Arctic Development

JOINT SERVICES EXPEDITION TO BOROP FIORD - ELLESMERE ISLAND - FINAL REPORT PART II

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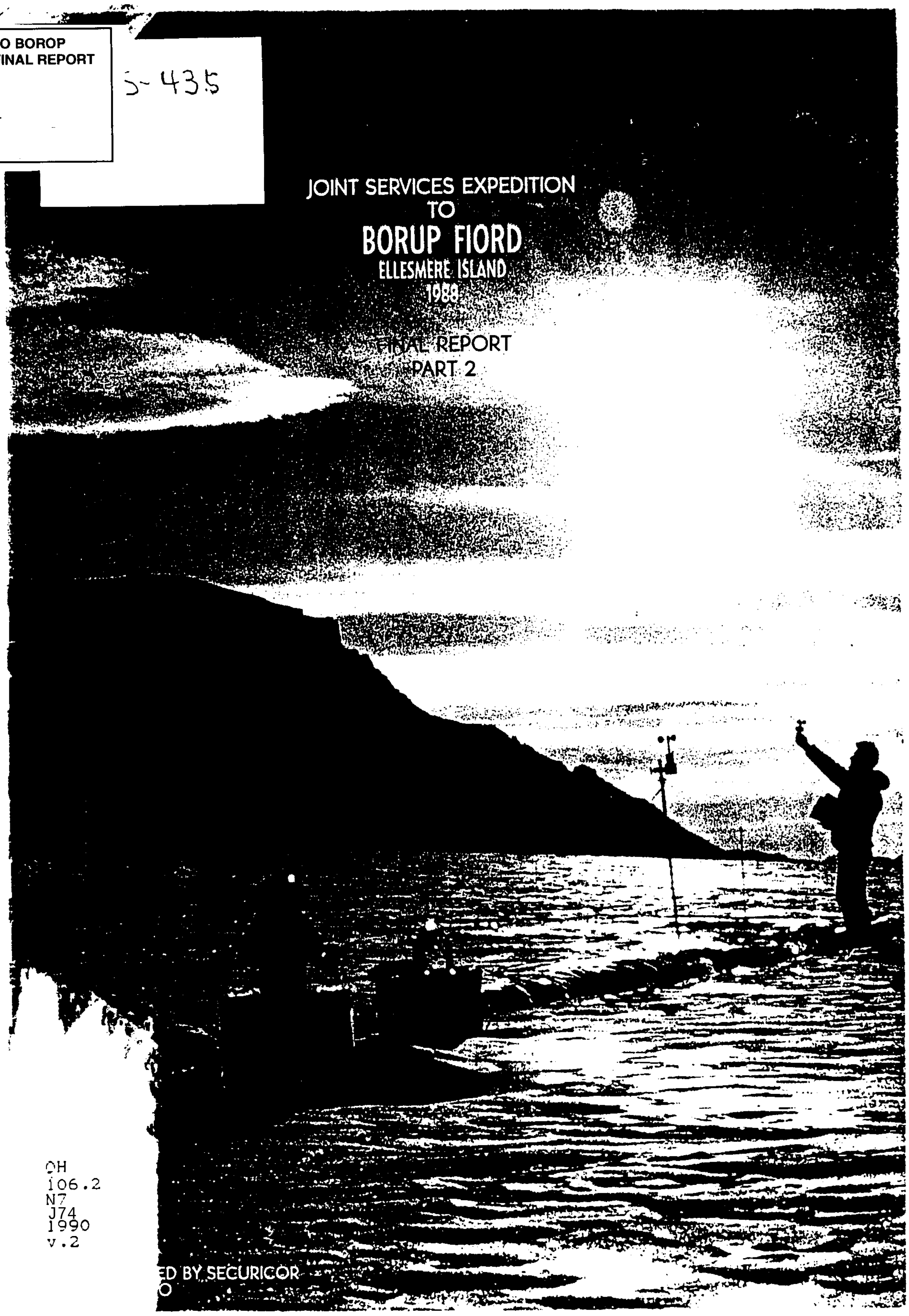
JOINT SERVICES EXPEDITION TO BORUP FIORD

ELLESMERE ISLAND 1988

FINAL REPORT PART 2



INTRODUCTION

The Joint Services Expedition to Borup Fiord waa a broad-baaed study of a part of Ellesmere Island that had been generally ignored by other researchers. The team comprised 12 men end one woman,drawn from the armed forces, and 4 civilians; the papers that follow are the results of their work. Not all aspects of the expedition are covered; the paper on the breeding behaviour of anow buntings is not yet complete while those on entomology and psychology failed to reach the standard required for publication. Offprinta of these papers will be available from the editor.

An account of the more general aspects of the expedition,including a diary and colour photographa, is in part one of the report. Copies of this may be obtained,price £5 or $10,from the editor below to whom all questions regarding the expedition should be addressed.

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AN ARCHAEOLOGICAL SURVEY OF BORUP FIORD, ELLESMERE ISLAND HIGH ARCTIC CANADA

Roger F Smith

INTRODUCTION

Ellesmere island was first occupied some 4000-4500 years ago by hunters whose material culture is known to archaeologist as the Arctic Small Tool Tradition. Originating in Siberia, they spread eastwards across the Canadian Arctic to Northern Greenland; thereafter, over a period of 3000 years, their descendants evolved regional cultures distinguished by different types of equipment and dwelling. On Ellesmere Island these regional variants include the Independence II, Pre-Dorset and Dorset cultures, named after the places at which they were first identified (Maxwell 1960; McGhee 1978:56, 58; 1981:121; Schledermann 1978: 461-62; Bielawski 1988:68).

During the tenth and eleventh centuries AD a second wave of peoples, originating in Alaska, swept rapidly across the Arctic as far as Greenland. Known archaeologically, as the Thule people, after Thule in north western Greenland, they are the ancestors of the Inuit (McGhee 1978:74-102, Morrison 1983). The earliest Thule settlements on Ellesmere Island are of eleventh century date (Schledermann 1978:467-72; Schledermann and McCullough 1980).

Contemporary with the migration of the Thule was the discovery and colonisation of Greenland by the Norse. Norse material recovered from Thule encampments on eastern and western Ellesmere Island, is perhaps evidence of hunting and trading by Norse from Greenland, rather than of settlement by them on Ellesmere Island (Schledermann 1978; Schledermann and McCullough 1980; McGhee 1984a:15-17).

Knowledge of Ellesmere Island's prehistory is derived principally from surveys and excavations conducted in northern and eastern Ellesmere Island. Western Ellesmere Island is less well known archaeologically, though Tanquary Fiord to the east and the Fosheim Peninsula and Eureka Sound to the south of Borup Fiord have been surveyed and some sites excavated. Discoveries include encampments of the Arctic Small Tool Tradition, Independence II, Dorset and Thule peoples; while a portion of a Norse bronze balance was recovered from a Thule site in Slidre Fiord (Sutherland Severs 1977, Sutherland 1980). Borup Fiord, however, had not been the subject of any previous archaeological survey.

METHOD

The purpose of our survey was to locate and record evidence of past human activity in the Fiord and its environs and thereby establish the area's potential for future archaeological research. To complete the survey, during the six weeks in which the ground was free from snow, it was necessary to balance the requirement for detailed recording with the need to cover ground.

Consequently while all the structures found were photographed and the majority measured and sketch-planned, accurately measured 1.20 scale plans were made of a representative selection of tent rings and walled shelters only. The exceptions were the lakeside settlement at the head of Essayoo Bay (site 12), planned in its entirety at a scale of 1.20, and the settlement on the island in Oobloyah Bay (site 2), planned at a scale of 1.100.

Conducted on foot, after the spring melt in July and August, 135kms of coastline were searched and twenty nine archaeological sites, including encampments and possible caches, were discovered. The largest encampment, located on an island in Oobloyah Bay (site 2), comprised thirty-five tent rings, walled shelters and possible caches, and the smallest, a single tent ring. Inland, a tent ring was discovered in a valley, to the east of Essayoo Bay (site 19), 11 kms from the coast. Fox traps were also found: one at the head of Midnight Sun Valley (site 18) and four on hills between Essayoo Bay and Mount Leith (sites 13-17), together with other structures that might also have been trapa.

Almost certainly sites were missed; since the ground was often boulder strewn or covered by vegetation, tent rings were hard to spot, the majority being visible at distances of 20m or less. This may explain the apparent dearth of encampments on Borup Fiord's west coast where only one site was found. The example of our initial reconnaissance of the Elmerson Peninsula's coastline, which resulted in the discovery of one encampment (site 32), is salutary. A subsequent survey of the same coastline, by the writer and another member of the expedition, led to the discovery of fifteen additional encampments.

During our survey of Borup Fiord the only artefacts found were a small carved stone lamp and a flat stone disc, both of which were left in situ. The absence of artefacts and also of food debris in the form of discarded bones is probably the result of natural processes. Excavations in the Arctic have established that artefacts and faunal remains will percolate down through shingle; the great majority of Borup Fiord's encampments were located on shingle. Wind and water actions may also have dispersed artefacts and faunal remains, while weathering may have caused the latter to disintegrate (Savelle 1986:321, 1987: 436; Bielawski 1988:70). At several sites too, noteably the encampments on the island in Oobloyah Bay (site 2) and at the head of Essayoo Bay (site 12), any surviving artefacts or bones would have been concealed by moss and plants.

Descriptions of the archaeological sites discovered in the fiord are given in the final section of this paper. The structures found are discussed below under the appropriate subheadings.

TENT RINGS

Tent rings comprise the stones used to hold down the sides of animal skin tents which, when the tenta were struck, were left on the ground. Those found in Borup Fiord were composed either of a single course of intermittently placed stones (figs 6, 7, 9, 10) or of drystone walls, several courses high (fig 4). In plan they were variously circular, oval, trapezoid, rectangular or subrectangular with sides that were either straight or convex.

Insight into how the tents represented by the tent rings might have been erected is provided by the Inuit of historic times. The Netsilik Inuit, for example, when erecting their tents would first mark out the floor by laying down a ring of stones. A tent pole was then placed upright, resting on a flat stone, inside the ring. Seal skin thongs attached to the upper end of the pole and fastened to the heaviest stones in the tent ring formed a frame over which a seal skin sheet was stretched. The base of the sheet was pulled tight beneath the stones that formed the ring. The floor space was divided with a line of flat stones, into a sleeping area at the back of the tent and a kitchen and working area in the front, near to the entrance. Cooking hearths were often placed outaide the tent so as to avoid filling the interior with smoke (Savelle 1987).

In Borup Fiord tent rings with their interiors similarly divided into two distinct areas were found in Oobloyah Bay at sites 2 and 4 (figs 4,5,6), at inland site 19 (fig 8c) and on Cape Brainard at 32 (fig 10). Tent rings were also found with two compartments joined together in the form of a figure 8: in Oobloyah Bay at site 2 (fig 4) and on the Elmerson Peninsula, sites 22 and 29 (fig 9b). As with the tents of the Netsilik Inuit, one compartment was probably for sleeping while the other was perhaps a kitchen and working area. None of the tent rings found had recognizable hearths, either inside or outside of the rings.

Several tent rings had small stone enclosed compartments or alcoves projecting from their side walls: at Cape Brainard's sites 31 and 35 (fig 11b), on the Elmerson Peninsula at sites 26, 28 and 30 and on the island in Oobloyah Bay, at site 2 (fig 4); these features were perhaps larders. Tent rings with similar alcoves have been found elsewhere on Ellesmere Island (Bentham and Jenness 1941: 46, Maxwell 1960:31).

HOUSES

Walled structures that were probably houses, classified as walled shelters on figure 1, were discovered at three locations in Borup Fiord: On the island on Oobloyah Bay (site 2), on a headland to the south-west of the latter (site 1) and at the head of Essayoo Bay (site 12). Variously oval and angular in plan, their drystone walls, up to 1.5m wide, ranged in height from 0.4m to 1m. With the exception of the house described below their walls were built with large stone slabs, often stood on edge, combined with angular blocks stacked one on top of another. Some of the stones used in their construction weighed in excess of 200lbs.

House 1, at the encampment at the head of Essayoo Bay (site 12), differed from the other houses found in that its walls were built with stones laid in tabulated courses. Oval in plan and measuring internally 1.7m by 1.4m, its walls tapered slightly inwards. Moss covered rubble inside the house was perhaps the remains of a collapsed stone roof.

A dome-shaped structure at the island site had its slab-built roof intact (fig 3.13); 2.5m in diameter it was 0.9m high. Apparently without an entrance it was either a house, the entrance to which had been blocked, or a cache. Partially collapsed structures to the west of this structure seemed also to have had stone roofs. Other walled shelters at all three locations, which like house 2 at site 1 (fig 2a) did not have stone roofs, may have had tents erected either on or over their walls.

TENT RINGS AND HOUSES - SEASONAL OCCUPATION

In Borup Fiord the houses and tent rings comprising low dry stone walls were probably occupied for longer periods than were the less substantial tent rings composed of intermittently placed stones. An occupation lasting weeks or months, rather than days, would perhaps warrant the greater expenditure of time and effort required for the construction of the walled structures. Stone-built caches at two of the locations at which the latter were found and the fox traps, near to the Essayoo Bay site 12, would be in keeping with long term occupations. They may also have been occupied at different times of the year.

While the tent rings probably represent the summer encampment of mobile hunting banda, the houses and tent rings with walls affording greater protection against the weather, were perhaps the spring or autumn residences of more sedentary populations. Only two of the structures found can be identified as probable winter dwellings: structure 2 (fig 2) on the headland in Oobloyah Bay and the sunken floored structure on the nearby island (site 2). The former had what might have been a collapsed cold-trap entrance which is a characteristic of Thule Winter houses; being downslope from the living and working areas this entrance would have prevented cold air from entering the interior.

The locations at which the walled shelters were found may also accord with occupation during the spring or early winter. All three sites lay near to where the outflowa from rivers cause the sea ice to break up early and probably to freeze late. Attracting seals and birds the resulting open waters in an otherwise frozen sea were and indeed still are a potential food resource for hunters. Fox traps on the hills above the settlement at the head of Essayoo Bay may indictate occupation of that site in the spring, since all were positioned on ground that became free of snow early in the spring melt.

Fox TRAPS

Four stone-built fox traps were discoverd on hills to the north east of site 12, at the head of Essayoo Bay. A fifth trap was found at the head of Midnight Sun Valley, 6 kms from the coast. Of similar design and built on flat-topped boulders, these traps comprised a narrow chamber, open at one end, with a relatively large lintel stone over the entrance. Reinforced with stone slabs and boulders they had pronounced hogsback profilea. Bait placed at the traps closed end drew the fox inside. Presumably a trigger mechanism, activated by the fox when it seized the bait, released a blocking stone from above the entrance. Dropping into place between two guide posts, positioned either side and slightly forward of the entrance, the fallen stone would have trapped the fox inside the chamber. All five traps were discovered with their blocking stones in the down position; none were opened. Bones and a fox's skull could be seen inside one of the traps, through chinks in the side-walls.

CULTURAL AFFILIATIONS AND CHRONOLOGY

In the Arctic the age and cultural affiliations of an archaeological site may be determined by the presence there of equipment characteristic of a particular period or culture and by architectural features that are culture-specific. Dates may also be obtained by Radio Carbon dating, that is by measuring the ratio of Carbon 14 to Carbon 12 isotopes, which alters through time at a predictable rate in organic materials recovered from archaeological sites, such as wood, charcoal, horn, antler, bone and shell. In addition, where an archaeological site is located on a raised beach the elevation of the beach relative to present sea level may indicate the approximate age of the site. This is because since the end of the last ice age land masses over much of the Arctic have been rising steadily. Radio Carbon dates obtained for materials recovered from raised beaches have enabled isobase maps to be prepared for the Canadian Arctic. Isobases are lines joining sites with similar postglacial uplift over the same interval of time. Thus when an archaeological site of unknown date is found on a raised beach, the elevation of the beach may be compared with those of the predicted isobases and an approximate date thereby obtained. The method assumes that people who travelled and hunted on the sea would have camped on the first beach above the shoreline of that time, save during the winter months when camps may have been positioned at higher elevation with better visibility (Andrews et. al. 1971).

Since neither items of equipment nor materials suitable for Radio Carbon dating were recovered from any of the sites discovered in Borup Fiord, we are dependant for their dating on the elevation of the beaches on which they were located and alao, where appropriate, comparison with dwellings found elsewhere in the Arctic for which dates have been obtained. Archaeological sites were discovered on raised beaches at seventeen locations in the fiord, at elevations ranging from 0.5m to 2m above the high water mark. According to estimates of isostatic uplift for the area, raised beaches at those elevationa in Borup Fiord may have emerged from the sea approximately 800 years before present, that is in the twelth centry AD (Andrews et.al. 1971:224). That the beaches in question may have emerged from the sea, however, at an earlier date is suggested by one of the structures at site 1, in Oobloyah Bay. Roughly rectangular in plan and measuring 7.15m by 3m this tent ring, defined by a course of irregularly laid stones, was convex at one narrow end and open at the other (fig 2b). Similar structures have been discovered on the east coast of Ellesmere Island and elsewhere in the Arctic. Artefacts associated with them relate to a late phase of the Dorset culture (Schledermann 1978:465), while Radio carbon dates from one of the structures on Ellesmere Island's east coast place it in the eighth or ninth century AD (McGhee 1984b: 18).

If Borup Fiord's rectangular tent ring was contemporary with those on the east coast of Ellesmere Island, then the date range of the structures found, on raiaed beaches at the same elevation in the fiord, may extend back in time from the present to the ninth or tenth century AD. Accordingly, there might be among them late Dorset and Thule tent ringa and perhaps also Inuit encampments of the more recent past; unfortunately, however, dated parallels are hard to find and precise dating is therefore impossible. This , as we shall ace, is in large part due to the lack of published plans and photographs with which to compare Borup Fiord's tent rings.

None of Borup Fiord's tent rings was equipped with the narrow stone-built box hearths characteristic of late Dorset tent rings on Dundas Island, to the southwest of Ellesmere Island (McGhee 1981:41-79). This does not exclude the possibility, however, that some at least of Borup Fiord's tent rings were late Dorset constructions since Dorset dwellings, including tent rings, surface built and sunken floored, occur in a variety of forms of which too few have been published (Maxwell: 1980 506-510). This is true also of Thule tent rings for, as several Arctic prehistorians have remarked, Thule tent rings have not been the subject of any detailed study (Linnamae and Clark 1976:57, McGhee 1984b:84, McCartney and Savelle 1985:21).

Extensive use of rock slabs and boulders for constructional purposes seems to be a Thule rather than a Dorset cultural trait. The structures built with slabs and boulders on the island in Oobloyah Bay (site 2), on the headland to the southwest of the island (site 1) and at the settlement at the head of Essayoo Bay (site 12), might therefore be regarded as Thule constructions, though low-walled tent rings which are perhaps Dorset or pre-Dorset are reported on Baffin Island (Jacobs and Stenton 1985:65). Nearer to Borup Fiord, however, In the Lake Hazen region of northern Ellesmere Island, excavations of two low-walled tent rings have established that they were probably occupied early in the Thule period. Early Thule and late Dorset artefacts were recovered from one ring, while the other, which yielded no artefacts, was stratigraphically later. Moreover one of these structures had a small compartment, probably a larder, projecting from the enclosing wall (Maxwell 1960: 80-81), as did two tent rings (fig 4) on the island in Borup Fiord's Oobloyah Bay. The latter tent rings, (fig 4a) may also be compared with a proven Thule house on the Bathe Peninsula, eastern Ellesmere Island, which like them had two compartments joined together in the form of a figure 8 (Schledermann 1978: 470, fig 6).

A comparison, too, can be made between one of two low-walled structures (fig 2a) on the headland in Oobloyah Bay with Thule winter housea in west Greenland (Holtved 1954: 85). Like these houses it was built on slightly sloping ground so that the longitudinal section, stepped up the slope, comprised an entrance passage and a semi-sunken living area and sleeping platform. Like these Thule houses, too, the lower front wall was more substantial than the upper back wall, as a consequence of the slope. That unlike the great majority of the Thule winter houses, its walls appeared not to have been reinforced with turf and gravel, is perhaps the result of erosion; the lack of a stone-built sleeping platform may relate the Oobloyah Bay structure to an early phase of Thule settlement. Thule winter houses without these features, on eastern Ellesmere Island, have been dated by the Radio Carbon method to the eleventh or twelfth century AD (Schledermann and McCullough 1980). The Oobloyah Bay structure is perhaps of similar age.

Fox traps seem to be a Thule rather than a Dorset phenomenon (McGhee 1978: 97) and the trapa discovered at the head of Essayoo Bay may therefore be proof of Thule occupation, presumably of site 12, which with its slab and stone-built houses is the only known settlement in that locality.

Unfortunately, fox traps, like tent rings, have not been the subject of detailed study and those found in Borup Fiord cannot therefore be assigned, on topological grounds, to a specific century. Stone-built caches, too, are often found near to Thule settlements (McGhee 1978: 95) and the presence of possible caches at the island settlement (Site 2) lends support to the suggestion that its low-walled tent rings and houses, were probably Thule constructions.

CONCLUSION

Our survey established that Borup Fiord had been occupied during the previous 1200 years. Of the structures found one was tentatively identified as late Dorset, being similar to structures of that culture, dated to the eighth or ninth centry AD, on eastern Ellesmere Island. Tent rings and houses at three sites were probably Thule. That only one possible Thule winter house was found would suggest that winters were either spent in snow houses on the sea ice or outside of the Fiord. The majority of the tent rings found could not be attributed to a specific culture, though their elevations above sea level indicate that they could be late Dorset, Thule or Inuit. Evidence of earlier occupation by Arctic Small Tool Tradition, Independence II and pre and early Dorset peoples may yet be found at higher elevations in the fiord, not examined in 1988.

SITE DESCRIPTIONS

OOBLOYAH BAY - WEST COAST

Site 1

Two walled shelters and a rectangular and a circular tent ring located on the point of a boulder strewn headland, on raised shingle beaches, 1-2m above the high water mark. A stream flowing into the cove on the north side of the headland was the nearest source of freshwater.

Shelter 1. Oval plan, single compartment, 2m by 2.5m. The enclosing wall, built with angular blocks and slabs, was 0.3m - 0.7m high and 0.5 - 1.4m wide.

Shelter 2 (fig 2a). On sloping ground to the south of Shelter 1, its walls stood 0.6m high. A passage, 0.7m wide, through the east and lower side-wall gave access to a chamber, 2.6m by 2m. A line of flagstones divided the chamber widthwise into two compartments, comprising shallow scrapes, not more than 0.10m deep; dug 1m by 1.3m, the lower compartment was the smaller of the two. A flat-topped stone, in the angle of the north and east wall, formed a shelf on which there lay a stone lamp and a flat circular disc; these were left in situ. The second and upper compartment, 1.7m by 2m, was probably for sleeping in. An opening through the compartments south wall, 0.5m wide, gave access to a third compartment, 1.55m by 0.88m.

Rectangular tent ring (fig 2b). Measuring c.7m by 2.50m, above and to the west of shelter 2, the walls comprised a single course of blocks and slabs laid in discontinuous lines. Open on the seaward side, the opposite narow-end wall was curved.

Tent ring. A circle of small stones, 1.5m diameter, on.a flat shingle surface above and to the west of the rectangular structure.

OOBLOYAH BAY - ISLAND

Site 2 (fig 3, pl I)

An irregular shaped island in Oobloyah Bay, c.900m by 300m, dominated by an east-west orientated ridge rising in a series of terraces to c.20m - 25m above the high water mark. Located at the western extremity of the ridge, the encampment comprised at least thirty-five tent rings, shelters and caches disposed in rows along south and south-west facing terraces. The structures depicted on figure 3 represent the minimum number present; vegetation obscured the remains of others which were not recorded.

The tent rings and shelters were variously oval and angular in plan with one to a maximum of four compartments. Two at least were enclosed by rings of intermittently placed stones. Others had more substantial walls, composed of one or more stone courses, varying in height from 0.3m to 0.9m. At least one of the structures found was sunken floored (fig 3:12); it comprised a declivity, c.7.5m by c.2.5m, bound by vegetation covered banks.

One structure waa roofed with stone slabs (fig 3:18): dome shaped and 0.9m high it had a maximum diameter of 2.5m; apparently without an entrance, it was perhaps a cache. Two partially collapsed structures, to the west of the latter (fig 3:15,17), had also been roofed with stone slabs.

Detailed 1.20 scale plans were made of three tent rings of which descriptions are given below.

Tent ring 2 (fig 4a). On the lower terrace, walls 0.4m high; two compartments arranged in a figure 8. The north-east compartment, 1.6m by 2.4m, was enclosed by walls that were more substantial than those of the adjoining compartment. The second compartment, 1.3m by 2m, had an opening 0.5m wide in its east side. A small triangular chamber, roofed with stones and measuring 0.5m by 0.3m, projecting from the latter compartment's south-west side it was perhaps a food store.

Tent ring 8 (fig 4b). Lying c.2m to the north of shelter 2 it comprised two compartments joined together in the form of a figure 8. The smaller of the two compartments was semicircular, measuring 1.7m by - 1.2m it was enclosed by walls 0.6m high; slabs protruding from the inner face of the west wall separated two alcoves. The second compartment was crescent shaped and measured 3m by 1.4m; its walls, less substantial than those of the smaller compartment, had been demolished. A chamber, possibly a food store, lay to the north-west of the latter. Roughly triangular in plan, 2.3m by 1.75m its stone roof had collapsed; an inward leaning triangular slab on its north-east side would have stood when upright, c.1m high.

Tent ring 20 (fig 5a). Located on a gently shelving shingle beach at the site's western extremity. Measuring 6m by 3, with a 1.6m wide entance on the north side, it comprised three compartments; one at the front next to the entrance and two at the rear. The outer compartment measured 2.2m by 2m and the two inner compartments 3m by 2m and 1 m by 0.95m, respectively. A pile of stones on the south-west side of the structure, c.2.8m by 1m and 0.6m high might have been a food store.

00BLOYAH BAY - NEIL PENINSULA

Site 3

Tent ring on a shingle beach, eroded by ice action, 0.4m from and 0.4m-0.5m above the high water mark. The ring comprised intermittently placed boulders arranged in a circle, 2.2m by 2m; the interior was overgrown with moss.

Site 4

Four tent rings on a raised and boulder free shingle beach, on the south-west side of a cove, 1-2m above the high water mark. Three of the rings were clustered together, c.15m from the high water mark and 16m from the fourth ring. The latter lay c.46m from the high water mark. A gulley c.60m to the south of the site was the nearest source of fresh water and also of the stones used in the construction of the rings.

Tent ring 1 (fig 6a). Four curved sides, 3m by 2m, with an entrance , 1.2m wide, on the north side, flanked by two relatively large slabs.

Tent ring 2 (fig 6b). TWO of its four sides were poorly defined; 3.2m by 2.2m.

Tent ring 3 (fig 6c). Rectangular, 3m by 1.8m, divided widthwise into two compartments, one 1.8m by 0.6m, the other 1.6m by 1.6m.

Tent ring 4 (fig 6d). Circular, 2m diameter, with a 1m by 1.2m extension on the north side.

A scatter of stones, to the north-east of tent ring 4, were perhaps the disturbed remains of a fifth tent ring.

Site 5 (pl II)

Tent ring on a boulder strewn shingle beach on the south-west side of a headland, c.1.5 and c.1.7m from the high water mark. Circular in plan, with a diameter of 3.5m, the floor comprised a level surface of compacted gravel.

Site 6

Possibly a meat cache, on a shingle beach c.13m from and 0.6-0.8m above the high water mark; comprising a ring of boulders, 1.2m diameter, the interior was overgrown with moss.

Site 7 (fig 5b)

Tent ring on the shingle beach of a cove, c.1m above and 11m from the high water mark. Fresh water might have been obtained from a stream c.20m to the south, though it was dry when the site waa discovered early in August 1988.

Oval in plan, 3m by 2.2m, an entrance on the north-west side, flanked by two relatively large stones, was 0.8m wide. A curved line of stones, 1.7m to the north-east of the ring, was perhaps the back wall of a second compartment.

Site 8

Two boulder rings, possibly meat caches, lying 100M apart on a level boulder strewn shingle beach, 0.5m - 0.75m above and respectively 13m and 31m from the high water mark.

The circle of boulders nearest to the high water mark had a diameter of c.2m and was infilled with boulders. The second feature was roughly circular with a diameter of c.1.8m.

Site 9

Tent ring and a possible cache on level boulder strewn shingle, c.1m - above and 15m-16m from the high water mark. Oval in plan the tent ring measured 2.3m by 2m; inside there waa a musk oxen skull. The possible cache lay 5m from the latter; oval in plan it measured 1.6m by 1.9m and comprised an inner and an outer ring of stones.

Site 10 (fig 7a)

Tent ring on a flat shingle beach at the most southerly point of the Nell Peninsula, c. 0.7m above and c.2m above the high water mark. Trapezoid in plan, 5.8m by 3.4m, it had an entrance on the east side.

NEIL PENINSULA - ESSAYOO BAY

Site 11

Two tent rings, 9m apart, on a level boulder-free shingle beach, 60m by 30m, on the west side of a rocky headland, c.1.5m above and c.27m from the high water mark.

Tent ring 1 (fig 7b). Cicular, 3m in diameter.

Tent ring 2 (fig 7c). Circular, 3m in diameter, with a semicircular extension, 1m by 1.6m, on the east side and an entrance 1m wide on the west side. Stones forward and either side of the entrance may represent a porch or an entrance pasaage.

ESSAYOO BAY

Site 12

Encampment on a rocky knoll, south-east of and in the angle between a lake and an outflowing stream, 40m-45m above and c.700m from the high water mark. Four walled shelters, two shelters of uncertain character, a tent ring and five possible food stores occupied the three highest points of the knoll.

Shelter 1 (fig 8a, pl III). Oval plan, 2.2m by 2.4m, the enclosing wall, c.1m high, was composed of angular slabs and boulders. A raised entrance, 0.3m wide, on the south-east side was protected by a ? windbreak, comprising three large boulders.

A concentration of slabs and boulders, 2m to the north of shelter 1, was perhaps the remains of a dismantled cache.

Shelter 2. Tumbled walls, partially overgrown with vegetation, suggested an oval plan shelter, c.3m by c.2.5m, built with boulders and flat angular slabs, stood on edge.

Shelters 3 and 4. Two concentration of vegetation covered slabs and stones, c.2m apart, with four convex sides each, were probably the tumbled walls and possibly the stone floors of two shelters; one measured 6m by 5.4m and the other, which seemed to comprise three compartments, 6m by 6m.

Shelter 5 (pl IV). Oval plan, 3m by 2.6m; partially collapsed walls, originally c.1m high, comprised flat angular slabs, stood on edge, and angular blocks. A rectangular extension, 1m by 0.8m, on the shelter's north side was perhaps an entrance passage.

Shelter b (pl V). Subrectangular, 2.8m by 2.2m, lying 1.5m to the north of shelter 5. Three of its four walls had collapsed; they comprised two courses of angular blocks originally 0.8m high. The one surviving wall consisted of a flat slab, stood on edge.

Tent ring 7 (fig 8b). A four-aided structure, 3.6m by 4m; one side comprised a tumbled wall, originally 0.9m high; boulders and stones marked the corners of the other three sides.

Structure 8. Possibly a food store, 3.5m to the south-east of tent ring 7, measuring 1.2m by 0.8m, with walls 0.4m high capped with a large flat slab. An opening on the north-east side was 0.5m wide.

Structures 9,10, 11 (pl VI). Three possible food stores built against near vertical rock faces on the periphery of the knoll. Side walls comprised flat stone slabs stood upright and capped with slabs laid crosswise. Two of these structures were located south of and below shelter 2. One measured 0.6m by 0.7m and was 0.35m deep; the other of similar depth measured 0.7m by 0.3m. The third structure, east of and below tent ring 7, was 0.9m by 0.8m and 0.55m deep.

Sites 13-17

Sites 13-17 were located on a range of hills, rising to 600m, to the north-east of site 12.

Site 13. Two fox traps on a rocky spur. Remains of what might have been a third trap or cache lay inside a circle of stones; possibly a tent ring.

Site 14. TWO fox traps, a cairn or route marker, and two piles of stones that were perhaps intended for the construction of fox traps.

Site 15. One fox trap.

Site 16. TWO possible fox traps or caches.

Site 17. Two fox traps.

MIDNIGHT SUN VALLEY

Site 18. One fox trap.

OOBLOYAH BAY - INLAND

Site 19 (fig 8c)

Tent ring on a flat clay lias terrace, on the north side of a valley, 3-4m above and c.45m from a river. Stones used for the construction of the ring were probably obtained from the river bed. Oval in plan, 2.4m by 2.6m, it comprised two compartments, one 1.3m by 0.7m, the other 1.1m by 2.6m. The entrance 0.6m wide, on the south-west side of the ring was flanked by two large stones.

ESSAYOO BAY - ELMERSON PENINSULA

Site 20 (fig 9a)

Possibly a tent ring; on the lower terrace of a delta fan, c.30m to the south of a stream and c.11m from the shore. Stones may represent the disturbed side-walls of a tent ring with two compartments. Overall dimensions are c.2.6m by 1.8m.

Site 21

Possibly a tent ring, on boulder covered ground on the east side of a delta fan, 6m-8m above and c.100m from the sea, c.25m to the east of a stream. It comprised a trapezoid pattern of boulders, c.2.5m by 2m, with a stone enclosed alcove in the south-east corner.

Site 22 (fig 9b)

Tent ring on west side of a delta fan on relatively boulder free ground. Measuring 4.4m by 3.2m it comprised two compartments, one 3m by 1.4m and the other 2.6m by 2.4m, joined together in the form of a figure 8. An opening on the north-east side of the structure was perhaps an entrance.

Site 23 (fig 9c)

Tent ring on a raised shingle beach on the west side of a headland, 1m-1.5m above and c.30m from the high water mark. Overall it measured 4.5m by 2.5m and comprised two compartments of which the largest was circular; with a diameter of 2.5m it had a level floor of fine gravel that contrasted with the coarse shingle of the beach. The second compartment, 2m by 1.5m, was partially enclosed with stones; its floor comprised a thin spread of fine gravel.

Site 24

Tent ring on a boulder strewn slope, overlooking a cove, 1m-1.5m above and 18m from the high water mark. Comprising two subrectangular compartments, one c.1.5m by c.1m and the other c.0.5m by 1.2m, the enclosing stones abutted and overlapped one another.

Site 25

Tent ring on west side of a delta fan, c.0.5m-0.6m above and c.100m from the high water mark. Oval in plan, it measured 2.4m by lm; an entrance on the north (seaward) side was 0.8m wide.

Site 26

Tent ring on sand and fine gravel, overgrown with dryas and moss, and possibly a raised beach, c.1m above and c.60m from the high water mark. There was a stream c.70m to the east. Trapezoid in plan the tent ring had convex sides with a stone-enclosed alcove on the north seaward side.

Site 27 (fig 9d)

Tent ring on moss and dryas covered shingle on the east side of a cove, c.0.5m above and 7m from the high water mark. It comprised a semi-circle of stones, 2m in diameter. A stone filled declivity, 0.9m by 0.7m, on the east side of the ring was perhaps a cache or larder.

ELMERSON PENINSULA - west **coast**

Site 28

Tent ring on a dryas covered terrace on the south-west side of a delta fan, c.2m above and c.40m from the high water mark. A stream c.25m to the north was the nearest source of fresh water.

Comprising two circular compartments, joined together in the form of a figure 8, the enclosing rings were 2-3 stones wide. One compartment measured 2.3m by 1.7m and the other 2.4m by 1.4m. A small stone-enclosed declivity, next to the entrance and projecting from the west side of the larger of the two compartments, contained a musk oxen skull.

Site 29

Tent ring on dryas and willow covered shingle in a cove, c.0.6m above and c.25m from the high water mark. One-half of this structure was roughly circular while the other was trapezoid.

Site 30

Tent ring on the dryas covered terrace of a delta fan, c.1.5m-2m above the high water mark. Sub-rectangular and sunken floored, measuring c.2m by 2.5m, it lay behind a gravel bank. A triangular alcove projecting from its south-west side was possibly a larder.

Site 31

Tent ring on dryas covered shingle on the north side of a cove, c.2m above and c.35m from the high water mark, c.150m to the south of the site 30. Oval in plan the ring measured 3.5m by 4.3m; the entrance was on its south-west side. A small circular alcove, 0.5m wide, on the west side of the entrance was possibly a larder.

CAPE BRAINARD

Site 32 (fig 10)

Three tent rings in extended line on the second of a series of raised shingle beaches, 1-1.5m above and c.20m from the high water mark. Detailed plans were made of two of the tent rings. The unplanned ring which lay at the centre of the group was similar to tent ring 1, described below.

Tent ring 1 (fig 10a). Oval in plan, 4m by 3m, divided diagonally by a line of small flat stones into two compartments: one 2m by 3.4m and the other 1.6m by 3.4m.

Tent ring 3 (fig 10b). Measuring 4m by 3.4m it had four convex sides and was broader at the rear than it was at the front. A curved line of small flat stones divided the interior into a large crescent-shaped inner compartment and a small outer compartment to which an entrance on the south-east side gave direct access.

CAPE BRAINARD - Greely Fiord

Site 33

A subrectangular tent ring on the second of a series of raised shingle beaches , c.30m from the high water mark.

Site 34 (fig ha)

Tent ring, c.900m to the east of site 33, on the third of the raised shingle beaches. Overall dimensions were 5m by 5m; the southern half contained an enclosed space, 1.2m by 0.8m.

Site 35 (fig 11b)

Two tent rings, lying 30m apart, on the third raised shingle beach, c.210m to the east of the site 34. One ring only was recorded in detail. Subrectangular, with a semi-sunken floor c.0.05m deep, it measured 3.2m by 2.6m. A triangular alcove, 2m by 1.6m, projected from the south east corner and a subrectangular alcove, 1m by 0.8m, from the north-west corner. An opening, 0.9m wide, in the east wall was probably an entrance.

Site 36

Tent rings disposed in two groups, one of three and the other of seven, c.18m apart, on the third raised shingle beach, 1m-2m above and c.35m from the high water mark. Ice action had severely eroded the shoreline; ice surgea had gouged the beaches up to 50m inland. Shallow ponds had formed in the hollows between the beaches.

The tent rings were variously oval and angular in plan with either one or two compartments. One ring waa recorded in detail (fig 11c). Rectangular and measuring 2.4m by 3.4m it had a sunken floor, not more than 0.1m deep. A shallow declivity in the south-west corner was 1.4m by 1m.

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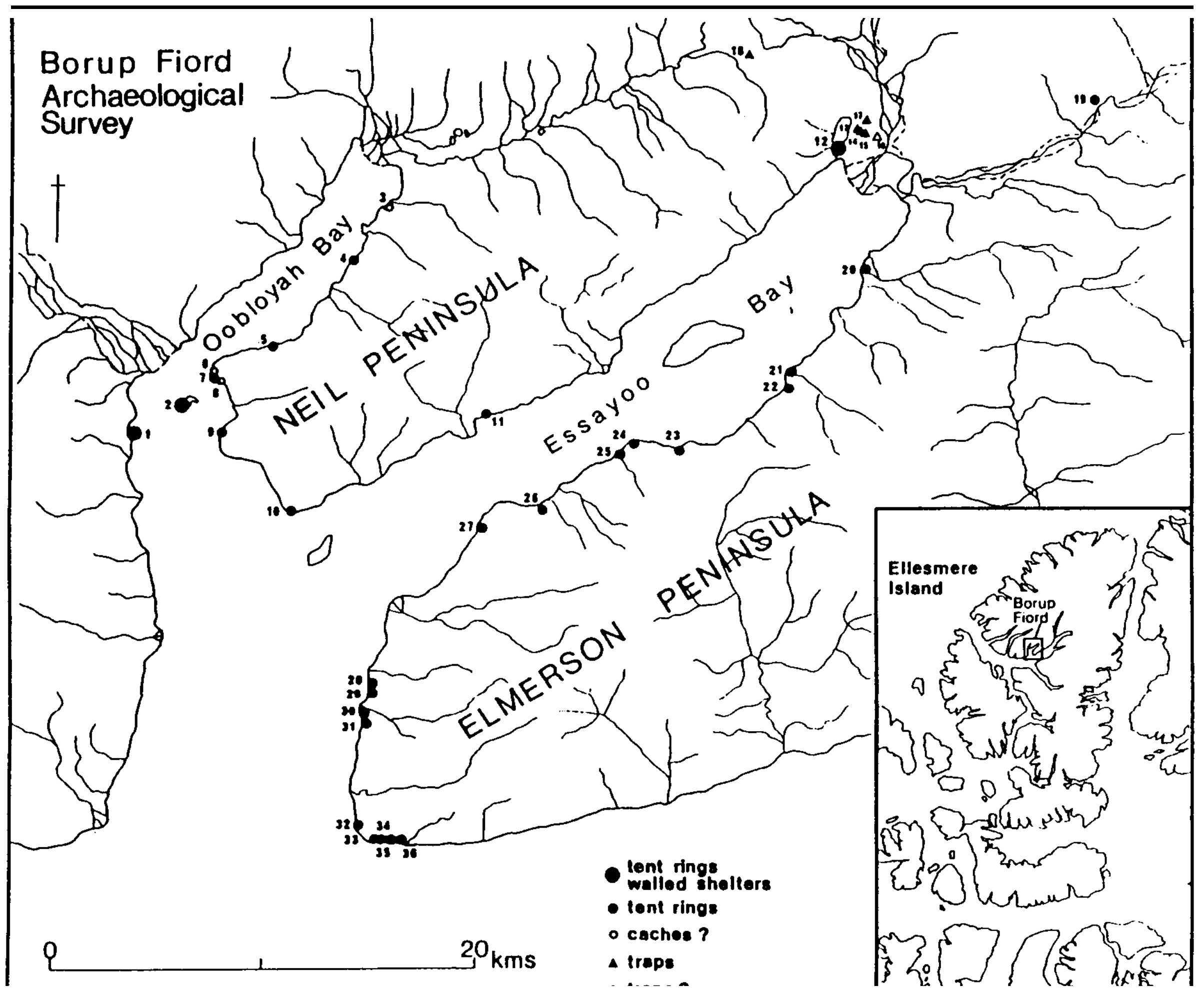
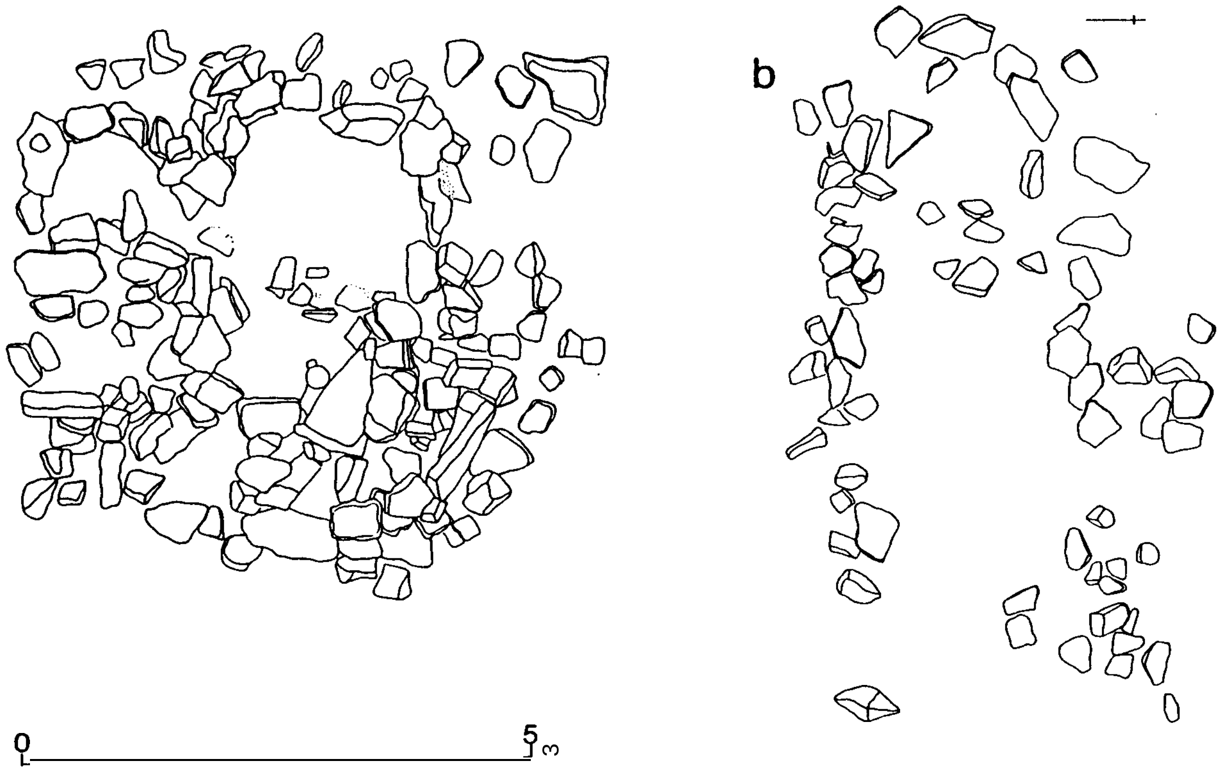


1. Archaeological Sites in Borup Fiord

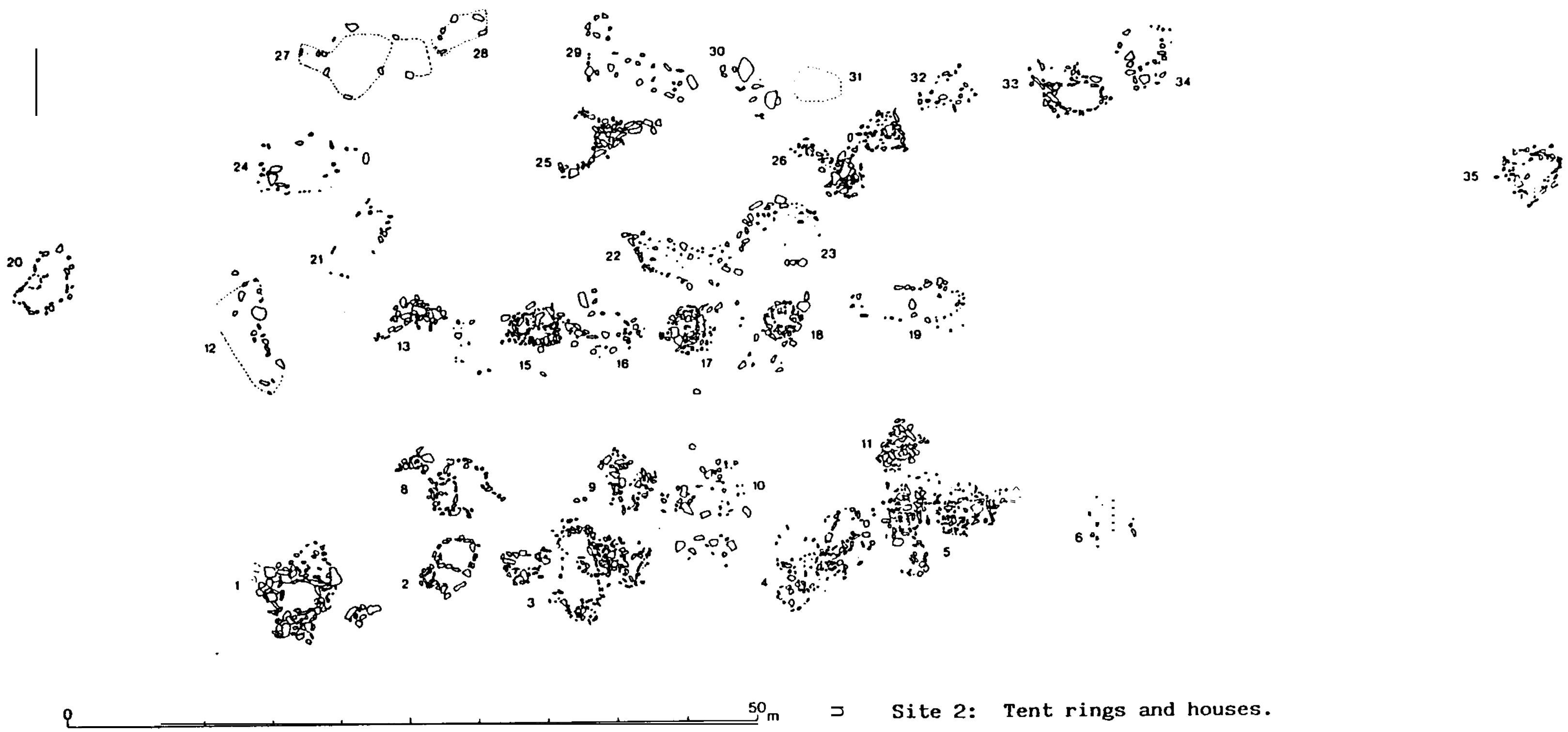
a

b

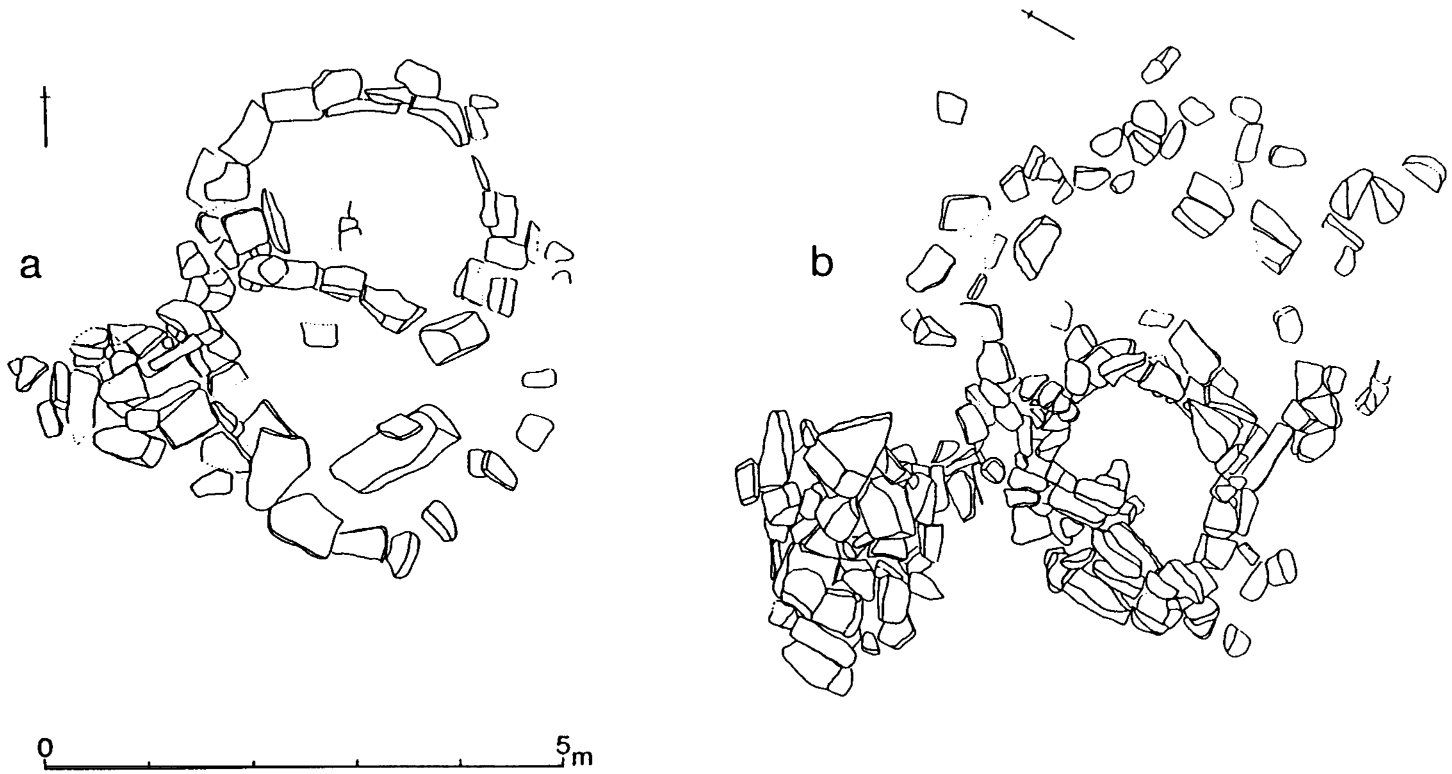


a Site 1: Thule winter house

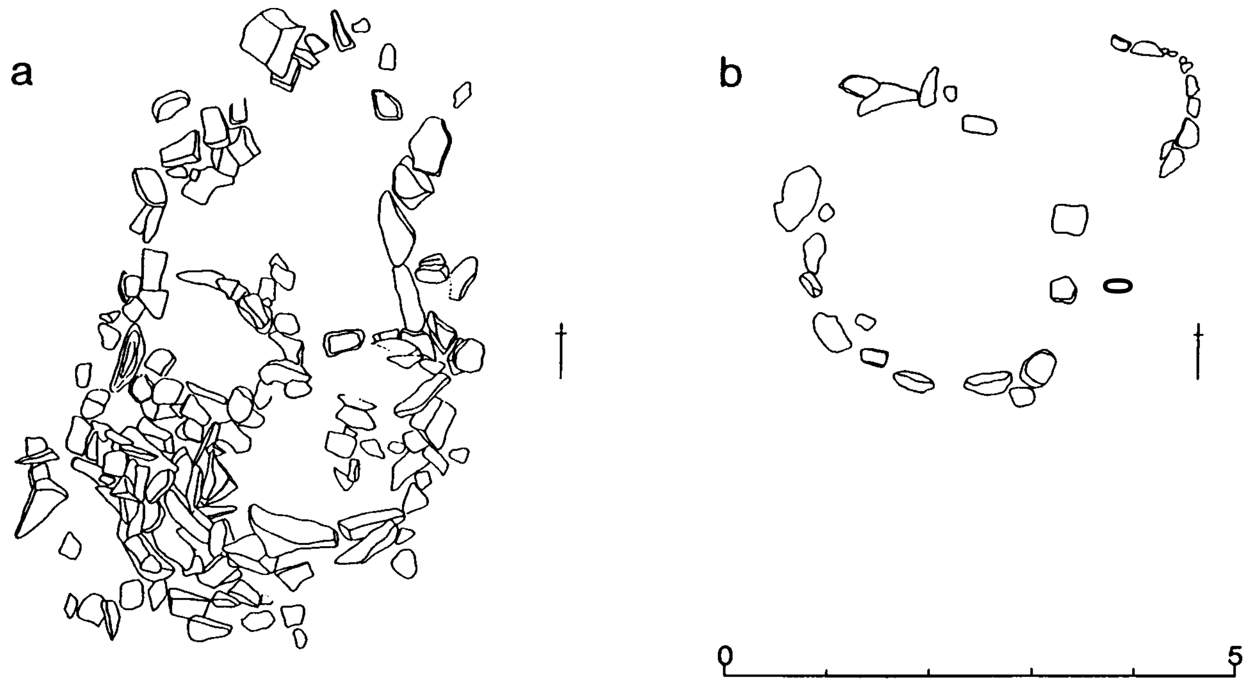
b Late Dorset tent ring.



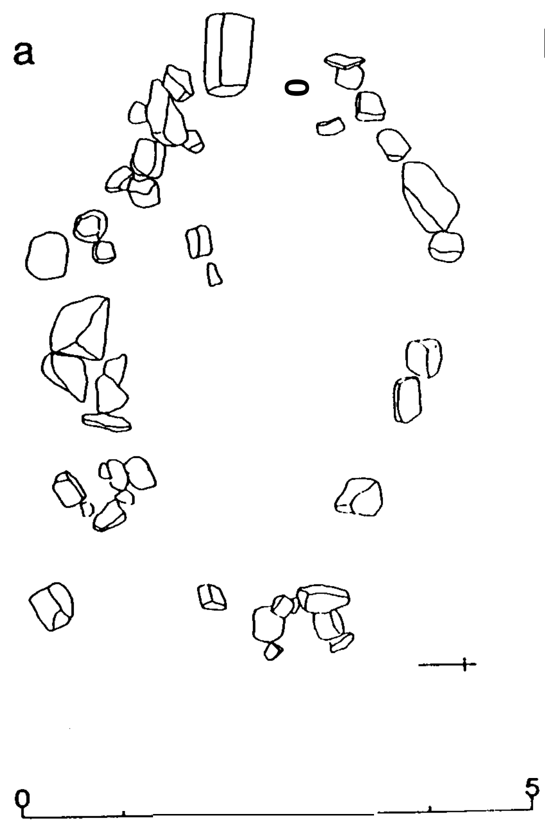
⊐ Site 2: Tent rings and houses.



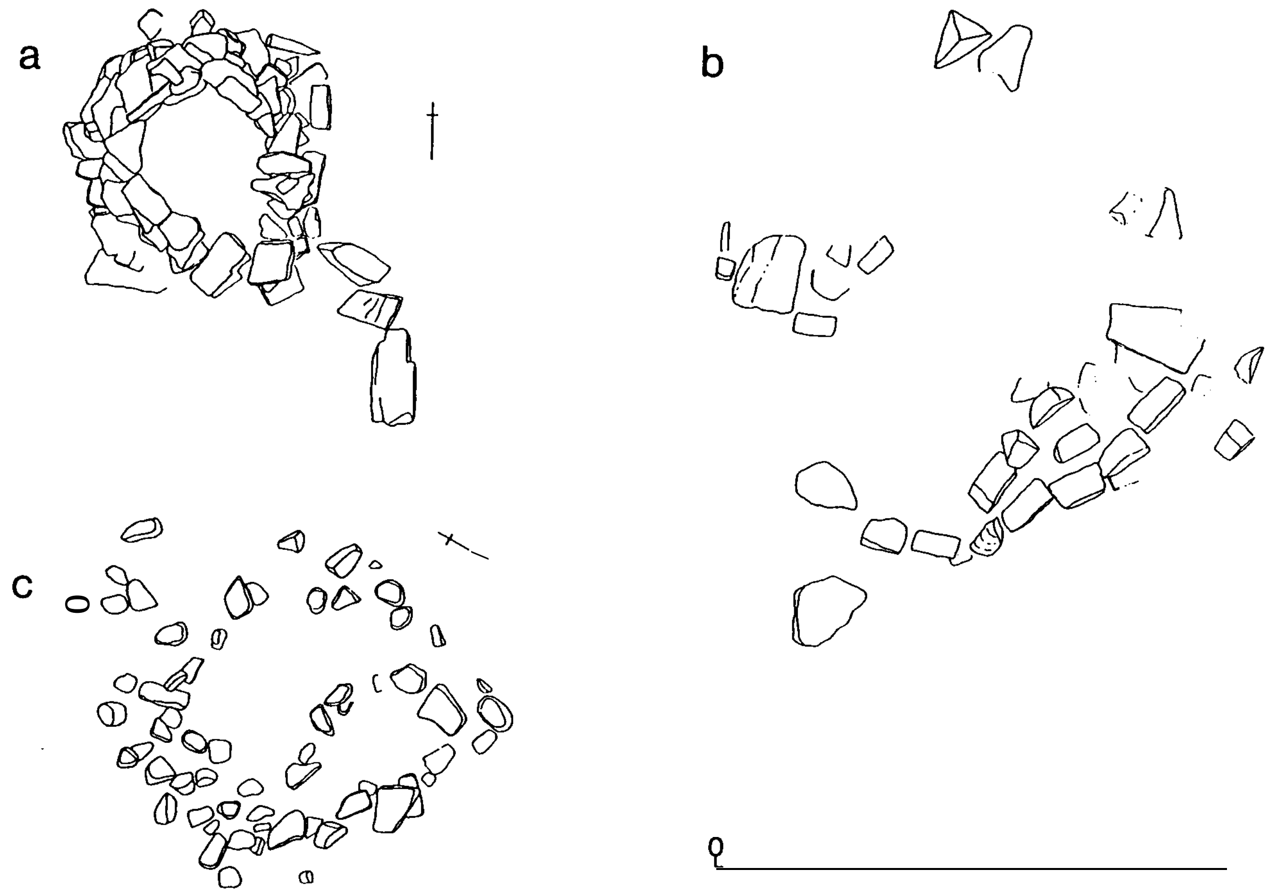
4. Site [illegible] a: Tent ring 2. b Tent ring 8.



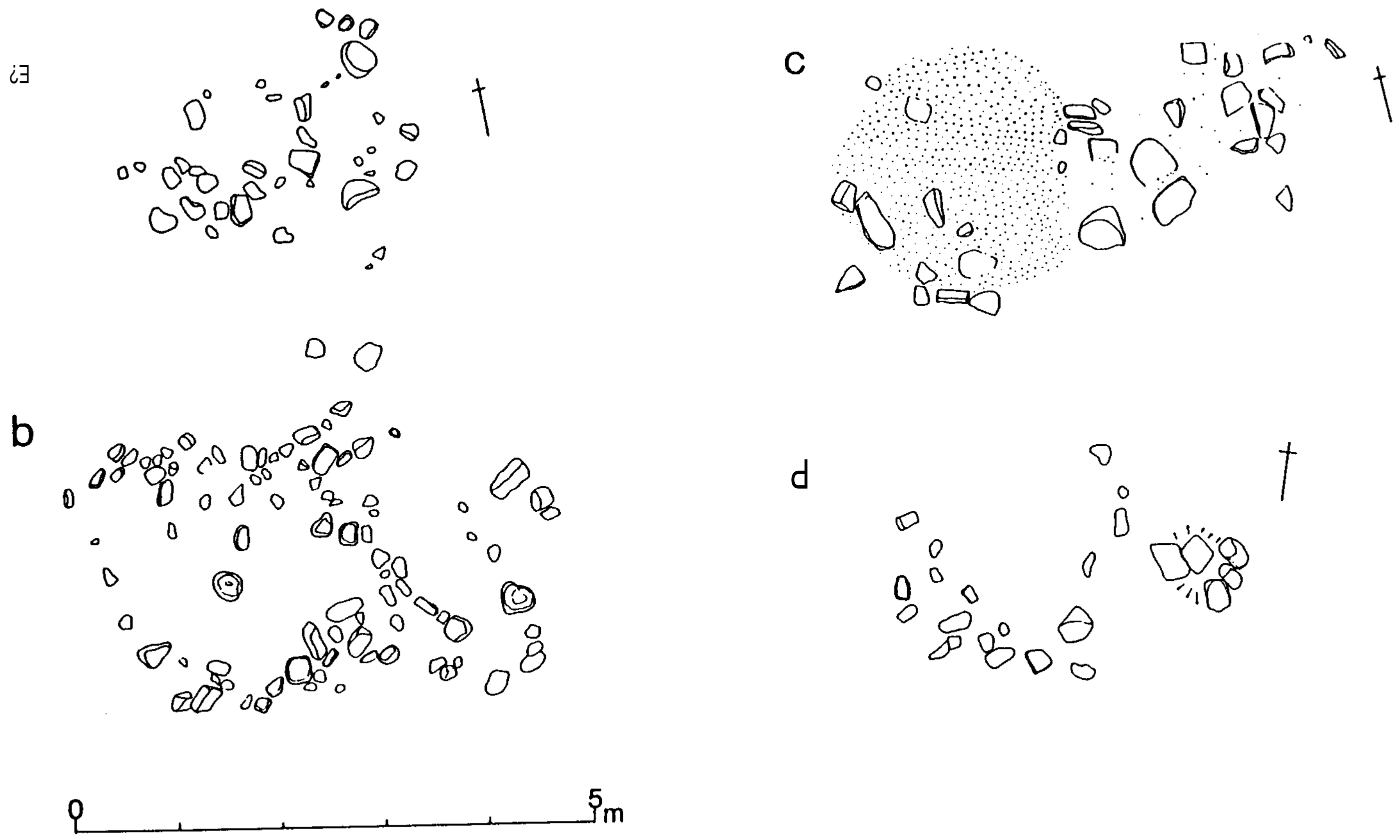
5 . a. Site 2 tent ring 20.
b. Site 7 tent ring.



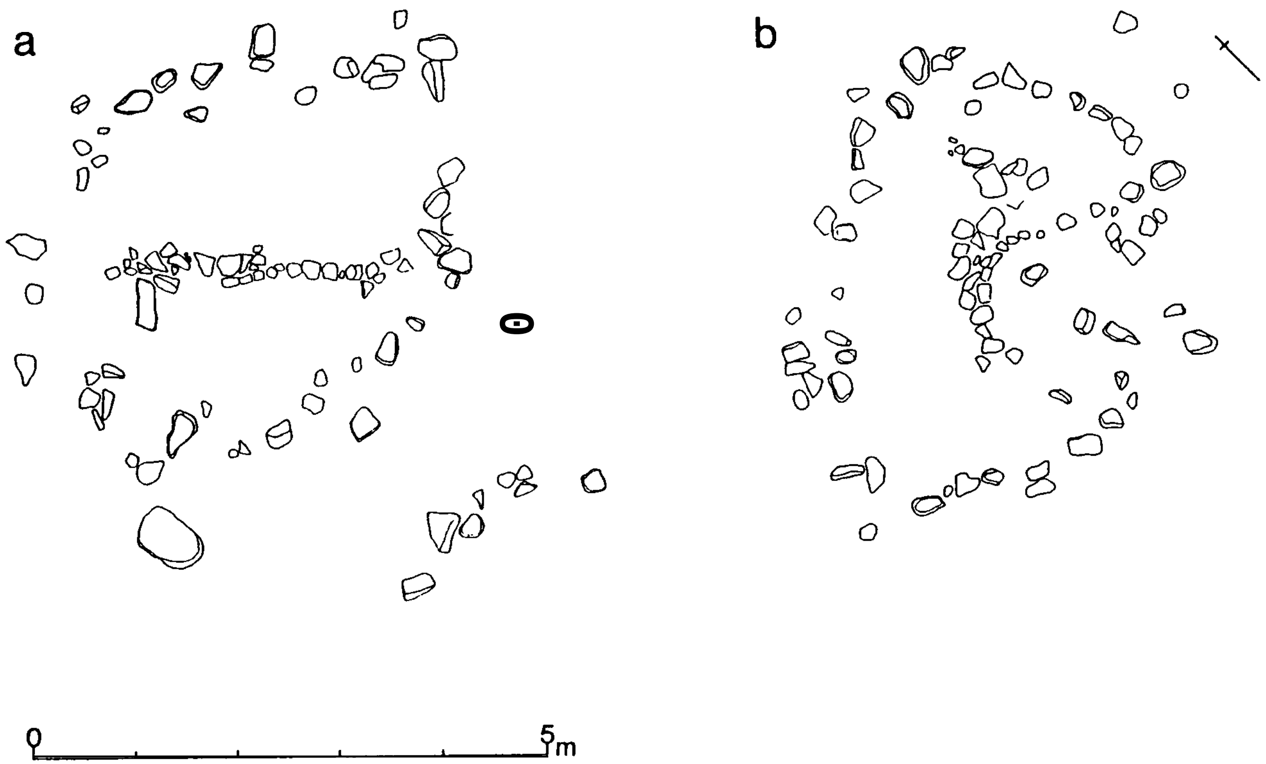
7. a. Site 10: Tent ring. Site 11: b. Tent ring 1.
c. Tent ring 2.



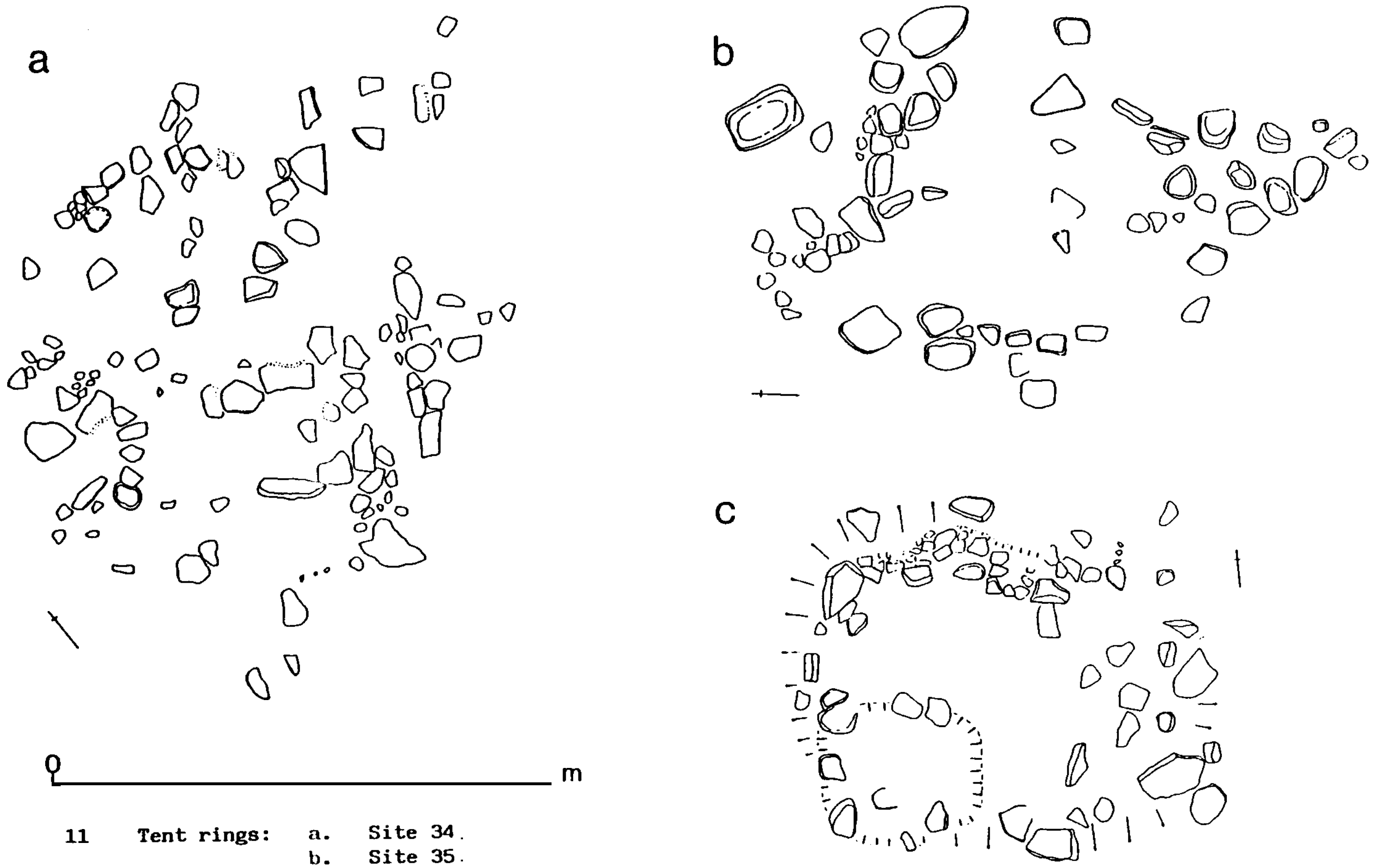
8. Site 12: a. House 1.
b. Tent ring.
c. Site 19: Tent ring



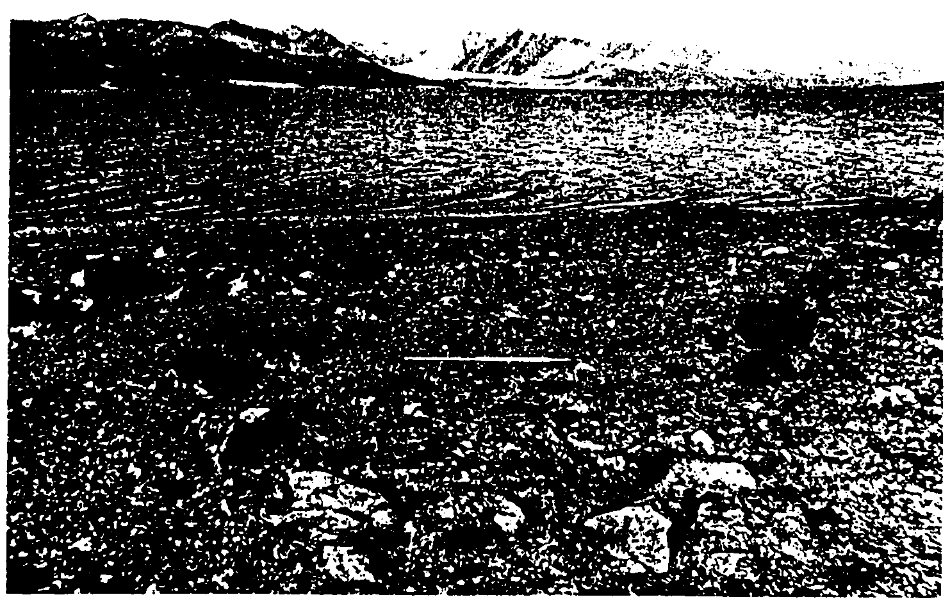
9. Tent rings: a. Site 20.
b. Site 22.
c. Site 23.
d. Site 27.

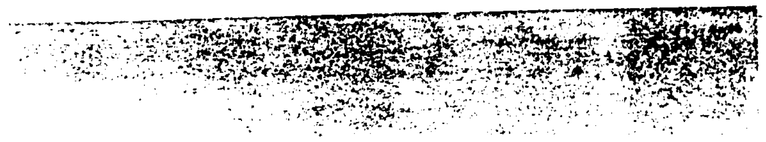


10. Site 32: a Tent ring 1 b Tent ring 3.



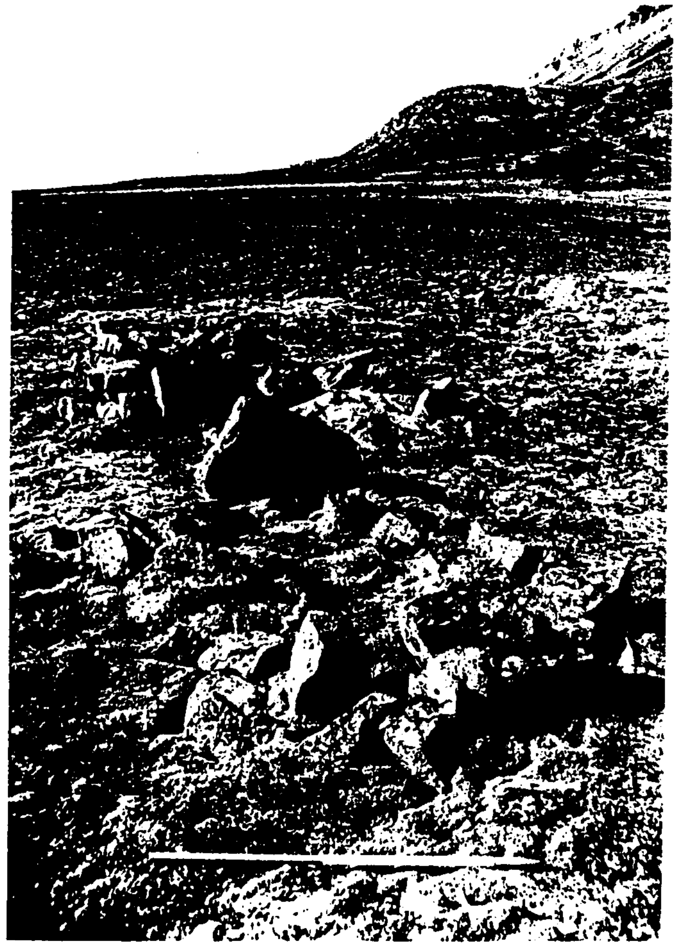
11 Tent rings: a. Site 34.
b. Site 35.
c. Site 36.





III . Essayoo Bay, site 12: autumn or winter house 1.

IV - Essayoo Bay, site 12: autumn or winter house 5.



V. Site 12: tumbled walls of house 6

VI. Site 12: slab-built meat store

STRATIGRAPHY OF THE BORUP FIORD AND BLUE MOUNTAINS AREA

ELLESMERE ISLAND

S Young

ABSTRACT

A brief resume is provided of the geological history and stratigraphy established by previous workers for the Sverdrup Basin All strata examined in the expedition area are described, along with sections from 6 previously undocumented sites and details of fossil finds. Field specimens returned to the UK are now retained by the Cambridge Arctic Shelf Program me.

PAST WORK

1. The stratigraphy within the Sverdrup Basin of Arctic Canada was established during the late 50s and early 60s by a number of workers, largely as a result of fieldwork undertaken throughout the Queen Elizabeth Islands during Operation Franklin. The work of Tozer and Thorsteinsson was used to produce, in 1969, a geological map including the expedition area and covering the western part of Greely Fiord on a scale of 1:250 000 (Geological *Survey* of Canada Map 1311A) . Within the expedition area, compilation of the map involved aerial survey and the use of aerial photographs to interpolate between sections measured in the Blue Mountains and Krieger Mountains, near Hare Fiord and Mount Leith, and on the Elmerson Peninsula.

2. More recently, work throughout the Queen Elizabeth Islands, including oil exploration wells, has further refined the stratigraphy, particularly of the Mesozoic sediments (largely after Embry 1982-86). In the expedition area, the Blue Mountains and Krieger Mountains were revisited by Moore (1981) and an exploration well has been sunk on the Neil Peninsula at the head of Ooblayah Bay (Neil 0-15).

PRESENT WORK

3. <u>Aim</u>. The aim of the geology project was to collect field data and sedimentary samples from the expedition area on behalf of the Cambridge Arctic Shelf Programme (CASP).

4. <u>Method</u>. Wherever possible, geological samples were collected from measured sections, though these were often discontinuous and difficult to work due to many horizons being obscured by scree, vegetation or snow. For position information, the fieldwork depended upon the use of 1:60 000 vertical air photographs; the largest scale mapping available for the expedition area is 1:250 000, with a contour interval of 500 ft (Series A501, Map 340B, 'Elmerson Peninsula').

5. <u>Locations</u>. The areas chosen for detailed study were determined, in part, by logistic considerations, since all travel in the expedition area was by ski (early season), boat (late season only) or on foot. Nevertheless, the following localities allowed examination of most of the available rock types:

   a. <u>'Ptarmigan Ridge' (80° 54′ N 81° 34′ W)</u>. Two sections (A and B) were measured, to the north of the large glacier between Mount Leith and Mount Burrill, during the period 1-4 June.

b. Mount Burrill (80° 56′ N 81° 30′ W). Two sections (C and D) were measured, to the north-west of Mount Burrill, during the period 10-12 June.

c. Mount Leith (80° 52′ N 81° 40′ W). Section E was measured, at the tip of the northern glacier from the Mount Leith icefield, during the period 13-14 June. The western slopes of Mount Leith were briefly examined on 11 August.

d. Elmerson Peninsula (80° 46′ N 81° 50′ W). The foothills along the Elmerson Peninsula east of Jean Island were examined, during the period 29 June to 2 July, and section F measured.

e. Blue Mountains (80° 45′ N 84° 50′ W to 80° 37′ N 85° 32′ W). The foothills of the Blue Mountains and Blackwelder Mountains were examined during the period 17-29 July. No sections were measured as there has already been some geological work in this area.

f. 'Mount Shackleton' (81° 03′ N 81° 00′ W). A small nunatak to the west of the 5300 ft spotheight (given the unofficial name Mount Shackleton) was visited on 7 August.

Figure 1

Steeply dipping Heiberg Formation, exposed between dolerite sills. Beds 11-20 Section B

GEOLOGICAL SETTING

6. The sedimentary rocks of the expedition area were deposited near the north-eastern rim of the Sverdrup Basin - a site of deep subsidence and thick sedimentation from Middle Carboniferous to late Cretaceus time - which extended across most of the area now occupied by the Queen Elizabeth Islands. The Sverdrup Basin is superimposed on sediments of lower Paleozoic age, which were deposited within an earlier basin (the Franklinian geosyncline) and then deformed by the Ellesmerian orogeny of Devonian age.

7. up to 13000 m of predominantly marine sediments were able to accumulate in the axial region of the Sverdrup Basin, though they thin considerably toward the basin margins and undergo progressive facies changes. As the basin evolved, there was considerable variation amongst the sediments which accumulated within it. After early, shallow-water carbonate and evaporite deposits, later sediments are dominated by land-derived detritus and indicate a cratonic source area to the south-east, with a more minor contribution from an area to the north-west of the basin. On at least 3 occasions the rate of deritus supply was sufficiently great to choke the basin, leading to the establishment of non-marine conditions. Dolerite sills, dykes and basalt lavas which occur within the sedimentary succession have been dated by Balkwill (1978) as 190 to 85 Ma, indicating that the Sverdrup Basin was also subject to igneous activity whilst it was an active depocentre. A detailed description of the igneous rocks exposed in the expedition area is given in this publication by R Dow.

8. The role of the Sverdrup Basin as an active depocentre was ended by the Eurekan reformational phase; this affected the area from late Cretaceus to Miocene time and was characterised by episodic uplift, erosion and syntectonic deposition, along with folding and faulting. The depositional and tectonic history of the Sverdrup Basin is summarized in Figure 2.

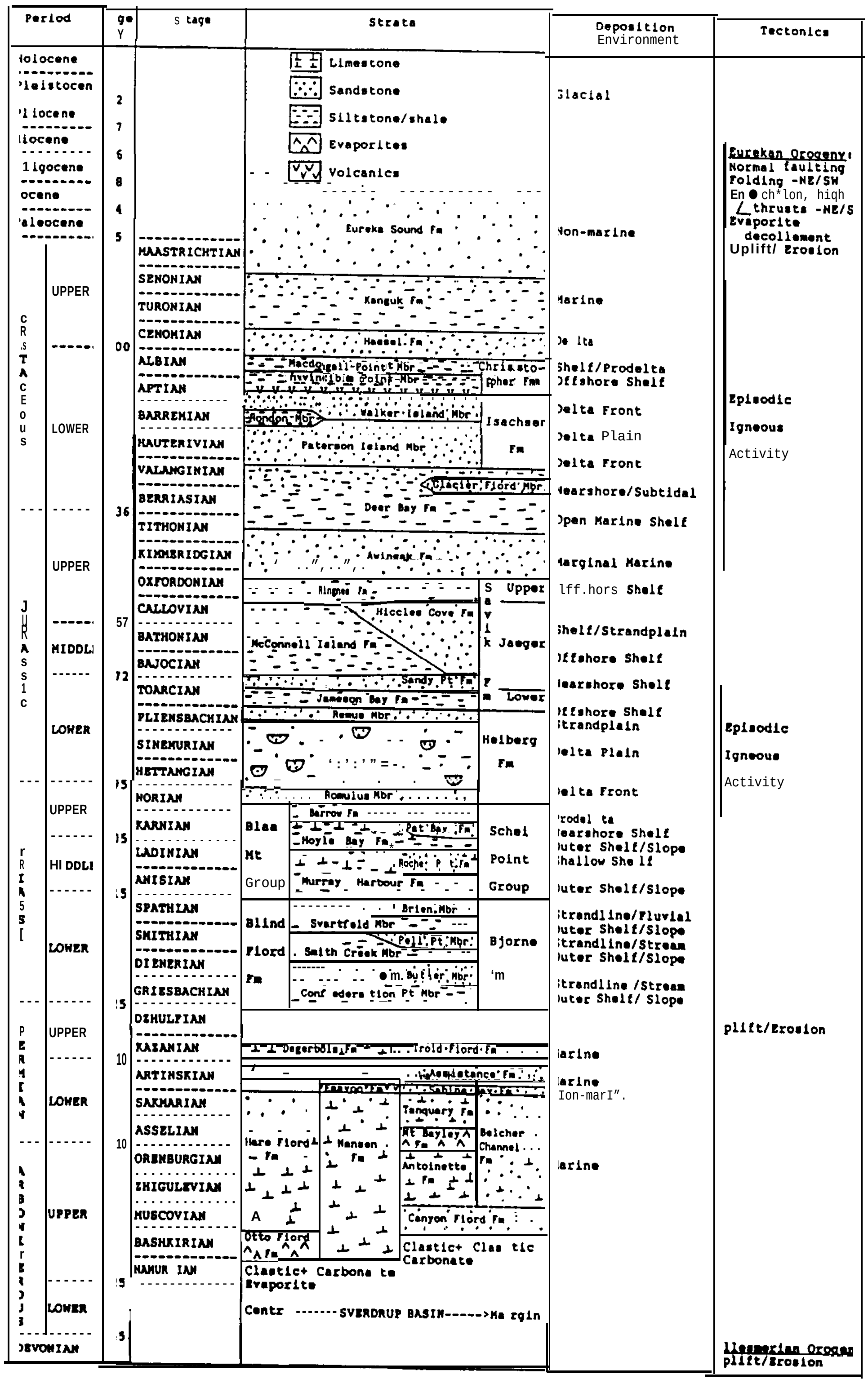
STRATIGRAPHY

9. The sedimentary rocks of the expedition area are divided into the units named in Figure 2, which is based upon the work of Thorsteinsson (1974), Balkwill (1978) and Embry (1982-86). Brief notes on the units examined during the expedition are given in the succeeding paragraphs; fossil finds, based upon provisional identifications, are given in Figure 6. The sections measured during the expedition are recorded as Annexes to this paper.

10. Nansen Formation. The expedition base camp lay within the south-east carbonate belt as defined by Thorsteinsson (1974). The formation was examined on the western slopes of Mount Leith, where debris from this horizon forms much of the extensive scree. Fallen blocks are mainly of a hard, thickly-bedded, greyish-yellow limestone and often contain well-preserved corals.

11. Esayoo Formation. Mount Leith is the type section for the Esayoo Formation and samples were obtained from the western scree slopes. The formation also outcrops nearby on 'Mount Rabbit', though this

Figure 2 Stratigraphic column for the expedition area



exposure is not shown on GSC map 1311A. The formation is an amygdaloidal basaltic lava which has areas of copper veining.

12. Degerböls Formation. The Degerböls Formation was seen on the south-west flanks of Mount Schuchert in the Blue Mountains (80′ 49′ N 84° 50′ W), where it consists of yellow-weathering, cherty limestone containing numerous brachiopods (often very large in size) and crinoid fragments.

13. Trold Fiord Formation. The Trold Fiord Formation is the near-shore equivalent of the basinal Degerböls Formation: the line of facies change is shown on map 1311A as occurring in the Krieger Mountains. Specimens of *Productus sp* indicate that the upper beds of the formation occur at the base of section D, near Mount Burrill, though it was not possible to identify a definite boundary here with the overlying Blind Fiord Formation. The Trold Fiord Formation was also examined at Mount Leith and close to 'Mount Shackleton'. Other than for the absence of crinoids, the fossil assemblage is similar to that found in the Degerböls Formation.

Figure 3 Fallen block of sandstone from the Heiberg Formation, Blue Mountains. The ripple marks indicate a variable current direction during deposition.

14. Blind Fiord and Bjorne Formations. The line of facies change between the basinal, siltstone/shale-rich Blind Fiord Formation and the near-shore, sandstone-rich Bjorne Formation is assumed on map

1311A to lie beneath the Ooblayah Bay syncline. Both formations have recently been subdivided by Embry (1986), though it was not possible on the present survey to recognize individual members with certainty. The Blind Fiord Formation was examined near Mount Burrill, in sections C and D, whilst the top of the Bjorne Formation (Cape O'Brien Member) occurred near Mount Leith, at the base of section E.

15. Blaa Mountain Group. The Blaa Mountain Group, consisting of dark shale with interbeds of calcareous siltstone , was divided by Tozer (1963) into lower shale, lower calcareous siltstone, middle shale, upper calcareous siltstone and upper shale units. During the expedition, these units were examined *in* the Blue *Mountains* at a site described by Moore (1981-section 1), who recorded a total thickness of 1530 m for the group; fossils were found in the upper calcareous siltstone (including *Gryphaea sp*) and from calcareous siltstone beds within the middle shale. Recent work by Embry (1984) has led to the recognition of 3 formations within the Blaa Mountain Group: the Murray Harbour Formation (equivalent to the lower shale plus lower calcareous siltstone) , Hoyle Bay Formation (equivalent to the middle shale plus upper calcareous siltstone) and Barrow Formation (equivalent to the upper shale) .

16. Schei Point Group. The Schei Point Group is the near-shore equivalent of the basinal Blaa Mountain Group; map 1311A shows the line of facies change as being in the Krieger Mountains. Embry (1984) shows that the 3 shale/siltstone formations from the Blaa Mountain Group extend across to the Schei Point Group but are separated by 2 sandstone-dominant formations named the Roche Point and Pat Bay Formations; the Pat Bay Formation is equivalent to the Gryphaea Bed recognized by Tozer (1963). The Schei Point Group was examined at 'Ptarmigan Ridge' and Mount Leith (sections A and E respectively) , on opposite *limbs* of the Ooblayah Bay syncline. Both sections give a thickness for the group of about 190 m only, indicating a rapid easterly thinning from the Blue Mountain section through the equivalent Blaa Mountain Group. The Pat Bay Formation (approxiamately 45 m thick) is prominent in both sections, yielding a rich fauna of brachiopods and *Gryphaea sp*; in section E it contains a thin bed of red shale and green-weathered breccia which Moore (1981) recorded in the Blaa Mountain Group of the Krieger Mountains, at a similar stratigraphic level and over a distance of at least 18 Km.

17. Heiberg Formation. The Heiberg Formation, consisting of inter-bedded sandstone, siltstone and shale of deltaic or strandplain origin, has been divided into 3 members by Embry (1983). The lower members were examined to the north of the glacier between Mount Leith and Mount Burrill (section B) and showed a wide range of features such as ripples, *convoluted* bedding, mud flakes, channel fills, cross-bedding, conglomerates, rootlets and plant debris. The formation was also seen in the Blue Mountains where the highest 60 m consists of poorly-bedded sandstone with distinctive bands of large ironstone concretions which contain ammonites of Upper Pliesbachian (Domerian) age; this lithology has been mapped by some workers as the Borden Island Formation, but is included by Embry within the Remus Member of the Heiberg Formation.

18. <u>Savik Formation</u>. In the expedition area, the strata between the Heiberg and Awingak Formations are most easily sub-divided using-the system of Tozer (1963) , who recognized upper and lower shale members separated by a sandstone unit called the Jaeger. At the locations visited during the expedition, the shale members are very poorly exposed, whereas the Jaeger forms a Prominent marker horizon of mottled, iron-rich sandstone containing belemnites. In the Blue Mountains, the Jaeger is only 2 m thick and, other than belemnites and occasional bivalves, contains few fossils; on the Elmerson Peninsula (section F), however, it is about 40 m thick and ammonites found in fallen scree indicate a Lower Toarcian age. Moore (1981) gives a total thickness for the formation in the Blue Mountains of 180 m; it would appear to be slightly thinner on the Elmerson Peninsula (140 m).

19. <u>Awingak Formation</u>. The Awingak Formation consists mainly of cross-bedded, often massive, quartzose sandstone along with intervening sandy shale and siltstone. The formation was examined both in the Blue Mountains and on the Elmerson Peninsula (section F) ; it is easily identified at both localities by the occurrence of large 'pillow' concretions, up to 15 m in diameter, within some of the sandstone beds. The highest beds seen at section F yielded large bivalves (*Camptonectes sp)* along with fairly well-articulated plant debris, indicating deposition in a low-energy , marginal marine environment. Moore (1981) recorded a thickness between 130 m and 260 m for the formation in the Blue Mountains. The lower 230 m only was visible at section F.

Figure 4 Awingak Formation seen on the Elmerson Peninsula at Section F. Note the large 'pillow' concretions typical of this formation.

20. Deer Bay Formation. The Deer Bay Formation was examined only in the Blue Mountains where it consists of dark shale containing small, scattered spherical concretions. Other than very small bivalves, fossils are sparse. Moore (1981) recorded a thickness of 400 m for the formation.

21. Isachsen Formation. The Isachsen Formation, of deltaic origin, was viewed in the Blue Mountains and consists of fine to very coarse-grained, white, pebbly, quartzose sandstone with minor shale and siltstone. The formation contained some thin coal lenses and wood debris but no other fossil material, and according to Moore (1981) is about 2200 m thick here. A basalt laval flow (around 25 m thick) separates the Isachsen Formation from the overlying Christopher Formation.

22. Christopher Formation. The Christopher Formation consists of soft dark shale and is but poorly exposed amongst the north-western foothills of the Blackwelder Mountains. Isolated outcrops yielded plentiful, but in the main poorly-preserved, bivalves and occasional ammonites (of Middle Albian age) . The formation contains a variety of concretions, ranging from small, polished, black, angular nodules near the base to large, and sometimes septarian, sideritic concretions at higher levels.

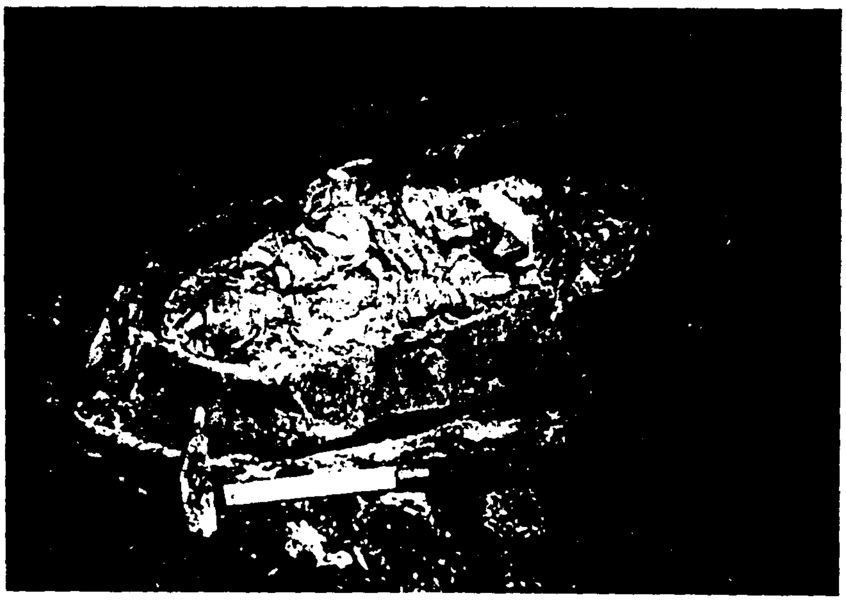


Figure 5 Sideritic concretion with septarian interior, Christopher Formation, Blackwelder Mountains.

Christopher Formation BM		
Beudanticeras Sp. ?	*Inoceramus* sp.	*Nucula pectinata*
Gyrodes cf. genti	*Neohibolites* sp.	
Deer Bay Formation BM		
Cerithium sp.	*Inoceramus* sp.	*Terebratula* sp.
Awingak Formation		
Astarte sp. BM	Plant leaves E	*Pseudolimea duplicata* BM
Camptonectes sp. E	Plant stems E	Wood debris BM
Inoceramus sp. BM/E		
Savik Formation		
Upper Shale		
Camptonectes sp. BM		
Jaeger		
Belemnites sp. E	*Dactylioceras* sp. E	*Harpoceras* sp. E
Catacoleoceras sp. ? E	*Gresslya cf. abducta* BM	*Modiolus* sp. E
Heiberg Formation BM		
Remus Mbr (Borden Island Fm)		
Amaltheus sp.	*Pleuromya cf. costata*	*Terebratula* sp.
Modiolus sp.	*Rhychonella* sp.	*Tetrarhynchia tetraedra*
Pinna sp.		
Schei Point Group		
Pat Bay Formation		
Cardinia sp. ML	*Meleagrinella* sp. PR	*Oxytoma* sp. PR
Gryphaea sp. ML/PR	*Orbiculoidea townshendii* PR	*Rhychonella* sp. PR
Lyriomyophoria posters ML	*Ornithella* sp. ML/PR	*Spiriferina* sp. ML/PR
Hoyle Bay Formation		
Apiocrinites sp. ML	*Lyriomyophoria cf. posters* ML	*Pentacrinites* sp. ML
Chlamys cf. valoniensis ML/PR	*Meleagrinella* sp. PR	*Pseudopecten* sp. ML
Inoceramus sp. PR	*Modiolus sp.* ML	
Roche Point Formation		
Modiolus sp. PR		
Blaa Mountain Group BM		
Hoyle Bay Formation		
Amberleya sp. (Middle Shale)	*Mactromya sp.* (Middle Shale)	*Plicatula* sp. (Upper Calc Mbr)
Gryphaea sp. (Upper Calc Mbr)	*Meleagrinella* sp. (Middle Shale)	*Terebratula* sp. (Upper Calc Mbr)
Blind Fiord Formation MB		
Mytilus sp.		
Trold Fiord Formation		
Fenestella cf. retiformis ML	*Productus sp.* MB/ML/MS	*Spirifera* sp. MS
Degerbols Formation BM		
Neophricadothyris asiatica	*Productus* Sp.	*Pterospirifer alatus*
Nansen Formation ML		
Productus sp.	*Sokineophyllum* sp. ?	

Locality Key: BM Blue Mountains (80 43 N 8500 W) ML Mount Leith (including Section E)
E Elmerson Peninsula (Section F) MS Mount Shackleton (81 03 N 8103 W)
MB NW of Mount Burrill (Section C/D) PR Ptarmigan Ridge (Section A/B)

Figure 6 Fossil Specimens (provisional identifications)

CONCLUSION

23. The strata examined during the expedition conform to the statigraphic framework established by previous workers. Around 300 rock and fossil samples were collected on behalf of CASP. Whilst having Svalbard as their major area of interest, CASP maintains a comprehensive database which covers many aspects of Arctic geology and is available for use by both research workers and commercial agencies. The specimens from Ellesmere Island gathered during the course of this project, along with relevant field data, now form part of this database and may be examined upon application to CASP.

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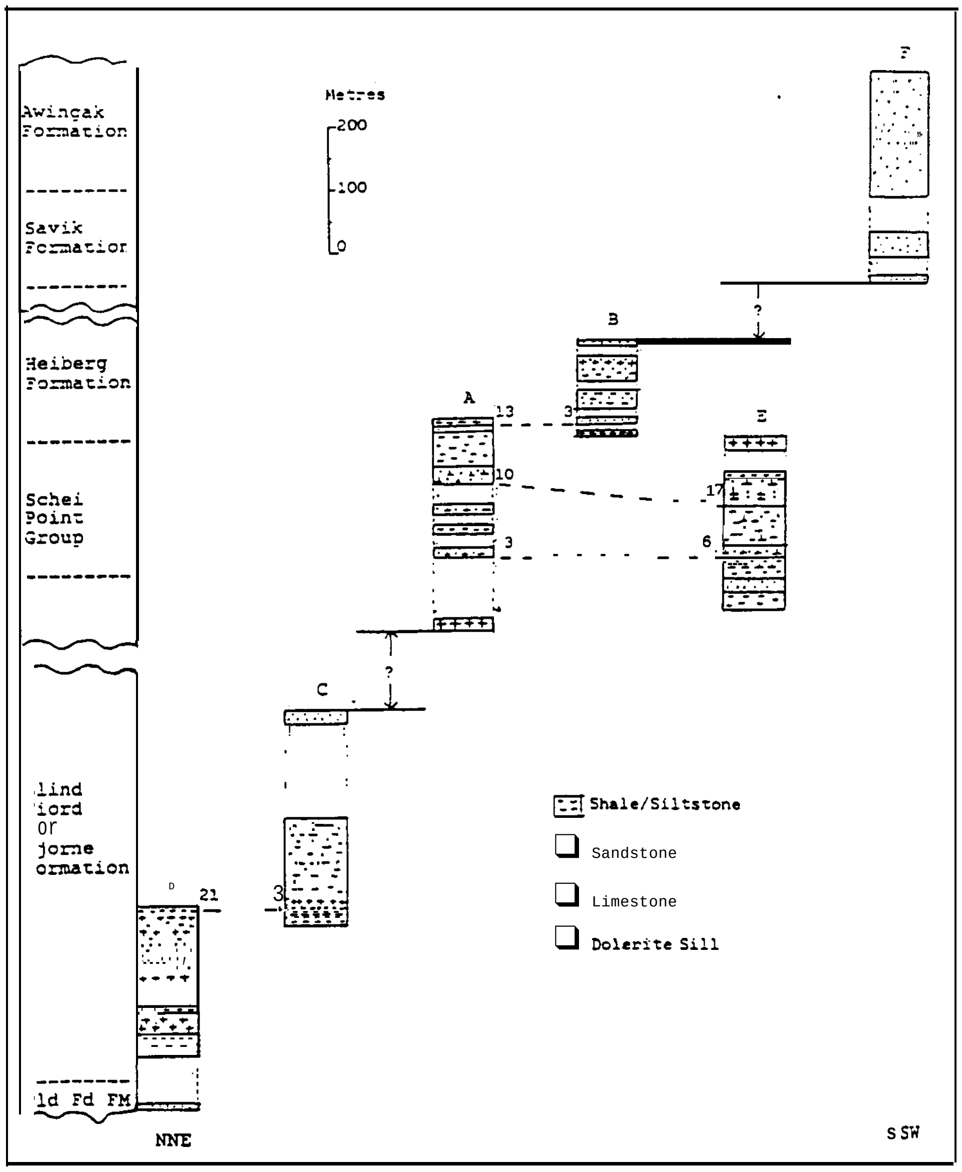
SECTION SUMMARY



1

SECTION A - Southern slope of 'Ptarmigan Ridge'
(80" 54'N 81 30'W)

Strata orientation - 260/45

Unit	Bed No	Description	Thick -ness (m)
Heiberg Formation	14	Dolerite sill with chilled margins.	20
	13	Medium-bedded, fine-grained, grey sandstone with iron-rich nodules and carbonaceous material.	7
?-?-?-?			
Barrow Formation	12	Dark shale with bands of finely laminated, cross-bedded siltstone (up to 30cm thick) showing load casts and groove marks. Bioturbation and many worm burrows.	8
	11	Strata hidden by scree - black shale?	35
Pat Bay Formation	10c	Fine-grained, grey, calcareous sandstone, weathering yellow with clusters of *Gryphaea sp.*	22
	b	Fine-grained, flaggy, calcareous sandstone or sandy calcarenite with areas of iron staining. Well articulated specimens of *Spiriferina sp.* or *Ornithella sp.* in discrete clusters. Also *Oxytoma sp.*	5
	a	Medium-bedded limestone with thin bioclastic seams packed with shells: *Orbiculoidea cf. townshendii, Rhynchonella sp.* and *Meleagrinella sp.*	2
	9	Thinly-laminated to medium-bedded alternations of red-weathering and white sandstone. Hardened areas with calcareous cementation occur along with bioclastic horizons. Cross-bedding, ripple marks and mud flakes.	12
?-?-?-?			
Hoyle Bay Formation	8	Strata hidden by scree.	30
	7	Dark limestone lenses up to 1.5m thick interspersed with bioclastic areas containing *Meleagrinella sp., Rhynchonella sp., Chlamys cf. valoniensis* and *Inoceramus sp.* Conglomerate areas with medium pebbles.	8
	6	Strata hidden by scree - shale?	10
	5	Thinly to medium-bedded, siltstone with shaley partings, ripple marks, rainspots and load structures.	20
	4	Strata hidden by scree.	20
?-?-?-?			
Roche Pt Formation	3	Very poorty consolidated calcarenite with shell debris (including *Modiolus sp.*), overtain by a hard fine-grained quartzose sandstone. Channel structures.	12
?-?-?-?			
Murray Hbr and Bjorne Formation	2	Strata hidden by scree.	100
	1	Dolerite sill.	20

SECTION B - Small valley to the north of the spout of Ptarmigan Glacier (80°53'N 81°37'W)

Strata Orientation - 260/30-80

Init	Bad No	Description	ick ss n)
	26	Medium-bedded, fine-grained, white sandstone with hard calcareous bands, red mud flakes, linguoid ripples and discoidal areas of convoluted bedding.	6
	27	Strata hidden by scree.	2
	26	Medium-bedded, medium-grained, quartzose Sandstone with silty laminae, showing channel and ripple structures.	2
	25	Very thinly-hddad, grey siltstone with black shaley partings, showing trace fossils, ripples and calcitized wood remains.	2
	24	Fine-grained sandstone with black silty lenses, containing ripple structures and mud flakes.	2
	23	Dolerite sill with chilled edges and alteration of country rock.	!4
	22	Medium-bedded, fine-grained sandstone with black slity lenses, showing cross-bedding, ripples and channel fills.	6
oshelm	21b	Poorly sorted, matrix-suported, calcareous conglomerate with sub-rounded, non-calcareous clasts up to 5cm in size. Top surface is reddened.	1
	a	Shale with slickenside structures and calcite veining. Mudstone channel-fills with nodular base.	1
	20	Strata hidden by scree.	2
	19	Hard, siliceous mudstone with *roots,* underlain by a dark, calcareous mudstone with burrows.	3
	18	Strata hidden by scree.	3
	17	Very fine to medium-bedded, dark calcareous mudstone.	1
Aember	16	Strata hiden by scree.	2
	1s	Irregular, *ferruginous mudstone* weathering red/green.	0.:
	14	Grey shale.	1
	13	White quartzose siltstone.	0.
	12	Grey shale.	1
	11	Transgressive dolerite sill, with fine-grained, green-coloured margin containing feldspar phenocrysts and calcareous *xenoliths.*	3
	10	Strata obscured.	12
	9	Red-weathering, massive, grey, calcareous mudstone.	0.
	8	Strata obscured - grey shale?	11
	7	Red-weathering conglomerate. Clast orientation parallel to bed with largest (1 5cm) at base. Clasts, which are generally rounded but poorly sorted, include calcareous mudstone and chart(?), Calcite veining present.	4
f-?-?-?	6	Strata obscured - grey shale?	12
Romulus	5	Variable, fins-grained, calcareous sandstone with lenses of carbonaceous material and plant debris. Rock surface reddened by weathering and often has a yellow powdery texture (limonite?). Spherical nodules up to 50cm in diameter.	5
Member	4	Strata obscured.	1C
	3	Medium to thickly-bedded, fine-grained, grey sandstone with undulatory ripples (Index 9).	13
	2	Strata obscured.	14
	1	Dolerite sill.	6

SECTION C - Small valley on the north-west slope of Mount Burrill (80°56′N 81°30′W)

Strata orientation - 250/20

Unit	Bed No	Description	Thick -nass, (m)
	7	Grey-white siltstone and very fine-grained sendstone with cross-bedding.	20
	6	Strata obscured.	1 40?
3lind	5	Fine to medium-bedded, hard, crystalline siltstone of variable green-grey colour, and increasing sand content toward the top. Channel structures occur, often with mud flake bases. Bioturbation and worm tubes are common, often overlain by calcareous horizons containing poorly preserved shells including *Mytilus sp.* Ripple marks and thin shaley interbeds aLso occur.	130
⁻iord	4	Dolerite sill.	8
	3c	Dark siltstone.	6
ormation	b	Red-weathering mudstone showing dessication cracks and rain marks. Worm tubes occur, surrounded by aureoles of green-coloured rock.	3
	a	Hard crystalline siltstone with interlaminated red and green-coloured beds showing small-scale cross-bedding.	5
	2	Dolerite sill.	12
	1	Brittle siltstone with a welldeveloped bedding fracture showing internal flaser bedding.	12

SECTION D - Between the tips of the finger glaciers to the north-west of Mount Burrill (80° 57' N 81° 30' W)

Strata orientation - 250/30

Unit	Bed No	Description	Thickness (m)
Blind Fiord Formation	21	Red/green-weathering mudstone with hard siltstone lenses. Cross-bedding and bioturbation.	8
	20	Coarse-grained dolerite sill showing some banding. Centre characterised by large laths of weathered feldspar.	20
	19	Red/green-weathering, banded mudstone.	8
	18	Dolerite sill.	6
	17	Green-weathering, hard, brittle siltstone.	4
	16	Red-weathering, fine-grained, cross-bedded sandstone.	4
	15	Micaceous *red* siltstone, with mud flakes and burrows, containing lenses of green-white siltstone up to 30cm thick.	8
	14	Very fine-grained, white sendstone, overlying a red, micaceous siltstone with cross-bedding and mud cracks.	6
	13	Strata hidden by scree - grey shale seen to 3m.	23
	12	Hard, graan-weathering, bioturbated siltstone.	4
	11	Dolerite sill.	6
	10	Very thinly-bedded, grey siltstone.	6
	9	Strata hidden by scree.	35
	8	Thinly-bedded, dark mudstone.	8
	7	Dolerite sill with feldspar(?) phenocrysts.	40
	6	Soft shale with yellow-weathering on bedding planes.	5
	5	Strata hidden by scree.	15
	4	Fine-grained dolerite sill with feldspar phenocrysts.	4
	3	Very thinly-laminated, hard siltstone with bands of yellow-weathered, corroded nodules.	10
-?-?-?-?- Trold Fiord Formation	2	Strata hidden by scree.	80
	1	Very fine-grained sandstone, with red-weathered, bioclastic, calcareous areas containing *Productus sp.*	5+

SECTION E - Tip of northern glacier from Mount Leith Icefield (80°52' N 81°35' W)

Strata Orientation - 060/70

Unit	Bed No	Description	Thickness (m)
Barrow Formation	20	Dolerite sill.	20
	19	Strata hidden by scree.	35
	18	Grey-black shale with bands of thinly laminated, micaceous siltstone. Bioturbation and tram fossils.	15
Pat Bay Formation	17d	Thickly-bedded, yellow-weathering sandy calcarenite with silty horizons. Plentiful Gryphaea sp. in lenses.	9
	c	Very thickly-bedded, sandy calcarenite with areas of Iron staining. Large Spiriferina sp. and Ornithella sp. occur in isolated shelly pockets.	8
	b	Finely-crystalline limestone, grey on weathered surface with poorly-sorted, coarse sandstone layers containing worn shells and round black phosphatic pebbles.	4
	a	Calcareous sandstone with large channel bedding. Channel base variable: well sorted, sub-rounded, coarse sandstone to poorly sorted, well rounded conglomerate of imbricated phosphatic pebbles.	10
	16c	Red shale.	1,5
	b	Irregular, green/red-weathered breccia.	1
	a	Red shale.	1.5
	15	Medium-bedded, fine-grained, reddened, glauconitic sandstone with knobbly top surface. Pseudopecten ap., Modiolus sp., Apiocrinites sp. and Pentacrinites SP.	8
?-?-?-? Hoyle Bay Formation	14	Black shale.	4
	13	Silty biosparite with rounded black pebbles and angular red pebbles. Many fossils on top surface: Pseudopecten sp., Modiolus sp., Apiocrinites sp. and Pentacrinites SP.	0.2
	12	Black shale.	2
	11	Finely-crystalline, grey limestone with bioclastic top surface showing some pyritization. Chlamys cf. valoniensis, Lyriomyophoria cf. pesters and wind.	1
	10	Black shale, weathering yellow, with small ironstone nodules.	8
	9	Medium-grained sandstone with cross-balding, mud flakes and bioturbation.	4
	8	Coarse, calcareous sandstone with conglomerate top.	1
	7	Black shale with thinly-bedded mudstone layers.	30
?-?-?-? Roche Pt Formation	6	Thickly-bedded limestone with sandstone alternations. Limestone has poorly preserved shells. Sandstone shows ripple marks and bioturbation.	12
?-?-?-? Murray Harbour Formation	5	Black shale with siltstone band.	8
	4	Medium-bedded limestone with shaley partings. Top surface Is bioclastic and contains small pebbles.	20
	3	Shale with siltstone alternations and bioturbation.	14
?-?-?-? Bjorne Formation	2	Fine-grained, medium-bedded quartzose sandstone with basal mud flakes, Red/grsan-weathering areas and mud-chip conglomerates present.	22
	1	Shale, with thin bands of grey siltstone hemming more common toward the base.	35+

SECTION F - Foothills along the northern shore of the Elmerson Peninsula (80° 46´N 81” SO-W)

Strata orientation - 060/20

Unit	Bed No	Description	Thick -ness (m)
	10b	Grey shale, with bands of red-weathering, discoidal, siltstone concretions containing shell debris (*Inoceramus* sp.) and plant matter.	4
Awingak	a	Flaggy, grey-green, medium to fine-grained sandstone with large *Camptonectes* sp., *Inoceramus* sp. and plant leaves.	6
	9	Medium-grained, greyish-yellow sandstone. Hard and massive at the top, becoming softer and greenish at the basa. Shell debris and plant remains.	10
Formation	8	Thinly-bedded, fine-grained *grey* sandstone becoming more shaley at the base, and characterized by large pillow concretions up to 10m *in* diameter. Section cut by a small medium-grained dyke with chilled edges.	170
	7	Medium to coarse-grained, grey-brown sandstone with coarse cross-bedding.	10
	6	Fine sandstone with hard pillow concretions up to 15m in diameter.	20
U Savik	5	Black shale and siltstone - very poorly exposed.	60
Savik	4	Coarse, poorly-sorted sandstone with weathered siderite lenses and spherical, pyrite-rich nodules around 4cm in diameter.	10
Jaeger	3	Fine-grained sandstona with mottled red/white/green appearance and many, often large, belemnites (including the phragmacone). Also *Dactylioceras* sp., *Catacoleoceras* sp., *Harpoceras* sp. and *Modiolus* sp. Hard calcareous glauconitic areas occur, sometimes packed with fossils.	30
Fm L Savik	2	Strata hidden by scree.	40
-?-?-?-?- Heiberg F	1	Fine to medium-grained quartzose sandstone.	2+

BASIC INTRUSIONS OF BORUP FIORD AND THE BLUE MOUNTAINS. ELLESMERE ISLAND

By R. I. L. Dow

INTRODUCTION

The igneous rocks of Ellesmere Island have been divided into two categor es: the Lower Permian extrusive rocks which form the Essayoo Formation; and the younger Intrusive and extrusive rocks of Cretaceus age. The most extensive study of the younger igneous rocks of the Queen Elizabeth islands was done by Blackader in the 1950's and 60's (Blackader 196.4). He suggested there had been two separate periods of intrusive activity, one in late Cretaceus, and the other in early Tertiary. *None of* the upper most Cretaceus or Tertiary rocks are intruded by sills or dykes, and the Tertiary phase of activity was inferred by the relationship of dykes to the structures of the Eurekan orogeny. Blackader identified rocks with compositions varying from quartz to olivine, bearing gabbro Balkwill (1978) in his discussion of the evolution of the Sverdrup Basin suggested episodic emplacement of the sills and dykes over a period of nearly 100 my. He argued that it was unlikely for sills to be emplaced at shallow and deep levels of the basin at the same time. K-Ar age determinations (Lacrochelle 1965) for the igneous rocks of the Queen Elizabeth Islands give dates from 180 m.y. to 90 my. Balkwill envisaged intrusive episodes to be associated with basin subsidence prompted by crustal foundering.

In this study samples were collected from three locations (see Fig. i). An area to the north of the end of Essayoo Bay was mapped in detail (see Fig.2 and Fig. 2.1) this area consisted mainly of Triassic rocks and the succession contained considerable numbers of sills. Jurrasic rocks were mapped on the Elmerson Peninsular south of Essayoo Bay, a number of large and extensive dykes were mapped but no sills. In the Blue Mountains a succession from Carboniferous to Upper Creataceous rocks was mapped, sills were concentrated in the Triassic rocks but dykes were found to cut the Jurrasic and Cretaceus. A single lava flow outcrops between the Isachsen and Christopher formations. During the expedition samples were taken from the complete range of igneous rocks and 34 geochemical major and trace element analysis were done.

From previous studies the widespread nature of the Cretaceus igneous rocks of the Sverdrup Basin had been determined but to date only 10 geochemical analyses have been publised. By carrying out a detailed study on a relatively small part of the Sverdrup Basin and by putting this into wider context it is hoped to be able to fuel further discussion on the petrogeneses of the Queen Elizabeth islands igneous suite and on the tectonic implications.

FIELD RELATIONS

In the area north of Mt Leith (fig. 2) sills formed a significant part of the rocks in the Blaa Mountain and Blind Formations, The harder dolerites dominated the topography forming ridges, scarps and capping many of the peaks. including Mt Leith. The sills vary in thickness from 1-20 m and where the upper and lower contacts 1s exposed both are chilled margins. Most sills appeared to be homogeneous but a single 14m thick sill north of Mt Burrill appeared to be coarsley layered. The layering was evident because of a variation in grainsize rather than mineral composition. The sills are continuous along strike for many kilometers but change horizon by gently dipping discordances. In one location two sills merged to form one. Only three dykes were mapped in this area, the largest was 4m thick and was continuous for 200 m. Where the relationship between sills and dykes was exposed they passed into each other with no cross cutting relationship, suggesting both were intruded at the same time. The sedimentary rocks in this area are all Triassic and are mainly thinly bedded shales, sandstones, and siltstones. A detailed description of the sediments with measured sections is given in this publication by S. Young. All the rocks have been, folded during the Eurkan orogeny in latest Cretaceus and Tertiary times. The folds are upright symmetrical or asymmetrical large open folds which are cut by steeply dipping reverse faults. The result is that many of the sills now dip almost vertically.

On Elmerson Peninsula the geology and resulting topography is verv different. The Jurassic sediments are predominantly massive thickly bedded sandstones and do not appear to be Intruded by any sills. There are, however, a number of large dykes, up to 10m thick, that strike NW-SE and continue along stike for up to 6 km. On Elmerson the sediments are flat lying and the dykes near vertical. The dykes are homogeneous and have well developed chilled margins where they are exposed.

in the Blue Mountains a complete succession from Carboniferous to Upper Cretaceus was examined. Sills were again found to form prominent ridges in the Triassic but no sills were found to intrude the Jurassic or Cretaceus sediments. The sills are up to 30m thick and now dip steeply, although are still basically concordant with the sedimentary beds. Dykes, which are up to 10m thick, intrude all the rocks up to Lower Jurrasic They strike NW-SE and are continuous for up to 8 km. No dykes were seen to cut the lower Cretaceus rocks but in other localities dykes have been found to cut the Hassel Formation which is of upper Cretaceus age (Blackader 1964). In the valley running NE of Black Stripe Head (80 32'N 86 05'W) basaltic lava forms a cliff about 20m high and is cruddy columnar jointed. The outcrop is homogeneous with no internal divisions that might suggest it is formed from a series of flows. From a distance it is very similar to some of the sills which outcrop lower in the stratigraphic column. On closer examination the rock is uniformly fine grained with some phenocrysts of feldspar and pyroxene, there Is no coarsening of the grain size in the centre of the flow as is the case with the sills. In certain locations the rock is vesicular. The vesicular lava tends to be found in rounded pockets 4-5m across. These were most common near the base of the flow although did occur in the middle and top of the flow. The lava overlies the sandstones of the Isachen Formation and is overlain by the dark shales of the Christopher Formation and covers an area of approximately 100km. From fossils found above and below the lava it is possible to date the flow at about 110 my.

PETROLOGY

All the igneous rocks examined in the field have a basic composition and consist mainly of plagioclase, pyroxene and ore minerals.

INTRUSIVE ROCKS

The dykes and sills are petrographically similar. In the field they pass into each other uninterrupted. The rocks are dolemites or microgabbros and consist of plagioclase 50-60%, clino pyroxene 30-40% and ore mineral 10-20%. The cl inopyroxene 1s augite but in some cases a slightly pinky, green pleochroism suggest a higher than average titanium content. The rocks vary in grain size from fine to medium grained, which, as might be expected, depends largely on the thickness of the intrusion. The chilled margins are extremely fine grained and some have a concentration of ore minerals which are evident in hard speciment. The textures vary from equigranular to subophitic, and from porphyritic to non porphyritic. Where the rocks are porphyritic they have phenocrysts of both pyroxene and plagioclase. The ore mineral in some samples froms 20% of the rock. In most rocks it 1s present as interstitial crystalgrowths which appear to have late origin. Some of the rocks are almost unaltered but many are very altered to chlorite, mica, and epidote, these are often associated with calcite.

Basalt

The basalt typically has a very fine grained ground mass with phenocrysts of plagioclase and augite which reach Up to 3mm in length. The plagioclase phenocrytsds show albite twinning and some are partly altered to give a sieve texture. The groundmass consists of plagioclase laths, granular augite and ore mineral.' The ore mineral is typically acicular. The elongate minerals do not have a preferred orientation. The vesicules, where present, are most commonly infilled with a calcite.

GEOCHEMISTRY

34 geochemical analyses were done using the XRF at St Andrews University. Analyses were done for both major and trace elements (see Annex A) and covered the complete range of rocks found in the expedition area. The major element chemistry shows some variation but overall the samples have a fairly typical composition. On S102 vs Na20, K20 plot (see fig 3) all the analyses fall into the fields for tholeiitic or alkali olivine basalt. The average composition falls somewhere between the two, suggesting a basalt not very over or undersaturated, which would explain the absence of either olivine or quartz. On the FeO vs Na20, k20 vs MgO plot (fig 4) all the analyses form a single group on the tholeiitic curve with no trend of Fe enrichment. The magma was, therefore, not primative and no evolutionary trend is apparent. Blackader (1964) did a number of major element analyses and these fall into the same area on tholeiitic curve as the rocks analysed in this study. He only did 10 analyses and suggested that there was a trend of Fe enrichment but it appears that the composition remained more or less constant for either a considerable length of time, about 100 my., or at least while a very large volume of magma was emplaced in the upper crust, over a large area. In the sill below Mr Burrill where in outcrop it appeared to be layered and to have undergone some form of differentation the analyses from different levels in the sills proved to be similar.

The trace element data is consistant with all the rocks coming from a single magma source as on all the various plots either a single group is formed e.g. T:02 vs Zr (Fig 5) or a continuous variation is seen e.g. Zr/T102 vs Nb/Y (Fig 6). By using the fields defined by Pearce and Cann (Pearce and Cann 1973) and others to compare basalts from the various tectonic regions the rocks from the Borup Fiord area form fairly well defined groups. On the Zr, Ti/100, Y triangle (Fig. 7) the samples fall clearly into the "within plate" field. On the Ti, Zr, Sr plot (Fig. 8) the spread is from "ocean floor" to "low-k tholeiite" basalt,. Finally on the TiO_2, K_2O, P_2O_5 (Fig. 9) plot the rocks fall into the ocean floor basalts, as opposed to the continental basalt field. The inference from the data being that the rocks are fairly typical for within plate basalts but retain strong mantle affinities and have not undergone much chemical alteration in the continental crust.

DISW3S1ON

From the mineralogy and geochemical analyses the most striking feature is the apparent uniformity in rock type and chemistry. Samples were analysed from different levels in the stratigraphy and from different localities. There does not appear to have been any significant fractionation of the source. Blackader carried out a number of analyses from a very large geographical area covering Ellef Ringes Island, Cornwall Island, Axel Heiberg and western Ellesmere. The major element chemistry is consistant with the analyses done in this study and suggests that most of the igneous rocks of the Queen Elizabeth Islands have very homogeneous geochemistry. In speculating on the source and mechanism of intrusion either a single episode of emplacement occurred from a very large and extensive magma chamber, or if as Balkwill preferred, igneous activity continued over a period of 100 my. covering the time span for the development of the Sverdrup Basin. In this second hypothesis some *mechanism* **must have kept the chemistry of a continually tapped magma chamber constant, perhaps constant replenishment from a mantle source.**

Only a few dates have been determined for the mafic rocks of the Queen Elizabeth islands and those were done in the 1960's (Larochelle et al 1965). the ages (K-Ar from biotite and whole rock) vary from 180-90 my. with the majority of dates in the Upper Jurassic and Lower Cretaceus between 150-90 my. The age dates obviously support an hypothesis of igneous activity continuing throughout the development of the Sverdrup Basin. It might however be more conclusive if more determinations had been done and with more modern techniques. The lava in the Blue Mountains can be dated at about 110 my.

From looking at the evidence from the field relationships it seems easier to explain the situation by envisaging a single episode of igneous activ ty. As had been recognised before (Thorstein son et al 19711 the sills are cone ntrated in the rocks of he lower and midd e Triassic, the Blind and Blaa Mountain Formations. These formations are dominated by thinly bedded shales and sandstones. This zone has obvious y been a zone of lateral weakness at a critical level. Dykes are rare in this zone but much more common above and below it. Intruding dykes have reached this zone of weakness and spread laterally to form a network of sills. The sills mostly conform to the bedding but do change horizon, not as dykes but as discordant sills. In the field it seemed that all the dykes and sills had intruded at the same time, as dykes pass into sills and sills join other sills without cross cutting each other. Dykes are quite abundant in the Jurrasic and Cretaceus but none were seen cutting the sills in the Triassic rocks. A possible method of intrusion is one of dykes moving intruding to a level where there is less lateral than vertical resistance so spreading to form sills, then intruding again as dykes up fissures or faults to the more massive rocks above. This all occuring in a fairly short time span in response to some major tectonic event.

A picture emerges of a very large volume of magma intruding rocks of a wide geographical area either as a single episode as the field evidence suggests or over a period of time and many smaller episodes as the age ates seem to infer. In either case it must have been in response to some tectom c activity. To the east of Ellesmere running north between Greenland and El esmere i s he Ran

Ridge, a now non-active spreading ridge that extended northwards from the Labrador Sea toward the Arctic Basin. The Ran Ridge Is thought to have been active from 80 m.y.-40 my. (Le Pichon et al 1971). This 1s younger than the age for the activity on Ellesmere. It may, however, be that the activity on the Queen Elizabeth Islands is associated with the very beginning of the Labrador Sea?

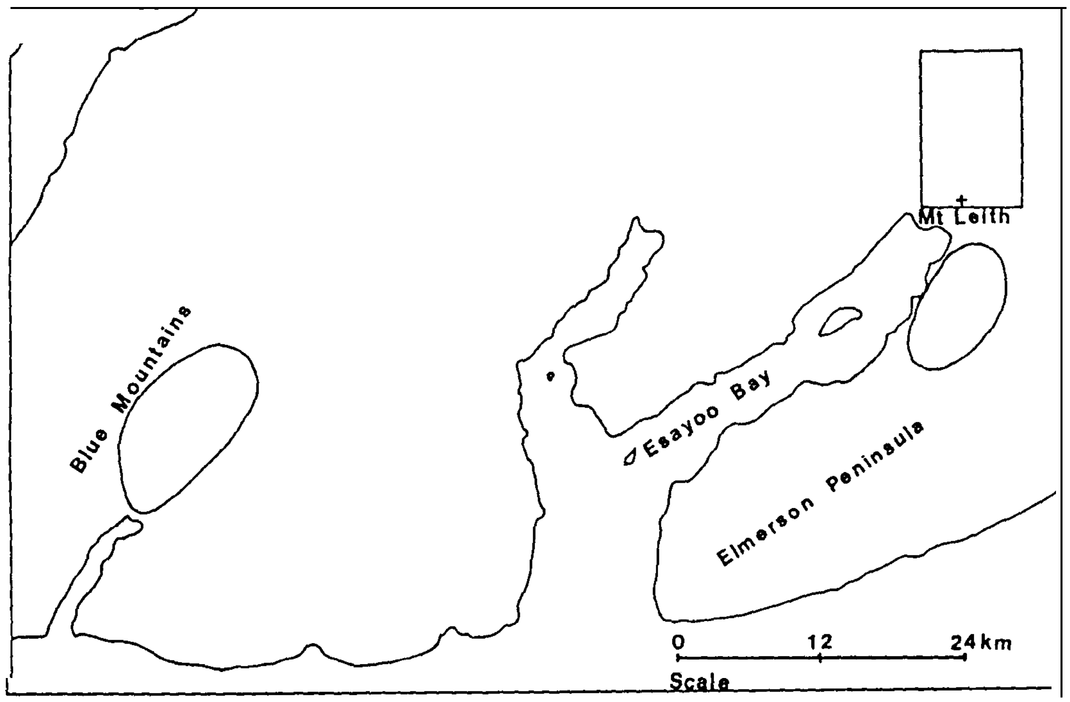
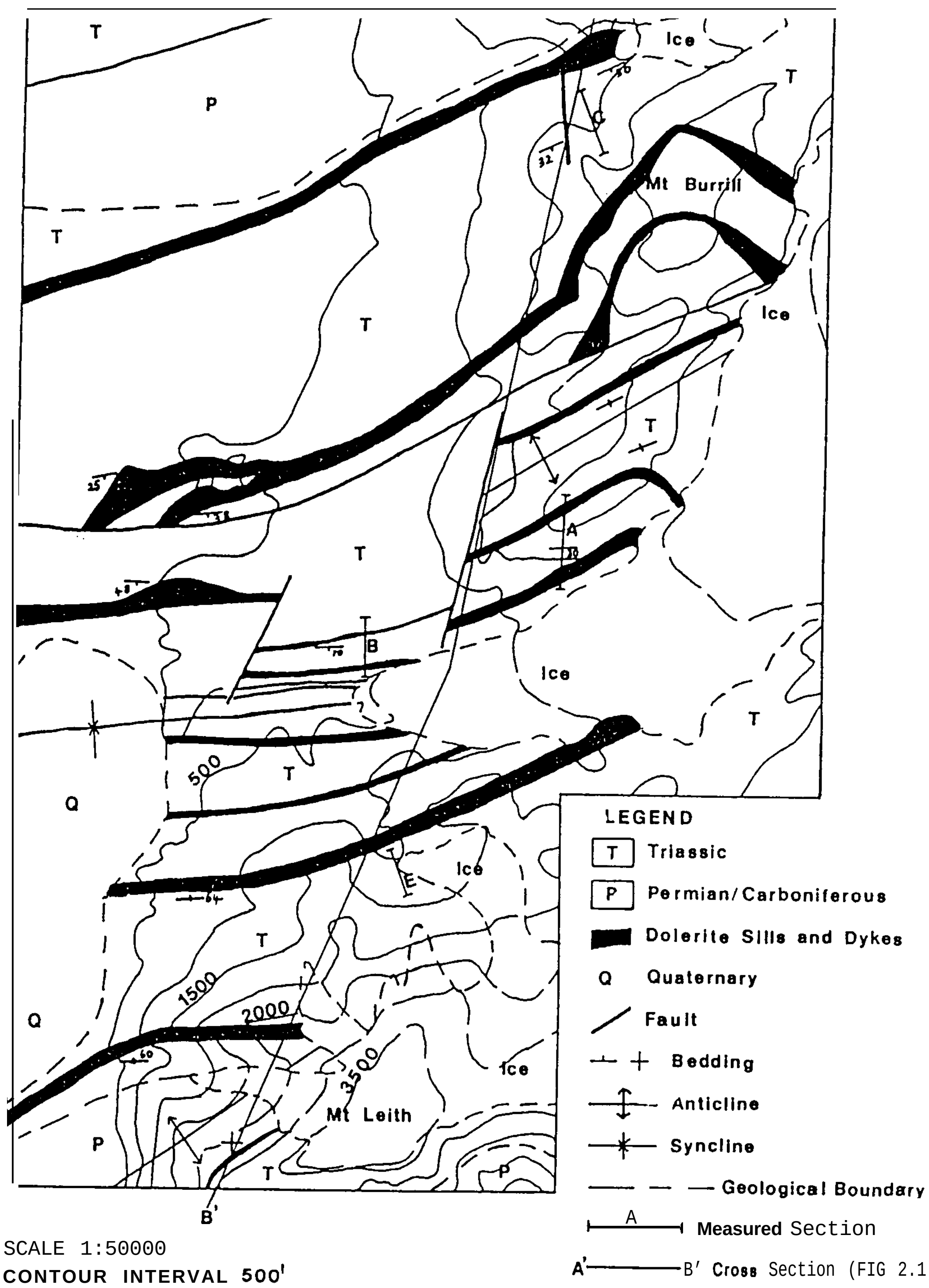


FIG1 GEOLOGICAL LOCATIONS

A′



SCALE 1:50000

CONTOUR INTERVAL 500'

FIG 2

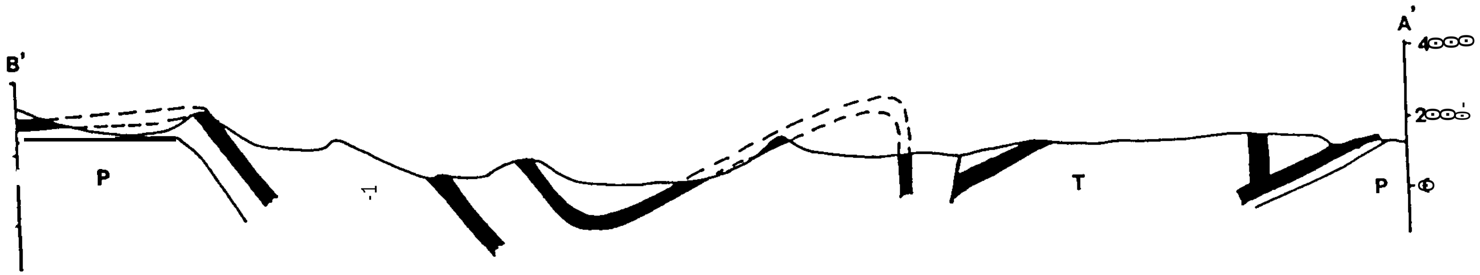


FIG 2:1

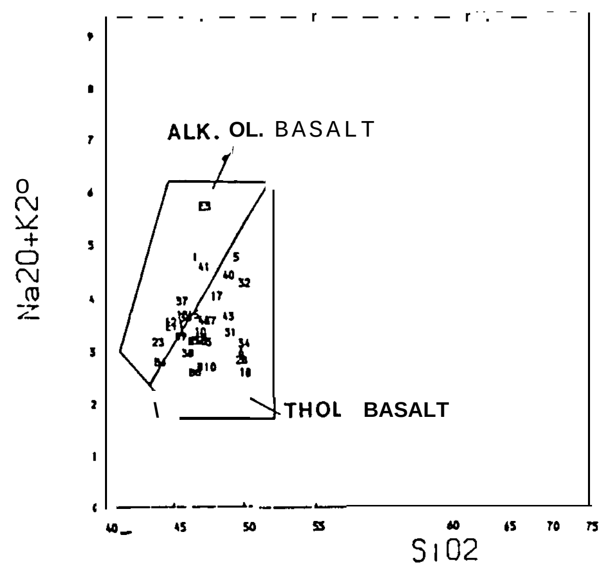


FIG 3

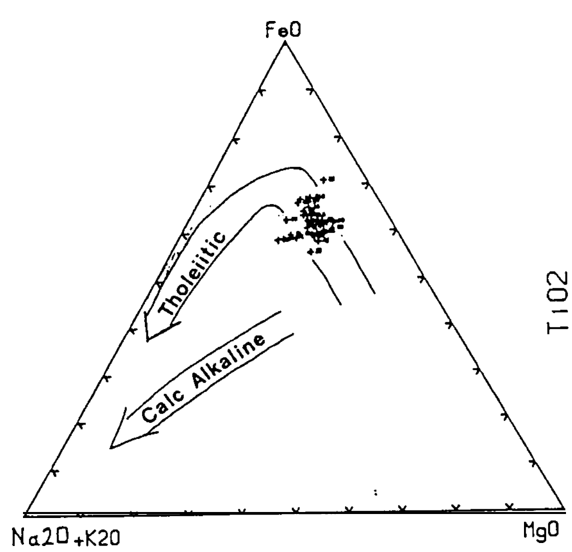


FIG 4

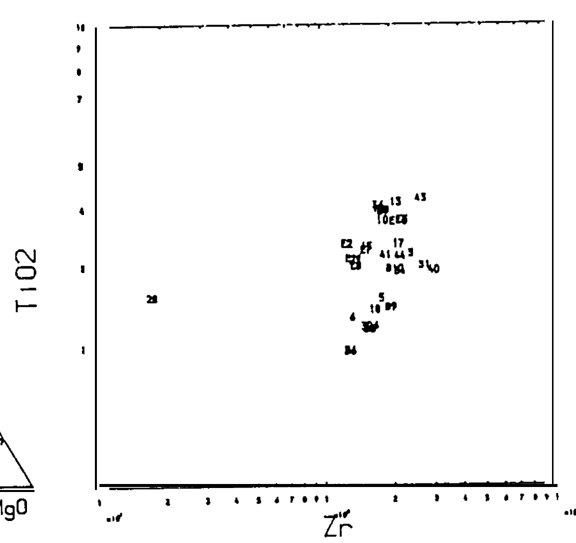


FIG 5

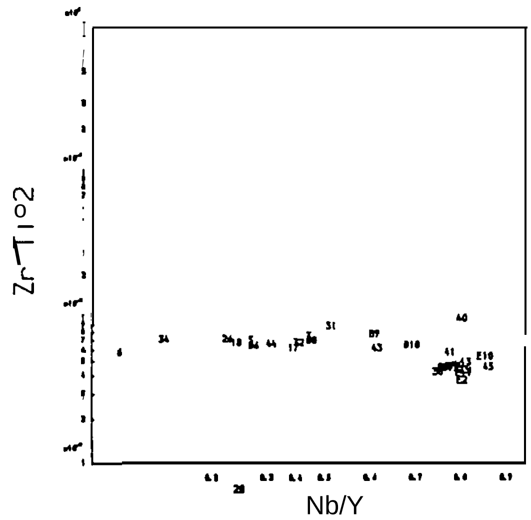


FIG 6

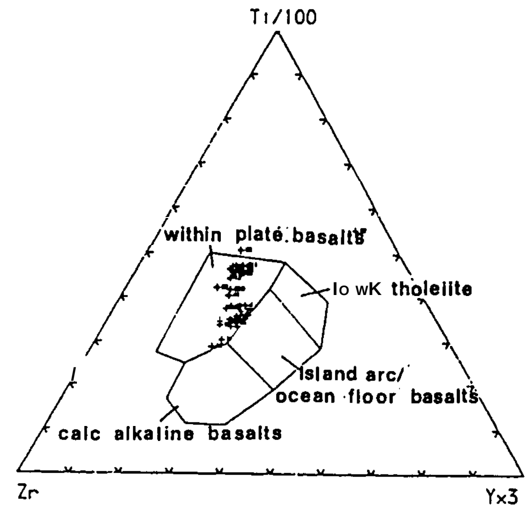


FIG7

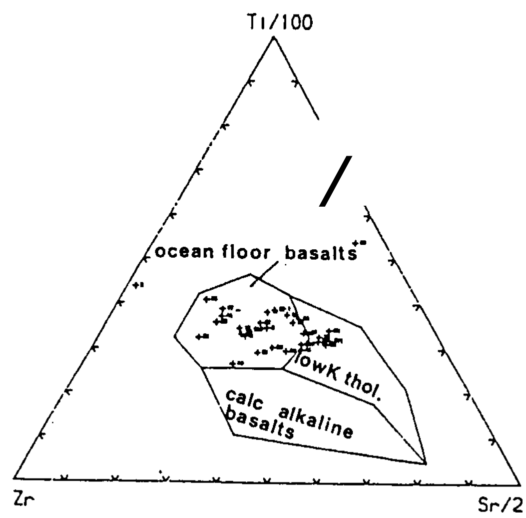


FIG8

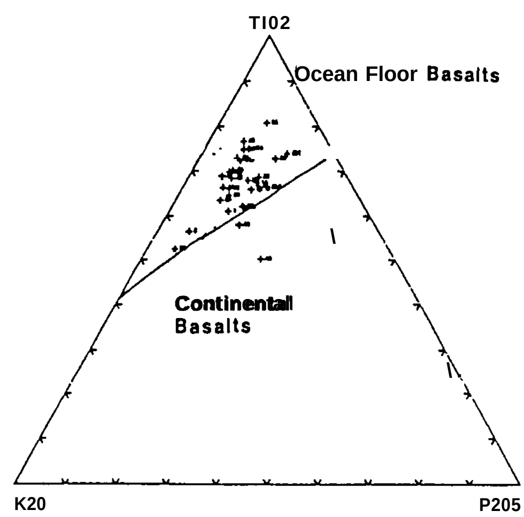


FIG9

R DOW ELLESMERE ISLAND ANNEX A

SAMPLE	1		3		5	6	10	11
S102	46.62	41.80	47.5.?	13.55	49.59	49.83	46.68	45.37
T102	3.97	3.51	3.19	0.17	2.55	2.32	2.75	3.87
A1203	13.25	14.01	12.92	3.95	14.38	14.93	14.88	13.09
Fe203	.?.93	2.52	3.22	0.69	2.86	.?.76	2.77	2.88
FeO	11.71	10.10	12.88	2.75	11.45	11.03	11.10	11.52
Mno	0.25	0.19	0.27	0.38	0.21	0.21	0.20	0.26
MgO	5.32	2.36	4.86	10.95	4.82	5.45	4.85	6.10
CaO	7.65	10.72	8.82	39.32	7.57	9.82	9.99	9.82
Na20	2.99	3.96	2.15	0.03	3.08	2.16	2.35	3.03
K20	1.77	0.21	1.03	0.64	1.68	0.83	1.03	0.47
P205	0.76	0.44	03.7	0.27	0.28	0.22	0.78	0.79
Loss	2.00	9.80	2.00	28.00	1.40	0.60	1.40	2.40
TOTAL	99.30	99.71	99.31	100.77	99.97	100.24	99.88	99.68
Nb	24	19	16	1	9	4	23	22
Zr	170	282	239	22	178	133	177	180
Y	32	53	48	11	36	31	33	32
Sr	410	116	15	634	270	260	542	344
Rb	37	4	36	31	45	21	23	11
Th	2	3	4	6	6	4	4	7
Pb	1	8	7	0	4	3	2	7
Zn	108	176	153	14	83	118	126	111
Cu	0	204	216	0	207	160	15	16
Ni	7	30	31	9	28	34	.?5	33
Cr	40	41	43	8	50	62	63	81
V	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ba	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hf	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
La	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

SAMPLE	12	13	17	18	23	26		28
S102	44.58	45.40	47.89	49.87	43.67	40.11	40.79	49.62
T102	3.94	4.10	3.34	2.41	3.08	2.22	2.80	2.57
A12O3	13.70	12.61	12.85	13.19	14.33	12.66	14.67	13.17
Fe2O3	2.92	3.17	3.33	3.04	2.69	3.53	1.69	2.97
FeO	11.69	12.68	13.32	12.18	10.74	14.12	6.77	11.88
MnO	0.22	0.25	0.25	0.25	0.22	0.37	0.77	0.24
MgO	5.26	5.25	5.36	6.52	4.87	5.15	1.66	6.14
CaO	9.53	9.25	7.99	9.82	9.52	9.51	16.88	9.66
Na20	2.3d	2.53	3.17	1.66	1.99	1.68	2.37	2.25
K20	1.22	1.16	0.87	0.93	1.19	0.27	0.56	0.58
P205	0.82	0.95	0.37	0.29	0.69	0.26	0.32	0.29
Loss	3.00	2.80	1.40	0.40	7.40	9.40	11.40	0.80
TOTAL	99.31	100.24	100.22	100.66	100.51	99.35	100.78	100.24
Nb	21	26	14	8	20	7	13	9
Zr	174	202	206	162	133	i 58	187	17
Y	31	36	4 6	35	28	32	40	36
Sr	441	396	221	226	496	160	292	230
Rh	30	30	31	27	21	6	13	13
Th	0	0	8	4	0	5	2	0
Pb	4	7	3	10	0	1	2	3
Zn	128	151	104	126	121	66	148	122
Cu	15	3	66	203	191	127	191	184
Ni	19	4	23	55	54	21	54	45
Cr	50	19	39	95	90	83	90	74
V	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ba	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hf	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
La	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

SAMPLE	31	32	34	36	37	38	40	41
S102	48.85	49.91	49.83	45.66	45.42	45.77	48.76	47.01
T102	3.01	2.21	2.92	4.04	3.90	3.95	2.94	3.16
A1203	12.95	13.89	12.17	13.72	13.45	13.61	13.22	16.13
Fe2O3	3.17	2.65	3.27	3.00	2.97	2.97	2.91	2.49
FeO	12.69	10.60	13.09	11.98	11.89	11.89	11.65	9.95
Mno	0.24	0.2	0.24	0.23	0.38	0.23	0.24	0.20
MgO	4.32	6.05	4.87	5.47	6.20	5.83	4.11	4.06
CaO	6.48	7.61	8.62	9.79	9.1	9.76	8.20	9.27
Na20	2.24	2.51	2.24	2.61	2.86	2.31	2.88	3.13
K2O	1.1.?	1.77	0.91	1.03	1.09	0.66	1.54	1.45
P205	0.42	0.23	1.33	1.81	0.85	0.82	1.38	0.84
Loss	2..?0	2.40	1.40	1.80	1.40	1.40	2.20	1.60
TOTAL	99.78	100.14	99.98	100.24	99.62	99.31	100.13	99.30
Nb	18	10	7	22	21	22	34	22
Zr	265	149	207	170	179	180	290	181
Y	49	32	44	35	31	34	48	33
Sr	220	311	212	497	385	488	392	528
Rb	42	49	23	26	24	17	33	37
Th	6	3	0	6	1	5	5	3
Pb	6	1	2	6	6	7	5	0
Zn	122	99	123	137	113	92	172	117
Cu	160	104	215	20	12	2	0	3
Ni	17	53	2	32	32	37	0	6
Cr	25	102	37	74	79	79	6	18
v	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ba	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hf	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
La	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

SAMPLE	43	44	45	E2	E3		E7	E8
S102	48.70	46.97	46.19	46.49	47.12	46.18	47.43	46.75
T102	4,18	3.15	3.30	3.34	3.76	3.15	3.24	3.00
A12O3	12.62	12.29	13.63	15.16	13.88	13.73	14.69	15.51
Fe203	3.23	3.45	2.76	2.67	2.95	2.92	2.67	2.63
FeO	12.92	13.82	11.05	10.68	11.82	11.68	10.69	10.52
Mno	0.30	0.26	0.20	0.24	0.19	0.19	0.21	0.17
MgO	4.44	5.45	6.14	5.10	4.63	5.41	5.36	5.42
CaO	8.03	8.87	9.63	10.12	6.72	9.53	9.81	10.05
Na20	2.79	2.57	2.59	2.22	4.24	2.10	2.33	2.12
K20	0.87	1.02	1.11	0.99	1.48	0.82	1.25	1.15
P205	0.41	0.36	0.41	0.59	0.58	0.39	0.72	0.70
Loss	1.80	1.20	2.60	3.00	2.40	4.20	2.20	2.80
TOTAL	100.37	99.53	99.71	100.69	99.87	100.39	100.70	100.92
Nb	23	12	21	17	31	23	18	18
Zr	259	208	150	123	214	181	149	134
Y	50	44	26	24	32	27	27	28
Sr	211	224	478	531	384	491	541	533
Rb	34	34	25	15	31	16	27	24
Th	7	9	1	0	4	3	7	6
Pb	7	7	8	6	10	6	11	7
Zn	122	150	109	10	U 3	106	109	123
Cu	104	298	45	13	8	33	9	6
Ni	0	45	45	20	4	24	19	16
Cr	13	60	132	87	20	3a	76	71
V	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ba	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hf	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
La	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

SAMPLE	E10	E11		B6	B8	B7	B10
S102	46.24	44.65	30.65	43.79	46.26	45.31	46.89
T102	3.73	3.11	3.97	1.96	2.18	2.44	,2.96
A1203	13.92	14.01	13.93	13.18	13.06	12.01	12.86
Fe203	2.90	2.63	3.37	2.49	2.74	2.85	2.99
FeO	11.59	10.52	13.47	9.99	10.94	11.42	11.98
Mno	0.24	0.20	0.21	0.17	0.22	0 . 2 2	0.23
MgO	5.00	4.85	4.99	5.39	60.8	4.43	4.43
CaO	9.74	9.65	7.35	10.73	10.02	9.01	9.35
Na20	2..25	3.09	1.70	2.16	2.14	2.23	1.91
K20	0.95	0.39	1.83	0.64	0.46	1.06	0.79
P205	0.93	0.71	0.53	0.21	0.27	0.34	0.34
Loss	3.20	5.80	18.20	9.00	5.20	7.20	5.20
TOTAL	100.80	99.70	100.28	99.79	99.65	99.60	100.01

Nb	29	19	29	7	10	15	19
Zr	201	128	195	126	153	189	192
Y	37	27	29	28	30	33	35
Sr	589	542	229	308	220	333	302
Rb	18	5	25	9	6	31	22
Th	3	4	6	4	3	3	1
Pb	0	2	9	2	0	2	4
Zn	124	73	124	54	95	115	125
Cu	15	0	19	28	142	46	36
Ni	26	15	36	29	57	19	21
Cr	49	64	95	64	110	52	50
V	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ba	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hf	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Ce	n.d	n.d	n.d	n.d	n.d	n.d	n.d
La	n.d	n.d	n.d	n.d	n.d	n.d	n.d

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<u>THE KITE PROJECT - A LOW COST METHOD OF REMOTE SENSING IN THE HIGH ARCTIC</u>

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<u>INTRODUCTION</u>

1. Comparatively little research has been done on remote sensing of vegetation in the arctic, and even less on that of the high arctic. Research that has been undertaken (in arctic and non-arctic regions) has identified some problem areas which may have discouraged further activity. One problem is that of thresholding - the inability of remote sensing systems to detect or quantify vegetation below a certain level of cover or biomass (Rouse et al, 1973; Harlan et al 1979; Thomson et al, 1980; Brown et al, 1983). Another is that the spatial distribution of arctic vegetation is commonly dispersed in highly localised discrete patterns which are at a smaller scale than the resolving power of current spaceborne sensors (Stow et al, 1989).

2. A further problem area is that of temporal variability. The growing season in the high arctic is very short (commonly about 6 weeks), and this is likely to have major implications, especially on the thresholding problem. Nevertheless, it is one aspect that does not appear to have been considered in the literature (in an arctic context). It was decided to investigate this temporal problem using kite borne aerial infrared photography at Borup Fiord, Ellesmere Island, Canada (80″ 50′ North) during the British Joint Services Expedition of 1988.

<u>TEMPORAL FACTOR</u>

3. Seasonal changes in vegetation are obvious to all, although perhaps less so in the tropics. The significance of these changes to remote sensing are somewhat more complex than may appear at first sight, especially in the high arctic context. Optical remote sensing (ie non-microwave) of vegetation is primarily effected by examining reflectance in the near infrared portion of the spectrum, and comparing that to the visible reflectance (especially visible red). Chlorophyll pigments in living vegetation absorb visible red light (and blue, causing it to appear green to human eyes). In the near infrared plant mesophyll tissues reflect strongly, even stronger than visible green. Because the visible and near infrared reflectance behaviour of plants are caused by quite different factors (pigment and tissue structure) there can be significant variation in one and not the other. For example cut vegetation draped over an object may be indistinguishable from its surroundings in visible green but may be obviously different in the near infrared, which is why a “camouflage detection” colour infrared film was developed by Kodak during the last war. Relatively little is known of the spectral behaviour of arctic plants, although Tieszen and Johnson (1968) and Tieszen (1970) have examined the pigment structure of some species, and Tieszen (1972) noted seasonal variations in chlorophyll production, with dicotyledons generally exhibiting higher early season concentrations compared to monocotyledons. Tieszen and Johnson (1968) also showed that mosses contributed over one third of the total chlorophyll from a dry sedge community. Petzold and Goward (1988) have shown that the reflectance of (some) sub-arctic lichens in the near infrared is comparable to vascular plants, but the lichens do not exhibit such a marked contrast in the visible. A further factor is plant geometry, where shadowing effects caused by plant leaves are of very great importance, especially in the high arctic where solar angles are very low. (Otterman in 1981 concluded that the pronounced seasonal changes in the reflectivities of sparse vegetation in a hot arid region were due to shadowing effects). Plants

with erect leaves (such as most arctic grasses and sedges) are very efficient at intercepting solar radiation (Miller and Tieszen, 1972; Wielgolaski et al, 1981) and shadow far more of their neighbors than cushion forbs, but, because plant leaves transmit a high proportion of near infrared radiation, the shadowing effect is more significant in the visible compared to the near infrared.

4. A number of other factors affect the spectral reflectance from a vegetated or semi-vegetated surface. These include aspect (slope angle and orientation relative to solar illumination angle), soil mineral composition and soil moisture. The latter may be particularly problematic in permafrost regions where long warm and dry spells of weather may result in an increase in soil surface moisture due to the melting of permafrost at some depth. This process was frequently observed at Borup Fiord in mid to late July 1988, although mainly on moderate to steep slopes. These factors must be controlled or measured in any remote sensing study.

5. During the growing season plant tissues change in both structure and pigment content (and moisture content which affects their response in the mid infrared). Plant geometry also changes as new growth emerges, often from a mat of standing brown vegetation left from the previous season. In the very short growing season in the high arctic dramatic changes in the spectral behaviour of plants are likely to be compressed into very short periods of time. It would appear to be desirable to obtain some measurements of these changes, and this was my objective.

METHODS OF MONITORING SPECTRAL RESPONSE

6. Field measurements of spectral reflectivity (in the visible/near infrared region) can be made by photographic techniques or by using electro-optical radiometers. Photographic techniques tend to be cheaper, smaller, lighter, simpler, and more robust, but are more difficult to calibrate in relative terms, and are less precise in absolute terms. Photographic techniques can be quite effective at indicating fairly coarse changes such as were anticipated in the case of seasonal changes in high arctic vegetation.

7. Of more significance than the type of instrument used to measure spectral reflectivity is the way in which it is used. If the objective is to provide data of significance to normal remote sensing techniques (air or spaceborne) then it is important that a similar viewpoint is obtained - ie vertical or nearly vertical views of the earth's surface. This is even more important in a study aimed at determining temporal change - it is important that illumination and viewing angle variations are reduced to the minimum. The easiest method of doing this is to use vertical views obtained at a standard local time. Ground instruments (cameras and radiometers) have been quite successfully used in agricultural cropland where there is a fairly homogeneous vegetation surface. They would be quite unsuited to the high arctic where many different classes (types) of vegetation can be found, necessitating many different areas to be sampled. Yet each class is locally variable with, for example, patches of bare ground and large shadows from hummocks and occasional boulders. It is therefore necessary to gain a wide angle view from some height above the ground so that the sampled area is sufficiently large to be statistically valid. Although it might be theoretically possible to obtain such a view from a large number of high towers dotted across the landscape, this would be impracticable and undesirable for a variety of reasons, including unnecessary ecological damage. An aerial platform of some sort is therefore indicated.

POTENTIAL AERIAL PLATFORMS

8. There are a number of alternative potential aerial platforms:

a. Conventional aircraft.

b. **Microlight** aircraft.

c. Hang gliders.

d. Remote Piloted Vehicles (RPVs)

e. Balloons.

f. Kites.

9. Bearing in mind the requirement was for repetitive cover over a period of weeks, conventional aircraft could be immediately ruled out on the grounds of coat, and hang gliders on the grounds of being impracticable (they have to be manhandled to the top of a mountain for each short duration flight). **Microlights** have been successfully used for remote sensing (Graham and Read, 1984; Gregoire and Zeyen, 1986; Graham, 1988; Bartholomew et al, 1988) and have been suggested for military reconnaissance (Hogarth, 1990). However, **microlights** were (somewhat reluctantly) ruled out on the grounds that they would change the whole nature of the expedition which was using minimal transport technology (no skidoos or all terrain cycles). RPVS can be both fixed and rotary winged (helicopter) and can be of virtually any size (RPVs are also known as Unmanned Airborne Vehicles (UAVs) and drones are outwardly similar, but with internal autonomous guidance). Air photographs have been obtained from quite small model aircraft (Walker, 1988); from more sophisticated aircraft with wingspans over 3.5m (Tomlins and Lee, 1983); and from enormous military aircraft such as the Boeing Condor which has a wing span larger than a 747 jumbo jet, and costs about .$20 million US - excluding sensors (Henderson, 1990). Sensibly sized and priced RPVS could have been used for a project such as ours, but we lacked experience in operating them (which is not easily gained) and there are a number of problems in operating RPVS in an environment like Borup Fiord, especially since we had no prior knowledge of either the location of potential target areas or of possible landing sites (if not co-located there are very real problems of control). Whilst none of these problems are insuperable in themselves, in combination they caused us to discount RPVs. That left balloons and kites.

10. <u>Balloons.</u> It is often forgotten that the first air photographs had been taken from a balloon, in 1858 by the Frenchman Felix Tournachon (Nadar), which predated those taken from aircraft by half a century. Early experiments with balloons used both free flying and tethered types. It was soon realised that the spherical balloon shape which is cheap and easy to construct is ideal for free flying balloons (such as standard meteorological radiosondes, or sport hot air balloons). Free flying balloons are at the mercy of the wind and their route cannot be predicted with any great degree of confidence, except in the most general terms, as the Austrians discovered when using them as unmanned flying bombs in 1849. Free flying balloons are therefore not practicable for a remote sensing project such as the one envisaged. Early tethered balloons were also spherical in shape, but this shape is quite unstable in anything except the very lightest of breezes (as the British army discovered when using them for aerial reconnaissance photography in the Boer War) . A stable tethered balloon must be of the cigar shape, similar to airships such as the German Zeppelins. However, such a shape is much more complicated (and expensive) to manufacture, and the envelope is much heavier for the same volume, which in turn means that the balloon must be much bigger,

to contain more gas to lift both its own envelope weight and any payload (including the tethering line). After much helpful discussion with the balloon section of the (British) Meteorological Research Unit at RAF Cardington it was decided that the logistic problems of the gas supply would be too great for the Borup Fiord expedition.

11. Kites. Kites are the oldest of all aerial structures, whose invention and use in the East predates the historical record. Even in Europe they are fairly ancient, and may have been used by the Greek Archytas of Tarentum in the fifth century BC. The most famous scientific experiment with a kite was that of Benjamin Franklin investigating lightning in 1752. The German Navy in World War II developed the Fa 330 Bachstelze (Wagtail) which was a rotary winged kite towed behind a Type IX U-boat, lifting an observer to a height of 500 ft which gave an immensely greater horizon compared to the *conning* tower. Sometimes, instead of merchant ship targets, potentially hostile aircraft were sighted, and there might be insufficient time to recover the observer before the submarine was forced to dive, in which case, to quote an official report, he "drowned in the usual way" (BBC, 1978). Apart from difficulties such as this the main problem with kites is that *unless towed* they require a significant breeze to provide sufficient lift. Thus, tethered spherical balloons can only be used in calm or nearly calm conditions and kites can only fly in moderate to strong breezes. It would seem sensible to consider a hybrid kite/balloon.

THE STEWKIE GAS-FILLED KITE

12. Keith Stewart of Stewkie Ltd has developed the Stewkie semi-sail which is an aerofoil section 5.15 sqm kite about 3m across, inflated with about 70 cu ft (2 cu m) of helium (or hydrogen). When inflated and with bridle attached (a cats cradle of lines similar in design and purpose to the lines of a parafoil (aerofoil parachute)) it can lift itself and a payload of about 0.5 kg in still air. In even a gentle breeze additional lift is provided by the aerofoil section, and it can be steered by means of a pair of control lines. Two (or *more)* kites can be stacked together and so provide additional payload capability. It was decided to purchase a pair of these semi-sails as a platform for aerial photography.

CAMERA OPERATION

13. Mount. The simplest method of mounting a camera to obtain vertical air photographs is to use a gimbal and attach the camera in such a way that its centre of gravity causes it to *point* directly downwards to nadir. The gimbal is positioned on the centreline of the kite, near the trailing surface, which allows an unobstructed field of view even with very wide angle lenses (20 mm on 35 mm camera). Two gimbals were made, one for 35 mm cameras and another for large format cameras.

14. Camera Control. Although cameras may be triggered by a variety of methods it was considered that radio control is the simplest, most reliable and most flexible. Accoms radio control systems designed for model aircraft operation were adapted so that an electrically powered servo fired the shutter. Such a system is extremely flexible in that virtually any camera type can be so operated. A few grams of weight could be saved by hard wiring the radio receiver into camera circuitry, but this limits camera choice considerably, and normally requires camera modification which can be undesirable, and expensive.

15. Camera Selection. The main requirements for a camera system were considered to be:

a. Capable of taking colour infrared photographs.

b. Good optics.

c. Automatic film advance.

d. Automatic exposure control.

e. Automatic exposure bracketing.

f. Light weight,

Colour infrared film is only available in 35 mm and 70 mm or larger formats. 70 mm aerial or ground cameras (such as the Hasselblad) are fairly hefty when fitted with motordrives and batteries etc, and would be on the heavy side for even two kites operating in moderate wind conditions. This was (rightly) considered likely to severely restrict their use and so the 35 mm format was selected as main camera for colour infrared photography. A larger format camera would be desirable for use as a secondary camera.

16. 35 mm Camera. Bearing in mind all of the requirements the Nikon F 301 camera was selected. This has a wide range of high quality lenses, and is one of the lightest 35 mm SLR cameras available with automatic film advance and exposure control. (NB compact cameras are unsuitable because of lens quality, maximum lens aperture and range of shutter speeds, and they also have a severely restricted range of focal lengths). The F 301 does not have an automatic exposure bracketing facility, but in 1988 this was only available on much heavier cameras. Automatic exposure bracketing is desirable for colour infrared photography because exposure meters measure visible and not infrared light.

17. Large Format Camera. A large format camera was considered highly desirable for obtaining large area index photographs in natural colour (and black and white). Mainly because it was already owned by the author, a Wista 5 x 4 Field camera was selected. Although the Wista is a modern camera, it is conspicuously different to 35 mm cameras like the Nikon F301. There is absolutely nothing automatic about it, requiring manual film insertion in dark slide, lens alignment and pre-focussing (not as straightforward as it sounds), lens aperture selection, shutter speed selection, and cocking of the shutter. The main lens intended for kite use was a Rodenstock Grandagon F 4.5 75 mm wide angle which is designed for use at small apertures only, but would have to be used wide open in order to enable a reasonable shutter speed to be used. (All field cameras are intended for tripod operation only). All these disadvantages were offset by the inherent advantages of the 5" x 4" (127 x 102 mm) negative format, the Wista outfit's relatively light weight (2.1 kg complete with gimbal) and the ease of fitting the radio control gear to operate the shutter. Only one photograph could be obtained on each "flight", so this large format system is unsuited for repetitive photography, but was considered ideal for obtaining one-off index photos of large areas. Trials with weighted sandbags established that a single kite could (just) lift this payload in ideal conditions and it was anticipated that there would be no problems with a pair of kites.

18. Camera Use. Some operational aspects of camera use are discussed below:

a. Filters. Camera lenses were always fitted with filters. A Wratten 12 or equivalent (yellow) was used with colour infrared film. Skylight

1B filters were used for natural colour and black and white film. It is essential that a filter is always fitted for lens protection purposes.

b. Lens Hoods. Although not essential for photographic reasons (for vertical air photographs) a lens hood is always desirable, especially for lens protection. Metal lens hoods offer more protection than rubber (they progressively deform under shock loading). However, we did not have a lens hood suitable for the Nikon 20 mm f2.8 lens when a filter was already attached, the shallowest lens hood we had caused some vignetting and the filter was more important (essential for infrared film) than the lens hood. This lens was therefore used without a lens hood.

c. Lens Focus, Aperture and Exposure. These factors are all inter-related. It is desirable to use a high shutter speed to "freeze" image motion. However, a high shutter speed results in a large aperture which reduces depth of field, and furthermore infrared light is focussed differently from visible light. It is therefore essential that a compromise is established or there will be image blur due to motion or focus problems. When using infrared film, aperture priority exposure was selected with a medium aperture (f5.6 or f8). The lens would then be set very slightly below the hyperfocal distance for this aperture and taped in position. This allowed for the fact that the camera would be operating at a distance less than infinity (30 m say) and would be focussed (at this distance) midway between the infrared and visible planes of focus (extrapolated using the red mark on the lens). The depth of field offered by the medium aperture should then be sufficient to bring all image components into sharp focus. This procedure is a lot easier in practice than it is to write down. With natural colour or black and white film the lens needs merely be focussed at the hyperfocal distance for maximum aperture, and then high speed programmed exposure selected.

d. *Note*. It is perhaps worth mentioning that "superfast" lenses are highly undesirable for this application. Not only are they significantly heavier (and more expensive) but they would introduce more focus problems. In practice they would have to be stopped down to apertures achievable by their lighter and cheaper brethren, and since they are optimised for use at maximum aperture they would probably produce inferior results. Wide angle lenses of f2.8 or 3.5 are probably best, and standard lenses should be about f2.0. Autofocus lenses and cameras are also undesirable because they are heavier and the autofocus would have to be disengaged for infrafred photography.

KITE OPERATION

19. The kite operating method devised for air photography consisted of two men, a kite "pilot" and a camera operator. A third man, to relay signals, might be necessary in certain topography.

20. Kite Pilot. The kite pilot "flew" the kite by means of handle grips on the two control lines which are made of "Spectra" line and have a 200kg breaking strain. Pulling with the left hand would *move* the kite to the left, and vice versa. Keeping the tension on the lines equal would allow the kite to rise, and moving it from left to right and back again would cause it to descend. In order to avoid the kite being torn from the pilots grip, and also so that the muscle strain was reduced to a minimum, the two handles were attached together by a short length of rope which ran through a puny. This puny could then be anchored so that nearly all the strain was taken on the anchor point and not the hand grips. The anchor devised by the kite manufacturer consisted of dog screws (normally 3, each about 0.5 m long) which

are screwed into the ground. In late June the snow has melted but the ground is still frozen and dog screws cannot be used. Mountaineering hollow core ice screws (medium and long length sizes) had been taken in anticipation of this problem and were found to be entirely effective in all except the stoniest soils. From the start we also experimented with attaching the pulley to the kite pilot via a Whillans climbing harness and screwgate karabiner. Initially a safety belay from pilot to dog/ice screws was used in case the pilot started "taking off", but this was found to be unnecessary with a single kite in the winds experienced. The Whillans harness became the standard method used.

21. Camera Operator. Whilst the kite pilot can judge and control the altitude and azimuth of the kite fairly precisely, it is virtually impossible for him to determine the range distance to the ground target (any increase in kite altitude above ground reduces the horizontal ground distance). It is also difficult for him to see where the camera is pointing (even with the gimbal arrangement used, gusts or control movements could result in non-vertical orientation). He also literally has his hands full. Thus it is necessary to have a camera operator who positions himself on or close to the target, directs the kite pilot by simple hand signals and watches the camera closely. It was found to be fairly easy to select the right moment to fire the shutter by radio control. (Binoculars could be used if the kite was at high altitude). In the light winds experienced it was found possible to hear the shutter firing/film advance, and also to hear when the film had all been used (unlike a model aircraft, the kite is soundless). Secondary tasks for the camera operator included launching and "landing" the kite. Normal launch procedure would be for the kite to be tethered to the ground, the control lines being run out upwind. When all control lines had been checked (a tangle or cross over could have a dramatic and dangerous result) and the kite pilot had signalled he was ready, the camera operator would untether the kite, take up any slack on the line and wait for the right wind conditions before releasing the kite. Two methods were used for landing the kite. In moderate (or strong) wind conditions the safest method was to join the kite pilot and then, with gloved hands, run down the two control lines. Care was needed not to grip either line or to let go with one hand (which necessitated letting go with the other hand to avoid a crash). In light wind conditions the pilot could usually fly the kite close enough to the ground to be caught by the camera operator, but this had its hazards (more for the catcher than for the kite - the kite would be traveling sideways at quite some speed when close to the ground, and the "lightweight" camera didn't seem so light sometimes).

22. Third Man. On only one occasion was it found desirable to have a third person. Communication from the kite pilot to camera operator could fairly easily be effected by voice because the camera operator would always be downwind. Communication in the opposite direction (which wss that normally desired) was usually done by simple hand signals. An eskimo archaeological site was photographed which was located on elevated ground near a lake. Due to wind direction at the time the kite pilot was positioned well below the site on a convex slope, and it was impossible for the camera operator to position himself in the view of the pilot and also be near to the target. A third man was therefore positioned at an intervisible location to relay hand signals.

23. Operating Height and Field of View. The height of the camera above ground depends on a combination of factors, including payload weight, wind conditions and length of control lines. In average wind conditions the 35 mm camera could be lifted to about 35 m height with the short (100 m) control lines. If long and short control lines were used together (450 + 100 m) a maximum height of over 200 m could be anticipated in good wind conditions. Using a pair of kites in tandem would increase these figures significantly. These height figures relate to the height of the camera above the anchor point

– if the kite pilot was above or below the target (often the case in hilly country) then this height difference should be taken into account. The camera field of view varies with height above target and lens focal length. A 20 mm lens on the Nikon camera would provide a horizontal field of view of about 50 m at 30 m height, and 34o m at 200 m height. At the same heights a 50 mm lens would provide a hroizontal field of view of about 20 and 140 m respectively. For scaling purposes fluorescent orange markers were placed on the ground at 10 m intervals (measured by tape) across the main study site.

FIELD USE

24. The techniques described worked very well in the field with only one exception, which was unfortunately a very major one. Due to late delivery, the kites had *only* been test flown very briefly in the UK before departure, but had been problem free. The first launch attempt in Borup Fiord revealed a design or manufacturing fault when a 20 cm rip occurred in one kite. Analysis of the damage suggested that there were two such critically stressed areas on each kite, and so after the rip was repaired (with special self adhesive tape) trouble spots were reinforced. This kite flew without further major problems throughout the expedition.

25. The second kite was flown a few days later and two of the bridle attachment points ripped out within a few minutes of launch, probably caused by a manufacturing fault. This damage was not repairable in the field. Ground wind speed at the time was measured at 8-10 knots (15-19 km/hr), gusting 13-15 knots (24-28 km/hr), which was well within limits (safe up to 35 knots (65 km/hr) according to the manufacturer).

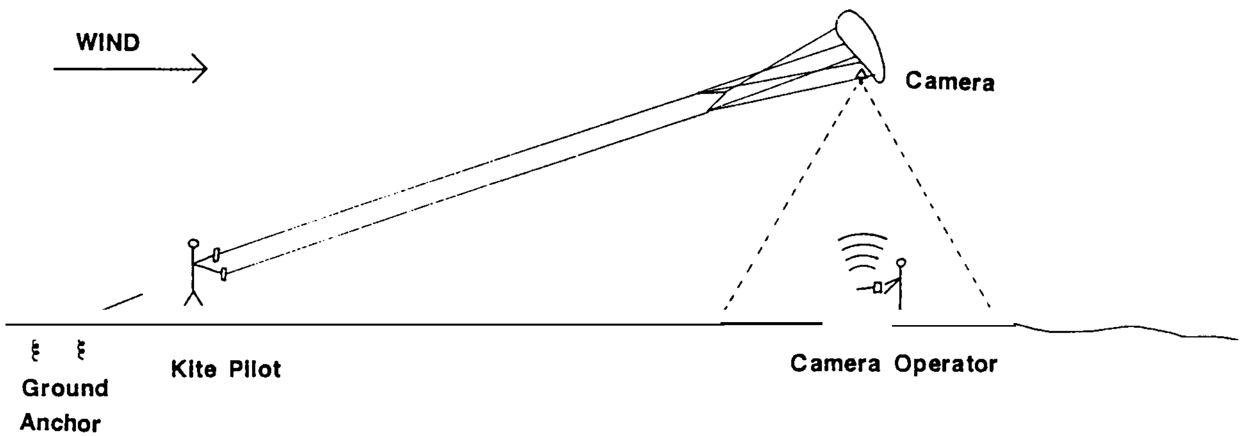
26. Thus, early in the expedition one of the two kites was a write-off. Although the kites could be flown individually, the main point of taking two was so that they could be stacked together to provide extra lift. In the light winds at Borup Fiord this would have been more or less essential for the heavier large format camera. Even with the lighter 35 mm camera it was found that a minimum ground wind speed of 6 knots (11 km/hr) was required in order to obtain a useful height even with a 20 mm wide angle lens.

27. In July 1988 at Borup Fiord there were very few days when winds were 6 knots (11 km/hr) or above (when the weather was also suitable for photography). Frustratingly wind speeds of 4-5 knots (7-9 km/hr) were fairly common, just below the required level. The main site for air photography had been selected because it contained a good range of co-located and representative vegetation classes. It proved also to be very sheltered (perhaps the two factors are related) and even when adequate winds occurred at base camp this site often proved to be in virtually calm air. This problem only became apparent in mid July by which time it was too late to select another site (the main objective was to get repetitive cover of the same area throughout the *season).* Although we do not know why this site was so sheltered, it is possible that proximity to a major glacier snout may have been a factor. The large expanse of clean ice that formed the Webber glacier snout was about 300 m above the study site, and the nearest part of the glacier about 3.5 km distant. It is possible that down draughts of cold air interfered with prevailing winds causing eddies, light turbulence and calms,

28. In an attempt to overcome the light wind problem we experimented with the kite pilot running backwards to give additional lift. This is not easy on the hummocky terrain, much of it covered with arctic white heather (*Cassiope tetragona*) with scattered boulders and holes not to mention the odd stream. All these obstacles make it virtually impossible to apply a steady controlled pull to the control lines and consequently the kite and camera tend to jerk violently and photography of the sort desired is not practicable. (It is also

KITE OPERATIONS

(Simplified and not to scale)



fairly hazardous/painful, not to mention hard work, but we were British Servicemen, and used to such things).

29. The reaction of the local wildlife to the kites had been a topic which engendered some discussion prior to the expedition. In the event birds appeared to ignore the kite, although it should be noted that we did not fly it in the vicinity of known nests, nor near arctic terns who have notoriously aggressive territorial instincts. As regards land mammals it was interesting to observe the behaviour of a pair of Peary caribou who approached a ground tethered kite showing every sign of inquisitive curiosity. It is unlikely that any motorised aerial platform (such as RFVS or microlights) would have had so little impact on the wildlife.

EQUIPMENT ASSESSMENT

30. This project established the feasibility of using gas filled kites to obtain air photographs. Individual items of equipment are assessed below.

31. 35 mm Camera. The Nikon F 301 performed well producing excellent results and standing up to some harsh treatment. Objects with which it collided (such as the author's head) tended to come off worse.

32. Gimbal Mount. The gimbal mount developed worked well and vertical air photographs were obtained fairly easily. Minor modifications aimed at damping down oscillations are indicated as desirable.

33. Radio Control. The Accoms Techniplus digital proportional radio control system worked faultlessly despite the rugged conditions of use. It was extremely flexible and was used for the Wista 5 x 4 field camera as well (but not from the kite, due to the problems described).

34. Kite Control and Tethering System. The short (100 m) kite control lines worked well. It proved impracticable to use the long (450 m) lines due to the wind conditions. The tethering dog screws and hollow core ice screws worked well. The Whillans climbing harness proved excellent at this unconventional use.

35. Helium Gas Supply. Small 40 cu ft (1.1 cu m) cylinders proved ideal for topping up purposes at deployed sites. Large 260 cu ft (7.4 cu m) cylinders were kept at base camp since they weigh over 50 kg and the author, for one, is not a masochist. All gas cylinders were old, discontinued sizes which had been written off and did not need to be airfreighted back to the UK. A spanner and short lengths of hose were the only equipment needed to transfer the gas into the kites. In order to save weight it had been decided not to take a pressure guage. This is not required for kite inflation which is done by common sense and "feel". However a gauge would have been desirable, to enable gas reserves to be accurately monitored.

36. Kites. One kite was damaged beyond repair early in the expedition, probably because of a manufacturing fault. The other kite had a design/manufacturing fault causing a 20 cm rip, but this was repaired quite easily. However, by the end of July this kite was "leaking" gas at a much higher rate than the manufacturer had advised. This could have been due to stresses caused by flights being greater than the manufacturer anticipated because we were using a heavier payload than the manufacturer normally employs. It could also have been due to microscopic punctures resulting from occasional (fairly gentle) contact with the ground in landing operations. (Ground sheets and nets were used to secure the kite safely when not being flown). Because we had sufficient gas reserves this "leakage" problem was an inconvenience rather than anything more serious, but it does indicate that a

stronger envelope material is required before these kites could he seriously considered for extended use in a harsh environment like Borup Fiord.

37. Kite Transport. Although not an equipment item as such it is worth discussing kite transport in the field, because it has implications for the quantity of gas consumed. Gas cylinders are heavy and it is highly undesirable to hump them over rugged terrain to deployed sites. It is therefore desirable to inflate the kite at base camp and transport it to and from deployed sites whilst fully inflated. In a complete calm this would pose no problems because it is (with no payload attached) lighter than air. It would be much *more* difficult in *even* light breezes unless the breeze happened to be in the right direction, and Murphy's law (well known in RAF circles) dictates that this is never the case. However, by inverting the bridle attachment arrangement (simply accomplished by the use of the mini-karabiners shortening the lines to the rear of the kite) the kite no longer presents an aerofoil section and it will bob around as if it were an ordinary balloon, more or less unaffected by any breeze, regardless of direction. The control lines could then be attached to a rucksac (preferably using a short rubber shock cord to absorb jerks caused by traveling over rough ground). The only problem with this system is the invective hurled by spectators who are convinced that loads are not being shared equally.

RESULTS

38. Due to the combined effects of:

a. The loss of one kite early in the expedition.

b. The light winds encountered,

the large format camera could not be flown, and repetitive 35 mm cover of the study site could not be obtained at the necessary frequency for the multi-temporal study. Nevertheless, some results were achieved.

39. Concept Proving. 35 mm vertical air photographs were obtained from a single kite. Colour infrared, natural colour and black and white photographs were obtained, free of image motion blurring and free of focus problems (important in the case of colour infrared film). Photographs were unobstructed by the kite or control lines even when a very wide angle lens (2o mm) was used. The cameras, lenses, gimbal mount, radio control gear, gas supply, kite anchoring and control systems all worked extremely well. The only (major) problem was the durability of the kite envelopes themselves.

40. Vegetation Studies. Visual inspection of the colour infrared photography revealed that there was little infrared reflectance early in the season. Comparison with ground infrared photographs indicates that less infrared is reflected upwards than sideways, probably due to the geometrical effects of plants with erect leaves and the viewing angle. These results are not unexpected, but they do confirm the need for aerial as opposed to ground sensors, and also indicate that remote sensing early in the season is unlikely to reliably detect vegetation due to the thresholding problem. (NB spectral behaviour would have been quantified by digital sensitometry if an adequate range of images could have been obtained. In the circumstances this could not be justified and so visual inspection alone was used to assess spectral response) .

41. Base Camp. Air photographs were taken of the base camp (situated in a very wet area of Cassiope heath, (much to the surprise of the author when he joined the expedition in late June). These photographs provide a detailed record of ecological damage caused by trampling and the construction of

drainage channels around tents. It is intended to return to Borup Fiord in 1991 and rephotograph the area. Comparative studies should then be able to establish rates of recovery and vegetative regeneration.

42. Archaeological Site. Air photographs of an eskimo archaeological site were obtained. Due to wind conditions and the fact that the site is elevated above the surrounding terrain it was only possible to obtain low altitude photographs (20 - 80 ft, 6-24 m) but these may be of assistance in interpreting the relationship between structures. The photographs could have assisted in the preparation of a planimetric map, but a detailed ground survey rendered this unnecessary.

CONCLUSIONS

43. This project demonstrated that gas filled kites can be used to obtain air photographs in remote and rugged environments at low cost. There were problems with the durability of the kite envelopes but all other equipment and operating methods worked well. The loss of one of the kites early in the expedition severely hampered the main objective concerning multi-temporal study of the spectral response of vegetation, but did allow the confirmation of the value of an aerial sensor platform as opposed to ground based sensors, and also confirmed the low level of reflected near infrared radiation from high arctic vegetation early in the season. Aerial photographs of the base camp area and of an archaeological site indicated the flexibility and value of an aerial photography facility for small expeditions to remote locations.

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44. Apart from the main sponsors of the expedition who are listed elsewhere, grateful thanks are due to a number of individuals including the following: John Pitchforth of Nikon (UK) Ltd for advice and the loan of cameras; Mr Stringer of Richard Kohnstsm Ltd for advice and the provision of radio control gear; and Keith Stewart of Stewkie Ltd (Kites). Mr Lappworth and Mr Hignet of the Meteorological Research Unit, RAF Cardington provided a great deal of helpful advice on balloons. Corporal Huggett of the Servicing Section, JARIC, RAF Brsmpton provided valuable engineering assistance in gimbal modification.

A NOTE ON COSTS

45. A complete aerial photography system as described (including kitea, control and anchoring equipment, gas, cameras/mounts and radio control gear) would probably cost between £2,500 and £3,000 (in 1988 prices). The cost to this expedition was (due to generous assistance from sponsors) only a fraction of this amount. Any similar expedition could make significant savings by using dual purpose equipment (such as cameras, which are not specially modified and may be used normally, and any group engaged in mountaineering will have ice screws, karabiners, climbing harnesses etc). It may be possible to "borrow" the small amount of helium gas needed from a friendly local meteorological station, although they would probably want the cylinders back.

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Floristics and Phytogeography

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ABSTRACT. - One hundred and twenty three species and three subspecies of vascular plants are reported from Borup Fiord, Ellesmere Island. Carex subspathacea is reported from Ellesmere for the first time, while Arenaria humifusa, Pyrola grandiflora, and Saxifraga aizoides are new to northern Ellesmere. The vascular flora is comprised largely of species with circumpolar and arctic or arctic-montane distributions, but includes a large number of North American or Amphi-Atlantic species with arctic or arctic-montane distributions. Preliminary data indicate that the region posesses a moss flora of 135-145 species, and a hepatic flora totalling 30-45 species. Factors contributing to the high floristic diversity of the region include habitat diversity, climatic favorability, and the vegetational and glacial history of northern Ellesmere Island.

1. Introduction

The bryophyte and vascular plant floras of, northern Ellesmere Island have attracted the attention of botanists from the earliest days of exploration in that region (cf. Bessels 1876, Greely 1886, 1888, Hart 1889, Mitten 1878, Rydberg 1911, 1912), and interest continues to the present day.

Two factors contributing to ongoing interest in the region are the relatively high species diversity found there (Alt & Edlund 1989, Brassard 1971a,b, 1976, Brassard & Beschel 1968, Soper & Powell 1985), and the presence of species that are disjunctive to low arctic-boreal and/or temperate regions of North America; the latter has been taken by some authors as evidence of plant persistence in northern Ellesmere throughout at least the last (Wisconsin) glacial period (Brassard 1970, 1971a,b,c, Schuster et al. 1959, Simmons, 1913). Other workers have shown that both

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areas of high species diversity and the presence of "southern" disjunctive taxa in the Queen Elizabeth Islands coincide with favorable thermal conditions, and suggest that mild summer temperatures may, at least in part, explain both phenomena (Edlund & Alt 1989, Bridgland & Gillett 1983).

The north shore of Greely Fjord can be numbered among the botanically better known areas of northern Ellesmere Island, and plant diversities there are among the highest in all the Queen Elizabeth Islands. (Brassard 1971a,b, 1976, Brassard & Beschel 1968; Brassard & Longton 1970, Mausbacher 1981, Soper & Powell 1985). However, enormous gaps still exist in the floristic data for the region, and the primary objective of botanical research at Borup Fjord was to augment floristic knowledge of the Greely Fiord area in particular, and of northern Ellesmere in general.

Collections of vascular plants and bryophytes were made at Borup Fjord in the period June 25 to August 20. For the vascular plants, emphasis was placed on collecting at least one voucher of every species present in the study area, rather than on detailed documentation of local distribution (eg. by habitat or altitude). Collecting effort for vascular species was concentrated on the area at the head of Esayoo Bay and virtually all the collections are from within four km. of Base Camp. Approximately 240 collections of vascular plants were made, usually in sufficient quantity for at least two duplicates. A complete set of voucher specimens will be deposited at the Agnes Marion Ayre Herbarium, Memorial University of Newfoundland, and a second, nearly complete, set will be deposited at the herbarium of the University of Lancaster.

For the bryophytes, an attempt was made to to collect in all the recognizable habitats, and special collecting effort was directed at habitats particularly rich in species (eg. snowmelt slopes). For each species, all morphological variants encountered in the study area were collected in the hope that the specimens will contribute to the data required for systematic evaluation of numerous Arctic bryophyte taxa. Collections of bryophytes were made at 19 localities scattered around Borup Fjord, and a total of 1487 bryophyte specimens were collected, usually in sufficient quantity for at least three duplicates. On identification, the specimens will be disposed as follows: complete sets to the Bryophyte Herbarium, Memorial University of Newfoundland and The National Herbarium of Canada; virtually complete sets to the University of British Columbia and University of Michigan; and a representative set to the personal herbarium of TAH.

This paper deals primarily with the vascular flora of Borup Fiord, and a selectively annotated list of the vascular plants collected in 1988 is presented, along with a phytogeographical analysis of the vascular flora. Although the bryophyte specimens are mostly still unidentified, a brief bryofloristic summary is included, based largely on field determinations.

2. RESULTS

2.1.1 Selectively Annotated List of Vascular Plant Species

The following list contains the 123 species and three sub-species, in 56 genera, collected at Borup Fiord in 1988. One of these species is reported for the first time from Ellesmere Island (preceded by **), and three are additions to the northern Ellesmere flora (preceded by *). Taxonomic concepts and nomenclature used in this list largely follow Porsild (1964), except for the genus Draba where the treatments of Mulligan (1974, 1976) are used. Brief annotations are given for a few rare or phytogeographically noteworthy taxa.

Eauisetum arvense L.

Equisetum variegatum Schleich.

Lycopodium selago L. Occasional in Rhacomitrium lanuginosum - Cassiope tetragona heath over igneous rocks, especially in slight seepage areas below snowbeds. In the study area, this somewhat acidophilous species is very near its northern limit of distribution within the Canadian arctic.

Cystopteris fragilis (L.) Bernh.

Woodsia glabella R.Br.

Agropyron violaceum (Hornem.) Lange.

Alopecurus alpinus L.

Arctagrostis latifolia (R.Br) Griseb.

Colpodium vahlianum (Leibm.) Nevski Very rare. A single sparse population was found on wet clay flats of a river delta.

Deschampsia brevifolia R.Br. Surprisingly rare in the study area, found once on silty riverside soil.

Dupontia fisheri R.Br. Rare. Found twice on thin turf over sandy soil along meltwater streams. In the study area, this species is very near its northern limit of North American distribution.

Festuca baffinensis Polunin

Festuca brachyphylla Schultes

Phippsia algida (Sol.) R.Br. Rare. On wet, silty, braided river flats and on wet clay slopes.

Pleuropogon sabinei R.Br. Very rare. A few plants of this species were found growing with Ranunculus hyperboreus among mosses on the margin of a shallow pond.

Poa abbreviate R.Br.

Poa arctica ssp. caespitans (Simm.) Nannf.

Poa glauca M. Vahl.

Poa hartzii Gand.

Puccinellia angustata (R.Br.) Rand. & Redf.

Puccinellia phryganodes (Trin.) Scribn. & Merr.

Puccinellia poacea Th. Ser.

Trisetum spicatum (L.) Richt.

Carex amblyorhyncha Krecz. Occasional in wet sedge meadows where it was usually intermixed with Carex stans, and rarely grew as pure populations. This is but the third record of the species from Ellesmere Island where it was previously known from the Hayes Sound and Lake Hazen areas (Bridgland & Gillett 1983, Soper & Powell 1985).

Carex atrofusca Schk.

Carex capillaris L. ssp. capillaris Rare in the study area and found on dry, sunny, clay-shale slopes. This subspecies is known elsewhere on Ellesmere only from the Lake Hazen area (Soper & Powell 1985)

Carex capillaris L. ssp. robustior (Drej. ex Lange) Bother

Carex glacialis Mack. Rare in the study area where it was found once on a dry gravel slope. This species is known in the Queen Elizabeth Islands from only Ellesmere Island and Axel Heiberg. Elsewhere on Ellesmere, known from Hayes Sound (Bridgland & Gillett 1983), Lake Hazen (Soper & Powell 1985), and one other locality on the south coast of the island (Porsild 1964, Map 91).

Carex membranacea Hook. Common and abundant in wet sedge meadows. Apparently rare elsewhere on Ellesmere Island (Brassard & Beschel 1968, Bridgland & Gillett 1983)

Carex misandra R.Br.

Carex _ Fr. var. atriceps Kuk.

Carex rupestris All.

Carex scirpoidea Michx. Uncommon. On dry turfy slopes, and shallow peat near pond margins. Previously recorded only once from northern Ellesmere from Princess Marie Bay (Torrens-Spence 1981). Apparently very rare on Ellesmere and in the Arctic Archipelago. Recorded elsewhere in the Queen Elizabeth Islands only from Dundas Harbour, Devon Island (Polunin 1940).

Carex stans Drej.

**Carex subspathacea Wormskj. New to Ellesmere Island, and known elsewhere in the Queen Elizabeth Islands from a single locality on Devon Island (Porsild 1964, Map 87), this species seems uncommon throughout the Arctic Archipelago. At the single site where it was found at Borup, C. subspathacea was abundant (covering an area ca. 15 m^2) on wet clay around a small brackish lagoon ca. 0.5 m above the high tide line.

Carex ursina Dew.

Eriophorum angustifolium Honck. Very rare. Found twice in shallow pools in wet sedge-moss meadows. This species is known only from Ellesmere in the Queen Elizabeth Islands.

Eriophorum callitrix Chain. Rare. On thin turfy soil over gravel in seasonally wet moss-dominated areas. Recorded only once previously for northern Ellesmere from Princess Marie Bay (Torrens-Spence 1981) and seemingly very rare on all of Ellesmere. This species seems not to have ben recorded elsewhere in the Queen Elizabeth Islands and the Ellesmere populations are disjunct from populations on Bank!s and Victoria Islands as well as those on Baffin and in East Greenland (Porsild 1964, Map 62).

Eriophorum scheuchzeri Hoppe

Eriophorum triste (Th.Fr.) Hadac & Love

Kobresia myosuroides (Vill.) Fiori & Paol. Uncommon. On dry clay hummocks with Dryas integrifolia and on gravel-clay slopes with Carex nardina.

Kobresia simpliciuscula (Wahl.) Mack. Very rare. Collected once, from a S-facing gravel slope where it was growing with Carex rupestris, Arnica alpina, and Erigeron eriocephalus. Rare on Ellesmere, known from only 5 localities (Bridgland & Gillett 1983). Elsewhere in the Queen Elizabeth Islands, known only from Devon Island (Porsild 1964, Map 70).

Juncus albescens (Lange) Fern. Very rare. Two sparse populations were found on silty soil of braided stream deltas. The distribution of this species in the Arctic Archipelago is very similar to that of Kobresia simpliciuscula.

Juncus biglumis L.

Luzula confusa Lindebl.

Luzula nivalis (Laest.) Beurl.

Salix arctica Pall.

Oxyria digyna (L.) Hill.

Polygonum viviparum L.

*Arenaria humifusa Wahlenb. Rare. Found only on stony clay soil on somewhat seepy slopes. New to northern Ellesmere, and known otherwise on the island from the Hayes Sound Region and Harbour Fiord (Bridgland & Gillett 1983). Elsewhere in the Queen Elizabeth Islands, known only from Cornwallis Island (Porsild 1964, Map 147).

Cerastium alpinum L.

Cerastium arcticum Lange.

Cerastium beeringianum Chain. & Schlecht.

Cerastium regelii Ostenf. Occasional. On wet clayey soil, often near the sea-shore or on margins of shallow ponds. All of the plants seen in the study area were the dense, pulvinate form. Only two populations were found with flowers.

Melandrium affine J. Vahl.

Melandrium apetalum (L.) Fenzl. ssp. arcticum (Fr.) Hult.

Minuartia rubella (Wahl.) Hiern.

Silene acaulis L. var. exscapa (All.) DC.

Stellaria crassipes Hult.

Stellaria edwardsii R.Br.

Stellaria laeta Richards.

Stellaria monantha Hult.

Ranunculus aquatilis L. var. eradicates Laest. Rare, found only once in shallow water along a lake margin. This population did not flower in the 1988 season.

Ranunculus hyperboreus Rottb. Rare, found only twice on moss mats at the margin of shallow ponds. At both sites the species was abundant and flowering profusely.

Ranunculus nivalis L,

Ranunculus sabinei R.Br.

Ranunculus sulphureus Sol,

Papaver cornwallisensis D. Love

Papaver radicatum Rottb.

Braya humilis (C.A. Mey.) Robins. ssp. arctica (Bother) Rollins
Occasional, occurring on clay or silt slopes or gully ridges. Rare on Ellesmere Island, known only from the Lake Hazen area, Fosheim Peninsula, (Soper & Powell 1985), and Tanquary Fiord (Brassard & Beschel 1968). The Ellesmere populations are considerably disjunct from populations in the southwestern part of the Arctic Archipelago and adjacent Mackenzie District, and those in eastern Greenland (Porsild 1964, Map 200)

Braya purpurascens (R.Br.) Bunge

Braya thorild-wulfii Ostenf.

Cardamine bellidifolia L.

Cardamine pratensis L. var. angustifolia Hook. Very rare. A single population of ca. 30 plants was found on marshy ground at the margin of a shallow pond. Although C. pratensis is reportedly sterile at Lake Hazen and Cape Herschel (Bridgland & Gillett 1983, Soper and Powell 1985), plants in the Borup population were flowering profusely.

Cochlearia officinalis L.

Draba alpina L.

Draba cinerea Adams

Draba corymbosa R.Br.

Draba glabella Pursh. Rare. Found twice on gravelly soil near bird perches. This species has been recorded elsewhere in the Queen Elizabeth Islands from two additional localities on Ellesmere (Bridgland & Gillett 1983), and from Axel Heiberg (Porsild 1964, Map 193).

Draba lactea Adams

Draba nivalis Liljebl.

Draba oblongata R.Br. ex DC.

Draba subcapitata Simm.

Erysimum pallasii (Pursh.) Fern. Very rare. Found once on a dry, S-facing igneous gravel slope.

Eutrema edwardsii R.Br.

Halimolobus mollis (Hook.) Rollins. Uncommon. On moist clay on moderately sloping ground. Elsewhere on Ellesmere, and in the Queen Elizabeth Islands, known only from Lake Hazen and Hayes Sound (Bridgland & Gillett 1983, Soper & Powell 1985). The northern Ellesmere populations, with those in adjacent northwest Greenland, are considerably disjunct from those in Baffin and adjacent southwest Greenland and from those in continental northwestern America.

Lesquerella arctica (Wormskj.) S. Wats. Surprisingly rare. Found only twice on dry clay ridges.

*Saxifraga aizoides L. Occasional, usually abundant where found. In shallow, seasonally wet meadows over gravelly soil, and on clay of slightly seepy slopes. New to northern Ellesmere, and a substantial northern range extension from the south coast of Ellesmere and adjacent northwest Greenland (Porsild 1964, Map 206). Known only from Ellesmere in the Queen Elizabeth Islands.

Saxifraga caespitosa L. ssp. exaratoides (Simm.) Engl. & Irmsch. emend. Porsild. Rare. Two small populations were found on seepy gravel-clay slopes at the base of igneous sills. Known elsewhere on Ellesmere, and in the Queen Elizabeth Islands, only from Lake Hazen (Soper & Powell 1985) and a single locality on the south coast (Porsild 1964, Map 210). This subspecies is otherwise restricted to Paleozoic parts of the Hudson Bay region (Porsild 1964).

Saxifraga caespitosa L. ssp. uniflora (R.Br.) Porsild

Saxifraga cernua L.

Saxifraga flagellaris Wind. ssp. platysepala (Trautv.) Porsild

Saxifraga foliolosa R.Br.

Saxifraga hieracifolia Waldst. & Kit. Occasional on seepy clay slopes and in moist moss mats in slight seepage at higher elevations. Previously known on Ellesmere only from Oobloyah Bay (Mausbacher 1981) and known from fewer than 6 localities in all the Queen Elizabeth Islands. S. hieracifolia is sporadically distributed throughout its North American range (Porsild 1964, Map 214)

Saxifraga hirculus L. var. propinqua (R.Br.) Simm.

Saxifraga hyperborea R.Br.

Saxifraga nivalis L.

Saxifraga oppositifolia L.

Saxifraga rivularis L.

Saxifraga tenuis (Wahl.) H.Sm.

Saxifraga tricuspidata Rottb.

Dryas integrifolia M.Vahl.

Geum rossii (R.Br.) Ser. Not common, but usually abundant where it does occur. On wet clay of solifluction lobes or near the foot of glaciers.

Also on wet mossy tundra in areas of late snow. A predominantly Beringian species which also occurs in a few scattered localities on Melville Island, Axel Heiberg, and the Nares Sound-Greely Fiord area of Ellesmere Island. The populations in the study area are the easternmost known for the species.

Potentilla hyparctica Malte

Potentilla nivea L. ssp. nivea Very rare. Found once on a steep, S-facing basaltic scree slope. Otherwise known on Ellesmere and in the Queen Elizabeth Islands only from Lake Hazen (Soper & Powell 1985).

Potentilla nivea I... ssp. chamissonis (Hult.) Hiit.

Potentilla rubricaulis Lehm.

Potentilla vahliana Lehm.

Epilobium latifolium L.

*Pyrola grandiflora Rad. Occasional in dry habitats, especially on dry, s-facing, diabase gravel slopes. New to northern Ellesmere. Elsewhere on the island recorded from the Hayes sound region (Bridgland & Gillett 1983) and from southern Ellesmere (Porsild 1964, Map 263).

Cassiope tetragona (L.) D.Don. Very common. Especially abundant in late snow areas and on seepy slopes dominated by Rhacomitrium lanuginosum.

Vaccinium uliginosum L. var. alpinum Big. Occasional. Often quite abundant on S-facing, igneous gravel slopes. All the populations seen in the study area produced abundant fruit in the 1988 season.

Empetrum nigrum L. ssp. hermaphroditum (Lge.) Both. Rare. Found twice with Vaccinium uliginosum on S-facing, igneous gravel slopes. An acidophilic species near its northern limit in the study area. Both this species and the preceding are restricted in the Queen Elizabeth Islands to Ellesmere, Axel Heiberg, and Devon Islands (Edlund & Alt 1989).

Armeria maritima (Mill.) Wind. ssp. labradorica (Wallr.) Hult.

Pedicularis arctica R.Br.

Pedicularis capitata Adams

Pedicularis hirsuta L.

Pedicularis lanata Chain. & Schlecht.

Pedicularis sudetica Wind.

Arnica alpina (L.) Olin ssp. angustifolia (Vahl.) Maguire Frequent. Most often on dry igneous gravel slopes but also on sheltered clay-gravel slopes. In the Queen Elizabeth Islands restricted to Melville, Axel Heiberg, and Ellesmere Islands (Edlund & Alt 1989).

Antennaria compacta Malte. Very rare. Found once on a dry S-facing clay-gravel slope below an igneous dyke. In the Queen Elizabeth Islands, restricted to a few localities on Melville, Axel Heiberg, and

Ellesmere Islands. Otherwise known in North America from Alaska-Yukon, the Mackenzie district of the continental Northwest Territories, and from Banks and Victoria Islands in the southwestern part of the Arctic Archipelago.

Chrysanthemum integrifolium Richards Common. Most frequent on Dryas dominated clay slopes but also found on gravel or scree slopes and, rarely, on moss mats in slight seepage. Rare in the Queen Elizabeth islands where it occurs on Devon Island and northern Ellesmere (Brassard & Beschel 1968, Brassard and Longton 1970, Soper & Powell 1985, Porsild 1964 Map 316).

Erigeron compositus Pursh Very rare. A single population of ca. 15 plants was found on a dry S-facing diabase gravel slope. The distribution of this species in the Queen Elizabeth Islands is very similar to that of Antennaria compacta (Edlund & Alt 1989).

Erigeron eriocephalus J. Vahl. Occasional. On dry gravels and screes, or on steep walled stream embankments. The distribution of this species in the Queen Elizabeth Islands is very similar to that of Antennaria compacta (Edlund & Alt 1989).

Taraxacum pumilum Dahlst. Very rare. A single population of ca. 10 plants was found on a very dry, S-facing, diabase gravel slope.

2.1.2 Phytogeography

A two-way phytogeographical classification of the Borup Fiord vascular flora is presented in Table 1. This classification is based on information in Porsild (1964), Porsild & Coady (1980), Hulten (1962, 1971), and Soper & Powell (1985). Plants are grouped on the basis of longitudinal extent of distribution into Circumpolar, Amphi-Atlantic, North American, and Amphi-Beringian elements and, on the basis of latitudinal extent of distribution, these are subdivided into Arctic, Arctic-montane, and Arctic-boreal elements. Of the 12 resulting distributional classes, 10 occur at Borup Fiord. None of the plants in the study area show Amphi-Atlantic and Boreal or Amphi-Beringian and Boreal distributions.

The majority (77 species or 66.1%) of the Borup Fiord flora is comprised of species with circumpolar distributions. Of these, 42 (33.3% of the total flora) are arctic-montane, occurring throughout the circumpolar arctic region and extending south in mountains (eg. Epilobium latifolium, Fig. 1). Twenty-seven of the circumpolar species (21.4% of the total flora) are restricted to arctic regions (eg. Cassiope tetragona, Fig. 2), and an additional eight species (6..4% of total) are widespread in both arctic and boreal regions of the northern hemisphere (eg. Cystopteris fragilis, Fig. 3).

With 23 species (18.2% of flora), the next largest element occurring at Borup Fiord is that made up of species endemic to North America. Of these, 12 (9.5% of flora) are restricted to arctic regions (eg. Potentilla rubricaulis, Fig.4), 9 (7.1% of flora) are arctic-montane (eg. Festuca baffinensis, Fig. 5), and 2 (1.6% of flora) are widespread in arctic and boreal regions of the continent (eg. Carex scirpoidea, Fig. 6).

The Amphi-Atlantic element, with 21 species (16.7% of the flora), is only slightly smaller than the North American element. Of these, 13 species (10.3% of flora) have arctic distributions (eg. Pedicularis hirsuta, Fig. 7), while 8 species (6.4% of flora) have arctic-montane distributions (eg. Cerastium alpinum, Fig. 8).

A small Amphi-Beringian element, including only 5 species (4% of flora), also occurs in the study area. Of these, 3 (2.4% of flora) are restricted to arctic regions (eg. Papaver cornwallisensis, Fig. 9), while 2 (1.6% of flora) show arctic-montane distributions (eg. Geum rossii, Fig. 10).

If only the latitudinal aspect of distribution is considered, then the vast majority (92.4%) of the Borup Fiord vascular flora is either arctic-montane (48.4%) or restricted to the arctic (43.7%). Only 10 species (7.9%) have distributions which extend into the boreal biome.

2.2 Bryology

At least 122 moss species and 19 hepatic species occur at Borup Fiord. These totals are based on species which could be identified with a reasonable degree of confidence in the field and must be considered conservative estimates. Several genera, within which field identification was impossible (most notably Bryum, Brachythecium, Drepanocladus, Grimmia, Lophozia s.l., Hypnum, and Pohlia), were counted as one species, even though several species of each occur in the study area. Thus, the number of mosses recorded from Borup Fiord might reasonably be expected to rise to at least 135-145 species, and the number of hepatics to 30-45 species.

Several of the mosses occurring at Borup Fiord are of outstanding phytogeographical significance. Newly recorded from the Canadian Arctic are Seligeria diversifolia and Tetrodontium repandum (Hedderson & Brassard in prep.). Both species are of temperate affinity and disjunct by ca. 2,300 km. from the nearest stations in northern Alaska. The Alaskan stations are themselves disjunct from the main range of each species in temperate eastern North America. Other boreal or temperate mosses disjunctive to northern Ellesmere and occurring at Borup Fiord are Pohlia atropurpurea, Seligeria pusilla, and Trichodon cylindricus.

Considerable among-habitat variation in species diversity is apparent from the available data. Habitats with highest species diversity include sheltered clay gulley embankments, igneous rock cliffs and their associated boulder-soil slopes, tundra slopes with continuous water supply from melting snowbanks, and seasonally wet, fen-like meadow areas over coarse sand or gravel. Lowest diversity was seen on dry gravel slopes, exposed rock knolls, and on dry clay flats.

3. Discussion

The one hundred and twenty-three species of vascular plants recorded here is likely an underestimate of the total vascular flora of the Esayoo Bay area. Several species seemingly widespread on northern Ellesmere (eg. Poa alpigena (Fr.) Lindm., Festuca hyperborea Holmen., Calamagrostis purpurascens R.Br. Epilobium arcticum Samuelss.) were not collected in the study area. The majority of these are in taxonomically difficult groups and may have been missed through inexperience, or are species of habitats which were not covered particularly well in the present study. Additional collecting in the study area may bring the total flora to 135 species or more.

Even with 123 species, the vascular flora of the head of Esayoo Bay is among the most diverse in the Queen Elizabeth Islands. Comparable species numbers have been reported from Lake Hazen (127 (Soper & Powell 1985)), Tanquary Fiord (119 (Brassard & Beschel 1968)), Devon Island (117 (Muc & Bliss 1977)), Hayes Sound (117 (Bridgland & Gillett 1983), and the Fosheim Peninsula (130 (Edlund _et al_. 1989)). However, the area covered by each of these reports is at least one order of magnitude greater than the _ca_. 35 km^2 covered in the present work. Species numbers from areas of more comparable size are usually much lower than that found at Borup Fiord. For example, in the Hayes Sound region, individual collecting localities have between 20 and 91 species each, and the Trulove Lowland of Devon Island, with an area of 40 km^2, has 93 species.

The moss flora, with at least 122 spp. and more likely 135-145 species, is also among the most diverse in the Queen Elizabeth Islands. Species numbers listed by Brassard (1976) for localities on northern Ellesmere range from 120 (Tanquary Fiord) to 60 (Lincoln Bay), and 131 moss species have been recorded for the northern lowlands of Devon Island (Vitt 1975).

A number of factors contribute to the diversity of the Borup Fiord flora. Habitat diversity in the area is high, largely as a result of physiographic diversity, but lithographic diversity is also important. While the majority of the underlying bedrock is calcareous and sedimentary in origin, acidic rocks, largely of volcanic origin, also occur in the area. The presence of these acidic outcrops accounts for the occurrence of acidophilic plants (Porsild 1964) which are otherwise rare or absent on northern Ellesmere (eg. _Empetrum nigrum_, _Lycopodium selago_, _Saxifraga_ caespitosa ssp. exaratoidea), and such species are, in the study area, completely restricted to igneous rocks. Littoral habitats are well developed in the study area and account for the local presence of a number of halophytic taxa (eg. Carex maritima, C. subspathacea, C. ursina, Cochlearia officinalis, Puccinellia phryganodes).

The climatic favorability of the study area may also be a major factor contributing to the plant diversity found there. A positive relationship between summer temperature and plant species diversity has been well documented for the circumpolar arctic area in general (Young 1971) and for the Queen Elizabeth islands in particular (Edlund & Alt 1979, Bridgland & Gillett 1983). On the basis of criteria given in Edlund & Alt (1989), Borup Fiord falls clearly into their Zone 4, characterized by high species diversity (100+) and well developed vegetation dominated by shrubs and sedges. Summer temperatures in the study area are among the highest recorded for the Arctic Archipelago. The mean July temperature of 9.3 Co, for example (Hankinson this vol.), is exceeded in the arctic archipelago only at Hot Weather Creek on the Fosheim Peninsula (Edlund et al., 1989).

Another climatic feature of Borup Fiord which may contribute to high plant diversity is the relatively high precipitation found there (Hankinson this vol.). Relationships between water availability and both species occurrence and vegetation zonation have been noted in many arctic botanical studies (eg. Bliss & Svoboda 1984, Sheard & Geale 1983).

Eleven of the species occurring in our area are listed by Edlund & Alt (1989) as showing disjunctions and/or highly restricted distributions within the Canadian high arctic:

Antennaria compacta	Erigeron eriocephalus
Arnica alpina ssp. angustifolia	Erysimum pallasii
Cassiope tetragona	Geum rossii
Empetrum nigrum ssp. hermaphroditum	Pyrola grandiflora
Epilobium latifolium	Vaccinium uliginosum
Erigeron compositus	

Using the same criteria, an additional 24 of the vascular plant taxa occurring at Borup Fiord should be placed in this category:

Agropyron violaceum	Halimolobus mollis
Braya humilis	Juncus albicans
Chrysanthemum integrifolium	Pedicularis lanata
Carex amblyorhyncha	Potentilla nivea ssp. chamissonis
C. scirpoidea	P. nivea ssp. nivea
C. glacialis	P. rubricaulis
C. subspathacea	Ranunculus aquatilis var. eradicates
C. capillaris ssp. robustior	Saxifraga aizoides
Draba cinerea	S. caespitosa ssp. exaratoides
D. glabella	S. hieracifolia
Eriophorum angustifolium	Stellaria monantha
E. callitrix	Taraxacum pumilum

These species show distributions within the arctic which are largely coincident with areas of high summer temperature (Edlund & Alt 1989, Bridgland & Gillett 1989, Young 1971), and temperature limitation has been considered to constitute a sufficient explanation of their present distribution.

Explanations of how the disjunctive species have attained their present distribution are more varied. Edlund & Alt (1989) appear to suggest quantum dispersal from more southerly locations. This explanation seems fraught with difficulty since, as these authors note, it requires dispersal against prevailing winds and, in any case, many of the species with disjunctive distributions within the arctic archipelago show no particular adaptation for long-distance transport,

A more plausable explanation, offered by Bridgland & Gillett (1983), is that the "southern" plants migrated northward in a post-glacial warm period and, with subsequent cooling, have become restricted to the warmest parts of the Queen Elizabeth Islands. Such plants may thus be thought of as thermal relicts.

It has also been postulated that the quite sizeable disjunctions exhibited by some of the species occurring in the study area (eg. Halimolobus mollis, Potentilla nivea), may be the result of anthropochore dispersal (Bother 1951, Bridgland & Gillett 1983, Young & Hall 1969). Species thought to fall in this category are ones that are often associated with human habitation or that have been used by Inuit for food or medicinal purposes

At least some of the disjunctive plants may have survived the last glaciation in ice-free areas of northern Ellesmere Island (Bother 1951, Brassard 1971, Simmons 1913), and have failed to colonize intervening regions. The areas occupied by many of the species listed above coincide quite well with those thought, on the basis of geomorphology, to have been ice free throughout the Wisconsin glaciation (Dyke & Prest 1987). The climate of such ice free areas, especially in the warm intermontane (sensu Edlund & Alt 1989) region of the Queen Elizabeth islands, may not have been more severe than it is today. With the present data, however, it seems impossible to choose between the "thermal relict" and "glacial relict" hypotheses, and it is quite conceivable that both have played a role in determining the modern composition of the Borup Fiord flora.

The floristic composition of the vascular flora of the study area appears similar to that found in Other parts of the Queen Elizabeth Islands. Most floras in the region are dominated by circumpolar or amphi-atlantic species with arctic or arctic-montane distributions, and North American elements usually comprise 17-20% of the species present (cf. Brassard & Beschel 1968, Brassard & Longton 1970, Bridgland & Gillett 1983, Muc & Bliss 1977, Soper & Powell 1985).

In summary, the flora of Borup Fiord must be considered unusually diverse, especially in the context of floristic patterns in the Queen Elizabeth Islands. Reasons for this diversity include habitat diversity (resulting largely from lithographic and physiographic diversity), the favorable climatic regime, and the vegetational and glacial history of Borup Fiord and northern Ellesmere.

3.3 Future Plans

The high species diversity and well developed vegetation present at Borup Fiord make it ideal for many types of botanical studies. It is hoped to revisit the study area to undertake the following:

1) Continue documentation of the vegetation, and of the vascular and bryophyte floras of the region. Results of research on vegetation and the vascular flora will be published by Meiklejohn and myself. Bryofloristic results will be published in collaboration with Dr. G.R. Brassard of Memorial University.

2) A comparative study of environmental regulation of growth and CO_2 exchange in Arctic endemic mosses and their more widespread congeners.
3) Continue a study, begun in 1988, of patterns of bryophyte species association and their relationship to variation in key environmental factors.

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Table 1. Phytogeographical classification of the Borup Fiord vascular plant flora. Numbers in parentheses are percentages of total flora.

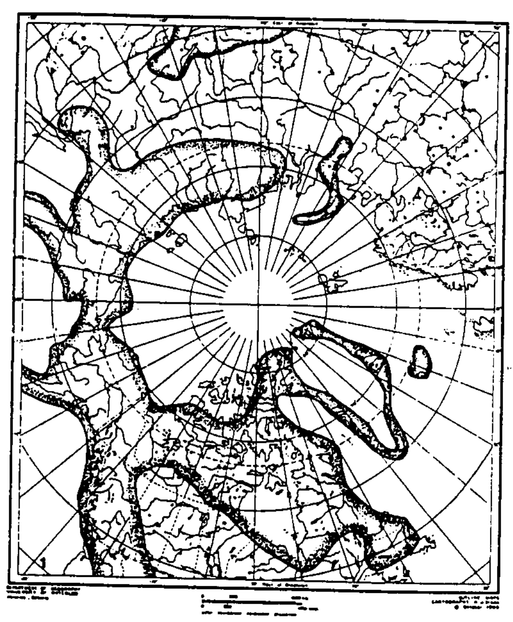
	Latitudinal Element			
Longitudinal Element	Arctic	Arctic-montane	Arctic-boreal	TOTAL
Circumpolar	27 (21.4)	42 (33.3)	(6^{8}4)	77 (61.1)
Amphi-Atlantic	13 (10.3)	8 (6.4)	(0°0)	21 (16.7)
North American	12 (9.5)	9 (7.1)	2 (1.6)	23 (18.2)
Amphi-Beringian	3 (2.4)	2 (1.6)	0 (0.0)	(4^{5}0)
TOTAL	55 (43.7)	61 (48.4)	10 (7.9)	126

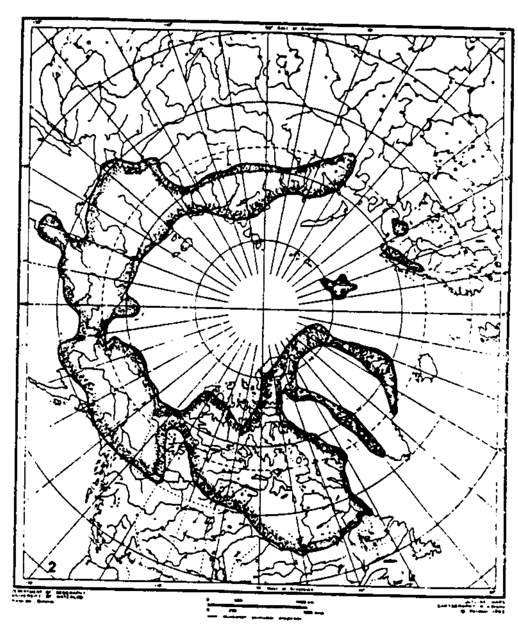
Figure Legends

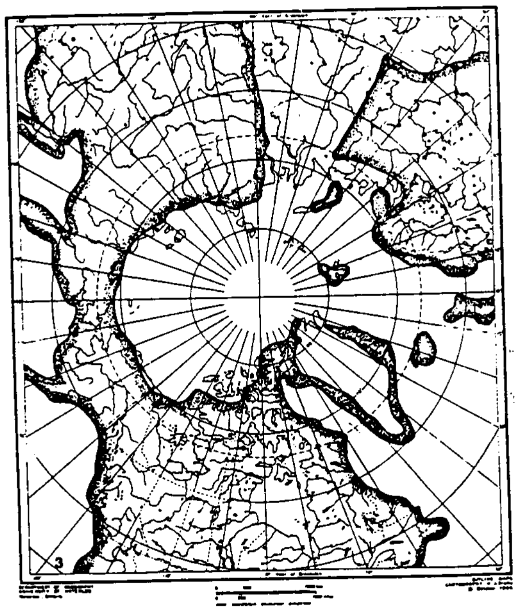
Figures I-4. Range maps for selected vascular plant species occurring at Borup Fiord. 1- Epilobium latifolium. 2- Cassiope tetragona. 3- Cystopteris fragilis. 4- Potentilla rubricaulis.

Figures 5-8. Range maps for selected vascular plant species occurring at Borup Fiord. 5- Festuca baffinensis. 6. Carex scirpoidea. 7- Pedicularis hirsuta. 8- Cerastium alpinum.

Figures 9-10. Range maps for selected vascular plant species occurring at Borup Fiord. 9- Papaver cornwallisensis. 10- Geum rossii.



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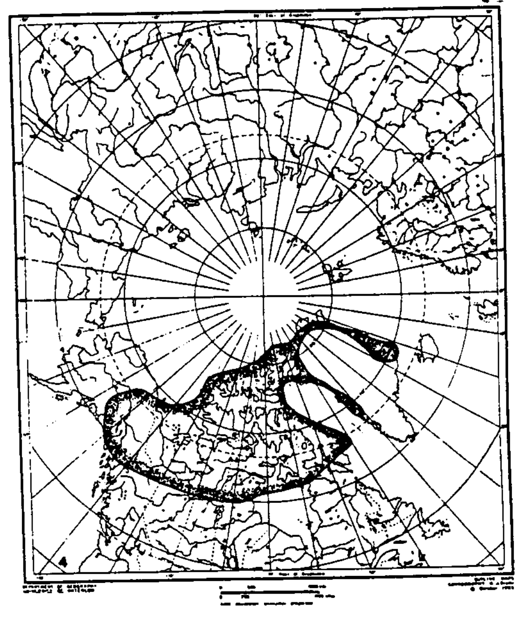
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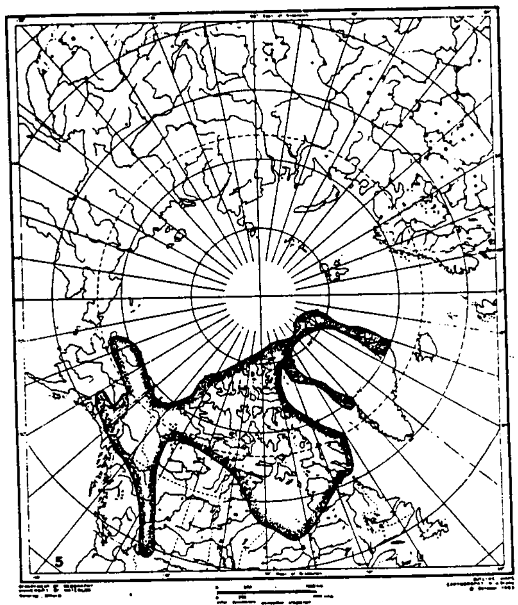
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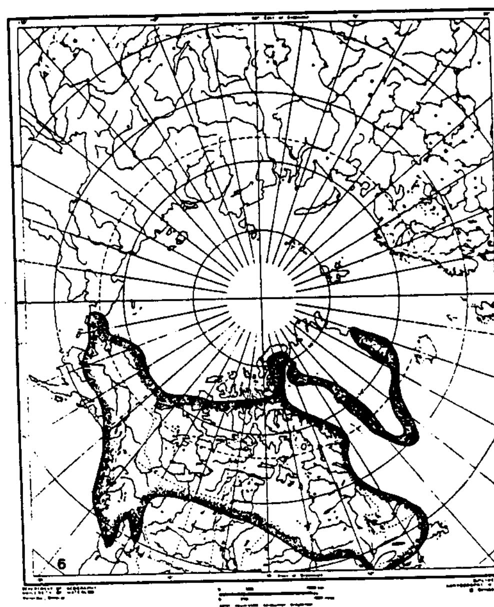
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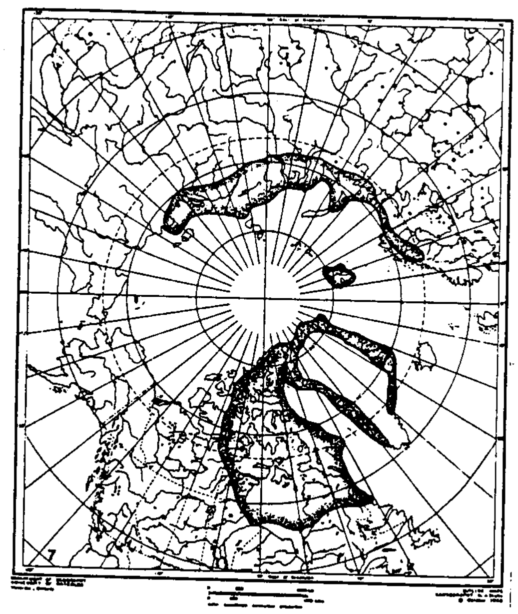

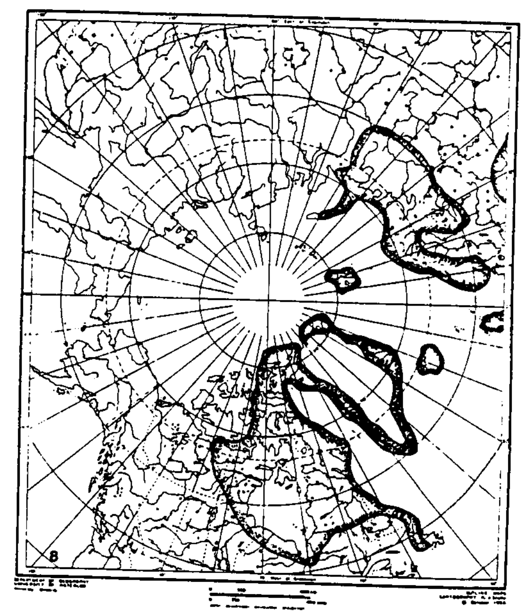

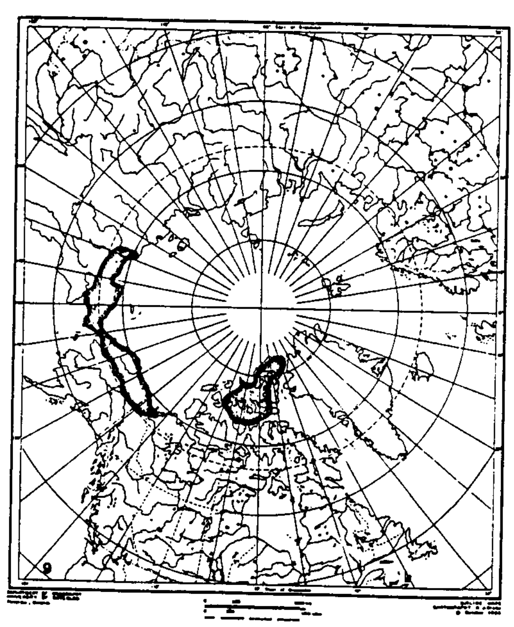

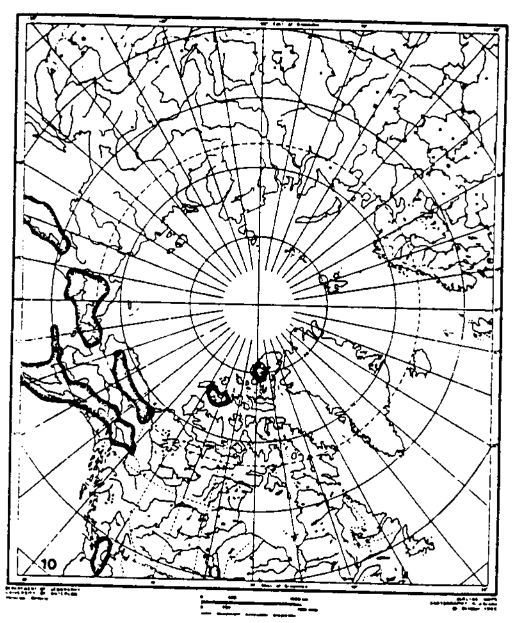

METEOROLOGY
K W HANKINSON

INTRODUCTION

The meteorology project was, from the expedition's inception, seen as an important but subsidiary activity that would serve as a source of data; this limited objective was achieved and in addition we were able to make sufficient observations to contribute to studies undertaken by other inatitutions. The climate of the Nansen Sound area has been well researched in recent years but increasing doubt, Alt et al (1989), Barry (1967) and Ohmura (1967), has been cast on the extent to which the climate of Eureka represents that of the region. Projects such as this, although running for only a few months, help to build a much clearer picture.

The project had 4 aims:

a. To send regular aviation weather reports to PCSP Resolute Bay.

b. To provide climatological data required by other expedition projects.

c. To contribute to the long-term study of high-arctic climate undertaken by Geological Survey of Canada.

d. To attempt to make comparisons of the climates of Borup Fiord and Eureka.

PREVIOUS OBSERVATIONS

Only the most sporadic meteorological observations were made in the region prior to 1947. The weather station at Eureka was established in April 1947 and has made data records ever since. No other long-term observations are available for the Nansen Sound region but a number of projects have made them over several years - though usually not without a break. In the last 2 decades the number of short-term projects, such as our own, reporting to PCSP has risen sharply but almost all of these are in the field only from mid-June to mid-August. Of these, relatively few relate to the northern shore of Nansen Sound and only one, King (1981), has direct relevance to Borup Fiord.

CLIMATE OF NW ELLESMERE ISLAND

The standard work, Maxwell (1980), considers that Borup Fiord falls within the same climatic sub-zone as Nansen Sound, Fosheim Peninsula, Tanquary Fiord and Lake Hazen. This sub-zone is essentially continental with few outside synoptic influences, although in summer there is a mean flow from the Central Arctic Ocean into the Queen Elizabeth Islands. Precipitation in the zone is the lowest in Canada and the annual temperature range is the highest; summer temperatures, however, at Eureka are anomalously high for latitude 80°N. This continentality, and the long-term station at Eureka is probably in the least continental part of the zone, is caused by the mountains of Axel Heiberg and NW Ellesmere Island acting as mechanical barriers to most weather from the polar ocean; cloud minima and low relative humidity are associated with broad-scale subsidence in the lee of the mountains (Alt and Maxwell, in press). The view of the zone as being essentially homogeneous has recently been challenged with Maxwell (1980) considering that the low density of the station network means that sub-synoptic systems are frequently undetected while Ohmura (1967) concluded thst there is as much climatic diversity in the high latitudes as in other regions. More recently Alt et al (1989) concluded that temperatures at Eureka are in fact lower than might be expected for the intermontane zone and that Eureka could not be considered representative.

TOPOGRAPHY

Observations were made at base camp which was moved some 4kms during the expedition. Both sites were at the baae of a well-watered and vegetated valley surrounded by ice-capped mountains rising to 5,000 ft; the valley runs generally north-south and is dominated by an extensive braided river and 'Henry's' Lake. While the first observation site was completely sheltered from westerly winds the second was to some extent open Esayoo Bay; otherwise, apart from 50m in altitude, there were no significant differences between them. When compared with the rest of Ellesmere Island, the dominant features of Borup Fiord are its proximity to substantial icecaps, the two bays reaching deep inland, the large area of open water in 'Henry's Lake' and the very high proportion of vegetated ground. These combine to produce a topography which perhaps has more in common with Lake Hazen or Tanquary Fiord than Eureka or Fosheim Peninsula.

OBSERVATIONS

Limited observations were made every 3 hours and full observations, to UK Meteorological Office Standards, every 6 hours; those taken at 0001 and 1200 houra UTC were transmitted to PCSP Resolute Bay. The 3-hourly observations were restricted to temperature, insolation and wind velocity and were intended to identify patterns not apparent in 6-hourly observations. Upon analysis it has become apparent that their publication was not justified; they may be obtained from the author if required. Observations were controlled by the author, who is not a meteorologist, and taken by any available member of the expedition; readings should be utilised with this in mind. Instruments were positioned immediately north of base camp (80°51.75'N 81°52.5'W, alt 53M) where observations were made from 14 May to 2 Aug; following a move of base camp observations were made from the head of Esayoo Bay (80°50.3'N 81°57.OW, alt 3M) until 20 Aug.

EQUIPMENT

The equipment used during the project was obtained on loan from the Meteorological Office, Bracknell, courtesy of Mr P Godwin, or Vector Instruments; the Campbell-Stokes Solarimeter was provided by PCSP. No difficulties, apart from the breakage of a soil thermometer and some inaccuracy in one of the barometers, were experienced. The following items were used:

Met Office Ref	Description	Quantity
21772	Thermometer Screen Ordinary	1
21777	Stand Screen Ordinary	1
21001	Thermometer Ordinary -30°C to +45°C	3
21202	Thermometer Minimum -50°C to +25°C	1
21101	Thermometer Maximum -20°C to +55°C	1
21410	Soil Thermometer 5cm -7°C to +38°C	1

Met Office Ref	Description	Quantity
	Raingauge comprising:	
2069	Bottle quart	1
2840	Raingauge 5 in mk 2	1
24810	Measure rain mm tapered 5 in	1
20780	Barograph small	1
1715	Clock	1
2414	Drum	1
20050	Barometer Aneroid mk 3	1
25800	Solarimeter type CM5	1
25965	Delta-T integrator Type MV1	1
	Hygrometer, whirling comprising:	
	Frame whirling hygrometer	2
	Thermometer alcohol -25° to +60°C	2
	Case, whirling hygrometer	2
2351	Anemometer, hand	2
	Anemometer, cup contact type A100R	
	run of wind counter (LED display)	2
	2m pole for above	2
	Campbell-Stokes Solarimeter	1
Metform 4237	Barograms	25
512	Muslins and wicks	2 pkts
22986	Tubular wick 10mm	1 pkt
112	Brush camel hair	1
224	Bottle, plastic, wet bulb	3

VEATHER SUMMARY

General. Most published data are collated by calendar months; these are used in the text where appropriate although they do not fit very well with perceived seasons.

May. Mid and late May was much warmer than expected with temperatures above freezing by 16 May and mean daily temperature did not fall below -4°C after that date. Air pressure remained high and stable giving slack winds with only a few warm fohns exceeding 10 km/hr. Skies were generally clear with the cloud that did form being altocumulus or cirrus. Insolation was at its maximum with an average of 18.4 hrs sunshine per day giving 26.5 Megajoules/M^2 of energy per day. Precipitation was light with traces recorded on 17 occasions.

June. After an exceptionally warm May, the weather in June was much closer to that expected. Temperatures stabilised at around +1°C and the daily mean did not exceed +3°C until 26 June. Air pressure was much lower than May but remained stable and mean winds only once exceeded 10 km/hr. The onset of the melt was accompanied by a msrked increase in cloudiness with a change to stratus and stratocumulus. Insolation dropped sharply with 7.8 hrs of sunshine per dsy giving 21.1 Megajoules/M^2 of energy, the increasing sun angle being offset by increasing cloudiness. Precipitation remained light apart from 8 June, 12mm of rain and sleet, 27 June, 3.0mm, and 29 June, 3.6mm.

July. Despite encouraging signs at the end of June, July was initially cool and by 12 July the daily mean had reached only +4.4°C. Thereafter, temperatures rose rapidly and the expedition's maximum of +17.2°C was reached on 18 July; high temperatures were maintained until 30 July when they fell suddenly to stabilise around +9°C. Although there was no obvious reason for this sudden drop it was associated with a change to Southerly winds and was probably caused by an influx of colder maritime air - see figure 1. Air pressure reached the summer minimum rather later than expected but daily changes were small and winds remained slack with only 19 records above 10 km/hr. Heavy cloud cover early in the month gave way to clearer skies from 11 July onwards aa the melt passed its peak. Insolation rose sharply with 18.1 hours of sunshine per day and an increase in energy, despite the reducing sun angle, to 23.1 megajoules/per M^2 per day. Precipitation was light with only 6.5mm for the month and only 2 days with measurable precipitation.

August. Following the fall in late July, temperatures stabilised around +9°C; a further sudden drop on 18 Aug was probably the onset of winter but records were not *maintained long* enough to establish this. Air pressure fell rapidly to the late summer minimum then recovered to give stable conditions with light winds; there were only 13 records above 10 km/hr and a peak of 20km/hr on 19 Aug. Cloud cover increased as temperatures fell and layer clouds predominated. Sunshine fell sharply as the sun dropped below the horizon for the first time with an average of 9.1 hrs per day giving only 12.8 megajoules/M^2 per day. As expected precipitation was much heavier with measurable rain on 8 days and a monthly total of 24.2mm; *it* is **notable, however, that 50% of this fell in one 6-hour period. See Figure 2.**

NOTES ON OBSERVATIONS

Temperature. Temperature recordings were taken from the Stevenson screen at 3-hourly intervals; 2 thermometers were used as a cross-check. No great difficulties were encountered but the records should be regarded as being ±0.2°C. The progress of air temperature is shown at figures 3 and 4; this accords reasonably well with the progress of the seasons described earlier.

Station Pressure. A continuous trace of station pressure was made using a UK Meteorological Office barograph. Although the apparatus was reliable there is always the possibility of error when replacing the paper and the readings should be considered ±0.5mb for instrument error and ±0.5mb for computation of station altitude. The progress of air pressure is shown at figure 5. This was much as forecast except that the late-summer minimum was later than expected. Pressure movements did not accord very well with changes in the weather although the precipitation on 8 June, 6 July and 19 August was accompanied by small, but clearly defined, falls in pressure.

Precipitation. Experiences on previous expeditions had taught us the difficulty of measuring precipitation in polar regions. No problems were experienced with the equipment supplied and calculations were simplified since all measurable precipitation fell as *rain or* sleet. Precipitation too light to be measured was arbitrarily considered to be 0.1mm rain equivalent. The conversion factor for precipitation falling as snow has caused difficulties for many years. The Canadian and British Meteorological Offices use a factor of 10:1 whereas Rae (1951), Koerner (1979) and Maxwell (1980) advocate ratios of 5:1 *or even* 3.5:1. Woo et al (1983) consider that this leads to an under reporting of winter precipitation by 40 to 400%. We attempted to ascertain the winter precipitation in Borup Fiord by determining the water equivalent of snow pits and measuring mean snow depth on transects across the valley; although this method is prone to error the uniform snow depth and absence of drifting suggest that the method is valid and would not lead to an over-estimate of precipitation. Our results suggested a *winter* snowfall in excess of 160mm rain equivalent giving en annual total of about 215mm or about 220% of the figure cited in the 1980 Canadian

Climate Normals (AES 1982). This gave us a snow/rainfall conversion factor of about 3:1 - the same found by Ohmura (1967) on Axel Heiberg Island. Precipitation during the expedition is shown in figure 6.

Relative Humidity. Relative humidity was measured with a meteorological office sling psychrometer; during the early part of the expedition we had difficulty in obtaining a suitable ice bulb but figures after 30 May can be considered reliable. The continuing presence of surface water long after the melt, caused by melting of permafrost and ground ice, undoubtedly contributed to the high relative humidity experienced on many days. King (1981) suggested an inverse relationship between humidity and temperature and his work in Midnight Sun Valley showed a good correlation. Our readings for July, figure 7, show a much poorer correlation. The daily progress of relative humidity is at figure 8.

Cloud Cover. Cloud cover was estimated by eye and can be considered accurate only to ±10%. Reports of cloud cover give a false impression since this was frequently only a thin veil and there were several days where substantial reported cloud cover was allied to considerable sunshine; a good example is 16 July with 9/10 cloud yet 16.2 hours sunshine. Cloudiness increased during and after the melt but the changes were not as marked aa those experienced on eastern Ellesmere Island, Hankinson (1981). The daily changes in cloudiness are shown in figure 9.

Visibility. Visibility was estimated by reference to known features; it was restricted only by fog and low stratus with little sign of haze. Visibility of less than 25km was reported on only 39 out of 397 observations.

Wind Velocity. Mean wind speeds were measured using Vector Instruments totalising anemometer while instant speeds were taken with a meteorological office hand-held anemometer; both figures were taken at 2M and corrected to 10M elevation. Direction was established by reference to known features. Wind speeds were found to be low with little variation between seasons; although Maxwell (1980) considers that local wind speeds and direction are governed by katabatic influences we found little evidence. Wind direction, figure 10, did show some variation but the number of observations where there was no dominant direction make attempts to determine a trend fruitless. There was some evidence to link increases in wind speed with rises in temperature during fohn conditions as suggested by Barry and Jackson (1969) but our records could be read either way.

Insolation. Sunshine hours were measured using a Campbell-Stokes solarimeter provided by Bea Alt of Geological Survey of Canada; this is obviously not a popular item since it was in the same ration boxes we had used for packing after the 1980 expedition. Total radiation was measured using a CM5 pyranometer connected to a Delta-T integrator type MV1. Both sets of readings were very much an experiment and we were by no means sure what we hoped to establish. As expected, there is marked variation in sunshine hours and total solar radiation between seasons - even allowing for changes in sun angle. What was more interesting was the relatively poor correlation, figure 11, between sunshine hours and total solar radiation. It was apparent that precise measurement of sunshine hours, defining when the recording card was marked, was very difficult and sometimes bore little relation to total radiation; a good example is to compare the perioda 12-1800 UTC on 15 and 16 May where total radiation is 1.23 MJ/M^2 greater on 16 May despite 0.6 fewer hours recorded sunshine. Seasonal changes in sunshine and insolation are at figures 12 and 13.

COMPARISON WITH OTHER STATIONS AND PREVIOUS YEARS

Valid comparisons with long term records can only be made with Eureka (80°00'N -- 85°36'W, 3M); Alert (82°30'N 62°20'W, 66M) on the northern tip of the island has little in common with Borup Fiord and ia under the influence of the polar pack for much of the year. Eureka is only 60nm from Borup Fiord and ita location, - close to a deep sea fiord, is to some extent comparable to that of Borup Fiord; any synoptic-scale influences on Eureka, such as lee-wave effects from Axel Heiberg, can reasonable be expected to affect Borup Fiord as well. Eureka has operated since 1947 and ita long-term data usually relates to the period 1951-80 although some is available for 1947-86. Other stations in the Greely Fiord area have operated for much shorter periods often only a few weeks. Comparisons are limited to Tanquary Fiord (81°25'N 76°55'W, 6M) (1963-67), Oobloyah Bay (80°51'N 83°53'W, 110M) (1978) and Hot Weather Creek (79°58'N 84°26'W, 70M) (1988). The weaknesa in each comparisons is that the homogeneity of the climate of NW Ellesmere Island is by no means established; several authorities particularly Ohmura (1967) consider that the effect of sub-synoptic systems are such that comparisons must be made with care.

Temperature. In comparison with previous years Summer 1988 at Eureka, and thus by assumption elsewhere on Ellesmere Island, waa markedly warmer than the long-term average. This hides some variations since late May and late July were unusually warm whereas mid and late June were cooler than average.

Table 1
Eureka Mean Temperature 1951-80 and 1988 "C

	1951-80	1988
15-20 May	-9.8	-1.5
21-31 May	-6.0	-2.5
1-10 June	-1.3	+0.7
11-20 June	+2.3	+1.6
21-30 June	+4.4	+3.8
1-10 July	+5.2	+5.3
11-20 July	+5.4	+7.4
21-31 July	+5.6	+8.9
1-10 August	+5.3	+7.4
11-20 August	+3.8	+5.9

Thus June waa only 0.2°C above the 30-year mean whereas July was 1.8°C above and the second warmest July since 1947. For 1988 Borup Fiord may be compared with Eureka and, for the period 15 June to 18 August, with Hot Weather Creek. This shows that Borup Fiord is warmer than Eureka but considerably cooler than the inland site of Hot Weather Creek.

Table 2
Temperature at Eureka, Borup Fiord and HWC 1988 °C

	Eureka	Borup	HWC
15-20 May	-1.5	-1.5	
21-31 May	-2.5	-2.0	
1-10 June	+0.7	+0.5	
11-20 June	+1.6	+1.0	
21-30 June	+3.8	+2.8	+6.7
1-10 July	+5.3	+5.6	+9.7
11-20 July	+7.4	+10.5	+14.2
21-31 July	+8.9	+11.6	+14.0
1-10 August	+7.4	+ 8.9	+11.6
10-20 August	+5.9	+ 7.1	

The contrast is more marked if thawing degree days and growing degree days (mean temperature above +10°C) are compared.

Table 3
Comparison of Thawing Degree Days and Growing Degree Days
Eureka, Borup and HWC

	Eureka (1951-80)	Eureka (1988)	Borup	HWC
TDD	323.7	407.2	498.0	681.0
GDD		6.0	41.0	129.3

Of other stations Tanquary Fiord, whose topography haa much in common with that of Borup, is of interest since it is warmer than Eureka by about the same margin. Observations made at Midnight Sun Valley, described as Oobloyah Bay in the records, during July 1978 suggest that it also wss warmer than Eureka by about the same amount as was Borup Fiord in 1988.

Table 4
Meen June and July Temperature Eureka end Tanquary Fiord 1963-67 ‘C

	TANQUARY	EUREKA
JUNE	+3.2	+1.6
JULY	+5.9	+4.6

Table 5
July Temperatures Eureka and Oobloyah Bay 1978 "C

Eureka	+6.8
Oobloyah Bay	+9.7

Precipitation. Because of the short duration of records at other stations, only Eureka is useful for inter-station comparison. Moreover, because of the effect of even one large shower on monthly totals, inter-station monthly figures can be misleading and annual totals give a better picture. Difficulties in measurement are described elsewhere but in addition several authorities, Muller and Roskin-Sharlin (1967), Barry and Jackson (1969), Maxwell (1980) and Woo et al (1979) have cast doubt on the accuracy of Eureka data.

Table 6
Comparison of 1988 and Longer-Term Precipitation in mm of Rain Equivalent

	MAY	JUNE	JULY	AUG	ANNUAL
Eureka (1947-80)	3.0	3.6	12.2	9.7	64.0
Borup Fiord (1988)	**1.8**	**23.5**	**6.5**	**23.6**	**217.4**

Cloud Cover. It could reasonably be expected that the heavier precipitation, persistence of damp ground and large areas of open water would lead to greater cloudiness at Borup Fiord than elsewhere. As discussed earlier, comparisons are complicated by the substantial amounts of high cloud and the difficulties in accurately estimating cloud amounts.

Table 7
Comparison of Cloud Cover by Month %

	May	June	July	August
Eureka (1950-72)	54	52	67	75
AES Normal (1959-79)		65	68	
Princess Marie Bsy (1980)	70	52	74	63 (1-25)
Borup Fiord (1988)	38	77	42	60 (1-20)

Insolation. Sunshine figures are not readily available for the past periods of most stations end at the time of publication the figures from the 1988 Eureka season were not available in the UK. The data obtained corresponds reasonably well with that obtained by Muller and Roskin-Sharlin (1967) on Axel Heiberg Island.

Table 8
Hours of Effective Sunshine as Percentage of Total Hours

	May	June	July	August
Eureka (1975-80)	66	60	56	37
Princess Marie Bay (1980)	33 (23-31)	62	47	28 (1-25)
Borup Fiord (1988)	78 (16-31)	33	75	48 (1-20)

Wind Velocity. Terrain effects make inter-station comparisons of wind speed useful only in the most general terms. Base camp location appeared to be relatively sheltered, it experienced few of the katabatics prevalent in Midnight Sun Valley, and the limited information we have available supports the subjective impression that Borup Fiord is less windy than Eureka.

Table 9
Wind Speeds by Month km/hr

	MAY	JUNE	JULY	AUG
Eureka (1947-80)	14.0	22.2	19.5	14.7
Borup (1988)	3.5 (14-31)	5.1	7.2	6.5 (1-20)

DISCUSSION

There is little virtue in attempting to draw firm conclusions from a single season's readings; the best that can be achieved is to suggest tendencies in the region's climate and challenge some assumptions. Of the data recorded temperature and precipitation are of the greatest interest, being the main determinants of biological activity, and discussion will be concentrated in those areas.

The concept of homogeneity of the climate of the high arctic has repeatedly criticised and both Ohmura (1967) and Maxwell (1980) have stressed the importance of sub-synoptic systems going undetected in a region with few reporting stations. Only more recently have Alt (1989) and others analysed the considerable variations in summer temperatures between locations a few miles apart; in particular they have demonstrated that although Eureka is anomalously warm, at least in summer, for latitude 80°N it is considerably cooler than many nearby areas. While some of these, such as Hot Weather Creek, are warmer by nature of their inland location and others, such as Tanquary Fiord, benefit from fohn winds no simple explanation is available for Borup Fiord. When allied to the results of King (1981) it is reasonable to suggest that the mean July temperature on the northern shore of Greely Fiord is some 2-3°C greater than that of Eureka and that the long-term mean July temperature must be in the region 7.5 to 8.5°C. Such a summer temperature would place Borup Fiord well into vegetation zone 4 as defined by Alt and Edlund (1989) and the current record of vascular species, 123, for Borup Fiord accords well with this proposition. Little comparative data is available but Borup Fiord temperatures aPPear to be unusually high for a coastal location and it can be suggested that the area shows more continentality, at least in terms of temperature, than would be expected from its location and topography. Comparison of thawing and growing degree days shows a greater contrast. Comparative records suggest that Borup Fiord experiences a long-term mean for thawing degree days of about 400; this is comparable to much more southerly locations such as Pond Inlet, 445 TDD, Maxwell (1980).

As discussed earlier, precipitation measurement and comparisons of data are fraught with difficulty since there is little agreement on conversion factors. For a single season's results the problems are compounded since a single, isolated shower can account for up to 50% of the precipitation for a month. Nevertheless, it seems likely that summer precipitation at Borup Fiord is higher than for many parts of Nansen Sound. Alt (1989) recorded less than 3mm of rain equivalent in the period 15 June to 18 August at Hot Weather Creek; Borup Fiord recorded 21.5mm. This would suggest that, in summer at least, Borup Fiord is less continental than Fosheim Peninsula and that the influence of deep sea fiords is dominant. Annual precipitation, although estimated by very crude methods, also appears to be much higher than that for comparable locations; Elmer Ekblaw, upon discovering Borup Fiord in 1915, remarked upon the unusually deep snow and found the going more difficult than anywhere else on Ellesmere Island. Certainly the substantial snow depth provided sufficient meltwater to ensure that small streams and ponds persisted well into July. Unlike Hot Weather Creek, Alt (1989), where almost all water must come from the melt of subsurface ground ice by penetration of the active layer, Borup Fiord should receive sufficient precipitation to support its vascular plant community. A mechanism for this increased precipitation is not easily provided although it is possible that Nansen Sound provides a clear track for polar maritime air and that the mountains of Neil and Elmerson Peninsulas provide sufficient lift.

Despite the limited sires and resources of this project it is felt that . sufficient evidence was obtained to suggest that the link between the anomalous temperature and precipitation of Borup Fiord and its botanical diversity *justifies* further work.

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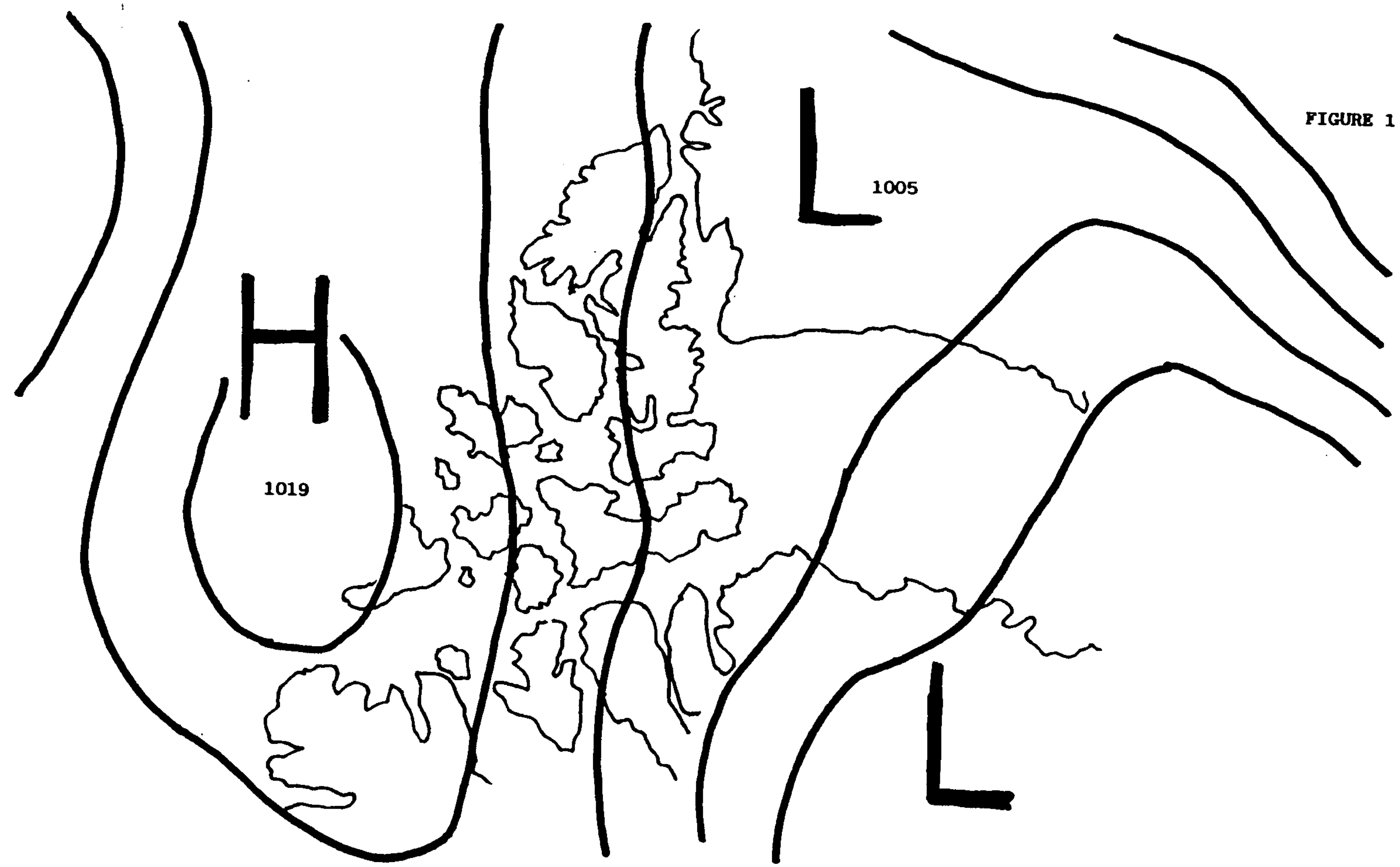
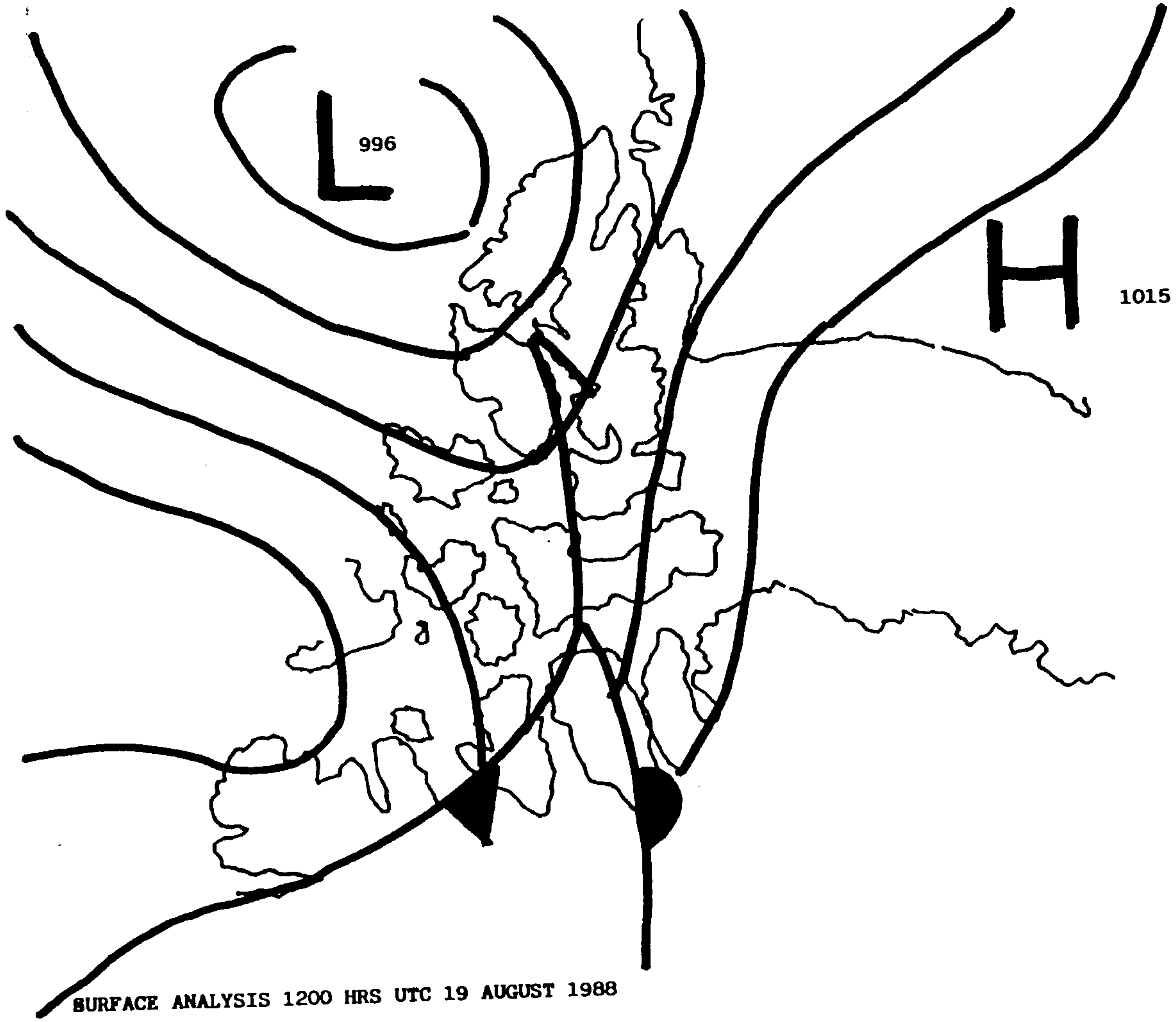
FIGURE 1



SURFACE ANALYSIS 1200 HRS UTC 30 July 1988

FIGURE 2



SURFACE ANALYSIS 1200 HRS UTC 19 AUGUST 1988

FIGURE 3

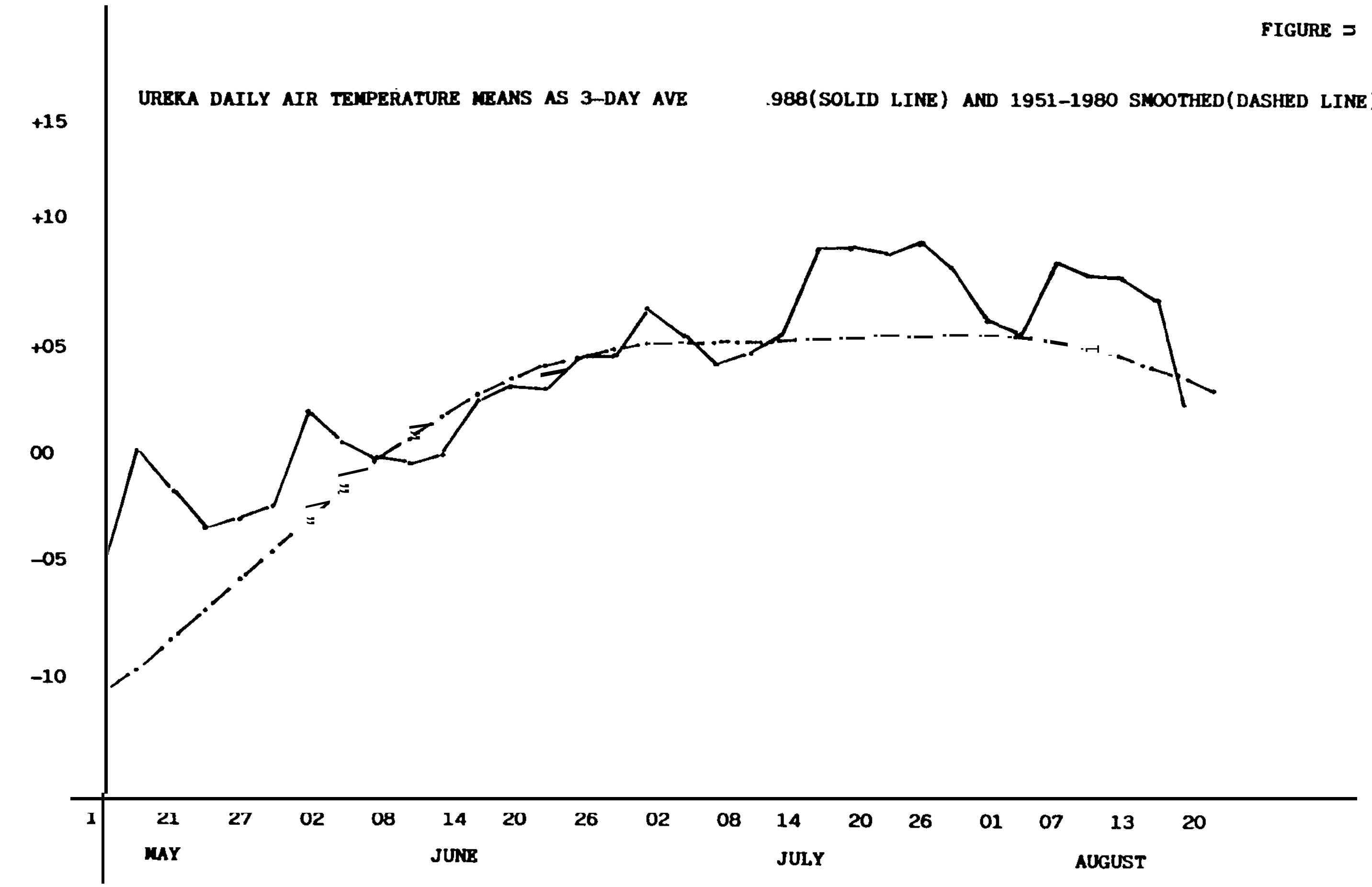

UREKA DAILY AIR TEMPERATURE MEANS AS 3-DAY AVE .988(SOLID LINE) AND 1951-1980 SMOOTHED(DASHED LINE)
+15
+10
+05
00
-05
-10
1
21
27
02
08
14
20
26
02
08
14
20
26
01
07
13
20
MAY
JUNE
JULY
AUGUST

FIGURE 4

DAILY MEAN AIR TEMPERATURES AS 3-DAY AVERAGES 1988 EUREKA(SOLID LINE) AND BORUP FIORD(DASHED LINE)

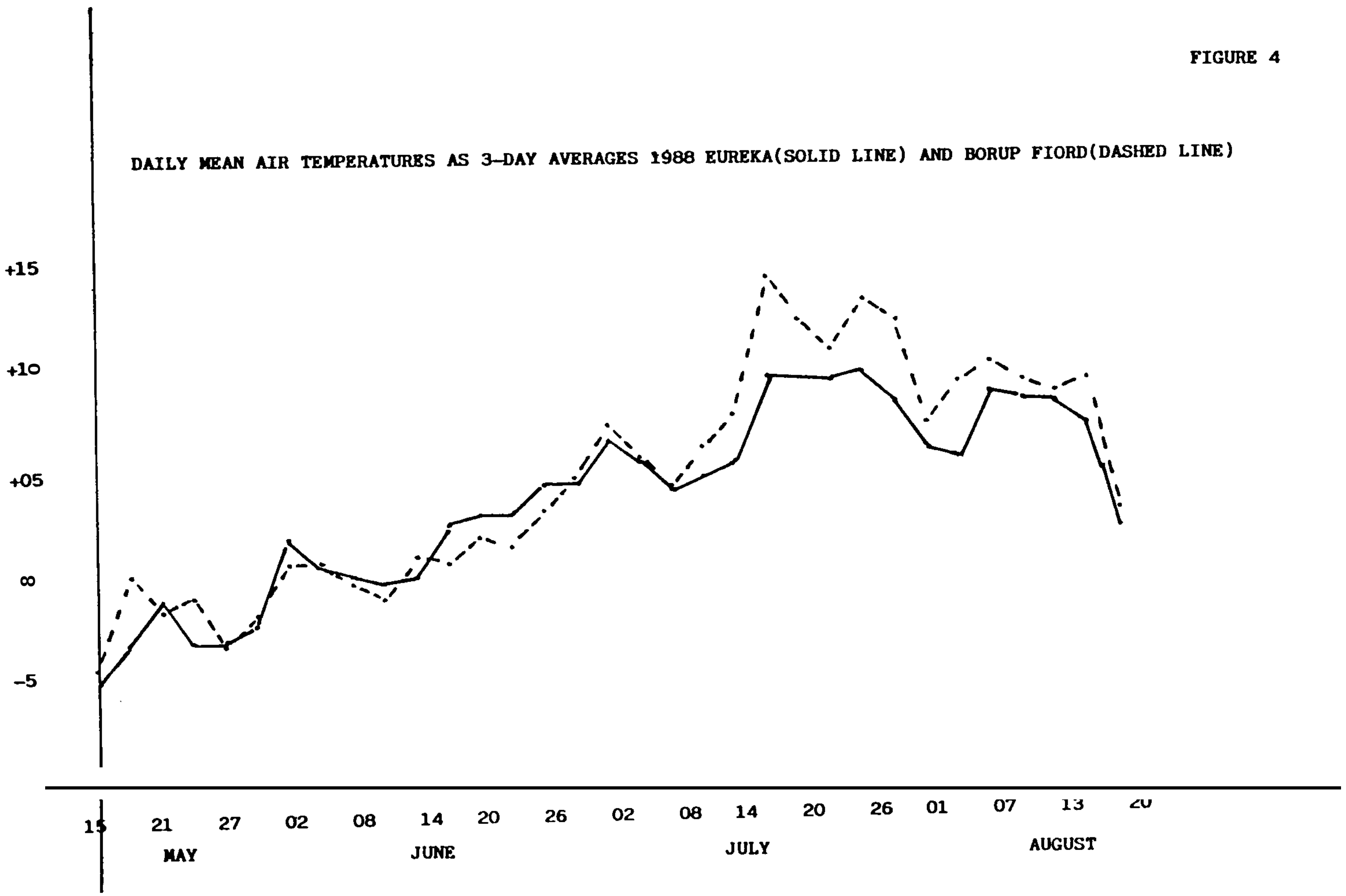


FIGURE 5

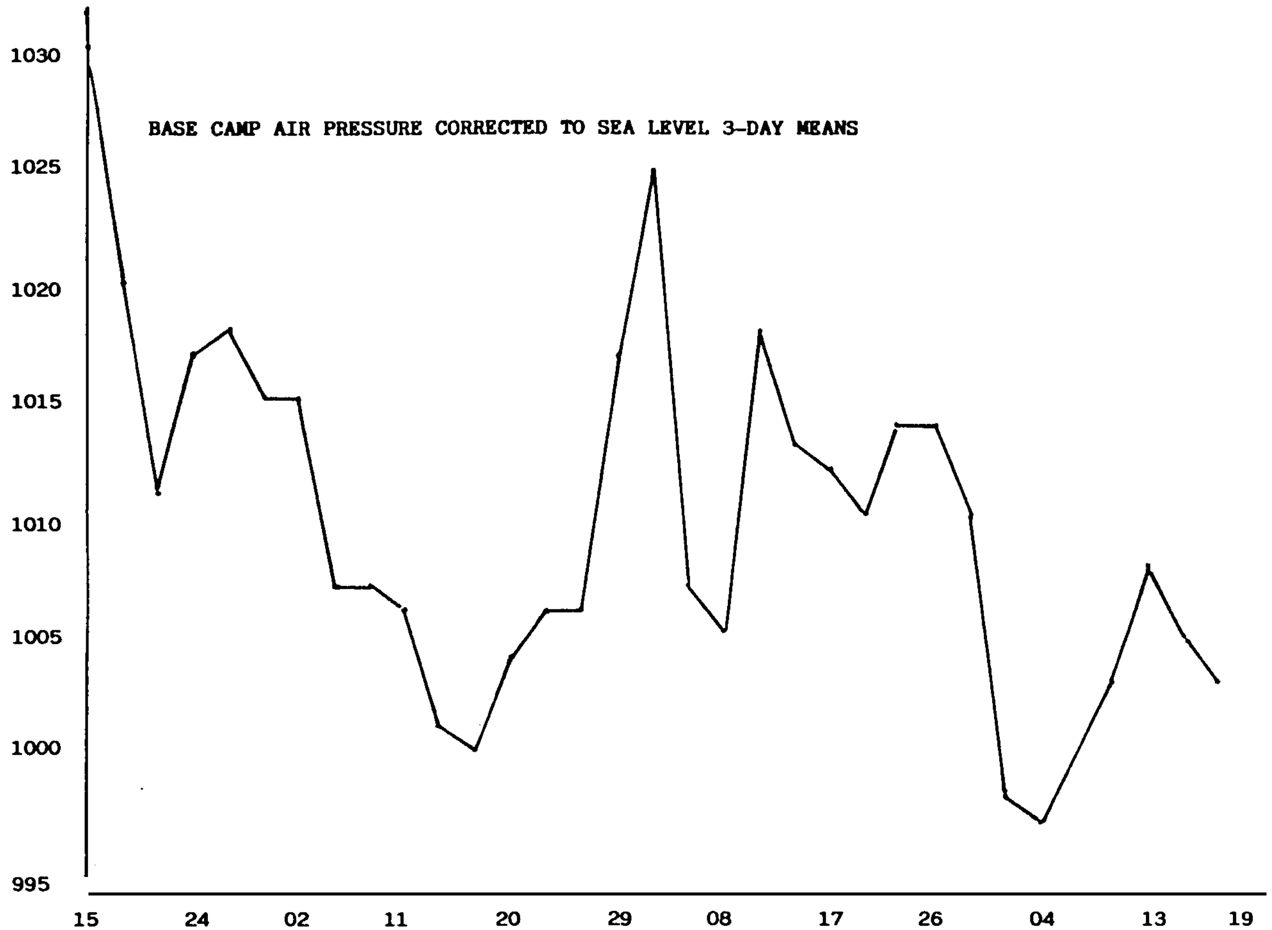
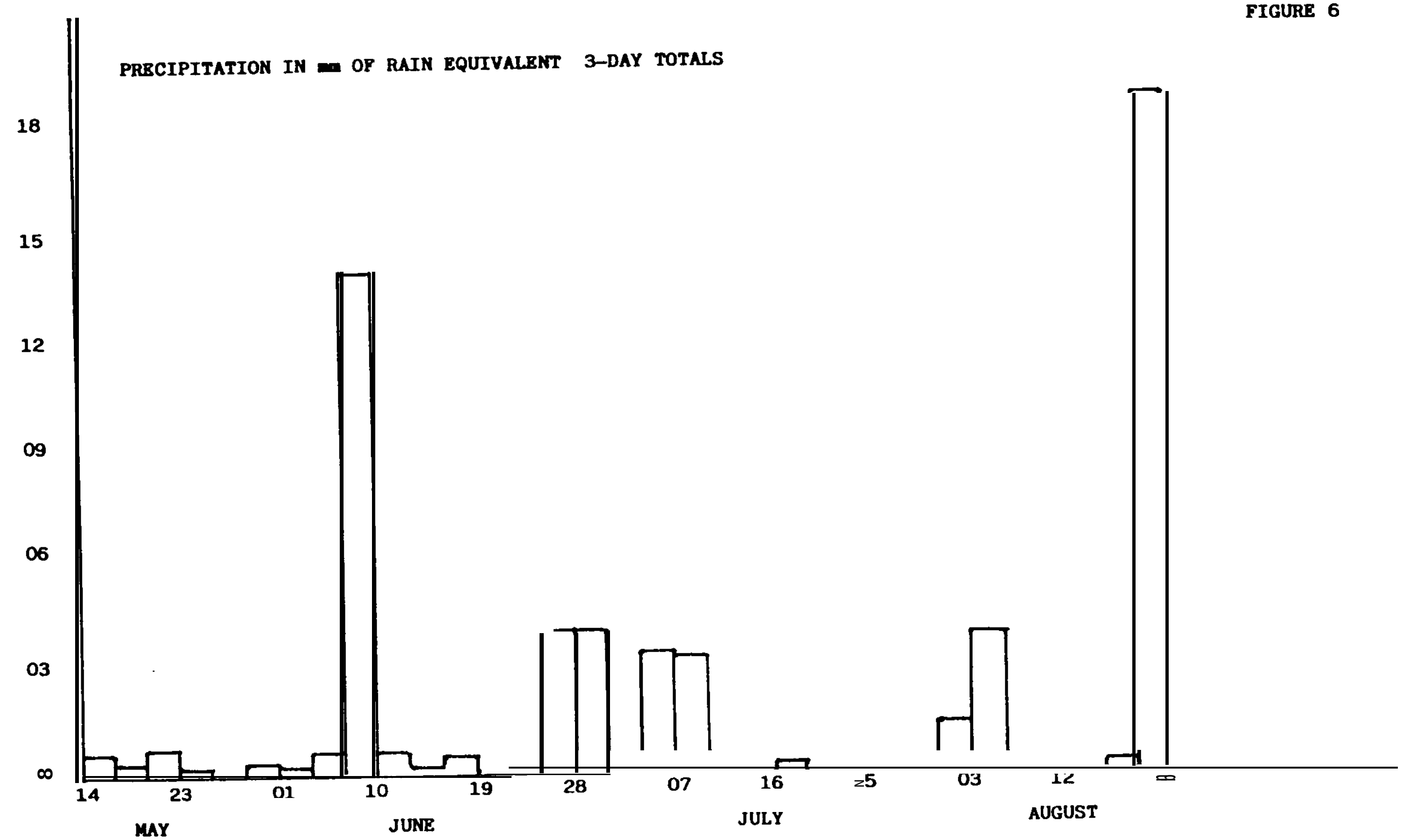
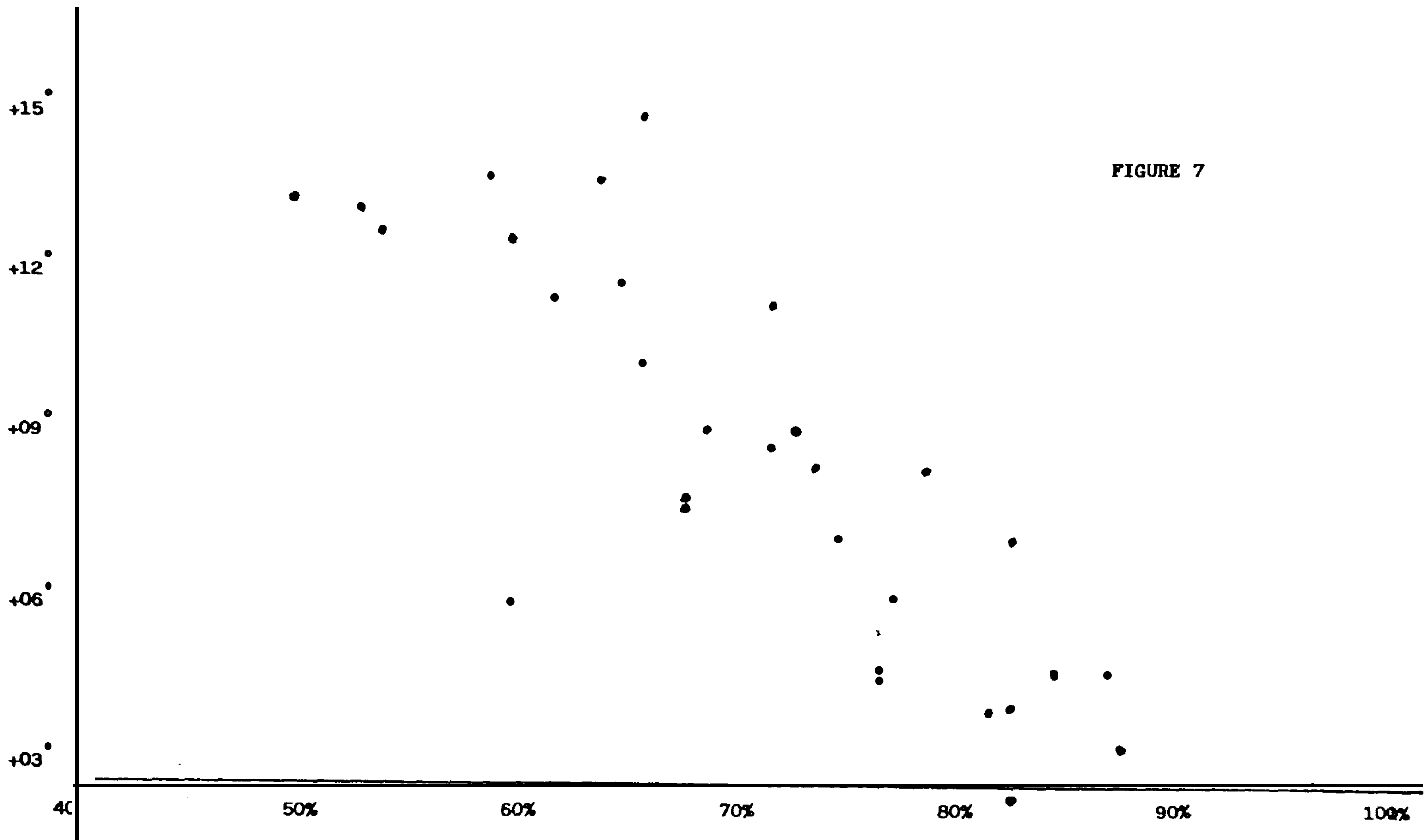

BASE CAMP AIR PRESSURE CORRECTED TO SEA LEVEL 3-DAY MEANS
1030
1025
1020
1015
1010
1005
1000
995
15
24
02
11
20
29
08
17
26
04
13
19

FIGURE 6



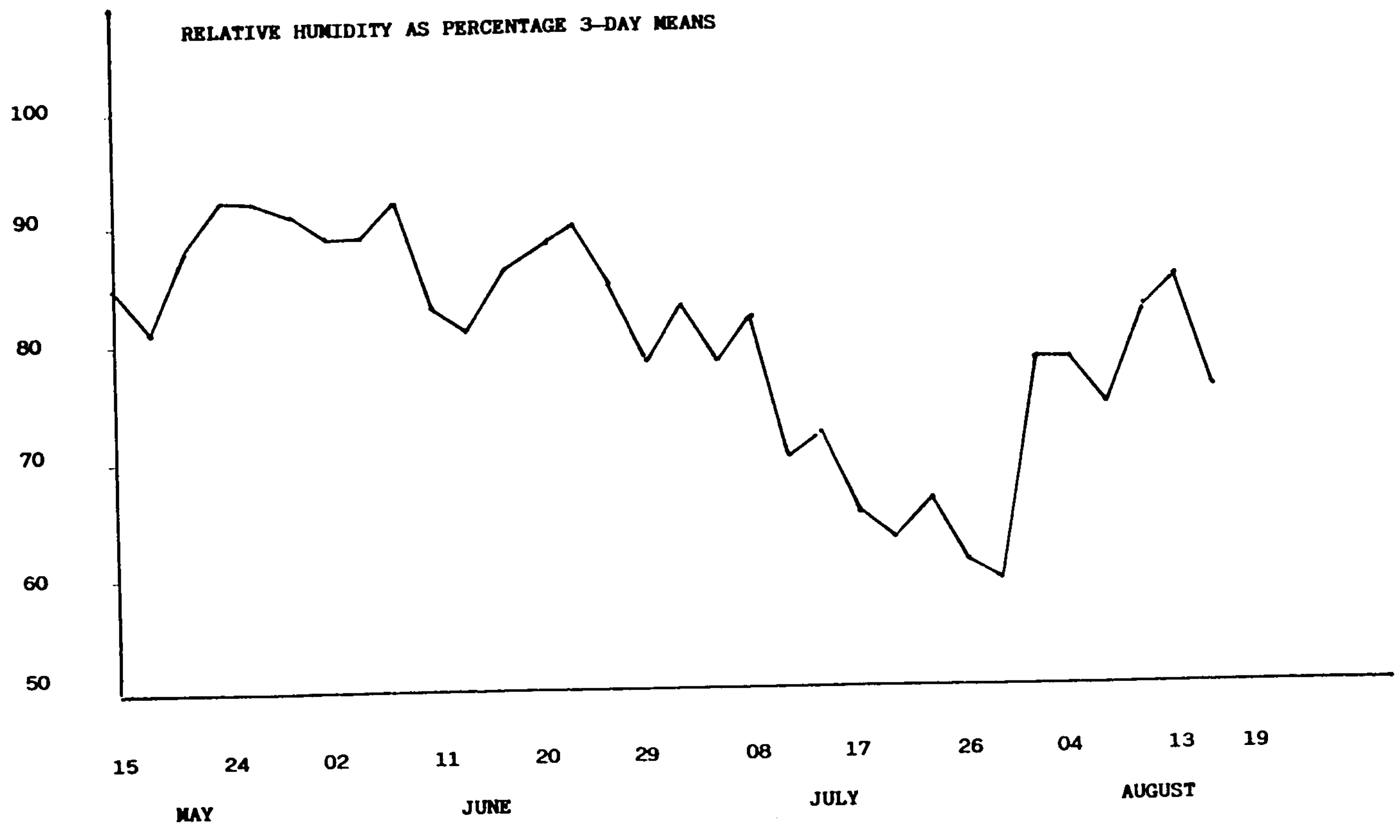
PRECIPITATION IN mm OF RAIN EQUIVALENT 3-DAY TOTALS
18
15
12
09
06
03
14
23
01
10
19
28
07
16
12
MAY
JUNE
JULY
AUGUST

FIGURE 7



MEAN DAILY TEMPERATURE °C AGAINST MEAN DAILY RELATIVE HUMIDITY % JULY 1988

FIGURE 3



RELATIVE HUMIDITY AS PERCENTAGE 3-DAY MEANS
100
90
80
70
60
50
15
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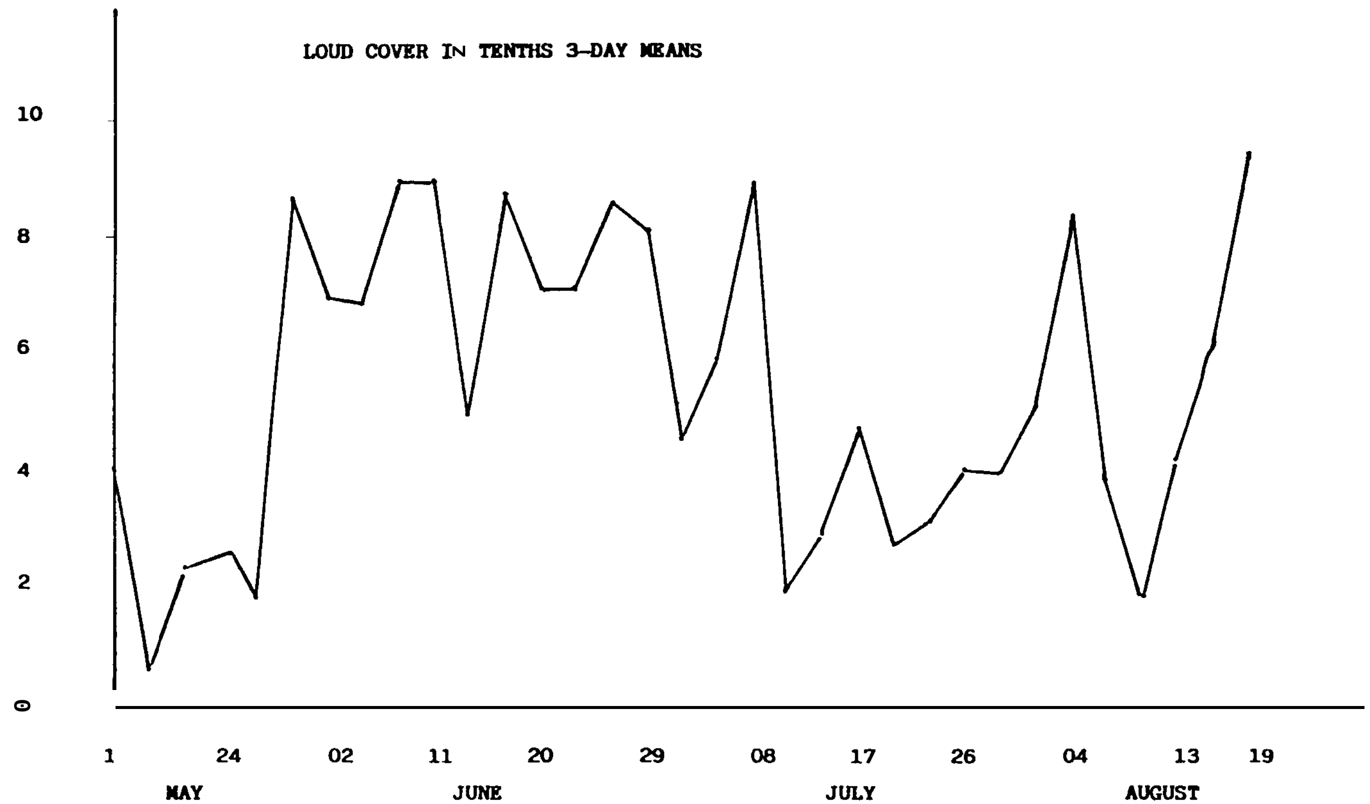
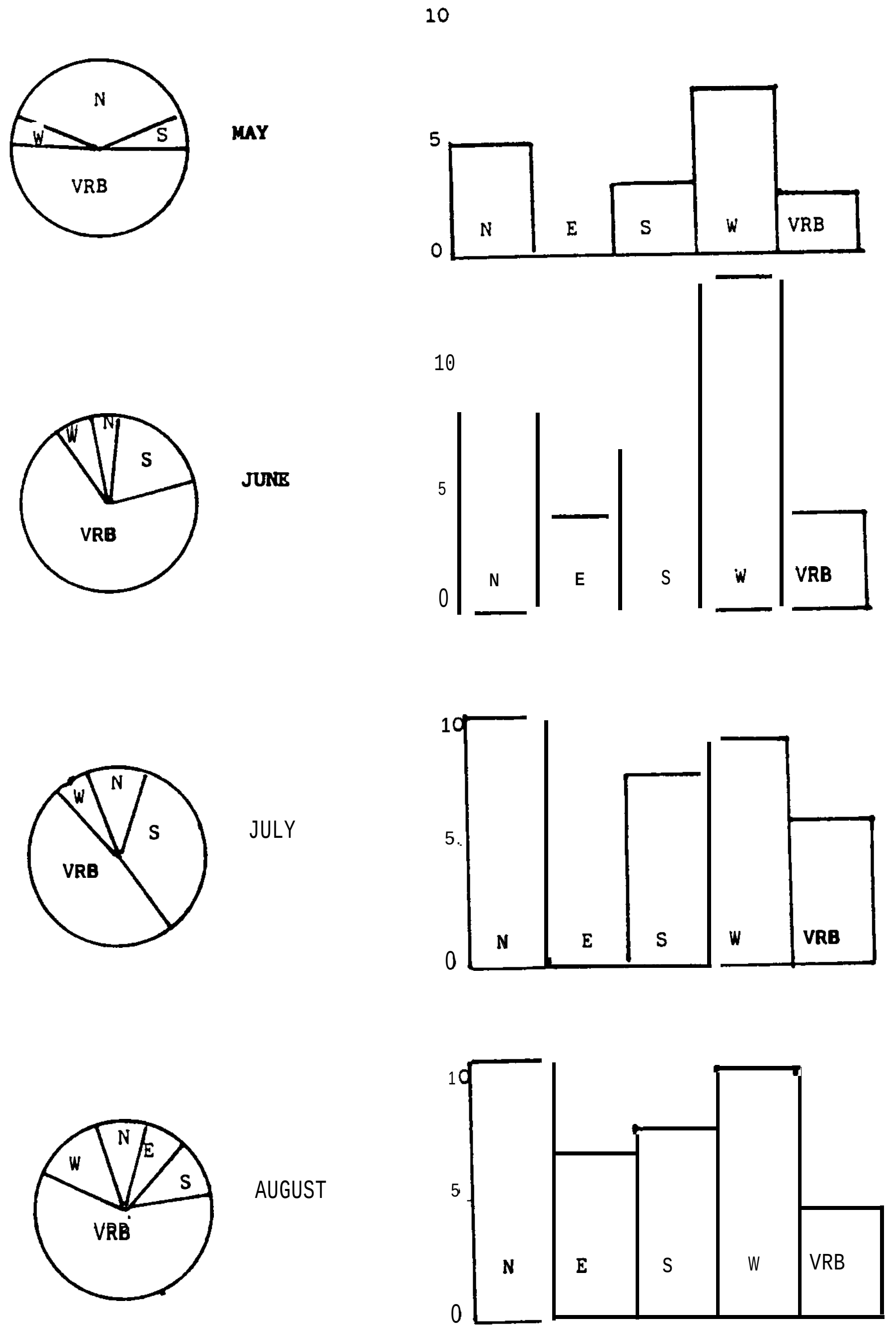
02
11
20
29
08
17
26
04
13
19
MAY
JUNE
JULY
AUGUST

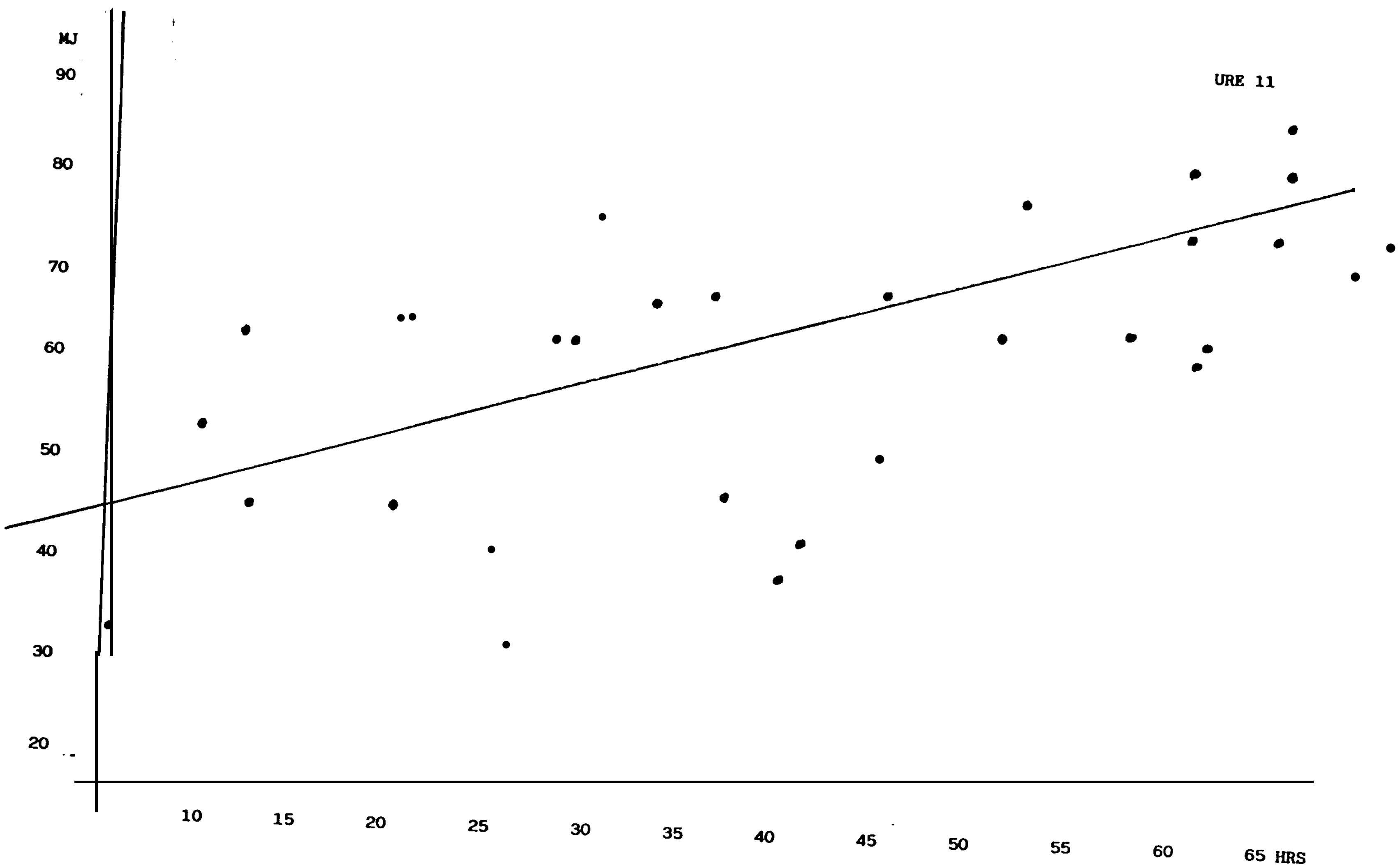
URE 9



LOUD COVER IN TENTHS 3-DAY MEANS
10
8
6
4
2
0
1
24
02
11
20
29
08
17
26
04
13
19
MAY
JUNE
JULY
AUGUST

WIND VELOCITY: FREQUENCY OF DIRECTION AND MEAN MONTHLY QUADRANTAL SPEEDS KM/HR





TOTAL SOLAR RADIATION IN MEGAJOULES PER SQUARE METRE AGAINST TOTAL HOURS OF SUNSHINE PLOTTED AS 3-DAY TOTALS

FIGURE 1

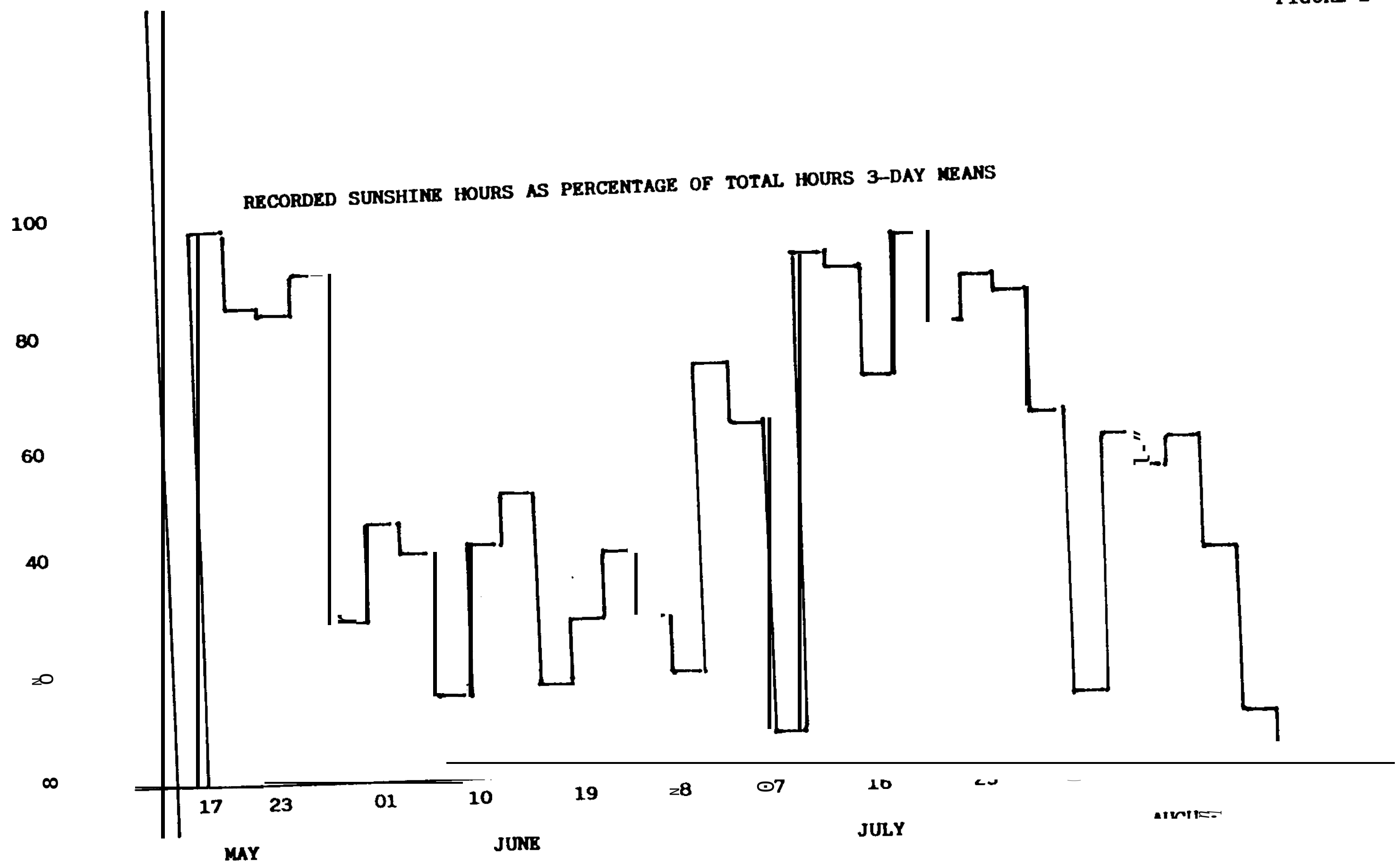
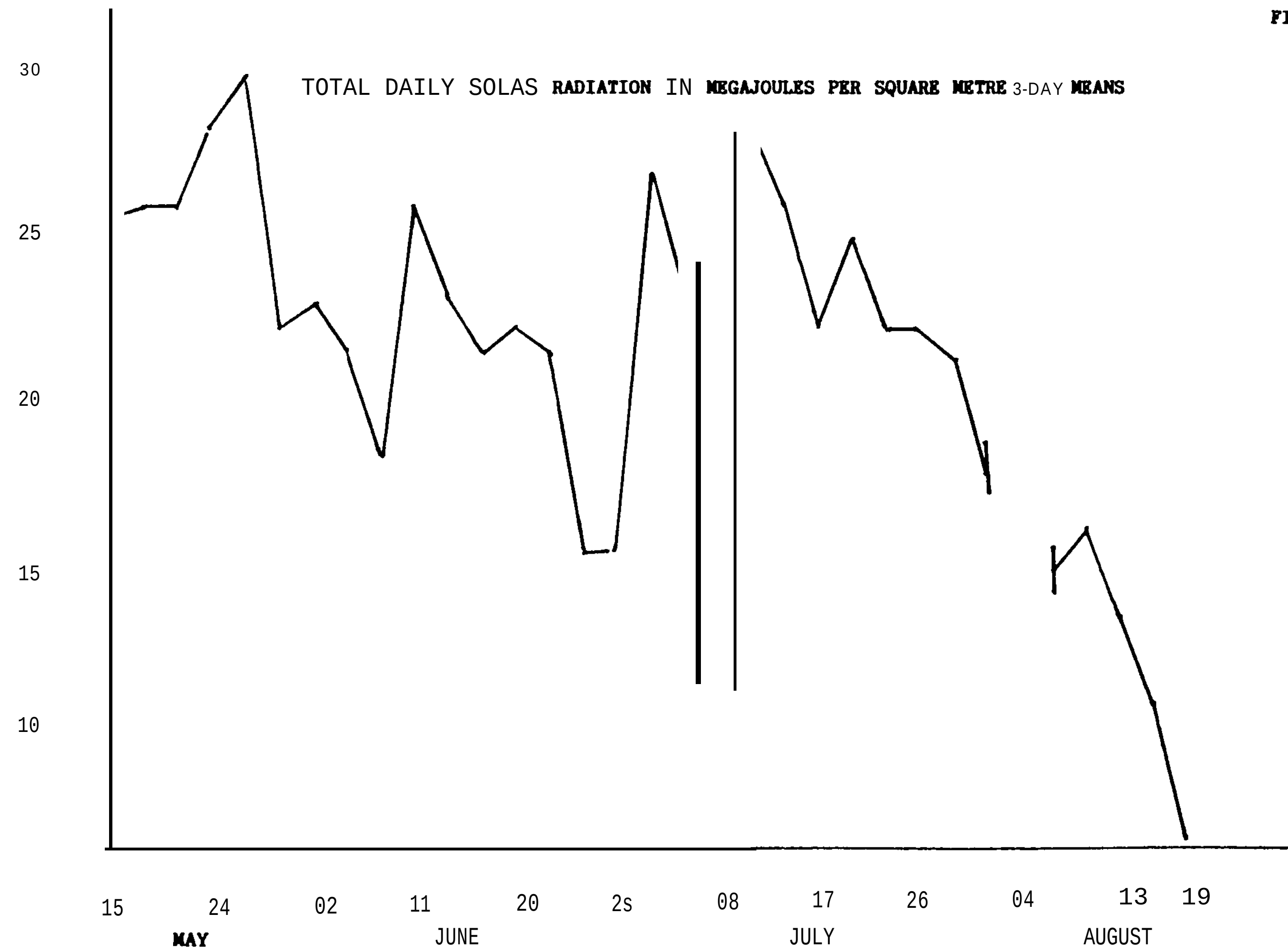

RECORDED SUNSHINE HOURS AS PERCENTAGE OF TOTAL HOURS 3-DAY MEANS
100
80
60
40
17
23
01
10
19
MAY
JUNE
JULY

FIGURE 13


TOTAL DAILY SOLAS RADIATION IN MEGAJOULES PER SQUARE METRE 3-DAY MEANS
30
25
20
15
10
15
24
02
11
20
2s
08
17
26
04
13
19
MAY
JUNE
JULY
AUGUST

DAILY WEATHER SUMMARY

			TENPER R				CLOUD						ISOLATION	
ATS	IBR	ISSURE		IAILY 1111	ELATIVE IMIDITY	OVER	?111	IEIGHT	ITB/ IOU	ISIB LITY	PEED	DIR	IN SIDE	INERGY
a	b	e	d	e	f	g	h	i	j	k	l	m	n	o
	TC	mb	°C	°C	%	1111		t x 100	mm	km	m/hr	° x 10	hrs	MR-2
May 14	00	10SJ3	-1.0		I/A	)	C	90	r	25+	V/A		N/A	N/A
	06	N/A	-7.0		I/A	I/A	l/A	V/A	NIL	25+	V/A	N/A	N/A	N/A
	L2	1027	-5.0		l/A	)	'u	50	r	25+	V/A	N/A	V/A	N/A
	18	1033	-5.7	-4.7	I/A	3	:U	30	r	25+	V/A	N/A	V/A	N/A
15	00	1033	-5.7		16	1	:U	40	NIL	25+	2.8	03	V/A	N/A
	06	N/A	-7.5		16	I/A	I/S	V/A	NIL	25+	5.7	30	1.8	2.82
	12	1036	-9.4		'8	CLR			r	25+	5.0	01	3.0	4.33
	18	1035	-6.0	-7,.?	12		T	40	r	25+	9.6	30	5.2	11.21
16	00	1033	-0.5		12		C	30	NIL	25+	14.8	01	5.2	7.82
	06	1027	-1.5		18	)	C	30	NIL	25+	13.2	36	2.8	2.94
	12	1028	-3.5		17		C	30	NI L	25*	5.4	36	1.3	N/A
	18	1029	+1.5	-1.0	'8	3	S	100	r	25+	6.4	34	5.6	10.0!
17	00	1027	-1.0		'6	3	C	120	r	25+	4.0	36	6.0	7.43
	06	1027	-2.8		l/A	3	C	120	NI L	25+	4.0	35	6.0	N/A
	12	1028	0.0		10	L	:ICU	200	NIL	25+	3.0	36	6.0	5.49
	18	1026	+2.8	-0.3	'5	CLR			NIL	25+	2.0	36	6.0	10.2:
18	00	1025	+1.4		90	CLR			NIL	25+	3.0	34	6.0	8.54
	06	1021	+1.6		35	CLR			NIL	25+	4.0	35	6.0	3.77
	12	1020	-0.4		35	CLR			NIL	25+	1.3	36	6.0	3.53
	18	1016	+2.4	●1,3	30	CLR			NIL	25+	2.3	01	6.0	9.11
19	W	1014	+1.5		70	CLR			NIL	25+	5.4	36	6.0	8.36
	06	1014	-7..2		75	CLR			NIL	25+	3.6	36	6.0	4.43
	12	1014	-3.5		30	CLR			NIL	25+	3.4	35	6.0	4.46
	18	1014	+2.0	-0.5	34	CLR			T	25+	3.3	36	6.0	9.40
20	00	1011	-0.4		30	1	AS	100	T	25+	3.3	18	6.0	9.11
	06	1011	-4.5		98	K	FG		T	0.2	3.0	01	5.0	4..36
	12	1010	-5.2		37	K	FG		T	0.2	6.6	03	0.0	2.53
	18	1010	-1.2	+2.8	30	3	AC	80	NIL	25.	4.0	01	3.5	8.78
21	00	1012	+1.2		34	6	CU	60	NIL	25+	3.6	01	6.0	9.55
	06	1013	-1.8		36	3	ST	40	NIL	25+	3.6	01	5.3	4.61
	12	1013	-1.0		39	CLR			NIL	25+	3.6	36	6.0	3.66
	1s	1013	-1.0	-0.6	30	CLR			T	25+	4.2	36	6.0	8.37
22	00	1012	-0.2		84	1	SC	40	T	25+	4.8	VRB	6.0	9.33
	06	1013	-2.0		33	3	AS	100	T	25+	3.8	VRB	6.0	4.84
	12	1013	-2.6		96	9	ST	02	T	15	1.6	VRB	6.0	3.80
	1s	1015	+0.2	-1.1	30	3	ACSL	100	NIL	25+	1.1	VRB	6.0	9.14
23	W	1016	+0.2		91	2	AS	120	T	25+	3.1	VRB	6.0	9.29
	06	1016	-1.6		90	6	CU	40	NIL	25+	1.0	vRB	1.2	5.06
	12	1016	-1.6		89	8	ST	10	NI L	25+	1.0	VRB	3.0	N/A
	1.9	1010	+0.2	-0.7	81	1	ST	40	NIL	25+	2.0	18	6.0	9.54
24	00	1017	+0.5		90	CLR			NIL	25+	2.9	VRB	5.0	9.20
	06	1017	-3.5		100	x	FG		NIL	4	2.1	VRB	5.2	4.15
	12	1018	-1.1		99	5	ST	05	NIL	.?5.	3.5	VRB	5.2	5.47
	1s	1019	+0.7	-0f	91	5	ACSL	100	NIL	25+	2.0	VRB	6.0	10.8
25	00	1020	-1.2		99	1	CI	150	NIL	25+	6.3	36	6.0	8.93
	06	1020	-3.0		95	N/A	N/A	N/A	NIL	25+	1.9	VRB	6.0	5.(I7
	12	1021	0.0		91	1	CI	150	NIL	25+	1.6	VRB	6.0	4.26
	18	1021	-0.3	-1.1	91	CLR			NIL	25+	3.1	VRB	6,0	9.35
.?6	00	1021	-1.1		90	2	AC	120	NIL	25+	.?.9	VRB	6.0	9.3a
	06	1021	-5.0		95	2	ST	02	NIL	25+	2.7	vRB	6.0	5.19
	12	1022	-6.0		97	1	CI	200	NIL	25+	1.?	VRB	6.0	4.77
	18	1022	-2.0	-3. !	96	1	CI	200	NIL	25+	3.9	VRB	6.0	11.6
27	00	1022	-1.4		09	1	CI	200	NIL	25+	2.4	VRB	6.0	6.39
	06	1020	-3.4		97	cLR			NIL	25+	3.2	VRB	6.0	6.12
	12	1018	-5.0		91	CLR			NIL	25+	1.6	VRB	6.0	4.64
	18	1018	-1.5	-2. [	100	1	CI	200	NIL	25+	5.8	VRB	6.0	9.42
28	00	1018	-0.5		82	1	AS	100	NIL	25+	4.8	VRB	3.2	9.72
	06	1016	-4.8		86	8	AC	100	NIL	25+	2.4	VRB	2.3	5.06
	12	1015	-5.5		95	4	ST	05	NIL	10	2.4	vRB	5.8	4.84
	18	1015	-2.8	-3.4	89	1	AC	120	NIL	25+	3.6	VRB	6.0	11.1
29	00	1013	-2.4		86	6	ST	70	NIL	25+	3.2	VRB	3.5	9.3a
	06	1013	-4.8		89	9	ST	30	NIL	25+	2.4	VRB	2.3	4.12
	12	1014	-4.3		98	10	AC	100	NIL	25+	2.4	VRB	3.5	4.06
	18	101s	-1.7	-3.:	87	8	SC	40	T	25+	1.9	VRB	2.2	8.13
30	00	1015	-?.0		90	9	ST	20	T	25+	2.1	VRB	0.3	6.62
	06	1016	-3.9		92	7	SC	35	NIL	25+	2.1	VRB	0.5	3.31
	12	1016	-3.6		99	10	ST	20	NIL	25+	3.6	18	C.2	3.23
	18	1017	+0.4	-2.:	88	8	Sc	30	NIL	25+	1.0	VRB	1.0	6.33

DAILY WEATHER SUMMARY

			TEMPERATURE			CLOUD							INSOLATION	
DATE	TIME	PRESSURE		DAILY MEAN	RELATIVE HUMIDITY	COVER	TYPE	HEIGHT	RAIN/ SNOW	VISIB-ILITY	SPEED	DIR	SUN SHINE	ENERGY
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
	UTC	mb	°C	°C	%	1/10		ft x 100	mm	km	km/hr	° x 10	hrs	MJm-2
May	00	102.'3	+2.0		93	7	SC	35	NIL	25+	2.4	VRB	2.6	10.31
31	06	1018	-0.5		87	10	SC	35	NIL	25+	2.0	VRB	0.0	3.91
	12	1018	-0.6		87	10	SC	40	NIL	25+	2.6	VRB	0.0	2.47
	18	1018	0.0	-0.2	90	10	Sc	50	NIL	25+	3.8	VRB	5,0	5.99
June	00	1020	+0.6		86	10	SC	50	NIL	25.	2.3	VRB	3.5	9.36
01	06	1020	-1.0		88	6	ST	40	NIL	25.	6.2	VRB	0.1	3.57
	12	107.1	-0.4		87	9	ST	40	NIL	25.	2.2	VRB	1.5	5.36
	18	1020	+0.6	-0.3	93	8	ST	35	NIL	25.	6.9	VRB	1.2	5.81
02	00	1019	.2.0		93	4	SC	50	T	25+	2.1	VRB	5.5	6.80
	06	1020	-0.4		83	7	SC	40	NIL	25+	1.3	VRB	1.7	3.71
	12	1017	.0.5		93	4	ST	60	NIL	? 5+	1.9	VRB	1.9	4.16
	18	1013	.2.3	.1.1	87	5	SC	50	NIL	25+	3.1	VRB	1.s	8.49
03	00	1011	+1.5		93	6	SC	60	NIL	? 5+	1.9	VRB	1.7	6.05
	06	1010	.1.0		9.?	8	AC	100	NIL	25+	1.6	VRB	2.5	2.32
	12	1010	.1.7		90	9	ST	60	NIL	25+	2.3	VRB	6.0	4.56
	18	1010	.2.0	+1.6	77	7	AC	100	NIL	25+	1.8	VRB	6.0	8.99
04	00	1010	+2.0		90	4	AC	100	NIL	? 5.	1.4	VRB	.4. ?	6.3S
	06	1009	+3.2		93	1	AS	80	NIL	75+	5.0	VRB	2.2	4,13
	12	1009	-2.1		90	4	ACSL	150	NIL	25,	4.0	VRB	6.0	6.44
	18	1009	-0.6	+0.6	93	4	AC	100	NIL	25+	5.2	VRB	6.8	10.71
05	00	1007	-0. s		100	10	AC	100	NIL	25+	3.'!	VRB	NIL	6.08
	06	1005	+2.5		84	9	ST	20	NIL	25+	8.1	04	1.5	?.80
	12	1005	+3.8		75	8	AC	100	NIL	25+	6.0	04	3..s	5.11
	18	N/A	N/A	+1.8	N/A	N/A	N/A	N/A	NIL	25+	5.0	N/A	2.1	N/A
06	00	1007	.1.4		87	6	CU	50	NIL	25+	6.9	18	2.8	8.82
	06	1007	0.0		86	9	CU	50	NIL	25+	6.3	15	1.8	4.03
	12	1008	-0.6		93	10	Sc	10	T	5	5.7	18	NIL	3.82
	18	1010	-1.2	-0.1	91	10	SC	?0	0.5	5	13.7	15	NIL	6.65
07	00	1010	-.10		90	9	ST	02	0.s	10	6.9	VRB	0.0	5.95
	06	1 007	-1.6		95	10	ST	10	NIL	10	2.0	VRB	0.2	3.03
	12	1008	-0.1		87	10	ST	7.0	NIL	25+	.?.5	VRB	0.0	3.15
	18	1008	+2.1	-0.7	90	10	Cu	30	T	15	2.5	VRB	0.2	5.35
08	00	1008	.0 .7.		96	10	ST	01	1.0	.?	4.0	VRB	0.0	4.60
	06	100s	0.0		100	10	ST	01	1.0	6	3.5	VRB	0.0	1.79
	12	1004	0.0		100	10	ST	01	5.0	2	7.8	18	0.0	1.83
	18	1004	.0.7	.0.2	93	10	ST	10	5.0	6	6.2	36	0.0	6.36
09	00	1006	.0.5		93	10	ST	10	1.0	8	3.9	VRB	1.5	6.94
	06	10437	-1.1		91	7	ST	20	NIL	25	1.9	VRB	2.3	5.S2
	12	1010	-1.7		100	10	ST	03	T	6	3.5	VRB	1.2	3.43
	18	1013	-1.4	-0.9	73	3	Cu	30	NIL	25+	3.4	20	5.2	7.40
10	00	1014	-1.0		81	7	Cu	50	NI L	25+	1.4	VRB	2.5	B.66
	0s	1014	-4.0		83	6	Cu	30	NIL	20	3.3	VRB	4.0	5.09
	12	1012	-1.8		?7	10	ST	20	NIL	25+	1.8	VRB	4.6	4.80
	18	1011	+1.2	-1.4	77	8	CU	30	NIL	25.	3.4	VRB	4.7	10.58
11	00	1o11	+0.1		67	10	Sc	30	NIL	25.	3.7	VRB	0.5	7.3B
	06	1009	-2.0		?9	10	Sc	40	NIL	25+	4.4	VRB	0.2	3.11
	12	1008	-1.5		89	10	ST	20	T	10	5.7	VRB	3.2	6.80
	18	1 C05	-0. B	-1.1	93	10	ST	10	T	6	1.8	VRB	3.9	0.73
12	00	1002	.2.1		81	10	Cu	10	T	6	1.3	VRB	0.0	5.10
	06	1000	-0.6		89	10	Cu	30	T	25+	3.9	VRB	0.3	2.73
	12	1000	-1.5		86	7	ST	15	t	25+	2.5	18	3.0	5.80
	18	1 001	+1.1	+0.3	90	9	ST	02	T	10	2.1	VRB	3.1	9.79
13	m	1032	4.2		63	6	CU	40	NIL	25+	4.3	VRB	4.3	3.05
	06	1032	+1.2		n	7	CU	40	T	25+	B.4	VRB	2.5	5.07
	12	1033	+1.0		56	4	CU	40	NIL	25+	8.6	36	0.5	4.17
	18	1003	+2.5	..1.1	84	2	SC	60	NIL	25+	5.4	VRB	0.0	5.40
14	00	1 004	+1.6		90	9	AC	70	NIL	25+	3.4	VRB	0.1	6.01
	06	1003	+1.5		76	8	CU	60	NIL	25+	6.6	34	1.5	3.89
	12	1003	+1.0		75	5	Cu	W	NIL	25+	10.0	34	3.0	5.75
	18	1002	.0.5	+1.1	86	7	AC	80	NIL	25+	5.6	VRB	3.2	8.50
15	00	1002	+4.0		77	3	AC	80	NIL	25+	2.1	VRB	5.9	N/A
	06	1002	+2,3		90	CLR	-	-	NIL	25+	8.5	02	5.9	6.03
	12	10Q1	-2.5		86	3	AC	100	NIL	2s+	6.6	02	4.0	6.97
	16	1002	-1.1	+0.7	90	7	CU	40	NIL	25+	9.0	19	5.9	9.91
16	00	1001	-0.4		91	10	Cu	35	NIL	2s+	7.2	VRB	1.2	7.34
	06	1000	-0.8		100	10	CU	35	T	25+	4.6	VRB	0.0	2.74
	12	999	-0.7		96	9	Cu	400	NIL	25+	2.7	VRB	0.5	3.55
	18	1000	0.0	-0.5	67	9	CU	30	NIL	20	4.1	VSB	0.1	7.33

DAILY WEATHER S-Y

			TEMPERATURE			CLOUD							INSOLATION	
DATE	TIME	PRESSURE		DAILY MEAN	RELATIVE HUMIDITY	COVER	TYPE	HEIGHT	RAIN/ SNOW	VISIB- ILITY	Itlll	DIR	SUN SHINE	ENERGY
a	b	c	d	e	f	g	h	i	j	k	1	m	n	o
	UTC	mb	°C	°C	%	1/10		ft x Ill	mm	km	km/hr	° x 10	hrs	MJm-2
une	00	1001	+1.8		78	10	ST	15	T	25+	2.1	VRB	0.5	5.87
7	06	1000	+2.1		90	10	Sc	30	T	25+	2.9	VRB	0.0	3.04
	12	1000	+2.2		81	10	ST	15	T	25+	2.1	VRB	0.0	3.11
	18	1001	+1.2	+1.8	78	10	ST	20	NIL	25,	4.4	VRB	0,2	6.56
8	00	1001	+1.5		90	8	CU	40	NIL	25+	2.0	VRB	0.5	4.74
	06	1003	,0.7		90	7	AS	70	NIL	25+	4.4	VRB	3..?	7.32
	12	1003	0.0		91	7	CU	25	NIL	25+	5.3	17	1.3	3.72
	18	1 005	+1.5	+0.9	77	5	CU	30	NI L	25+	11.9	21	4.7	9.93
9	00	1006	+0.5		91	10	ST	20	NIL	25+	7.3	21	0.0	7.25,
	06	1006	+0.4		93	2	CU	50	NIL	25+	2.5	VRB	4.2	3.12
	12	1004	.3.0		7s	3	CU	50	NIL	25+	3.5	VRB	3.0	4.88
	18	1004	+7.0	+2.7	74	1	CU	50	NIL	25+	3.7	VRB	6.0	11.3s
!O	W	1004	+4.0		88	2	CU	45	NIL	25+	3.4	VRB	6.0	9.50
	06	1006	+2.0		97	10	SC	60	NIL	25+	3.2	VRB	0.8	4.96
	12	1005	+2.5		85	10	SC	30	NIL	25+	3.5	VRB	0.0	7.36
	18	1005	+1.3	.2.4	64	10	SC	40	NIL	25+	4.6	VRB	0.0	4.38
!1	00	1006	+1.7		90	10	CU	35	NIL	7.5*	3.1	VRB	0.0	3.17
	06	10Q6	+1.4		97	9	SC	50	NIL	25+	2.7	VRB	0.0	1.98
	12	1007	.0.5		90	10	AC	65	NIL	25+	5.1	VRB	0.0	3.22
	18	1006	+0.1	+0.9	97	10	ST	25	NIL	25.	7,7	vRB	0.0	6.16
?7.	00	1006	+0.5		93	10	CU	40	NIL	25+	2.8	vRB	0.0	4.12
	06	1004	-0.2		91	10	ST	25	NIL	25+	4.0	vRB	0.0	2.16
	12	1005	-0.1		91	10	Cu	20	NIL	25+	6.9	18	0.0	2.80
	18	1007	.0.9	.0.3	90	9	CU	25	T	25+	7.8	18	2.0	6.32
?3	00	1009	.2.0		84	5	SC	35	T	25+	7.6	VRB	4.2	?.55
	06	1010	+1.5		93	3	CU	45	NIL	25+	3.1	VRB	2.6	4.17
	12	1010	-1.2		90	7	Cs	200	NIL	25+	6.5	18	5.2	6.22
	18	1010	+3.0	.1.8	93	?	AC	80	NIL	25+	8.7	18	5.5	8.27
!4	00	1008	+2.4		87	8	ST	50	NIL	25+	4.5	VRB	0.8	7.27
	06	1007	+3.0		88	6	ST	50	N] L	? 5+	4.5	VRB	0.0	.?.39
	12	1006	+1.5		91	10	AC	80	NIL	25.	5.4	VRB	2.7.	4.39
	la	1006	+2.0	+2.2	85	5	Cu	30	NIL	25+	10.0	14	6.0	9.77
?5	00	1006	+2.0		87	9	CU	50	NJ L	75.	6.5	VRB	5.3	9.84
	06	1005	.0.5		91	7	AC	100	NIL	25+	7.5	22	5.s	5.01
	12	1004	.2.0		87	1	AC	10U	NIL	25+	5.6	18	5.0	4.06
	18	1005	+2.7	.1.8	87	9	AC	100	NIL	25+	7.8	VRB	0.2	6.97
?6	00	1006	+5.5		78	10	CU	30	NIL	25+	5.1	18	0.2	'?.68
	06	1006	+2.0		85	10	CU	70	NIL	25+	6.1	VRB	0.0	2.56
	12	1006	+2.1		90	10	ST	10	T	? 5+	8.6	18	0.0	1.73
	18	100B	+2.8	+3.1	91	10	CU	10	0.8	25+	5.0	VRB	0.0	1.96
77	00	1010	+4.1		79	10	ST	10	T	25+	4.6	22	0.0	3.35
	06	1o11	+4.0		100	10	ST	10	2.7	10	5.0	18	0.0	0.94
	12	1009	+4.5		86	10	ST	15	T	?0	17.3	?7	0.0	N/A
	18	1013	+4.8	.4.3	59	7	CU	20	T	25+	15.2	27	3.9	4.14
?8	00	1020	.5.0		64	7	CU	45	NIL	75+	5.3	VRB	4.4	7.42
	06	1021	+3.4		90	5	CU	30	NIL	25+	4.9	VRB	2.0	3.50
	12	1019	+4.8		69	7	CU	20	NIL	25+	9.3	16	0.0	3.51
	18	1018	..?.8	+4.0	91	10	ST	40	0.3	1?	13.8	VRB	0.0	4.76
29	00	1016	+3.1		91	10	ST	10	3,4	20	1.9	VRB	0.0	1.90
	06	1013	+3.2		87	10	3T	05	T	25+	.?.2	vRB	0.0	0.49
	12	1013	+4.8		86	8	CU	15	T	75.	3.9	12	0.0	1.87
	18	1015	+6.5	+4.4	66	9	CU	30	NIL	25.	6.6	32	0.1	7.05
30	00	1017	.6.8		69	77	CU	25	NIL	25+	11.9	02	3.7	5..?5
	06	1018	.5.0		70	8	CU	50	NIL	25+	14.1	34	1.2	4.17
	17	1019	.5.0		72	10	CU	30	NIL	25.	6.3	VRB	0.0	2.78
	18	1021	+7.2	+6.0	75	8	AS	60	NIL	25+	15.6	36	1.3	4.53
July	00	1073	.5.7		81	8	CU	20	NIL	25+	4.3	VRB	2.2	6.18
01	06	1024	.4.0		82	7	CU	50	NIL	25+	4.2	vRB	2.3	3..?1
	12	1075	+4.0		85	6	AC	70	NIL	25+	6.7	VRB	,?.0	3.07
	18	1028	+6.0	+4.9	92	5	AC	80	NIL	25+	10.3	18	5.9	10.32
0?	00	1029	+8. 0		82	6	AC	60	NIL	25+	9.3	VRB	5.0	9.81
	06	1029	+7.5		90	8	AC	60	NIL	25+	4.3	VRB	3.3	4.86
	12	1028	.6.0		81	?	AS	90	NIL	25+	6.3	21	2.0	4.39
	18	1026	+8.5	+7.5	81	1	AC	100	NIL	25*	9.6	27	6.0	9.99
03	00	1025	.8.9		84	NIL	-		NIL	25+	7.5	18	6.0	10.12
	06	1025	+8.1		82	6	CI	200	NIL	25.	4.8	VRB	6.0	5.15
	12	1025	+7.9		75	4	c1	180	NIL	25+	11.5	18	6.0	4.11
	18	1025	+10. 5	.8.9	77	2	CI	150	NIL	25+	8.0	18	6.0	9.92

DAILY WEATHER SUMMARY

DATE	TIME	PRESSURE	TEMPERATURE	DAILY MEAN	RELATIVE HUMIDITY	CLOUD COVER	TYPE	HEIGHT	RAIN/SNOW	VISIBILITY	SPEED	DIR	INSOLATION SUN SHINE	ENERGY
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
	UTC	mb	°C	°C	%	1/10		ft x 100	mm	km	km/hr	° x 10	hrs	MJM-2
July	00	1023	+13.9		60	6	Cu	70	NIL	25+	7.8	VRB	4.5	10.10
34	06	1070	+9.0		82	9	AC	70	NIL	25+	3.4	VR B	1.,?	4.05
	12	1016	+8.2		75	3	AS	70	NIL	25+	6.1	18	3.9	3.64
	18	1012	+7.0	.9.5	74	2	CU	50	NIL	25+	11.2	18	6.0	10.16
05	00	1008	+6.9		74	3	AC	60	NIL	25+	10.0	16	6.0	9.89
	0.3	1005	.4.9		72	1	AC	60	NIL	25+	6.4	VRB	6.0	5.05
	12	100.?	+3.0		85	5	AC	60	NIL	25+	7.8	18	4.9	5.63
	18	lore?	.5.2	+5.0	77	6	AC	60	NIL	25+	10.1	18	5.5	9.78
06	00	1007	+3.9		77	7	ST	40	NIL	25+	11.6	VRB	4.0	8.00
	06	1002	.2.2		70	10	SC	30	T	25+	7.2	16	2.2	3.33
	12	1003	.2.4		87	10	ST	10	1.7	25+	7.9	20	NIL	0.63
	18	1001	+2.2	.2.7	97	10	ST	05	1.5	6	9.3	VRB	NIL	1.??
n?	00	loin	+4.9		80	10	ST	30	T	15	2.7	VR 6	NIL	0.88
	06	998	+3.2		94	10	ST	01	1.5	8	12.5	20	NIL	0.31
	12	999	+4.7		80	10	ST	25	0.4	25+	3.8	VRB	NIL	1.62
	18	1001	+1.6	+3.6	97	10	SC	10	1.0	6	8.5	VRB	NIL	7.55
08	00	1004	+2.7		87	10	ST	10	NIL	70	5.5	VRB	NIL	2.03
	06	1006	+3.5		85	10	SC	30	NIL	20	3.8	VRB	NIL	1.06
	12	1006	.4.8		77	10	ST	50	NIL	25+	9.1	1'7	0.2	1.25
	18	1008	+6.2	.4.3	7B	6	Cu	50	NIL	7.5.	7.6	VRB	0..?	3.36
39	00	1001	+6.8		80	6	AC	50	T	25+	10.7	VRB	4.9	8.71
	06	1011	+3.1		80	6	CU	30	NIL	25+	8.7	18	NIL	3.28
	12	1011	+3.6		77	10	Cu	30	NIL	25+	11.9	36	NIL	2.26
	18	1014	+6.2	.4.9	70	8	CU	30	NIL	? 5+	23.1	36	NIL	6.49
10	00	1016	+6.5		61	3	AC	100	NIL	25+	14.7	36	5.9	9.90
	06	1017	+5.2		61	4	CI	200	NIL	25+	13.3	36	6.0	5.39
	12.	1017	+6.2		55	6	AC	100	NIL	25+	14.1	36	6.0	5.07
	18	1017	+6.5	.6.1	61	8	AC	100	NIL	25+	7.1	VRB	1.7	5.94
11	0c	1016	+7.0		64	1	AC	100	NIL	25+	5.6	20	6.0	9.86
	06	1019	+4.9		64	cLR	-		NIL	25+	5.7	20	5.3	4.17
	12	1019	.9.0		67	CLR	-	-	NIL	25+	6.2	02	6.0	3.84
	18	1020	+12.0	+8.2	75	CLR	-		NIL	25+	7.3	18	6.0	N/A
12	00	1020	.5.0		80	CLR	-	-	NIL	25+	9.4	20	6.0	N/A
	06	1021	+3.0		65	CLR	-	-	NIL	25.	7.8	VRB	6.0	6..?9
	12	10.?1	+3.2		85	CLR	-	-	NIL	25+	8.9	23	6.0	4.66
	16	1021	.6. S	●4.4	79	CLR	-		NIL	25+	11.0	25	6.0	10.28
13	00	1021	+8.0		77	CLR	-	-	NIL	?5.	10.5	VRB	6.0	9.14
	06	1020	+3.6		82	CLR	-		NIL	25+	6.7	18	6.0	3.87
	12	1017	+5.0		80	cLR	-		NIL	25+	5.s	20	6.0	4.64
	la	1016	+9.2	.6.4	73	2	AC	90	NIL	25+	10.1	23	6.0	10.19
14	00	1015	.9.7		63	2	Cu	80	NIL	25+	10.3	18	6.0	8.97
	06	1014	+10.2		57				NIL	25+	3.5	VRB	6.0	4.84
	12	1011	+4.7		80	8	Cu	40	NIL	25+	7.9	23	3.0	3.50
	18	1011	+8.4	+8.2	71	4	Cu	50	NIL	25+	10.4	20	5.7	.9.73
15	00	1011	+7.9		76	5	Cu	50	NIL	25+	9.3	20	6.0	8.92
	06	1011	,6.1		78	3	Cu	60	NIL	25+	3.8	21	4.7	4.28
	12	1011	+8.9		77	7	AS	60	NIL	25+	3.5	VRB	3.4	3.16
	18	1011	+14.0	,9.2	56	4	AC	100	NIL	25+	6.9	VRB	6.0	7.85
16	00	1011	+15.8		6S	B	CU	50	NIL	25+	6.2	VRB	4.9	7.70
	06	101.?	+10.9		68	9	SC	50	NIL	25+	3.4	VRB	4.8	3.81
	12	1013	+11 .1		60	10	CU	30	NIL	25+	5.6	VRB	2.8	3.37
	18	1014	+15.1	,13.2	61	9	AS	70	T	25+	9.2	18	3.7	7.52
17	W	1014	.15.0		63	9	AC	80	NIL	25+	5.0	VRB	0.1	3.92
	0.3	1012	+11.0		67	6	AC	BO	NIL	25+	2.2	VRB	0.1	2.16
	12	1013	+14. S		61	1	CICU	200	NIL	25+	4.2	VRB	5.0	3.48
	18	1013	+16.0	·14.1	66	2	CU	60	NIL	25+	7.9	VRB	6.0	9.81
18	00	1013	+17.2		66	2	Cu	60	NIL	25+	4.4	VRB	6.0	?.29
	06	1013	●13.3		67	CLR	-	-	NIL	25+	4.2	VRB	6.0	4.68
	12	1013	+13.3		65	1	c1	120	NIL	25+	4.2	VRB	6.0	4.38
	10	1013	+17.5	+15.3	66	2	CI	120	NIL	25+	12.7	VRB	6.0	8.99
19	00	1010	+16.5		43	7	CI	200	NIL	25+	9.8	18	4.7	7.19
	06	1010	+9.5		72	9	AC	60	NIL	25+	3.6	18	5.3	4.49
	12	1010	+11.5		57	1	AC	80	NIL	25+	5.6	VRB	5.0	4.06
	18	1010	+15.2	+13.2	42	1	Cu	60	NIL	25+	.s.5	24	6.0	8.72
20	00	1011	.15.8		40	3	CU	60	NIL	25+	7.9	VSB	6.0	6.22
	06	1012	+12.0		50	2	CICU	200	NIL	25+	3.3	VRB	6.0	4.55
	12	1013	+9.6		82	cLR	-	-	NIL	25+	5.1	CRB	6.0	4.20
	18	1014	+10.4	.11. 9	77	cLR	-	-	NIL	25+	9.3	15	6.0	8.83

DAILY WEATHER SUMMARY

			TEMPERATURE			CLOUD							NSOLATION	
	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
a	b	c	d	e	f	g	h	i	j	k	1	m	n	o
	[illegible]	[illegible]	°C	°C	%	1/10		x 100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
uly	00	1013	9..?		76	CLR			NIL	25+	3.0	21	5.0	3.37
1	06	1012	7.8		82	CLR			NIL	25+	5.1	VRB	5.0	4.88
	12	1011	13.1		62	4	I	200	NIL	25+	7.4	01	5.0	4.02
	18	1011	16.9	1.8	68	4	r	200	NIL	25+	5.3	VRB	5.0	9.16
2	00	1011	11.9		62	7	s	100	NIL	25+	5.6	VRB	5.0	7.76
	06	1011	12.0		62	4	CSL	100	NIL	25+	1.8	VRB	2.7	3.01
	12	1011	8.2		71	4	s	100	NIL	25+	5.2	VRB	5.0	3.78
	18	1012	10.8	0.7	70	4	s	70	NIL	25+	3.2	01	5.0	N/A
3	00	1011	11.2		67	4	s	70	NIL	25.	5.1	VRB	4.5	V/A
	06	1016	12.9		N/A	cLR			NIL	N/A	11.0	N/A	5.5	N/A
	12		12.6		50	7	T	so	NIL	25+	11.5	02	?.0	3.22
	18	1016	12.3	2.2	N/A	3	u	40	NIL	25+	3.9	VRB	1.0	5.35
4	00	1019	10.4		74	1	u	40	NIL	25+	7.0	18	5.8	7.10
	0-3	1019	.6.5		69	2	ICU	200	NIL	25+	7.6	20	5.0	4.52
	12	1021	·9.1		73	7	:I	200	NIL	25+	4.8	VRB	5.0	3.83
		1021	.13.1	).5	61	3	1	200	NIL	25+	5.9	VRB	5.0	7.70
!5	w	1021	.15.2		62	1	CI	200	NIL	25+	4.5	VRB	6.0	0.07
	06	1021	,13.9		55	4	ACSL	50	NIL	25+	9.2	VRB	6.0	4.10
	12		,12.1		6.?	6	CS	200	NIL	25+	4.6	VRB	5.5	3.50
	18	101B	·15.4	14.2	5.?	10	CS	200	NIL	25+	7..?	20	6.0	7.83
!6	00	1017	·14.0		54	6	CICU	200	NIL	25+	6.6	VRB	5.5	7.02
	06	1015	}12.0		60	7	AC	100	NIL	25+	2.7	VRB	3.4	3.48
	12	1013	,12.9		63	4	CICU	200	NIL	25+	5.9	70	5.0	3.81
	18	1012	,13.0	13.0	63	N/P.			NIL	25+	7.9	VRB	3.3	6.55
›7	00	1011	·13,1		64	4	CU	50	NIL	25+	6.6	VRB	6.0	7.02
		1011	.9.7		67	3	CICU	200	NIL	25+	7.6	VRB	5.7	4.17
	12	1011	·10.7		65	1	CI	200	NIL	25+	4.0	VRB	4.8	3.49
	16	1012	·15.1	12.2	66	CLR			NIL	25+	5.8	21	6.0	8.08
!8	00	1013	·14.9		46	CLR			NIL	25.	7.8	VRB	6.0	6.04
	06	1013	,11.5		59	1	AC	100	NIL	25+	3.6	0.4	5.8	4.54
	17	1013	,13.1		57	3	CU	60	NIL	25+	5.6	vRB	5.0	3.49
	18	1013	,14.9	13.6	51	2	CU	80	NIL	25+	5.4	VRB	6.0	6.89
?9	00	1013	,15.0		.42.	CLR			NIL	? 5.	3.3	34	5.3	6.83
		1013	.17.7		53	2	c1	200	NIL	25+	9.8	36	6.0	.4.02
	12	1011	,13.6		48	4	CI	250	NIL	25+	10.2	18	4.7	3.49
	18	1011	·14.0	13.8	58	4	CU	90	NIL	25+	6.3	20	6.0	7.86
30	00	1011	,11.3		69	6	CU	00	NIL	25+	6.7	vRB	5.5	7.63
	06	1008	·8.2		70	9	AC	100	NIL	25+	3.9	VRB	1.3	2.35
	12	1006	.6.8		84	8	CU	60	NIL	25+	5.3	7.0	.?.7	3.00
	18	1006	.9.0	9,6	74	4	CU	80	NIL	25+	10.4	18	5.7	6.72
31	00	1004	.8.5		71	CLR			NIL	25+	8.4	18	6.0	7.77
	06	1003	,6.0		81	CLR			NIL	25+	5.6	VRB	6.0	3.73
	12	1004	.6.9		74	CLR			NIL	75.	6.5	20	5.2	3.27
	18	1004	.8.5	7.5	73	3	CS	?50	NIL	25+	9.3	18	6.0	7.65
Aug.	00	1003	.8.0		?5	6	CU	60	NIL	25+	10.6	18	6.0	8.09
)1	06	1002	+5.8		al	8	AC	100	NIL	25+	6.6	vRB	7..3	2.86
	12	low	.6.5		76	3	AC	100	NIL	25+	9.0	18	4.7	3.47
	18	997	.8.0	7.1	?7	8	AC	100	NIL	25.	12.2	18	5.0	8.71
)2	0c	992	+7.1		79	10	ST	773	NIL	25+	7.1	20	1.0	3.22
	06	991	+5.0		89	10	CU	40	1.3	25.	4.9	VRB	NIL	1.37
	12	993	.5.8		N/A	9	ST	10	NIL	25+	4.4	VRB	NIL	1.43
	18	N/A	N/A	/A	N/A	N/A			NIL	25+	N/A	N/A	3.3	N/A
)3	0C	N/A	.9.5		63	9	CU	60	NIL	25+	4.6	VRB	0.5	N/A
	06	N/A	.8.0		87	9	CU	60	2.3	25+	5.3	VRB	NIL	0..99
	12	N/A	.8.5		78	10	CU	30	0.4	25+	4.5	23	NIL	0.37
	18	N/A	N/A	/A	N/A	N/A			NIL	N/A	N/A	N/A	NIL	N/A
)4	0c	996	+8 ..?		92	10	ST	75	0.4	25+	N/A	24	NIL	N/A
	0f	997	+8.0		80	10	ST	35	NIL	25+	7.1	VRS	NIL	N/A
	12	997	+8.1		82	10	CU	50	0.3	25+	7.9	09	NIL	N/A
	18	998	.11.5	9.0	59	9	Cu	55	NIL	2s.	7.4	VRB	NIL	N/A
)5	00	999	.9. s		5?3	9	CU	50	0.3	25+	11.9	36	NIL	3.81
	06	990	.8.0		80	9	ST	50	NIL	25+	10. !	33	NIL	1.59
	12	998	+10.8		71	1	CU	60	NIL	25+	6.7	05	2.0	.?.32
	18	998	+10.4	9.7	82	7	Cu	60	NIL	25+	6.1	20	6.0	7.40
06	00	998	+11.9		58	8	CU	60	NIL	25+	3.9	VRB	6.0	5.79
	06	996	+10.8		61	8	AC	60	NIL	25+	11. !	36	NIL	1.84
	12	996	+8.8		71	10	SC	60	NIL	25.	11.;	36	NIL	1.09
	18	998	.10.7	10.(	60	9	Cu	40	NIL	25+	lo. !	32	NIL	2.83

DAILY WEATHER SUMMARY

			TEMPERATURE			CLOUD							INSOLATION	
DATE	TIME	PRESSURE		DAILY MEAN	RELATIVE HUMIDITY	COVER	TYPE	HEIGHT	Mill SNOW	VISIB-ILITY	SPEED	DIR	m SHINE	ENERGY
a	b	c	d	e	t	g	h	i	j	k	l	m	n	o
	UTC	mb	°C	°C	%	1/10		ft x III	mm	km	km/hr	° x 10	hrs	MJ m-2
August	00	1000	.9.2		88	4	CU	40	NIL	25+	6.9	VRB	3.5	5.52
7	06	1001	+7.9		75	4	AC	50	NIL	25+	6.3	VRB	0.8	0.90
	12	1003	+9.2		81	2	CI	200	NIL	25+	4.2	VRB	6.0	2.70
	18	1003	.11.4	+9.4	78	3	AC	80	NIL	25+	5.2	VRB	6.0	7.68
B	w	1005	.11.3		69	NIL	-	-	NIL	25+	5.1	VRB	6.0	6.13
	06	1004	.10.3		71	NIL	-	-	NIL	25+	7.7	05	1.3	0.92
	12	1005	+8.8		90	NIL	-	-	NIL	25.	4.3	VRB	6.0	2.64
	18	1006	.11.0	+10.4	82	NIL	-		NIL	25+	5.0	VRB	6.0	7.5s
9	60	1007	+9.9		83	1	CI	200	NIL	25+	3.5	VRB	5.5	6.07
	06	1005	+11.4		7.9	NIL	-	-	NIL	25+	6.9	VRB	1.2	0.85
	12	1004	.10.3		84	2	CI	200	NIL	25+	3.3	VRB	6.0	2.56
	18	1001	.11.5	+10.8	74	3	CI	200	NIL	25+	4.6	VRB	6.0	7.32
0	00	999	●10.1		81	2	CI	200	NIL	25+	2.1	VRB	5.5	6.32
	06	999	+7.3		72	1	CI	200	NIL	25+	1.3	VRB	1.2	0.87
	12	999	.7.1		87	NIL	-	-	NIL	25+	5.5	22	6.0	2.42
	18	1002	.9.6	+8.5	76	2	CI	200	NIL	25*	6.2	VRB	6.0	7.33
L	00	1006	+8.3		80	4	CI	200	NIL	25+	6.5	22	5.5	6.42
	06	1005	.7.0		87	3	CI	?.00	NIL	25+	3.0	VRB	0.3	0.69
	12	1007	.9.0		9?.	2	CI	200	NIL	25+	1.4	VRB	6.0	2.06
	16	1008	+10.5	+8.4	86	2	CI	200	NIL	25+	5.6	19	6.0	7.04
2	00	100B	.8.6		83	1	CS	200	NIL	25+	8.2	VRB	5.5	5.73
	06	1007	+5.8		92	CLR	-		NIL	25+	2.8	VRB	NIL	0.65
	12	1007	.7.2		94	2	c1	200	NIL	25+	2..5	VRB	6.0	?..25
	16	100B	+9.1	+7.7	81	CLR	-		NIL	25.	7.7	23	6.0	7.04
3	w	1010	.8.7		83	4	Cu	60	NIL	25+	8.0	VRB	5.0	5.74
	06	1010	+5.9		92	7	AS	100	NIL	25+	3.2	VRB	NIL	1.00
	12	1010	,6.9		87	9	AC	80	NIL	25+	3.0	VRB	NIL	1.20
	18	1I310	.8. ?	+7.4	75	9	AC	80	NIL	25+	5.4	VR6	0.3	3.01
4	00	1010	+9.6		89	7	AS	80	NIL	25+	2.7	VRB	NIL	2.98
	06	1010	+7.2		84	9	CI	200	NIL	25+	2..9	VRS	0.2	0.69
	12	1010	+10.8		82	4	CI	200	NIL	25+	1.0	VRB	5.7	2.05
	18	1010	+12.0	+9.9	75	2	CI	200	NIL	25+	7.5	25	6.0	8.07
5	00	1010	+10.0		71	4	AC	10U	NIL	25+	3.9	VRB	4.5	4.14
	06	1010	.6.0		69	5	AC	120	NIL	25+	2.6	VRB	NIL	0.72
	12	1010	.9.5		81	6	ACSL	100	NIL	25+	3.6	VRB	2.3	1.84
	16	1010	.11.7	+9.8	78	3	ACSL	120	NIL	25+	6.0	VRB	3.7	5.04
6	00	1010	+10.4		95	10	AC	120	NIL	25+	3.1	VRB	0.7	3.02
	06	1010	.8 .21		76	9	AC	120	T	25+	3.4	VRB	NIL	0.52
	12	1006	.9.1		03	4	AC	120	NIL	25+	2.9	VRB	2.7	1.47
	18	1004	+11.0	+9. B	73	1	Cu	120	NIL	25+	8.2	32	6.0	6.64
7	00	loco	+10.8		61	8	CU	60	NIL	25+	2.9	VRB	6.0	5.70
	06	1000	+6.0		86	B	ACSL	80	NIL	25+	3.6	VRB	NIL	1.00
	12	999	+9.0		64	8	Cu	60	NIL	25+	3.8	06	0.5	1.17
	18	998	.8.7	+8.6	57	10	CU	60	NIL	25+	14.1	04	NIL	1.88
B	00	1001	+4.8		86	10	Cu	20	1.0	20	14.8	25	NIL	1.39
	06	1005	+3.3		6s	10	CU	10	0.5	20	11.1	VRB	NIL	0.65
	12	1009	+3.5		88	10	Cu	10	0.6	6	4.9	VRB	NIL	0.98
	18	1010	.5.5	+4.3	72	6	Cu	25	0.2	25+	12.4	23	3.5	5.63
9	00	1006	.5.5		75	10	CU	35	T	25+	3.3	VRB	1.5	3.40
	06	1 002	+2.1		100	10	CU	05	1.6	6	19.7	23	NIL	0.28
	12	1000	+3.0		100	10	CU	05	12.0	6	9.3	.?3	NIL	0.17
	18	1000	.3.1	+3.4	91	10	Cu	05	2.2	25+	7.0	09	NIL	1.69
0	00	1002	+3.5		100	9	ST	20	T	25+	8.8	06	NIL	2.60
	06	1004	+1.7		77	7	Cu	40	NIL	25+	7.7	25	NIL	0.83
	12	1005	.0.8		86	10	Cu	30	0.2	25+	8.3	23	NIL	0.02
	18	1005	.1.4	+1.8	87	10	se	10	NIL	10	8.8	23	NIL	2.s0
21	00	1005	.0.2	N/A	90	10	SC	05	0.6	10	15.2	23	NIL	N/A

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DIET AND MATERNAL BEHAVIOUR OF THE ARCTIC HARE

Robert Burton and Dominic Hargreaves

INTRODUCTION

The Arctic hare was chosen as a subject for study for three reasons: it is often abundant on western Ellesmere Island; it is remarkably tame; and a search of the literature revealed very little published work. It then transpired that Dr David Gray and his colleagues at the National Museum in Ottawa have been studying the breeding behaviour Arctic hares in neighboring parts of Ellesmere Island for several years so, at Dr Gray's suggestion, we undertook to investigate feeding ecology, and also to gather information on breeding for his study.

In the event, Arctic hares proved to be uncommon in the expedition valley. Six weeks elapsed before we found an animal near enough to study - at Bob's Camp 4 kilometres from Base Camp on the far side of a river. The data presented here are consequently limited.

Taxonomic note The Arctic hare is generally regarded in Canada as a full species *Lepus arcticus*, but as a subspecies of the mountain hare *L. timidus* in European literature (e.g. Corbet and Southern, 1977). The most recent study (Baker, et.al. 1983) recognises the division into species of the circumpolar hares but further study is needed to resolve the problem fully.

DIET

We had hoped to compare diet in three seasons: "winter" when the ground was still snow-covered, "summer" when plants were growing rapidly and temperatures were high, and "autumn" when plants are seeding and leaves are wilting. The period in which our hare was under observation coincided with "summer".

Published data on the diet of the Arctic hare are largely anecdotal but they indicate that Arctic willow (*Salix arctica*) is the principal component, together with sedges, grasses and various forbs (e.g. Bonnyman, 1975). Parker (1977) studied diet by collecting stomach contents from "winter" and "summer" samples. He confirmed that willow is the main food, especially in winter. The diet in summer (equivalent to the period of our observations) was more diverse, with 35 species identified, and willow, *Dryas* and the grasses *Puccinellia* and *Agropyron* the most frequent components (Table 1). Although Parker did not assess the vegetation quantitatively, he concluded that the Arctic hares were not selecting particular species of plants but were eating them in the proportion that occurred in the hares' preferred hillside habitat.

We hoped to investigate selectivity in the diet of Arctic hares and to link this with the nutritional value of plant species. Iason and Waterman (1988) have shown that reproducing female and juvenile mountain hares avoid eating heather *Calluna* because accumulated metabolizes in the plant's tissues impair digestion. (These metabolizes are substances, such as phenols and tannins, which have a poisonous effect on herbivorous animals, reducing their digestive efficiency and consequently affecting growth and reproduction). Male and non-breeding females with lower energetic requirements were less selective.

In particular, we envisaged a changing selectivity for the preferred Arctic willow. The high levels of nutrients (carbohydrates and proteins) in young leaves diminish within the first month of growth and metabolizes then accumulate (Dawson and Bliss, 1989). Kukal and Dawson (1989) have demonstrated the adverse effect of these metabolizes on the physiology of the "woolly bear" caterpillars of Gynaephora moths which feed selectively on fresh Arctic willow leaves in early summer.

Methods

The diet of an animal can be studied by investigating what goes in, what is inside and what comes out. Given our lack of working-up facilities, we decided against the latter two methods (sampling stomach contents and droppings for plant remains) and concentrated on the first (observing plants as they are eaten). This method would also allow us to compare the species eaten with those available to the hare as it grazed over a patch of ground and so calculate whether certain plants are selected or avoided.

We followed our hare, recording the plants that it ate and the track that it followed. We then retraced the track carefully to count the plants, and parts of plants, that had been eaten. At a later date, quadrats were thrown in the area enclosing the hare's track to obtain the frequency of plants available to the hare.

In practice, we found difficulties with this technique. Hares crop plants extremely close to the ground, so the animal's head and irregularities of the ground easily obscure the observer's view of its mouth. Small plants may be pulled out entire so no record remains.

Our observations cover the period of maximum plant growth and when the hare was suckling young. The hare occupied a range that covered the side of a sloping valley floor between the river and precipitous bluffs. The main habitat type, dominated by Dryas, occupied about 90 per cent of the range and there were smaller areas of sedge hummock, Cassiope heath and flush areas where steams had run during the melt. There were three scree fans where streams ran out of the mountain.

Feeding fell into two patterns. When traveling to and from the nursery, the hare stopped at intervals to feed "casually" for short periods ranging from a few seconds to a few minutes. It was usually impossible to catch up and, if we did, we could make no more than qualitative records. In "serious" feeding bouts, the hare did not move far, so enabling us to observe it closely.

Results and discussion

Table 1 shows the percentage of bites taken at each species of plant in 12 bouts of feeding where we could reliably observe the hare's behaviour, and compares them with Parker's results.

The amounts of willowherb (Epilobium) and Polygonum are underestimated because the hare sometimes pulled out the whole plant and left no trace that they had been taken. Purple saxifrage (Saxifraga oppositifolia) was also underestimated because the hare cropped the flowers from one 'button' without raising its head and i+ was impossible to tell how many flowers had been removed. It was not usually possible to distinguish between grasses and sedges, and we refer to them collectively as graminoids.

The amount of Arctic willow in the sample is not surprising considering previous reports of Arctic hares' preference for this species. It is more surprising that Dryas and graminoids were taken so rarely, in view of Parker's results. In our observations, the hare avoided habitats which were dominated by these plants. When she did feed in these habitats, it was "casual" feeding and our observations suggest that she was ignoring the most numerous species, such as Dryas and graminoids, and choosing less abundant species which were known to be favoured elsewhere. For instance, while traversing the hillside on her way to and from the nursery, the hare would divert 3-4 metres from her track to crop the flowers from a clump of poppies and then proceed on her way. On the one occasion that we were able to record "serious" feeding in Dryas heath, she ate sorrel (Oxyria), sedge and willow (all favorites) in equal proportions and ignored the very abundant Dryas. On two occasions she fed in Cassiope heath she selected Polygonum on one occasion and poppy (PaDaver) on the other, although both were uncommon.

Our observations also suggest a clear preference for rapidly growing parts of plants, especially flowering heads. All records for Dryas, Chrysanthemum and purple saxifrage as well as most for the graminoids were of flowers. It was noticeable that purple saxifrage was ignored after the flowers had faded. For sorrel, poppy, willowherb, Polygonum, the hare took mainly the flowerheads and part of the associated stems. Poppy leaves were cropped when the flowerhead was still short so that their ingestion may have been incidental. There was also an indication that Polygonum was eaten more often when the bulbils were ripening.

Coupled with the avoidance of the dry Dryas heath habitat, our observations suggest, without being numerous enough to draw significant conclusions, that our hare was choosing to feed in flush areas where the ground is disturbed by melt water in the spring thaw. These areas are colonised by willow, sorrel, willowherb and Polygonum, so providing good grazing for the hare.

Arctic willow Because it is so easily recognised in the field and because it is the major component of the hare's diet, we were able to make more detailed observations of this species. Figure 1 shows that the hare preferred male catkins until these withered and then ate more leaves. female catkins were eaten more as they began to ripen. These observations can be explained by ripe male catkins being rich in tissue nitrogen (Dawson and Bliss, 1989). The amount of starch and tissue nitrogen in leaves increases sharply in July and our observations hint that our hare was reacting to this. Ripening seeds in the female catkins would also be more nutritious. Observations unfortunately ceased before the period when metabolizes would have be building up to make leaves less palatable.

Conclusions

It is hardly possible to draw general conclusions from a sample - of one but it is clear that our hare was showing selectivity in her diet and was appearing to choose fast-growing parts of plants which are more nutritious. Although Parker's method of sampling is very different from ours, there is a marked contrast with his results. It is unfortunate that Parker did not distinguish betwen the sexes in his analysis of stomach contents.

MATERNAL BEHAVIOUR

David Gray and his associates have found that females suckle at intervals-of circa 18.6 hours. Some other lagomorphs suckle at 24 hour intervals. Our hare provided the opportunity for collaborative observations.

Observations

The litter of eight leverets was discovered on 26 June, when they appeared to be about one week old. The nursing site was among boulders in a gulley which opened onto a scree fan that fell down the side of the valley. It was 213 metres ASL and 181 metres above the river. Seventeen suckling bouts were observed, usually from the side of the gully about 50 metres away. Gray has suggested that an approach to 5 metres does not disturb the hares but we found that if we approached to this distance the hare covered the final 100 metres to the nursery more slowly and suckling bouts became shorter.

The pattern of suckling was for the leverets to approach the nursery up to an hour before the hare arrived. They gathered at the spot where they had been suckled previously and rested, groomed or nibbled leaves. As the hare's arrival became imminent, the leverets gather in a tight group and began to look alert, sometimes rearing onto their hindlegs, and there were occasional apparently aggressive interactions. In the latter part of the nursing period, the leverets became more active; one would break away from the huddle and the others would stream after it, but they would circle and quickly return to the original position.

When the hare arrived at the nursing site, the leverets ran to meet her but she avoided them and led them for a few metres before allowing them to suckle. This manoeuvre usually brought them back to the nursing site but it gradually moved down the gully through the leverets intercepting their mother before she reached the correct position. At weaning it had moved 80 metres.

The intervals between nursing bouts (Table 2) correspond with those recorded by Gray, but there was no sign of the erratic nursing just before weaning that he recorded. We made little attempt to follow the leverets after nursing bouts. They dispersed up and down hill, keeping to the boulders, occasionally gamboling with hindfeet flung into the air, and they were nibbling plants from the first day we saw them.

The duration of suckling was of the same order as Gray's average of 120 ± 32 seconds (Table 3). During nursing, the hare occasionally nosed the leverets, who struggled beneath her. Once or twice one emerged, ran around to her other flank and dived in again. Each bout was terminated by the hare running away.

Observations of weaning were complicated by the appearance of an Arctic fox. On 22 July, one leveret came running down the gully and past its siblings, chased by a fox. There followed a confused chase around the scree as the fox pursued a succession of leverets which were able to elude it by changing course among the boulders. Eventually, it latched onto one and chased it for several minutes, forcing it out of the boulders and, by cutting corners, caught up with it. The fox dismembered the body by shaking and tearing, buried the forepart and carried the rest out of sight.

While the fox was dealing with its victim, the adult hare arrived and suckled three leverets. For the first time she dispersed with them up the gully instead of going down the valley. On 23 July three leverets were suckled. Another arrived one minute late and was avoided by the doe. She went up the gully and was never seen again. Three leverets spent two hours at the nursery at the appropriate time on the 24th and two appeared after the correct interval on the 25th. The fox was seen again on the 23rd but none of the hares were not seen after the 25th despite extensive searching. Leveret droppings and signs of feeding were found up to 2000 metres up the gully.

Table 1. Plants eaten by Arctic hares

	Burton, 1988 1 hare %bites	Parker, 1977 23 hares %fragments
Salix	54	20.5
Dryas	2	16.6
Puccinellia		16.0
Agropyron		10.9
Arctagrostris		4.5
"Graminoid"	3	
Oxyria	10	2.9
Polygon=	16	0.1
PaDaver	12	0.1
Epilobium	5	0.5
Sax. oppositifolia	4	1.0
Draba	2	1.1
Species recorded	13+	35+

"Graminoid" refers to all grasses and sedges and is equivalent to Puccinellia, Agropyron and Arctagrostris in parker's sample.

Table 2 Nursing intervals

June	26	18.41 hours
	27	18.43
	28	18.23
	29	18.40
	29	18.41
	30	18.51
July	5	18.11
	6	18.21
	11	18.26
	17	18.51
	18	18.51
	19	18.25
	23	18.70

Mean of 13= 18.38hours

Table 3 Suckling duration

June	26	128 seconds
	27	124
	28	122
	29	108
	29	94
	30	104
July	4	126
	6	117
	10	106
	11	107
	16	101
	17	80
	18	104
	19	79
	22	115
	23	115

Mean of 16: 108 seconds.

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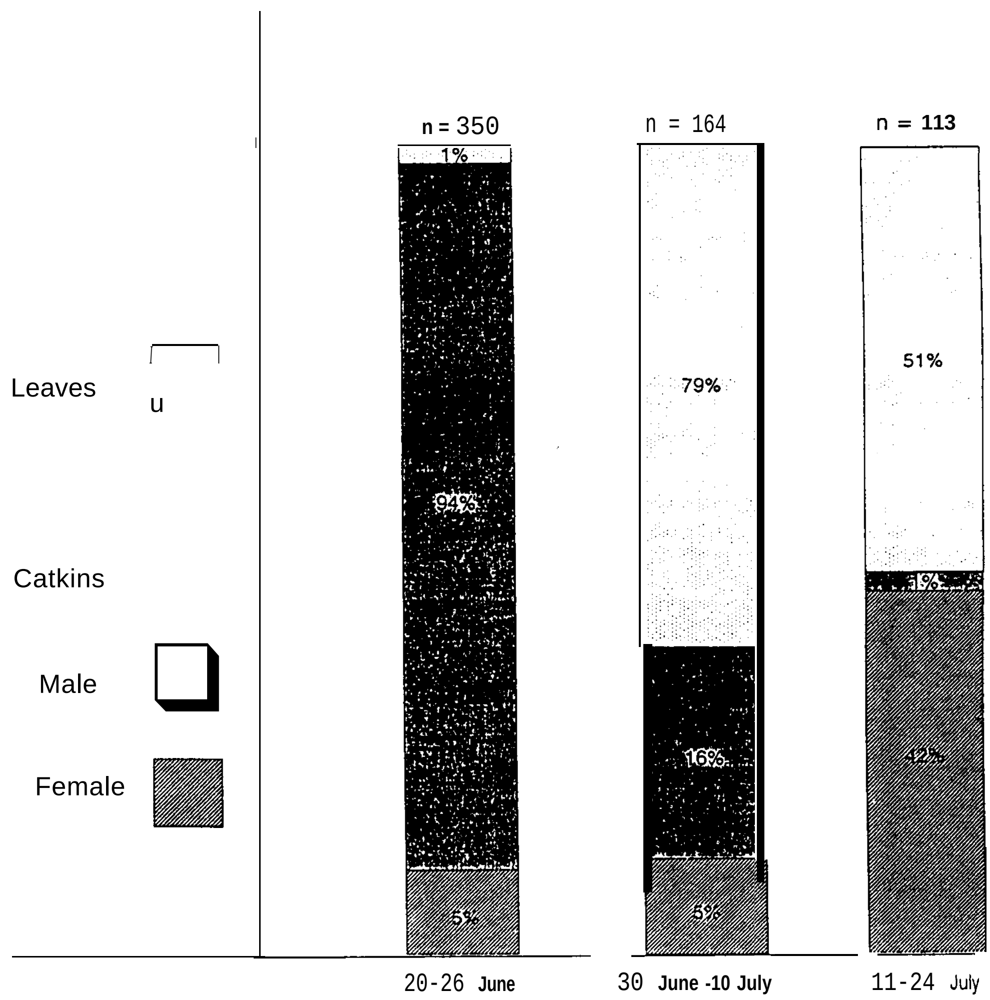
Figure 1 Number of bites at different parts of Arctic willow . expressed as percentages, in the space of three time periods.



TEE WADERS OF BORUP FIORD, ELLESMERE ISLAND

D.P. WHITFIELD & J.J. BRADE

1. GENERAL INTRODUCTION

Very few intensive studies have been carried out on the waders of Ellesmere Island. The work of Nettleship (1967, 1973, 1974) on the turnstone Arenaria interpres and knot Calidris canutus of Lake Hazen represents the most complete research to date. Recent work at Alert at the northern tip of the island (Morrison & Davidson 1990 ; Davidson & Morrison 1989) has provided significant insights but has concentrated on the post-arrival, pre-breeding phase only. Wader studies of the previous Joint Services Expedition, to Princess Marie Bay in eastern Ellesmere (Witts, undated), have also provided useful information, especially on Baird's sandpiper Calidris bairdii, but are largely unpublished.

Even basic knowledge of distribution and abundance is extremely limited and lags veil behind the equivalent botanical database (Hedderson, this volume; Edlund & Alt 1989). For example, Meltofte (1985) estimated the abundance of Ellesmere Island waders based on a single survey at a single site.

It was against this background that the present study took place. It gave us an advantage in placing fev restrictions on the scope of the project, but also gave us a disadvantage in allowing few comparative opportunities. The results of the study have been presented as a series of summaries of each topic that the project covered. This format has been adopted for two reasons, First, most of the vork has or will be submitted as papers to scientific journals and each section provides a precis of each paper to avoid pre-emption of publication in journals. Second, it allows presentation of the full range of the study in a form that will hopefully be more accessible to a vider audience.

2. NON-BREEDING AREAS OF STUDY POPULATIONS

2.1 Introduction

Three species were found breeding: turnstone, knot, and Baird's sandpiper. A single ringed plover Charadrius hiaticula was seen on Goose Flats during two days in June and calls were heard over the gravel terracing near Glacier River on two occasions in July, but there was no evidence of breeding.

The knot of Ellesmere Island are of the race C. canutus islandica which breeds in northern Greenland and in the Canadian arctic archipelago north of 75°N (the Queen Elizabeth Islands) (Snyder 1957; Salomonsen 1950; Roselaar 1983; Cramp & Simmons 1983; Godfrey 1986). This race winters on the seaboard of western Europe and uses migratory staging areas within the wintering area and in Iceland and northern Norway (Morrison 1975; Alerstam et al 1986; Uttley et al 1987; Morrison & Davidson 1990). The turnstone of Ellesmere Island form part of a population of A. interpres interpres whose breeding range and vintering range overlaps that of islandica knot (see references above and Branson et al 1978). Ellesmere Island is close to the northeastern extremity of the range of Baird's sandpiper (it also breeds in the Thule region of west Greenland) which extends across arctic North America to north east Siberia. It vinters in southern South America (Salomonsen 1950; Jehl 1979; Johnsgard 1981; Godfrey 1986).

Both ringing data and geographical variation in biometrics have been used to establish the breeding and non-breeding areas of particular population of waders. This approach vas adopted in the present study.

2.2 Methods

All birds captured vere ringed and most vere also given a unique combination of colour-rings. The following measurements were taken from all adults: bill length to the nearest 0.1 mm (bill tip to base of feathering), total head length to the nearest 0.1 mm (bill tip to rear of skull), using length to the nearest 1 mm (maximum chord, wing held parallel to the body), foot length to the nearest 0.5 mm (right angles of the tarsometatarsus and tibiotarsus to the tip of the longest flattened toe), and mass to the nearest 1 g or 0.5 g.

2.3 Results and Discussion

Sixty-two adult waders were captured and ringed: 22 knot, 28 turnstone, and 12 Baird's sandpipers. One hundred and thirty-seven chicks were ringed: 57 knot, 45 turnstone, and 35 Baird's sandpiper. A juvenile turnstone was also ringed, bringing the total to 200.

Two adult knot had been previously captured at the Wash, east England, one on 10 September 1983, the other on 7 March 1970. The latter bird gave the expedition the world longevity record for the knot, 6690 days, and as she was first captured as a 1 year+, she was at least twenty years old when captured at Borup Fiord. Another adult knot had been caught on 1 May 1978 at Morecambe Bay, northwest England and on migration in southwest Iceland on 14 May 1985. A knot ringed as a chick by the expedition was recaptured in the following October at Morecambe Bay. A breeding female turnstone had been ringed on 7 March

1988 at Zeeland in the Netherlands, and a dye-marked male turnstone was seen which had been caught at Morecambe Bay in the preceding April. Another British-ringed turnstone also bred at Borup but could not be captured. A male turnstone colour-ringed at Borup was seen wintering near Lisbon, Portugal in 1989. To date there have been no recoveries or controls of Baird's sandpipers ringed at Borup Fiord.

Adult biometrics are presented in Table 1. Bill length is the most useful character in separating knot races that is also relatively consistent between observers (e.g. Cramp & Simmons 1983; Tomkovich 1987; Morrison & Davidson 1990). The bill lengths of knot at Borup are similar to those from other parts of Ellesmere Island (e.g. Morrison 1975), and from Europe in winter (Dick et al 1976) and together with the ringing data confirm the expectations that Borup knot are of the islandica race.

Turnstone biometrics are of relatively little value in distinguishing between populations, because of poor repeatability of wing length between measurers, varying degrees of shrinkage in museum specimens, and because an individual bird's bill length may change as the bill grows continually (Whitfield 1985). There also appear to be relatively few genuine differences between populations. Thus, whilst biometrics of Borup turnstone are similar to those of birds in southeast Scotland and elsewhere in western Europe (within the presumed wintering range of Ellesmere birds) (Table 1; Cramp & Simmons 1983), they are also similar to the biometrics of birds breeding in subarctic Finland (Table 1). Finnish breeding birds use Britain during autumn migration as a stopover en route to wintering grounds in West Africa (Branson et al 1978; Whitfield unpublished), and during autumn join Nearctic breeders which winter in Britain. Distinguishing between the two populations is probably best achieved using foot length as this measure is consistently and significantly smaller in Finnish breeders (t-tests, $p < 0.05$ both sexes; Table 1). These drawbacks aside, the available evidence indicates that Borup turnstone, like their conspecifics in north Greenland and elsewhere in Ellesmere Island, winter on the Atlantic seaboard of Europe.

To our knowledge, biometrics of Baird's sandpiper have not been compared across the breeding range and relatively fev birds have been captured in winter. This limits further discussion of this species.

3. PLUMAGE

3.1 Introduction

In this section we consider aspects of plumage variation and moult. Prior to breeding all three species undergo an incomplete moult out of wintering plumage into breeding plumage (Prater et al 1977: Cramp & Simmons 1983). In the knot this involves the replacement of grey upperparts and white underparts by salmon-red plumage. In the turnstone, the browns and blacks of winter are replaced by black, white and chestnut-ginger. The grey-brown winter plumage of Baird's sandpiper is replaced by a more intense black, white and buff breeding plumage. After breeding all three species undergo a complete moult into wintering plumage.

3.2 Methods

First year and adult birds were distinguished as described by Prater et al (1977). Knot and turnstone were sexed on breeding plumage and behavioral differences (Cramp & Simmons 1983; Whitfield 1985; Whitfield & Brade in press). Baird's sandpipers vere sexed on behavioral differences (Reid & Montgomerie 1985; Witts undated). When captured all birds were examined for signs of moult. In each of four body areas (head and breast, mantle and scapulars, lesser and median wing coverts and tertials, belly) the extent of breeding plumage was scored to the nearest 5%. In turnstone and Baird's sandpiper the Z of breedin belly plumage vas not scored as breeding feathers and retained winter feathers could *not* be rapidly distinguished in this area. In other body areas breeding feathers were identified by colour and their less abraded appearance. Every captured bird was also photographed from a lateral, dorsal and ventral view. In addition, the extent of breeding plumage of several birda was scored in the field.

3.3 Results

All captured breeding birds of all species vere aged as adults. No captured bird showed signs of moult in the remiges and rectrices. No knot shoved signs of active body moult except those captured late in the season which had many new feathers emerging from in and around the brood patches. None of the eight turnstone examined from 10-20 June shoved signs of body moult, whereas two of twelve between 21-30 June had small (< 20) numbers of feathers in pin on the head only (both birds caught on 30 June). Four of eight birds caught 1-13 July also had small numbers of pins on the head, and all but one had many pins around the edges of the brood patches. None of the six Baird's sandpiper caught 18-24 June shoved signs of body moult, although two of three examined on 28 June had severeal pins on the head and neck and all three examined 8-15 July had large numbers of pins and emerging feathers all over the body.

There was no significant differences between the Z breeding plumage scores for the same individual birds scored either in situ when captured, from photographs or in the field. Since all three scoring techniques yielded comparable results, the data were pooled. In all three species there was no evidence that birds paired assortatively according to Z breeding plumage i.e. 'bright' males (with a high Z of breeding plumage) did not pair with 'bright' females. For both male and female knot and turnstone the total Z breeding plumage score was not correlated vith any measure of body size or with the timing of breeding, although sample sizes vere small for some comparisons i.e. 'bright' birds were not larger and did not breed earlier. In all three species males had a significantly higher Z of breeding plumage than did females.

3.4 Discussion

The observations on moult for knot and turnstone are similar to those of Parmelee & MacDonald (1960) elsewhere on Ellesmere Island. Witts (undated) indicated that Baird's sandpiper underwent pre-nuptial moult of the body and head feathers throughout incubation. Results from Borup Fiord indicate a gradual intensification of body moult throughout the breeding season, representing a relatively early start of the post-nuptial moult.

The absence of assortative mating by Z breeding plumage in knot, turnstone and Baird's sandpiper is similar to findings for purple sandpipers *Calidris maritima* and dunlin *C. alpina*, for example, but unlike findings for golden plovers *Pluvialis apricaria* and black-tailed godwits *Limosa limosa* (Whitfield unpublished). The reason for these differences between species is unclear at present. It can be argued that birds with similar plumage should tend to pair together if plumage reflects a bird's 'quality' (Whitfield 1986), but obviously such expectations are not upheld in a variety of wader species. The results from Borup Fiord will be used as part of a wider study of the factors affecting the extent of the pre-nuptial moult across a vide range of wader species.

4. ABUNDANCE OF BREEDING WADERS

4.1 Introduction

There are few accurate estimates of breeding wader densities in the high arctic (e.g. Morrison & Myers 1987). Meltofte (1985), however, drew on the results of several studies to produce breeding population estimates for several species in Greenland and Ellesmere Island. He concluded that all species' numbers had been underestimated and singled out the knot as a species where there was a particularly glaring disparity between the breeding population estimate and the more accurate vintering population estimate. This disparity may result from underestimating breeding density in known areas but may also be due to a lack of coverage in areas where there are concentrations of breeding knot.

Because of the difficulty in accurately censusing breeding knot and the relatively high conservation profile of this species, our studies on breeding abundance concentrated on the knot. We compared several methods of censusing knot, estimated abundance at several sites in the Borup Fiord area, and used revised estimates and 'best guess' estimates to look for any patterns in the distribution of islandica knot across its breeding range (see section 2.1).

4.2 Methods

We aimed to accurately assess breeding abundance at one 22 km^2 site ('Esayoo Bay' - base camp valley) and to use this estimate as a baseline from which to estimate abundance at other sites. We estimated abundance at Esayoo Bay by a two stage calculation: first, a mark-recapture technique of young broods vas used to estimate the number of nests that hatched, and then an estimate of hatching success (Mayfield 1975) was applied to this number to give an estimate of the total number of nests that were initiated. Subtracting 10Z from this total (to account for replacement nests) gave an estimate of the number of breeding pairs. Knot abundance was also estimated by the two most frequently employed methods of previous studies: counting broods, and repeated localised registrations (a minimum of three in this case) of songflighting and territorial activity. The effect of snow cover on breeding density was examined by dividing the site into several sub-areas and then relating the extent of snov cover on 10 June to the density of breeding pairs for all sub-areas,

Knot abundance relative to the Esayoo Bay site (80°51'N,81°50'W) was assessed at five other sites: Elmerson Peninsula (80°46'N,81°45' W), Midnight Sun Valley (80°51'N,82°50'W), Etukashoo River delta (80°44'N,83°53'W), foothills of Mount Schuchert (80°46'N,84°30'W) and Blue Mountains valley (80°42'N,85°10'W).

4.3 Results and Discussion: Knot

The most accurate method estimated knot abundance at Esayoo Bay to be 4.55 pairs km^{-2}. Only 332 or 672 of breeding pairs were recorded by counting broods or registering songflights and territorial behaviour respectively. Within the site, abundance ranged from 0.4 to 12.7 pairs km^{-2} and was negatively correlated with snow cover i.e. more knot bred in the earlier melting sub-areas. At other sites in the Borup Fiord area density was judged to vary between O snd 5.5 pairs km^{-2}. Most estimates were considerably higher than previous estimates of _islandica_ knot breeding density. **Counting broods underestimates breeding** abundance because not all broods are located and not all nests hatch. Registering songflights and territorial activity underestimates abundance because phsses of activity are *very* brief, knot rarely feed on-territory and are not demonstrative about the territory.

Using our assessments of the reliability of the relevant censusing methods we revised previously published estimates of breeding density and made rather more subjective judgments of density from other more descriptive observations across the range of _islandica_ knot. Dena ity in northern Greenland is variable but not high, and the highest densities have been recorded in Ellesmere Island, particularly the central area. Density in the other Queen Elizabeth Islands is usually low . The apparent pattern of knot abundance in the Queen Elizabeth archipelago shows a congruence with climatic and vegetational patterns. There is also evidence from Greenland which suggests abundance is greatest in the early melting well-vegetated sites. These lines of evidence suggest that knot abundance may be predicted from climatic information, the distribution of certain thermophilous plant species, and the diversity of high arctic flora. We suggest that the highest concentrations of _islandica_ knot will be found in those parts of Ellesmere and Axel Heiberg Islands surrounding Eureka Sound and Greely Fiord.

4.4 Results and Discussion: turnstone and Baird’s sandpiper

Accurate estimates of breeding density for these two species have not been calculated as yet. Preliminary estimates (territorial and brood registrations only) give minimum densities at Esayoo Bay of 2.4 and 2.0

pairs km-z for turnstone and Baird's sandpiper respectively. Both species were found breeding at four of the other five sites around Borup Fiord, although Baird's sandpiper vas only common at the Esayoo Bay and Blue Mountains sites.

5. BREEDING BEHAVIOUR OF THE KNOT

5.1 Introduction

Very few observations of knot breeding behaviour have been published, yet it would appear that the knot is dissimilar to many of its congenerics (Johnsgard 1981): a comparative behavioral study may help to shed more light on the knot's taxonomic position.

5.2 Methods

The methods were simple: detailed notes were made on all aspects of knot behaviour. Individual birds were recognised by their unique colour-ring combinations and by individually distinctive feather patterns on the wing coverts (the position and abundance of red and black 'nuptial' feathers in relation to retained grey 'winter' feathers).

5.3 Results and Discussion

High songflights by males involved phases of gliding and wing-quivering in figures-of-eight flight paths at heights of around 140 m. These appeared to serve mainly in mate attraction. Lov songflights up to 30 m high (V-wing flights), without the alternate glide-wing quiver phases, were used in territorial defence, as vas singing from the ground, threat displays (a horizontal point display) and fighting.

Territorial activity ceased after clutch completion and relatively little feeding took place within the territory. Unlike many of the knot's congenerics, a two wing lift display was normally seen before and after flight only.

The commonest heterosexual display was a tail-up display seen in a vide variety of contexts and performed mainly by males. This display is unlike the postures assumed by other calidridine sandpipers uncle r similar circumstances. Males attracted females to a nest scrape with a nest scrape advertisement display, and if a female was attracted to a nest scrape the male assumed a ground point display which has no apparent equivalent in other calidridine sandpipers. Copulation was preceded and followed by a variety of behaviors but tail-up displays were usually involved. Most pre-incubation behaviour consisted of the male following the female as she fed, whilst he periodically performed tail-up displays and nest scrape advertisement displays. A tail drop fan display was seen occasionally but its function was unclear. Both sexes incubated and all pairings appeared to be monogamous.

Knot sat very tight on the nest in the presence of long-tailed skuas _Stercovarius longicaudus_, arctic fox _Alopex lagopus_, and humans. If a human was less than 1 m away knot would jump off the nest and then perform distraction displays and alarm call.

Only males cared for chicks. Anti-predator behaviour depended on the proximity and activity of the predator in relation to the chicks.

Much of the ritualised behaviour of the knot is unlike other calidridine sandpipers and suggests that the knot occupies a rather peripheral position within the genus _Calidris_.

6. EGGS, NESTS AND CHICKS

6.1 Introduction

The purpose of this section is to present information which was used as a part of the main studies and which may also prove useful to future studies. Like most other waders, the waders of Borup Fiord were ground-nesting, produced large eggs relative to female body size, and synchronously hatched precocial self-feeding chicks.

6.2 Methods

The following data vere recorded at all nests: nest cup length and depth (to the nearest 0.5 cm), nest lining depth after hatch or clutch loss (to the nearest 0.5 cm), nest lining composition, clutch size, egg length and maximum egg breadth (to the nearest 0.1 mm), egg weight (to the nearest 0.1 g), the flotation angle between the mid line of the egg and the bottom of a transparent container of warm water or the breadth of the area of the egg exposed above the surface of the water. The latter 'flotation' methods are used to estimate the stage of incubation because as the embryo develops the egg's air cell gradually expands and egg density decreases (see Westerkov (1950), van Paasen et al (1984) for further details). We made limited use of the technique due to our worries over the possibility of egg chilling (despite the use of warm water only), preferring to make use of the egg's gradual reduction in density during incubation, vith the equation:

days since start of incubation - a-b. $\frac{W}{LB^2}$, where W = egg weight (g), L = egg length (mm), B = egg breadth (mm), and a and b are species specific constants derived from a least squares linear regression of W/LB^2 on the number of days before hatching for clutches with known hatching dates. Clutches vith chipping or heavily starred eggs vere excluded. Incubation periods of 21, 22 and 22 days vere assumed for Baird's sandpiper, knot and turnstone respectively (references in Green et al (1977) and this study). Using similar calculations ve also derived formulae for estimating the stage of incubation from egg flotation angles (for relatively fresh eggs which sink below the water surface) and from the breadth of egg exposed above the water surface + the egg's maximum breadth (for relatively older eggs which rise to the water surface).

Hatching success vas calculated according to Mayfield (1975), and by calculating the percentage of found nests that hatched (apparent hatching success).

The following measurements were taken from most chicks: wing length (where possible), foot length, bill length, total head length, and veight. Under conditions where rapid processing vas required, only chick weight vas recorded. All chicks were metal ringed and most vere given individual colour-ring combinations.

6.3 Results and discussion: hatching success

Thirteen knot nests vere found. Four nests were excluded from calculations of hatching success: one nest vas not revisited after discovery, one nest vas deserted as a result of human activity (the pair then produced a replacement clutch 5 days after desertion 350 m away), another nest vas found as the (incomplete) clutch was being taken by a pair of skuas, and a fourth nest was abandoned after one egg vas laid (the same pair produced a four egg clutch 170 m away). Of the remaining nine nests two vere deserted, one vas robbed by a skua during hatching, and six hatched (Table 2). Hatching success was similar to other estimates for *islandica* knot (Nettleship 1974, Witts undated).

Twenty turnstone nests vere found. One nest was deserted as a result of human activity (10 days after desertion the pair initiated a four-egg replacement clutch 3 km away] and no bird was seen near another nest after discovery: these two nests were excluded from calculations of hatching success. Five of the remaining eighteen nests failed to hatch: two were predated (one by an arctic fox, one by a skua) and three vere deserted (Table 2). All turnstone and knot nests which vere deserted were either late nests or had a history of sporadic nest attendance by the parents. Limited observations suggested that in the latter instances one parent finished an incubation shift some time before its mate initiated the next shift and that most incubation vas undertaken by one parent so the eggs vere often left uncovered for lengthy periods.

Apart from the exceptions noted earlier, in no caae did desertion coincide with or appear to result from human activities at the nest. Late nests vere probably deserted because of the seasonal decline in the probability of successfully rearing chicks (Meltofte 1985) and other nests may have been desertea as a direct response of one parent to the reduced parental investment of its mate or because poor nest attendance caused embryo death through chilling (eggs from two deserted nests which were examined were not viable).

Twelve Baird's sandpiper nests were found. Four nests vere excluded from calculations of hatching success: one vas not revisited after discovery, two vere found after the chicks had just hatched, and one nest had been produced, and probably deserted, in an earlier year. The remaining eight nests all hatched (Table 2).

Nest predation rates were low. The eggs from five deserted knot and turnstone nests were not collected and their survival was monitored for around ten days (similar to the *monitoring* period for most 'live' nests). Comparison of predation rates on 'live' (all knot and turnstone nests excluding those deserted) with those of deserted nests should indicate if there are differences between nests attended and unattended by parents respectively. The estimates of Z predation on attended ('live') nests *were* 23.22 and 13.62, and for unattended ('deserted') they were 20.52 and 202 (Mayfield and Apparent estimates respectively) (no significant difference for each comparison). We would tentatively conclude that the presence of parents at a nest neither increased or decreased the likelihood of nest predation.

Several authors have found heavier predation on early nests, attributing this to an effect of snow cover (a high snow cover reduces the area which predators must search, making it easier to find nests) (Meltofte 1985). There was little evidence to suggest that nest losses to predators were higher early in the 1988 season at Borup Fiord: three of the four nest losses occurred after all snow had gone. The lack of any marked bimodality in the temporal distribution of breeding attempts also suggested that there were few replacements of early clutch losses. Both early clutch 'losses' (through human-mediated desertion) that we recorded resulted in a replacement clutch, indicating that the 10V number of replacement clutches probably reflected a 10V rate of early clutch loss rather than a 10V rate of replacement.

Summers & Underhill (1987) have proposed that three-year cycles in the productivity of brent geese Branta bernicla and waders breeding on the Taimyr peninsula, USSR are cussed by prey switching by arctic foxes and other lemming predators. Lemmings show three-year cycles of abundance and when lemmings are abundant they are the main prey of foxes, allowing high breeding success of geese and waders, but when lemming numbers are 10V, foxes switch to the birds' eggs and chicks. What evidence there is suggests thst waders breeding in NE Canada and Greenland do not shov three-year cycles of productivity (e.g. Summers et al, 1989). Meltofte et al (1981) reported heavy predation on wader nests by foxes in Greenland, despite an abundance of lemmings. In 1988 at Borup Fiord there vere very fev lemmings (Burton, this volume) yet predation on wader nests and young appeared to be 10V. Foxes vere seen infrequently but took the eggs of four of the five snov goose (Chen caerulescens atlantica nests on the study site. This is not consistent vith one suggestion, that snow geese are relatively immune to fox predation by virtue of their size and capability to defend the nest. Indeed a fox was seen to kill an incubating snov goose at Borup Fiord.

6.4 Results and discussion: estimating the stage of incubation

Formulae for estimating the stage of incubation are presented in Table 3. Standard errors for individual estimates around the middle of incubation using 'density' formulae were 4.2 days, 3,2 days and 1.1 days for knot, turnstone and Baird's sandpiper respectively. The comparable standard errors for estimates derived from the 'flotation' formulae were 0.3 days, 0.7 daya and 0.5 days (if egg sinks), and 0.8 days, 1.0 days and 1.3 days (if egg floats) for knot, turnstone and Baird's sandpiper respectively. Thus, whilst the flotation method of estimating the stage of incubation requires more cumbersome field techniques than the density method it appears to produce more accurate estimates. The relationship between egg flotation and the stage of incubation for all three species is shown in Fig. 1.

6.5 Results and discussion: nests

The dimensions of nest cups and linings are shown in Table 2. Relationships between nest parameters, eggs and females are shown in Table 4. Baird's sandpiper females produced relatively large eggs which were incubated in relatively large nests with deep linings. Relative to egg size, however, Baird's sandpiper nests vere similar to those of the other species. In other words, the size of Baird's sandpiper nests was related more to the size of the eggs rather than to the size of the bird. Because the eggs were large in relation to the parent which had to incubate them, however, it was noticeable that in the nest the eggs were orientated closer to the vertical than were those of the other species. Had they lain more flat in the nest, like those of knot and turnstone, the parent would probably have been unable to cover them adequately. Baird's sandpiper nests vere relatively deeper than they were long, probably in keeping vith the more vertical orientation of the eggs.

Turnstone nests were relatively shallow with shallow linings and this does not appear to be due to small eggs which required less insulation. It may be connected with the marked propensity of incubating turnstone to leave the nest to mob or attack intruders or potential predators of eggs which could require a shallow neat to allow an elevated position from which to detect predators. On the other hand, in the Finnish archipelago of Valassaaret the many turnstone nests that vere placed under rocks, from which predators could not be seen, were even more shallow and contained less lining than those at Borup Fiord (Whitfield unpublished).

Knot nest linings were all composed mainly of two unidentified species of tubular lichen, vith fragments of Cassiope tetragona and/or dead leaves of Salix and Dryas integrifolia. More lichen vas found in the nest than was expected from the vegetation within 1 m of the nest. Turnstone and Baird's sandpiper nests vere less likely to contain lichens than vere knot nests and usually contained dead leaves of Salix and/or Dryas. The selection of strands of tubular Lichens may be related to their greater insulative quality although this requires testing.

6.6 Results and discussion: chicks

The volume of turnstone eggs was calculated from the equation of Väisänen (1977): $V(cm^3) = 0.335 + 0.44916LB^2$, where L - egg length (cm), B = egg breadth (cm). There was a highly significant between-nest correlation between the weight of chicks still in the nest and egg volume ($r_s = 0.99$, $p < 0.001$, $n = 8$): larger eggs produced heavier chicks. Sample sizes vere too small to examine this possible relationship in the other two species. There vas no correlation between egg volume and female size in knot and tumstone but sample sizes vere small (n = 7, n = 11). Newly hatched chicks weighed about 70% of fresh egg weight (knot, 70.6; turnstone, 66.5; Baird's sandpiper, 67.0) (Table 2).

Growth curves of turnstone and knot are shown in Fig. 3. Knot chicks gained weight at a faster rate than turnstone chicks, enabling them to fledge at about the same age of 17-18 days, despite being a larger species. Knot chicks at Princess Marie Bay, Ellesmere Island grev even faster than chicks at Borup Fiord, fledging at around 15-16 days (calculated from data in Witts undated: Fig. 3). Fledging weight of knot was around 90 g, for turnstone it was 75-80 g. In the later stages of the fledging period turnstone at Borup Fiord grew faster than turnstone at Valassaaret, Finland and as a consequence fledged around 4-5 days earlier (Fig. 3; Whitfield unpublished). Even so, chicks at

Germania Land, Greenland, appeared to gain weight even mOre rapidly than those at Borup Fiord (Fig. 3; Meltofte 1979). These differences between the rates of chicks from different populations and years caution against the assumption that growth data from one study can be used to age chicks in another (cf Green et al 1977). Relatively few growth data were obtained for Baird's sandpiper at Borup Fiord.

7, HABITAT SELECTION AND TERRITORIALITY

7.1 Introduction

Whilst general descriptions of the breeding habitats of waders are common in the literature, quantified analyses for both individual species and species communities are relatively rare. Very few studies have simultaneously examined the habitat selection of an arctic wader community in a quantified fashion (e.g. Ferns 1978; Connors et al 1979). There is academic interest in how and why different species may differ in their selection of the relatively simple and limited availability of arctic habitats. But quantifying habitat selection is also extremely valuable from a conservation viewpoint as it enables the formation of an assessment of the f actors limiting a species distribution, the potential impacts on a community of habitat loss, degradation, or change and, in conjunction with remote sensing of vegetation (Meiklejohn, this volume), may allow the prediction of wader numbers from aerial photographs alone.

Territoriality is one of the best established and veil-studied aspects of behavioral ecology, so it is surprising that for waders, especially arctic species, it is associated with ill-definition, misplaced assumptions and a lack of understanding of its functional significance. These problems stem from the paucity of good data on the subject and, in all probability, from the largely unrecognised diversity of wader territorial systems.

The present study aimed to address some of these problems by quantifying the habitat selection and territorial behaviour of the three species breeding at Borup Fiord. Analysis of the data is still in progress and this must temper any conclusions reached. In particular, a multivariate statistical analysis of species' habitat selection differences has yet to be performed so the summary presented here is based on relatively simple comparisons.

7.2 Methods

The dominant plant species and their percentage cover (to the nearest 5%) was recorded, along with the type and percentage cover of unvegetated ground, in an area of $0.04m^2$, $4m^2$ and $400m^2$ around each nest. Unvegetated ground was classified as either water, rocks (stones > 1 cm), gravel (stones < 1 cm), sand (stones < 1 mm), silt, or clay/earth. Aspect, slope (to the nearest 5°) and distance to the nearest water body (and type) was also recorded. A water body qualified for recording if it was over $10m^2$ for standing water or over 2 m wide for running water so that small ephemeral water bodies vere excluded. Soil moisture was also recorded as either dry, moist or vet. All these features were recorded at the end of the season in early August. By delaying data collection until the end of the season we avoided several pitfalls which could result from data collection at the time of nest discovery. For example, early in the season some plant species may not have emerged fully and so would have been under represented in early records. Similarly the distance to water and soil moisture would have varied according to the stage of the melt during which the nest was discovered. Recording soil moisture is of dubious value anyway with the instantaneous sampling technique used here. A better indicator of the long-term exposure of an area to water is the type of plants found in the area. Each $400m^2$ area around the nest was also placed into one of the following broad habitat types: Cassiope heath, Dryas heath, Racomitrium moss heath, clay/Dryas/Salix flat, Carex marsh, Eriophorum marsh, stony ridge, stream outwash, stable river terrace, and unstable river terrace (see also Meiklejohn, this volume) ,

The same methods were also used to record the habitat in the $400m^2$ around feeding birds of known status (e.g. pre-breeding, off-duty incubation, post-breeding) and birds with chicks. In the latter instance visual confirmation of the presence of chicks was usually obtained but sometimes it was assumed on the basis of the characteristic behaviour shown by chick-rearing adults.

A territory was defined as an area actively defended against conspecifics which had relatively fixed boundaries. This definition was designed to include confirmation of actual defence whilst excluding any defended area which moved with the defender. Defensive behaviour was taken to be any behaviour which effected the removal of a nonspecific from an area or which was given in response to the intrusion of a nonspecific within an area. The area of a territory vas ascertained by mapping the points at which defensive behaviour was shown and when it was curtailed despite the continued presence of an intruder, and the location of boundary disputes between neighboring territory holders. In areas where no clearly defined boundary was apparent the boundary vas taken to be the line beteveen the outermost positions where the territory holder was ‘seen but no other nonspecific was seen. These relatively strict requirements for territory mapping meant that in the typically 10V density populations of Borup Fiord relatively fev measures of territory area vere obtained. The habitat types within each territory were categorised as described earlier. In several areas there was evidence of territorial activity without confirmation of boundaries. The habitat types of such territories vere recorded for an area comparable in size to that of known territories, centred around the site of territorial activity.

The feeding sites of all known individual territory holders vere recorded vith particular regard to the position of the territory. If a territory holder flew avay from its territory and did not return to its territory vithin 5 minutes it was assumed that it was feeding off-territory. This assumption vas based on the observation that most flight paths were towards known feeding areas and that no territory holder was found roosting off-territory. Whenever a territory holder was located avay from a territory, it was always feeding. Trips away from the territory which were known or suspected to be associated vith songflights vere not classed as feeding trips. The relative time spent feeding on and off territory was based on the methods described in section 9.

7.2 Results

The nests of all three species were associated vith _Dryas integrifolia_, not surprising given the predominance of this plant over the whole study area. There was a strong tendency for turnstone nests to be surrounded by more _Dryas_ than were nests of the other two species, however. Turnstone nests also tended to have a greater area of bare earth in the vicinity. Knot tests vere comparatively strongly associated vith _Cassiope_ and _Racomitrium_ and were further away from a water body than the other species' nests. The most consistent predominant feature of Baird's sandpiper nests vas the presence of rocks and pebbles. Baird's sandpipers also clearly selected a discrete patch of vegetation within less well vegetation sites. A rough breakdown of nest site habitat selection can be found in Table 5.

Though there vas some overlap, each species tended to defend territories in different habitats. Knot territories were usually in Cassiope heath or, less often, in Racomitrium heath or Dryas heath. Turnstone territories usually encompassed Dryas heath and river terraces or Carex marsh. Baird's sandpipera usually defended rocky areas such as stable river terraces, stony ridges or sections of stream outwashes and often also included an area of river terrace close to the nest site.

Knot spent relatively little time feeding within the territory, in contrast to turnstone and Baird's sandpipers. Turnstones nesting furthest away from marsh and braided river terraces fed least within the territory, particularly early in the season, and commuted to feeding areas which were largely defended by other turnstones. Knot territorial defence abruptly stopped once the clutch vas completed, whereas male turnstone and Baird's sandpiper continued to defend the territory throughout incubation until cessation of defence at hatching.

Knot usually fed in Cassiope heath and on river terracea, turnstone fed in Carex marsh and river terraces (not usually in the Dryas heath in which the nest was often placed), and Baird's sandpiper fed in a variety of habitats ranging from dry stony ridges to Eriophorum marsh but river terraces was the commonest feeding habitat. Chicks were often reared away from the nesting territory and there was a shift in all three species to a greater reliance on river terraces. Post-breeding adults and juveniles usually selected river terraces or a variety of habitats on the lake shore as feeding areas.

7.3 Discussion

The association between *Cassiope* and knot is interesting, as like the knot, *Cassiope* appears to found most often in climatically favorable areas of the Queen Elizabeth archipelago (Edlund & Alt 1989). Several authors have remarked on this association in Greenland too (Ferns 1978, de Korte et al 1981, Prokosch 1987). In other areas, however, there does not appear to any direct relationship between knot and *Cassiope* (Nettleship1974 Witts undated) Any relationship between the two species probably does not reflect a dependence of knot on the plant but rather a congruence of climatic requirements such as an early melt, long growing season or high insolation.

Throughout its range Baird's sandpiper appears to be associated with dry stony habitats and the present study confirms this. On Ellesmere Island it appears to be commonest in areas where stony braided river terracing is in conjunction with vegetated ground (e.g. Freedman & Svoboda 1982; Witts undated). Surveys of several sites in the Borop Fiord area (see section 4) indicated highest densities of all three species at early melting sites where braided rivers ran through well-vegetated valleys. The reliance of high arctic waders on braided river systems for food has not been explicitly recognised before but at Borup Fiord the numerous pools, flats and streams created by the continually changing water courses appeared to produce an ideal breeding area for chironomid flies, the main food of waders. Another contributing factor was probably a relatively high input of organic ❑atter washed in to the river system from the well-vegetated slopes.

Clearly knot did not defend a territory to provide an exclusive feeding area for the occupants. One of the more plausible postulated functions of the knot's territorial system is that it serves to prevent other knot from nesting close to the defender's nest, thereby decreasing the chances that the defender's nest will be predated as predators tend to restrict their searching to areas where they have been successful. We conducted an experiment vith quail egg clutches which indicated that nests closer together were more likely to be predated. In contrast there was some evidence that in turnstone and Baird's sandpiper the defence of a territory served to increase the availability of food to the defender. This was particularly evident for turnstone as those birds that spent most time feeding on-territory defended areas which included marsh or braided river flats also bred earlier (see section 8). The breakdown of territorial boundaries at the hatch was possibly related to the increased mobility of adults to enable them to track the emergences of prey necessary for chicks, the increase in prey availability rendering territorial defence uneconomical, and/or the need to be close to the chicks for their protection and brooding.

8. SNOW, FOOD AND THE TIMING OF BREEDING

8.1 Introduction

Nettleship (1973, 1974) found that turnstone and knot tended to hatch chicks at around the peak of food availability, suggesting that breeding was timed so that the two events should coincide. In contrast Green et al (1977) have stressed the influence of snow cover on the timing of breeding of arctic waders, vith birds breeding earliest in early melting sites and latest in late meeting sites, and found no evidence of a peak in food for chicks. Meltofte (1985) has taken this analysis further, suggesting that the relationship between snov cover and breeding phenology is because the extent of snow cover reflects either food availability, the availability of nesting space, or the likelihood of nest predation (birds delay nesting in areas of extensive snov cover as predators find it easier to find nests in such areas - see section 6).

This aspect of the study aimed to assess the role of food and snov cover on the timing of breeding of waders at Borup Fiord.

8.2 Methods

The study site was split up into several areas and the extent of snov cover in each are was monitored by regularly taking photographs and then later assessing the Z cover from the photographs. Following Meltofte (1985) the Z snov cover on 10 June was used in analyses. The timing of breeding within each area vas assessed by recording egg laying dates, hatch dates, by estimating the stage of incubation of eggs which failed to hatch (section 6) and by estimating the age of chicks from growth curves (section 6).

The methods of monitoring of invertebrate numbers are described by Sunderland (this volume). The diet of waders was estimated by a Z volume analysis of faeces.

8.3 Results and discussion

The waders of Borup Fiord bred relatively early, with Baird's sandpiper nesting latest (mean hatch dates: knot, 6 July; turnstone, 6 July; Baird's sandpiper, 10 July). There was a positive correlation between snow cover and the timing of breeding of turnstone and Baird's sandpiper, but no correlation in knot. When clutches were first initiated, however, there were few differences in snow lie between the different areas, and despite area differences in the change in Z snow cover comparably sized sub-areas of snow-free ground were sometimes available. This suggested that extensive snow cover per se had only a minor influence on Laying dates but differences in the rapidity of snow melt may h ave reflected differences in food availability for pre-laying females. Turnstone and Baird's sandpiper relied on food within defended areas (section 7) so those females from territories with an early snow melt laid earliest. Hence, snow cover and breeding dates vere correlated. In contrast, knot fed little within defended areas so birds from different areas could potentially exploit the same food supplies. Hence, there was no correlation between snow cover and breeding dates. In one area turnstone and knot hatched chicks around the peak of food abundance for chicks, but in another area this relationship was not obvious. Baird's sandpiper chicks tended to hatch after the peak in food abundance. The availability of food for laying females seemed the best overall explanation of differences in the timing of breeding.

In June, adult knot fed on the shoots of the plant *Equisetum*, the larvae of small flies (chironomids), lepidopteran larvae, and spiders. Turnstone ate very little plant material, taking predominantly larval chironomids and spiders. In July, the diet of adults of both species consisted of adult chironomids and spiders, similar to the diet of both species' chicks. Late in the season, some knot again started taking plant material, but turnstone's reliance on adult chironomids was maintained. The fev samples of Baird's sandpiper diet suggested a similarity to turnstone diet.

9. TIME ACTIVITY BUDGET OF THE KNOT

The data collected during this part of the study have received only a cursory examination at present, partly due to the large size of the

Table 5. Mean values of Z cover for dominant plant species and bare ground within 400m[2] of wader nests, and the slope, aspect and distance to open water of nest sites. Ct - *Cassiope*, di = *Dryas*, rl = *Racomitrium lanuginosum*, cx = *Carex*, sa = *Salix*, er - earth, rk = rocks, ov = other vegetation, %v = % vegetation cover, sl = slope (degrees), as - aspect (flat = 0, east = 2, south = 4, west = 6, north = 8), dw = distance to water (m), K = Knot, T = turnstone, B = Baird's Sandpiper, n = sample size. Significance, tested by Mann-Whitney U tests, accepted at p - 0.05.

	ct	di	rl	cx	sa	er	rk	Ov	%v	sl	as	dw	n
K	19.2[tb]	33.5	14.2[t]	0.8	7.0	11.5	14.0	0.0	74.6	20.0	2.5	423[tb]	12
T	4.6	44.3	0.5	5.5	8.2	20.8[b]	11.5	3.0	65.8	17.3	2.7	141.9	20
B	3.8	32.9	15.8	3.3	9.8	8.8	25.0[t]	0.8	66.3	18.8	2.0	94.6	11

[k] denotes significantly greater than knot

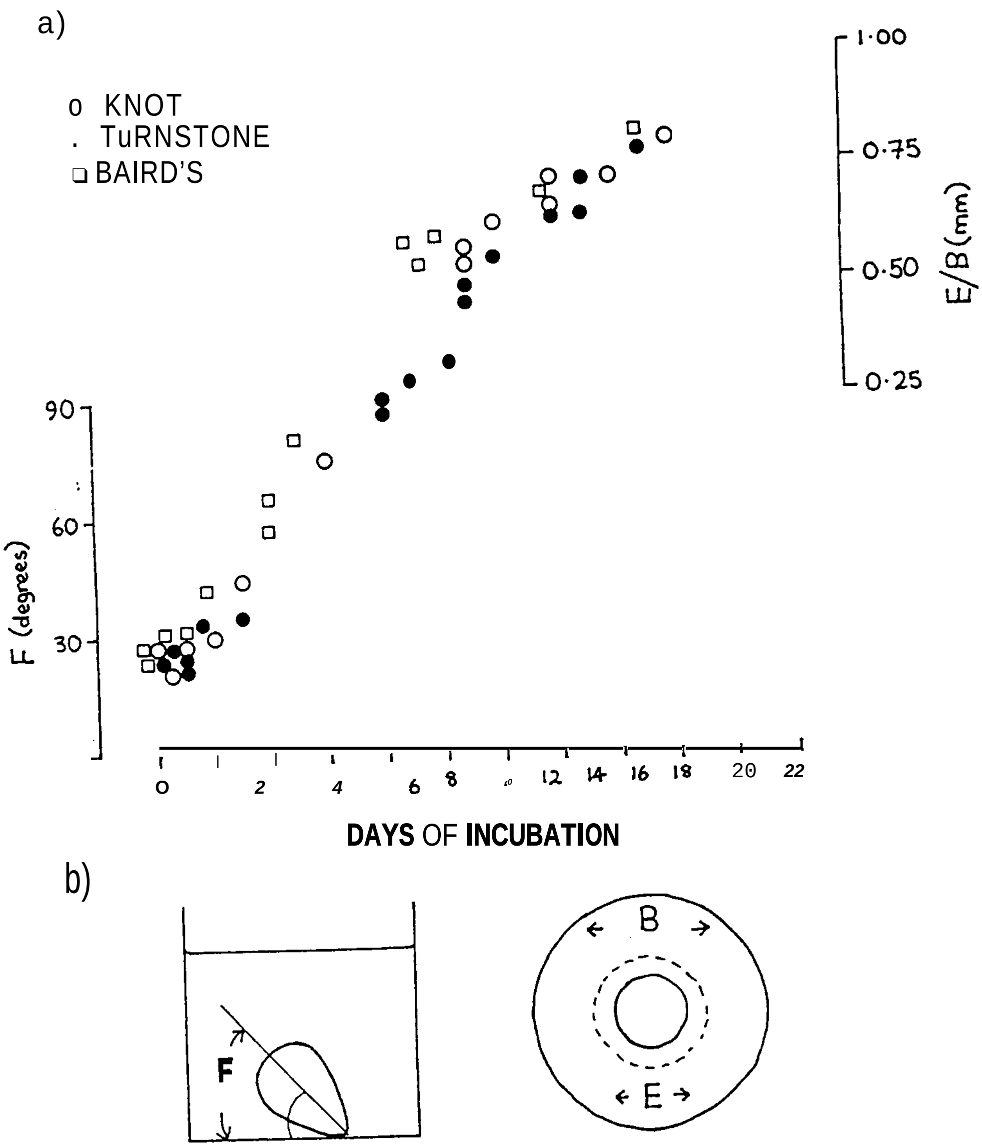
[t] denotes significantly greater than turnstone

[b] denotes significantly greater than Baird's sandpiper

FIGURE LEGENDS

Fig. 1 Estimating the stage of incubation from the flotation method. (a) the relationship between egg flotation values and the stage of incubation, (b) schematic representation of the method (see text for further details).

Fig. 2 (a) Growth curves for knot chicks at Borup Fiord and Princess Marie Bay (PMB : calculated from data presented by Witts (undated). (b) Growth curves for turnstone chicks at Borup Fiord, Valassaaret, Finland (Whitfield unpublished) and Danmarks Havn, Greenland (Meltofte 1979).


a)
o KNOT
. TuRNSTONE
□ BAIRD'S
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0·75
0·50
0·25
E/B (mm)
90
60
30
F (degrees)
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2
4
6
8
12
14
16
18
20
22
DAYS OF INCUBATION
b)
F
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E

Table 1. Biometrics of waders (mean ± SD). M - male, F = female.

Species and site	Sex	N	Wing	Foot	Bill	Head	Weight
Knot	M	15	172.9±3.0	57.3±1.9	31.1±1.3	61.7±1.5	118.8±8.3
Borup Fiord	F	7	175.3±4.4	58.6±1.2	32.2±1.1	63.0±1.9	130.9±7.0
Turnstone	M	16	158.3±2.7	54.0±1.8	21.9±0.7	50.8±1.1	103.3±4.6
Borup Fiord	F	12	160.7±2.9	54.7±1.4	22.3±0.8	51.2±0.9	105.1±4.9
Turnstone	M	16	159.0±4.0	51.7±1.4	22.6±0.9	50.7±1.1	103.8±5.0
Valassaaret	F	10	161.5±3.1	52.5±1.2	23.8±1.0	52.2±0.9	111.1±7.1
Finland[1]							
Turnstone	M	48	157.6±4.2	53.2±1.7	22.6±0.7	51.4±1.4	
SE Scotland[1]	F	39	161.4±3.7	54.0±1.1	23.4±1.2	51.9±1.2	
Baird's	M	7	125.5±3.0	43.8±1.4	22.0±0.6	46.1±0.7	39.5±2.2
Borup Fiord	F	5	130.6±1.8	44.1±1.1	22.4±0.3	46.6±0.5	45.2±4.0[2]

[1] D.P. Whitfield, unpublished data
[2] Excluding a female caught before clutch completion gives 43.6±1.4

Table 2. Summary of several parameters associated with eggs, nests and chicks of waders at Borup Fiord (mean±s.d. (n)).

	Knot	Turnstone	Baird's Sandpiper
Hatch success (Z, Mayfield)	43.7(9)	54.9(18)	100(8)
Hatch success (Z, Apparent)	66.7(9)	72.2(18)	100(8)
Clutch size	4.0±0.0(11)	3.9+0.3(18)[2]	4.0±0.0(11)
Fresh egg weight (g)[1]	19.7	17.3	9.7
Egg length (mm)	42.3±1.1(33)	41.1±1.5(71)	33.2±1.5(32)
Egg breadth (mm)	30.2±0.7(33)	28.6±0.7(71)	24.1±0.7(32)
Cup length (cm)	10.0±0.5(9)	9.9±1.1(18)	8.2±0.4(8)
Cup depth (cm)	4.2±1.1(9)	2.9±0.7(18)	4.3±1.0(8)
Lining depth (cm)	3.2±1.0(9)	1.9±0.6(18)	3.3+1.3(8)
Incubation period (days)	-	21.5(1)	21.0±1.0(3)
Chick weight (g)[3]	13.9±0.9(15)	11.511.1(25)	6.5±0.6(19)

Notes:

[1] Calculated using rate of weight loss in eggs of known or estimated age.

[2] Excludes one clutch of 3 which may have been deserted before clutch completion and one clutch of 2 for which partial clutch predation/destruction was strongly suspected.
[3] In or just out of the nest.

Table 3. Formulae for estimating the stage of incubation in knot, turnstone and Baird's sandpiper, c = days since incubation started, W = egg weight (g) L = egg length (mm), B = egg breadth (MM), F = flotation angle (degrees), E = breadth of egg exposed above water (mm).

	Krro t	Tumstone	Baird's Sandpiper
C =	$115.7-226094.3W/LB^2$	$93.7-182054.8W/LB^2$	$105.4-210452.6W/LB^2$
C =	$-1.18+0.095F$	$-1.99+0.113F$	$-2.37+0.098F$
c =	$-4.40+27.40E/B$	$-5.05+14.29E/B$	$-6.56+28.66E/B$

Table 4. Relationships between neat dimensions, eggs and females of the three species of wader breeding in Borup Biord.

	Knot	Turnstone	Baird's Sandpiper
Lining depth/nest depth x 100	76.2	65.5	76.7
Nest volume index (NV)[1]	329.9	223.2	174.3
Clutch weight/NV x 100	23.9	31.0	22.3
Female weight/NV x 100	39.7	47.1	25.0
Clutch weight/female weight x 100	60.2	65.8	89.0

[1] $NV = Pi \cdot \left(\frac{\text{nest length}}{2}\right)^2 \cdot \text{nest depth}$

data set. When fully analysed, estimates of the daily energy expenditure (DEE) will be produced for both sexes throughout the breeding season. If the proportion of time allocated to different activities is known (the time activity budget) then, vith knowledge of thermoregulatory costs, the DEE can be estimated by assuming each activity has a particular energetic cost. Time activity budgets will be formulated from observations of focal individual knot whose behaviour was noted every 15 seconds. Such observations were collected over the whole 24-hour clock throughout the breeding season. Nest watches, remote monitoring of nest attendance and instantaneous sampling vere used to estimate the attendance of the sexes on the nest during incubation. Birds were weighed whenever captured or recaptured to monitor any weight changes which may be associated with an energy deficit.

Prior to egg-laying, male knot divided their time between singing, territorial defence and feeding. Females spent most of their time feeding. Female knot spent more time feeding than did males and off-duty birds usually fed. Females lost weight during incubation, males did not. While caring for the chicks alone, male knot lost weight.

10. THE ECOLOGY OF PARENTAL CARE IN THE TURNSTONE

This aspect of the study will compare the behaviour and ecology of turnstone at Borup Fiord with turnstone at Valassaaret, Finland in the hope of understanding why female turnstone at Borup Fiord desert broods earlier than females at Valassaaret. Preliminary indications are that predation pressure is far more intense at Valassaaret which may select for extended female protection of the brood. Firm conclusions must await final analysis of all the data, however.

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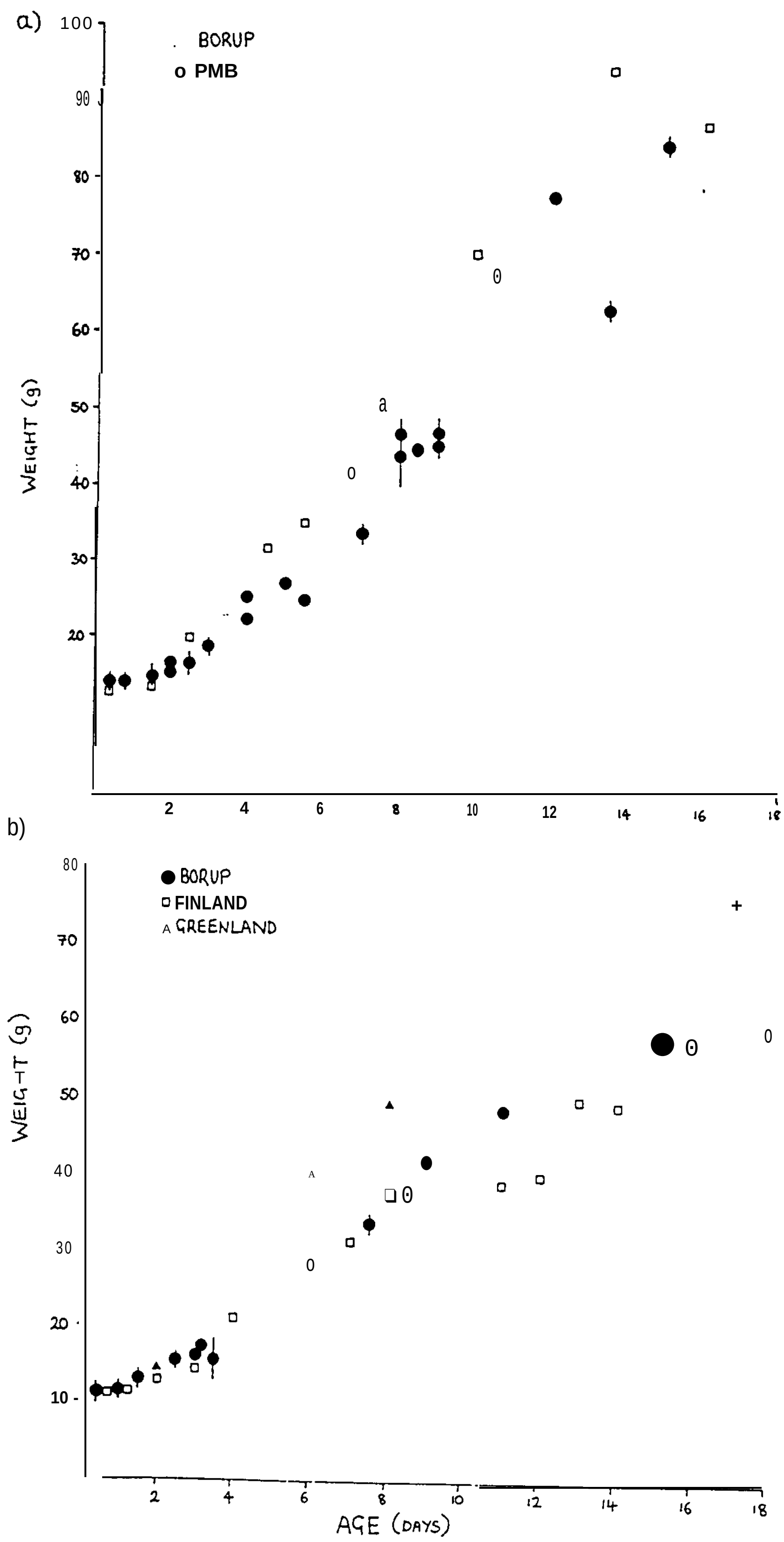

a)
BORUP
o PMB
WEIGHT (g)
b)
BORUP
FINLAND
GREENLAND
WEIGHT (g)
AGE (DAYS)

ARCTIC CHARR PROJECT.

POPULATION STRUCTURE, HABITAT SEGREGATION AND REPRODUCTION OF LANDLOCKED ARCTIC CHARR IN A SERIES OF FOUR LAKES IN THE CANADIAN HIGH ARCTIC.

Report by H H PARKER, supervised by Lionel JOHNSON
Assisted by B C CRAWFORD.

**** This report represents the first draft of a paper which was accepted by the 'The Journal of Fish Biology' in September 1990. It is the unedited results and conclusions of Lieutenant H H PARKER Royal Navy, and has not been checked by any other authority. For a fully refereed and referenced version the reader is refered to the journal. ****

ABSTRACT.

The landlocked Arctic Charr populations of four lakes at 81"N on Northern Ellesmere Island, Canada were found to contain two distinct size groups which both attained sexual maturity but differed in appearance and habitat. The smaller fish, retaining parr markings, existed in more marginal habitats; and those that reached maturity showed a tendency to spawn at a younger age and more often than the larger type. The larger fish, with smelt-like coloration, were indistinguishable from the mature smaller type in their 'juvenile' stages and were capable of cannibalism although this was only observed rarely over the period of the study. In general, the larger fish were older than the smaller ones, but considerable variation in size at a given age was observed, some age classes containing both types of charr. Of particular interest was that the population structures varied considerably between the lakes and that a high proportion of the large type correlated well with high average growth rate in the first few years of development. It is postulated that the two groups live in dynamic equilibrium where the advantages of progenesis in the smaller type are traded against the larger proportion of the energy resources available to the larger type.

INTRODUCTION.

In recent years the population dynamics of arctic fish populations has been the the subject of much discussion, but the high cost of research into the area has deprived that discussion of much hard data. Arctic ecosystems, and Arctic Lakes in particular, are a valuable scientific resource since their relative simplicity can provide reference systems and models for more complex communities. Of even greater Importance is that an Arctic lake can be regarded as totally undisturbed and unexploited, and a landlocked system can be seen as 'closed' in that negligible amounts of material enter or leave the lake each year. Furthermore, the 'buffering' effect of the large volume of water in a lake makes the system environmentally stable, a feature which distinguishes Arctic Lakes from Arctic systems in general.

The Arctic Charr has a circumpolar distribution and occurs as both anadromous and non-migratory populations. Whilst anadromous stocks are restricted to the more northerly populations, resident stocks exist as far South as Lake Windermere in the UK and mountain lakes of the European Alps. Whilst Arctic non-migratory Charr have been studied further South in Canada (eg Johnson 1983) and in Greenland (eg Riget et al. (1986), Sparholt (1984)), they have not so far been reported upon in the deep High Arctic.

This paper summarises the fieldwork undertaken by the British Joint Services Expedition to Borup Fjord 1988 in which the charr were studied in their unexploited state. The logistic difficulties necessitated the use of only the simplest equipment, particularity since it would have to be carried some distance for much of the work.

The objective was to look for trends in the populations studied in both temporal and physical frameworks. As such, the work is split into two sections. In one, habitat segregation and food were studied over mid-flay to late-August 1988 in a 75ha. lake. This size of lake made it easy to define different habitats whilst still allowing the whole lake to be sampled. In the second section, three small lakes of ca.4ha. and very similar limnological properties, were examined for possible changes in population structure with height above sea level. The small size of these lakes made it easier to obtain truely representative samples since more than one habitat could be fished at once.

In order to achieve the objectives of the project, length-frequency distributions, age composition, reproductive strategies, habitat segregation, food, fish condition and parasite infestation were assessed as far as possible for each lake. In addition, limnological studies were undertaken in a further attempt to place the results in context.

**** Note that 'Henry's Lake' is refered to as 'Lake H' throughout this report in order to maintain consistency with the paper for the 'Journal of Fish Biology'.****

A. GENERAL.

The area of the study consisted of the two valleys at the head of Borup Fjord, Ellesmere Island. Both valleys contain large braided rivers which take melt water from the glacial interior of the island to the North ends of Oobloyah and Essayoo Bays respectively.

The vegetation is tundra heath with patches of bare rock, and despite the generally glacial nature of the entire area, the water draining into all lakes is almost entirely the product of snowmelt. Rainfall is slight, 55.1mm in 1988.

The geomorphology of Midnight Sun Valley, the valley at the head of Oobloyah Bay, was studied in detail by a group from Heidelberg University in 1978. It is probable that the valley at the head of Essayoo has a similar history. According to Barsch, King and Mausbacher (1981) the valley was already free of glacier ice some 35,000 years ago. The broad valley floor was probably built up between 15,000 and 17,000 b.p. and later isostatically lifted to its present altitude some 80m above sea level. The formation of the lakes themselves are probably associated with a glacial advance tentatively put by King (1981) at 20,000 b.p.. Thus the lakes can be aged as not older than 15,000 to 20,000 years and are in any case no younger than 6,000 years.

Arctic Charr were the only fish present in all lakes. Other lakes in Midnight Sun Valley were examined for charr and found to be too shallow not to freeze solid during the winter. In these lakes, Epidurussp. were predominant

B. ESSAYOO VALLEY (Lake H) .

The large unnamed lake used in the study, and identified as Lake H is located at 80°51'N, 81°52'W at approximately 30m above sea level in the valley at the head of Essayoo Bay. The surface area is 75ha. with a catchment area of some 500ha.. The lake has a predominantly flat bottom consisting of silt between 12m and a maximum depth of 15m. With the exception of the south end where the only streams enter and leave the lake, the lake has narrow littoral zones with steep gravel sublittoral. At the south end the edge consists of a series of silt terraces which extend into the middle of the lake. By midsummer the flow of water in the streams is negligible. The full length of the ice-free season is not known precisely, but is probably in the region of 8 weeks.

The maximum surface temperature, measured in late August, was 11°C and the minimum, measured in mid-May was 0.8°C. Conductivity was approximately 200 µScm-1 with a pH of approximately 8. A separate report on the limnology of this lake is being prepared in conjunction with Dr.J C Ellis-Evans of British Antarctic Survey and it is intended to extend the work on return to Ellesmere Island in 1991.

The non-fish fauna of Lake H were predominantly insects and these are separately reported in a dedicated report.

C. MIDNIGHT SUN VALLEY (LAKES A,B,C)

The three unnamed small lakes of approximately 4ha., identified as Lakes A,B and C are shallow but in excess of 5m deep and are all near the same river in Midnight Sun Valley, the valley at the head of Oobloyah Bay. At the time they were sampled (early August) , they had a surface layer of 3-4 metres at a temperature of over 12°C and a dissolved oxygen concentration of approximately 10mg/l. Below this there was a sharp drop in temperature with a corresponding increase in dissolved oxygen concentration. Lake A was noticeably less weedy than the others with a negligible catchment area. Further readings are in Table 1.

Lake	Position	Altitude m	pH $-\log_{10}$ [H+]	Conductivity µScm-1
A	80°54'00"N 82°11'15"W	250	8.45	70
B	80°53'30"N 82°17'08"W	215	8.45	61
C	80°51'00"N 82°59'00"W	105	8.18	94

Table 1 - Limnological data from Midnight Sun Lakes

MATERIALS AND METHODS.

A. LAKE H (Habitat Segregation and Food Study)

Habitat zones were defined for Lake H, consisting of a gravelly shoreline zone which extended to a depth of 10m, a deepwater zone which consisted of the silty bottom of the lake, and the silty outlet zone at the South end. Samples were taken using identical fishing methods in each of these zones over three sessions in late-May, mid-July and mid-August.

During the late-May session, baited vertical static lines were set through holes in the ice, fishing with hooks at known depths. In an attempt to overcome the known bias for large fish associated with hooks, small hooks were included in the rigs, and funnel traps were also used at different depths.

During the mid-July and mid-August sessions, monofilament multimesh survey gillnets were used in pairs consisting of one floating and one bottom net one above the other. The nets were fished for a period of 24 hrs. roughly parallel to the shore at a known depth determined by a simple echo sounder.

B. MIDNIGHT SUN LAKES. (Population Structure Study)

The three lakes identified as Lakes A,B and C were visited in the first half of August and sampled in an identical fashion by setting a survey bottom net perpendicular to the shore by swimming.

C. TREATMENT OF SAMPLES.

Fork Length was measured to the nearest millimetre, and weight to 5g for large fish and 1g for those less than 100g. Age was measured by otolith analysis and gill rakers counted. Sex was recorded and the degree of sexual maturity assessed according to the scale proposed by Kesteven. Food items were analysed in the field using the points method of Hynes(1950) , allotting 10 points to a full stomach.

D. Parasites.

Examination of parasites formed a major part of the effort expended on each fish partly because little work in this area has been done in the High Arctic, and partly to see what they could indicate about their hosts. Charr were examined by standard techniques, and all major organs were examined for the presence of metazoan parasites. Protozoa were not searched for, nor was the blood system examined. The numbers of individuals of each parasite species was recorded for all fish from Lakes A,B and C and for a subsample of Lake H. All identifications were confirmed by Professor C R Kennedy of the University of Exeter. See separate report.

E. GILLNETS AND SELECTIVITY.

The nets were constructed of four metre long monofilament panels, 1.5 metres deep , each panel being of a given mesh size. The panels were arranged in a 'random' order and the stretched mesh sizes used were 18,24,32,43,48,58,71 and 90mm

The issue of gillnet selectivity has been much discussed in the literature (eg Johnson, 1983;Sparholt, 1984) and theoretical estimates of overall bias based on mesh-size bias can be made. In practise, it was found that the way the nets were used and the results interpreted is potentially a far greater source of bias than that determined by mesh size. In particular, fast-swimming predatory large fish with long patrol lines are much more likely to be caught in a statically fished net than a slower, smaller fish. A further indication of the irrelevance of mesh-size selectivity in practise is that gillnet gangs of different mesh-size composition produce very similar results. Finally, gillnets in common with any other fishing method are only noticeably effective in high densities of fish. A low density of fish living in a large volume can produce a large overall population which will be difficult to detect.

It can thus only be said that samples produced by gillnets are only representative of the habitats in which the gillnet has been fished effectively, and that there is an unassessable bias towards larger numbers of large fish caused by behavioral differences. By contrast, fishing in a habitat in which a gillnet is unlikely to be successful, for example in the large midwater volume of a lake where fish may be able to feed on zooplankton, will result in significant underrepresention of fish numbers from that habitat.

RESULTS

A. Appearance and Definition of Types.

Most of the' samples obtained were hi-modal in structure, with the size modes corresponding to fish of very different appearance. The smaller charr in all lakes had the appearance of 'parr', characterised by approximately ten bluish vertical bars along the flanks. The overall coloration was a well-camouflaged green with a white belly. To remain consistent with the rest of the literature (eg Klemetsen,1980), this type will be referred to as 'Dwarfs'.

In all but one of the lakes, a second larger type was also present. This had the appearance of 'smelts' with a grey-green back and bright siver-pink flanks. Eyes were larger than for the 'Dwarfs' and the larger specimens had hooked forward-facing jaws with an impressive array of backwards-sloping teeth. Towards spawning time, the males attained an orange coloration with white-edged bright red fins. These are known as 'Normal' charr.

A small number of fish, caught rarely, were of intermediate size and coloration.

B. HABITAT SEGREGATION AND FOOD. (Lake H)

Each type was loosely found to occupy a different habitat, separated by location of capture and stomach contents. The nature of this segregation varied as the opportunities for feeding changed over the period of the study and the overall impression was one in which the 'Normal' charr commanded the best feeding with the 'Dwarfs' making the best of what was left.

During late-May, while the lake was still ice-covered, 'Normal' charr were found in the colder upper layers of the lake and most had empty stomachs. 2 out of 25 were found to contain 'Dwarfs', and their size indicated that most 'Normal' charr are capable of predating 'Dwarfs' although few appear to. 'Dwarfs' were found to be bottom dwelling, feeding on substantial quantities of chironomid larvae. Fig. 1 illustrates the depth separation, whilst Fig. 2 shows the difference in stomach contents.

FIG. 1: **Habitat** segregation of Morphs by depth of water during late May.

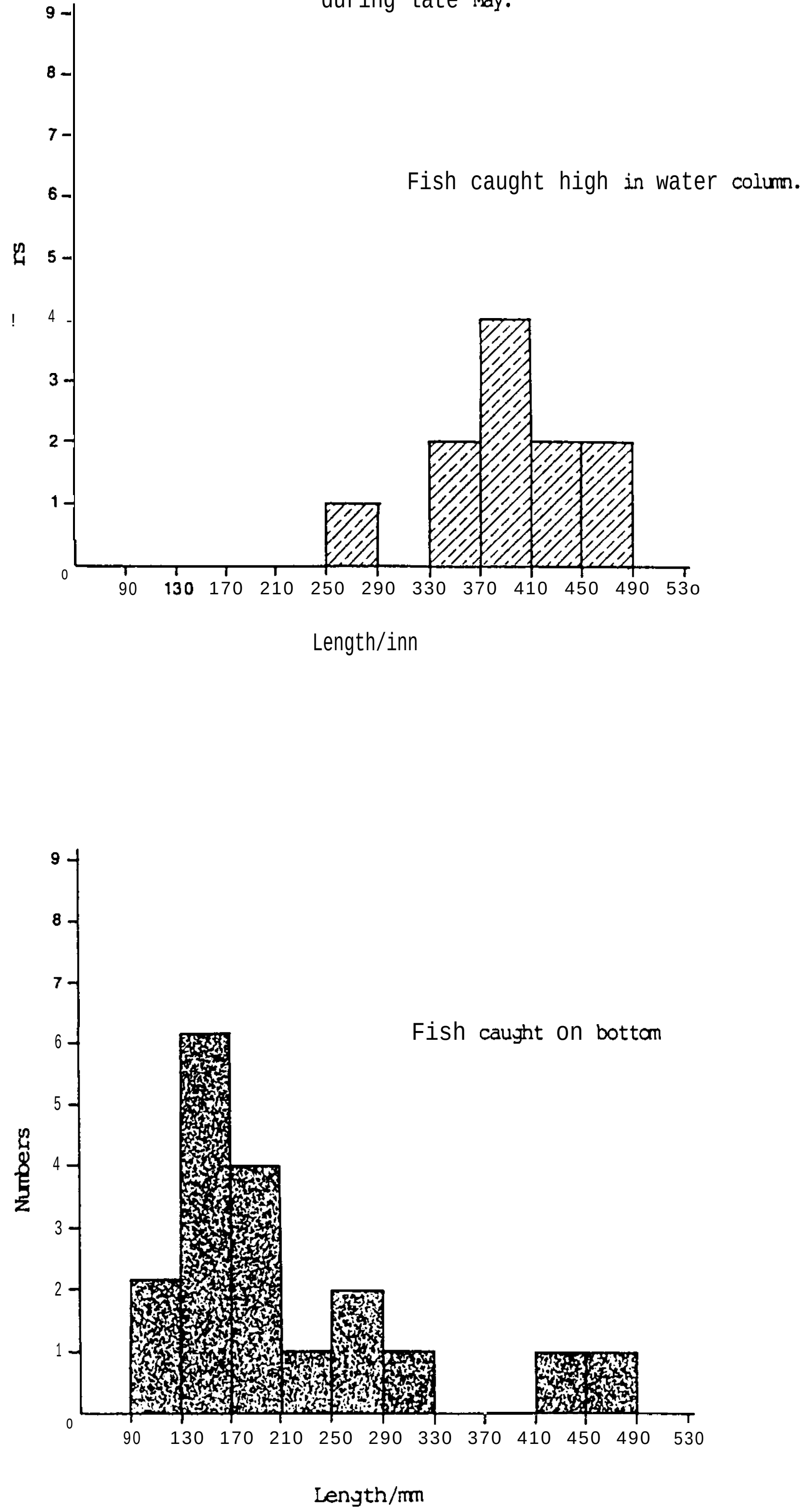
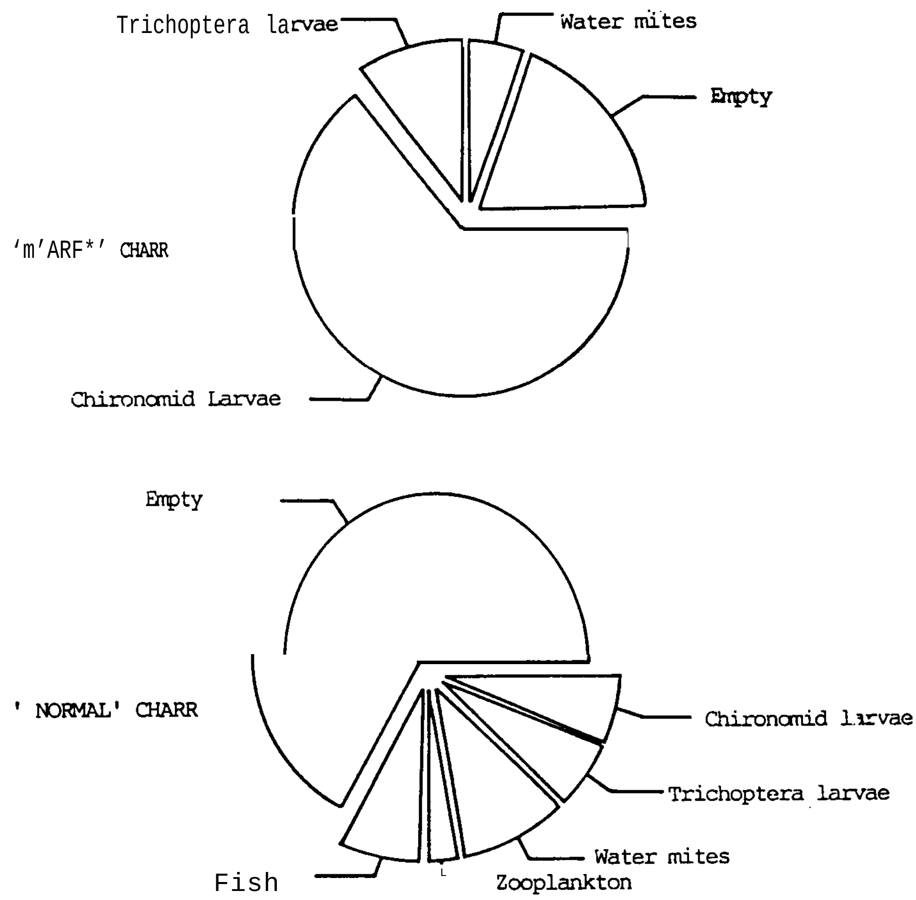


Fig. 2: Habitat segregation of morphs by stomach contents in late t-lay



Note: Sectors represent relative numbers of fish containing the labelled focal item.

During mid-July, about the time that ice finally cleared on 21 July, the 'Normal' Charr occupied the areas of the lake where the gentle prevailing southerly wind allowed them selective feeding on enormous numbers of large helpless chironomid pupae trapped in the surface film or in the remaining ice. As a consequence, surface feeding of "Normal' Charr was common, and the 'shoreline' zone was dominated by them. The 'Dwarfs' were restricted either to the very shallowest water of less than 1m depth, or occupied the 'outlet' zone where feeding was not as good as the 'shoreline' zone. The stomach contents of the 'Dwarfs' indicated more catholic feeding habits than the 'Normal' charr with a lower density of a wider variety of foodforms. The 'deepwater' zone was almost barren of fish, and attempts to catch pelagic fish by suspending a bottom net in midwater proved fruitless. Fig. 3 indicates the habitat segregation by zone, and Fig.4 by volume of stomach contents.

In the final session of mid-August, with winter fast approaching but spawning still some time away, habitat segregation was indicated by the 'Dwarfs' which just 'disappeared'. Plankton net hauls of 1-2 weeks before had qualitatively indicated a large increase in the zooplankton available so it is possible that the 'Dwarfs' were feeding in midwater at low density, and even if we had been able to fish for them would still have been hard to catch. The 'Normal' charr were now spread more evenly around the edge of the lake and were no longer surface feeding. The deepwater zone was still almost devoid of fish.

C. Length-Frequency Distributions.

The length-frequency diagrams for all lakes are shown in Fig.5.. Apart from Lake A, which contains only 'Dwarfs', the diagrams all show bi- or tentatively tri-modal distributions. The values of the modal length varies from lake to lake, as do the relative numbers of 'Normal' charr to 'Dwarfs'. Of further interest, the males of the 'Dwarfs' are smaller on average than the females. This is especially noticeable in the results from Lake A (Fig 6). By contrast, 'Normal' Charr males are larger than the females (Fig7) .

1

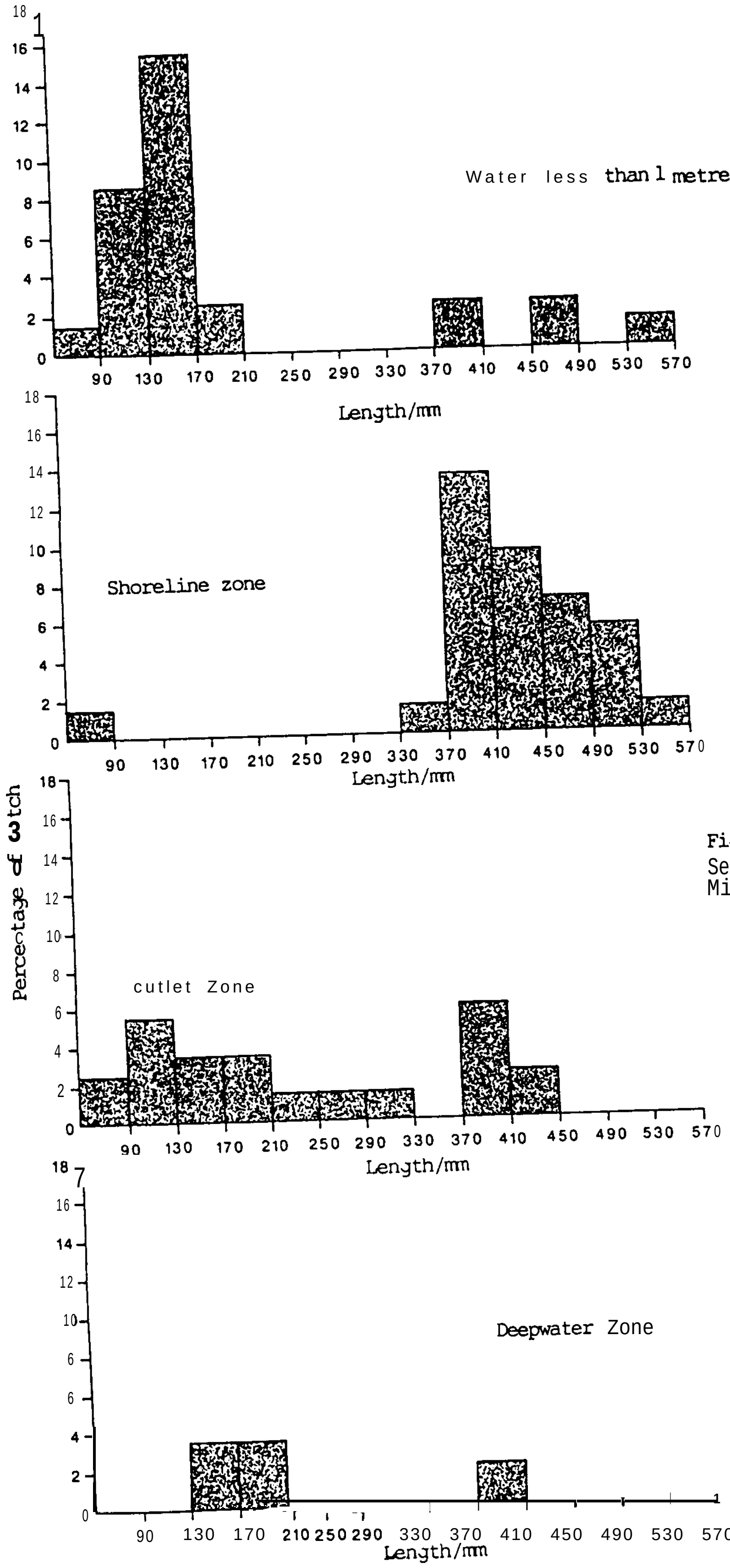
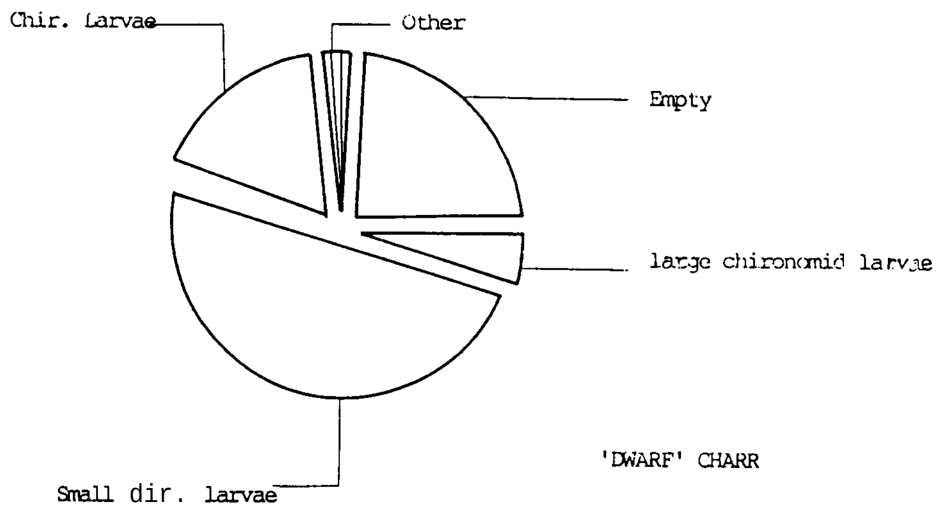
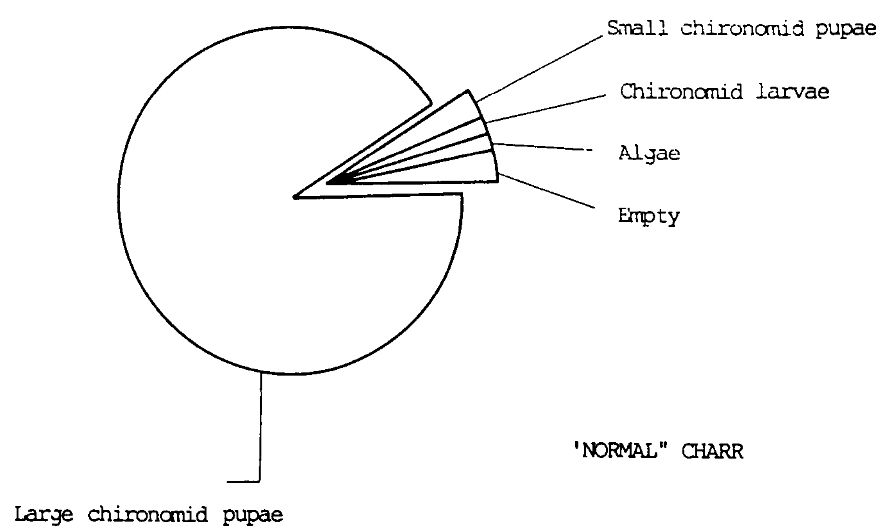


Fig.3 : Habitat Segregation by zone. Mid July

Fig. 4: Habitat segregation by stomach contents. Mid July



'DWARF' CHARR



'NORMAL" CHARR

Note: Sectors represent relative total volume of stomach contents

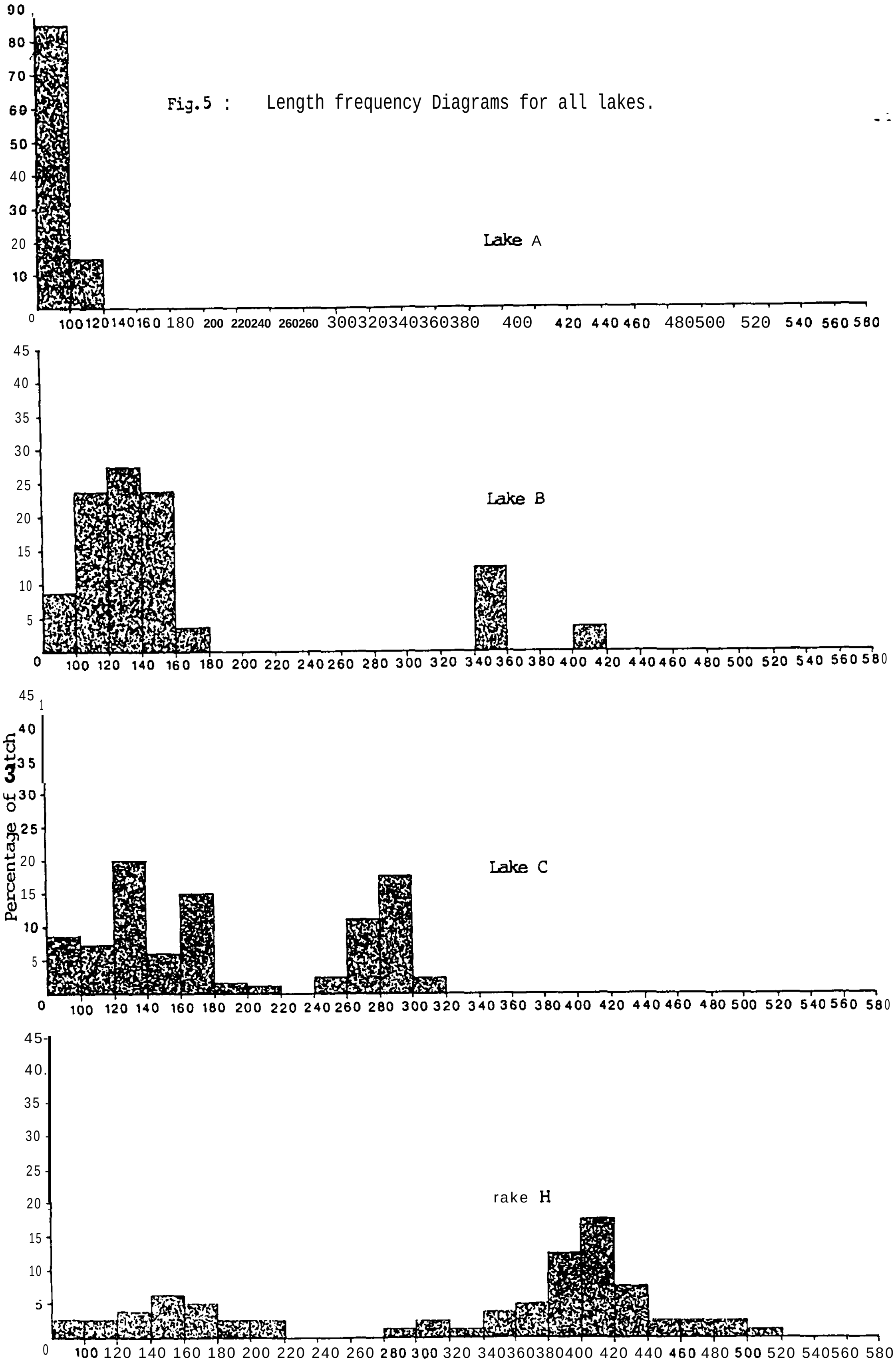


Fig.5 : Length frequency Diagrams for all lakes.

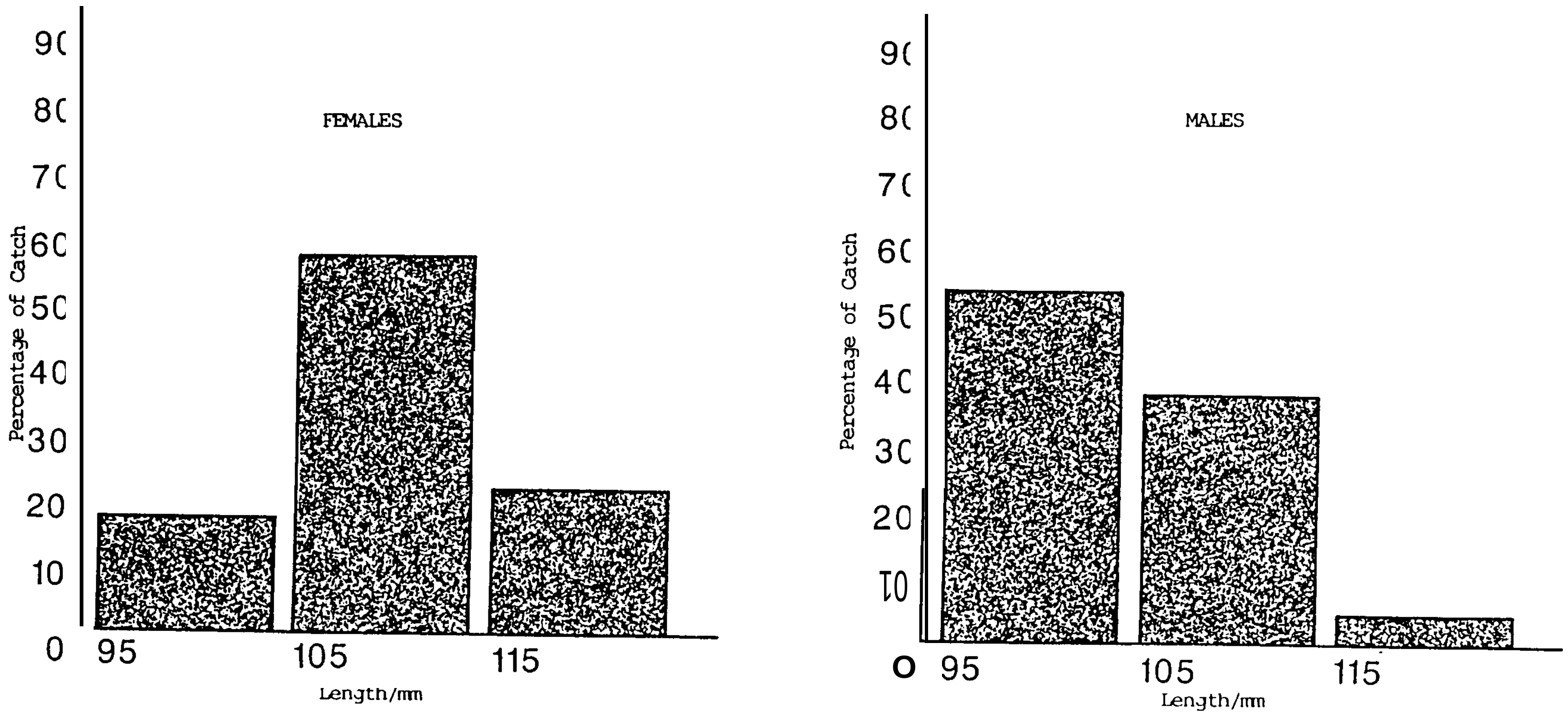
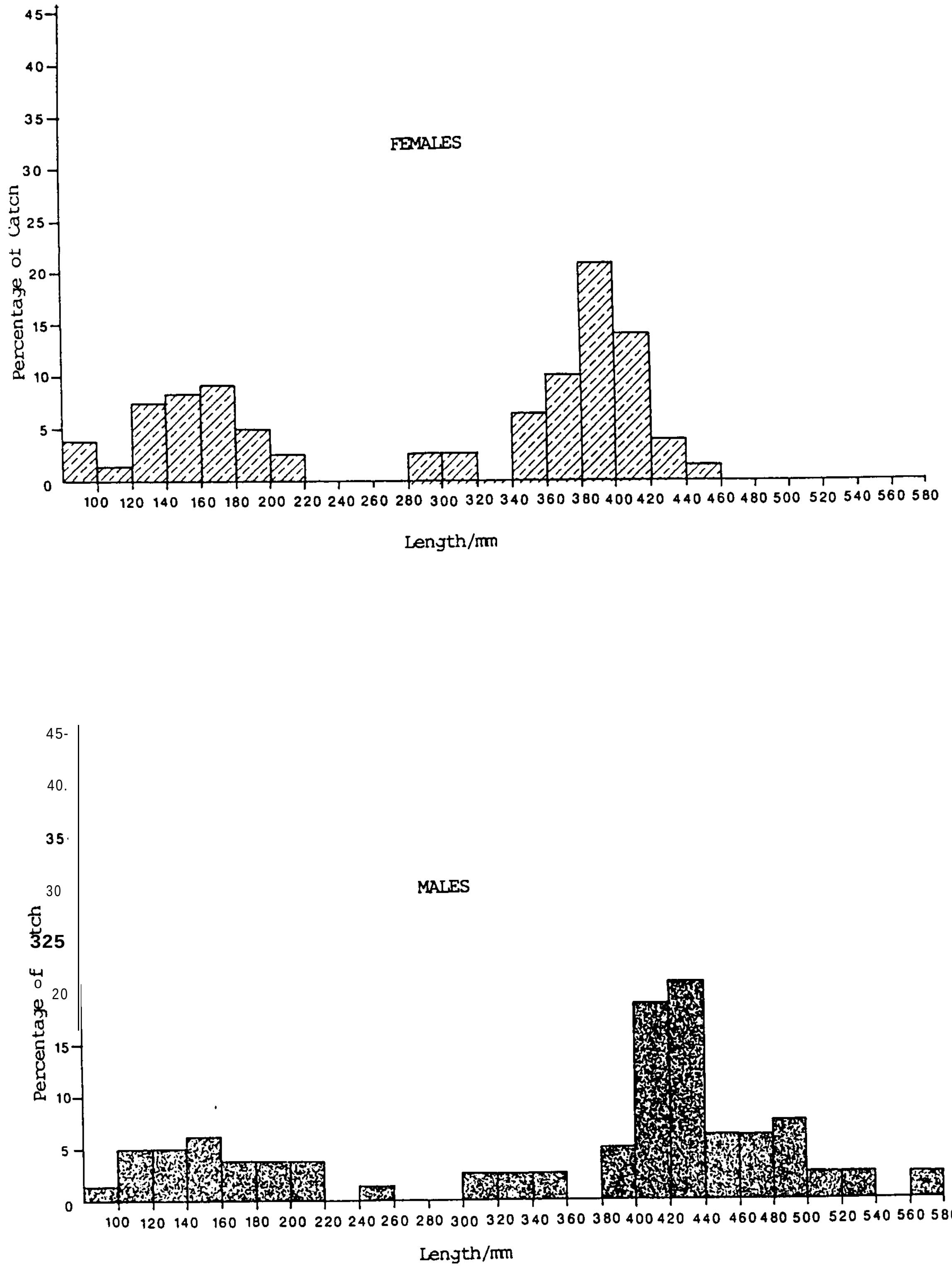


Fig. 6:- Length Frequency Diagrams for Lake A. Males and Females shown separately

Fig. 7: Length frequency diagrams for Lake H. Males and Females separately



D. Growth .

The length and weight distributions for each age class indicate a complex growth pattern with a considerable variation in size at a given age. Fig. 8, indicates the progression for all four lakes. It should be noted that no attempt has been made to plot the graphs on the same scale. The differences in the populations make this impracticable.

E. Age.

For the bimodal length-frequency distributions, the age structure is also bi- or trimodal(Fig.9) . This would suggest either some fault in the method of ageing the fish by otoliths, or a bias in the sample in which fish of the middle age group are missing. Low numbers of very young fish is probably a result of gillnet selectivity.

F. Length-Weight Relationship and Condition.

For Lake H,the length-Weight relation was determined by linear regression to be:

late May:

$$\log\ (\text{Weight/g}) = -5.17 + 3.01\ \log\ (\text{length/mm})\quad ;\ r=0.99$$

Mid August:

$$\log\ (\text{Weight/g}) = -4.94 + 2.95\ \log\ (\text{Length/mm})\quad ;\ r=0.99$$

For fish of modal length, 95% confidence intervals (Table 2) show that for both types, there is significant increase in weight at a given length between late-May and mid-August. In addition, the coefficients of the ' log (length) ' terms in the above equations show that this increase is least for the larger fish.

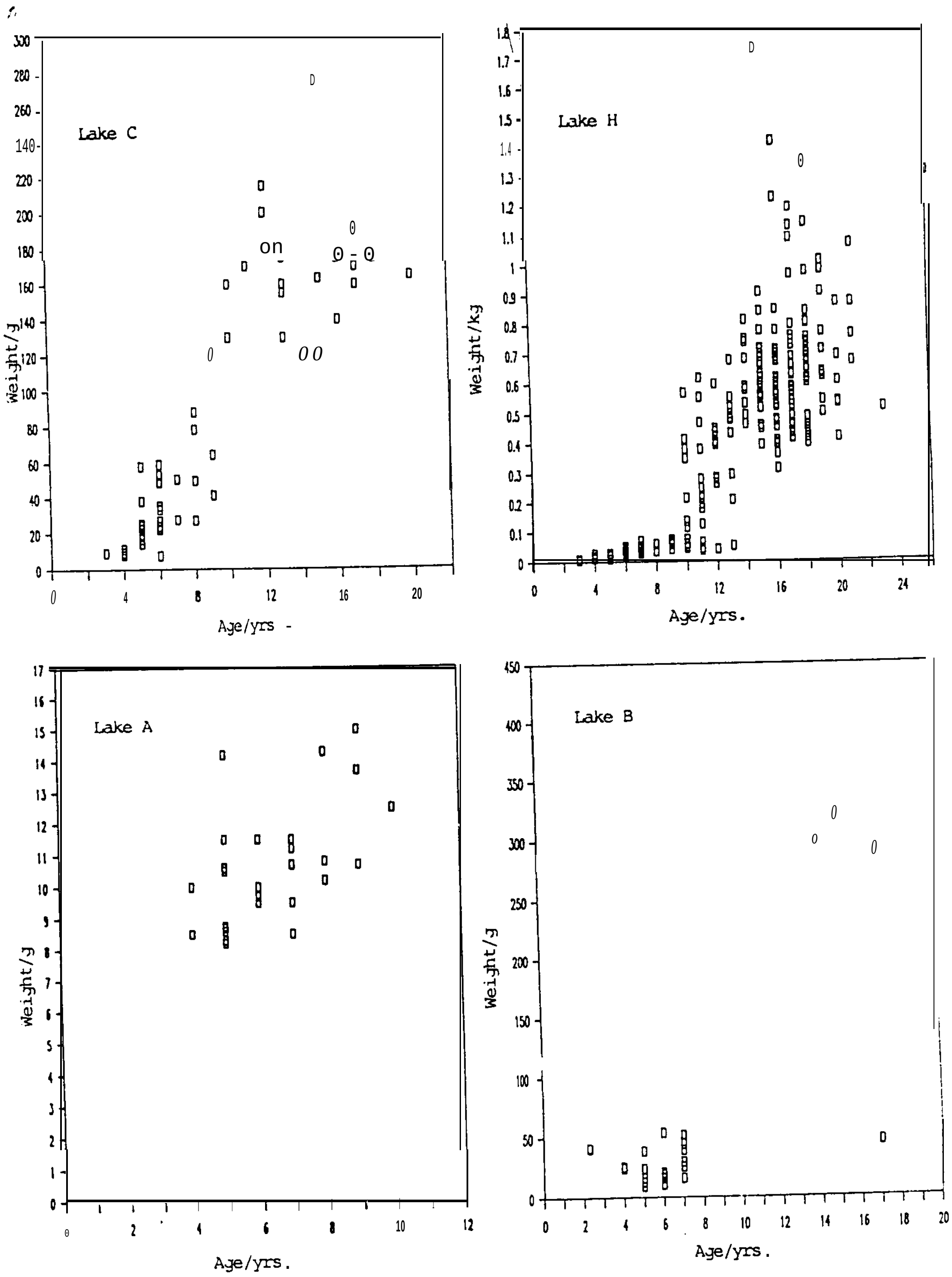


Fig.8:-Weight vs. Age diagrams for all Lakes. (Different Scales)

Table 2 - 95% confidence limits for weight/g of fish of modal length, obtained by regression.

Length/mm	late May	mid August
180	[39.2, 46.5]	[48.4, 54.9]
420	[512.4, 586.1]	[608.2, 650.2]

Scatter plots of length vs. Condition are shown for all lakes in fig.10. Condition is defined as:-

Condition factor = Weight/(Length; * 10^6

In general, condition declines with length, and the 'Normal' charr of Lakes B and C are of particularity low condition.

G. Sex Ratios.

Table 3 indicates the sex ratios for all lakes:- The probability calculated is for the null hypothesis that the sex ratio is equal.

		Lake A	Lake B	LakeC	LakeH
	males	15	11	11	31
'Dwarfs'	females	17	11	18	44
	P	0.13	0.17	0.06	0.03
	males	I	1	7	83
'Normal'	females	/	3	15	85
	P	/	0.25	0.04	0.06

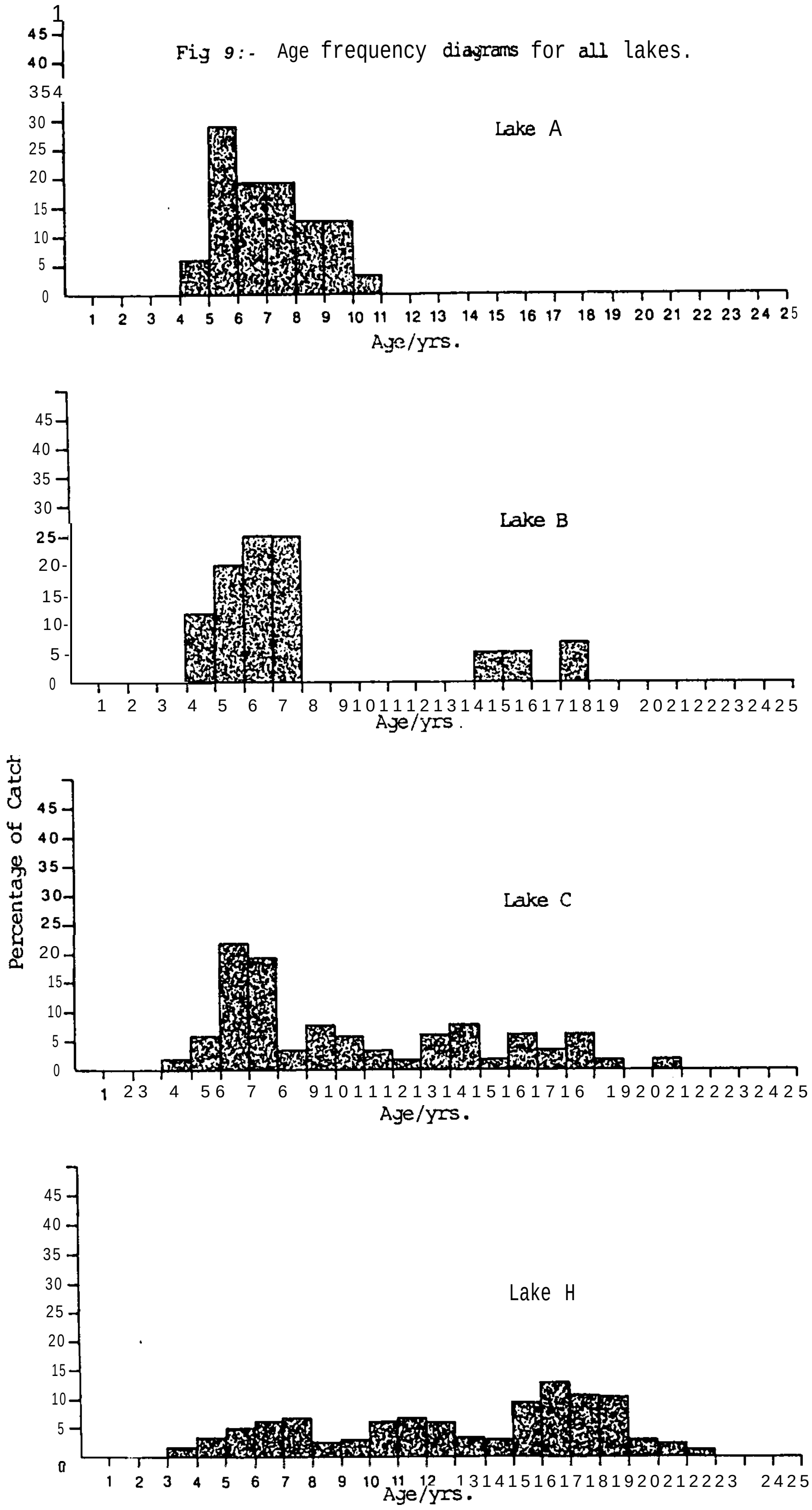


Fig 9:- Age frequency diagrams for all lakes.

H. Age of Maturity and Frequency of Spawning.

Table 4 shows the ratio of the number of fish identified as mature to the total number of fish of the same sex and type older than the observed age at first maturity. The reciprocal gives some idea of the spawning frequency once this age at first maturity has been reached, but some care needs to be taken in interpreting the data. For example, a spawning frequency of once every ten years for mature 'Normal' females must surely mean in practice that successful spawning may only occur once in a lifetime. Maturity is defined as spawning in the year of the. study.

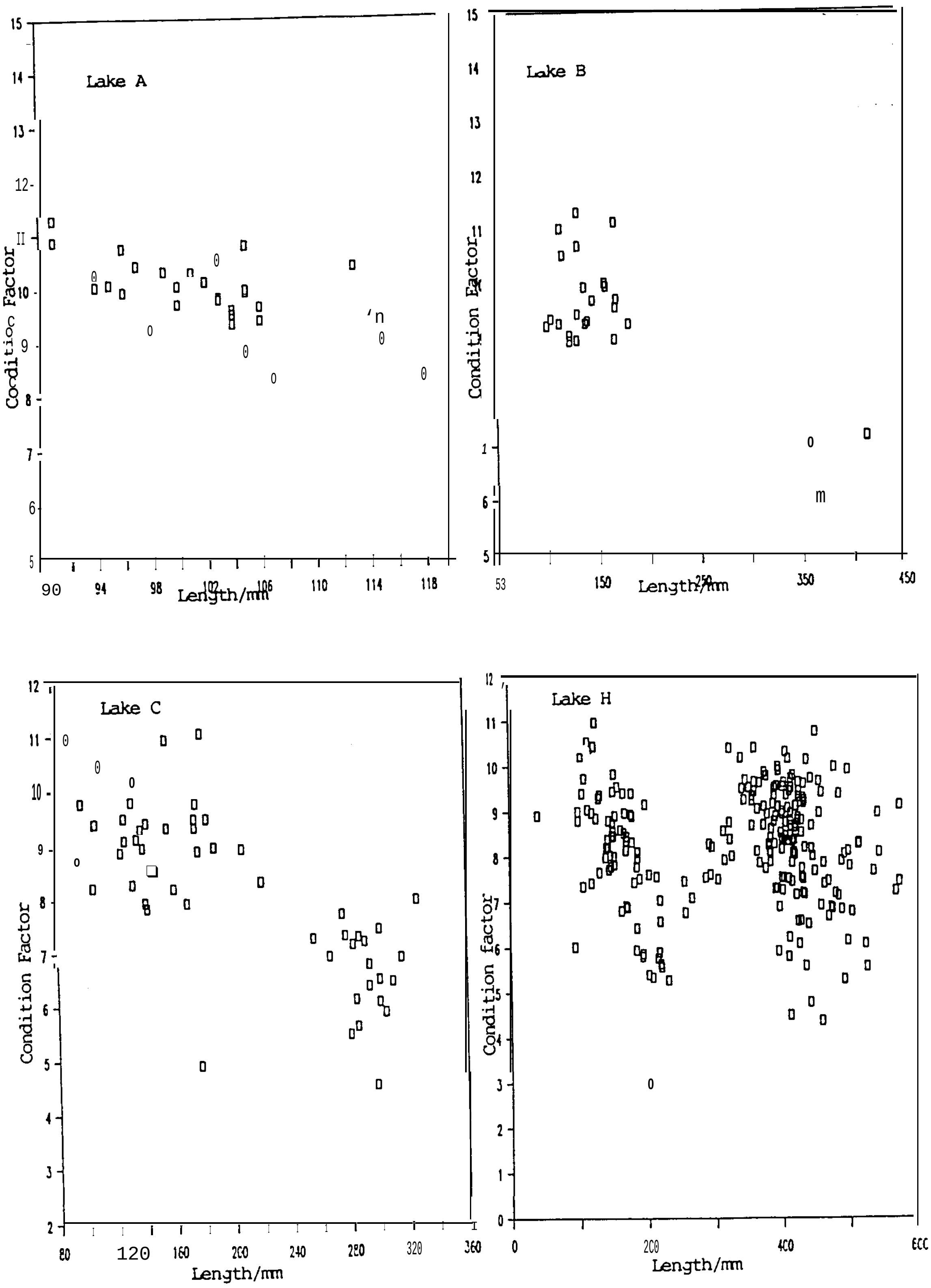
Lake A is particularity interesting because all members of its population can be classified as genuine 'Dwarfs'. In the other lakes, it is possible to confuse mature 'Dwarfs' with immature 'Normal' charr and so the data are less clear. Lake A shows almost all males caught to be mature, implying an annual spawning cycle; approximately a quarter of the females caught were mature indicating a 4-yearly cycle. Lake H provides the best picture of the 'Normal' charr. Once again twice as many males were mature as females. The frequency of spawning is however considerably less at 4-yearly for males, and 10-yearly for females.

Table 4:Sexual maturity (Note that the mid-May specimens from Lake H are excluded from this table because it was not possible to identify mature fish at that time)

Males:

	Observed age of 1st maturity,a		freq. of spawners older than a		Sample size	
	Dwarf	Normal	Dwarf	Normal	Dwarf	Normal
Lake A	4	/	0.73	/	15	/
Lake B	4	/	0.55	/	9	/
Lake C	9 (1 only)	/	insuf. data	/	/	/
Lake H	5	15	0.21	0.22	23	54

Fig. 10:- Scatter plots of condition factor against Age. All lakes.



Females:

	Observed age of 1st maturity, a		freq. of spawners older than a		Sample size	
	Dwarf	Normal	Dwarf	Normal	Dwarf	Normal
Lake A	5	/	0.24	/	17	/
Lake B	/	/	/	/	/	/
Lake C	/	15	/	(0.33) (insuf. data)	/	6
Lake H	7	13	0.15	0.09	19	55

J. Gonad Weight and Fecundity.

Fig. 11 shows Gonadosomatic index (Gonad Weight/ Body Weight) against length for mature fish of the two sexes. Data from all four lakes are included in these graphs in order to provide a wide spread of data. A number of regressions lead to some interesting observations:

Note abbreviations: Gd. Wt. = Gonad Weight

Males:

log (Gal. Wt./g) = -5.07 + 2.44 log (length/mm) ; r=0.982

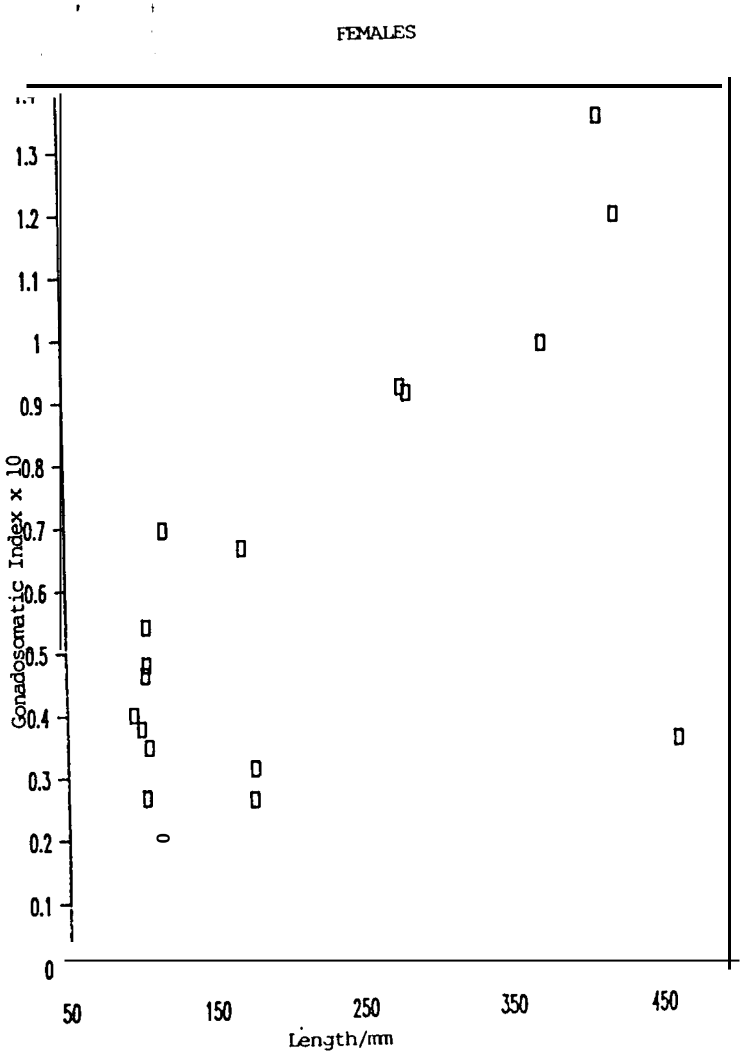
Females:

log (Gal. Wt./g) = -7.36 + 3.45 log (length/mm) ; r=0.976

log (No. of ovae) = -3.42 + 2.45 log (length/mm) ; r=0.985

These equations imply that:

1. Gonad weight per ova increases linearly with fish length. This agrees with the measurements taken of egg diameter for fish of different sizes. A 100 mm fish had egg diameters of approximately 3.5mm, whereas a 400mm fish had egg diameters of 5.5mm. Thus over this range the volume, and hence the weight, will increase to the cube of 5.5/3.5 (= 3.88). The regressions indicate a factor of 4.



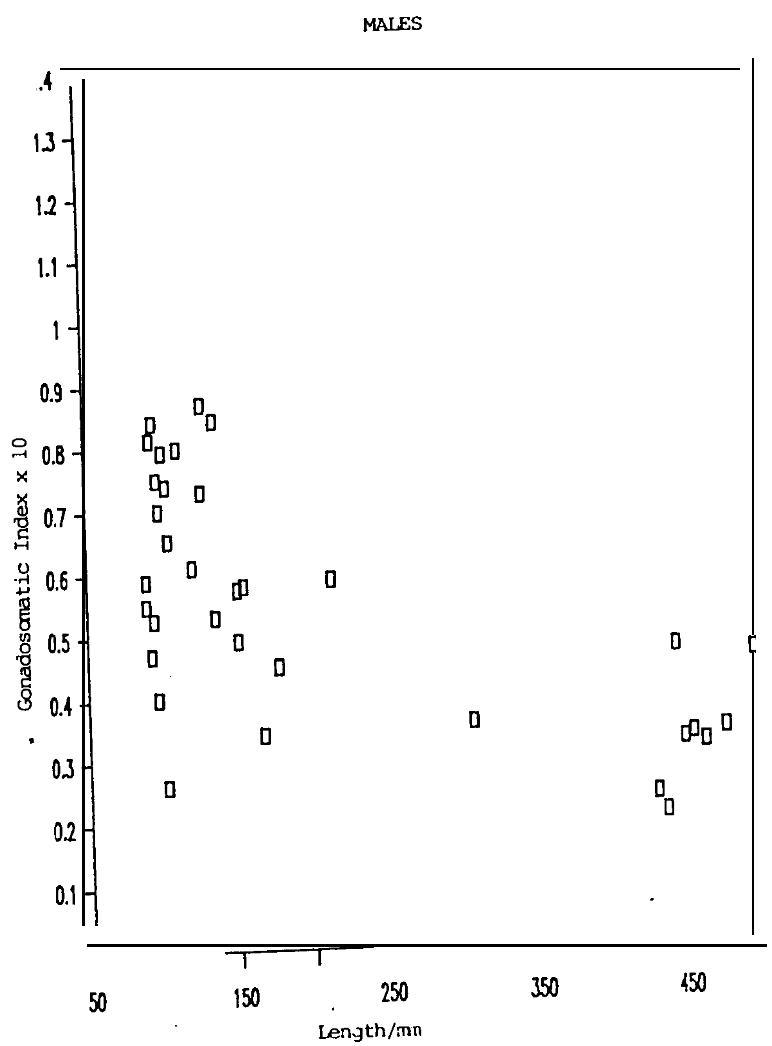


Fig. 11:- Graphs of Gonadosomatic Index versus length for mature individuals from all lakes

2. The gonad weight of the males increases at the same power as the number of ovae in the females.

K. GILL RAKERS.

For Lake H, 'Normal' charr had a significantly higher number of gill rakers (average 25.8) than the 'Dwarfs' (average 22.3).

DISCUSSION.

The evidence within this paper is that different semi-discrete habitats exist within the lakes which each supports an optimal size of fish, and that the nature of these habitats changes over the seasons. Reproduction, if it occurs at all, occurs at this optimal size in which the most energy is available to support spawning. It is also evident that occupancy of a given habitat is heirarchical and based on size. In other words that big fish are able to exclude the smaller ones from the habitats with the most abundant food supplies. Finally it is evident that reproduction has a heavy energetic cost, and that it precludes a high somatic growth rate, the same growth rate which is necessary to promote recruitment as a bigger fish to the next larger mode.

The regressions of gonad weight against length of mature spawners from all lakes shows a remarkably smooth progression from fish of 100mm up to fish of 500mm. At the same time, there is a progression in terms of other characteristics. The 100mm fish has some obvious juvenile characteristics such as 'parr'-like colouration, small mouths, and small eyes. The 500mm fish looks much more similar to the 'sea-run' adult charr which is common in many northern systems with silvery colouration, larger eyes, and a large mouth with numerous backwards-sloping teeth. This implys a process of heterochrony in which the age and size at maturity is optimised by the acceleration or retardation of sexual maturity with respect to other processes such as somatic growth.

A further remarkable aspect of systems similar to Borup Fjord's is the stability which distinguishes Arctic Lakes from most other Arctic Systems. A simple analogy could be made in which the morphs of charr are compared with the different species occupying their different habitats in a temperate lake. The variety of species in a given system is often supposed to be responsible for its stability. Similary, it may be that the formation of morphs and their accompanying modes is essential to the stability of the Arctic system. A further aspect may be shown by rearing experiments in which it has been shown that a parent from one morph is capable of producing offspring in another. Thus a catastrophic event in one mode could soon be compensated for by the progeny from another.

No paper on charr would be complete without discussion of what has become known as the 'charr problem'. This centres on whether the different morphs of charr have evolved allopatrically, that is to say in systems which are physically separated, or sympatrically whilst remaining at all stages of the evolution within the same system. The evidence of this paper supports the conclusion that heterochrony provides a mechanism for sympatric evolution and that allopatric evolution, whilst still not impossible, is unlikely. ,

CONCLUSIONS.

As previously mentioned, conclusions from this work are still subject to active theoretical investigation and comparison with previous work. It is hoped however to justify the following conclusions:

1. The lakes consist of a number of semi-discrete habitats which change or disappear altogether as the seasons offer their different feeding opportunities.

2. The occupancy of a given habitat by a given individual is dependent on its size. A large fish would not be able to support its *standing energy* costs in some habitats and is able to defend its share of its present habitat from smaller fish.

3. Heterochrony is a mechanism by which it is possible to obtain mature individuals in all the habitats examined and hence contributes to the multi-modal population structure observed.

4. The multi-modal composition of the charr population leads to a population structure which is considerably more stable than a unimodal composition.

5. The morphs are in dynamic equilibrium, and that the proportion of different types is dependent on the extent of the habitats they occupy.

ACKNOWLEDGEMENTS .

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Dr. Lionel Johnson, Freshwater Institute, CANADA, Supervise

Professor A Klemetsen, Tromso University, NORWAY, Adviser

CHARR PARASITE STUDY.

Report by Professor C R KENNEDY, Exeter University, UK
Fieldwork by H H PARKER and B C CRAWFORD

Introduction:

Although parasites of charr have been studied in many localities on the mainland of America, Asia and Europe, they have been studied in far fewer localities on Arctic Islands. Extensive investigations have been undertaken on Novaya Zemlya and on Bear Island in Europe, and thr results tend to show that the parasite fauna of charr on these islands is similar to those of mainland charr, and may or may not be as rich and diverse. In association with the studies on Charr themselves, therefore, the opportunity was taken to examine their parasites, with the specific aim of determining whether the parasites of charr on high Arctic Islands in Canada were similar to those of charr on high Arctic European Islands and more or less rich than on the mainland.

Methods:

Charr were examined by standard techniques, and all major organs were examined for the presence of metazoan parasites. Protozoa were not searched for, nor was the blood system examined. The numbers of individuals of each parasite species was recorded for fish in Lakes A, B and C. Some fish in Henry's Lake were very heavily infected and precise numbers of their parasites were not determined in all cases. The results in the table therefore only refer to the subsample of fish for which all parasite numbers were recorded. All identifications were confirmed on material brought back to England.

Results:

Four species of parasites were found altogether. The copepod Salmincola Edwardsii occurs on the gills and inner operculum : the tapeworm Diphyllobothrium dendriticum occurs as the larval stage, encysted on the stomach and other organs of the body cavity : the adult tapeworms Proteocephalus sp. and Eubothrium Salvelini occur in the intestine. Identification of Diphyllobothrium follows current opinion, but identification of proteocephalid tapeworms is both difficult and uncertain. The material was probably P.tumidocollus.

Infection Levels differed considerably from lake to lake (Table 1). Two species were found in all four lakes (D.dendriticum and Proteocephalus), and only these two in the highest lake (A). Lake B contained in addition E. Salvelini. The prevalence and intensity of each species also varied from lake to lake. S. edwardsii was most abundant and prevalent in Henry"a Lake. D.ditremum was least common in Lake B, was more common in Lake C and dominated Lake A, but reached its maiximum abundance in Henry's Lake where one fish harboured just over 4000 individuals. Levels of Proteocephalus were comparable in Lakes A,B and C but this species was very rare in Henry's Lake, where by contrast E.salvelini was the commonest and most abundant intestinal tapeworm. With the exception of Proteocephalus, therefore, all species were most prevalent and abundant in Henry's Lake.

Discussion:

All four species of parasite have been recorded from charr in other locations in Canada, and they. or their European equivalent, from charr in Europe. The general characteristics of the parasite fauna of charr on Ellesmere Island are fairly similar to those on Bear Island in the Norwegian Arctic. There an additional species of nematode was present, but otherwise the same four species and with all four increasing in abundance in the largest lake. On Bear Island also the fauna tended to be dominated by D. Ditremum. The variations in prevalence and abundance between the lakes may reflect differences in size and altitude of the lakes, or. probably related, differences in the composition of the zooplankton which serve as intermediate hosts for all three species of tapeworm or differences in the proportion of the different types of morphs of charr in the 1 ake .

It can thus be concluded that the parasites of charr on Ellesmere Island are indeed similar to those on the mainland. Most lakes on the mainland have a slightly richer parasite fauna, as species of fluke and nematodes may also be present. The restriction of parasite fauna to those species having a planktonic larval stage or utilising planktonic intermediate hosts was also characteristic of the parasitic fauna of charr on Bear Island, and indeed one of the most interesting conclusions of the survey was to see how similar was the parasitic fauna of charr on high Arctic Islands in Canada and Europe. It is intended that this similarity will form the theme of a publication elsewhere.

Table 1:- Parasitic infestations of the Charr.

	Lake A	Lake B	Lake C	Henry's
No. of fish examined	32	26	57	60
% of fish infected	81.2	65.4	57.9	86.7
Salmincola edwardsii				
Prevalence	0	0	5.3	18.3
Mean (Max) Intensity	0	0	1 (1)	11.7 (51)
Diphyllobothrium ditremum				
Prevalence	75.0	21.1	24.6	75.0
Mean (Max) Intensity	13.6 (75)	1.7 (3)	10.1 (84)	300.0(4242)
Proteocephalus sp.				
Prevalence	53.0	42.3	33.3	1.7
Mean (Max) Intensity	9.0 (48)	9.5 (32)	10.6 (48)	1.0 (1)
Eubothrium salvelini				
Prevalence	0	34.7	12.3	43.3
Mean (Max) Intensity	0	1.3 (2)	1.6 (3)	3.4 (20)

Prevalence = % of fish infected : Intensity = no. of parasites per fish

AQUATIC INSECT STUDY.

Identifications by Dr. O A SCHNELL et al.,
University of Bergen, Norway
Report and Fieldwork by H H PARKER and B C CRAWFORD.

The following species were identified from charr stomach samples preserved in alcohol:-

Trichoptera:-
- *Apatania zonella* (Zetterstedt)

Chironomids:-
- *Paracladius alpicola* (Zetterstedt)
- *Heterotrissoclaidus* n.sp.
- *Paratanytarsus natvigi* (Goetghebuer)
- New Genus near *Stictochironomus*
- *Micropsectra* sp.
- *Heterotrissocladius subpilosus* (Kieffer)

Lepidoptera: -
- *Apamea maillardi exulis* (Lef.)
- *Lymantridae groenlandicus* (Woe.)
- *Olethreuthes inauietana* (Walk.)

Terrestrial origin:-
- Empididae sp.
- Ichneumonidae sp.
- Muscidae sp.

Much further work can profitably be done in this area, and Dr. Schnell has expressed an interest in further material, particularly of the new genus near *Stictochironomus*. It is intended to attempt this on return to Ellesmere Island in 1991.

CASUAL BIRD AND MAMMAL SIGHTINGS

ROBERT BURTON

In addition to the projects previously described, records were kept of all bird and mammal sightings.

Collared Lemming There was a crash of lemming populationa in the Eastern Arctic in 1987 and no nests from that year were found. Nevertheless there were several sightings end 6 lemmings were seen on one day. A dead lemming was found at 3400ft on Mount Leith

Arctic Here The population was low with probably only 4 animals living in base camp valley. Three families of 8,5 & 4 leverets were seen.

Arctic Fox Seen on several occasions but no den was found end foxes never entered the camp. Foxes were observed predating hares and snow geese and being harried by parent ptarmigen,turnstone and skuas. A white fox was seen on 20 Aug.

Polar Wolf Some fresh tracka were found in several places.

Stoat(Ermine) Seen 3 times.On one occasion 2 stoata were seen together - one having a dead lemming in its mouth.

Muskox The few sightings were mainly of lone bulls. Three animals fed in the snow near Wader Marah on 29 May and 21,with 5 calves, were seen on 24 July.

Peary Caribou A few, mainly lone, animals were seen throughout the expedition. Seven were seen on 22 July, 8(including 4 calves) on 31 July and 15(including 7 calves) on 13 August. A single bull occupied a small island,1 km from the shore,in Oobloyah Bay in mid August.

Ringed Sesl A few were seen on the sea ice in Esayoo Bay end in open water throughout Borup Fiord. A dead,partly eaten, pup was found by a breathing hole.

Bearded Seal One sighting in Esayoo Bay on 22 June.

Red-throated Diver(Loon) First seen on 13 June when a pair flew close to baae camp. Two pairs were seen in open water on 14 June and a pair was copulating in a pool in Wader Marsh on 16 June. This pair was incubating on 28 June and had chicks on 24 July.One, sometimes 2, pairs were often seen on Henry's Lake but apparently nesting waa not attempted. The lake was often used for foraging and fish were carried to the nesting site on Wader Marsh and one of the ponds under Mount Leith. Divers were also seen at the top of Midnight Sun Valley, at Atwood Point and in the Blue Mountains.

Snow Goose Two pairs were seen on 31 May, Thereafter up to 27 were regularly seen feeding on anew-free sedge-covered mud flats at Goose Flats. From 9 June immatures were seen with adults; after mid June flocks were no longer seen until early July when about 60 geese, of which half were flightless, were found on the south side of Oobloyah Bay. The first nest was found on 16 June and goslings seen on 14 July; nest failure appeared high end en arctic fox waa watched robbing a neat end killing one parent. Boat-based counts around Borup Fiord revealed about 200 adult geese and 04 goslings.

Brent Goose(Brant) A pair was sighted among snow geese on 7 June. Five were seen in the Blue Mountains on 12 July and an adult with 5 goslings was seen there on 26 July.

Long-tailed Skua(Jaeger) A pair was seen on 29 May near base camp; nest-scraping and courtship ceremonies were seen on 10 June but this pair appeared not to lay. These birds predated a wader nest on 23 June and another skua took a wader chick on 22 July. Three skua nests with single eggs were found and a fledgling was seen on 24 July.

King Eider First seen in open water at head of Esayoo Bay on 9 June; a pair were on Wader Marsh on 10 June. A flock of 10 males and 7 females were at the river mouth on 16 July. Ducklings were first seen on 22 July and families were present until 14 August.

Long-tailed Duck(Oldsquaw) First seen in open water at river mouth on 13 June; first ducklings seen on 20 July.

Glaucous Gull First seen on 22 May. A pair nested on the western side of Mount Leith and frequently visited Base Camp;on 12 August they brought a fledgling to the shore by Base Camp II.

Ivory Gull Four gulls probably of this species were seen flying over Elmerson Peninsula on 24 June.

Thayer's Gull One gull probably of this species was seen on the south side of Elmerson Peninsula on 24 July.

Arctic Tern First seen on 21 June. Colonies were found on the 2 islands north west of Elmerson Peninsula and west of Neil Peninsula(about 100 birda inthe air over each) and Elsa May Island(6 birds); Scattered pairs were seen around the coast of Borup Fiord. A small colony was found on an island in a lake 4 miles inland in the Blue Mountains.

Turnstone(Ruddy Turnstone) First seen on 27 May; see chapter in part 2.

Knot(Red Knot) First heard calling on 24 May; see chapter in part 2.

Baird's Sandpiper First seen on 3 June; see chapter in part 2.

Ringed Plover One bird seen on 11 and 12 June.

Ptarmigan(Rock Ptarmigan) First seen, in a pair, on 18 May. A nest was found on 26 May and another was hatching on 15 June. Females had started to moult by 23 May and males by 17 June.

Peregrine A pair was seen flying together near Base Camp II on 23 June and a female waa seen attacking a Knot on 30 June.

Gyrfalcon A single bird was seen at irregular intervals from 8 June to 10 August. A dark-phase Gyrfalcon landed by Base Camp II on 20 August and 2,probably male and female, flew low overhead on 21 August while one was seen at Atwood Point later that day.

Lapland Bunting(Lapland Longspur) A male was seen on 15 and 30 July.

Snow Bunting First seen on 22 May; see chapter in part 1.

Hoary Redpoll First seen on 21 May. Six,including 2 juveniles, on 15 July; a juvenile was trapped in Base Camp II on 10 August.