and in the area north of Bernard River just west of the mouth of Egina River.

Age and Paleomagnetic Record

On the basis of floral and faunal content and comparisons with other Neogene sites, Hills *et al.* (1974) suggested that the Beaufort sediments at Duck Hawk Bluffs (= Mary Sachs gravel of Fyles, 1990-this issue) were of late Early to early Middle Miocene age (i.e., Seldovian) and that the upper part of the Beaufort Formation at Ballast Brook (=Beaufort

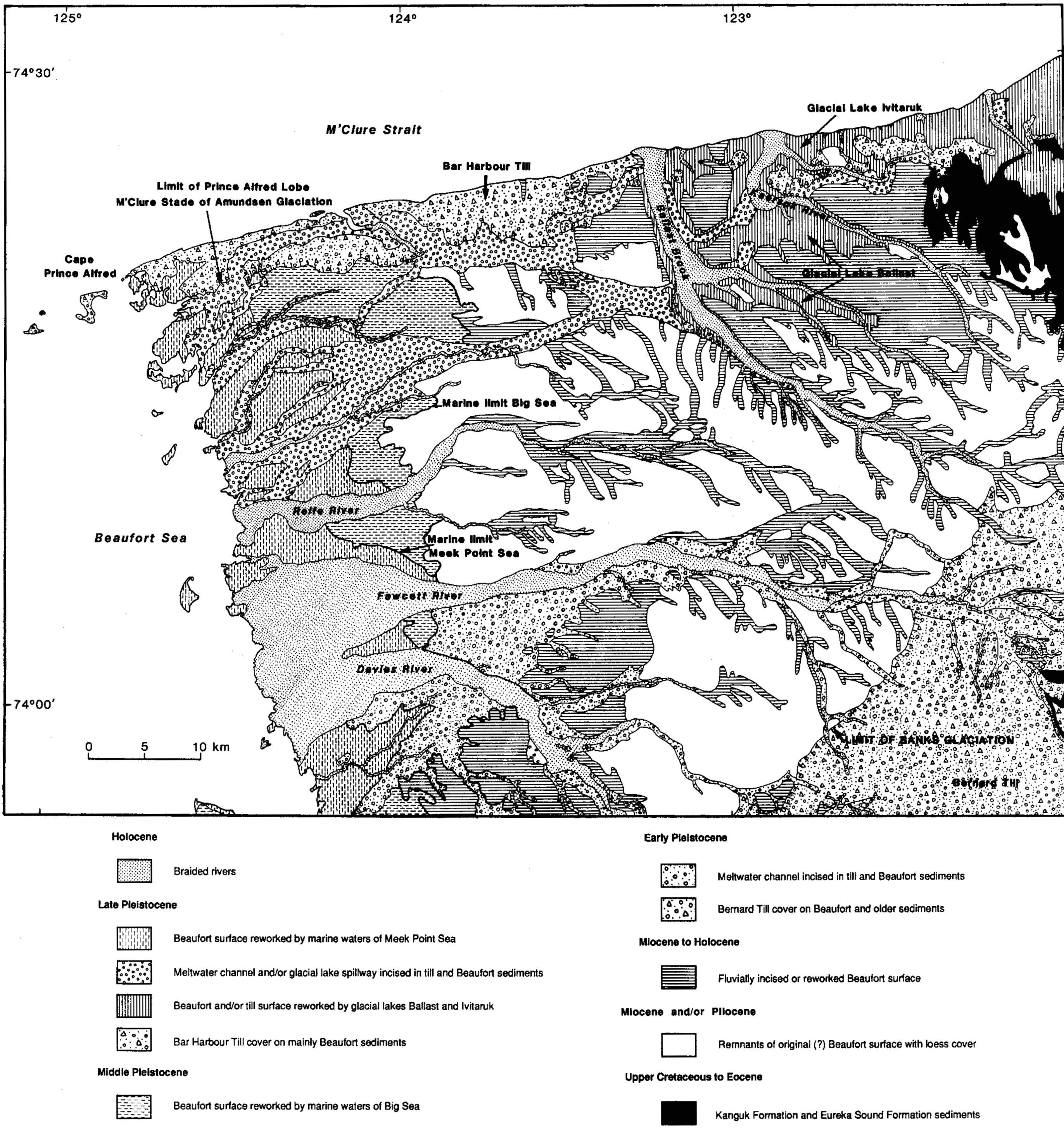

FIG. 5. Map of northwestern Banks Island showing the location of possible remnants of the original Beaufort deposition surface as well as the areas that have been modified by preglacial(?) and Pleistocene events.

Formation *sensu stricto* of Fyles, 1990-this issue) was of late Miocene (Homerian) age. Fyles (1990-this issue) considers that the Beaufort Formation (*sensu stricto*) in the Ballast Brook area is of Pliocene and/or latest Miocene age.

Barendregt and Vincent (1990) completed paleomagnetic studies in the Duck Hawk Bluffs and found that the main sand and gravel deposits were reversely magnetized and that a finer grained channel fill sequence incised in these (named unit Tb2 in section G; Vincent *et al.*, 1983; Matthews *et al.*, 1986) clearly showed a top to bottom normal-reversed-normal sequence. Even though it is not possible to accurately relate this paleomagnetic record to distinct polarity chrons, the results indicate that with further work it should be possible to establish a paleomagnetic (and therefore chronologic) record for the Beaufort Formation and related sediments.

Relative Level of Land and Sea

Present observations indicate that on Banks Island all Beaufort Formation and related sediments were laid down on land by rivers. No associated marine facies, as on Meighen Island (Matthews, 1987), has been identified. Since clearly fluvial beds are found at present-day sea level, relative sea level during deposition of the sediments was distinctly lower than today or crustal subsidence may have lowered the beds to their present level. Another alternative is that the marine sediments have been stripped off.

Extent in Bordering Areas

Figure 6 shows the distribution of other known outliers of late Tertiary alluvial gravels in the regions surrounding Banks Island. On Dundas Peninsula of Melville Island, Hodgson *et al.* (1984) have identified several outliers of the Beaufort Formation. On the mainland, Norris (1981) and Yorath and Cook (1981) have respectively identified late Tertiary sand and gravel outliers in the area east of the Mackenzie River north of Inuvik and on the Horton River upland. Recent field work by the author has led to the identification of other outliers in areas south of Darnley Bay and near the West River (Fig. 6). At both sites the sands and gravels overlie Cretaceous sediments and underlie thick glacial deposits. At the site near West River (Fig. 7), abundant plant macrofossil remains have been identified by J.V. Matthews, Jr. (see Matthews and Ovenden, Horton River site, 1990-this issue). They represent assemblages similar to those in late Tertiary sediments found elsewhere in the arctic islands. More work obviously has to be done to ascertain that all the observed beds are in fact Beaufort Formation or other related deposit equivalents, but these observations imply a much wider distribution of late Tertiary alluvial beds than previously acknowledged and must be taken into account in future paleogeographic reconstructions.

THE PREGLACIAL WORTH POINT FORMATION

Definition and Past Studies

On Banks Island, nonglacial beds between Beaufort Formation or related sands and gravels and Early Pleistocene marine and glacial deposits associated with the oldest well-documented glaciation (Banks Glaciation - Duck Hawk Bluffs Formation) have been assigned to the Worth Point Formation by Vincent (1980c, 1983) and Vincent *et al.* (1983). Sediments in this stratigraphic position (Table 1) have thus far only been definitely identified at Worth Point and in the Duck Hawk Bluffs (Fig. 1) but may also be present on Bernard Island.

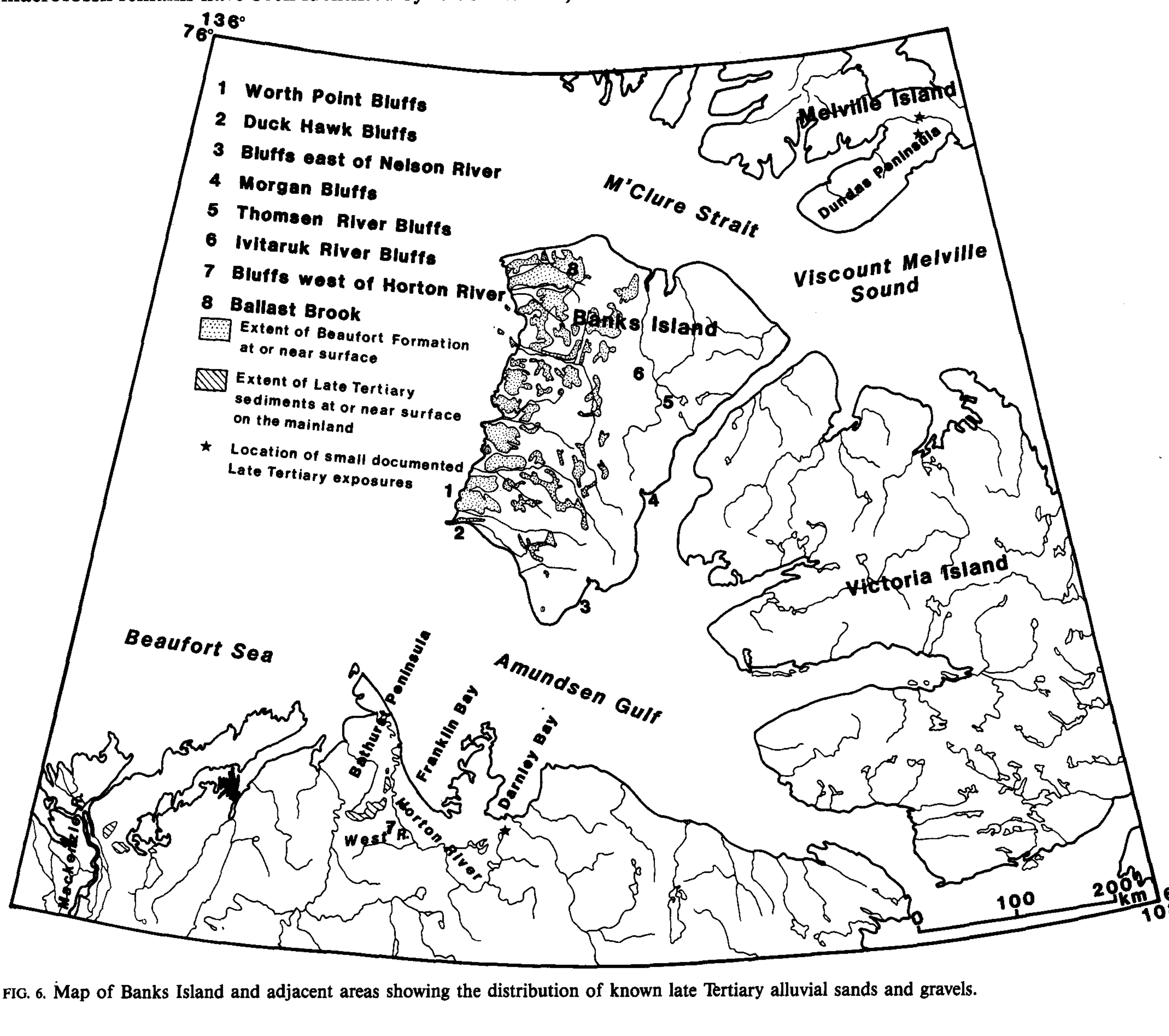

FIG. 6. Map of Banks Island and adjacent areas showing the distribution of known late Tertiary alluvial sands and gravels.

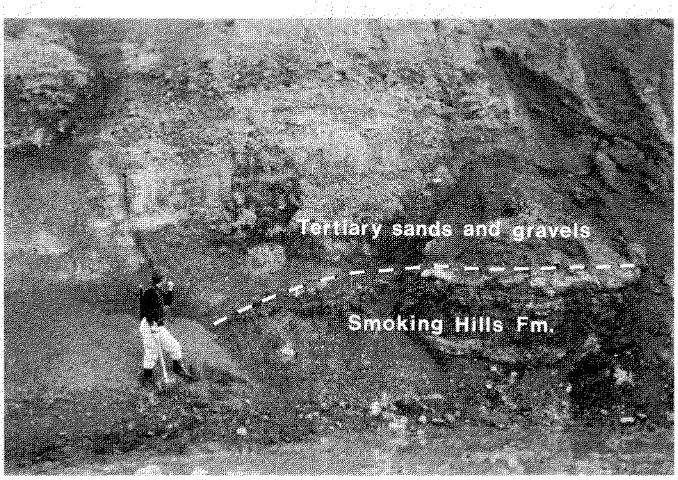

FIG. 7. Section on a tributary of the Horton River (north of West River) showing late Tertiary sands and gravels overlying upper Cretaceous Smoking Hills Formation (GSC photo 204737-30A).

TABLE 1. Late Tertiary and Pleistocene lithostratigraphic units and events recognized on Banks Island

General Chronostratigraphy	Geological Events	Formation	Stratigraphy
Holocene	Interglaciation		
10 ka			
LATE PLEISTOCENE – WISCONSINAN – Late	(Russell Stade)	Prince of Wales Fm.	Schuyter Point Sea Seds. Passage Point Seds. Schuyter Point Sea Seds.
23 ka – Middle – 65 ka	Amundsen Glaciation	Prince of Wales Fm.	Non Glacial Seds. ?
Early	(M'Clure Stade)	Prince of Wales Fm.	Carpenter Till East Coast, Meek Point, Investigator Sea seds. Jesse, Sachs, Bar Harbour, Mercy tills Pre -Amundsen Sea Seds.
80 ka			
SANGAMONIAN	Cape Collinson Interglaciation		Cape Collinson Formation
132 ka			
MIDDLE PLEISTOCENE	Thomsen Glaciation	Nelson River Fm.	Big Sea Seds. Lake Parker and Lake Dissection seds. Kellett Till, Baker Till and Kange Till Pre-Thomsen Sea Seds.
790 ka – Brunhes/Matuyama boundary	Morgan Bluffs Interglaciation		Morgan Bluffs Formation
EARLY PLEISTOCENE	Banks Glaciation	Duck Hawk Bluffs Fm.	Post-Banks Sea Sediments *Lake Egina and Lake Storkerson sediments* Bernard Till, Plateau Till and Durham Heights Till Pre-Banks Sea Sediments
	Erosion and sedimentation during Preglacial Interval		Worth Point Formation
1.64 Ma	Early glaciation(s) ? ? ?		?
2.48 Ma – Matuyama/Gauss boundary			
LATE TERTIARY	Fluvial Sedimentation on Coastal Plain		Beaufort Formation

The Worth Point site (Fig. 8, section A) was discovered by J.G. Fyles in 1959 and later investigated by M. Kuc in 1969, by J-S. Vincent in 1974 and 1981, and by R.W. Barendregt, J.G. Fyles, J.V. Matthews, Jr., L. Ovenden, and J-S. Vincent in 1988. Following the initial work of J.G. Fyles (Craig and Fyles, 1960, 1965) and of Kuc (1970, 1974), the existence of probable "interglacial" beds at Worth Point was established, but the problem of the precise stratigraphic position of the beds was not resolved. It was particularly difficult to identify the genesis of diamictons (till or slope deposits) in the poorly exposed section and to reliably ascertain the stratigraphic position of these in relation to the nonglacial beds (only beneath?, only above?, both beneath and above? the organic-bearing beds). Vincent (1982, 1983) suggested that the beds could be "preglacial" rather than "interglacial," but the question of the precise stratigraphic position of the nonglacial beds at Worth Point remained unanswered. The problem was finally resolved during the 1988 field season when Worth Point Formation beds were seen to rest directly on Beaufort Formation or related deposits and to underlie Bernard Till of the Banks Glaciation.

The Duck Hawk Bluffs site (Fig. 9) was also discovered and studied by J.G. Fyles in 1959 and later investigated by L.V. Hills in 1970, J-S. Vincent in 1975, S. Occhietti and J-S. Vincent in 1981, R.W. Barendregt and J-S. Vincent in 1983, L.D. Carter, D.M. Hopkins, M. Lamothe, J.V. Matthews, Jr., J-S. Vincent, and J.A. Westgate during a joint GSC/USGS field program in 1985, and briefly by R.W. Barendregt, J.G. Fyles, J.V. Matthews, Jr., L. Ovenden, and J-S. Vincent in 1988. Vincent (1982, 1983) and Vincent *et al.* (1983) established that Worth Point Formation sediments were present in the Duck Hawk Bluffs between Beaufort Formation (=Mary Sachs gravel of Fyles, 1990-this issue) deposits and marine and glacial sediments associated with the Banks Glaciation. On the basis of paleomagnetic investigations, a Matuyama Polarity Chron age (>790 ka) was also assigned to the deposits by Vincent *et al.* (1984) and Barendregt and Vincent (1990).

Floral remains at Worth Point were initially studied by Kuc (1974), who concluded that the fossils represented an open larch-dominated forest-tundra environment — a conclusion supported by Matthews *et al.* (1986).

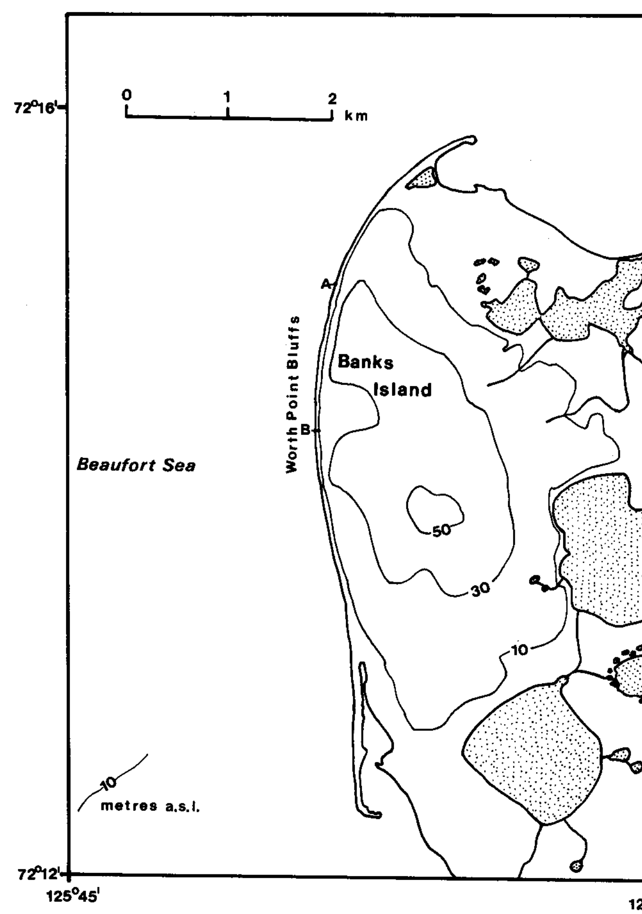

FIG. 8. Map of Worth Point area, Banks Island, showing location of studied sections.

Description of Worth Point Formation Deposits at the Type Section

Deposits at the Worth Point type locality (Figs. 10 and 11) are preserved in a valley incised by a small stream. Beaufort or related deposits are present beneath the valley fill and form the north wall of the valley. The south wall of the valley, on the other hand, is made up of Upper Cretaceous Kanguk Formation silts and clays.

Stratigraphic units at the type locality are shown on Figure 11. The Worth Point Formation deposits rest uncomformably on Beaufort Formation or related sands and gravels and are unconformably overlain by Bernard Till of the Duck Hawk Bluffs Formation discussed later. The Worth Point Formation sediments can be subdivided into two distinct members.

The 10–11 m thick lower member is a diamicton made up of colluvial material derived from Beaufort Formation or related deposits and Kanguk Formation deposits. Randomly incorporated in these slope deposits are large tree trunks (particularly near the contact with the underlying Beaufort Formation or related deposits) and branches, as well as reworked peat mats and other disseminated organics (Fig. 12). The

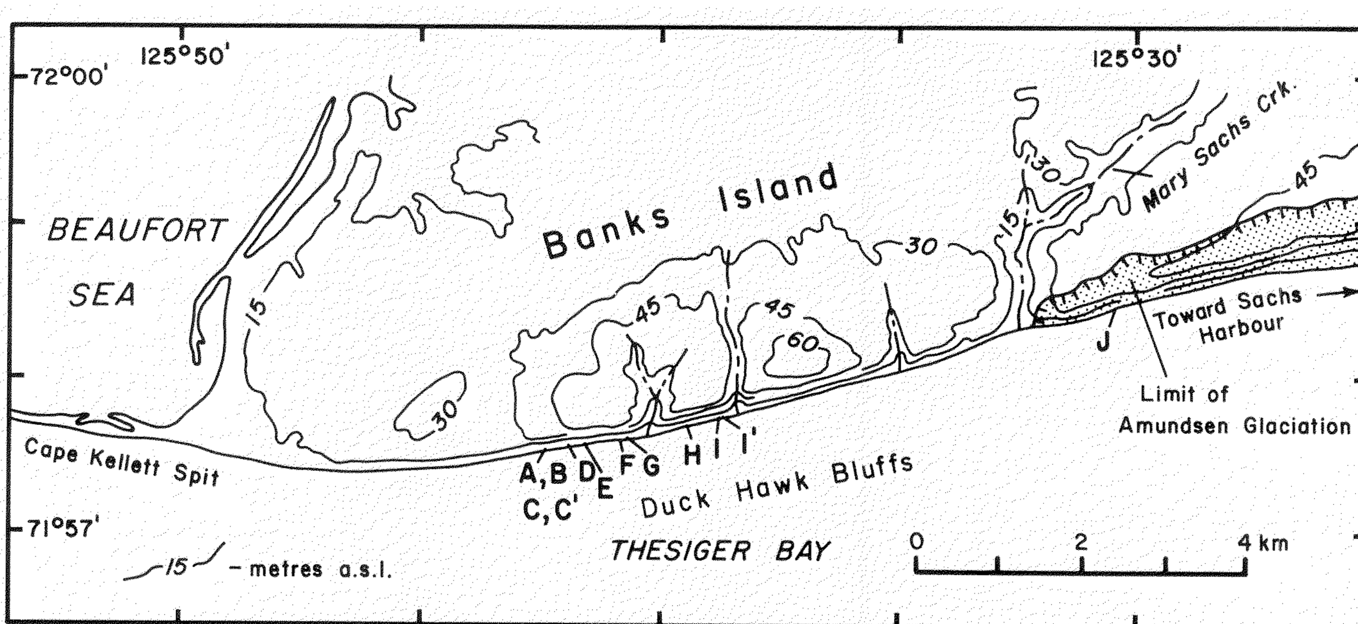

FIG. 9. Map of Duck Hawk Bluffs area, Banks Island, showing location of studied sections.

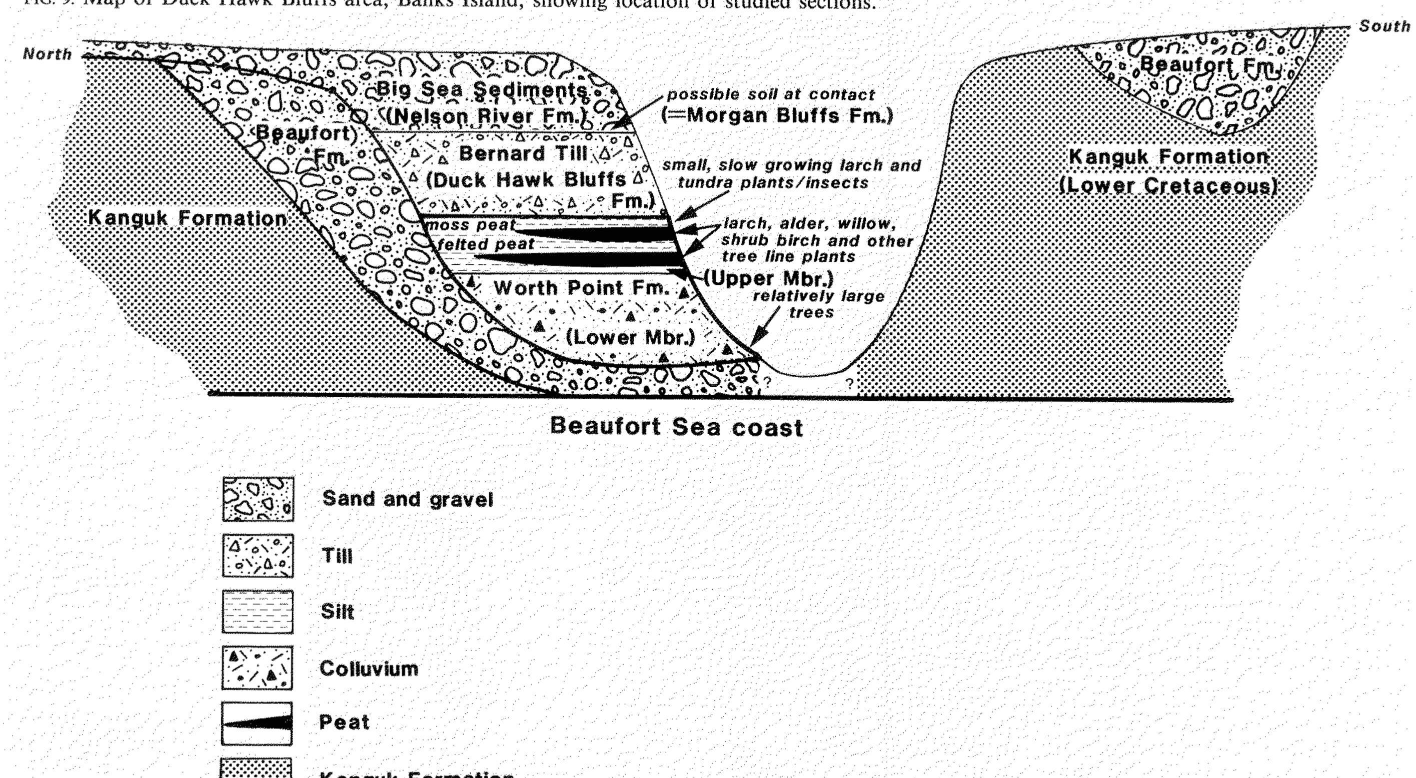

FIG. 10. Cross section of the Worth Point Formation type locality showing the relationship of the valley fill with other lithostratigraphic units.

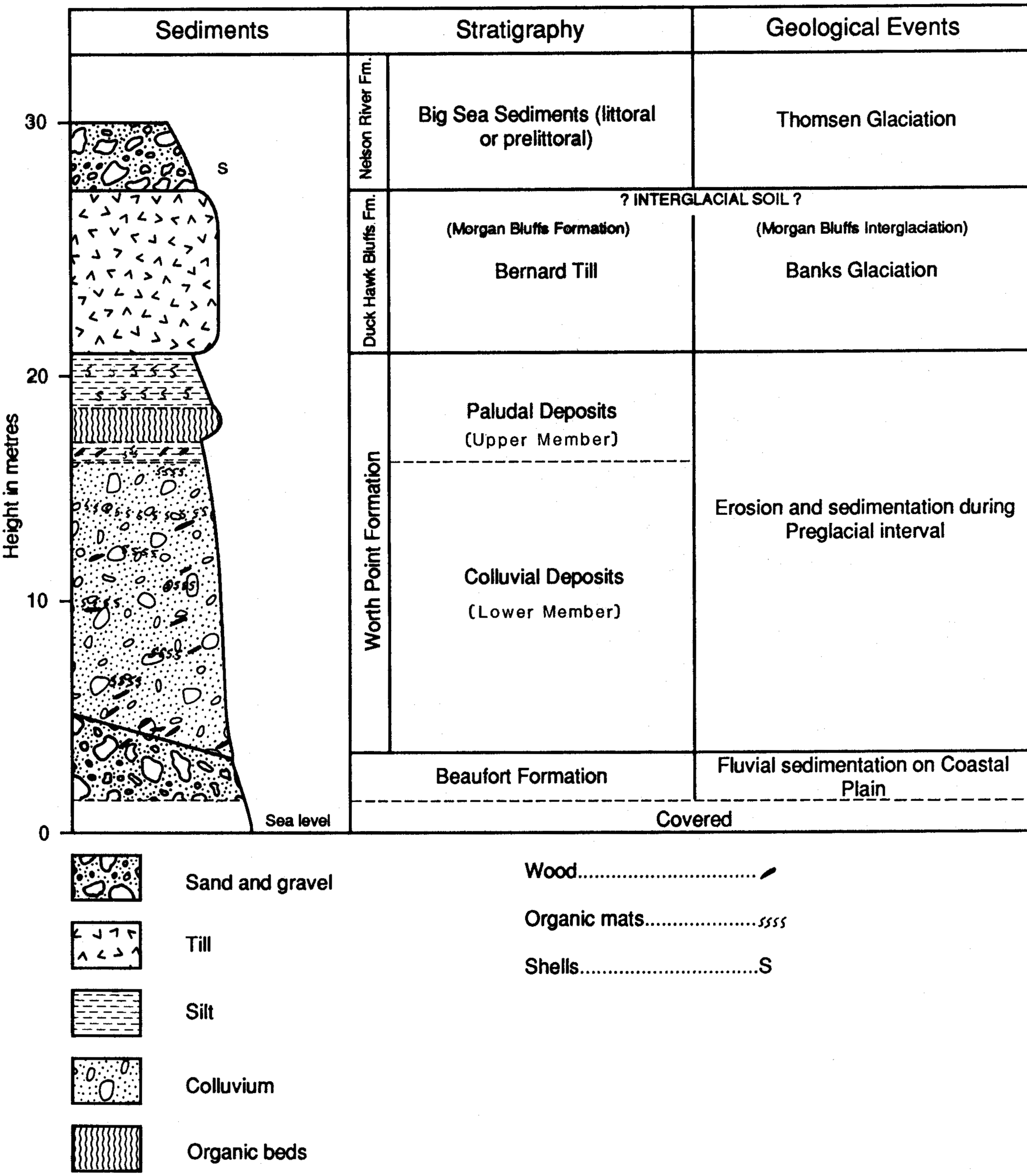

FIG. 11. Stratigraphy at the type section for the Worth Point Formation, Banks Island.

recognition of this deposit as a nonglacial colluvial unit rather than a glacial diamicton is critical to the interpretation of the Worth Point Formation. Both J.G. Fyles (1959 field notes) and Vincent (1983) had initially identified the presence of a diamicton below the clearly nonglacial beds, but the exposure was so poor that the genesis of the diamicton could not be determined. During the 1988 field season, thanks to a storm that had removed much debris at the base of the bluff and with the help of a water pump, the entire lower portion of the section was cleaned until unquestionable *in situ* deposits were exposed. Study of the section clearly indicates that, as in the exposures in the Duck Hawk Bluffs (Vincent *et al.*, 1983), there are no glacial deposits underlying the Worth Point Formation deposits at the type

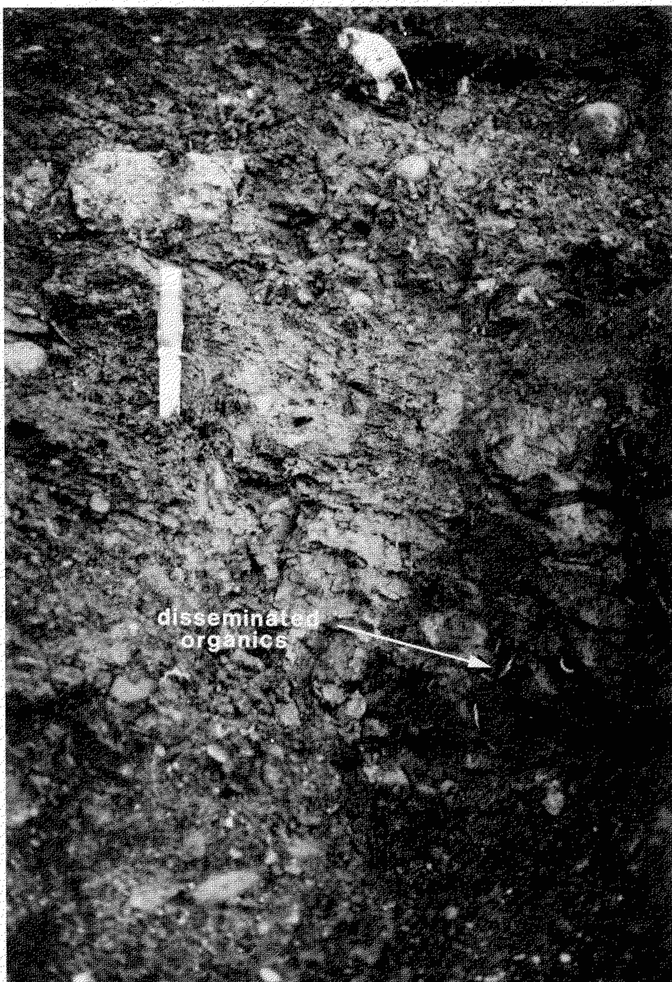

FIG. 12. Organic rich colluvial deposits in the lower member of the Worth Point Formation at the Worth Point type section (GSC photo 204737-18A).

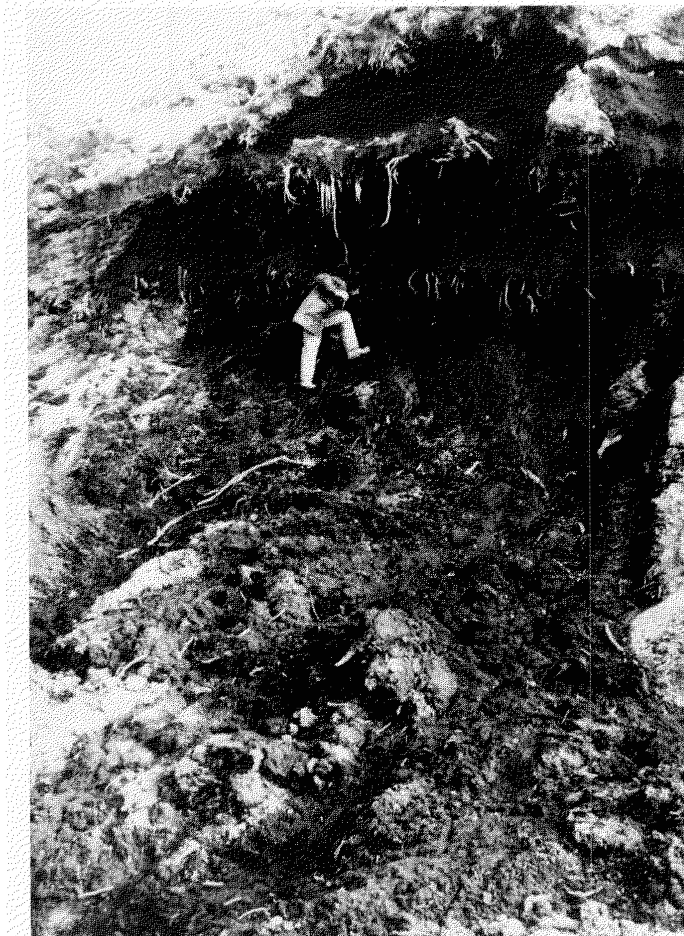

FIG. 13. View of the organic-rich beds in the upper member of the Worth Point Formation at the type section (GSC photo 204959-A).

locality and therefore the Worth Point Formation is preglacial in nature.

The lower member grades into a 5 m thick sequence of interstratified silts and thick peat mats. As shown on Figure 13, the peat mats are horizontal and extend for tens of metres laterally on the seaward-facing part of the section, as well as inland from the coastal cliff, since they can be traced along the lateral faces of nivation hollows on both sides of the main exposure. Tree trunks and shrubs (some retaining leaves and in growth position) are present within the upper member. It is likely that the vegetation probably grew on a flat, locally waterlogged (and periodically flooded?) valley bottom and was gently buried by colluvial and other depositional processes. Despite close inspection, no evidence of ice wedge pseudomorphs was observed.

In a coastal bluff (Fig. 8, section B) some 2 km south of the type locality, complex sequences of silts and coarser materials interstratified with peats have been briefly observed in another valley fill sequence incised into Kanguk Formation deposits. In places, Bernard Till of the Banks Glaciation is mixed with the sediments and much evidence of glaciotectonic disturbance is apparent. Much more work is needed at this site but it is very likely that this locality contains sediments correlative with the Worth Point Formation. Fossils in one sample were identified as freshwater mollusc shells of *Sphaerium* (*Musculium*) *lacustre* (Müller), *Pisidium* (*Cyclocalyx*) *casertanum* (Poli), and *Helisoma* sp. by G.L. Mackie, of the University of Guelph, and as freshwater ostracodes of *Candona* cf. *caudata*, *Candona* sp., *Cyclocypris* cf. *sharpei*, *Cypria palustera* and *Limnocythere* cf. *liporeticulata* by J.P. Guilbault, of the University of Montreal. In the same sample, a fish scale from a minnow of the subfamily Leuciscinae (family Cypridinae) was identified by D.E. McAllister, of the National Museum of Natural Sciences. The family Cyprinidae is completely absent today from the Arctic Archipelago and a freshwater link between Banks Island and the mainland must have existed for the species to be present, since it occurs only in freshwater and it is unable to cross marine straits. The connection with the mainland could have existed at the time of deposition of these presumed Worth Point Formation sediments, but it is also possible that the minnow was a relict that survived on the island after the rifting that created the interisland channels.

Description of the Worth Point Formation Deposits at the Duck Hawk Bluffs

In the Duck Hawk Bluffs, Vincent *et al.* (1983) assigned nonglacial deposits found between Beaufort Formation (=Mary Sachs gravel of Fyles, 1990-this issue) sands and gravels and marine and glacial sediments associated with the Banks Glaciation (Duck Hawk Bluffs Formation) to the Worth Point Formation. Two members were initially recognized, a lower one, only in section G (Fig. 9), made up of lacustrine and fluvial beds, and a widespread upper one consisting of eolian deposits. Subsequent paleoecological work by Matthews *et al.* (1986) permitted the reassignment of the channel-fill fluvial and lacustrine deposits found in section G to the Beaufort Formation or related deposits. Even though these generally fine-grained beds were sedimentologically quite different from typical late Tertiary sediments, their faunal and floral content was not. This means that Worth Point Formation beds in the Duck Hawk Bluffs now are considered to consist mainly of eolian sediments with associated pond deposits.

The 2–3 m thick eolian member was continuously traced over a distance of more than 2 km between sections A and I′ (Figs. 9, 14, and 15). The beds consist of finely stratified and quite indurated yellowish fine sands and silty sands. As in Holocene eolian sediments (Pissart *et al.*, 1977), disseminated organics and woody peat beds are interstratified with the sands and silts (Fig. 16). In section H, ventifacts were present in the sediments. In 1985, peat-rich deposits, typical of those associated with tundra ponds, were found with the eolian deposits in section A′. L.D. Delorme, of the Canada Centre for Inland Waters, identified ostracodes collected in section D as *Prionocypris glacialis* (Sars) and a large cyprid. Ice wedge pseudomorphs and clear evidence for cryoturbation were also observed in sections A′, D, and H. These features bear witness to the presence of permafrost at the time of deposition of Worth Point Formation sediments and are among the oldest such features recognized in the late Cenozoic record of Canada. Finally, between sections C and D, still unstudied woody peat, in what seemed to be overbank deposits, were observed between Beaufort (=Mary Sachs gravel of Fyles, 1990-this issue) and eolian sediments. All in all, the Worth Point Formation deposits in the Duck Hawk Bluffs record a period during which eolian activity was predominant. Fine-grained late Tertiary sediments and those of floodplains of rivers flowing on the Beaufort surface were being mobilized by wind and redeposited. Tundra ponds or small lake basins, associated with the eolian deposits, were present, as well as at least discontinuous permafrost.

Extent and Thickness

Worth Point Formation deposits up to now have been clearly identified only at Worth Point and in the Duck Hawk

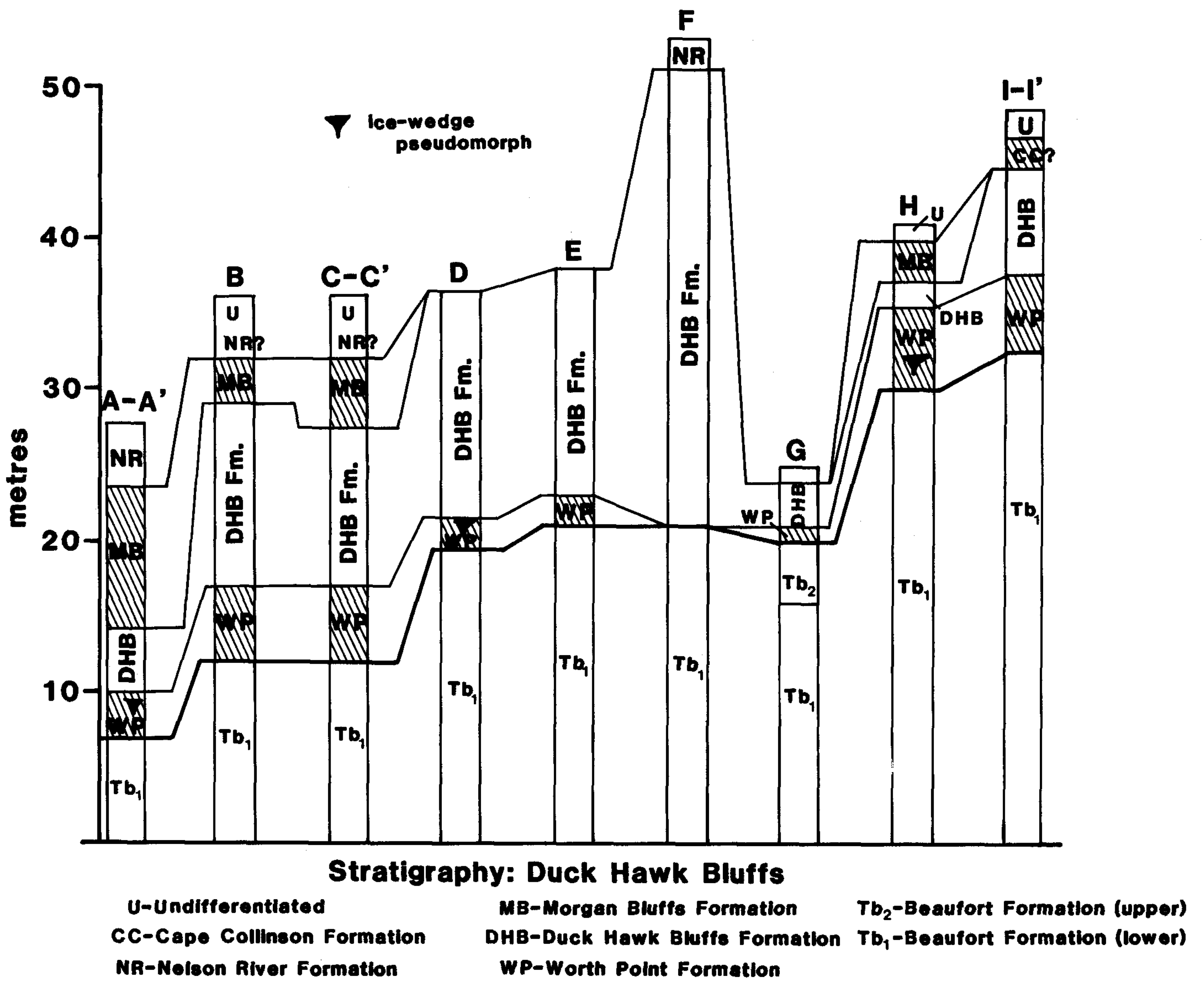

FIG. 14. Correlation of lithostratigraphic units present in sections A to I′ of the Duck Hawk Bluffs (modified from Vincent *et al.*, 1983, and Matthews *et al.*, 1986).

FIG. 15. View of the eolian deposits of the Worth Point Formation in section E of the Duck Hawk Bluffs. The nonglacial beds are underlain by Beaufort Formation (=Mary Sachs gravel of Fyles, 1990-this issue) sands and gravels and overlain by Bernard Till and sediments of the Post Banks Sea (Duck Hawk Bluffs Formation; GSC photo 204959-B).

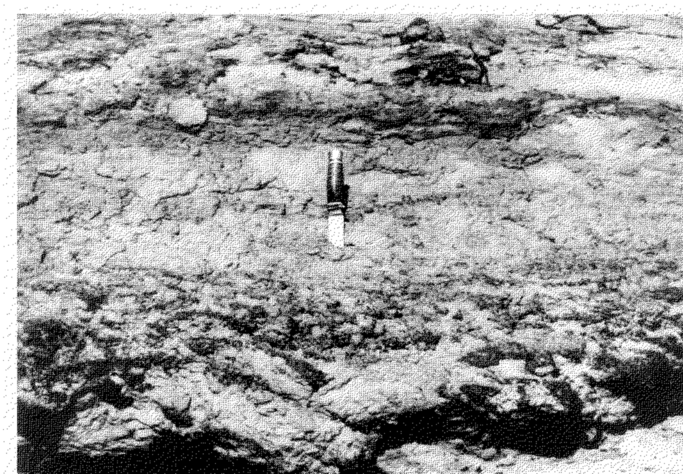

FIG. 16. Detail view of indurated Worth Point Formation eolian sands, with peat mats, in section E of the Duck Hawk Bluffs (GSC photo 202775-S).

Bluffs. The total thickness does not exceed 16 m in the first area and about 5 m in the second. Few exposures of western Banks Island, where material of Worth Point age could be preserved, have been studied and it is likely that future investigations will provide new sites.

Faunal and Floral Content

Lists of the flora and/or fauna identified in Worth Point Formation deposits have been provided by Kuc (1974), Matthews *et al.* (1986), and Vincent (1989). Appendix 1 is an updated version. The many taxa that do not occur on Banks Island today are identified by an asterisk. The significance of the Worth Point fauna and flora is discussed in the above-mentioned papers and in Matthews (1989). The macrofossils are only diagnostic at the Worth Point type locality and indicate that conditions in coastal areas of Banks Island were warm enough to allow growth of conifers but that the forest was probably not closed.

Age and Paleomagnetic Record

On the basis of the record preserved on Banks Island, the Worth Point Formation precedes at least three full continental glaciations (Banks, Thomsen, and Amundsen) and two pre-Holocene interglaciations (Morgan Bluffs and Cape Collinson) (Table 1 and Vincent, 1983, 1984, 1989). Five nonfinite radiocarbon age determinations, the oldest of which was >54 ka (GSC-1236), were obtained on wood and peat at the type locality (see details in Vincent, 1983). The assignment of the formation at the Duck Hawk Bluffs to the Matuyama Reversed Polarity Chron, initially proposed by Vincent *et al.* (1984), has been confirmed by the more detailed investigations of Barendregt and Vincent (1990). The Worth Point Formation deposits, as well as the overlying glacial deposits of the Duck Hawk Bluffs Formation (Banks Glaciation) and of the interglacial deposits of the Morgan Bluffs Formation, are characterized by a reversed polarity (negative inclinations and southerly mean pole positions). The Worth Point Formation must therefore be somewhat older than 790 ka (the age of the Brunhes Normal/Matuyama Reversed-Polarity Chron boundary, according to Johnson, 1982), since the major Banks Glaciation and part of the Morgan Bluffs Interglaciation occurred during the Matuyama Chron after the deposition of the preglacial beds. On the other hand, the Worth Point Formation must be younger than 2.48 Ma (the age of the Matuyama Reversed/Gauss Normal-Polarity Chron boundary, according to Mankinen and Dalrymple, 1979). The Worth Point Formation likely could not have formed during an earlier reversed polarity chron for the reasons given below.

After comparing the relatively modern-looking Worth Point Formation floral and faunal assemblages with those of other arctic late Cenozoic localities, Matthews *et al.* (1986) and Matthews (1989) have concluded that the beds are likely younger than the Kap København beds of Greenland (Funder *et al.*, 1985; Bennike, 1990; Bennike and Böcher, 1990-this issue), the high level alluvium on Ellesmere Island (Fyles, 1989), the Meighen Island beds of the northwestern Canadian Arctic Archipelago (Matthews, 1987), and the Ocean Point assemblages of the Alaskan Arctic Coastal Plain (Carter and Galloway, 1985; Nelson and Carter, 1985). On the basis of the above paleomagnetic and paleoecologic information, it is assumed that the Worth Point Formation could be of very late Pliocene age but that it is more likely Early Pleistocene. It is still impossible to narrow it down more closely (Table 1).

Relative Level of Land and Sea

At present, Worth Point Formation deposits in both the Duck Hawk Bluffs and the Worth Point Bluffs lie some 6-7 m a.s.l. on a coast being transgressed by the sea. The Worth Point type locality deposits are within a former stream valley and in an area of active coastal retreat. The deposits in the Duck Hawk Bluffs were laid down in interfluve areas and are also found within bluffs subjected to rapid coastal erosion. It is therefore evident that relative sea level at the time of deposition of the Worth Point Formation deposits was not higher and perhaps was considerably lower than it is today. As for late Tertiary sediments, crustal subsidence may nevertheless have lowered the beds to their present level.

In the Morgan Bluffs of eastern Banks Island, fine-grained sediments, at least 25 m thick, underlie glacial deposits (Bernard Till) of the Duck Hawk Bluffs Formation. These contain marine diatoms and shells of *Astarte borealis* and *Portlandia arctica* and have been assigned to the Pre-Banks Sea (Vincent, 1983), a marine transgressive episode immediately predating the oldest recognized advance of the Banks Glacier. The marine sediments are not typical of other glacio-isostatic sea deposits found on Banks Island, and the possibility that they in fact represent a preglacial eustatic marine transgression should not be ruled out. If this was the case, these marine deposits would bear witness to a marine transgression on the east coast of Banks Island in preglacial times. With further work, the deposits could eventually be correlated with those of one or the other well-documented (Carter *et al.*, 1986) late Tertiary Alaskan Arctic Coastal Plain transgressions. Dating these marine deposits is also very important, since it would provide a minimum estimate of the time of inception of Prince of Wales Strait, whether by rifting or erosion during lower sea level, because the strait had to be open for marine sediments to have accumulated at this locality.

THE DUCK HAWK BLUFFS FORMATION AND THE BANKS GLACIATION

Definition and Past Studies

Glacial and marine deposits associated with the Banks Glaciation have been recognized and assigned by Vincent (1980c, 1983) to the Duck Hawk Bluffs Formation. Deposits of this formation unconformably overlie sediments of the Worth Point Formation at Worth Point and in the Duck Hawk Bluffs and underlie interglacial sediments of the Morgan Bluffs Formation (Table 1) in seven localities. The Banks Glaciation is the oldest well-documented advance of a continental (mainland provenance) glacier onto the southwestern Arctic Archipelago.

Since the reconnaissance work of J.G. Fyles in the Western Arctic (Fyles, 1962; Craig and Fyles, 1960, 1965) it has been suspected that glacial deposits of pre-Wisconsinan age were present on Banks Island. Vincent (1983) established the stratigraphy and mapped the distribution of various pre-Wisconsinan glacial deposits, which he associated with two distinct continental glacial advances: the Banks Glaciation and the younger Thomsen Glaciation. The age of the Banks Glaciation was not known until paleomagnetic investigations by Vincent *et al.* (1984) indicated that till and marine deposits laid down during the Banks Glaciation were magnetically reversed and therefore most likely of Matuyama (Early Pleistocene) age.

Deposits and events associated with the Banks Glaciation are described in detail in Vincent (1983) and summarized in Vincent (1982, 1984, 1989).

General Description

During the Banks Glaciation, a continental ice sheet flowing from an ice centre situated west of Hudson Bay on the mainland overrode Cretaceous and Tertiary sediments and covered most of Banks Island except for the northwest sector (Fig. 17). Till plains left by the Banks Glacier cover much of western and northern Banks Island. The geographically separated but correlated Bernard, Plateau, and Durham Heights till sheets (Duck Hawk Bluffs Formation; Fig. 17) can be examined at or near the surface in numerous exposures over much of the western and northern portions of the island. The tills are generally thicker than younger Middle or Late Pleistocene ones and can be as much as 20-25 m thick in places. Bernard Till unconformably overlies Worth Point Formation deposits in the Duck Hawk Bluffs (Fig. 14) and at Worth Point (Fig. 11). In section A of the Duck Hawk Bluffs, extremely well-preserved tree trunks were found incorporated in Bernard Till (Vincent *et al.*, 1983). The glacier obviously eroded a pocket of Worth Point deposits (or a stand of trees?) as it advanced. Banks Glaciation till was also found to underlie thick interglacial (Morgan Bluffs Formation) and Middle and Late Pleistocene deposits in several sections of eastern and southern Banks Island (Fig. 17). Of these, coastal sections of the Morgan Bluffs (Figs. 18 and 19) and in the area east of the mouth of the Nelson River (Figs. 20 and 21) have been the most studied (Vincent, 1983).

As the ice was advancing towards and onto Banks Island, the crust was glacio-isostatically depressed. Marine and glacial marine deposits of the Pre-Banks Sea record this event and can be found underlying Banks Glaciation till at both the Duck Hawk Bluffs (Fig. 14) and Morgan Bluffs (Fig. 19). As the glacier retreated southeastward, glacial lakes were locally formed, and in coastal areas marine waters of the Post-Banks Sea inundated newly deglaciated but isostatically depressed terrain. Deposits of this sea can be examined in Duck Hawk (Fig. 14) and Morgan (Fig. 19) bluffs and in bluffs east of the mouth of Nelson River (Fig. 21). Extensive terrace and deltaic sediments on the west coast of the island, particularly north of Bernard River, are graded to high stands of the Post-Banks Sea.

Age and Paleomagnetic Record

The Banks Glaciation, during which till and marine sediments of the Duck Hawk Bluffs Formation were laid down, precedes at least two full continental glaciations (Thomsen and Amundsen) and two pre-Holocene interglaciations (Morgan Bluffs and Cape Collinson) (Table 1; Vincent, 1983, 1984, 1989). On the basis of preliminary (Vincent *et al.*, 1984) followed by detailed paleomagnetic investigations in the Duck Hawk Bluffs (Barendregt and Vincent, 1990), the Pre-Banks Sea/Bernard Till/Post-Banks Sea deposits were found to be magnetically reversed. They are therefore >790 ka old and of Matuyama (very late Pliocene to Early Pleistocene) age. Since deposits of the younger Morgan Bluffs Interglaciation are also mostly magnetically reversed, it is clear that the Banks Glaciation is not likely "very late" Early Pleistocene but could date from a somewhat earlier part of this interval. The establishment of a more detailed chronostratigraphic framework in the Arctic Ocean basin may help in eventually pinpointing the age of the Banks Glaciation. The ice during this continental advance was by far the most extensive of the well-documented Quaternary glaciations and the one that extended the farthest into the Beaufort Sea. The sediments it brought to the ocean basins should therefore be conspicuous in marine cores. Already Clark *et al.* (1984) have suggested that the Banks Glaciation correlates with unit J of the central Arctic Ocean sedimentary sequence (Clark *et al.*, 1980). This unit is the coarsest glacial marine unit present in the Matuyama reversed-polarity chron and precedes a long nonglacial period (i.e., the Morgan Bluffs Interglaciation).

Evidence for Multiple Glacial Events in the Early Pleistocene?

Generally no evidence has been found for more than one major continental ice advance in the areas where the Bernard,

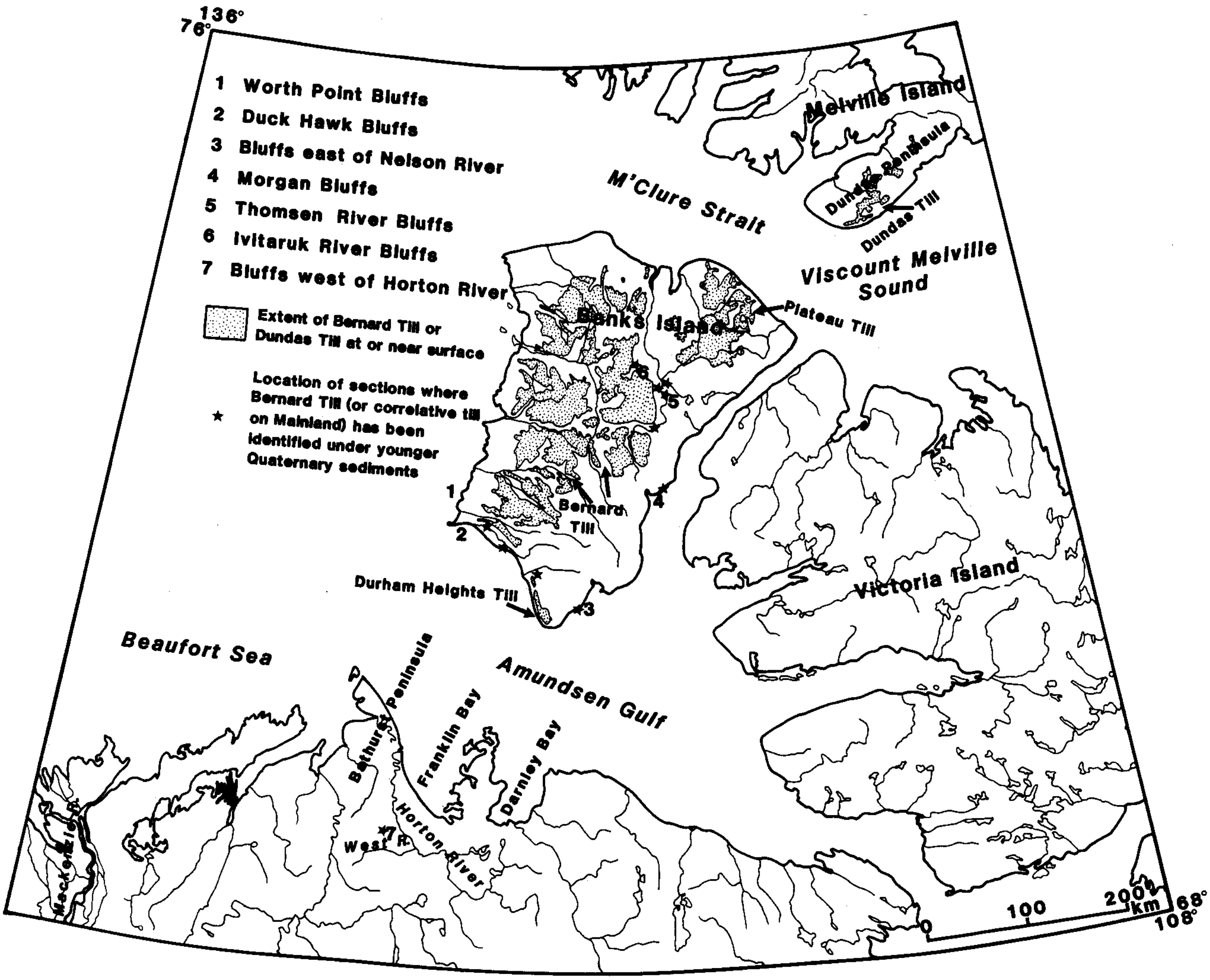

FIG. 17. Map of northwestern Canadian Arctic showing the distribution of Duck Hawk Bluffs Formation on Banks Island and of other Early Pleistocene glacial deposits in adjacent areas.

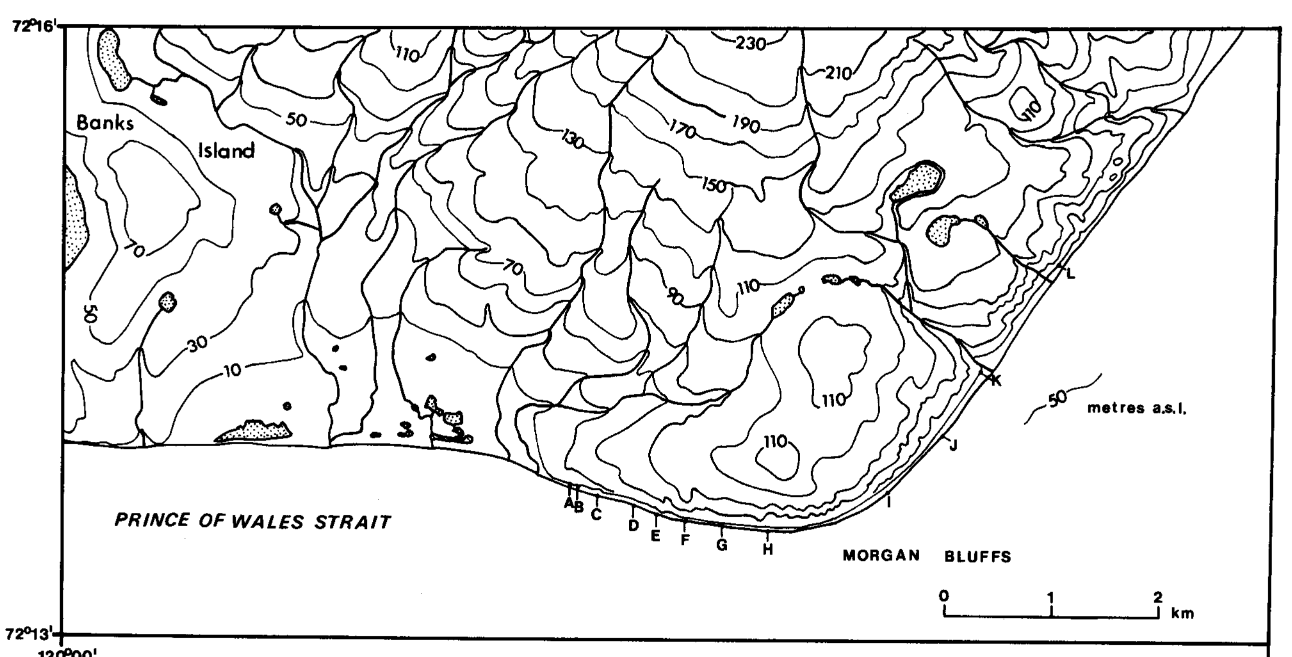

FIG. 18. Map of the Morgan Bluffs area, Banks Island, showing location of studied sections.

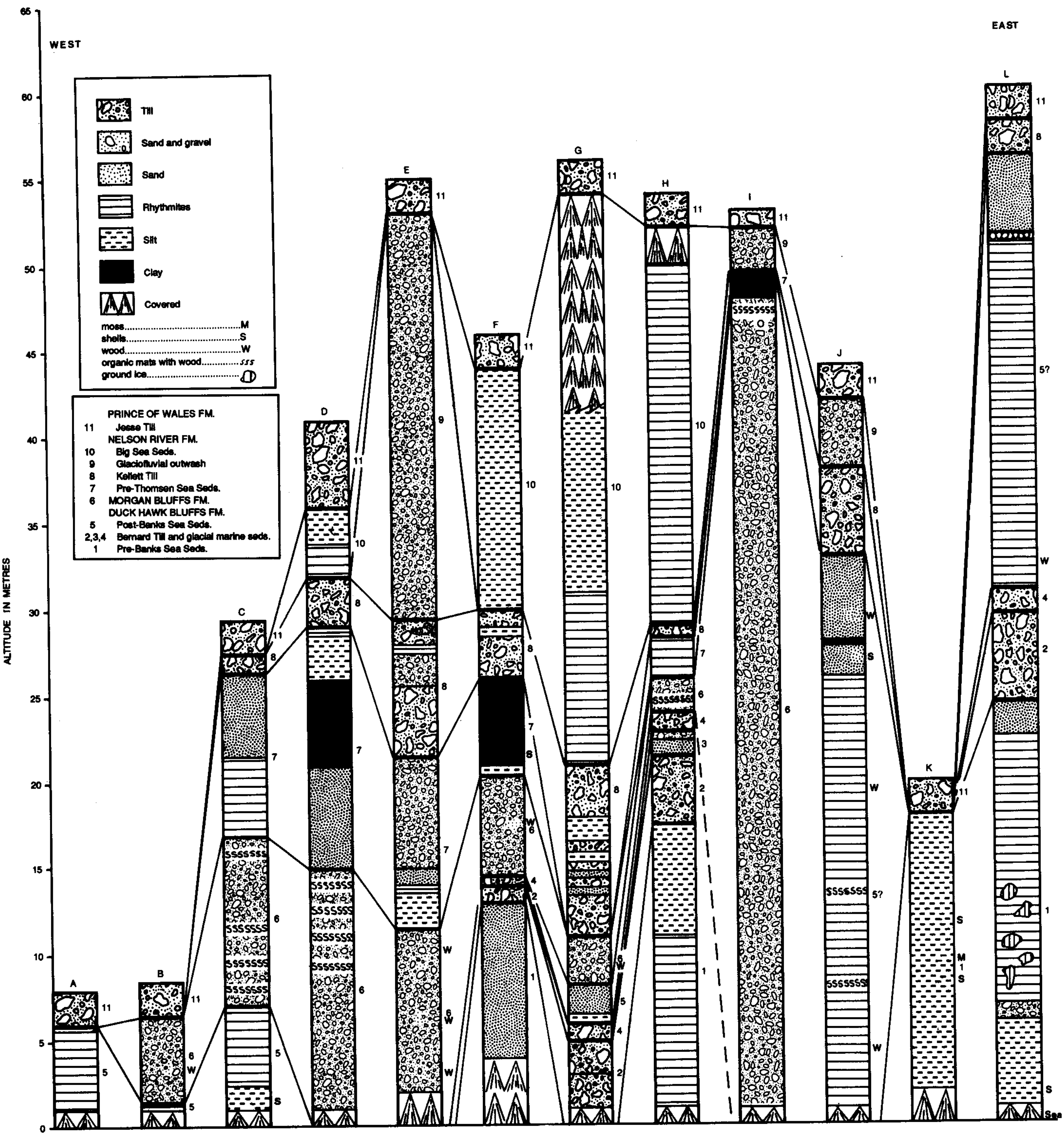

FIG. 19. Correlation of lithostratigraphic units present in sections A–L of the Morgan Bluffs (modified from Vincent, 1983).

Plateau, and Durham Heights tills are present at or near the surface (i.e., only one distinct till sheet was observed in numerous sections). Nevertheless in section A of the coastal bluffs east of the mouth of Nelson River (Figs. 20 and 21), near the southern tip of Banks Island, five distinct till sheets, in places separated from each other by glacial marine sediments or boulder pavements, are also present (Vincent, 1983). These may well represent advances of more than one continental glacier onto at least very southern Banks Island.

Canadian Shield and other large erratics have been found on the surface of Beaufort Formation deposits in the northwestern portion of Banks Island (in an area not covered by the Banks Glacier; Figs. 5 and 17) and in the westernmost Queen Elizabeth Islands (Hodgson, 1989). These could be regarded as indirect evidence, as previously stated by Vincent (1989), for a continental glacier that would have advanced into the area before the Banks Glaciation. Observations, during the 1990 field season, of large *boulders* lying distinctly

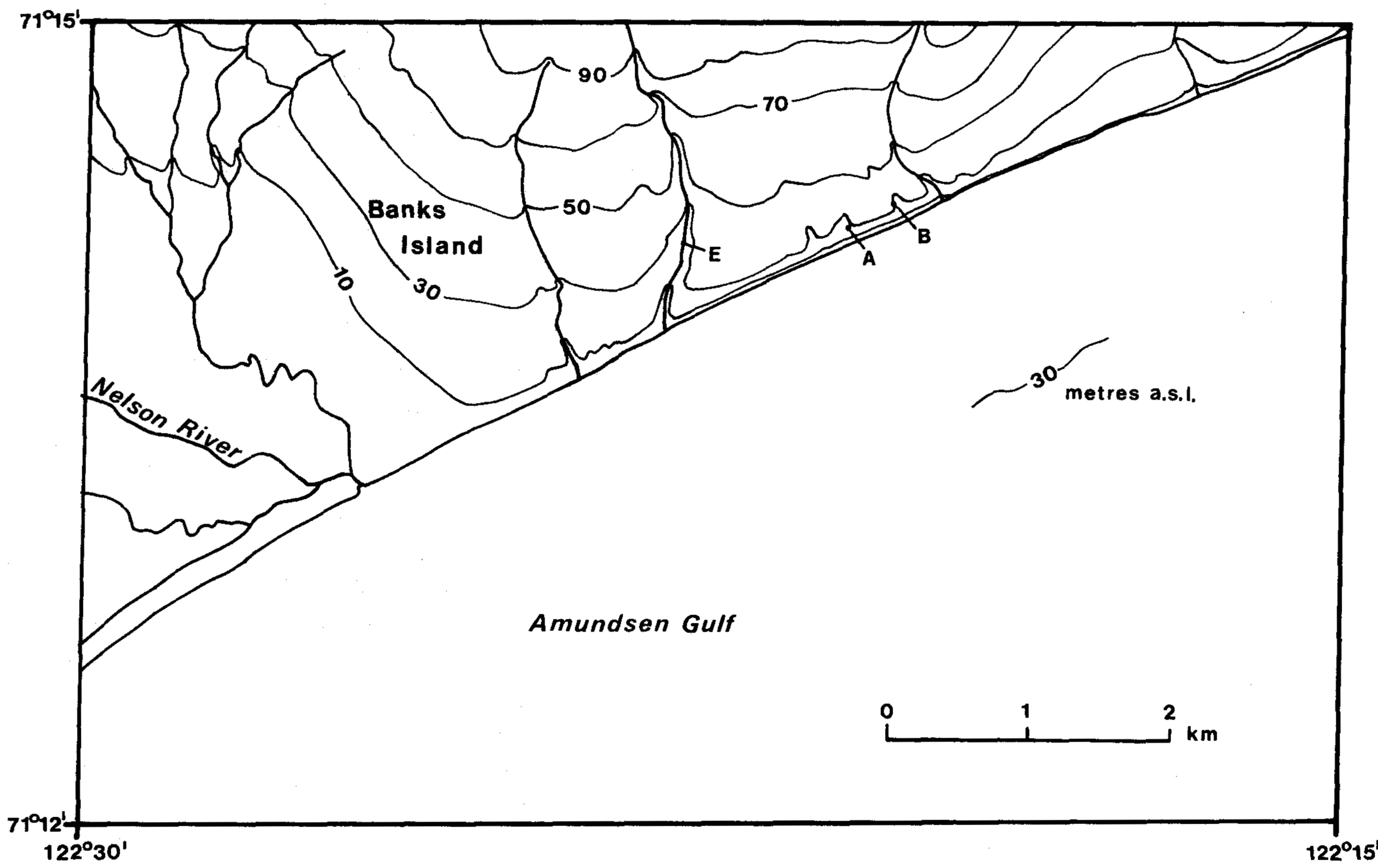

FIG. 20. Map of the area east of the mouth of Nelson River, Banks Island, showing location of studied sections.

within the Beaufort Formation *sensu stricto* in the Ballast Brook basin could negate this possibility. The boulders within the sediments and on the surface could also have been brought by river ice or carried in tree stumps at the time of deposition of the Beaufort sediments.

Relative Level of Land and Sea

The Post-Banks Sea sediments, which were laid down on the newly deglaciated and isostatically depressed coastal areas of the island during the retreat of the Banks Glacier, are found up to some 30 m and perhaps as high as 50 m above present sea level. This last figure should probably be considered as the minimum altitude reached by the glacio-isostatic Post-Banks Sea on the southern and eastern coasts of Banks Island. On the west coast of the island, north of the Bernard River, the maximum level of the sea was probably somewhat less than 50 m. Subareal meltwater channels carved by the Banks Glacier and deltas found at the mouth of these are present to about 40 m, indicating a lower altitude of the maximum water plane in the northwest. This would be expected, since that area lies farther from the glacial loading centre than the southern or eastern coasts of the island.

On Bathurst Peninsula on the mainland southwest of Banks Island, a marine wave-cut platform up to 75 m above present sea level has been assigned by Rampton (1988) to the Horton Sea. The platform predates a Middle Pleistocene glacial advance and may well be equivalent in age to the Post-Banks Sea. If so, glacio-isostatic sea levels were even higher on the mainland.

Extent of Other Early Pleistocene Glacial Deposits in Bordering Areas

The Banks Glaciation is by far the most extensive continental glaciation recorded on Banks Island. It inundated much more area and covered higher ground than any of the younger Middle or Late Pleistocene advances. Evidence for this event should therefore also be found in areas adjacent to Banks Island.

On central Melville Island, an unnamed glaciation responsible for deposition of the Dundas Till on Dundas Peninsula (Fig. 17) has been correlated with the Banks Glaciation by Hodgson *et al.* (1984). The glaciation could possibly be Middle Pleistocene but the character and areal and altitudinal distribution of the deposits have more affinity with those of the Banks Glaciation. On the mainland's coastal plain from west of Bathurst Peninsula to the Yukon/Alaska border, paleomagnetic investigations of all older beds, sampled by the author and analyzed by R. Barendregt, of the University of Lethbridge, have failed to identify any deposits with reversed magnetic polarities. On the other hand, in the Horton River basin north of the West River (Fig. 17) preliminary results for tills that lie directly on the late Tertiary sands and gravels discussed earlier (Fig. 7) indicate they are magnetically reversed. These Early Pleistocene tills lie up-ice from Banks Island and therefore can be correlated with the Banks Island glacial deposits of the same age.

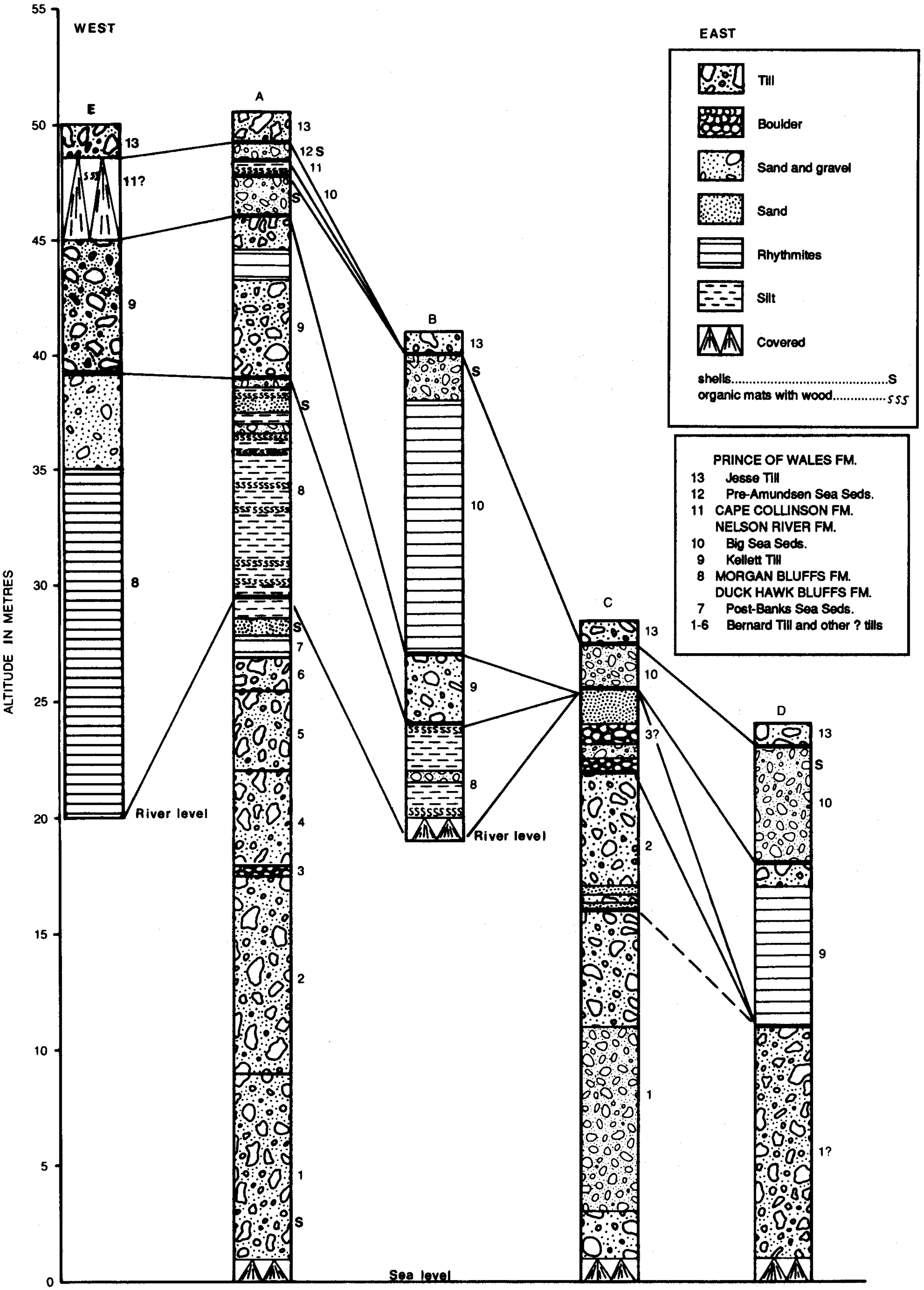

FIG. 21. Correlation of lithostratigraphic units present in sections A–E of the bluffs east of the mouth of Nelson River (modified from Vincent, 1983). Section E is a new exposure studied in 1988.

THE INTERGLACIAL MORGAN BLUFFS FORMATION

Definition and Past Studies

On Banks Island, organic-bearing nonglacial beds that overlie glacial and marine sediments of the Early Pleistocene Duck Hawk Bluffs Formation (Banks Glaciation) and underlie glacial and marine deposits of the Middle Pleistocene Nelson River Formation (Thomsen Glaciation) have been assigned by Vincent (1980c, 1983) to the Morgan Bluffs Formation (Table 1). Vincent (1983) initially recognized deposits of this formation at five locations: Morgan Bluffs, bluffs east and west of the mouth of Nelson River, Thomsen River bluffs, and Ivitaruk River bluffs (Fig. 1). Subsequently, Morgan Bluffs Formation deposits were discovered in the Duck Hawk Bluffs (Vincent *et al.*, 1983) and are probably present in the Worth Point Bluffs (this paper). The interglacial deposits were known to be old since they predated sediments of two full glaciations (Thomsen and Amundsen) and one pre-Holocene interglaciation (Cape Collinson). However it was not until paleomagnetic investigations (Vincent *et al.*, 1984) that an old age was confirmed. At least part of the deposits are magnetically reversed, suggesting a minimum Early to Middle Pleistocene age. These results were later confirmed in a more detailed paleomagnetic investigation of the Duck Hawk Bluffs (Barendregt and Vincent, 1990). The floral and faunal remains contained in the various nonglacial beds (Matthews *et al.*, 1986) show that the vegetation cover was low arctic in character and the climate was warmer than today during the interglaciation.

General Description

Deposits of the Morgan Bluffs Formation were laid down in various nonglacial environments. The sediments vary in origin and include fluvial, lacustrine (tundra pond), colluvial, paludal, eolian, marine, and perimarine facies, as well as paleosols developed within deposits of the formation or on older Banks Glaciation sediments. In all the seven localities briefly described below, Morgan Bluffs Formation sediments are found in sections between Duck Hawk Bluffs Formation and Nelson River Formation glacial and marine sediments.

In coastal sections B to H of the Morgan Bluffs (Figs. 18 and 19), the beds consist of a sequence of sands and gravels up to 48 m thick (Vincent, 1983). The sediments are distinctly fluvial and contain abundant autochthonous peat layers as well as detrital wood (Appendix 2). The sediments probably accumulated on the floodplain of a river that aggraded or degraded in response to an eustatically fluctuating sea level. A nonfinite uranium disequilibrium series age determination of >200 ka (UQT-118; Causse and Vincent, 1989) was obtained for wood.

In the bluffs east of the mouth of Nelson River (Figs. 20 and 21), an up to 9 m thick sequence of interstratified fine-grained sediments and autochthonous fossil-bearing peat layers (Fig. 22 and Appendix 2) is present in sections A and B. As initially described by Vincent (1983), the sequence is distinctly perimarine. Some shell-bearing shallow marine sediments and what are probably overbank deposits are interstratified with the peat beds. In a new site west of section A (section E, Figs. 20, 21, and 23), discovered in 1988, the formation consists of 15 m of fine-grained and stratified deltaic marine sediments, with a rich foraminifera assemblage

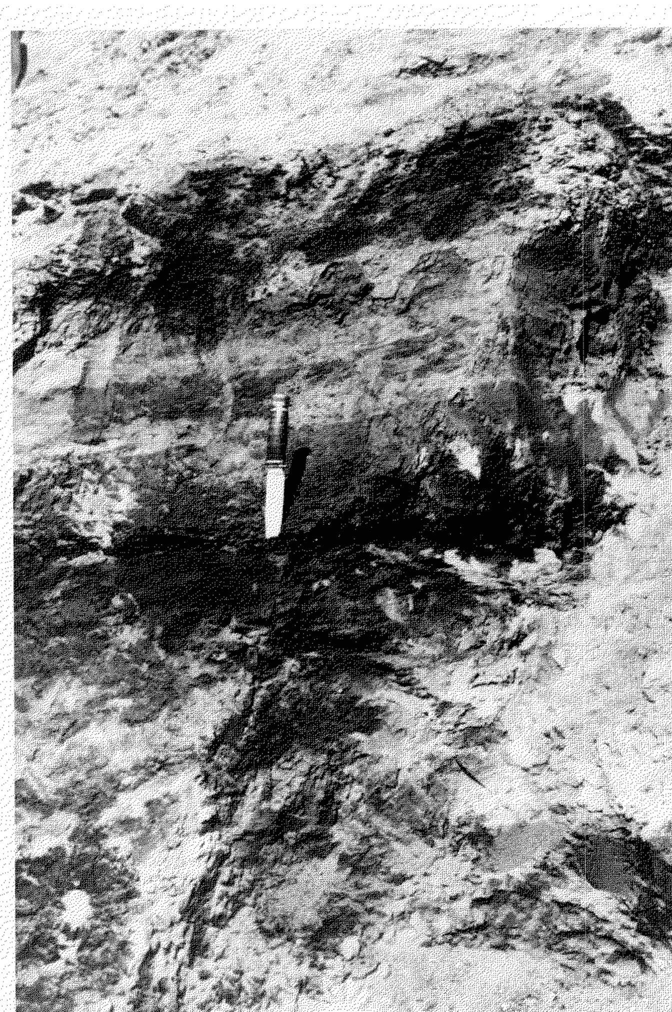

FIG. 22. Interstratified organic beds (indicated by knife) and perimarine and/or overbank deposits of the Morgan Bluffs Formation in section A east of the mouth of Nelson River (GSC photo 166174).

(Appendix 3), overlain by 5 m of sand and gravel. It is now quite apparent that the Morgan Bluffs Formation sediments at the sites east of Nelson River were laid down in a marine delta at the mouth of an ancestral Nelson River. The finer grained deposits in section E represent sedimentation more in the core of the delta, whereas deposits in sections A and B were probably laid down near land on the edge of the delta. At another site 12 km southwest of the mouth of Nelson River, thick, stratified sand and gravel and silt, with wood, are present in the same stratigraphic position. This site was discovered by J.G. Fyles in 1960 and briefly described by Blake (1976) and Vincent (1983). The beds are probably part of the same major complex of perimarine deltaic and fluvial beds laid down at the mouth of the ancestral Nelson River. An age of 47 100 ± 1000 (GSC-222-2), which should undoubtedly be considered nonfinite, was obtained on wood collected in the deposits.

On the right bank of the Thomsen River, at a site located on Figure 1 and first described by Vincent (1983), some 10 m of fluvial sands between Banks Glaciation and Thomsen Glaciation tills are present. The flora and fauna identified in organic beds within the Thomsen River bluffs sequence are listed in Appendix 2 and provide information of conditions in a more northerly site of Banks Island during the Morgan Bluffs Interglaciation.

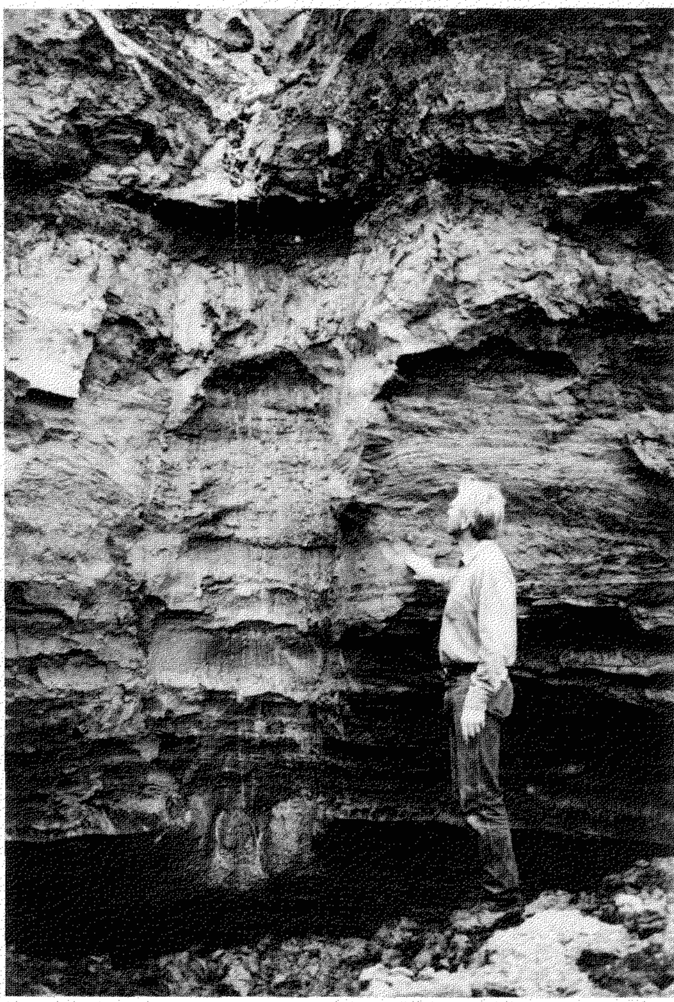

FIG. 23. View of section E, east of the mouth of Nelson River, showing marine deltaic beds of the Morgan Bluffs Formation that were laid down at the mouth of the ancestral Nelson River (GSC photo 204737-16A).

At the Duck Hawk Bluffs (Fig. 9 and 14), Morgan Bluffs Formation deposits are present in sections A, B, C, and H (Vincent *et al.*, 1983). In section A, thin, organic-rich tundra pond deposits with freshwater molluscs (Appendix 2) are overlain by a 9 m thick sequence of colluvial deposits containing wood and organic material. These last deposits, derived from Bernard Till, are *in situ* in the section and are overlain by Middle Pleistocene marine beds. In sections B and C, complex sequences of fluvial, eolian, lacustrine, and possibly marine (presence of abundant marine diatoms) deposits have been identified. In section H, wind-blown silts with up to 0.5 m thick compressed moss peat beds have been observed. All these deposits contain a wide array of floral and faunal remains, which are listed in Appendix 2. Twigs in peat from section H have provided a radiocarbon age of >39 ka (GSC-3585) and a thorium/uranium age of >200 ka (UQT-229).

Finally, paleosols have been recognized in two localities. In the "Ivitaruk" River bluffs (see location on Fig. 1), a paleosol developed on thick fluvial or more probably glaciofluvial deposits overlying Bernard Till of the Banks Glaciation and underlying Baker Till of the Thomsen Glaciation has been identified (Vincent, 1983). Similarly, a possible paleosol that was developed on Bernard Till and underlies sands and gravels of the Middle Pleistocene Big Sea is present in section A at Worth Point (Figs. 8, 10, and 11). Little work has been completed on these deposits, but on the basis of their stratigraphic position, both record soil-forming intervals during the Morgan Bluffs Interglaciation.

Faunal and Floral Content

Lists of the flora and fauna identified in Morgan Bluffs Formation deposits at the various localities have been provided by Matthews *et al.* (1986) and by Vincent (1983, 1989). Appendix 2 is an updated version. The many taxa that do not occur on Banks Island today are identified by an asterisk. The significance of the Morgan Bluffs fauna and flora is discussed in Matthews *et al.* (1986). In general the data indicate that conditions not only in coastal areas of Banks Island but also inland in the northern part of the island were low arctic in nature and distinctly warmer than the present, though certainly not as warm as during the Worth Point interval. On the basis of the presence of *Larix* fossils from Duck Hawk Bluffs, southern Banks Island may have been south of the tree line (if the fossils are not in fact rebedded; Matthews *et al.*, 1986).

Age and the Paleomagnetic Record

On the basis of the record preserved on Banks Island, the Morgan Bluffs Formation precedes at least two full continental glaciations, the Thomsen and Amundsen, and two interglaciations, Cape Collinson and Holocene (Vincent, 1983, 1984, 1989). The nonfinite thorium/uranium age determinations (>200 ka) also indicate the antiquity of the formation. By far the best age estimate comes from the paleomagnetic investigations of the Duck Hawk Bluffs. The initial proposal of Vincent *et al.* (1984) that the Brunhes/Matuyama boundary occurred within the Morgan Bluffs Formation has been confirmed by detailed investigations of Barendregt and Vincent (1990). It has been demonstrated that the lower portion of the Morgan Bluffs Formation deposits in section A is magnetically reversed (negative inclinations and southerly mean pole positions) and that the upper portion of the sequence exhibits normal polarity (positive inclinations and northerly mean pole positions). Sediments between the definite reversely and normally magnetized zones document the gradual change from reversely inclined directions to normally inclined ones. Since sediments of the underlying Worth Point and Duck Hawk Bluffs formations are magnetically reversed and those of the overlying Nelson River and younger formations are normally magnetized, it is evident that the 790 ka Brunhes/Matuyama boundary lies within the Morgan Bluffs Formation deposits. Its position within the formation in section A can be accurately pinpointed. It should also be noted that the deposits in sections B and C were magnetically reversed, whereas those in section H were normally magnetized.

The Morgan Bluffs interglacial sequence may correlate, as suggested by Clark *et al.* (1984), with unit K of the Central Arctic Ocean basin (Clark *et al.*, 1980), a unit considered to have been deposited during reduced glacial activity coinciding with the Brunhes/Matuyama boundary.

Although paleomagnetic sampling of the bluffs east of the Nelson River mouth and of the Worth Point bluffs was done in 1988, results are not yet available. It is therefore not possible to provide a definite age assignment for the Morgan Bluffs deposits in these localities or in the other five localities discussed above. Results from the Duck Hawk Bluffs nevertheless indicate that the Morgan Bluffs Formation represents an interval of time that straddles the Early and Middle Pleistocene. Future paleomagnetic investigations should help to identify which sediments at the various localities were deposited before or after the time of the Brunhes/Matuyama reversal.

Relative Level of Land and Sea

Marine and/or perimarine deposits, identified in the sections east of the mouth of Nelson River and in the Morgan Bluffs and Duck Hawk Bluffs, are observed up to 30 m above present sea level within the Morgan Bluffs Formation. At the first two localities, the sediments seem to record a eustatic level considerably higher during the Morgan Bluffs Interglaciation than it is today. This situation resembles the record on the Alaskan Arctic Coastal Plain (Carter *et al.*, 1986), where several well-documented marine transgressions are known to have reached similar altitudes during the late Tertiary and Pleistocene. Given the Early to Middle Pleistocene age of the Morgan Bluffs Interglaciation, the high eustatic sea level record on Banks Island during the Morgan Bluffs Interglaciation is tentatively correlated with either the Fishcreekian or Wainwrightian Alaskan Arctic Coastal Plain transgressions.

CONCLUSION

Sediments on Banks Island provide an excellent record of events and conditions that prevailed in arctic Canada during the late Tertiary and Early Pleistocene. Deposits of the Beaufort Formation and related deposits recording fluvial sedimentation on the coastal plain and of the Duck Hawk Bluffs Formation recording an early continental glaciation are very extensive and well preserved. The distribution of these sediments can be readily traced on the surface and numerous exposures can be used to infer the full extent of the deposits where they are covered by younger sediments. The late Tertiary sands and gravels on Banks Island and in adjacent areas on the mainland are even more extensive than previously thought. Preglacial Worth Point Formation deposits have been documented in only two locations of southwestern Banks Island. A systematic survey of the western part of the island, now that the stratigraphic context of the deposits is well understood, should lead to the discovery of new sites. Sediments of the Morgan Bluffs Formation have now been described in seven widely separated localities. The easily traceable overlying Middle Pleistocene till sheets or marine sediments provide excellent marker beds, which should assist finding new sites during future systematic surveys.

Establishing the precise age of the Beaufort Formation and other related late Tertiary fluvial sands and gravels at various localities still involves uncertainty (see Fyles, 1990-this issue; Matthews and Ovenden, 1990-this issue). Some of the deposits may be as old as early Tertiary and others as young as Pliocene. It is hoped that the study of extremely well-preserved faunal and floral remains at Duck Hawk Bluffs and Ballast Brook will lead to more precise age assignments. Thanks to paleomagnetic investigations, assignment of a minimum age to the overlying Worth Point, Duck Hawk Bluffs, and Morgan Bluffs formations is possible. The Worth Point and Duck Hawk Bluffs sediments, being magnetically reversed, date between 2.48 and 0.79 Ma, an interval including the very late Pliocene and Early Pleistocene. On the basis of paleoecologic information, the Worth Point Formation is Early Pleistocene rather than Pliocene. The Brunhes/Matuyama boundary lies within the Morgan Bluffs Formation; therefore it is Early to Middle Pleistocene in age. More refined age assignments cannot yet be put forward. Detailed future paleomagnetic investigations may reveal events of the Matuyama Chron, such as the Jaramillo or Olduvai, which would help to pinpoint the ages more closely. It may also be possible to use the last appearance of certain fossils for dating some units. For example, the remains of the extinct plant *Aracites* occur in most Beaufort and related deposits, in the 2 Ma Kap København site, and in sediments from interior Alaska dated at a minimum of 2.1 Ma (Matthews and Ovenden, 1990-this issue). *Aracites* is conspicuously absent from the Worth Point Formation and from the Cape Deceit Formation in western Alaska (Matthews and Ovenden, 1990-this issue; Matthews, 1974, 1989). The age of the latter is variously estimated on the basis of its mammalian fossils to be 2.4–1.2 Ma. Significantly, the Cape Deceit Formation, like the Worth Point Formation, records a time when larch formed the tree line slightly beyond its present limit.

Establishing the precise time at which the first Quaternary (or late Pliocene?) continental glaciers advanced to the Western Arctic remains an unsolved problem. Glacial and marine deposits of the Duck Hawk Bluffs Formation certainly record a very extensive glaciation in Matuyama time but it is still impossible to assign a more precise age to it. The Banks Glacier, which covered much more area of Banks Island and the adjoining Beaufort Sea than the younger Middle or Late Pleistocene glaciations, should have left an easily recognizable record of its presence in the Arctic Ocean Basin. Collection of future cores in the ocean and more refined dating of these will certainly help establish when continental glaciations occurred in the bordering continental areas and when an event of the magnitude of the Banks Glaciation took place.

The record on Banks Island provides an indication of the altitude of relative sea level during the period of concern in this paper. Indirect evidence seems to indicate that relative sea level was lower than present during deposition of the late Tertiary and Worth Point sediments. During the Banks Glaciation, glacio-isostatically controlled sea levels were some 50 m higher than today. Finally during the Morgan Bluffs Interglaciation, eustatic sea level may have been as much as 30 m above the present level.

The nature of the vegetation cover on Banks Island during the late Tertiary and the Early Pleistocene has been briefly mentioned. At the time of deposition of the Beaufort Formation (=Mary Sachs gravel of Fyles, 1990-this issue) in the Duck Hawk Bluffs, mixed deciduous/coniferous forests existed on Banks Island. During deposition of the Worth Point Formation, an open larch-dominated forest-tundra existed on southern Banks Island. With the advent of the Banks Glaciation, the vegetation cover naturally disappeared. During the Morgan Bluffs Interglaciation, the tree line may have extended to southern Banks Island, but generally the various fossil-bearing localities indicate that the vegetation cover was typically low arctic in character. The vegetation therefore indicates that conditions became progressively and generally cooler on the island from the late Tertiary to the

Middle Pleistocene. In fact the fossil record during the last interglaciation (as recorded by the Sangamonian Cape Collinson Formation; Table 1) and during the hypsithermal of the Holocene indicates that this trend has continued to the present.

S.A. Edlund, of the Geological Survey, through studies of the distribution of present-day plants in the Canadian Arctic, has been able to suggest isotherms that mark the latitudinal limit of extent of many arctic species. When fossil plants identified in older deposits are known to lie well outside their present-day range, it is possible to infer mean July temperatures that were necessary for them to exist. Nowadays, mean July temperatures at Sachs Harbour, not far from the Duck Hawk and Worth Point bluffs, are 6°C. By this method, it looks as if mean July temperatures during the late Tertiary were roughly 10+°C warmer than present (16+°C), 5-7°C warmer in Worth Point times (11-13°C), and 2-5°C warmer in Morgan Bluffs times (8-11°C).

With temperatures becoming progressively cooler from the late Tertiary to the Middle Pleistocene, permafrost also progressively developed on Banks Island. The first indication of frozen ground is found in Worth Point Formation sediments at Duck Hawk Bluffs. The lacustrine, eolian, and colluvial deposits all have characteristics typical of those produced in periglacial environments. Permafrost could well have been continuous since larch forests occur in areas of continuous permafrost in Siberia and since areas of northern Alaska have mean July temperatures of 11-13°C. During the interval documented by the Morgan Bluffs Formation, permafrost was certainly continuous since plants were generally all low arctic types and no trees with deep root systems were able to live on the island.

From the above, it can be seen that the late Tertiary and Early Pleistocene record preserved on Banks Island provides information on periods in the Arctic during which conditions were significantly warmer than the present. By gaining an understanding of the nature of the vegetation cover and of the geological processes occurring during these warmer periods, we will be in a better position to understand and forecast the nature and impact of future man-induced atmospheric warming in the Arctic. In fact, the minimum 5°C mean yearly warming predicted for the Arctic would rapidly reinstate conditions that have not existed for hundreds of thousands of years. Such changes would have more catastrophic impact on the landscapes and living communities than any geological event, except glaciation, that has affected the fragile northern environments.

ACKNOWLEDGEMENTS

John G. Fyles and John V. Matthews, Jr., of the Geological Survey of Canada (GSC), L. David Carter, of the United States Geological Survey, and Len Hills, of the University of Calgary, kindly reviewed earlier versions of this paper. J.V. Matthews, on the basis of his study of several new samples, updated the faunal and floral lists. S.A. Edlund, also of the GSC, generously provided the critical phytogeographic and bioclimatological information used in estimating past temperatures. The Polar Continental Shelf Project has provided field and logistic support to the author since 1974. Mrs. L. Mauriće drafted most illustrations. The contributions of the above-mentioned individuals and organizations are very gratefully acknowledged.

APPENDIX 1. Floral and faunal macrofossils from the Early Pleistocene Worth Point Formation, Banks Island (modified from Matthews *et al.*, 1986)[1]

Taxa	Worth Point Bluffs	Duck Hawk Bluffs
PLANTS		
Lichenes		
Peltigeraceae		
Peltigera aphthosa (L.) Willd.	+	
Cladoniaceae		
Cladonia sp.	+	
C. deformis (L.) Hoffm.	+	
C. sp. (cf. *bellidiflora* [Ach.] Schaer.)	+	
C. rangiferina (L.) Wigg. –s.l.	+	
Bryophyta		
Hepaticae		
Ptilidiaceae		
Ptilidium ciliare (L.) Hampe	+	
Lophoziaceae		
Lopozia sp.	+	
L. quadriloba (Lindb.) Evans –s.l.	+	
Anastrophyllum minutum (Schreb.) Schust.	+	
Musci		
Sphagnaceae		
Sphagnum teres (Schimp.) Aongst.	+	
Polytrichaceae		
Polytrichum strictum Brid.	+	
P. juniperinum Hedw.	+	
Ditrichaceae		
Ditrichum flexicaule (Schwaegr.) Hampe	+	
Distichium capillaceum (Hedw.) B.S.G.	+	
Dicranaceae		
Kiaeria glacialis (Berggr.) I. Hag.	+	
Dicranum leioneuron Kindb.	+	
Bryaceae		
Pohlia nutans (Hedw.) Lindb.	+	
Bryum sp.	+	
B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.	+	
B. neodamense Itzig.	+	
B. ovatum Jur.	+	
Miniaceae		
Mnium affine Bland. –s.l.	+	
Aulacomniaceae		
Aulacomnium palustre (Hedw.) Schwaegr.	+	
A. p. var. *polycephalum* (Brid.) Hüb.	+	
A. p. var. *serratum* Warnst.	+	
A. p. var. sp.	+	
A. turgidum (Wahlenb.) Schwaegr.	+	
Meesiaceae		
Meesia uliginosa Hedw.	+	
M. triquetra (Richt.) Aongst.	+	
Bartramiaceae		
Philonotis sp.	+	
P. tomentella Mol.	+	
Timmiaceae		
Timmia norvegica Zett.	+	
Theliaceae		
Myurella tenerrima (Brid.) Lindb.	+	
Thuidiaceae		
Thuidium abietinum (Hedw.) B.S.G.	+	
Helodium blandowii (Web. & Mohr) Warnst	+	

(continued)

APPENDIX 1. (continued)

Taxa	Worth Point Bluffs	Duck Hawk Bluffs
Amblystegiaceae		
Campylium stellatum (Hedw.) C. Jens	+	
C. polygamum (B.S.G.) C. Jens.	+	
Amblystegium cf. *kochii* B.S.G.	+	
Drepanocladus exannulatus (B.S.G.) Warnst.	+	
D. revolvens (Sw.) Warnst.	+	
D. uncinatus (Hedw.) Warnst.	+	
Calliergon cordifolium (Hedw.) Kindb.	+	
C. giganteum (Schimp.) Kindb.	+	
C. richardsonii (Mitt.) Kindb.	+	
C. aftonianum Steere	+	
C. stramineum (Brid.) Kindb.	+	
Brachytheciaceae		
Tomenthypnum nitens (Hedw.) Loeske	+	
Brachythecium salebrosum (Web. & Mohr) B.S.G.	+	
Eurhynchium pulchellum (Hedw.) Jenn.	+	
E. p. var. sp.	+	
Hypnaceae		
Hypnum sp.	+	
H. callichroum Funck	+	
H. hamulosum B.S.G.	+	
Isopterygium pulchellum (Hedw.) Jaeg. & Sauerb.	+	
Rhytidiaceae		
Rhytidium rugosum (Hedw.) Kindb.	+	
Hylocomiaceae		
Hylocomium splendens (Hedw.) B.S.G.	+	
Pteridophyta		
Equisetaceae		
Equisetum sp.	+	+
Spermatophyta		
Gymnospermae		
Pinaceae		
**Larix laricina* (Du Roi) K.	+	
Angiospermae		
Sparganiceae		
**Sparganium* sp.	+	
Potamogetonaceae		
**Potamogeton* sp.	+	+
Cyperaceae		
Carex aquatilis Wahlenb.	+	
Carex sp.	+	+
Eriophorum sp.	+	
Juncaceae		
Luzula sp.	+	
Salicaceae		
Salix sp.	+	
S. niphoclada Rydb.	+	
S. alaxensis (And.) Cor.	+	
**S. ovalifolia* Trautv.	?	
Betulaceae		
**Alnus crispa* (Ait.)	+	
**Betula glandulosa/nana* type	+	
Caryophyllaceae		
Stellaria sp.	+	
**Arenaria humifusa* Wahlenb.	?	
Nyphaeaceae		
Nymphea	+	
Ranunculaceae		
Ranunculus sp.	+	
R. trichophyllus type		+
**R. lapponicus* L.	+	
Rosaceae		
Dryas integrifolia Vahl	+	
Potentilla sp.	+	+
Haloragaceae		
Hippuris vulgaris L.	+	
Pyrolaceae		
Pyrola grandiflora Rad.	+	
Empetraceae		
**Empetrum nigrum* L.	+	
Ericaceae		
**Ledum decumbens* (Ait.) Lodd	+	
**Arctostaphylos uva-ursi* (L.) Spreng.	+	
**Vaccinium uliginosum* spp. *microphyllum* Lange	+	
**V. u.* L. var. *uliginosum*	+	
**V. u.* var. *alpinum* Big.	+	
**V. vitis-idaea* var. *minus* Lodd	+	
Gentianaceae		
**Menyanthes trifoliata* L.	+	

ARTHROPODS

Taxa	Worth Point Bluffs	Duck Hawk Bluffs
Coleoptera		
Carabidae		
**Carabus truncaticollis* Eschz.	+	+
**Notiophilus* sp.	+	
Elaphrus sp.	+	
Elaphrus lapponicus Gyll.	+	
Bembidion sp.	+	
Pterostichus sp.	+	
**P. nearcticus* Lth.	+	
Amara alpina Payk.	+	
Amara sp.	+	
**Trichocellus mannerheimi* Sahlb.	+	
Dytiscidae		
Hydroporus sp.	+	
Agabus sp.	+	
Staphylinidae		
Genus?	+	
Olophrum sp.	+	
Micralymma type	+	
**Tachinus brevipennis* type	+	
Byrrhidae		
Genus?	+	
Chrysomelidae		
Chrysolina sp.	+	
Curculionidae		
Genus?	+	
Apion sp.	+	
**Lepidophorus lineaticollis* Kirby	+	
**Vitavitus thulius* Kiss.	+	
**Notaris* sp.	+	
**Cleonus* sp.	+	
Trichoptera		
Family?	+	
Diptera		
Family?	+	+
Chironomidae		
Genus?		+
Crustacea		
Notostraca		
Lepiduris sp.		+
Ostracoda		
Candona cf. *caudata*	+	
Candona sp.	+	
Cyclocypris cf. *sharpei*	+	
Cypria palustera	+	
Limnocythere cf. *liporeticulata*	+	
Prionocypris glacialis (Sars)		+
Arachnida		
Acari-Mesostigmata		
Trachytes type	+	

(continued)

APPENDIX 1. (continued)

Taxa	Worth Point Bluffs	Duck Hawk Bluffs
Acari-Orbatei		
Ceratozetidae	+	
Damaeidae		
Epidamaeus sp.	+	
Family?	+	
Mollusca		
**Sphaerium (Musculium) lacustre* (Müller)	+	
**Pisidium (Cyclocalyx) casertanum* (Poli)	+	
Helisoma sp.	+	
Vertebrata		
*Cypridinae (Leuciscinae)	+	

[1]Compiled from Kuc (1974), from unpublished GSC macrofossil and arthropod identification reports by J.V. Matthews, Jr.; and from unpublished GSC wood identification reports by R.J. Mott and L.D. Farley-Gill. Molluscs were identified by G.L. Mackie, ostracodes by L. Delorme and J.P. Guilbault, and the fish by D.E. McAllister.
+ = present.
* = taxon that probably does not occur on Banks Island at present. Absence of vascular plants confirmed by S.A. Edlund, Geological Survey of Canada.

APPENDIX 2. Identified floral and faunal macrofossils from the Morgan Bluffs Formation, Banks Island (modified from Matthews *et al.*, 1986)[1]

Taxa	Morgan Bluffs Formation				
	MB[2]	ENR	DHB	IR	TR
PLANTS					
Characeae					
Chara/Nitella sp.			+		
Pteridophyta				+	
Equisetaceae					
Equisetum sp.	+	+		+	
Pinaceae					
**Larix* sp.			+		
Sparganiaceae					
**Sparganium* sp.	+	+			
Potamogetonaceae					
**Potamogeton filliformis* Pers.					+
**Potamogeton* sp.	+	+	+		+
Cyperaceae					
Carex aquatilis Wahlenb.	+	+	+		+
Carex sp.	+	+	+		+
**Scirpus* sp.	+	+			
Salicaceae					
Salix sp.	+	+	+		+
Betulaceae					
**Alnus* sp.			?		
Betula glandulosa type			+		+
**Betula* sp.	+	+	+		
Caryophyllaceae					
Melandrium sp.					?
Stellaria sp.	?	?			
Ranunculaceae					
Ranunculus sp.	+	+	+		
R. trichophyllus type			+		
**R. lapponicus* L.	+	+			
Cruciferae					
Genus?					+
Rosaceae					
Dryas integrifolia Vahl		+	+		+
**Sibbaldia procumbens* L.			+		
**Potentilla palustris* (L.) Scop.			+		
Potentilla sp.			+		+
**Rubus chamaemorus* L.	+				
Haloragaceae					
Myriophyllum sp.			+		
Hippuris sp.		+			+
Empetraceae					
Empetrum nigrum L.			+		
Ericaceae					
Cassiope sp.			+		
Arctostaphylos alpina/ruba type			+		
Gentianaceae					
**Menyanthes trifoliata* L.	+	+	+		+
ARTHROPODS					
Bryozoa					
Cristatella mucedo L.			+		
Arthropoda					
Insecta					
Hemiptera					
Coleoptera					
Carabidae					
Genus?			+		
**Carabus truncaticollis* Eschz.	+				
**Notiophilus* sp.	+	+		+	
**Elaphrus* sp.	+	+		+	
**Elaphrus lapponicus* Gyll.	+	+		+	
**Dyschirius* sp.	+	+	+	+	
Bembidion (Platophodes) sp.			+		
Bembidion umiatense Lth.	+	+	+		+
Bembidion sp.	+	+			+
Pterostichus sp.	+	+	+	+	
**P. nearcticus* Lth.		+	+		+
P. (Cryobius) cf. *kotzebuei* Ball					+
P. (Cryobius) ventricosus Eschz.	+		+		+
**P. (Cryobius) brevicornis* Kby.	+		+		+
P. (Cryobius) sp.	+	+	+	+	
Amara alpina Payk.	+	+		+	+
Amara sp.	+	+		+	
Harpalus sp.			?		
**Trichocellus mannerheimi* Sahlb	+	+		+	
Dytiscidae					
Genus?	+				+
Hudroporus sp.	+	+		+	
Agabus sp.	?	?		?	
Ilybius sp.	?	?		?	
Colymbetes sp.			+		
Hydraenidae					
Genus?	+				
Staphylinidae					
Genus?	+	+	+	+	
Bledius sp.			+		
Omalinae			+		
Olophrum sp.	+	+		+	
Olophrum latum Makl.	+	+		+	
Macralymma brevilinque type	+	+		+	+
Stenus sp.	+	+		+	
**Euaesthetus* sp.		+			

(continued)

APPENDIX 2. (continued)

Taxa	Morgan Bluffs Formation				
	MB[2]	ENR	DHB	IR	TR
Tachinus sp.	+		+		
Tachinus apterus Maklin					+
Tachinus brevipennis Sahlb.	+	+		+	
**Tachinus instabilis* Maklin	+				
Aleocharinae	+		+		
Genus?		+	+		
Leiodidae					
Genus?	+				
Byrrhidae					
Genus?	+	+		+	
Simplocaria sp.					+
Curculionidae					
Genus?			+		
Apion sp.	+	+		+	
**Lepidophorus lineaticollis* Kirby	+	+	+	+	
**Vitavitus* sp.			+		
**Vitavitus thulius* Kiss.	+	+	+	+	+
Hypera sp.			+		
Hypera diversipunctata Schrank			+		
**Notaris* sp.	+	+		+	+
Rhynchaenus sp.			+		
**Cleonus* sp.	+	+		+	
Ceutorhunchus sp.					+
Trichoptera					
Family?			+		
Lepidoptera					
Genus?			+		+
Diptera					
Family?			+		
Chironomidae					
Genus?	+	+	+	+	
Hymenoptera					
Family?			+		
Symphyta					
Tenthredinidae					+
Ichneumonoidea					+
Genus?		+			
Diapriidae					+
Crustacea					
Cladocera					
Daphina sp.			+		+
Notostraca					
Lepiduris sp.			+		+
Arachnida					
Acari					
Oribatei					
Genus?			+		
Araneae					
Lycosidae?			+		
Mollusca					
Valvata sincera helicoidea (Dall)			+		
Gyraulus sp.			+		
G. deflectus (Say)			+		
Lymnaea kennicotti (Baker)			+		
Pisidium idahoense Roper.			+		
Mammalia					
Rodentia					
Dicrostonyx torquatus	+				
Aves					
Galliformes					
Lagopus sp.	?				

[1]Compiled from unpublished GSC macrofossil and arthropod identification reports by J.V. Matthews, Jr., and from unpublished GSC wood identification reports by R.J. Mott and L.D. Farley-Gill. The mammal and bird were identified by C.R. Harington of the National Museum of Canada and the molluscs by M.F.I. Smith and G.L. Mackie.
[2]MB = Morgan Bluffs; ENR = Bluffs East of Nelson River mouth; DHB = Duck Hawk Bluffs; IR = "Ivitaruk" River Bluffs; TR = Thomsen River Bluffs; location of bluffs shown in Figure 1.
\+ = present.
* = taxon that probably does not occur on Banks Island at present. Absence of vascular plants confirmed by S.A. Edlund, Geological Survey of Canada.

APPENDIX 3. Foraminifera, identified by J.P. Guilbault of the University of Montreal, in marine deltaic beds of the Morgan Bluffs Formation found in section E east of the mouth of Nelson River

Quaternary taxa	Number	%
Elphidium excavatum	97	49
Cassidulina reniforme	43	22
Epistominella cf. *vitrea*	19	9.5
Haynesina orbiculare	15	7.5
Islandiella islandica	4	2.1
Virgulina concava	3	1.5
Nonion affine	3	1.5
Cassidulina cf. *teretis*	3	1.0
Buccella frigida	2	1.0
Elphidium ustulatum	2	1.0
Cribrostomoides cf. *crassimargo*	2	1.0
Trifarina fluens	2	1.0
Islandiella norcrossi	1	0.5
Elphidium frigidum	1	0.5
Epistominella sp. A	1	0.5
Elphidium albiumblicatum	1	0.5
Elphidium hallandense	1	0.5
Indeterminate Cassidulinidae	9	
Indeterminate Elphidiidae/Haynesinidae	8	
Indeterminate	16	
Neogloboquadrina pachyderma	(1) planctonic	
Total Quaternary taxa	232	

Pre-Quaternary taxa	Number	%
Quadrimorphina albertensis	22	27
Globorotalites alaskensis	17	21
Intermediate form between *G. alaskensis* and *Q. albertensis*	14	17
Marginulinopsis cf. *collinsi* variety	1	1.2
Discorbis norrisi	12	15
Gavelinella intermedia	2	2.5
?Eponides morani	3	3.7
cf. *Gyroidinanitida*	1	1.2
cf. *Haplophragmium*	1	1.2
Saracenaria cf. *projectura*	1	1.2
Nodosaria sp.	1	1.2
Lenticulina sp.	1	1.2
Dentalina sp.	1	1.2
Astacolus sp.	2	2.5
Praebulimina cf. *nannina*	1	1.2
Psammosphaera sp.	1	1.2
Haplophragmoides cf. *gigas*	heavy fraction	
Total Pre-Quaternary taxa	81	

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