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GEOLOGY OF HVITLAND BEDS
(LATE PLIOCENE), WHITE POINT LOWLAND,
ELLESMERE ISLAND, NORTHWEST TERRITORIES

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Cover illustration

View north across the stream towards sites #3, 4, and 5, type locality of the Hvitland beds. Photograph by John Fyles. GSC 1997-55

Critical reviewer

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GEOLOGY OF HVITLAND BEDS (LATE PLIOCENE), WHITE POINT LOWLAND, ELLESMERE ISLAND, NORTHWEST TERRITORIES

Abstract

The marine strata here named the Hvitland beds occur above Paleogene sand and beneath glacial diamicton. They contain marine molluscs, ostracodes, and benthic foraminifers, and represent water depth of 10-30 m and water temperature slightly warmer than present. The assemblage comprises a mixture of Atlantic/Arctic and Pacific faunas. Mosses, vascular plants (herbs) and insects in the marine strata record tundra conditions on adjacent land. The foraminifers represent the Cibicides grossus Zone (minimum age of 2.4 Ma) which is also known from late Pliocene sites in the North Sea, Baffin Island, Greenland, the Beaufort-Mackenzie Basin, and Arctic Alaska. Ostracodes in the Hvitland beds include four extinct (since 2.4 Ma) species also present in the Gubik Formation of northern Alaska, and at Kap København and Loden Elv in northeastern Greenland. The paleomagnetically reversed Hvitland beds (with tundra vegetation) are younger than the Beaufort Formation (with forest vegetation) which, on Meighen Island, includes paleomagnetically reversed strata dating from the youngest (ca. 3 Ma) reversed zones of the Gauss magnetic chron. Thus, the Hvitland beds (also reversed but no younger than 2.4 Ma) must date from the earliest (reversed) part of the Matuyama magnetic chron which commenced ca. 2.5 Ma. Correlation with the Bigbendian unit of the Gubik Formation is suggested.

Résumé

Les strates marines dont il est question dans le présent document ont été dénommées «couches de Hvitland». Elles reposent sur du sable paléogène et sont sous-jacentes à un diamicton glaciaire. Elles renferment des fossiles marins, dont notamment des mollusques, des ostracodes et des foraminifères benthiques. Elles ont été déposées sous une colonne d'eau de 10 à 30 mètres d'épaisseur dont la température était légèrement supérieure à celle d'aujourd'hui. L'assemblage comprend un mélange de faunes provenant soit de l'océan Atlantique et de l'océan Arctique, soit de l'océan Pacifique. Les fossiles de mousses, de plantes vasculaires (herbes) et d'insectes dans les strates marines témoignent de conditions de toundra sur les terres voisines. Les foraminifères sont représentatifs de la Zone à Cibicides grossus (âge minimum de 2,4 Ma), aussi signalée à des sites du Pliocène tardif de la mer du Nord, de l'île de Baffin, du Groenland, du bassin de Beaufort-Mackenzie et de l'Alaska arctique. Les ostracodes identifiés dans les couches de Hvitland comprennent quatre espèces disparues (depuis 2,4 Ma) également présentes dans la partie nord de l'Alaska (Formation de Gubik), ainsi que dans la partie nord-est du Groenland (régions du Kap København et de la Loden Elv). Les couches de Hvitland (végétation de toundra) à paléo-aimantation inversée sont plus jeunes que la Formation de Beaufort (végétation forestière), laquelle comprend, sur l'île Meighen, des couches appartenant aux zones à paléo-aimantation inversée les plus jeunes (env. 3 Ma) du chron magnétique de Gauss. Ainsi, les couches de Hvitland (également à paléo-aimantation inversée et vieilles d'au moins 2,4 Ma) doivent dater du début (paléo-aimantation inversée) du chron magnétique de Matuyama, établi a environ 2,5 Ma. Ces couches pourraient être corrélatives de l'unité de Bigbendian de la Formation de Gubik.

SUMMARY

The late Neogene record of environmental change in the Canadian Arctic Islands is of particular interest in that it provides evidence of the transition from the temperate conditions that prevailed at high latitudes during the Tertiary to the "arctic" conditions that characterize the region today. This story can only be known by study of well dated sites in

SOMMAIRE

Dans l'archipel arctique canadien, les indices d'un changement environnemental au Néogène tardif sont d'intérêt particulier, car ils témoignent de la transition des conditions tempérées qui caractérisaient les hautes latitudes pendant le Tertiaire aux conditions «arctiques» qui existent actuellement. Cette évolution ne peut être reconstituée que par

the region. For eras beyond the resolution range of radio-carbon method, "well dated" sites are those containing marine fossils whose geological range is known and/or sediments suitable for paleomagnetic analysis.

Although fossiliferous late Neogene fluvial deposits are widely distributed in the Beaufort Formation along the Arctic Ocean margin of the archipelago and as "high terrace" sediments on Ellesmere Island and other islands, onshore occurrences of marine deposits of late Tertiary age are rare. Therefore, the Hvitland beds, the subject of this multi-author report, are an exception. Even though they constitute only a single, unspectacular exposure on the White Point lowland on northwest Ellesmere Island (near Nansen Sound), they are the first clearly defined, in situ Pliocene marine unit discovered within the continental landmass of the Arctic Islands. Fossils from the Hvitland beds help both to date the sediments and to define the climatic and environmental conditions under which they were deposited.

The shelly clayey and gravely strata that make up the Hvitland exposure were initially thought to be of Quaternary age. They are very near to the elevation of Holocene deposits in the region, but early radiocarbon dates on shells showed that the unit was probably older than the Holocene, possibly interglacial. The authors of this bulletin marshal several lines of evidence (paleontological, Sr-isotopic, amino acid racimization, and paleomagnetic) to show conclusively that the Hvitland beds are late Pliocene in age, probably deposited about 2.5 Ma.

The marine fossils, which include molluscs, ostracods, and foraminifera of both Arctic Atlantic and Pacific origin show that the beds were deposited in a shallow water nearshore marine environment, under sub-frigid conditions (i.e. warmer than water temperatures prevailing at present).

Terrestrial fossils are not abundant, having been washed into the sea from nearby areas. However, they are revealing primarily for what types are absent. While some of the insect fossils suggest that climate was somewhat warmer than now, the assemblage lacks all evidence of trees. For example, entirely absent are wood and the other plant and insect indicators of forest or tree-line conditions that characterize the Beaufort Formation (early late Pliocene) on nearby Meighen Island and the "high terrace sediments" to the southeast on the Fosheim Peninsula and other parts of Ellesmere Island. The Hvitland assemblage of terrestrial fossils is also

l'étude de sites «bien datés» de l'archipel. Dans le cas des époques antérieures à la période d'application de la méthode de datation au carbone 14, les sites «bien datés» sont ceux contenant des fossiles marins dont l'extension géologique est connue ou des sédiments qui se prêtent bien à une analyse paléomagnétique.

Les dépôts fluviatiles à fossiles du Néogène tardif sont très répandus dans la Formation de Beaufort, le long du littoral de l'archipel donnant sur l'océan Arctique et sous la forme de sédiments de «terrasses élevées» sur l'île d'Ellesmere et sur d'autres îles. Cependant, la présence de sédiments marins datant de la fin du Tertiaire est rare vers l'intérieur des terres. Les couches de Hvitland qui font l'objet du présent rapport (rédigé en collaboration) constituent donc une exception. Elles ne présentent qu'un affleurement peu remarquable sur les basses terres de la pointe White (partie nord-ouest de l'île d'Ellesmere, près du détroit de Nansen), mais n'en constituent pas moins la première unité marine du Pliocène clairement définie qui ait été découverte au sein de la masse continentale de l'archipel arctique. Les fossiles des couches de Hvitland permettent non seulement de dater les sédiments, mais aussi de déterminer les conditions climatiques et environnementales dans lesquelles ils se sont déposés.

Au départ, les strates argileuses et graveleuses à coquilles constituant l'affleurement des couches de Hvitland ont été associées au Quaternaire. Leur altitude est en effet très proche de celle des dépôts holocènes de la région, mais les premières datations au carbone 14 sur les coquilles ont démontré que cette unité avait probablement été formée avant l'Holocène, peut-être au cours d'un interglaciaire. Les auteurs du présent bulletin ont fait appel à diverses méthodes (paléontologie et paléomagnétisme, datations au Sr et racémisation des acides aminés) pour conclure que les couches de Hvitland datent du Pliocène tardif et qu'elles ont probablement été déposées il y a environ 2,5 Ma.

Les fossiles marins, dont notamment les mollusques, les ostracodes et les foraminifères provenant soit de l'océan Atlantique et de l'océan Arctique, soit de l'océan Pacifique, indiquent que les couches de Hvitland ont été déposées en milieu marin littoral, dans des eaux peu profondes et moins froides que celles d'aujourd'hui.

Les fossiles terrestres ne sont pas abondants car, des régions voisines, ils ont été emportés vers la mer. Ils sont cependant révélateurs quant aux types de fossiles qui sont absents. Bien que certains des fossiles d'insectes laissent supposer que le climat était légèrement moins froid qu'aujourd'hui, l'assemblage est dépourvu de tout indice de la présence d'arbres. Ainsi, les fossiles observés dans la Formation de Beaufort (début du Pliocène tardif) sur l'île voisine de Meighen ainsi que dans les sédiments de «terrasses élevées» plus au sud-est sur la péninsule Fosheim et sur d'autres parties de l'île d'Ellesmere sont totalement absents des couches de Hvitland; les fossiles en question sont du bois et d'autres végétaux et insectes témoignant de conditions typiques des forêts et

markedly impoverished compared to that from the late Pliocene Kap København Formation on northern Greenland.

Hvitland beds appear to have been deposited at a time when the northwestern part of Ellesmere Island was tundra, though a tundra slightly richer in species than at present. This early phase of cold climate postdates the Beaufort Formation on Meighen Island, when treeline exited at about the same latitude as the Hvitland locality, but predates the Kap København beds, deposited when open forests grew as far north as northernmost Greenland. Thus the Hvitland beds, when viewed in the light of information from other sites in the Arctic, hint that the transition from late Tertiary temperate climates to the fully Arctic climates of the Quaternary was not gradual. Instead it was probably marked by drastic terrestrial climatic fluctuations – the same fluctuations that are evident in the marine isotopic record starting at about 2.5 Ma.

Hvitland beds may represent one of the first cold pulses to affect the Arctic regions in late Pliocene time, that is, the first manifestation of a type of environment that has characterized Ellesmere Island for perhaps all of Quaternary time. Significantly, amino acid ratios from the Hvitland shells fall within the range of values from the oldest glacial deposits on the Fosheim Peninsula, south of the White Point Lowland. Even though there is no direct evidence that deposition of Hvitland beds is associated with glaciation, this nesting of amino acid ratios may mean that the Hvitland interval of tundra climate was also a time of glaciation on Ellesmere Island. Glacial loading would certainly help to explain the current high elevation of the Hvitland beds.

The significance of the Hvitland beds only emerged because they and the fossils were re-examined by a series of specialists long after the initial investigation. There are many other sites in the Canadian Arctic that to date have only received the type of cursory study first given to Hvitland fossils in the early 1960s. One wonders what intriguing details concerning the development of present day Arctic environment would emerge if some of these other sites were studied at the same level of detail as is the case for the Hvitland beds.

des zones à la limite forestière. L'assemblage de fossiles terrestres est en outre sensiblement moins diversifié en regard de celui de la Formation de Kap København du Pliocène tardif, dans le nord du Groenland.

Il apparaît donc que les couches de Hvitland ont été déposées à une époque où la partie nord-ouest de l'île d'Ellesmere était une toundra, mais une toundra légèrement plus riche en espèces qu'aujourd'hui. Cette phase précoce de climat froid est postérieure au dépôt de la Formation de Beaufort (île Meighen), mais antérieure à celui de la Formation de Kap København; la sédimentation de la première remonte au moment où la limite forestière se terminait à peu près à la même latitude que le site des couches de Hvitland et celle de la seconde à une époque où des forêts claires s'étendaient jusqu'à l'extrême nord du Groenland. Ainsi, l'interprétation des couches de Hvitland en tenant compte de données recueillies à d'autres sites de l'Arctique porte à croire que la transition des climats tempérés du Tertiaire tardif aux climats entièrement arctiques du Quaternaire n'a pas été graduelle. Elle aurait plutôt été marquée par des fluctuations très accusées du climat terrestre; ces mêmes fluctuations ressortent des données isotopiques marines et auraient débuté il y a environ 2,5 Ma.

Il est possible que les couches de Hvitland représentent une des premières périodes froides ayant touché les régions arctiques à la fin du Pliocène, c'est-à-dire la première manifestation d'un type d'environnement qui a caractérisé l'île d'Ellesmere pendant peut-être la totalité du Quaternaire. Donnée significative, les rapports des acides aminés dans les coquilles extraites des couches de Hvitland s'inscrivent dans l'intervalle de valeurs des plus anciens dépôts glaciaires sur la péninsule Fosheim, au sud des basses terres de la pointe White. Malgré l'absence de preuves directes que le dépôt des couches de Hvitland soit lié à une glaciation, cette correspondance des rapports des acides aminés signifient peut-être que l'intervalle hvitlandien de climat de toundra était également une époque de glaciation sur l'île d'Ellesmere. Quant à l'actuelle altitude élevée des couches de Hvitland, elle pourrait s'expliquer en partie par l'étude de la charge glaciaire.

L'importance des couches de Hvitland n'est apparue que parce que, longtemps après les premiers travaux visant à les étudier, un groupe de spécialistes a réexaminé les roches qui les composent ainsi que les fossiles qu'on y trouve. Il existe beaucoup d'autres sites dans l'Arctique canadien qui, à ce jour, n'ont été l'objet que d'une étude sommaire, à l'instar des couches de Hvitland et de leurs fossiles au début des années soixante. On peut se demander quels détails intrigants relatifs à l'évolution du milieu arctique actuel seraient mis au jour si certains de ces autres sites étaient étudiés de manière aussi approfondie que ne l'ont été les couches de Hvitland.

INTRODUCTION

The late Neogene record in the Canadian Arctic Islands is of particular interest in that it provides evidence of the transition from the temperate conditions that prevailed at high latitudes during the Tertiary to the "arctic" conditions that characterize the region today. Although late Neogene fluvial deposits are widely distributed in the Beaufort Formation along the Arctic Ocean margin of the archipelago and as "high terrace" sediments on Ellesmere Island and other islands (Fyles, 1989, 1990; Matthews and Ovenden, 1990), onshore occurrences of marine deposits of late Tertiary age are rare. The single site that is the subject of this paper is one of these occurrences (Fig. 1); others occur on Meighen Island (Fyles et al., 1991) and on the Qivituq Peninsula and Clyde Foreland of eastern Baffin Island (Feyling-Hanssen, 1985). The Meighen Island marine strata (within the Beaufort Formation) are part of the northwest-thickening late Tertiary wedge of clastic sediment along the North American margin of the Arctic Ocean Basin (Fyles, 1990); the Baffin Island marine sediments border Baffin Bay at the opposite margin of the continent. In contrast, the Hvitland beds form a thin local body of nearshore marine sediment on a low-lying part of the continent itself.

The marine clayey and gravely strata informally designated here as the Hvitland beds were initially described as interglacial (Craig and Fyles, 1965, Fig. 3) based on their mode of occurrence and the "old" radiocarbon date of shells of *Hiatella arctica* (GSC-65, Dyck and Fyles, 1963). On the other hand, a hint of greater age was contained in an unpublished report by F.J.E. Wagner (GSC internal report P1-3-62, 1962) which notes that the assemblage of foraminifers contained in Fyles' 1961 samples from the site "has most species the same as found in post-glacial and Recent collections, but also has several species apparently in common with the ?Miocene or ?Pliocene Carter Creek fauna of northwestern Alaska". In 1987 when reviewing available information on Late Tertiary and "old" Quaternary occurrences on the Arctic Islands, Fyles drew Wagner's report to the attention of D.H. McNeil. He subsequently restudied Wagner's slides, and the remainder of the original samples, and concluded that the foraminifers are late Pliocene (McNeil, 1990).

LOCATION

The Hvitland beds (Fig. 2, 3) occur on the White Point lowland which borders the west (Nansen Sound) coast of Ellesmere Island north of Otto Fiord at the western extremity of the Hvitland Peninsula. The names "White Point" and "Hvitland" were applied (in the 19th century) to this coastal lowland by British and Scandinavian explorers, in recognition of the snow-covered aspect of its low-relief surface, contrasting with the dark rocky face of the adjoining upland. The Hvitland strata are exposed at 81°10′N, 90°00′W on the north wall of the valley of an unnamed west-flowing stream, about 4 km upstream from where the
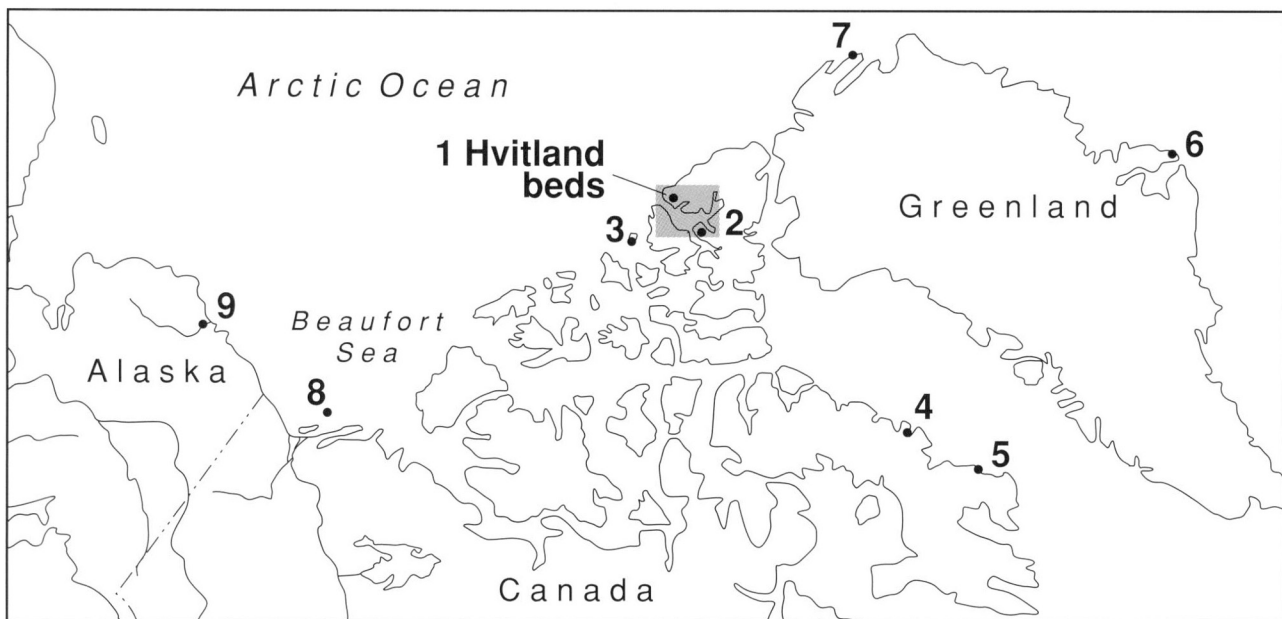

Figure 1. Location map, Arctic North America and Greenland. 1=Hvitland beds, Ellesmere Island; 2=Fosheim Peninsula; 3=Meighen Island; 4=Clyde Foreland, Baffin Island; 5=Qivituq Peninsula, Baffin Island; 6=Lodin Elv, Greenland; 7=Kap København, Greenland; 8=Beaufort–Mackenzie Basin; 9=Colville River area, North Slope of Alaska. Shaded area is shown enlarged in Figure 2.
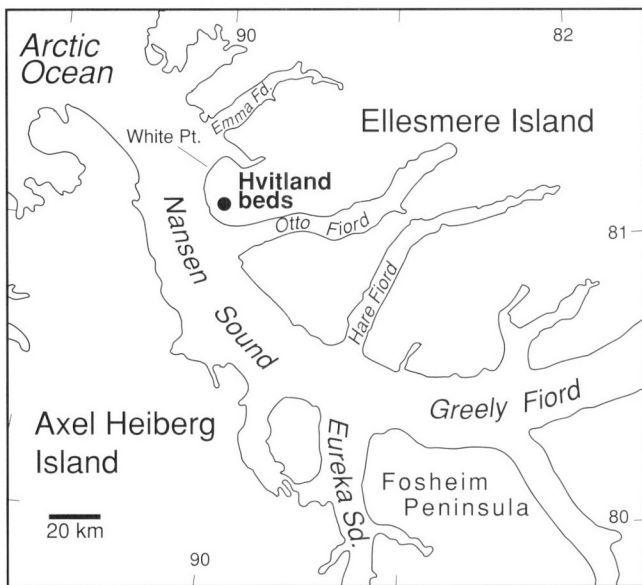
Figure 2. Hvitland region showing parts of Axel Heiberg and Ellesmere Islands (see Fig. 1)

stream enters Nansen Sound (Fig. 3). The mouth of the stream is 10.5 km south along the coast from White Point (Fig. 2).

GEOLOGICAL SETTING

The White Point lowland rises from sea level to about 250 m in elevation over a distance of 5 km and terminates at the foot of broad highlands which reach altitudes of over 600 m above sea level. In contrast with the highlands, where bedrock is continuously exposed, the lowland is largely mantled by unconsolidated sediment of glacial, colluvial, fluvial, and marine origin. The underlying bedrock is chiefly folded and faulted late Paleozoic limestone, chert, shale, and siltstone, and fine to coarse clastic rocks of Triassic age (Thorsteinsson and Trettin, 1972). Information on the occurrence of glacial and glaciomarine sediments in the region is provided by Bednarski (1995) and by Lemmen and England (1992).
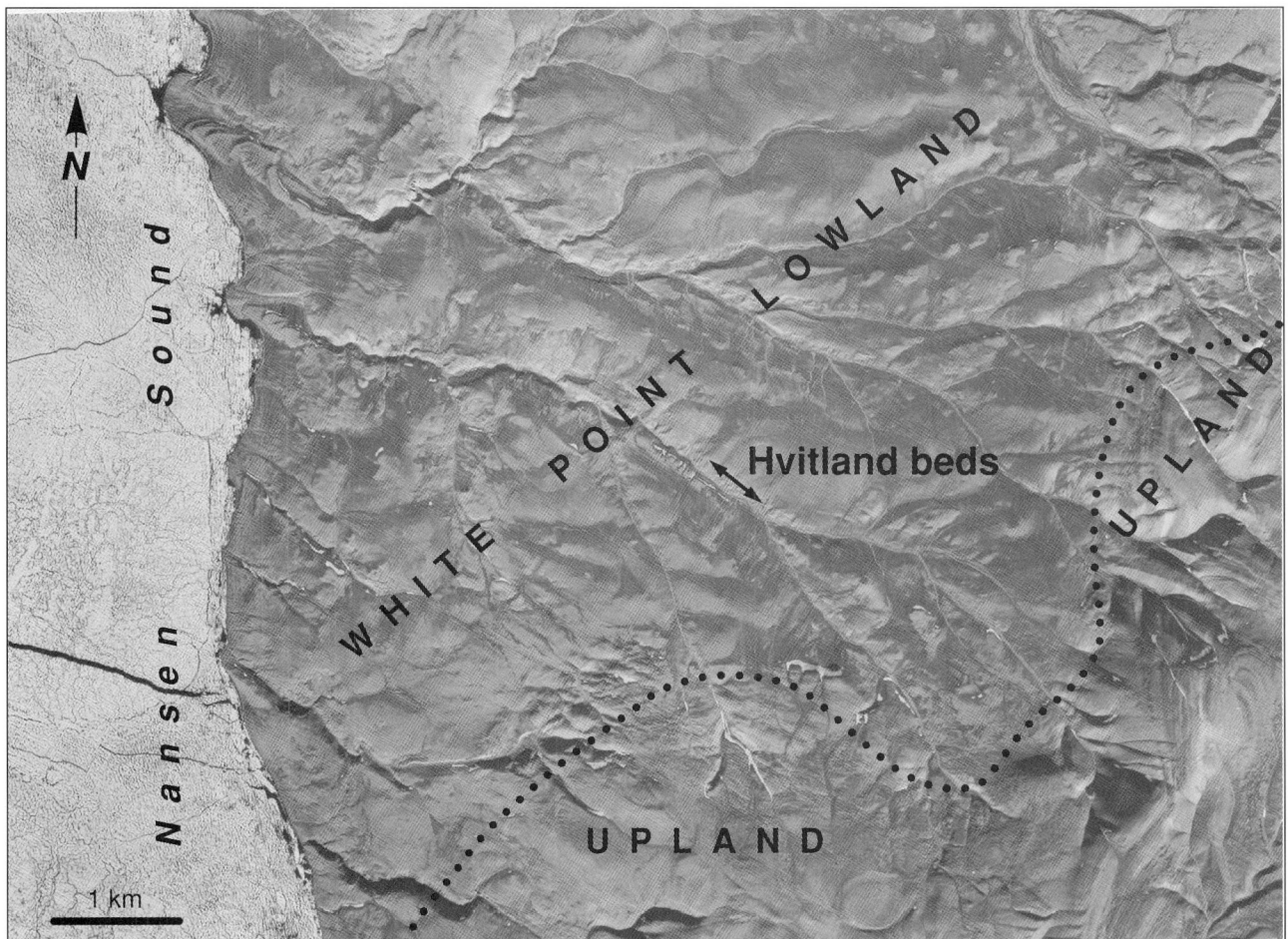

Figure 3. Aerial view of the discovery site of the Hvitland beds and surrounding landscape. The double arrow bar at the site corresponds to Figure 4. The dotted line is the approximate boundary between the White Point lowland and the upland. Air photo base is part of A16863-38 (National Air Photo Library).

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Holocene marine silt dominates the surface cover along the coast up to 100 m above sea level. Flights of raised beaches made of coarser, winnowed sediments commonly overlie the silt below 20 m above sea level. Farther upslope, the silt has been extensively disturbed by periglacial mass wasting and a silty diamicton dominates the cover. Less disturbed silt is found within Holocene raised deltas. An indurated silty diamicton containing numerous shell fragments is exposed in a tributary valley at 80 m a.s.l., 2.5 km down valley from the exposures of the Hvitland beds: this diamicton contains abundant striated clasts and is interpreted as till. Deltas of sand and gravel have prograded over the finer sediments at mouths of the larger streams. The deltaic sediments are commonly fossiliferous, containing marine shells in growth position and fine plant detritus, and they occur up to a maximum elevation of 105 m. At a site west of the Hvitland beds, the highest prominent shoreline, at the 105 m level has a radiocarbon age of 8370 ± 130 BP

(S-2639) for paired shells of *Mya truncata* in deltaic silt (Bednarski, 1995, Table 1, Site 11). The surficial cover above this level, and up to 200 m a.s.l., consists of soliflucted silty diamicton and sand/gravel terraces: abraded shell fragments have been found in silty pockets up to about 200 m a.s.l.

TYPE LOCALITY AND STRATIGRAPHY

To date, the Hvitland beds have been clearly recognized only at the locality marked on Figures 2 and 3. The sequence of strata exposed at this site (Fig. 4, 5), approximately 15 m in thickness, is designated as the type section of this informal formation. The exposed strata are 110 to almost 130 m above present sea level, and thus 5 to >20 m higher than the prominent Holocene raised marine features referred to above. The valley in which this type section occurs appears to be of recent origin, with actively
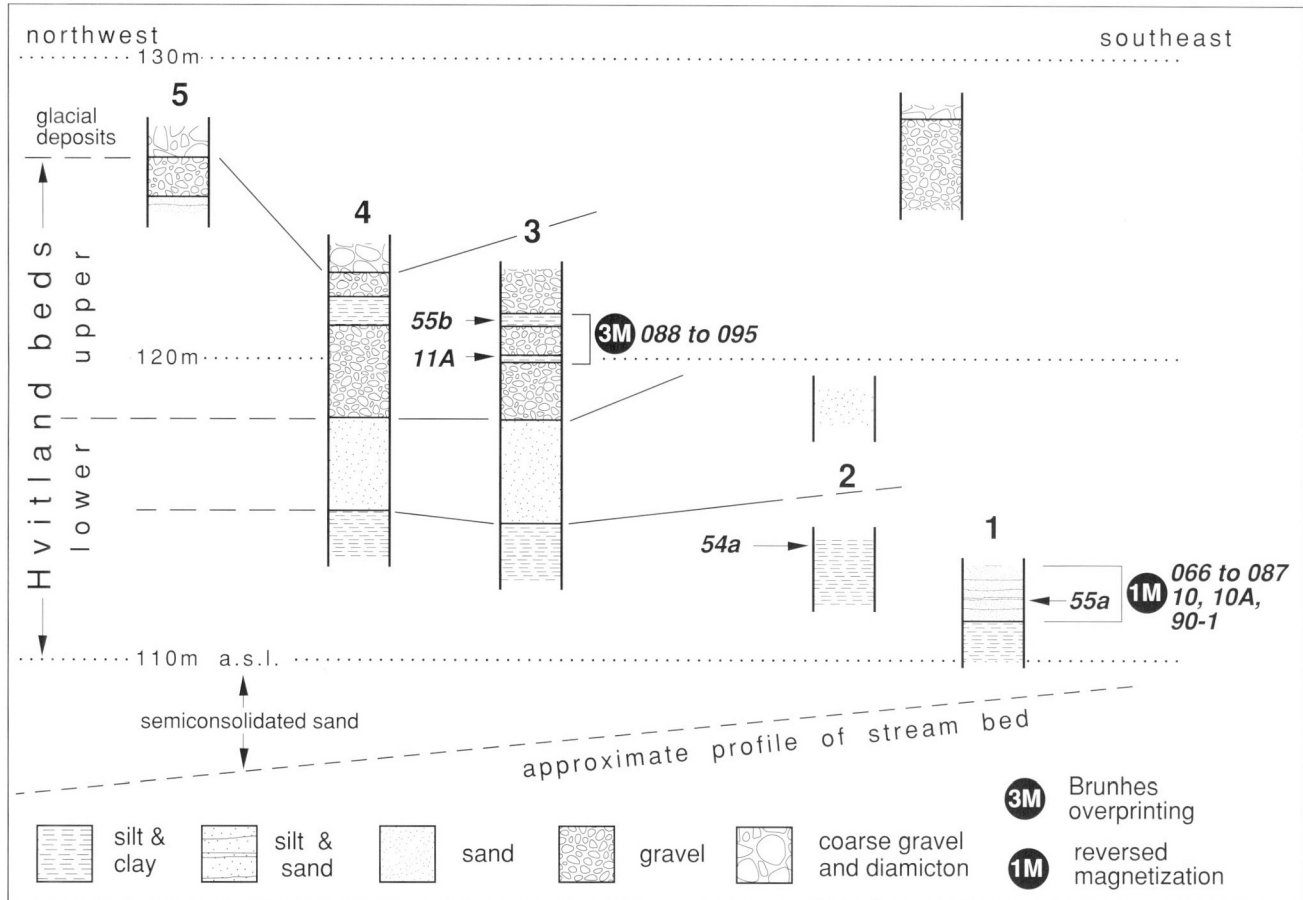
Figure 4. Stratigraphy of the Hvitland beds at the type locality. Labels 54a, 55a, and 55b indicate location of samples F6-88-54a, FG-88-55a, and FG-88-55b; 10, 10A, and 11A are 90-LM-10, 90-LM-10A, and 90-LM-11A; 90-1 is MRA-8-9-90-1; 066 to 087 comprise magnetic sample series #1M while 088-095 comprise magnetic sample series #3M. Samples FG-61-149a, FG-61-149c, and FG-61-149d, referenced elsewhere in this paper, were collected within the area covered by this figure but their specific locations are unknown: FG-61-149a was collected from the upper part of the section; FG-61-149c and FG-61-149d from the lower part.

slumping bluffs of unconsolidated sediments, and a steep-walled inner canyon through limestone (a few hundred metres downstream from the exposures comprising the type section). The valley cuts through rolling, largely drift-covered lowland terrain with interfluves about 150 m above sea level.

At the type locality (discovery site), the Hvitland beds comprise at least 20 m of horizontal gravel, sand, silt, and clay, including strata that contain shells of marine molluscs (particularly *Hiatella arctica* Linnaeus) and fine detritus of terrestrial plant material. The relative position of the principal exposures and their lithological characteristics are shown in Figure 4. The exposures are discontinuous, some

Figure 5. *Hvitland beds at the type locality: **a)** View north across the stream towards sites #3, 4, and 5; **b)** view downstream with site #1 (prior to excavation) in the foreground, white dashed line outlines area excavated in collecting samples. Note, person at lower right in both Figure 5a and 5b. Photographs by John Fyles. GSC 1997- 56B; GSC 1997-56A*

details of stratification are concealed by slumping, and the upper and lower boundaries of the formation are not well exposed.

The lower part of the Hvitland beds, as seen in the upstream (eastern) part of Figure 4 (locality #1) and Figure 5b, consists of horizontal beds a few centimetres to less than a centimetre thick of grey-brown silt, silty sand, and sand becoming coarser grained upwards. Some beds contain small mollusc shells (some paired) and layers with twig-sized fragments of wood and herbaceous terrestrial plants. Paired robust shells of *Hiatella arctica* were found on the surface of clayey silt at the adjacent locality #2 (Fig. 4). Approximately 4 m of section have been seen at localities #1 and #2. Silty and clayey sediments (mainly slumped) along the base of exposures farther west (localities #3, #4) have yielded shells of *Hiatella arctica* and other molluscs, and are assumed to be stratigraphic equivalents of the beds at localities #1 and #2.

The upper part of the Hvitland beds, discontinuously exposed at localities #3, #4, and #5 (Fig. 4, 5a), comprise about 15 m of flat-lying interbedded gravel, sand and silt. Gravel is the dominant component and consists of cobble- to pebble-size subangular to angular clasts in a coarse- to medium-grained sand matrix. Beds of medium- to coarse-grained sand and pebbly sand are associated with the gravel. Individual beds of sand and gravel are lenticular and some are inclined, but distinct crossbedded sequences were not recognized. Silt beds, a few centimetres to 50 cm thick, are horizontal and more uniform than the enclosing gravel and sand. Shells of *Hiatella arctica* are present, but not numerous, in all these sediment types. Pebbles and cobbles are dominantly angular (with slightly rounded corners) to subangular and consist principally of dark grey to grey-brown siltstone, argillite, and chert; dark limestone is a minor component. The sand has two distinct phases in roughly equal proportions. Medium to coarse sand grains are not well rounded (some are angular), and they consist of dark grey to black, cherty rock. Fine- to very fine-grained pale brown sand is rounded and is mainly quartz.

Based on the foregoing characteristics, the Hvitland beds are considered to have been derived from local sources. Probably they were deposited in a nearshore, shallow marine environment. Although the basal contact of the Hvitland beds has not been seen, the position of the lowest exposures relative to nearby outcrops of the Paleogene Eureka Sound Group suggests that the Hvitland beds lie on an eroded surface with relief of at least several metres.

The uppermost exposed Hvitland strata are overlain (erosional contact) by 1 to 7 m of poorly sorted bouldery material believed to be a slope-modified glacial till. Large striated clasts occurring abundantly in the stream bed in the valley floor are inferred to have been derived from this layer at the top of the valley wall. The lowest part of the valley wall is mantled by slumped Hvitland clay and gravel with
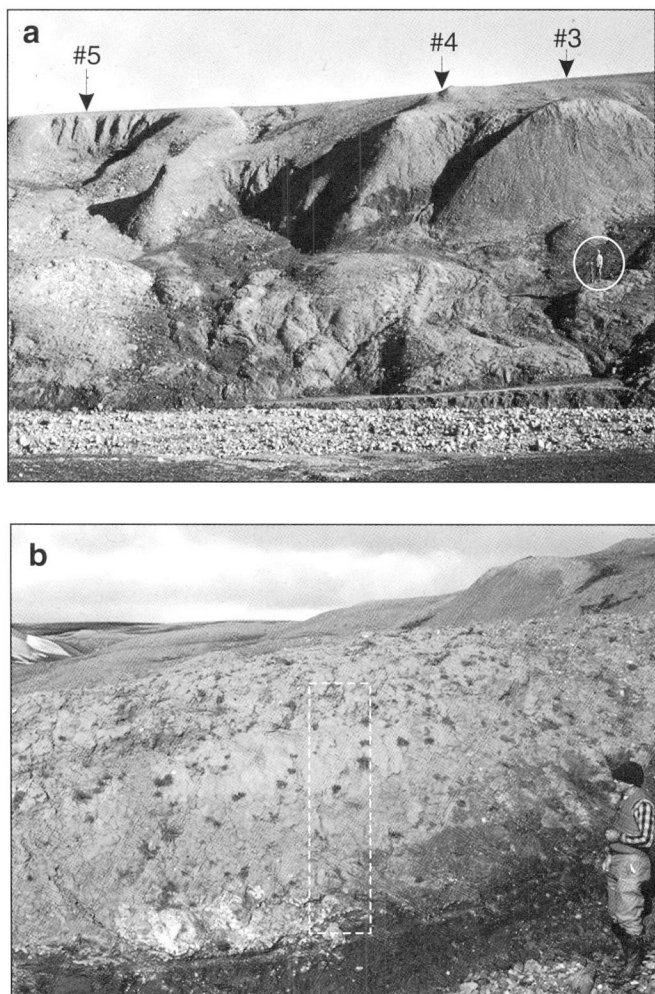
shells, and nowhere is the bottom contact of the Hvitland beds exposed. At one locality, however, (between #5 and #4, Fig. 4) the undercut stream bank exposes about 1 m of horizontal white, semiconsolidated quartz sand below slumped Hvitland material. The first author considers this sand(stone) to belong to the Paleogene Eureka Sound Group. Similar horizontal sand(stone) interbedded with brown shale and soft coal, aggregating 20 m or more in thickness, are exposed in the stream bank a few hundred metres upstream from the Hvitland exposures shown in Figure 4.

GLACIALLY REWORKED HVITLAND BEDS

Although the Hvitland beds have so far been identified only at the discovery site described in the preceding paragraphs, J. Bednarski has recognized in the vicinity glacially transported sediments containing reworked Hvitland materials. For instance, fragments of shells of marine molluscs (*Hiatella* or *Mya*) collected from glacial till downvalley from the Hvitland discovery site have amino acid ratios that suggest an age of at least early Pleistocene/late Pliocene (UA-2349, Bednarski, 1995, Table 2). Amino acid ratios for a second sample of shell fragments (*Hiatella*) found at the same location (UA-2348, Bednarski, 1995, Table 2) suggest a similar age. Further information concerning amino acid ratios is presented in a later section.

Glacial meltwater not only eroded the Hvitland beds but also reworked fossiliferous tills. For example, glacial outwash about 1.7 km upstream from the type locality of the Hvitland beds has yielded Pliocene or younger foraminifers, as well as a silicified Permian age fossil probably derived from the Van Hauen Formation (D.H. McNeil, GSC internal report 2-DHM-1992, 1992).

A clear-cut example of reworking has been found in a prominent raised delta downstream from the type locality of the Hvitland beds. A radiocarbon date on paired *Mya truncata* shells (8370 ± 130; S-2639; Bednarski, 1995, Table 1, Site 11) provides an unequivocal date on the delta, but foraminifers from the delta sediment include *Cibicides grossus* Ten Dam and Reinhold, characteristic of the Hvitland beds, and indicative of late Pliocene age (D.H. McNeil, internal report 2-DHM-1992, 1992).

PALEOMAGNETISM

Samples for paleomagnetic work were collected by R.W. Barendregt in plastic cylinders and oriented by sun compass. The samples were processed in the laboratory supervised by E. Irving at the Pacific Geoscience Centre of the Geological Survey of Canada at Sidney, British

Columbia. Measurements were obtained on 30 samples from two sites. Site 1M (samples 066 to 087, location 1, Fig. 4) spanned 1.5 m of fossiliferous marine deltaic silts and sands. Site 3M (samples 088-095, at location 3, Fig. 4) spanned 1.8 m of marine clay interbedded with gravel and sand. The average intensity of remanent magnetization at site 1M is 0.46×10^{-2} amperes/metre (A/m) and at site 3M is 0.50×10^{-2} A/m.

Four pilot samples were demagnetized in steps by alternating magnetic fields (AF). In fields above 60 millitesla (mT) the magnetizations began to disintegrate and the directions became random. Subsequently all samples were demagnetized in 3 or 4 steps between 10 and 40 mT. As a measure of precision, the index k_{sn}, defined by Irving et al. (1985), was used. Samples with a k_{sn} less than or equal to 4, indicating very low within-sample precision, were rejected. There were two such samples.

Twelve samples, all from site 1M, yielded reversed magnetizations (R-magnetizations) after removal in low AF of magnetizations along the present Earth's field (Brunhes overprints). An example is shown in Figure 6. Their mean direction ($N= 12$, $D = 245°$, $I = -83°$, $k = 17°$, $\alpha_{95} = 11°$) is not significantly different from the reversed geocentric axial dipole field (0°, -86°) (Fig. 7).

Nine samples initially had low inclinations which became increasingly negative without ever reaching satisfactory end-points (Fig. 7b). A reversed magnetization is present, but the large Brunhes overprints are not fully removed by AF demagnetization before the magnetization begins to disintegrate. Hence, their polarities are probably reversed, but this is less well established than in R samples. They are referred to as R′ magnetizations. All except two R′ samples are from site 1M.

Nine samples from site 3M have initial magnetization directions directed steeply downwards, close to the present Earth's field. Their mean direction ($N= 9$, $D = 306°$, $I = 83°$ $k = 33°$, $\alpha_{95} = 10°$) is not significantly different from the normal geocentric axial dipole field. Their intensities fall rapidly and become incoherent at 30 mT and no trace of original magnetization is present. They are interpreted as Brunhes overprints.

Site M1 has yielded 12 R samples and seven R′ samples. Hence it seems probable that the paleofield at the time of deposition of the sediments at site 1M was reversed. Most samples from site 3M contain no clear record of the paleofield at the time of deposition but the two R′ samples are consistent with the paleofield being reversed. The age implications of this reversed paleofield are discussed later under "Age of the Hvitland beds".
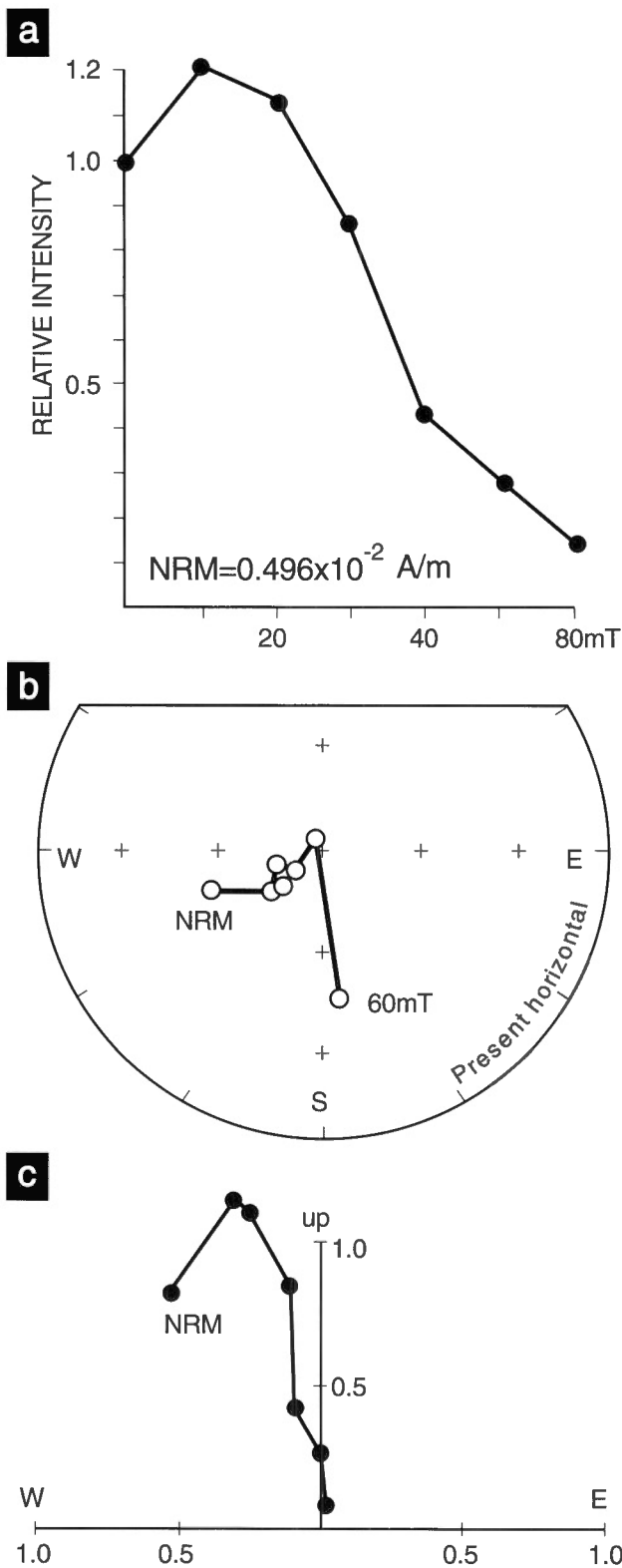
Figure 6. R magnetization at site #1M: **a)** the decay of intensity with increasing AF; **b)** the direction variations during AF demagnetization; **c)** the corresponding orthogonal plot. Because the magnetization is near vertical only one plot is shown.

OCCURRENCE OF FOSSILS

Field investigation of the finer strata of the Hvitland beds has revealed the presence of shells of marine molluscs, some of them paired, and of less obvious fragments of leaves and stems of small terrestrial plants, together suggestive of deposition in a nearshore marine environment. As noted in the introduction, initial paleontological study of samples collected by Fyles in 1961 revealed the presence of pelecypods, foraminifers, and ostracodes

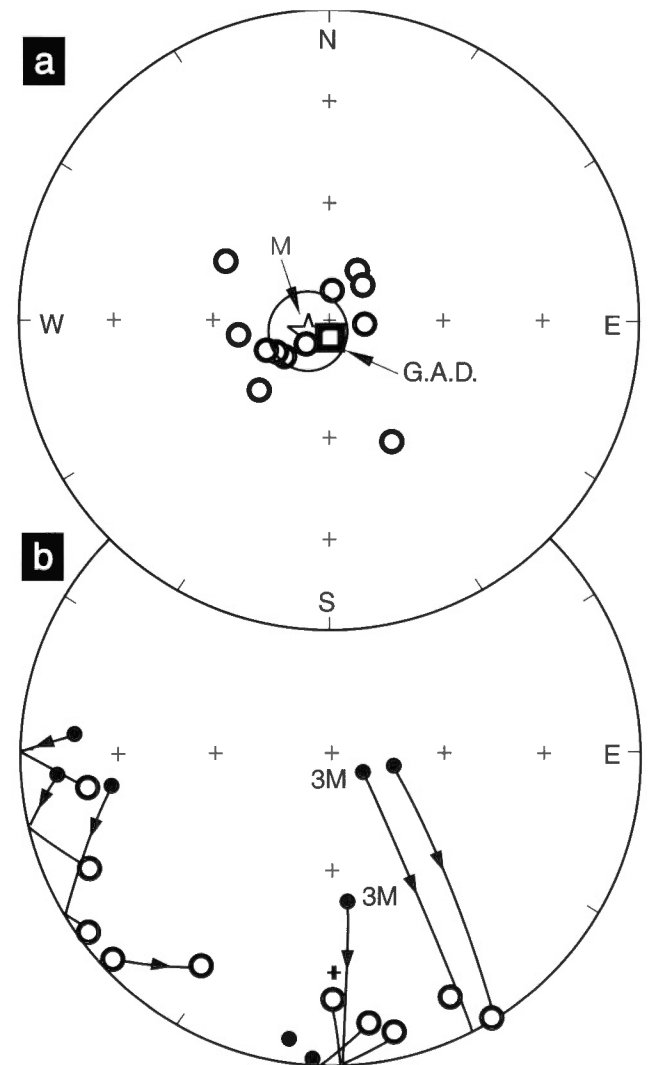**Figure 7.** R and R' magnetization directions : **a)** R magnetization directions, their mean M compared with the direction of the reversed geocentric axial dipole (G.A.D.) field. **b)** R' magnetization directions before (dots) demagnetization and after (circles) demagnetization (30 mT) showing migration towards a reversed direction. Points labelled 3M are from site 3M, the remainder from site 1M.

(F.J.E. Wagner, GSC internal report P1-3-62, 1962). During the past five years, the original samples, as well as samples collected by Fyles in 1988, and by Fyles, Marincovich, and Matthews in 1990, have been investigated paleontologically as recorded below.

MOLLUSCS

Six taxa of marine molluscs from the Hvitland beds have been identified by L. Marincovich, Jr. (Table 1). The bivalve *Hiatella arctica* is the most common of these and occurs as paired valves in sample 90-LM-10 (Fig. 4) and elsewhere. Its occurrence as paired valves indicates little or no post-mortem transport for these shells or their enclosing sediment. This species commonly lives as shallow as the intertidal zone, but at some Arctic Ocean sites in northern Alaska it occurs only below 25 m (MacGinitie, 1959; Bernard, 1979). *H. arctica* evidently originated in the North Pacific during the middle Tertiary and entered the Arctic Ocean when Bering Strait opened.

A small bivalve that probably belongs to the species *Portlandica lenticula* (Møller) is represented by several well-preserved juvenile valves. This species lives in depths of 27-360 m throughout the Arctic Ocean and in the North Atlantic south to Maine, but not in the Pacific Ocean. Its prior fossil record is in Pleistocene deposits of Chukotka (northeast Asia) and Maine (Bernard, 1979), so its presence in the Hvitland beds extends its chronostratigraphic range into the Pliocene. The modern and fossil records of *P. lenticula* suggest that it evolved in the North Atlantic or Arctic Ocean.

The small pectinid *Arctinula greenlandica* Sowerby occurs as a single valve in the present collection, but was earlier noted from what are now the Hvitland beds by

Table 1. Species of molluscs from the Hvitland beds.

BIVALVES
Arctica sp. indet.- a fragment each from FG-88-55a, FG-61-149a, and 90-LM-10 (float)
Arctinula greenlandica (Sowerby) - 1 valve from FG-88-55a
Astarte sp. indet.- a fragment each from FG-88-55a and 90-LM-10 (float)
Hiatella arctica (Linnaeus) - many fragments from FG-88-55a and 90-LM-10, and closed valves and fragments from 90-LM-10 (float)
Portlandia cf. *P. lenticula* (Møller) - 4 valves and many fragments from 90-LM-10 (float)
SCAPHOPOD
Dentalium sp. indet. - 1 fragment from FG-88-55a

F.J.E. Wagner (GSC internal report P1-3-62, 1962). It lives today throughout the Arctic Ocean and into the boreal North Atlantic, but not in the Pacific Ocean. Its bathymetric range is cited as 19-2560 m in the western Beaufort Sea (Bernard, 1979). The oldest known fossil occurrence is in Lower Pliocene deposits of northeastern Alaska (MacNeil, 1957), indicating that *A. greenlandica* probably evolved in the Arctic Ocean.

Indeterminate fragments of the bivalve *Astarte* were found at two localities. The genus dwelled in the Arctic Ocean throughout the Cenozoic and first appeared in the Pacific when Bering Strait opened.

An indeterminate fragment of the scaphopod *Dentalium* occurs at one locality (Table 1). The only previous citation of this genus as a fossil in the Arctic Ocean region is an early Paleocene occurrence in the Mount Moore Formation of Ellesmere Island (Marincovich et al., 1990). The two species are not similar in morphology. *Dentalium* is not useful as an age or paleoenvironmental indicator.

A shell fragment probably of the bivalve genus *Arctica* is present in each of three samples (Table 1) from the Hvitland beds. *Arctica* is an Arctic-Atlantic element of the fauna. On Meighen Island (Fig. 1) *Arctica* occurs prominently in the late Early to early Late Pliocene Beaufort Formation (Fyles et al., 1991; J.V. Matthews, Jr., J.G. Fyles, L. Ovenden, R.W. Barendregt, L. Marincovich, Jr., E. Brouwers, J. Brigham-Grette, V. Behan-Pelletier, D.H. McNeil, E. Irving, and J.Baker, unpub. manuscript, 1996): its presence in the Hvitland beds (if authenticated) would extend its range in this part of the Arctic Ocean into the later part of the late Pliocene. The genus is today represented by only a single living species, *A. islandica* Linnaeus, which occurs in the temperate northwestern Atlantic at depths of 9-146 m. The modern and Quaternary range of this species is not known to extend into the Canadian segment of the Arctic Ocean adjoining the Canadian Arctic Islands.

In summary, it seems that the molluscan fauna in the Hvitland beds lived at a water depth of about 25-30 m (mainly based on occurrence of *Hiatella arctica*). There apparently was little postmortem transport of shells. The molluscan assemblage is a mixture of Pacific species that entered the Arctic Ocean following the opening of the Bering Strait and of Atlantic-Arctic taxa that survived competition of the Pacific migrants.

BENTHIC FORAMINIFERS

The presence of abundant foraminifers in the fine grained sediments of the Hvitland beds was first published on by McNeil (1990), who recognized that this microfauna is diagnostic of the widespread *Cibicides grossus* Zone (sensu Feyling-Hanssen, 1980, 1985). An age of approximately 3.4

to 2.4 Ma was assigned. The upper limit was based on the assumption that *Cibicides grossus* ten Dam and Reinhold became extinct during widespread climatic deterioration and commencement of glaciation at approximately 2.4 Ma. The following text as well as Figure 8 and Plates 1, 2, and 3 present the results of more extensive investigation and interpretation of foraminifers in samples from the Hvitland beds. In addition, the discussion section of the paper catalogues the occurence of the *Cibicides grossus* Zone throughout arctic North America and on Greenland.

In the current study, five samples of Hvitland strata were examined following field investigations by Fyles and others in 1988 and 1990. The assemblage (Fig. 8; Table 2) is dominated by *Cassidulina teretis* Tappan, followed by *Cribroelphidium excavatum* (Terguem), *Cassidulina* cf. *C. teretis* Tappan, *Haynesina orbiculare* (Brady), *Cribroelphidium albiumbilicatum* (Williamson), *Cibicides grossus*, *Cribroelphidium asklundi* (Brotzen) and *Buccella frigida* (Cushman). *Cribroelphidium bartletti* (Cushman), *C. ustulatum* (Todd), and *Haynesina nivea* (LaFrenz) occur consistently in low numbers, as do several species of the polymorphinids and glandulinids. *Elphidiella gorbunovi* (Stschedrina) and *Glabratellina wrightii* (Brady) are rare to common but in separate samples. All samples are assigned to the *Cibicides grossus* Zone and there are insufficient data to warrant any further biostratigraphic subzonation. Faunal variations within the five samples are considered to result from local variations in depositional environment. There is some evidence for reworking in the form of fragments of terrestrial plants such as mosses and of older material such as siliceous spicules and chert fragments typical of the Permian van Hauen Formation. The foraminiferal microfauna, however, is apparently in situ, being quite well preserved and in an apparently natural association.

Planktonic foraminifers are absent in the Hvitland collections, suggesting shallow water sedimentation. The benthic microfauna also points to shallow water, but with salinities only moderately less than normal marine. *Buccella frigida*, *Cribroelphidium albiumbilicatum*, *C. asklundi*, *C. bartletti*, *C. ustulatum*, *Elphidiella gorbunovi*, *E. rolfi* Gudina and Polovova, *Glabratellina wrightii*, and *Haynesina orbiculare* are typically abundant in inner shelf environments. Normal marine salinities, influenced by cool water, seem to be indicated by the abundance of *Cassidulina teretis* (Mackensen and Hald, 1988). There is no evidence of a severely stressed environmental milieu which would be indicated by the predominance of one or two tolerant species.

The foraminifers recovered from Hvitland beds are arctic-boreal in aspect and evolved after the Miocene in response to climatic cooling. The foraminiferal record suggests a climate that was cool, but somewhat warmer than that of the present day. Evidence for this statement is based on what is present and also on what is absent. *Cibicides grossus*, *Cassidulina teretis*, *Glabratellina wrightii*, *Nonion barleeanum* (Williamson), and *Cribroelphidium albiumbilicatum* are not typical of glacially-influenced marine sediments (Feyling-Hanssen, 1980). This inference is supported by the absence of typical colder water species such as *Islandiella helenae* Feyling-Hanssen and Buzas, *I. islandica* (Nørvang), and *Cassidulina reniforme* Nørvang.
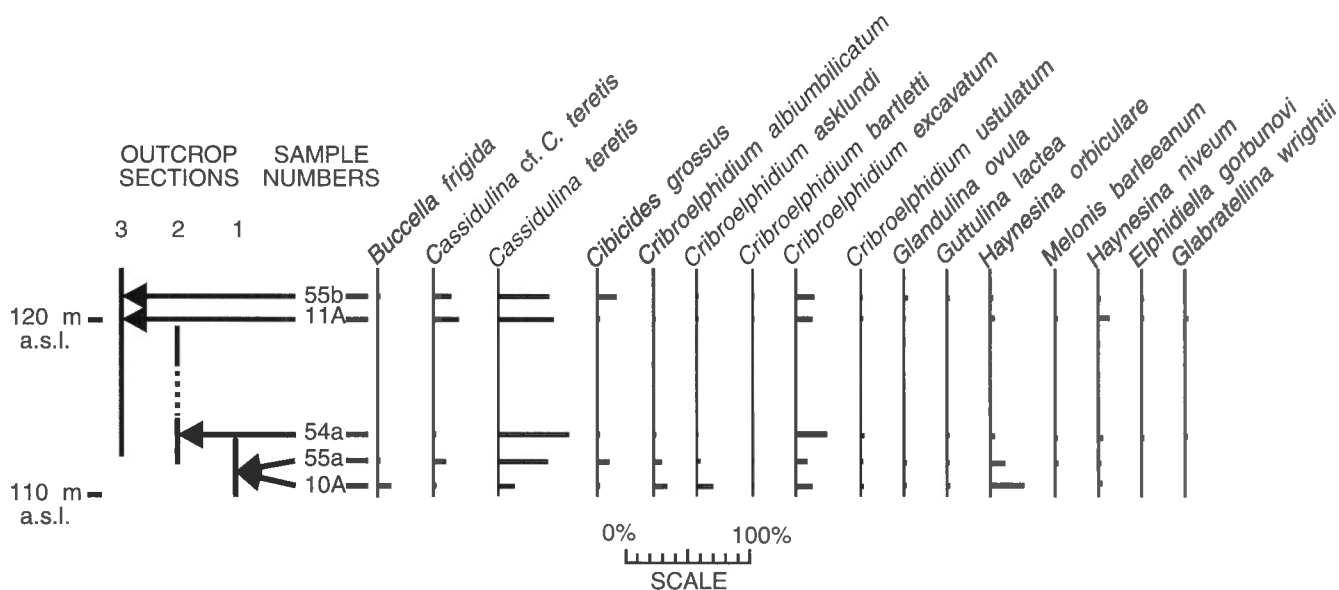

Figure 8. Per cent distribution of benthic foraminifers in five samples from the Hvitland beds. See Figure 4 for stratigraphic details.

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Table 2. Counts of foraminifers from 100 g samples from the Hvitland beds (see Fig. 4 for stratigraphic positions).

Foraminifers	Sample identification				
	55a	10A	54a	11A	55b
Buccella frigida (Cushman)	4	3	98	0	1
Cassidulina teretis Tappan	172	124	394	789	125
Cassidulina cf. *C. teretis* Tappan	42	11	6	386	43
Cibicides grossus ten Dam and Reinhold	45	2	5	34	46
Cribroelphidium albiumbilicatum (Weiss)	28	97	6	29	0
Cribroelphidium asklundi (Brotzen)	13	122	1	3	1
Cribroelphidium bartletti (Cushman)	6	8	0	15	4
Cribroelphidium excavatum (Terquem)	43	122	176	253	48
Cribroelphidium ustulatum (Todd)	4	9	24	25	1
Dentalina ittai Loeblich and Tappan	0	0	1	0	0
Elphidiella gorbunovi (Stschedrina)	0	0	12	1	1
Elphidiella rolfi Gudina and Polovova	0	1	0	0	0
Elphidiella cf. *E. hannai* (Cushman and Grant)	0	0	1	0	0
Glabratellina wrightii (Brady)	0	0	1	12	0
Glandulina ovula d'Orbigny	3	3	0	2	13
Globulina glacialis Cushman and Ozawa	0	0	1	0	0
Globulina inaequalis Reuss	2	0	0	0	0
Globulina lacrima Reuss	0	0	2	0	0
Guttulina dawsoni Cushman and Ozawa	0	0	1	0	0
Guttulina lactea (Walker and Jacob)	6	14	6	0	2
Haynesina niveum (Lafrenz)	2	9	10	152	1
Haynesina orbiculare (Brady)	58	245	21	51	7

Age of Cibicides grossus Zone

The geographically widespread distribution of *Cibicides grossus* over a fairly narrow stratigraphic range has been well documented by Feyling-Hanssen (1980), King (1983), Slobodin et al. (1986), McNeil (1990), and Knudsen and Asbjörnsdóttir (1991), who demonstrated occurrence of the species from the Netherlands, North Sea, Greenland, Baffin Island, Beaufort Sea, and Taymyr Peninsula. The older limit (first appearance) exceeds 3 Ma. In the Netherlands the last appearance datum for *C. grossus* occurred within the Reuverian Stage, below the Reuverian/Praetiglian boundary dated with paleomagnetic support at about 2.3 Ma (Van Montfrans, 1971; Feyling-Hanssen, 1980, 1987). From there, similar ages were assigned based on occurrences in the North Sea boreholes (King, 1983). Feyling-Hanssen (1980) recognized that *C. grossus* disappeared with the widespread climatic deterioration that is generally dated at about 2.4 Ma. King (1989), however, revised the last appearance datum for *C. grossus* based on the occurrence of *C. grossus* above the base of sinistral *Neogloboquadrina pachyderma* (Ehrenberg) (1.75-1.65 Ma) in the northern North Sea. Sejrup et al. (1987) also recorded *C. grossus* in lower Pleistocene beds of the North Sea Basin, but placed little reliance on these occurrences due to their scarcity and the possibility of reworking.

A more detailed study of Pliocene-Pleistocene microfaunas from three boreholes in northernmost North Sea off Norway has recently been completed by Seidenkrantz (1992). *Cibicides grossus* disappeared at the same time as *Neogloboquadrina atlantica* (Berggren) dated at 2.3 Ma, by reference to the North Sea stratigraphic zonation of King (1989) and magnetostratigraphy of Weaver and Clement (1986). These disappearances coincide with a markedly increased abundance of species of arctic affinity such as *Cassidulina reniforme*, *Nonionellina labradorica* (Dawson), *Islandiella helenae*, *I. norcrossi* (Cushman), and *I. islandica*. Seidenkrantz's (1992) data support the idea that *C. grossus* became extinct or was at least greatly diminished at the time of the 2.4 Ma climatic deterioration.

These North Sea interpretations can be extrapolated to the *C. grossus* Zone in the Hvitland beds and at other localities in Arctic North America. On this basis, the Hvitland beds are considered to have a minimum age of 2.4 Ma. The microfaunal changes from the *C. grossus* Zone to the *C. teretis* Zone are consistent with climatic deterioration, presumably the same documented in the Deep Sea Drilling Project cores by Shackleton et al. (1984) and Ruddiman and Raymo (1988), among others.

OSTRACODES

The presence of ostracodes in samples from the Hvitland beds was reported in passing by both F.J.E. Wagner (GSC internal report P1-3-62, 1962) and McNeil (1990). E. Brouwers, United States Geological Survey, has analyzed the ostracodes recovered from samples collected from

the Hvitland beds (Table 3). Samples FG-61-149a, -149c, and -149d were collected by J.G. Fyles in 1961, samples FG-88-54a, -55a, and -55b were collected by Fyles in 1988, and samples 90-LM-10a and -11a were collected by L. Marincovich, Jr. in 1990.

Twenty six ostracode species, represented by 950 valves, occur in the eight samples from the Hvitland beds (Table 3, Plates 4 and 5). In three of the samples (54a, 11a, and 149a) ostracodes are quite abundant and include 12, 11, and 13 species, respectively. The dominant taxa in these three samples are *Elofsonella concinna* (Jones), *Rabilimis mirabilis* (Brady), *Sarsicytheridea bradii* (Norman), *Krithe glacialis* Brady, Crosskey and Robertson, *Paracyprideis pseudopunctillata* Swain, and *Pterygocythereis vannieuwenhuisei* Brouwers. Of the 26 total species, 18 are extant, 4 are extinct, and 4 are placed in open nomenclature.

The four extinct species are *Cytheromorpha kalikpikensis* Brouwers, *Cytheropteron paralatissimum* Swain, *Pterygocythereis vannieuwenhuisei* Brouwers, and *Rabilimis paramirabilis* Swain. These taxa are known from Bigbendian, Colvillian, and pre-Colvillian deposits in northern Alaska (Brouwers, 1994), which have been dated between 4.0 and 2.4 Ma. *Cytheromorpha kalikpikensis* is known from Bigbendian sediments in northern Alaska (2.48-2.4 Ma; Carter and Hillhouse, 1991), from unit B2 of the Kap København Formation in northern Greenland (3.0-2.0 Ma; Brouwers et al., 1991; Penney, 1993) and from Member B of the Lodin Elv Formation in East Greenland (2.6-2.3 Ma; Penney, 1993 as *Cytheromorpha* sp.). *Cytheropteron paralatissimum* is known from Bigbendian and pre-Colvillian (>3.0 Ma) sediments (Brouwers, 1994), from Member A and unit B2 of the Kap København Formation, and from Member B of the Lodin Elv Formation

Table 3. Counts of ostracode valves from samples from the Hvitland beds (carapace equals two valves). <u>See</u> Figure 4 for stratigraphic positions.

	149a	149c	149d	54a	55a	55b	10A	11A
Acanthocythereis dunelmensis (Norman)	9	1	0	30	0	0	0	0
Bythocythere sp.	0	0	0	1	0	0	0	0
Cytheromopha macchesneyi (Brady and Crosskey)								14
Cytheromorpha kalikpikensis Brouwers	0	2	0	2	0	0	0	4
Cytheropteron montrosiense Brady, Crosskey & Robertson	0	0	2	0	0	0	0	0
Cytheropteron paralatissimum Swain	0	0	0	0	0	0	0	4
Cytheropteron pseudomontrosiense Whatley and Mason	0	0	0	0	0	5	0	28
Cytheropteron simplex Whatley and Mason	1	0	0	2	1	0	0	0
Cytheropteron sp.								
Elofsonella concinna (Jones)	2	0	0	3	0	0	0	0
Eucythere sp.	4	2	0	38	2	0	9	2
Heterocyprideis sorbyana (Jones)	0	0	0	0	1	0	0	0
Krithe glacialis Brady, Crosskey and Robertson	0	6	2	2	0	0	0	0
Loxoconcha sp.	0	5	1	0	0	4	0	65
Paracyprideis pseudopunctillata Swain	0	0	0	0	0	0	0	2
	56	2	5	17	1	4	0	81
Paracytheridea sp.								
Pteroloxa venepuncta Swain	5	0	0	0	0	0	1	0
Pterygocythereis vannieuwenhuisei Brouwers	2	1	0	0	1	0	0	0
	2	4	0	27	0	2	3	58
Rabilimis mirabilis (Brady)								
Rabilimis paramirabilis (Swain)	0	1	13	46	0	6	0	0
Robertsonites tuberculatus (Sars)	38	3	0	0	0	0	1	21
Sarsicytheridea bradii (Norman)	0	0	1	0	0	0	0	0
Sarsicytheridea macrolaminata (Elofson)	12	1	1	47	3	0	8	0
	3	0	0	0	0	0	0	0
Sarsicytheridea punctillata (Brady)								
Semicytherura concentrica (Brady, Crosskey and Robertson)	6	7	0	35	3	2	6	53
	0	0	0	0	0	0	1	0
Semicytherura complanata (Brady, Crosskey and Robertson)	1	0	0	0	0	0	0	0

(Penney, 1993). *Pterygocythereis vannieuwenhuisei* is known from Bigbendian and Colvillian sediments (3.0-2.48 Ma; Brouwers, 1994), from unit B2 of the Kap København Formation, and from Members A and B of the Lodin Elv Formation (Penney, 1993). *Rabilimis paramirabilis* is known from Bigbendian and Colvillian sediments, from Member A and units B1 and B2 of the Kap København Formation, and from Member B of the Lodin Elv Formation (Penney, 1993). Taken together, the total age range for these four taxa is >3.0 Ma to 2.3 Ma.

Penney's data (1993) for ostracodes from the Lodin Elv and Kap København Formations of eastern and northern Greenland, respectively, indicate that all four extinct species occur in Member B of the Lodin Elv Formation and that *Pterygocythereis vannieuwenhuisei* also occurs in the basal Member A. Additional samples to those examined by Brouwers et al. (1991) from the Kap København Formation extend the ranges of *Cytheropteron paralatissimum* and *Rabilimis paramirabilis* into the basal Member A.

The ostracode assemblage in the Hvitland beds includes a mixture of Pacific-derived genera (*Elofsonella*, *Robertsonites*) and Atlantic-derived genera (*Heterocyprideis*, *Paracyprideis*, *Pterygocythereis*, *Rabilimis*, *Sarsicytheridea*), indicating that the Hvitland beds postdate the opening of Bering Strait, variously dated as 3 Ma (Brouwers, 1994) to 4 Ma (Gladenkov, 1981; Gladenkov et al., 1991). The pre-Colvillian deposits in Alaska are pre-Bering Strait and include only Atlantic- and Arctic-derived genera. The maximum age of the Hvitland beds therefore postdates the opening of Bering Strait and is <3.0 Ma (or <4.0 Ma, Gladenkov et al., 1991). The minimum age for the Hvitland beds must be about 2.4 Ma, just prior to the Fishcreekian transgression of Alaska, as this is the minimum known age for the co-occurrence of the four extinct species listed above. Based on the occurrence in northern Alaska of *Cytheromorpha kalikpikensis* only in Bigbendian deposits and not in Colvillian deposits, the age range of the Hvitland beds might be narrowed to 2.48-2.4 Ma. The upper limit agrees with the age inferred for the Hvitland beds based on foraminifers. This inferred age agreement is presumably a consequence of the common cause of extinction of the four ostracode species (and of a number of foraminifer species), namely, the climatic deterioration and marked cooling event at about 2.4 Ma.

The samples represent both the lower and upper lithostratigraphic units of the Hvitland beds (Fig. 4; Table 3). Ostracode species composition does not vary much between the two units. In general, the upper group includes a higher number of shallow, nearshore species such as *Sarsicytheridea* spp. and *Paracyprideis*.

The assemblage of ostracodes records inner shelf to shallow middle shelf water depths (about 10-30 m); *Rabilimis mirabilis* is known today only from water depths greater than 10 m. The assemblage shows a mix of endemic Arctic species such as *Cytheromorpha macchesneyi*, *Cytheropteron montrosiense*, *Cytheropteron pseudomontrosiense* Whatley and Mason, *Cytheropteron simplex* Whatley and Mason, *Krithe glacialis*, *Paracyprideis pseudopunctillata*, *Pteroloxa venepuncta* Swain and *Rabilimis mirabilis*, which imply frigid to subfrigid marine climates (e.g. Davis Strait-Iceland), and of more temperate species such as *Paracytheridea* sp. and *Pterygocythereis vannieuwenhuisei*, which imply cold-temperate to subfrigid marine climates. Taken together, the assemblage indicates subfrigid shallow bottom water temperatures (i.e. distinctly warmer than the frigid water temperatures prevailing today in the Arctic Ocean and in the vicinity of the Hvitland site).

PLANT FOSSILS

Leaves and stem fragments of bryophytes were abundant in some of the Hvitland samples -- in fact, they are the most abundant of plant fossils. L.E. Ovenden identified approximately 25 species in sample FG-61-149d (Table 4). Most of the mosses in this sample grow on calcareous mineral soil (i.e. not on peat) in arctic regions today. Some are commonly found on wet soil, often in seepage areas or along streams, but most occur on drier sites (e.g. *Ditrichum*, *Ceratodon*, *Didymodon*, *Tortula*, *Schistidium*, *Timmia*, *Hypnum*). The presence of a leafy liverwort, as well as the generally good preservation of the moss fragments, suggests that the organics have not been transported far.

All moss species reported in Table 4 occur today in northern Ellesmere Island and elsewhere in the Canadian Arctic Islands. *Orthothecium chryseum* is rare outside the Arctic, which suggests that the deposit formed in an arctic setting. The single exception to the above statement is the species *Fissidens bryoides* (Brassard, 1971), which is extremely rare on the Arctic Islands but widespread at lower latitudes. *Fissidens arcticus* is a similar arctic endemic that now is widespread on northern Ellesmere Island; it may be an environmentally reduced form of *Fissidens bryoides* (Steere, 1978). Otherwise, the fossil moss assemblage shows no indication of environmental conditions different from present.

Vascular plant fossils in Hvitland sediments (identified by J.V. Matthews, Jr.) include abundant leaves of *Dryas* and of *Saxifraga oppositifolia*. Since both taxa grow on the slopes at the site today, it might be argued that they are contaminants that invaded the samples during field collection. Arguing against this, however, the *Dryas* leaves differ in form from the species *Dryas integrifolia* that grows in the area today. They are more similar to fossils that Bennike (1990) referred to *Dryas octopetala* at Kap København. Currently, *D. octopetala* is a plant of mountain areas in North America, though it does occur on Greenland and across northern Eurasia.

The *Saxifraga oppositifolia* fossil leaves from the site are no different from modern leaves washing into the creek from the slopes at the site today, except that they are not nearly as well preserved. This is a good indication that the *Saxifraga* fossils in the samples are not modern contaminants.

Finally, among the plant fossils from the Hvitland beds is a small cluster of ericaceous seeds. They come from a sample (MRA8-9-90-1, lower unit) from an excavated exposure where the chances of modern contamination are slim. The seeds, although too poorly preserved for confident identification, represent neither of the ericaceous species (*Vaccinium uliginosum,* and *Cassiope tetragona*) known to grow on northern Ellesmere Island today (S. Edlund, pers. comm., 1990).

Pollen grains (occurring in very small quantities) in samples from the Hvitland beds have been identified by R.J. Mott (GSC internal report 92-02, 1992) as *Picea, Pinus, Betula, Alnus, Tilia, Carpinus/Ostrya,* and *Carya.* They could all have been reworked from the terrestrial sediments of the Paleogene Eureka Sound Group outcropping close to the sampled exposure of the Hvitland beds. Additional palynofossils mentioned by D.C. McGregor (GSC internal report F1-3-1992-DCM, 1992) probably are mainly reworked from Mesozoic sources.

Both the vascular plants and mosses in the Hvitland beds (recorded above) differ from those in the Kap København Formation on northern Greenland (Mogensen, 1984; Bennike, 1990). Differences in the mosses at the two localities may be the result of different substrata and sedimentary conditions (during growth) rather than climatic differences. On the other hand, the presence of tree species in Unit B at Kap København indicates warmer conditions than those recorded by the herbaceous tundra plants at Hvitland. As indicated above, the *Dryas* leaves from the Hvitland beds are similar to those found at Kap København and are different from the type of *Dryas* leaves commonly shed by the Arctic species *D. integrifolia*: the latter type is common in Quaternary samples from the Hvitland region.

All of the mosses and most of the vascular plants in the Hvitland deposits are relatively well-preserved, which suggests that they have not been transported a great distance. Moreover, leafy liverworts are seldom found in sediments, presumably because they are fragile. The same conclusion can be drawn on the basis of the *Dryas* leaves, (i.e. *D. octopetala* type leaves) which are more fragile than those from the resident *D. integrifolia*. Nevertheless, the sediments in which the plant fossils occur are marine, and the plant fossils must have been transported to some degree.

INSECT FOSSILS

A few insect fossils (identified by J.V. Matthews, Jr.) occur in the sediments. One is a fragment of the thorax of an Ichneumonid wasp, a group well represented in the Arctic (Danks, 1981) and recently collected in abundance during an insect survey at Hot Weather Creek (F. Brodo, unpub. report, 1992) on Fosheim Peninsula on Ellesmere Island (Fig. 1). The only identifiable fossil is the pronotum of a ground beetle (Carabidae). In the inventory of living insects presently at Hot Weather Creek (Ellesmere Island), no carabid beetles were found, adding strength to the long standing assumption that Devon Island represents the present northernmost extent of carabid beetles (Dyke and Matthews, 1987). The carabid fossils in the Hvitland beds represent a species in the *ventricosus* group of the subgenus *Pterostichus* (*Cryobius*), which though common beyond treeline in the Holarctic region, does not occur much beyond the middle of Banks Island in the Canadian Arctic, this being further evidence of climate warmer than present. On the other hand, the Kap København beds contain abundant carabid fossils, representing many taiga species (Böcher, 1995). This certainly means that the climate during deposition of the Hvitland beds was colder than the climate during deposition of the Kap København units. The entire group is apparently missing from Ellesmere Island today; hence the single unassigned fossil means that climate was somewhat warmer than at present (and warmer than Hot Weather Creek). Even so, the tundra distribution of the *Cryobius* species, especially those in the *ventricosus* group, suggests that nearby terrestrial sites, from which the beetle fossil must have come, were treeless at the time (as is evident from the absence of tree remains in the Hvitland beds). The paucity of insect taxa in Hvitland beds compared to Kap København (Böcher, 1995) may be due to the small sample size or mode of deposition. However, the difference probably shows that climate was colder than at Kap København.

ISOTOPIC ANALYSES AND AMINO ACID RATIOS

Molluscan shells and Foraminifera extracted from Fyles' 1961 sample FG-61-149a have been analyzed for radiocarbon, strontium isotope ratios, and amino acid ratios. A radiocarbon age of 38 600 +3700/-2600 (GSC-65) was determined for shells and fragments of *Hiatella arctica*: the published comment for this date (Dyck and Fyles, 1963, p. 30) notes that "as the shells were collected from the ground surface where they could readily be contaminated with the minute amount of modern carbon required to give

the measured activity, the date should probably be regarded as a minimum." Three Sr-isotope analyses were performed on *Hiatella* shell fragments and mixed species of benthic Foraminifera from sample FG-61-149a. Standard ion exchange techniques were used to separate strontium for analysis on a VG Sector mass spectrometer at Rutgers University (Miller et al., 1991). At Rutgers, NBS987 was measured as 0.710252 at the time the FG-61-149a samples were analyzed; interrun variability is estimated as ±0.000030 or better (Miller et al., 1991). $^{87}Sr/^{86}Sr$ values for *Hiatella* (0.709090 ± 15, 0.709111 ± 5; mean value 0.709101) are slightly higher than the foraminiferal value (0.709049 ± 14). This 0.000051 difference is outside 2σ of

the reported interrun variability and may reflect inhomogeneities in either the shells or the foraminiferal tests. Still, both the *Hiatella* and foraminiferal measurements yield $^{87}Sr/^{86}Sr$ values that indicate a Pliocene age. The foraminiferal Sr isotope measurements suggest an early late Pliocene age of approximately 2.5 Ma (using published data of Hodell et al., 1990), while the *Hiatella* measurements indicate a latest Pliocene age (~1.8 Ma using published data from Hodell et al., 1990). While the data of Capo and DePaolo (1990) indicate that the age estimates based on Hodell et al. (1990) may be too young, they also indicate that the FG-61-149a sample is upper Pliocene. It is interesting to note the similarity of the $^{87}Sr/^{86}Sr$ values for

Table 4. Plant and Anthropod fossils from the Hvitland beds.

PLANTS	Ecol.[1]	149d	90-1
Amber/coal		++	++
Bryophyta			
Fissidentales			
Fissidentaceae			
Fissidens bryoides Hedw.		+	
Dicranales			
Ditrichaceae			
Ceratodon purpureus (Hedw.) Brid.	D	+	
Distichum capillaceum (Hedw.) B.S.G.	C	++	
Ditrichum flexicaule (Schwaegr.) Hampe	C	+++	
Pottiales			
Encalyptaceae			
Encalypta alpina Sm.		+	
Pottiaceae			
Didymodon rigidulus icmadophila (Schimp. ex C. Müll.) Zand	C	++	
Tortula ruralis Gaertn., Meyer & Scherb.		++	
Pottiales, undet.		+	
Grimmiales			
Grimmiaceae			
Schistidium apocarpum (Hedw.) B.S.G.	D	+	
Bryales			
Bryaceae			
Bryum spp.		++	
Mniaceae			
Cinclidium arcticum (B.S.G.) Schimp.	C,W	cf	
Cyrtomnium hymenophylloides (Hüb.) Nyh. ex Kop.		+	
Mnium sp.		+	
Timmiaceae			
Timmia megapolitana spp. *bavarica* (Hessl.) Brass.	C	+	
Hypnobryales			
Amblystegiaceae			
Campylium sp.	C,W	++	
Drepanocladus badium (C.J. Hartm.) Roth	C,W	+	
Drepanocladus sp.	C,W	cf.++	
Platydictya jungermannioides (Brid.) Crum	C	+	
Scorpidium sp.	C,W	+	

+ = taxon present; ++ = taxon common; +++ = taxon abundant (dominant)
149d = sample FG 61-149d; 90-1 = sample MRA 8-9-90-1

Hiatella cited above with those reported for the same genus from the Bigbendian of the central Arctic Coastal Plain of Alaska by Kaufman et al. (1993, Table 2 and p. 525).

Table 5 records amino acid ratios determined by J. Brigham-Grette (in 1993) for shells of *Hiatella arctica* from the Hvitland beds. The data in this table supersede the numbers published earlier by Brigham-Grette under "White Point, Ellesmere Island" (Brigham-Grette and Carter, 1992, Table 1). These newer data support the inference that the Hvitland beds are late Pliocene: the data are consistent with the specific age and correlation of the Hvitland beds presented later in this report. Information concerning the methodology and use of amino acid dating is contained in Muller and Brigham-Grette (1989).

PALEOENVIRONMENT AND CLIMATE

The Hvitland beds were deposited in a nearshore, shallow marine environment. As noted earlier, the ostracodes include endemic arctic species and subfrigid species together indicating subfrigid bottom-water temperatures and pointing to conditions somewhat warmer than those presently characterizing the area, and particularly the absence of the present perennial sea ice cover. On the other hand, the terrestrial plant and insect macrofossils in these nearshore marine sediments represent tundra conditions; some of them presently live on Ellesmere Island. Nonetheless, one of the identified bryophyte species is more common at lower latitudes, the *Dryas* leaves are not typical of the resident species – *D. integrifolia*, some of the

Table 4. (cont.)

PLANTS	Ecol.[1]	149d	90-1
Hypnaceae			
Hypnum bambergeri Schimp.	C	+	
Hypnum revolutum (Mitt.) Lindb.		+	
Hypnum vaucheri Lesq.	C	+	
Orthothecium chryseum (Schwaegr. ex Schultes) B.S.G.	C,W	++	
Orthothecium strictum Lor.	C	+	
Thuidiaceae			
Myurella julacea (Schwaegr.) B.S.G.	C,W	+	
Myurella tenerrima (Brid.) Lindb.	C	+	
Family ?			
Brachytheciaceae			
Tomenthypnum nitens (Hedw.) Loeske		+	
liverwort		+	
Vascular plants			
Polygonaceae			
Oxyria digyna (L.) Hill	D	+	
Salicaceae			
Salix sp.	D,A	+	+
Caryophyllaceae			
Melandrium sp.	D		+
Saxfragaceae			
Saxifraga oppositifolia L.	C,D	++	++
Rosaceae			
Dryas octopetala type	C,D	++	
Potentilla Sp.		+	+
Ericaceae			
Genus ?	A		+

ANIMALS	Ecol.	149d	90-1
ARTHROPODA			
Insects			
Coleoptera			
Carabidae			
Pterostichus (Cryobius) ventricosus grp	A,W		+
HYMENOPTERA			
Ichneumonoidea, Family?			+

[1]Ecological preferences:
  D, disturbed or exposed ground
  C, calcareous and alkaline substrate
  A, acidic-neutral substrate
  W, wet site

Table 5. Isoleucine epimerization in molluscan shells from Hvitland beds and related sites.

Lab. ID	Field No.	Mollusc	Free alle/Ille	Total alle/Ille	No.
Hvitland beds:					
AGL 1970	FG-61-149a	*Hiatella*	0.700±0.067	0.096±0.022	4
AGL 2195	90-LM-10-1	*Hiatella*	0.649±0.025	0.121±0.007	3
AGL 2160	90-LM-10-2	*Hiatella*	0.718±0.025	0.134±0.024	3
Glacial deposits, vicinity of Hvitland beds:					
UA-2348		*Hiatella* or *Mya*	0.726±0.045	0.096±0.004	6
UA-2349		*Hiatella*	0.85±0.001	0.139±0.003	3
Old glacial deposits, Fosheim Peninsula:					
Group 1 (oldest): range of analyses		*Hiatella, Mya*	0.372-0.714	0.089-0.185	
Group 2 (younger): range of analyses		*Hiatella, Mya*	0.146-0.355	0.047-0.086	

Notes: Analyses for Hvitland beds from J. Brigham-Grette, June 18, 1993. Fosheim Peninsula data from Bell and England, 1993, p. 90: Analyses by J. Brigham-Grette, University of Massachusetts (AGL). Analyses for glacial deposits in vicinity of Hvitland beds from Bednarski, 1995, Table 2.

Laboratory Standards:
AGL Internal Lab Standard analyzed every other day: mean=0.100±0.0026, coefficient of variation=2.6%, n=11, April 1993. Wehmiller Interlaboratory standards for April, 1993. Analyses for comparison are reported in Table 1 of Miller and Brigham-Grette (1989).

Total alle/Ille	Lab ID
81-ILC-A=0.158	AGL-2133
81-ILC-B=0.508	AGL-2134
81-ILC-C=1.102	AGL-2135

ericaceous seeds represent a species not now growing on northern Ellesmere Island, and the single ground beetle fossil represents a species group now having its northern limit in low-arctic tundra.

Conspicuously absent from the Hvitland beds are the wood and other near-treeline plant remains abundantly present in the Beaufort Formation on nearby Meighen Island (Fyles et al., 1991), in the high terrace sediments of central Ellesmere Island (Fyles, 1989; Matthews and Ovenden, 1990), and in part of the Kap København Formation of North Greenland (Bennike, 1990). If such a forest/tundra environment had existed on northwest Ellesmere Island at the time of deposition of the Hvitland beds, the assemblage of vascular plants and insects would be much richer than that found in the Hvitland beds, even when allowance is made for the marine origin of the sediments.

Thus, even though there is a danger of drawing detailed conclusions on the basis of only a few fossils, the combined evidence of mosses, vascular plants, and insects strongly suggests that adjacent land areas were dominated by tundra at the time of Hvitland bed deposition. Nonetheless, the plant fossils do indicate that climate was slightly warmer than on northern Ellesmere Island today, thus corroborating the nearshore marine evidence presented above.

The significance of the elevated position of the Hvitland beds (between 110 and 130 m above present sea level) is conjectural. The elevated position may record a late Pliocene high stand of worldwide sea level, although the difference from modern sea level seems larger than expected from records elsewhere (e.g. Dowsett et al., 1994). Alternatively, depression of the land (relative to present sea level) at the time of deposition of the Hvitland beds might

be explained in terms of local glacio-isostatic loading (highest Hvitland beds are only a few metres above the Holocene glaciomarine limit at White Point and differ little from marine limits along Nansen Sound; Bednarski, 1995), although direct evidence of glacial conditions associated with the Hvitland beds has not been found.

AGE OF THE HVITLAND BEDS

Several lines of evidence presented in the foregoing text combine to indicate that the Hvitland beds are late Pliocene and that they may date from the earliest reversed part of the Matuyama magnetic polarity chron (Gauss-Matuyama boundary) commonly dated in recent literature at about 2.5 Ma. The revised paleomagnetic chronology of Cande and Kent (1995) dates the Gauss-Matuyama boundary as 2.6 Ma. Age numbers used in the following are the same as those appearing in the various referenced source documents, and they have not been adjusted in an attempt to fit the Cande and Kent chronology.

1. The presence (in the Hvitland beds) of mollusc and ostracode species of Pacific origin is consistent with an age younger than the opening of Bering Strait three or four million years ago (Gladenkov et al., 1991).

2. The foraminifer *Cibicides grossus* in the Hvitland beds and in other marine strata in the Arctic and north Atlantic region indicates age no younger than 2.3 Ma.

3. The four species of extinct ostracodes in the Hvitland beds also occur in the Gubik Formation of northern Alaska and at the Kap København and Loden Elv sites of northeast Greenland: in these locations the age range of the extinct ostracodes is considered to be >3 to 2.4 Ma.

4. Amino acid ratios for shells of *Hiatella arctica* from the Hvitland beds (Table 5) are similar to published amino acid data for the same species from the Gubik Formation of northern Alaska. In particular, two of the three groups of total alle/Ille ratios for the Hvitland samples (0.121 ± 0.007; 0.134 ± 0.024) are closely comparable to those for shells of the same species published for the Bigbendian beds of the Gubik by Brigham-Grette and Carter (1992) and Carter and Hillhouse (1991), thus suggesting correlation of the Hvitland beds with the Bigbendian beds. Although the third group of total alle/Ille ratios for Hvitland beds (Table 5, 0.096 ± 0.026) is similar to ratios published in the same documents for the Fishcreekian beds, the ostracode data indicate that Hvitland beds are older than Fishcreekian, for which the latest age estimate is 1.7-1.2 Ma (McDougall, 1995). Nonetheless, in the absence of information on the temperature histories of the Hvitland and Gubik sites (separated by 11 degrees

of latitude) since burial of the shells, deductions regarding their relative age based on comparison of the amino acid ratios should be used with caution.

5. The Hvitland beds are interpreted to be distinctly younger than the Beaufort Formation on Meighen Island 200 km to the southwest (Fyles et al., 1991; J.V. Matthews, Jr., J.G. Fyles, L. Ovenden, R.W. Barendregt, L. Marincovich, Jr., E. Brouwers, J. Brigham-Grette, V. Behan-Pelletier, D.H. McNeil, E. Irving, and J.Baker, unpub. manuscript, 1996) and younger than the "high terrace sediments" on Ellesmere Island an equivalent distance to the southeast (Fyles, 1989), both of which contain an extensive record of tree species and near treeline vegetation.

6. Evidence for the reversed magnetic polarity of the Hvitland beds is presented earlier. Recognizing that the reversed strata of the Beaufort Formation on Meighen Island have been assigned by Fyles et al. (1991) to the youngest reversed units of the Gauss (Mammoth and Kaena) with age ca. 3.5-3 Ma, then the Hvitland beds must be younger than the Gauss. Hence, it is probable that the Hvitland beds date from the earliest reversed part of the Matuyama, commencing at 2.6 Ma (Cande and Kent, 1995). Equivalence to part of the Bigbendian unit of the Gubik Formation is probable.

DISCUSSION

Equivalence of Hvitland beds to other sites on Ellesmere Island

As noted in the introduction to this paper, the Hvitland beds comprise the first clearly identified, in-place late Pliocene marine unit within the continental landmass of the Arctic Islands (as distinct from continental-margin sites such as Meighen Island or Clyde Peninsula on Baffin Island). On the other hand, glacially transported "old" marine molluscan shell fragments are known to occur on a number of islands at altitudes distinctly above the highest Holocene beaches. In the Hvitland area, identification of the late Pliocene foraminifer *Cibicides grossus* in Holocene deltaic sediment points to glacial and fluvial reworking of the Hvitland beds fossils. The same conclusion is supported by the general similarity of amino acid ratios for molluscan shell from the Hvitland beds and from glacial sediments at nearby sites on the White Point lowland (Table 5).

Numerous amino acid ratios are reported by Bell (1992) and by Bell and England (1993) for "ice-transported" marine shell fragments from tills representing two "old" glaciations on the Fosheim Peninsula of Ellesmere Island about 100 km southeast of the Hvitland site. The small amino acid data set for the Hvitland beds samples (Table 5) falls within and covers almost the same range as the much larger data set for the shells from the oldest till on the

Fosheim Peninsula (Table 5). Based on this similarity, it is inferred that the undiscovered source beds for the oldest glacially reworked shells on Fosheim Peninsula may be about the same age as the Hvitland beds. Shells from till at Otto and Hare fiords also have amino acid ratios that fall into the same age range as the Hvitland beds samples (Bednarski, 1995).

Hvitland beds and landscape history

The Hvitland beds date from a stage when the landscape of the White Point lowland was generally similar to that of today, but with local relative sea level about 150 m above present, slightly above the Holocene maximum in this area. The present topographic distinction between the White Point lowland and the upland of the Hvitland Peninsula existed at that time. The semiconsolidated sands and shales of the Eureka Sound Group (presently beneath the Hvitland beds) probably were restricted, as today, to depressions in the surface of the underlying resistant bedrock units. A marine embayment connected to the Arctic Ocean occupied the present position of Nansen Sound at the time of accumulation of the Hvitland beds, but it is not known whether the deep fiord valley of Otto Fiord (fiord mouth 10 km south of discovery site of Hvitland beds) and deep closed basins in the floor of Nansen Sound (e.g. 20 km southwest of the discovery site of the Hvitland beds) existed at the time of deposition of the Hvitland beds or originated at a later time. In contrast, the older Pliocene high terrace sediments to the southwest in mid-Ellesmere Island clearly originated prior to erosion of deep fiord valleys (J.G. Fyles in Caley et al., 1962, p. 4-6; Fyles, 1989; Matthews and Ovenden, 1990, Fig. 12).

Cibicides grossus Zone, Arctic North America and Greenland

The occurrence of the *C. grossus* Zone in the Hvitland beds provides an important link to a number of other late Pliocene localities in Arctic Canada, Greenland, and Alaska. Figure 9 illustrates correlation of the foraminiferal zones at most of these localities. Figure 10 illustrates the distribution of the most common benthic foraminifers in the Pliocene-Pleistocene zones of Arctic North America.

AGE	BEAUFORT-MACKENZIE BASIN	HVITLAND, ELLESMERE ISLAND	CLYDE FORELAND, BAFFIN ISLAND		QIVITUQ, BAFFIN ISLAND	KAP KØBENHAVN, GREENLAND		LODIN ELV, GREENLAND	
HOLOCENE	Cassidulina reniforme								
PLEISTOCENE	Cribroelphidium ustulatum					Elphidiella gorbunovi	MEMBER B		
			Islandiella islandica	F	Islandiella islandica	Cribroelphidium excavatum			
			Cassidulina teretis	G	Cassidulina teretis	Cribroelphidium cf. C. excavatum	II	Cassidulina cf. C. teretis	MEMBER B
						Elphidiella rolfi			
PLIOCENE		Cibicides grossus	Cibicides grossus	H	Cibicides grossus	Cassidulina laevigata	MEMBER A I	Cibicides grossus	MEMBER A
	Cibicides grossus		*Haynesina niveum	I	**Haynesina niveum	Cribroelphidium funderi			

*H. niveum = N. tallahattensis of Feyling-Hanssen (1986)
**H. niveum = N. cf. N. tallahattensis of Feyling-Hanssen (1980)

Figure 9. *Correlation of benthic foraminiferal zones from the Canadian Beaufort Sea to Lodin Elv, east Greenland. Compiled and modified slightly from McNeil (1989) and Feyling-Hanssen (1980).*

Baffin Island

The foraminiferal assemblage in the *C. grossus* Zone at Clyde Foreland (Fig. 1) on northeastern Baffin Island is virtually identical to the assemblage recovered from the Hvitland beds. Feyling-Hanssen (1986, Fig. 3) recognized four subzones at Clyde Foreland. The Hvitland assemblage compares most closely to the *C. teretis-H. orbiculare* Subzone in that *C. reniforme* and *C. subarcticum* (Cushman) are not present. As noted by Feyling-Hanssen (1985), *Haynesina orbiculare*, which is the second most abundant species in the assemblage, is characterized by a conspicuous number of compressed individuals in comparison to its Quaternary representatives. The *C. grossus* Zone has also been documented farther south on Baffin Island, at Qivituq Peninsula. A notable contrast in this section is the rarity of *C. teretis*, which is abundant in the Hvitland beds. In this regard, the Qivituq section resembles the upper part of the *C. grossus* Zone at Clyde Foreland. At present, these differences are unexplained, but may be attributable to local environmental controls.

Greenland

The widespread distribution of the *C. grossus* Zone is illustrated by its occurrence at Lodin Elv on the east-central coast of Greenland (Feyling-Hanssen et al., 1983) in the lower part (Member A) of the Lodin Elv Formation (Fig. 9).

At this location (Fig. 1), *C. grossus* is again associated with abundant *C. teretis* as at Clyde Foreland and in the Hvitland beds, and therefore is suggestive of the lower part of the zone. Rare occurrences of *C. grossus* in the upper member (Member B) of the Lodin Elv Formation (on eastern Greenland) were dismissed by Feyling-Hanssen (1982) as reworked. Feyling-Hanssen (1982) noted the remarkable high percentage (52%) of boreal (i.e. warmer than arctic) species in the *C. grossus* Zone at Lodin Elv and concluded that the assemblage represented a strong amelioration of climate compared to present-day high arctic conditions (see also McNeil, 1990).

The northernmost occurrence of *C. grossus* is situated just north of latitude 82°N in the Kap København Formation (Fig. 1, site 7) on northeastern Greenland. *Cibicides grossus* occurs only sparsely at this locality in Member A (lower member of the formation), which was assigned to the *Cassidulina laevigata* Zone (Feyling-Hanssen, 1990) and correlated with other occurrences of the *C. grossus* Zone in Greenland and Baffin Island as shown in Figure 9. This correlation is suspect because *C. grossus* occurs only sparsely in Member A at Kap København. Furthermore, the associated microfossil assemblage and the geological context are not typical for the *C. grossus* Zone. For example, Member A is a diamict (Funder et al., 1985; Bennike, 1990) indicating a "glacial" climate: this conclusion is supported by the dominance of the cold-water, arctic
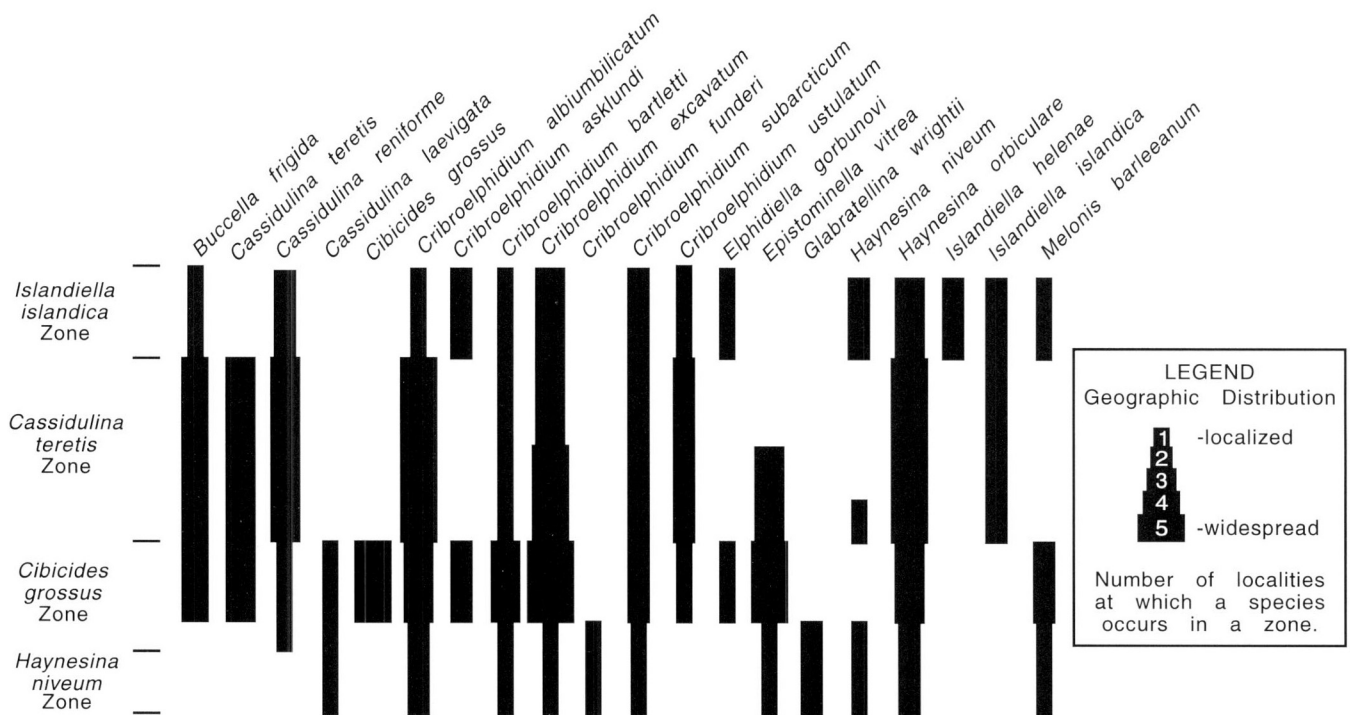
Figure 10. *Typical foraminiferal assemblages in upper Pliocene-lower Pleistocene strata of Ellesmere-Baffin-Greenland area. Compiled from Hvitland, Clyde Foreland, Qivituq, Kap København, and Lodin Elv. Rare species are omitted and total vertical ranges of species are not shown.*

species *Cassidulina reniforme* (Sejrup and Guibault, 1980) in Member A. *Cassidulina reniforme* is absent from the *C. grossus* Zone at Hvitland. In view of these geological interpretations and species distributions, it is alternatively possible that the Hvitland beds and other occurrences of the *C. grossus* Zone predate Member A at Kap København and that Member A correlates with Member B at Lodin Elv (Fig. 9), as has been suggested previously by Funder (1989) and Penney (1993, option 1).

Beaufort-Mackenzie Basin

The *Cibicides grossus* Zone is a prominent biostratigraphic unit in the lower part of the Pliocene-Pleistocene Iperk Sequence in the Beaufort-Mackenzie Basin (McNeil, 1989). The zone occurs in numerous wells but is particularly well developed in the Natiak O-44 well, situated in the northwest part of the basin (Fig. 1). At this site, the zone is 500 m thick and occurs in shelf and slope sediments which are clearly defined by seismic and mechanical log characteristics (J.R. Dietrich, pers. comm., 1993). The Iperk Sequence unconformably overlies Miocene strata of the Akpak Sequence and a nearly complete faunal change occurs at the boundary between these two sequences. *Cibicides grossus* and *Cassidulina teretis* are the two most conspicuous species in the initial deposits of the Iperk Sequence. The geometry of slope clinoforms suggest that water depths at this point during deposition were in the order of a few hundred metres. Other species in the lower part of the zone include *Cribroelphidium excavatum*, *Haynesina orbiculare*, *Cibicidoides scaldisiensis* ten Dam and Reinhold, *Melonis barleeanus*, and *Epistominella vitrea*. These species were the first Pliocene (about 3.5 Ma) benthos to colonize the Arctic marine shelf and slope subsequent to development of the regional unconformity that truncates Miocene and older sediments. A barren zone yielding detrital coaly sediments at about the shelf-slope break separates the lower part of the *C. grossus* Zone from the upper part, which is distinguished by the presence of *Cribroelphidium bartletti*, *Elphidiella itriaensis* Feyling-Hansen, *Cribroelphidium ustulatum*, *Cribroelphidium asklundi*, *Elphidiella gorbunovi*, *E.* cf. *E. gorbunovi*, *Glandulina ovula*, *Islandiella islandica*, *Islandiella helenae*, *Quinqueloculina seminulum*, and *Buccella frigida*. Increased abundances of *Cribroelphidium excavatum* and *Haynesina orbiculare* also typify the upper part of the *C. grossus* Zone in Natiak O-44. *Cibicides grossus* itself is less abundant in the upper part and occurs only rarely in the uppermost 100 m of the zone.

The *C. grossus* Zone in the Hvitland beds is comparable to the upper part of the thick succession at Natiak O-44. The species which support this correlation are *Buccella frigida*, *Cribroelphidium excavatum*, *Cribroelphidium ustulatum*, *Elphidiella gorbunovi*, *Glandulina ovula* d'Orbigny and *Quinqueloculina seminulum* (Linné) which occur in the upper zone at Natiak O-44 and in the Hvitland beds. An abundance of *C. excavatum* and *Haynesina orbiculare* also suggests the same correlation.

A noticeable dissimilarity between the upper *C. grossus* Zone at Natiak O-44 and in the Hvitland beds occurs in the abundance of *Islandiella islandica* and *I. helenae* at Natiak O-44. These species are characteristic of early Pleistocene zones in the Baffin-Greenland sections and are assumed to represent cool water masses (Feyling-Hanssen, 1980, 1990). Some of these distributions are not easily explained with the data at hand. Complete sections of Pliocene-Pleistocene strata from the Beaufort-Mackenzie subsurface would have great potential for resolving correlations of isolated outcrop sections around the Arctic continental margin (Fig. 9), just as the subsurface section in the North Sea has aided in establishing a reliable reference section for the Cenozoic of that region.

North Slope Alaska

Little has been published on foraminifera in the Gubik Formation despite its content of foraminiferal assemblages. Tappan (1951) described *Cassidulina teretis* from the Pleistocene strata of the Gubik Formation in the Point Barrow area. McDougall et al. (1986) described Pleistocene microfauna from boreholes on the adjacent marine shelf, but these deposits have no direct relevance to the assemblage on the lowland portion of the Hvitland Peninsula. McDougall (1995) has also discussed the significance of benthic foraminifera from the Fishcreekian transgression type locality in northern Alaska. The age of the Fishcreekian is controversial but relevant to the Hvitland discussion.

Representative samples from older sections of the Gubik Formation on North Slope Alaska, however, have kindly been sent to D.H. McNeil by E.M. Brouwers. These samples are from deposits referred to as Colvillian, Bigbendian, and Fishcreekian by Alaskan workers (e.g. Repenning and Brouwers, 1993). The samples were examined for the presence or absence of *Cibicides grossus*. Only two specimens of *C. grossus* were found, from the lowermost (Colvillian) part of the Gubik Formation at Colville River (Fig. 1). The associated assemblage is dominated by *Cribroelphidium asklundi* and *Elphidiella gorbunovi*, common ostracodes, abundant molluscan fragments, and common ophiurid fragments. A directly comparable assemblage of foraminifers, ostracodes, and molluscs occurs in the uppermost part of the *Cibicides grossus* Zone in the Iperk Sequence at Natiak O-44 in the Canadian Beaufort Sea. It is difficult to correlate this Alaskan assemblage precisely with the Hvitland beds assemblage except to say that it is probably a partial equivalent because numerous species such as *C. grossus*, *E. gorbunovi*, *C. asklundi*, and *C. ustulatum* are common to the two. Besides differences in the abundance or dominance of individual species, the major difference is the absence of

C. teretis at Colville River, but this may indicate environmental control, perhaps lower salinity, for the Colville assemblage.

SUMMARY

The Hvitland beds, known from a single site on northwest Ellesmere Island near Nansen Sound, were thought to record a late Quaternary interglacial event when they were discovered by the first author in 1961. In the last several years, further sampling and investigation involving study of marine foraminifers, ostracodes, molluscs, terrestrial plants, and insects, as well as paleomagnetic, amino acid, and strontium isotope analyses combine to indicate that the sediments are late Pliocene and originated in a shallow water nearshore marine environment, under subfrigid conditions (warmer than those prevailing at present). The assemblage of marine fossils indicates a mixture of Arctic-Atlantic and Pacific faunas.

The exposed section of the Hvitland beds, between Paleogene sand and Pleistocene glacial diamicton, comprises about 20 m of horizontal unlithified gravel, sand, and silt containing marine molluscan shells (including paired shells of *Hiatella arctica*) as well as marine microfossils. Terrestrial plant fossils, reworked into the marine sediments, record tundra conditions. Entirely lacking are the wood and other indicators of forest or treeline conditions that characterize the Beaufort Formation (early late Pliocene) on nearby Meighen Island and the "high terrace sediments" to the southeast on Ellesmere Island.

The contained assemblage of ostracodes includes four species (*Cytheromorpha kalikpikensis, Cytheropteron paralatissimum, Pterygocythereis vanniewenhuisei*, and *Rabilimis paramirabilis*) that became extinct about the time of the first major glaciation (ca. 2.4 Ma ago). These species also occur in the Colvillian and Bigbendian units of the Gubik Formation of the Alaska North Slope, and in the Kap København and Loden Elv formations of northeast Greenland. Benthic foraminifers in the Hvitland beds represent the *Cibicides grossus* Zone which is well known from the North Sea, Greenland, Baffin Island, and the Beaufort-Mackenzie Basin. *Cibicides grossus* likewise became extinct at about the time of the first major glaciation, ca. 2.4 Ma ago.

The Hvitland beds, formed under tundra conditions, are considered to be younger than the wood-bearing Beaufort Formation on Meighen Island, which includes paleomagnetically reversed strata correlated with the youngest (ca. 3 Ma) reversed zones of the Gauss paleomagnetic chron. Thus, it follows that the Hvitland beds (also reversed but older than about 2.4 Ma) represent the earliest, reversed part of the Matuyama chron which commenced at about 2.5 Ma.

Amino acid ratios for shells from the Hvitland beds are closely similar to published ratios (Bell, 1992) for shell fragments of the same species contained in "old" glacial tills on the Fosheim Peninsula of Ellesmere Island (100 km to the southeast) and to ratios (Bednarski, 1995) for shells from tills at sites near Otto Fiord and Hare Fiord (i.e. in the same general area as the Hvitland beds site). Thus, although the Hvitland beds is the only "in place" occurrence of late Pliocene strata recognized to date in the region, it may be that as-yet-undiscovered marine source beds for these shell fragments are of about the same age.

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PLATE 1

Scanning electron micrographs of Hvitland foraminifers. Scale bar = 100 μm.

Figure 1. *Cassidulina teretis* Tappan; a: enlargement of apertural area, b: lateral view, c: edge view; GSC 89604; field sample FG-88-55a; GSC loc. C-146560.

Figure 2. *Cassidulina* cf. C. teretis Tappan; a: enlargement of apertural area, b: lateral view, c: edge view; GSC 89605; field sample FG-88-55a; GSC loc. C-146560.

Figure 3. *Cassidulina* cf. C. teretis Tappan; lateral view; GSC 89606; field sample FG-88-55a; GSC loc. C-146560.

Figure 4. *Glandulina ovula* d'Orbigny; lateral view; GSC 89607; field sample FG-88-55b; GSC loc. C-146561.

Figure 5. *Glandulina ovula* d'Orbigny; lateral view; GSC 89608; field sample FG-88-55b; GSC loc. C-146561.

Figure 6. *Glabratellina wrightii* (Brady); megalospheric form; a: edge view, b: spiral view, c: umbilical view; GSC 89609; field sample FG-88-54a; GSC loc. C-146559.

Figure 7. *Glabratellina wrightii* (Brady), megalospheric form; a: umbilical view, b: edge view, c: spiral view; GSC 89610; field sample 90-LM-11A; GSC loc. C-194285.

Figure 8. *Glabratellina wrightii* (Brady), microspheric form; a: edge view, b: spiral view, c: umbilical view; GSC 89611; field sample 90-LM-11A; GSC loc. C-194285.
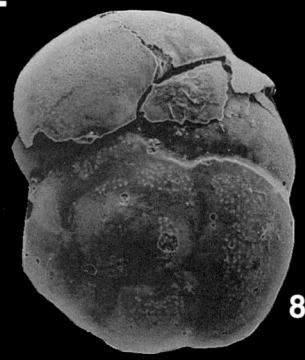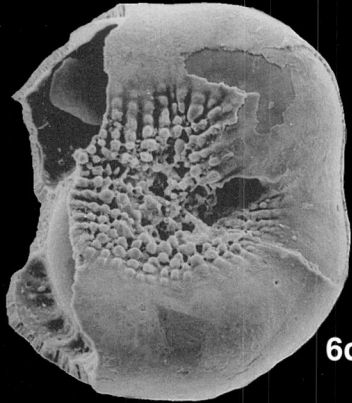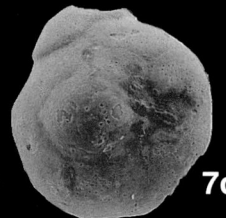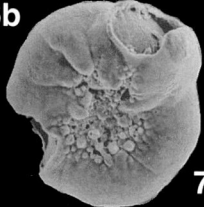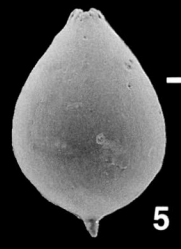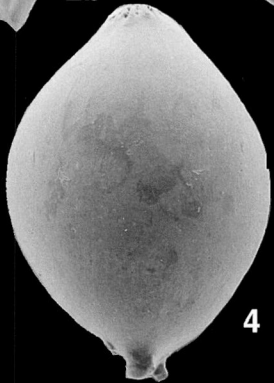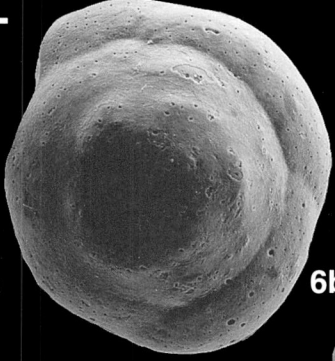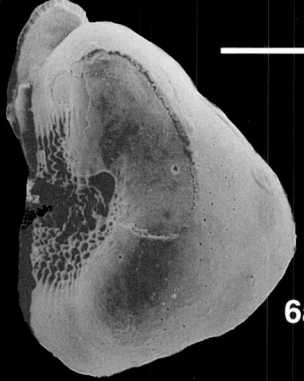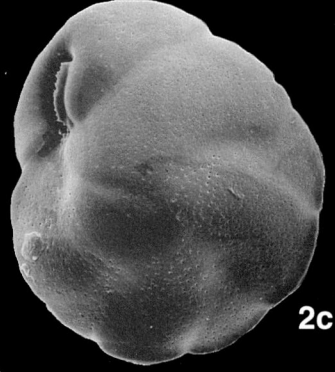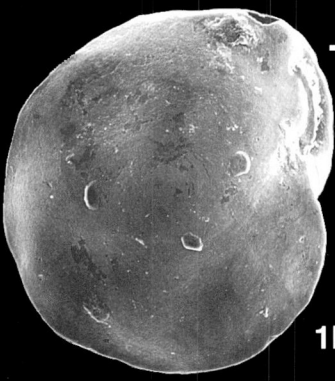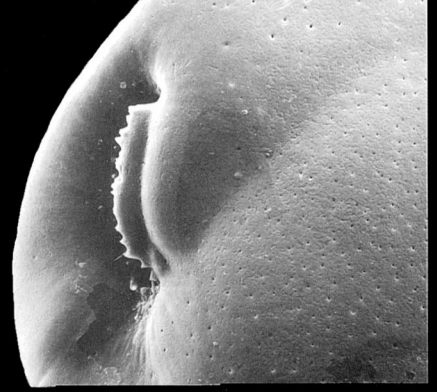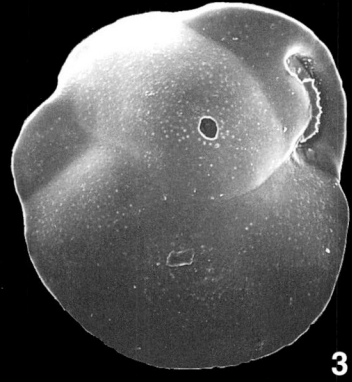
Plate 1

PLATE 2

Scanning electron micrographs of Hvitland foraminfers. Scale bar = 100 μm.

Figure 1. *Cibicides grossus* ten Dam and Reinhold; a: spiral view, b: edge view, c: umbilical view; GSC 89612; field sample FG-88-55b; GSC loc. C-146561.

Figure 2. *Haynesina orbiculare* (Brady); a: lateral view, b: edge view; GSC 89613; field sample 90-LM-10A; GSC loc. C-194292.

Figure 3. *Melonis barleeanum* (Williamson); a: lateral view, b: edge view; GSC 89614; field sample FG-88-54a; GSC loc. C-146559.

Figure 4. *Buccella frigida* (Cushman); a: spiral view, b: edge view, c: umbilical view; GSC 89615; field sample 90-LM-10A; GSC loc. C-194292.

Figure 5. *Cribroelphidium asklundi* (Brotzen); a: lateral view, b: edge view; GSC 89616; field sample 90-LM-10A; GSC loc. C-194292.

Figure 6. *Cribroelphidium asklundi* (Brotzen); a: lateral view, b: edge view; GSC 89617; field sample 90-LM-10A; GSC loc. C-194292.

Figure 7. *Elphidiella gorbunovi* (Stschedrina); a: lateral view, b: edge view; GSC 89618; field sample FG-88-54a; GSC loc. C-146559.
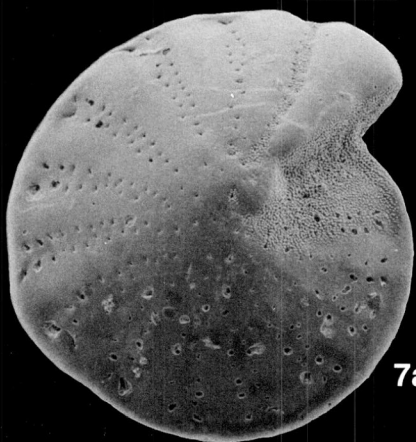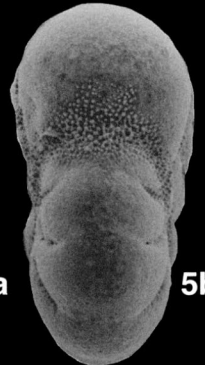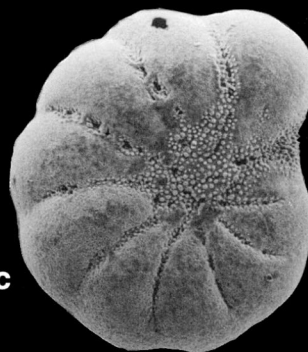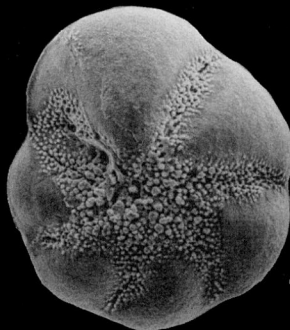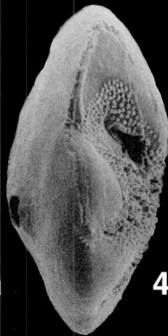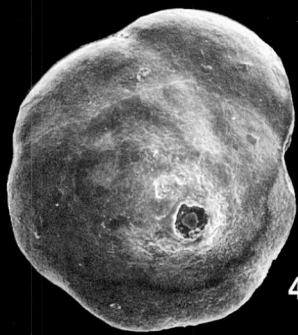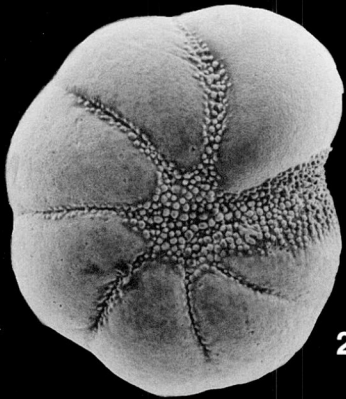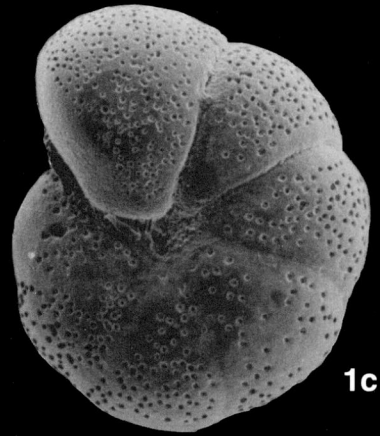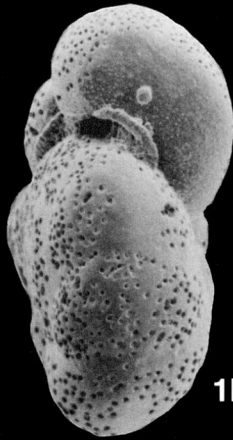
Plate 2

PLATE 3

Scanning electron micrographs of Hvitland foraminfers. Scale bar =100 μm.

Figure 1. *Cribroelphidium albiumbilicatum* (Weiss); a: lateral view, b: edge view; GSC 89619; field sample 90-LM-10A; GSC loc. C-194292.

Figure 2. *Cribroelphidium albiumbilicatum* (Weiss); a: lateral view, b: edge view; GSC 89620; field sample 90-LM-10A; GSC loc. C-194292.

Figure 3. *Cribroelphidium bartletti* (Cushman); a: lateral view, b: edge view; GSC 89621; field sample 90-LM-11A; GSC loc. C-194285.

Figure 4. *Cribroelphidium bartletti* (Cushman); a: lateral view, b: edge view; GSC 89622; field sample 90-LM-11A; GSC loc. C-194285.

Figure 5. *Cribroelphidium ustulatum* (Todd); a: lateral view, b: edge view; GSC 89623; field sample FG-88-54a; GSC loc. C-146559.

Figure 6. *Cribroelphidium excavatum* (Terquem); a: lateral view, b: edge view; GSC 89624; field sample 90-LM-10A; GSC loc. C-194292.

Figure 7. *Cribroelphidium excavatum* (Terquem); a: lateral view, b: edge view; GSC 89625; field sample 90-LM-10A; GSC loc. C-194292.

Figure 8. *Cribroelphidium excavatum* (Terquem); a: lateral view, b: edge view; GSC 89626; field sample 90-LM-10A; GSC loc. C-194292.

Figure 9. *Cribroelphidium excavatum* (Terquem); a: lateral view; b: edge view; GSC 89627, field sample 90-LM-10A; GSC loc. C-194292.

Figure 10. *Cribroelphidium excavatum* (Terquem); a: lateral view; b: edge view; GSC 89628, field sample 90-LM-10A; GSC loc. C-194292.
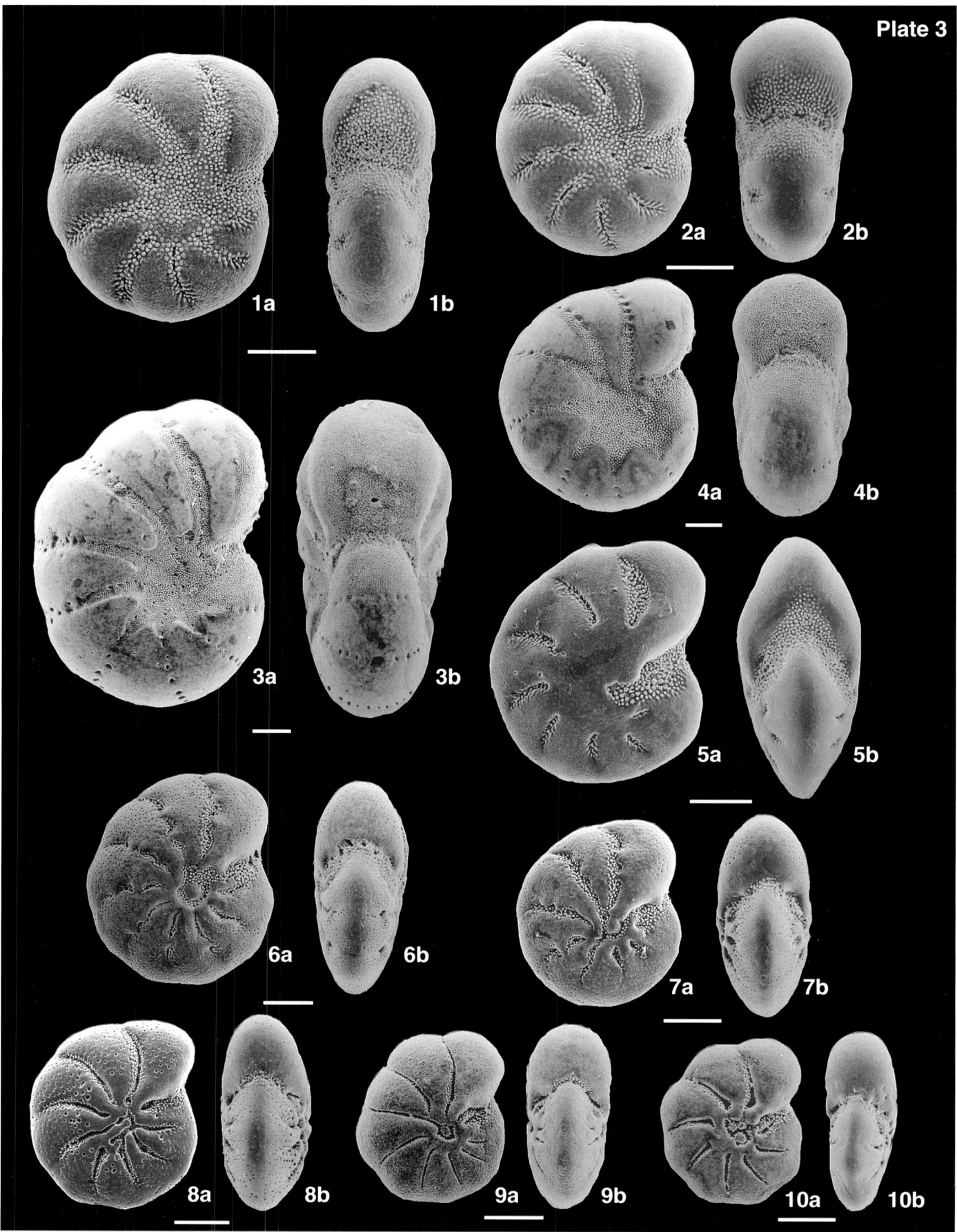
Plate 3

PLATE 4

Scanning electron micrographs of Hvitland ostracodes. Scale bar =100 μm.

Figure 1. *Pterygocythereis vanniewenhuisei* Brouwers, 1987; lateral view of left valve; GSC 117434; field sample FG-88-54a; GSC loc. C-146559.

Figure 2. *Acanthocythereis dunelmensis* (Norman, 1865); lateral view of male left valve; GSC 117435; field sample FG-88-54a; GSC loc. C-146559.

Figure 3. *Rabilimis mirabilis* (Brady, 1868); lateral view of male left valve; GSC 117436; field sample 90-LM-11a; GSC loc. C-194285.

Figure 4. *Rabilimis paramirabilis* (Swain, 1963); lateral view of female left valve; GSC 117437; field sample FG-88-54a; GSC loc. C-146559.

Figure 5. *Elofsonella concinna* (Jones, 1857); lateral view of female left valve; GSC 117438; field sample FG-88-54a; GSC loc. C-146559.

Figure 6. *Paracytheridea* sp.; lateral view of left valve; GSC 117439; field sample FG-61-149a; GSC loc. C-146551.

Figure 7. *Sarsicytheridea bradii* (Norman, 1865); lateral view of female left valve; GSC 117440; field sample FG-88-54a; GSC loc. C-146559.

Figure 8. *Krithe glacialis* Brady, Crosskey and Robertson, 1874; lateral view of male right valve; GSC 117441; field sample 90-LM-11a; GSC loc. C-194285.

Figure 9. *Paracyprideis pseudopunctillata* Swain, 1963; lateral view of left valve; GSC 117442; field sample FG-88-54a; GSC loc. C-146559.
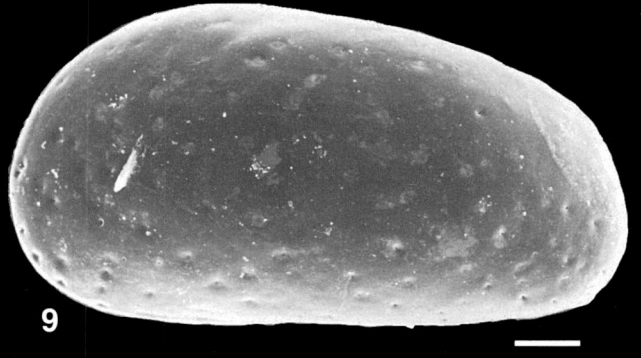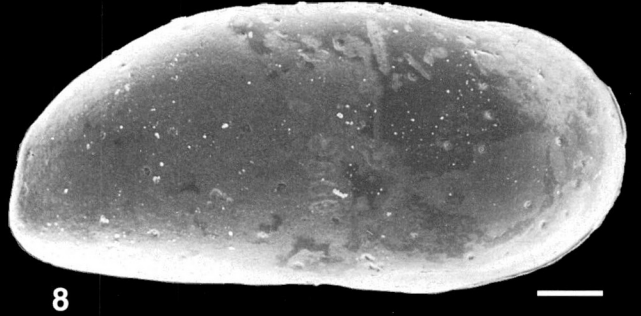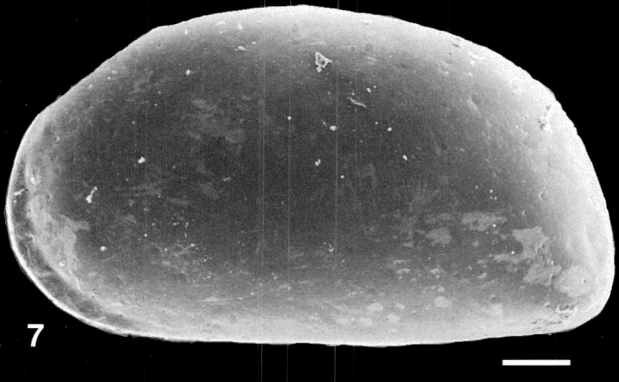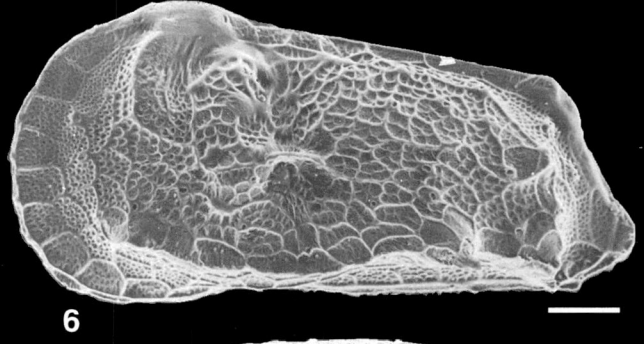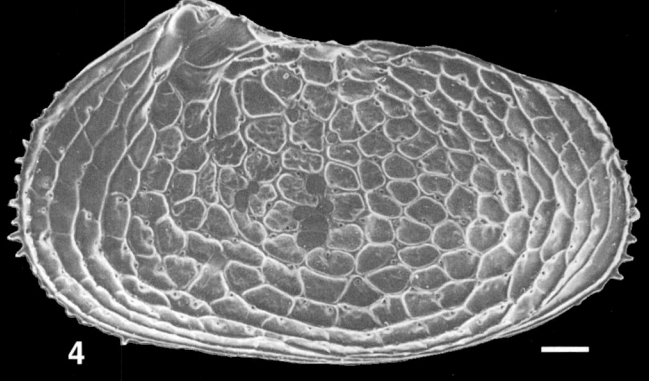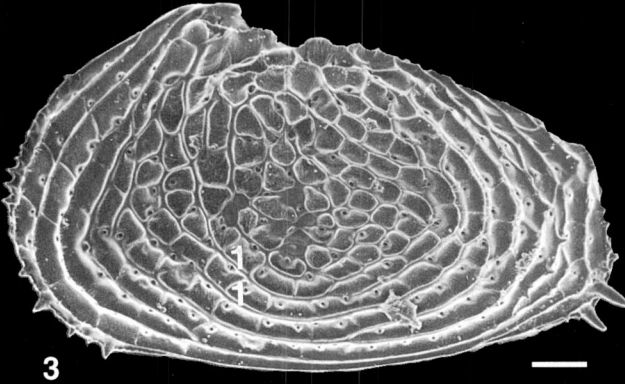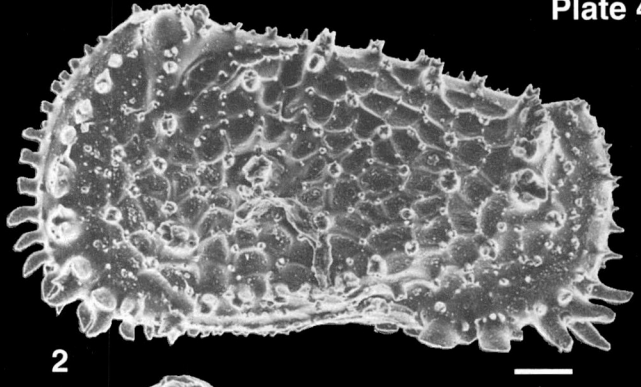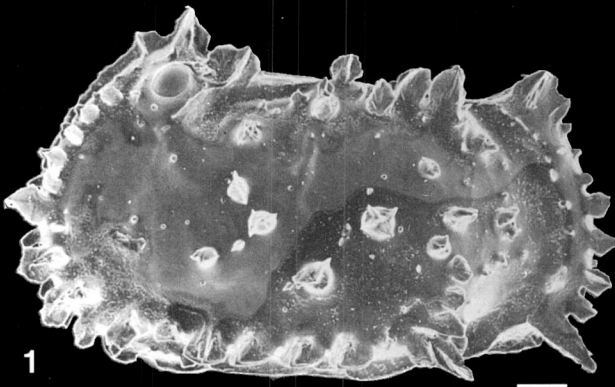
Plate 4

Plate 5

Scanning electron micrographs of Hvitland ostracodes. Scale bar =100 µm.

Figure 1. *Cytheropteron pseudomontrosiense* Whatley and Masson, 1979; lateral view of right valve; GSC 117443; field sample 90-LM-11a; GSC loc. C-194285.

Figure 2. *Cytheropteron paralatissimum* Swain, 1963; lateral view of left valve; GSC 117444; field sample 90-LM-11a; GSC loc. C-194285.

Figure 3. *Heterocyprideis sorbyana* (Jones, 1985); lateral view of female left valve; GSC 117445; field sample FG-61-149c; GSC loc. C-146552.

Figure 4. *Sarsicytheridea punctillata* (Brady, 1865); lateral view of male right valve; GSC 117446; field sample FG-61-149c; GSC loc. C-146552.

Figure 5. *Cytheromorpha kalikpikensis* Brouwers, 1993; lateral view of female left valve; GSC 117447; field sample FG-88-54a; GSC loc. C-146559.

Figure 6. *Pteroloxa venepuncta* Swain, 1963; lateral view of right valve; GSC 117448; field sample 90-LM-11a; GSC loc. C-194285.

Figure 7. *Cytheromorpha kalikpikensis* Brouwers, 1993; lateral view of male left valve; GSC 117449; sample 90-LM-11a; GSC loc. C-194285.

Figure 8. *Loxoconcha* sp.; lateral view of right valve; GSC 117450; field sample 90-LM-11a; GSC loc. C-194285.
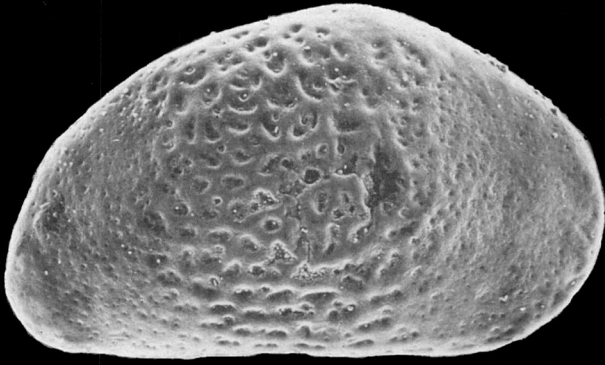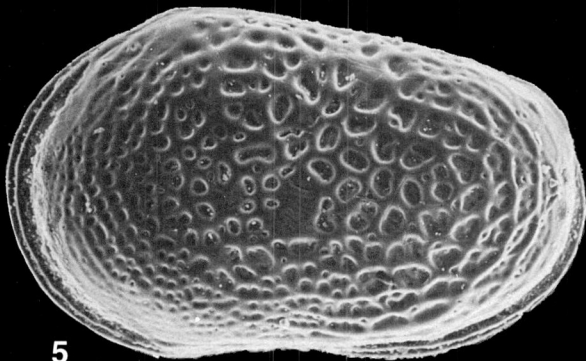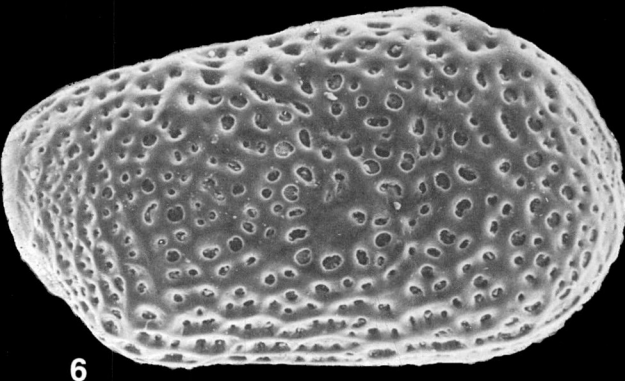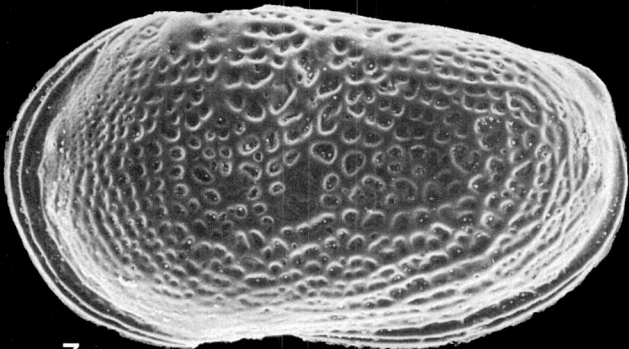
Plate 5