PALUDIFICATION AND CLIMATE ON THE QUEEN CHARLOTTE ISLANDS DURING THE PAST 8000 YEARS

by

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ABSTRACT

This study attempts to define the timing and causes of Holocene (last 10,000 years) peat bog growth and spread on the Queen Charlotte Islands. Published literature suggests the hypothesis that climatic change between approximately 6000 and 2000 ^{14}C years before present (yBP) was a likely cause of peat initiation and growth. From six sites investigated, three peat deposits were selected for detailed analysis, representing a range of latitudes and elevations. Cores or exposures were sampled to describe stratigraphy and changes in plant fossil composition. Quantitative pollen analysis was conducted on all three profiles resulted in pollen percentage and concentration diagrams. Plant macrofossils were also analyzed at the "Drizzle Pit Bog" to help interpret local vegetation succession. Twelve new radiocarbon dates provide the chronological framework for interpreting peat bog initiation and subsequent changes. Drizzle Pit and Kunghit Island bogs were first formed at 4320±100 yBP and 5150±70 yBP respectively. Argonaut Hill bog began forming at 7970±100 yBP, but significant peat deposition did not occur until about 5000 years ago. At Drizzle Pit, macrofossils and a stump indicate wetland expansion occured into forest (paludification), killing the preexisting trees. At all three sites, a second period of rapid *Sphagnum* peat deposition occurred circa 2500 yBP, probably in response to climatic change. A change in the flora at this time is consistent with successional changes due to acidic peat depostion. Climate is

seen as the ultimate controlling factor for these changes.

ACKNOWLEDGEMENTS

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Dr. Glen Rouse and, again, Dr. Rolf Mathewes deserve special thanks for showing me the stimulating research that lurks in the science of palynology and paleoecology.

DEDICATION

To my Mother and Father for their love and support.

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CHAPTER I

INTRODUCTION

Paludification and Climate

The Queen Charlotte Islands lie in a shroud of clouds and mist for most of the year. The excess moisture and cool temperatures of the maritime climate have created a temperate rain forest. The understory is inhabited by mosses, lichens, herbs and shrubs all attuned to life in an humid environment. The overstory contains some of the largest and oldest Sitka spruce and Western redcedar in Canada. Many lowlands and mountain slopes are covered with a complex veneer of peat bogs, fens, marshes and swamps.

This paleoecological study centres around the development of blanket bogs on the islands. Blanket bog formation on the Queen Charlottes follows two main pathways, with gradations between the extremes. In all cases, bog expansion follows an increase in moisture availability. This may occur with the onset of cooler temperatures and/or higher than normal precipitation (climatic deterioration). This new climate may favour the growth of small patches of *Sphagnum* peat under a forest canopy (Noble et al. 1984). The *Sphagnum* peat, acting as a water reservoir, expands vertically and laterally due to its morphological and physiological characteristics (Barber 1981, Kilham 1982, Noble et al. 1984). The expansion of *Sphagnum* continues until the moisture available to the bog's perimeter equals the moisture lost to evapotranspiration, runoff, and leaching. A blanket bog may ultimately form if the climatic conditions remain conducive for continued expansion. This process can occur on a flat or sloping surface, whether forested or not. Trees may be progressively killed by drowning in such areas.

Similar climatic conditions may also cause peat to collect in small depressions within a forest or valley. The formation of a small swamp, marsh or fen in these depressions often precedes *Sphagnum* invasion and subsequent bog formation. The almagamation of many of these smaller depression bogs, known as topogenous bogs will form a blanket bog. As their name implies, topogenous bogs are dependent on topography and may not be climatically initiated. For example, the re-routing of a stream to a previously dry depression will create a 'retention basin' for autochthonous peat (Moore & Bellamy 1974) allowing peat accumulation and bog establishment to occur. Blanket bog growth above the water table, whether episodic or continuous in nature and regardless of its origin, is solely dependent on climate (Barber 1981; Wells and Pollett 1983). The process of bog expansion laterally into previously mesic sites is known as paludification (Auer 1930). Site selection for a paleoclimatic investigation should therefore centre on sloping ombrotrophic bogs or open topogenous bogs which have expanded beyond the confines of their initial depressions. In either case, care must be taken when selecting sites to avoid bogs formed by other than climatic factors (Ugolini & Mann 1979, Jacobsen and Bradshaw 1981, Banner et al. 1983a, Wells & Pollett 1983).

Many paleoclimate studies using ombrotrophic peats have been completed in North America. Most of these studies indicate paludification is an episodic event occurring approximately 6000-2000 ^{14}C years before present (yBP).

In eastern Canada, the heaths of Newfoundland exhibit morphological and phytosociological similarities to those of the Queen Charlotte Islands. Davis (1984) used ombrotrophic peats to produce evidence for episodic paludification events in Newfoundland. In his paper he stated that most peat stratigraphies in Newfoundland indicate "marked environmental changes at approximately 3000-2500 yBP in response to climatic deterioration" (Davis 1984 p.299). He presented a sequence of retrogressive successions typical of events in eastern North America; forest to sedge to *Sphagnum*, all indicating increasing moisture surplus. Wells & Pollett (1983) cited evidence for a wet, cool period occurring in Newfoundland between 4800-3200 yBP with further climatic deterioration at 2800 yBP. Several dates of plateau bogs by Davis (Wells & Pollett 1983) in western Newfoundland indicate ages grouped at 2540 yBP and 4090 yBP.

Prince Edward Island also exhibits a decrease in mean annual temperatures and increase in precipitation during the same period. Anderson (1980 p.1162) noted "A significant decrease in the mean annual temperature and an increase in moisture" inferred after approximately 3000 yBP. The changes in climate are reflected by an increase in the eastern hemlock curve (*Tsuga canadensis*), spruce, Ericaceae and *Sphagnum*.

Nova Scotia pollen curves from peat deposits (Hadden 1975) mark the wetter, cooler climatic transition at 4000 yBP. Again, *Tsuga canadensis* maxima at approximately 4000 yBP are used to infer the climatic deterioration. Another core suggests a later date for the change in climate; 3300 yBP possibly due to the inland location of this core relative to the others in this study.

Lake histories in the same area of eastern maritime Canada support the climatic interpretations derived from bog investigations. Lamb (1980) prepared pollen diagrams for three lake sites in southeastern Labrador. Evidence from the lake cores suggests a marked deterioration in climate at 2500 yBP. Short and Nichols' (1977) analyzed six lake cores from the Labrador-Ungava region. They show a continuous record of vegetation beginning 10,300 yBP with a climatic cooling from 3000 yBP to present.

In central Alberta, Vance (1979) analyzed a lake core and bog. He proposed that a cool, moist climatic regime was well established by 2800 yBP, however, vegetation changes occurred at the onset of the climatic change 4000 yBP. The termination of the Hypsithermal in this study was marked by cooler, moister conditions (Vance 1979, Vance et al. 1983). Vance (1986) used calibration equations to reconstruct paleoclimate from Lofty Lake in central Alberta. The results indicated a cooling trend starting at 6000 yBP but remaining above current values until 3000 yBP. After 3000 yBP, continued cooling led to modern conditions by 1000 yBP. White and Mathewes (1982 p. 565) working in the Peace River district of Alberta stated "the persistent presence of alpine fir (*Abies lasiocarpa*) may be related to possible climatic cooling between 3000 and 4000 yBP." The initiation of modern conditions occurred 5500 yBP with a slightly cooler and probably moister climate at 3400 yBP (White and Mathewes 1982, 1986).

Kearney and Luckman (1983) postulated a return to moister and probably cooler conditions after 4300 yBP in Jasper National Park, Alberta. Based on their timberline work, they stated that regional temperatures have also decreased since 1700 yBP.

Results from studies on the west coast are similar to those from the east coast. Heusser's pioneering work (1960) suggested that cooler, wetter conditions began about 3000-3500 yBP. In a recent study by Heusser (1983), peat profiles for the Prince William Sound Region, south-central Alaska, are characterized by expansion of sedge tundra during major neoglacial episodes (3200-2500 yBP). Increases in both *Empetrum nigrum* [1] and Cyperaceae pollen influx suggest increasing moisture coincident with a neoglacial cooling. Peteet (1986) examined three muskeg

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[1]Taxonomic nomenclature for vascular plants follows that of Taylor & McBryde (1977) and for Bryophytes, Schofield (1969) (see appendix 1).

sections to determine the Holocene vegetational history of Icy Cape, Alaska. The results of her study indicated that wetter conditions began after 7600 yBP. By 3500 yBP, climatic cooling and increased atmospheric moisture occurred as suggested by the appearance of *Tsuga mertensiana*, *Selaginella selaginoides*, increased *Sphagnum* growth and coincident glacial advances. Peteet suggested that the rapid migration of *Tsuga heterophylla* northwestward into Prince William Sound from Icy Cape at 3860-2680 yBP is probably due in part to an increase in climatic and edaphic moisture accompanying neoglaciation. Pollen records from the Tangle Lakes area of Alaska by Ager and Sims (1981) indicated a rise of *Picea mariana* pollen percentages. The rise coincided with the onset of wetter, cooler conditions during neoglacial advances, and increased peat deposition. The correlation between the *Picea* curve, climate and tree line is not fully understood. Ager and Sims recognized a trend toward cooling and increased moisture about 2500 yBP. Ager's (1983) examination of data from sites in Alaska, including southwestern Alaska, indicated a shift to a cooler, moister neoglacial climate around 3500 yBP.

Bear Cove Bog, northeastern Vancouver Island is interpreted by Hebda (1983, p.3189) to indicate cooling and increased wetness. He stated that "by about 3000 yBP summers may have become sufficiently cool and winters sufficiently long and wet that extensive humus accumulation was possible, thus providing moist substrates even in mesic sites, a situation which favoured

Cupressaceae growth".

Mathewes (1973) has shown a Cupressaceae (*Thuja plicata*) population increase at Marion Lake, British Columbia occurring approximately 6000 yBP. *Lysichiton americanum*, often found together with *Thuja plicata* in seepage sites, is also present during the Cupressaceae increase. This suggested that "paludification may have contributed to more favourable growth of red cedar..." (Mathewes 1973, p.2098).

Banner et al. (1983a) presented a pollen-spore profile from Mt. Hayes near Prince Rupert. The conversion of productive forest to scrub and the subsequent development of blanket bog communities at this site may be related to a combination of the following: climatic deterioration, a change in drainage patterns and/or formation of placic horizons impeding drainage. They suggested that a trend to cooler, wetter conditions occurred between 7000-6000 yBP. This climatic shift set the stage for the development of blanket bog communities.

The Queen Charlotte Islands have also been the subject of some palynological research. Heusser (1955) sampled five peat sections on the Islands, which were not radiocarbon dated. Heusser divided his diagrams into periods, which reflect environmental and floristic events. Heusser's period IV refers to an increase in peat production, representing a possible paludification event. He interpreted period IV as one of relative coolness and wetness following the 'thermal maximum' and bases this on the increases in *Sphagnum* spore and heath pollen percentages. Heusser (1960) found that the date of the *Sphagnum*/heath proliferation began in northern British Columbia about 3500 yBP. Warner's work on the Queen Charlotte Islands, although not specifically concerned with the late Holocene climatic deterioration, does note that the change did begin "after 4500 yBP, but certainly by 3000 yBP" (Warner 1984 p.141). The Boulton Lake core confirms paludification occurred during this time period. Evidence from Serendipity Bog Lake suggests that major paludification was initiated after 5800 yBP with modern bog conditions developing by 2400 yBP. Further evidence from Warner's study suggests that *Thuja plicata* became a forest dominant by 3100-2700 yBP.

Hebda and Mathewes (1984) examined the fossil evidence of Cupressaceae pollen in the Pacific Northwest, interpreted to be mostly *Thuja plicata* in the sites studied. Low concentrations of *Thuja plicata* pollen prior to 6000 yBP are probably due to unfavourably warm and dry conditions of the 'early Holocene xerothermic' interval on the coast. Increased cedar type concentrations after this time have been interpreted as due to decreases in temperature and/or increases in moisture.

Temperature and precipitation curves produced for the southern British Columbia coast from palynological data indicate a decline in temperature and increase in precipitation from 7000 yBP stabilizing about 4000 yBP (Mathewes and Heusser 1981). Heusser et al. (1985) indicate decreasing temperature and increasing precipitation trends after 5000 yBP on coastal Alaska. Included in the paper is the assertion that storm activity was most intense in the late Holocene in southern Alaska.

From the studies presented, clear evidence exists for the occurrence of a North American climatic deterioration from 6000-2000 yBP. In some cases an argument can be made for two episodes of climatic deterioration (Wells and Pollett 1983). With continental climate changes in mind, including possible affinities between the history of mires in Europe and Eastern North American (Davis 1983) a paleoecological study of Queen Charlotte Islands peatlands was undertaken. Three peat deposits were sampled to reconstruct and date changes in vegetation, and to determine the causal factors involved. This study of the Pacific Coast of British Columbia will add to the proxy data base for understanding the Holocene climatic changes of this area.

CHAPTER II

STUDY AREA

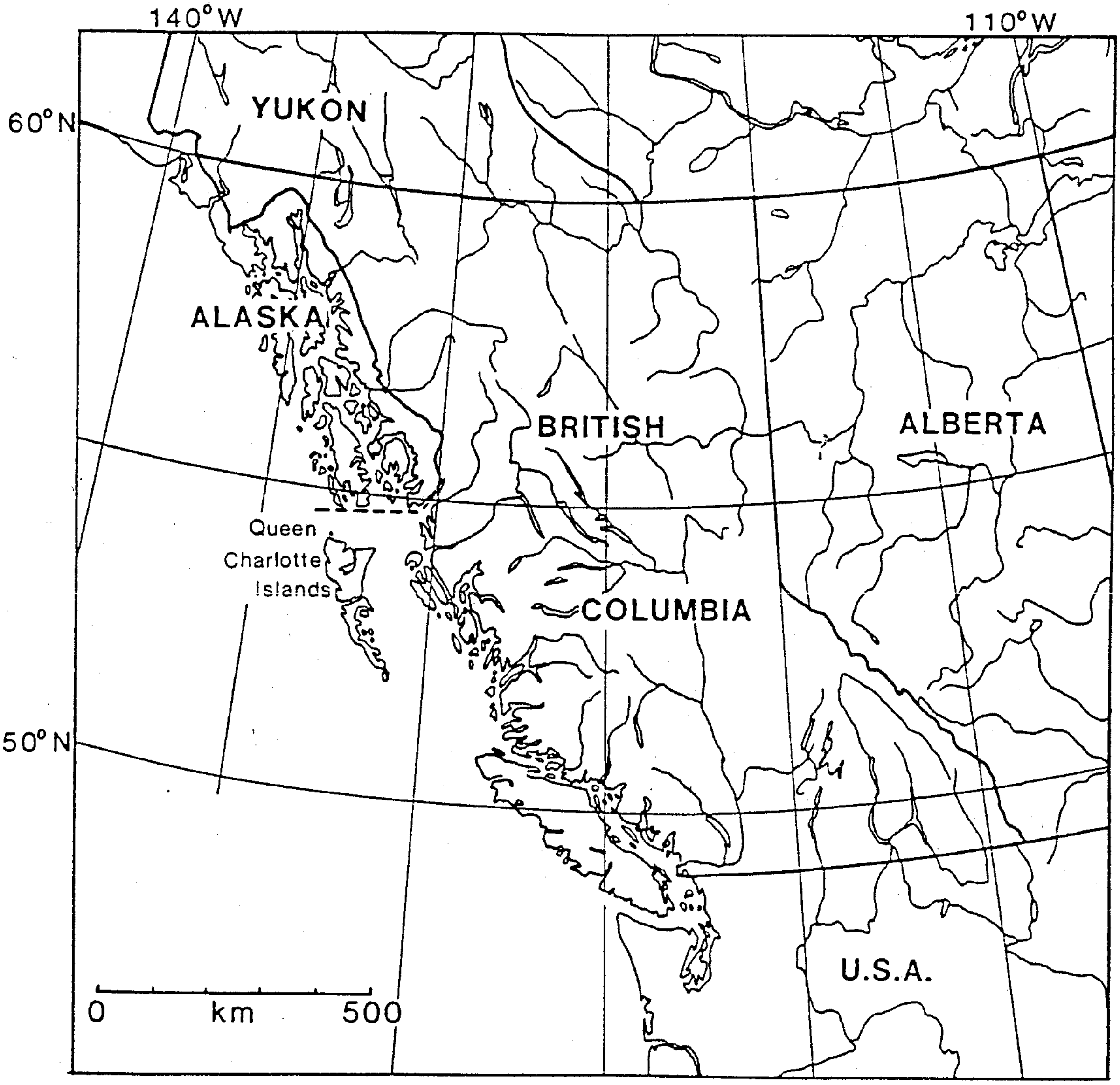
Geology and Physiography

Approximately one hundred and fifty islands make up the wedge shaped archipelago known as the Queen Charlotte Islands. This chain lies between 52 - 54°N latitude and 131 - 133°W longitude off the west central coast of British Columbia (Fig. 1). The two major islands, Graham and Moresby, contain 90% of the archipelago's landmass (Sutherland-Brown 1968). The total land area is 9945 square kilometers with terrain varying from a mountainous western spine to the eastern lowlands. The islands are a continuation of the western system of the Canadian Cordillera with three major physiographic subdivisions (Fig. 2):

1. Queen Charlotte Ranges,
2. Skidegate Plateau and
3. Queen Charlotte Lowlands.

The Queen Charlotte Ranges extend the length of the west coast from northwestern Graham Island to Kunghit Island in the south. The ranges are broken into three groups of high peaks with the San Christoval Range being the only lineal mountain range present. Elevations for the mountains never exceed 1,200m asl. The Skidegate Plateau includes a large part of Graham Island and a smaller portion of Moresby Island. This subdivision is sandwiched between the Queen Charlotte Ranges and the Queen Charlotte Lowlands. The plateau reaches its highest elevation of 610m in the west central part while the eastern region adjacent

FIGURE 1: Queen Charlotte Islands in relation to British Columbia.


140°W
110°W
60°N
50°N
YUKON
ALASKA
BRITISH
COLUMBIA
ALBERTA
Queen
Charlotte
Islands
U.S.A.
0
km
500

to the lowlands is about 460m asl. The Queen Charlotte Lowland covers the majority of Graham Island and a tiny part of Moresby Island. Most of the lowland is below 150m asl, however, a subdivision of the lowland known as the Argonaut Plain has a few flat topped hills with elevations reaching 120 - 140m asl.

The Islands during the height of the Fraser glaciation (about 21,000 yBP) supported an independent ice cap (Clague 1981). The eastern portion of this ice cap may have combined with the mainland ice originating in the Coast Mountains. As a result of the glaciation and presence of a stable ice front on northeastern Graham Island, an outwash plain was deposited forming the Argonaut Plain. ^{14}C dated mosses found between the basal layer of a peat bed and postglacial marine sediments date the deglaciation of the lowland before 13,700 yBP.

Climate

The Queen Charlotte Islands experience very mild winters and cool summers (Table 1). The Pacific Ocean moderates their year round temperatures while the mainland coast mountains prevent cold winter and hot summer continental air masses from entering the archipelago. Westerly winds generated by the Aleutian low dominate the air flow for much of the year, bringing repeated storms to the north and central coast. Sunny days are not uncommon in July and August, when high pressure systems displace the storm tracks to the north. The west coast of the Queen Charlotte Islands receives the bulk of precipitation due to the

TABLE 1: Precipitation (mm) and temperature (°C) data from stations near study sites (Environment Canada 1982).

STATION	MEAN ANNUAL PPT. (mm)	DRIEST MONTH	TOTAL PPT. DRIEST MONTH	WETTEST MONTH	TOTAL PPT. WETTEST MONTH	MEAN ANNUAL TEMP. °C	MEAN TEMP. COLDEST MONTH	MEAN TEMP. WARMEST MONTH	FROST FREE DAYS
APPLICABLE DATA FOR ARGONAUT HILL AND DRIZZLE PIT BOGS									
MASSET	1433.9	JULY	55.0	OCTOBER	207.9	7.6	1.4	14.4	158
MASSET CFS	1371.3	JUNE	55.0	OCTOBER	213.0	7.1	.3	13.5	
TLELL	1152.2	JULY	50.8	OCTOBER	172.4	7.4	1.2	14.2	
SEWELL-MASSET INLET	1343.0	AUGUST	52.2	OCTOBER	219.1	7.7	1.2	14.8	
APPLICABLE DATA FOR KUNGHIT ISLAND BOG									
CAPE ST. JAMES	1531.6	JULY	58.4	OCTOBER	197.6	8.4	3.9	13.8	266

orographic effect of the Queen Charlotte Ranges. The eastern lowlands sit in a rainshadow, however, the amount of precipitation is still high lending itself to bog formation (Table 1).

Vegetation

Four Biogeoclimatic Zones have been assigned to the Queen Charlotte Islands (Banner et al. 1983b). The 'Coastal Western Hemlock Zone, Western Hemlock-Sitka Spruce Subzone' (CWHg)[1] covers the lower eastern elevations of the Skidegate Plateau and the whole of the Queen Charlotte Lowlands. The 'Coastal Cedars-Pine-Hemlock Zone' (CCPH) is the second major zone and occupies the west coasts of Graham and Moresby Islands and all of Kunghit Island. It can be found on the exposed coast from sea level to montane elevations. Two biogeoclimatic zones of minor extent complete the list; the subalpine 'Mountain Hemlock Zone' (MH) and the 'Alpine Tundra Zone' (AT). The vegetation of the Mountain Hemlock zone is restricted to the higher levels of the Skidegate Plateau above 500-600m asl and is most developed in the Queen Charlotte Ranges. The Alpine Tundra Zone occurs as scattered patches above 650-800m asl in the Queen Charlotte Ranges.

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[1]Also known as The 'Queen Charlotte Subzone'.

Study Sites

Argonaut Hill Bog:

54° 02'15"N, 131° 42'45"W, 105m asl.

Argonaut Hill bog is located on the north-east limb of Graham Island on the Argonaut Plain (Fig. 2). The plain is gently rolling with a few flat topped hills never exceeding 160m asl. The surficial deposits are fluviolglacial in nature and were deposited by the early withdrawal of the mainland Fraser (Wisconsin) glaciation ice (Sutherland-Brown 1968, Clague 1981). They are composed of crossbedded, well-sorted fine to medium quartzo-feldspathic sand and overlie marine shale and sandstone of Tertiary origin. An extensive mosaic of bogs and bog-forest is developed between well drained hills and ridges. Argonaut Hill bog is an extensive ombrotrophic slope bog covering the top of Argonaut Hill and surrounded by a cedar-hemlock forest (Fig. 3). The bog is pockmarked by many open pools characteristic of poor drainage.

Argonaut Hill bog is situated within the Coastal Western Hemlock Zone, Queen Charlotte Island subzone. The climate of this subzone is cool temperate, oceanic humid-perhumid with a mean annual precipitation near the core site of approximately 1400mm (Table 1, Masset). Frost free days number 158 with a mean annual temperature of 7.4°C. Winters are cool, mild and very wet with an ephemeral snowpack along the coast. The summers are also

FIGURE 2: Location of bog study sites with basal ^{14}C dates and climatic stations:

<u>BOG SITES WITH BASAL DATES</u>

1. Serendipity Bog Lake (75m asl),
2. Argonaut Hill Bog (105m asl),
3. Drizzle Pit Bog (45m asl),
4. Cape Ball Peat (5m asl),
5. Geike Bog (30m asl),
6. Kunghit Island, K3 (465m asl),
   K2 (460m asl),

<u>CLIMATIC STATIONS</u>

A. Masset (3m asl),
   Masset CFS (12m asl),
B. Sewell-Masset Intlet (3m asl),
C. Tlell (5m asl),
D. Cape St. James (89m asl).

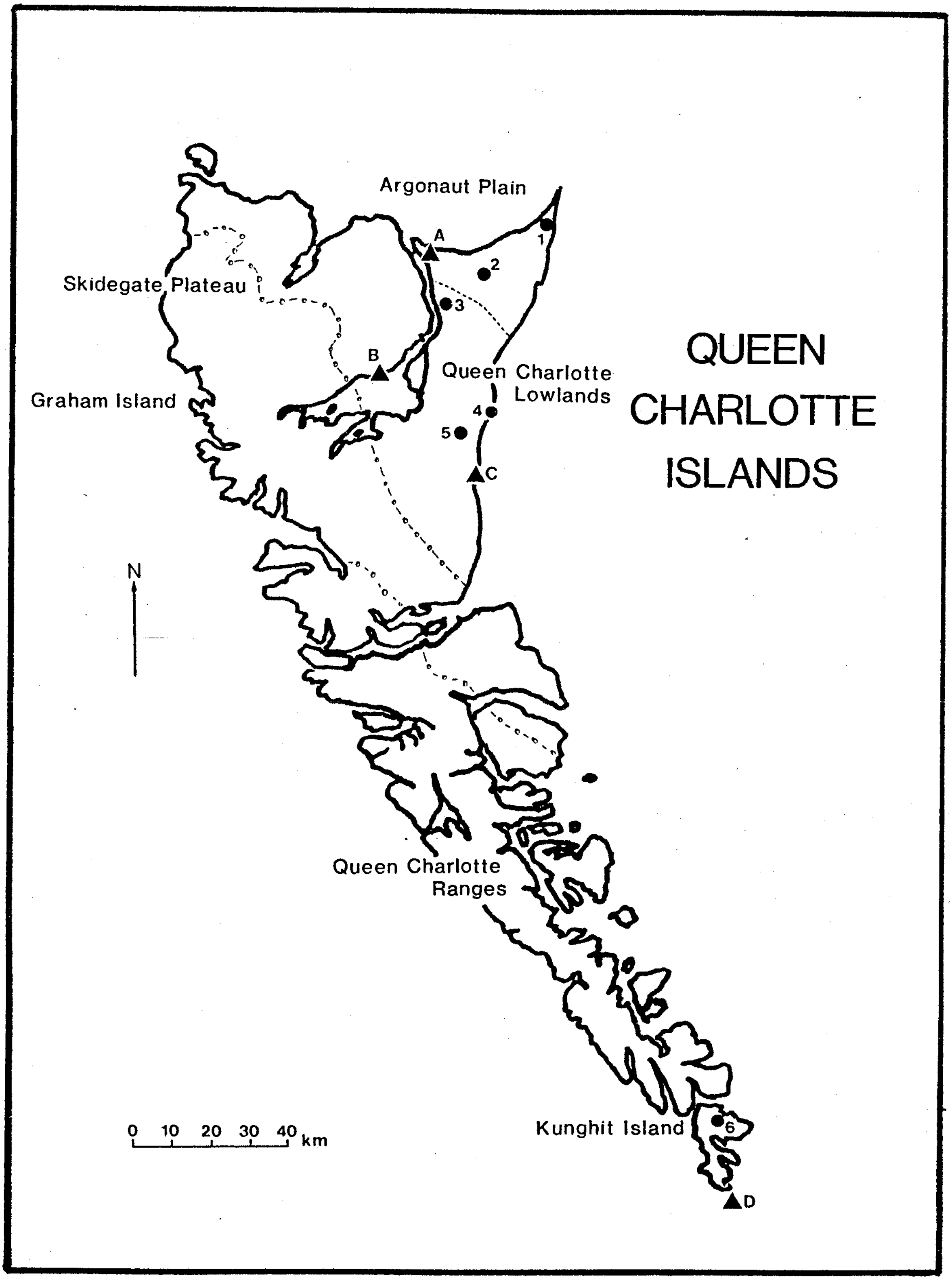
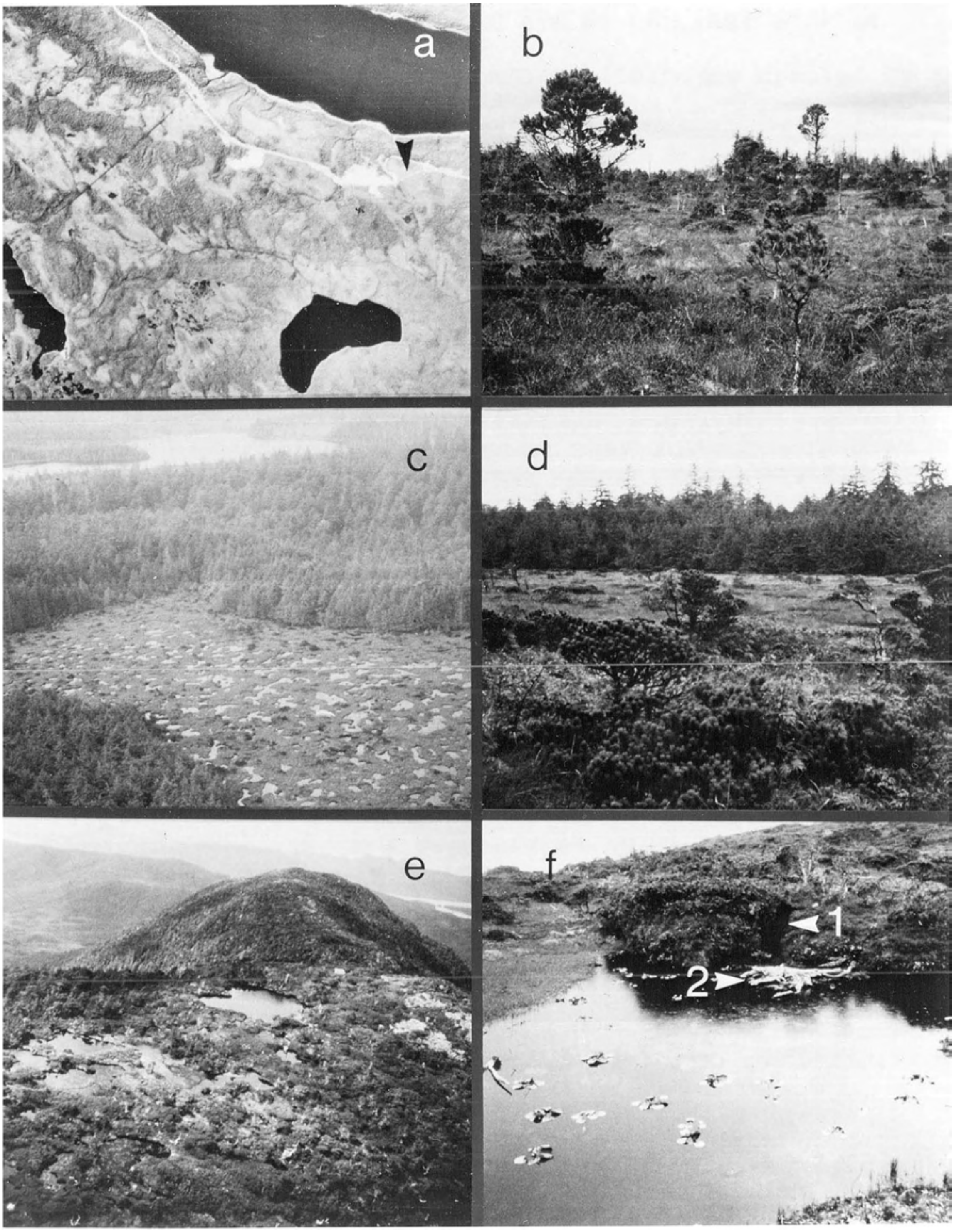

QUEEN
CHARLOTTE
ISLANDS
Argonaut Plain
Skidegate Plateau
Graham Island
Queen Charlotte
Lowlands
Queen Charlotte
Ranges
Kunghit Island
N
0 10 20 30 40 km
A
B
C
D
1
2
3
4
5
6

Figure 3: Photos of study sites:

a. Drizzle Pit Bog air photo,
   -arrow points to site.
b. Drizzle Pit Bog,
c. Argonaut Hill Bog slant aerial view,
d. Argonaut Hill Bog,
e. Kunghit Island Bog slant aerial view,
f. Kungit Island Bog,
   1. excavated peat section.
   2. exposed tree stump dated at 4650±70yBP.


a
b
c
d
e
f
1
2

cool, moderately wet and in contrast to Kunghit Island, contain warm dry spells. There is a definite absence of diurnal extremes in temperature and the seasonal temperature extremes are narrow. Drizzle Pit and Argonaut Hill bogs are on the east side of Graham Island and lie in an orographic rainshadow created by the Queen Charlotte Ranges.

Forests of the CWHg zone surrounding Argonaut Hill are composed of *Tsuga heterophylla*, *Thuja plicata*, *Picea sitchensis*, *Chamaecyparis nootkatensis* and *Pinus contorta* (Banner et al. 1983b). The climatic climax forests are composed of differing mixtures of *Tsuga heterophylla*, *Thuja plicata* and *Picea sitchensis*. The first two coniferous species dominate the forest surrounding the core site. This lowland forest is usually associated with transitions to wetland types. Shrubs and herbs in the Argonaut Hill Bog area include *Juniperus communis*, *Dodecatheon jeffreyi*, *Gentiana douglasiana*, *Sanguisorba officinalis*, *Coptis aspleniifolia*, *Rubus chamaemorus*, *Microseris borealis*, *Tolfieldia glutinosa*, *Eriophorum angustifolium* and *Carex* spp. The Ericales are represented by *Empetrum nigrum*, *Gaultheria shallon*, *Kalmia microphylla*, *Vaccinium uliginosum*, *V. vitis-idaea* and *V. oxycoccus*. Aquatics and emergents found in shallow bog pools include *Menyanthes trifoliata*, *Fauria crista-galli*, *Nuphar lutea*, *Lysichiton americanum* and *Juncus* spp. Ferns and fern allies found nearby include *Blechnum spicant*, *Polystichum munitum*, *Polypodium vulgare* and *Lycopodium annotinum*. Bryophytes at the core site are dominated by

Sphagnum. *Hylocomium splendens* is found under the forest canopy surrounding the bog.

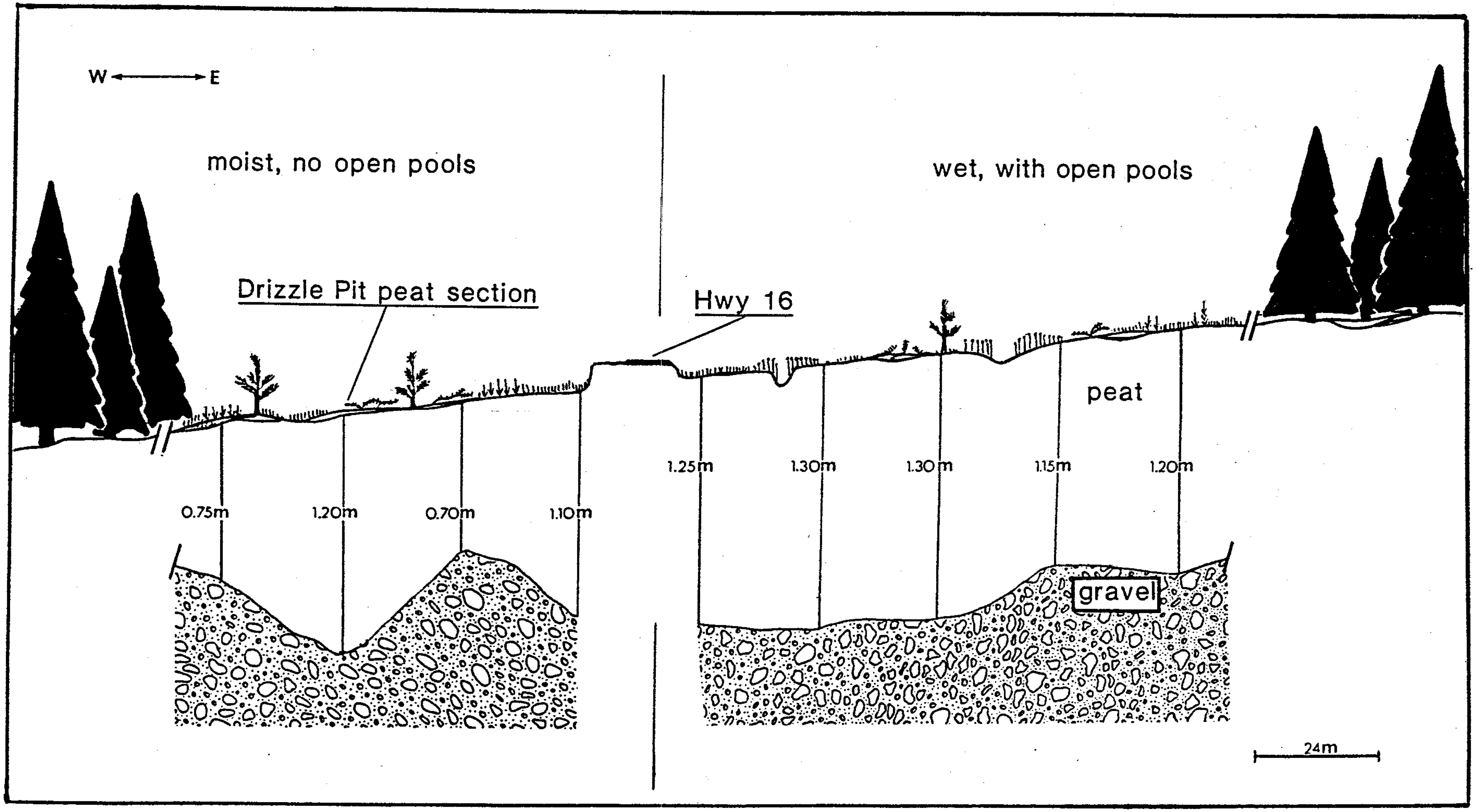
Drizzle Pit Bog

53° 55'30"N, 132° 05'30"W, 45m asl.

Drizzle Pit bog also lies on the fluviolglacial deposits of the Queen Charlotte Lowlands (Fig. 2). The sample site is situated on the west side of Highway 16. The bog slopes downwards from east to west and has been bisected by highway 16. The roadway has dammed the flow of water down the slope causing the formation of a number of open pools on the eastern side of the road (figs. 3 & 4). The climate, surficial geology and vegetation are similar to the Argonaut Hill area.

The vegetation consists of a surface moss layer dominated by *Sphagnum* species mixed with herbs and shrubs. Stunted *Pinus contorta* sporadically inhabit the centre of the bog, but increase in vigour and abundance as one approaches the surrounding forest. Around the perimeter of the bog the forest is represented by *Thuja plicata*, *Tsuga heterophylla*, *Picea sitchensis* and tall *Pinus contorta*. Herbs and shrubs at the Drizzle Pit bog site include *Juniperus communis*, *Microseris borealis*, *Rubus chamaemorus*, *Cornus unalaschkensis*, *Eriophorum angustifolium*, *Gentiana douglasiana*, *Drosera rotundifolia*, *Vaccinium uliginosum*, *Empetrum nigrum*, *Kalmia microphylla*, *Trientalis europaea* and *Carex* species.

FIGURE 4: Drizzle Pit bog profile.


W E
moist, no open pools
wet, with open pools
Drizzle Pit peat section
Hwy 16
peat
0.75m
1.20m
0.70m
1.10m
1.25m
1.30m
1.30m
1.15m
1.20m
gravel
24m

Kunghit Island bog

K3; 52° 06'18"N, 131° 02'30"W, 465m asl.

K2; 52° 06'18"N, 131° 02'30"W, 460m asl.

Kunghit (formerly Prevost) is the southernmost large island in the chain and lies in the Queen Charlotte Ranges physiographic region (Sutherland-Brown 1968)(Fig. 2). The bedrock is composed of Triassic volcanics, including amphibolites, greenstone, massive lavas and pillow lavas. The maximum elevation is 488m. The terrain is hilly with a gradation from moderate to steep slopes. The bedrock is covered with an organic veneer representing a range of bog types. The study sites on Kunghit Island are eroded peat beds of variable thickness, located on the top of a bedrock ridge. The area is composed of extensive sloping peatlands with many small pools. Kunghit Island K3 and K2 cores come from the edge of two different drained peat pools (Fig. 3). Site K3 was the deepest peat section and was therefore used for pollen analysis.

Kunghit Island receives the highest precipitation of the three sites, upwards of 1531.6mm/year. Kunghit Island bog also differs from the other two sites in the high number of frost free days, 266 days versus 158 days. Mean annual temperature is 8.4°C and the mean temperature of the coldest month is 3.9°C, both warmer than the other two sites. The climate is termed 'hyperoceanic' due to the extreme wetness (Banner et al. 1983b). Cool, moist summers rarely contain dry spells while the autumn is cool and very wet. Precipitation in the form of snow is infrequent with a short-lived snowpack.

The difference in climate from the other two sites alters the vegetation, placing it the CCPH biogeoclimatic zone. The forest on the slopes surrounding Kunghit Island bog is composed of scrubby mixtures of *Thuja plicata*, *Chamaecyparis nootkatensis*, *Tsuga mertensiana* on drier sites, *Picea sitchensis* and *Pinus contorta*. The bogs and bog woodlands of Kunghit Island can occur on slopes up to 60%. Non arboreal species of the bogs and bog woodlands around the site include: *Empetrum nigrum*, *Gaultheria shallon*, *Vaccinium caespitosum*, *V. oxycoccus*, *V. vitis-idaea*, *Ledum groenlandicum*, *Kalmia microphylla* and *Luetkea pectinata*. Herbs include *Gentiana douglasiana*, *Cornus unalaschkensis*, *Trientalis europaea*, *Geum calthifolium*, *Coptis aspleniifolia*, *Tolfieldia glutinosa*, *Microseris borealis*, *Drosera rotundifolia*, *Sanguisorba officinalis*, *Veratrum viride* and *Eriophorum*. The pools are inhabited by *Nuphar lutea*, *Sparganium minimum*, *Fauria crista-galli*, *Lysichiton americanum*, *Pinguicula vulgaris*, *Eleocharis* and *Juncus*. *Blechnum spicant*, *Lycopodium annotinum* and *Polypodium vulgare* are common cryptogams. *Hylocomium splendens*, *Rhytdiadelphus loreus*, *Rhacomitrium canescens* and *Sphagnum* are common mosses.

CHAPTER III

METHODS

Field Sampling

Three peat bog sites on the Queen Charlotte Islands were selected. Argonaut Hill bog was cored using a modified 5cm diameter Livingston sampler (Wright 1967). The peat core was collected after two long and four short drives. The long drives were 60cm in length and represent 100cm of uncompacted peat. The four short drives composed of uncompacted humified peat were 8cm long. The core samples were extruded on site, wrapped in plastic film, aluminum foil and labelled.

Drizzle Pit bog was an excavated pit. The basal organics were found at 120cm. One face of the pit was cleaned laterally, exposing an uncontaminated surface from which peat samples were removed every 5cm for pollen and macrofossil analysis. An extra sample was taken at a stratigraphic change (51-53cm) for ^{14}C dating. Each sample was individually bagged in a 'whirlpack' and labelled. A tree stump was encountered in life position at 90cm. Wood samples were removed for ^{14}C dating and species identification. The bog was probed every 24m for 216m to describe changes in peat depth along the slope (fig. 4).

Kunghit Island site K3 was an exposed peat bed 210cm in depth. After cleaning the exposed face laterally to remove any contamination, peat samples were collected every 10cm. All samples were individually bagged in 'whirlpacks' and labelled. Two extra samples were collected, one at 80-85cm for ^{14}C dating and 205cm for increased basal resolution. A fossil tree stump exposed in the base of a pond beside the K3 profile was sampled for ^{14}C dating and species identification. This stump was rooted in the mineral deposits which underlie the peat, and should date the formation of the peat bog.

All peat core segments and peat samples were transported to the lab and stored at 4°C in a cold room until processed.

Laboratory methods

Pollen processing

After the peat core and peat sections were described, two 1cm^3 subsamples were removed for pollen analysis and dry weight determinations. Each subsample used for pollen analysis was innoculated with *Eucalyptus globulus* pollen tablets (Stockmar, 1971; stock #903722). The tablets along with any calcareous minerals in the subsample were dissolved in 10% HCl, centrifuged and the supernatant discarded. The subsamples were processed by methods outlined in Moore and Webb (1983). When sand was present, the subsample received hot HF treatment for one hour. All subsamples were treated with hot 6% KOH for ten minutes in a hot water bath followed by acetolysis for three minutes. Deviation from this procedure occurred in the Kunghit Island Bog 0-40cm subsamples due to the high amounts of debris and low pollen recovery. These subsamples were treated with 6% KOH for one hour in a hot water bath followed by acetolysis for ten minutes. Pollen recovery improved without any appreciable damage to the pollen following this treatment. The residues were dehydrated using 95% ethanol and tertiary butyl alcohol. The pollen pellet was suspended in silicone oil (2000cks) in glass vials. A drop of pollen-bearing residue was placed on a microscope slide and mixed thoroughly to avoid uneven pollen distribution (Brooks and Thomas 1967). A coverslip was applied and sealed with nail polish, and all slides were duplicated. Pollen counting was accomplished with a light microscope using the 400X objective for routine work and the 1000X oil immersion objective for critical pollen determinations. Regularly spaced transects were examined until a minimum of 500 grains were counted for most samples. In some cases pollen scarcity necessitated a reduced total pollen count which was never less than 200 grains. When local pollen types were overrepresented, the pollen sum for that spectrum was increased to approximately 1000 grains. Following International Geological Correlation Programme (IGCP) standards (Berglund and Ralska-Jasiewiczowa 1986), the pollen sum (ΣTOT) used for percentage calculations equals the sum of arboreal pollen (ΣAP) plus the sum of non arboreal pollen (ΣNAP), excluding aquatic pollen and cryptogam spores.

Pollen percentages for upland types were calculated as follows:

1) $$\% = \frac{\text{POLLEN COUNT}}{\Sigma AP + \Sigma NAP} \times 100\%$$

and for spores:

3) $$\%\text{SPORES} = \frac{\Sigma \text{SPORE TYPE}}{\Sigma AP + \Sigma NAP + \Sigma \text{SPORES}} \times 100\%$$

Identifications were made with published keys (Belling and Heusser 1974, Fægri and Iverson 1975, Kapp 1969, McAndrews et al. 1973, 1976, Moore and Bellamy 1983) and with modern pollen reference material at Simon Fraser University. The confidence of identifications is indicated by the IGCP conventions of Birks (1986). Percent and concentration pollen diagrams were constructed for all three bogs and follow IGCP standards. The diagrams were generated using the MICHIGRANA computer program developed by Futyama and Meachum (July, 1986 version). Zonation of the diagrams was based on visual inspection.

Macrofossil processing

Subsamples for dry weight, macrofossil and pollen analysis were taken from the bulk samples collected at Argonaut Hill and Drizzle Pit bogs. The macrofossil samples were placed in a 1000ml graduated cylinder containing a known volume and weight of water. The volume and weight changes were noted allowing the density of the peat to be calculated. Peat samples were broken up in water and screened under a spray faucet. In some cases a hot KOH treatment was required to facilitate breakup (Wasylikowa 1979, 1986). The screening process involved three brass sieves of 1.0mm, 0.5mm and 0.25mm diameter stacked in descending order. Macrofossils were removed from the screens and placed in petri dishes. These were scanned systematically under a binocular dissecting microscope. Macrofossils were picked with tweezers and placed in labelled plastic boxes. Glycerol was added to hold the macrofossils in place and to prevent desiccation. Macrofossil identification was accomplished by comparison to modern reference material and various keys.

Peat description

Peat density was calculated knowing the volume and the weight of each sample and using the following formula (Bengtsson and Enell 1986):

$$\text{BULK DENSITY (D)} = \frac{\text{MASS}}{\text{VOLUME}} \text{ g/ml}$$

Aliquots of 1cm^3 were used to derive dry weight for peat at each pollen spectrum. The aliquots were weighed wet, oven dried for 24 hours at 90°C and reweighed dry. The following formula was used to calculate dry weight (Bengtsson and Enell 1986):

$$\text{DRY WEIGHT (DW)} = \frac{\text{DRY WEIGHT}}{\text{FRESH WEIGHT (FW)}} \text{ gDW/gFW}$$

Visual peat description involved the modified Troels-Smith system (Aaby 1979).

CHAPTER IV

RESULTS

^{14}C Dates from the Queen Charlotte Islands

Climatic deterioration and paludification events from across northern North America were outlined in the introduction. The fixing of these time transgressive, episodic events rely on ^{14}C dating. To establish the time scale during which these events occurred on the Queen Charlotte Islands, thirteen ^{14}C dates are presented in this study (Table 2). Twelve are new dates and one is from the recent study of Warner (1984). Samples selected in the field for ^{14}C dating include;

1. basal samples to date the appearance of first organics,
2. samples collected at visible peat type transitions and
3. samples taken from tree stumps found in life position.

Further ^{14}C samples were chosen in the lab to date zonal changes in pollen and spore percentage diagrams. Peat accumulation is too episodic and uneven to be described by curves based on multiple linear regression methods. Curves produced in this way would imply a smooth, unrealistic accumulation of peat deposits. For the same reason pollen influx diagrams were not created (Beckett 1979). The very presence of peat transitions indicates sharp changes in peat growth. Straight lines extrapolated between ^{14}C dates were deemed to be a more realistic

TABLE 2: ^{14}C dates and descriptions from sites on the Queen Charlotte Islands. Serendipity Bog Lake date from Warner (1984).

SITE	DEPTH cm.	AGE (uncorrected)	AGE (corrected)	LAB #	DESCRIPTION
ARGONAUT HILL	232-225	7970±100	7890±100	GSC-3785	Peat, dates appearance of first organics.
	195-190	5230±80		BETA-14270	Peat transition.
	70-75	2780±80		BETA-14271	Peat transition.
DRIZZLE PIT	115-105[1]	4320±100	4260±100	GSC-3817	Peat, dates appearance of first organics.
	90	2670±70		BETA-14269	Wood, tree stump found in life position.
	55-51	880±70		BETA-14268	Peat transition.
KUNGHIT ISLAND BOG 3	210-205	5150±70	5090±70	GSC-3990	Peat, dates appearance of first organics.
	210	4650±70		GSC-4007	Wood, tree stump found in life position.
	80-85	1890±70	1860±70	GSC-3972	Peat transition.
KUNGHIT ISLAND BOG 2	120-115	4390±60	4360±60	GSC-3979	Peat, dates appearance of first organics.
CAPE BALL	75-70	2810±80		BETA-14272	Peat, dates appearance of first organics.
GEIKE BOG	260-255	4120±80	4070±80	GSC-3787	Peat, dates apearance of first organics.
SERENDIPITY BOG LAKE	70-65	2440±100	2390±100	GSC-3707	Peat transition.

[1] Sample collected situated on basal gravel adjacent to site at a depth of 100-110cm (see ^{14}C Dates).

representation of peat accumulation patterns.

^{14}C dates must be used with care when associated with peat deposits, especially when taken near the surface. Roots of plants living at the surface of the bog may have penetrated the previously deposited peat. If these roots are included in the ^{14}C samples then the date produced will be too young.

Peat & Pollen Stratigraphy

Stratigraphy of each core or section are summarized to the left of pollen profiles as well as sediment, bulk density, dry weight curves. All three bogs have developed on a sand and gravel deposit composed of angular stones exhibiting little erosion.

Argonaut Hill bog

ZONE: AH I (232-183CM)
PINUS-ALNUS-LYSICHITUM-POLYPODIACEAE-FILICALES assemblage zone

Argonaut Hill bog contains a basal layer of sandy-peat dated at 7890±100 yBP (232-225cm). It contains high percentages of *Pinus contorta*, *Alnus* (probably *A. rubra*), *Lysichiton americanum* pollen as well as *Polypodium vulgare* and undifferentiated Filicales spores (Fig. 5). Throughout the Queen Charlotte Islands this assemblage is commonly found in the sediment which marks the base of many bogs. Another common characteristic of

FIGURE 5: Argonaut Hill percent pollen diagram.

ARGONAUT HILL, Graham Island

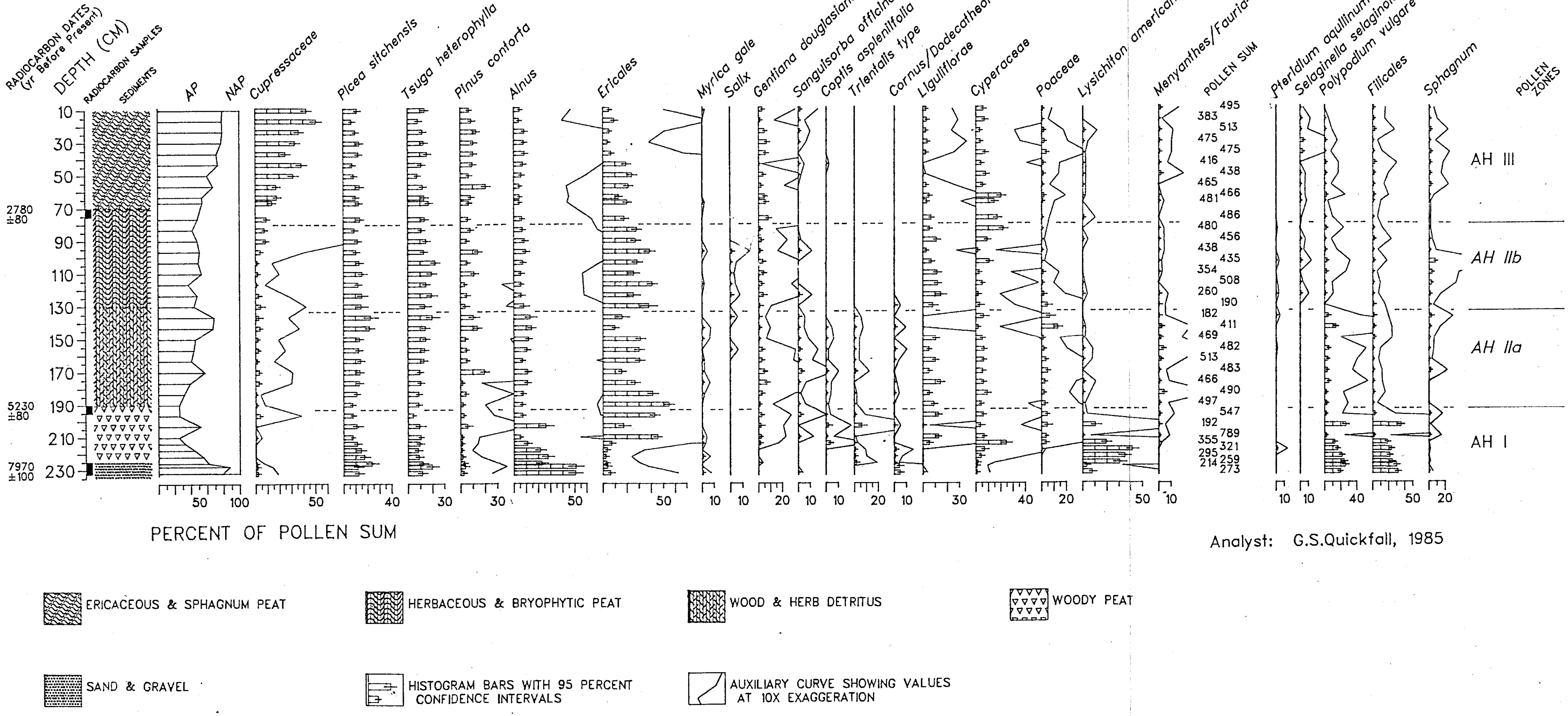


FIGURE 6: Argonaut Hill pollen concentration diagram.

ARGONAUT HILL, Graham Island

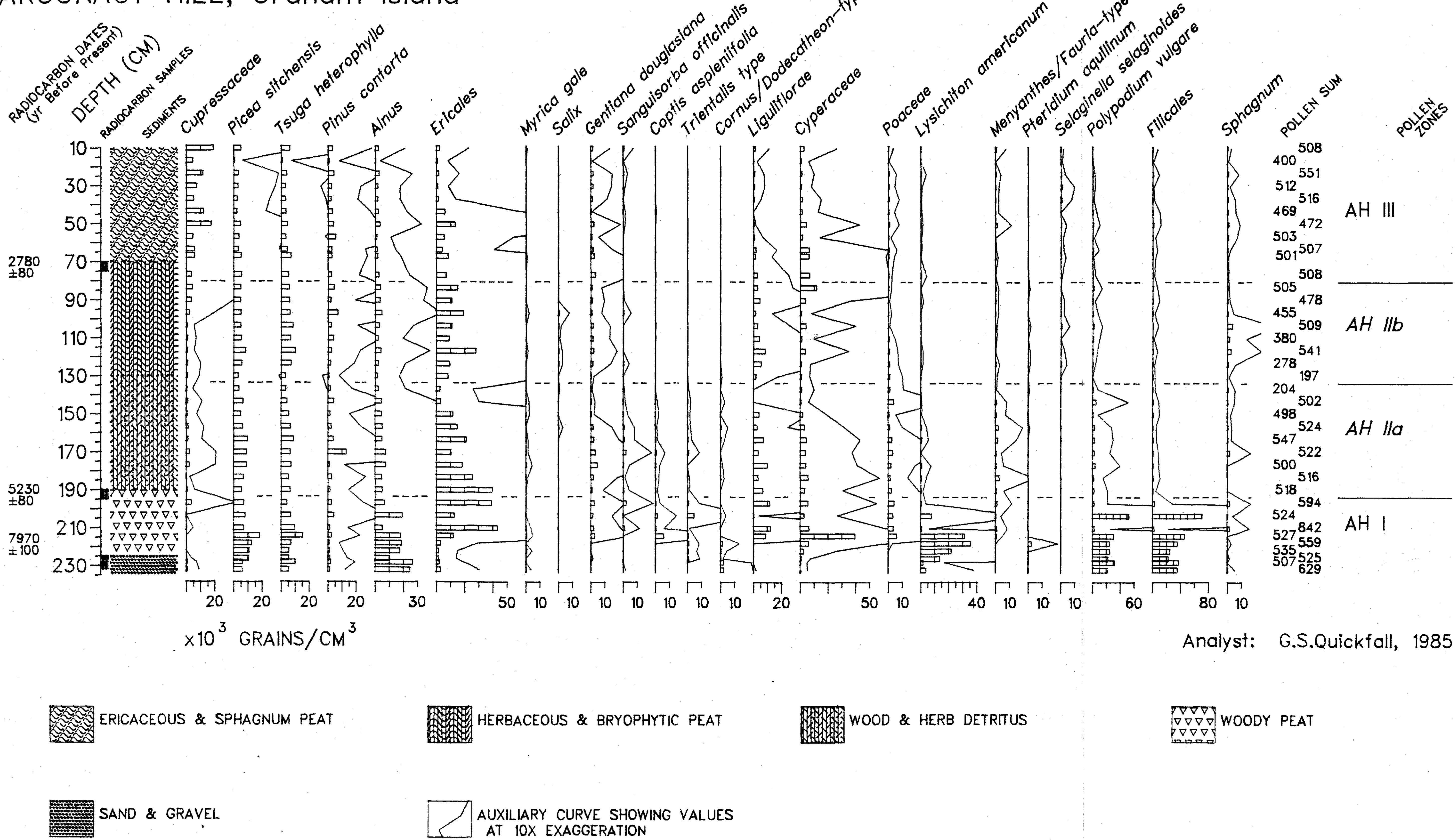
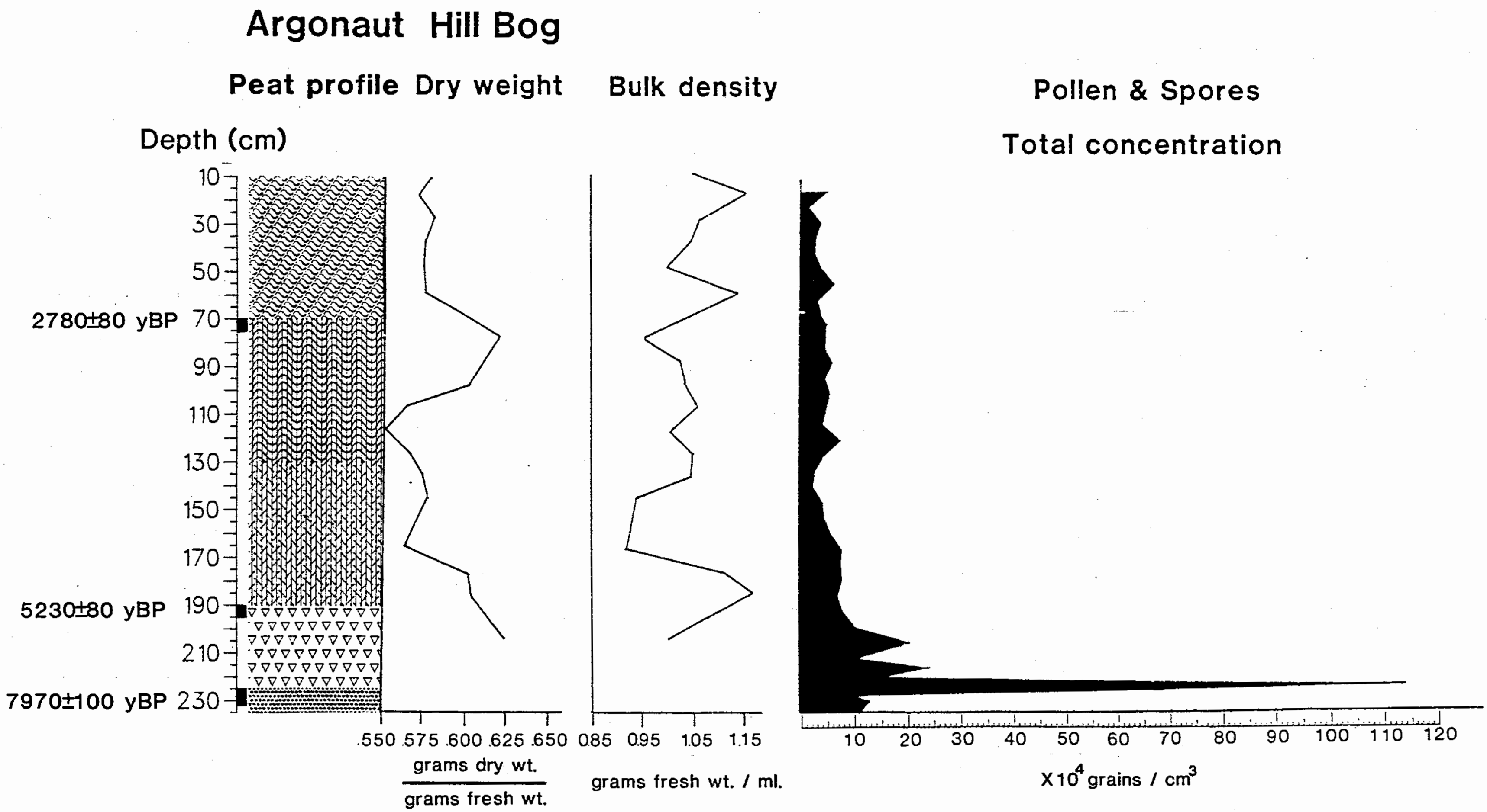


FIGURE 7: Peat profile, dry weight, bulk density and total pollen concentration for Argonaut Hill bog. For key to peat symbols see Fig. 6.



Argonaut Hill Bog
Peat profile
Dry weight
Bulk density
Pollen & Spores
Total concentration
Depth (cm)
10
30
50
70
90
110
130
150
170
190
210
230
2780±80 yBP
5230±80 yBP
7970±100 yBP
.550 .575 .600 .625 .650
grams dry wt.
grams fresh wt.
0.85 0.95 1.05 1.15
grams fresh wt. / ml.
10 20 30 40 50 60 70 80 90 100 110 120
X10^4 grains / cm^3

this basal sandy-peat is a high pollen and spore concentration (Fig. 6 & 7). Pollen concentrations range between 238,000grains cm^{-3} (204cm) and 91,000grains cm^{-3} (216cm). There is a lack of bog plant pollen in the basal spectra, 232-225cm. From 225-183cm *Alnus*, *Pinus contorta* and *Lysichiton americanum* decrease in percentage while the Ericales rise from <5% to 50% and herbaceous bog flora appear for the first time. The appearance of the bog flora coincides with a change in peat type. The peat becomes highly humified, dark brown with woody fragments and lacks herbaceous plant remains greater than 5mm. It does contain woody fragments up to 2cm in size. Identifiable macrofossils were not found. This layer lasts until 190cm, where a sudden change in peat composition from the dark woody-herbaceous to a lighter woody-herbaceous-moss layer occurs. Humification changes producing layers of peat, which exhibit differing rates of decomposition, can be used to infer apparent combined temperature and moisture trends. The distinguishable layers, known as 'recurrence surfaces', are thought to indicate changes in moisture regimes at the peat surface. A reduction in bog growth and increased weathering produces dark, well humified layers while light coloured, less humified layers represent peat production events. Increased moisture and/or cooler temperatures may produce the less humified lighter bands (Ogden 1960, Aaby and Tauber 1974, Aaby 1976, Barber 1981). The recurrence surface at 190cm is dated at 5230±80 yBP and marks a change in pollen stratigraphy.

SUBZONE: AH IIa (183-133cm)

PICEA-ERICALES-MENYANTHES assemblage zone

The peat in this subzone is brown to dark brown and is composed of a fine amorphous organic matrix. Some small woody fragments are present but are less than 1cm long. *Sphagnum* phyllidia make up the bulk of the herbaceous remains. This contrasts with the absence of *Sphagnum* spores in this zone. This zone is distinguished by a sudden decline of a fern spores and continuing presence of some herbaceous bog taxa. Palynomorph concentrations have decreased and range between 76,000 cm^{-3} (180cm) to 37,000grains cm^{-3} (133cm). Ericales reach their highest percentages at the AH I, AH IIa transition and fluctuate between 18-58% throughout the subzone. Liguliflorae (*Microseris borealis*), *Gentiana douglasiana*, *Menyanthes/Fauria*-type and towards the latter part of the subzone, Poaceae, all indicate changing soil conditions. Cupressaceae is still at background levels of 3% indicating a presence of *Juniperus communis* and not, at this time, *Thuja plicata*.

SUBZONE: AH IIb (133-76cm)

TSUGA-ERICALES-LIGULIFLORA assemblage zone

This zone differs from AH IIa by the loss of many of the herbaceous bog plants such as *Sanguisorba officinalis*, *Coptis aspleniifolia*, *Trientalis*-type and *Cornus/Dodecatheon*-type. *Polypodium vulgare* present throughout AH IIa exhibits a decrease in percentage as does *Menyanthes/Fauria*-type and Poaceae.

Selaginella selaginoides micro and megaspores first appear at the beginning of this zone while Cupressaceae and Cyperaceae pollen begin to rise at the end of this zone. *Selaginella* megaspores are the only identifiable macrofossils found throughout the core, however, some wood, roots and moss fragments were present. *Sphagnum* reaches its highest values of approximately 10% midway through AH IIb. Pollen concentrations vary from a high of 72,000grains cm^{-3} (103cm) to a low of 18,000grains cm^{-3} (126.7cm.). The peat associated with these changes in pollen and spores is a very fine brownish organic matrix. The brown peat contains herbaceous fragments <5mm in size and changes to a lighter fibrous peat in zone AH III.

ZONE: AH III (76-10cm)

CUPRESSACEAE-PINUS-CYPERACEAE-SELAGINELLA assemblage zone

A final change in peat colour and type occurring at 76cm results in an extremely light Ericaceous-*Sphagnum* peat which continues to the surface. The change is dated at 2780±80 yBP and applies to the second peat transition found. The lowest pollen concentration for the core occurs in AH III, 8,000cm^{-3}. The most distinct pollen curve is the increase in Cupressaceae pollen which probably represents *Thuja plicata* (Mathewes & Hebda 1984). Most of the arboreal pollen has remained constant throughout the core and the Cupressaceae pollen is responsible for the arboreal pollen (AP) rise at the top of Fig. 5. *Gentiana douglasiana* and Cyperaceae also reach their peak values in this last zone as does *Selaginella selaginoides*. *Sphagnum*, although not as high as in AH IIb does continue to produce spores. The peat is extremely fibrous containing whole *Sphagnum* remains interspersed with fragments of ericaceous leaves and stems.

Drizzle Pit bog

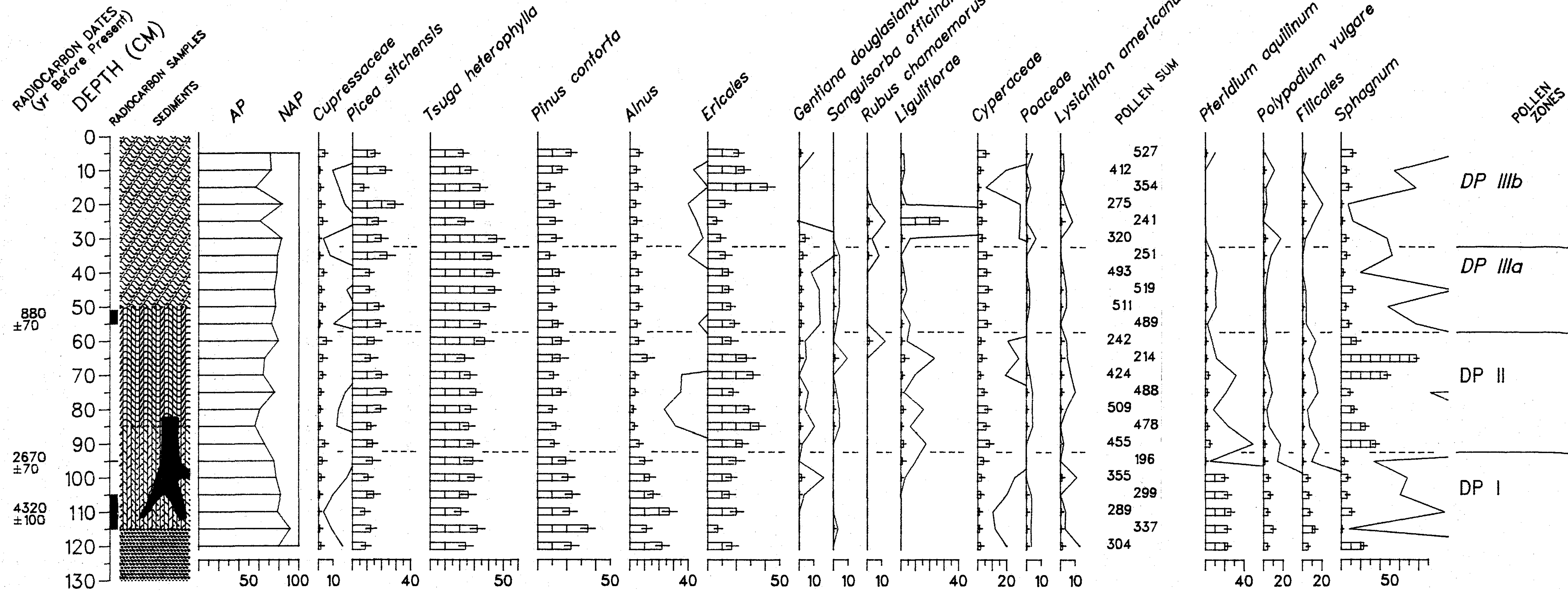
ZONE: DP I (120-93cm)

PINUS-ALNUS-PTERIDIUM assemblage zone

Drizzle Pit bog peat is separated from the underlying gravel matrix by a thin cemented hardpan 3cm thick. Sitting atop the hardpan is a thin layer of sandy-peat. The sandy-peat contains high percentages of *Pinus contorta*, *Alnus*, and *Tsuga heterophylla* pollen, *Polypodium vulgare* and undifferentiated Filicales spores (Fig. 8). As with Argonaut Hill bog this lower most zone contains the highest palynomorph concentrations ranging from 322,000grains cm^{-3} (115cm) to 22,000grains cm^{-3}(Fig. 9 & 10). One interesting spore profile to note is *Pteridium aquilinum* which is found in high percentages in this zone. At 105cm Drizzle Pit changes from the sandy-peat dated at 4260±100 yBP to an herbaceous, woody detritus zone. The detritus included fragments of wood and yielded a *Tsuga heterophylla* cone, *Taxus brevifolia* seed, *Juniperus communis* needle leaves and *Carex obnupta* seeds (Fig. 11a-d & 12). A buried tree stump identified as *Tsuga heterophylla* was found in life position and dated at 2670±70 yBP.

FIGURE 8: Drizzle Pit percent pollen diagram.

DRIZZLE PIT, Graham Island



Analyst: G.S.Quickfall, 1985

ERICACEOUS & SPHAGNUM PEAT

HERBACEOUS & BRYOPHYTIC PEAT

WOOD & HERB DETRITUS

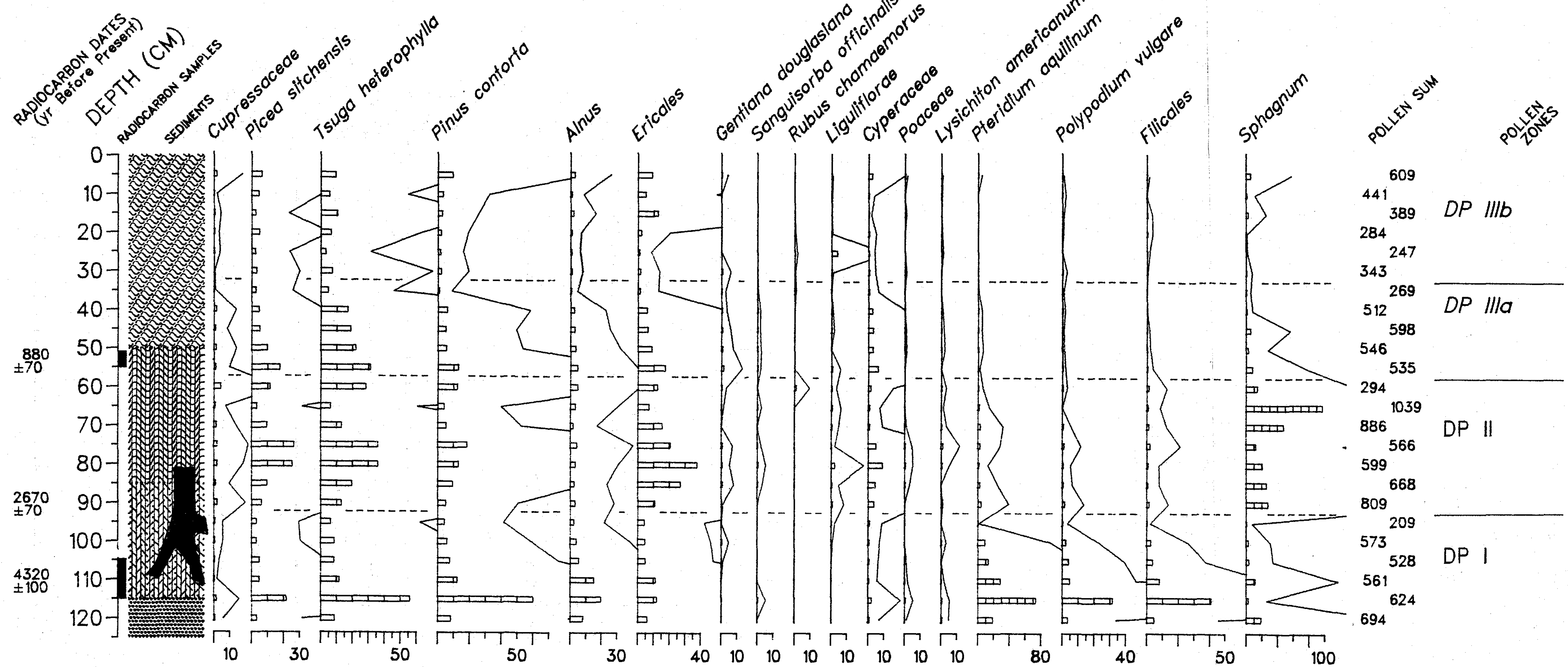
SAND & GRAVEL

TREE STUMP

AUXILIARY CURVE SHOWING VALUES AT 10X EXAGGERATION

FIGURE 9: Drizzle Pit pollen concentration diagram.

DRIZZLE PIT, Graham Island



Analyst: G.S.Quickfall, 1985

ERICACEOUS & SPHAGNUM PEAT

HERBACEOUS & BRYOPHYTIC PEAT

WOOD & HERB DETRITUS

SAND & GRAVEL

TREE STUMP

AUXILIARY CURVE SHOWING VALUES AT 10X EXAGGERATION

FIGURE 10: Peat profile, dry weight, bulk density and total pollen concentration for Drizzle Pit bog. For a key to peat symbols see Fig. 9.

Drizzle Pit Bog

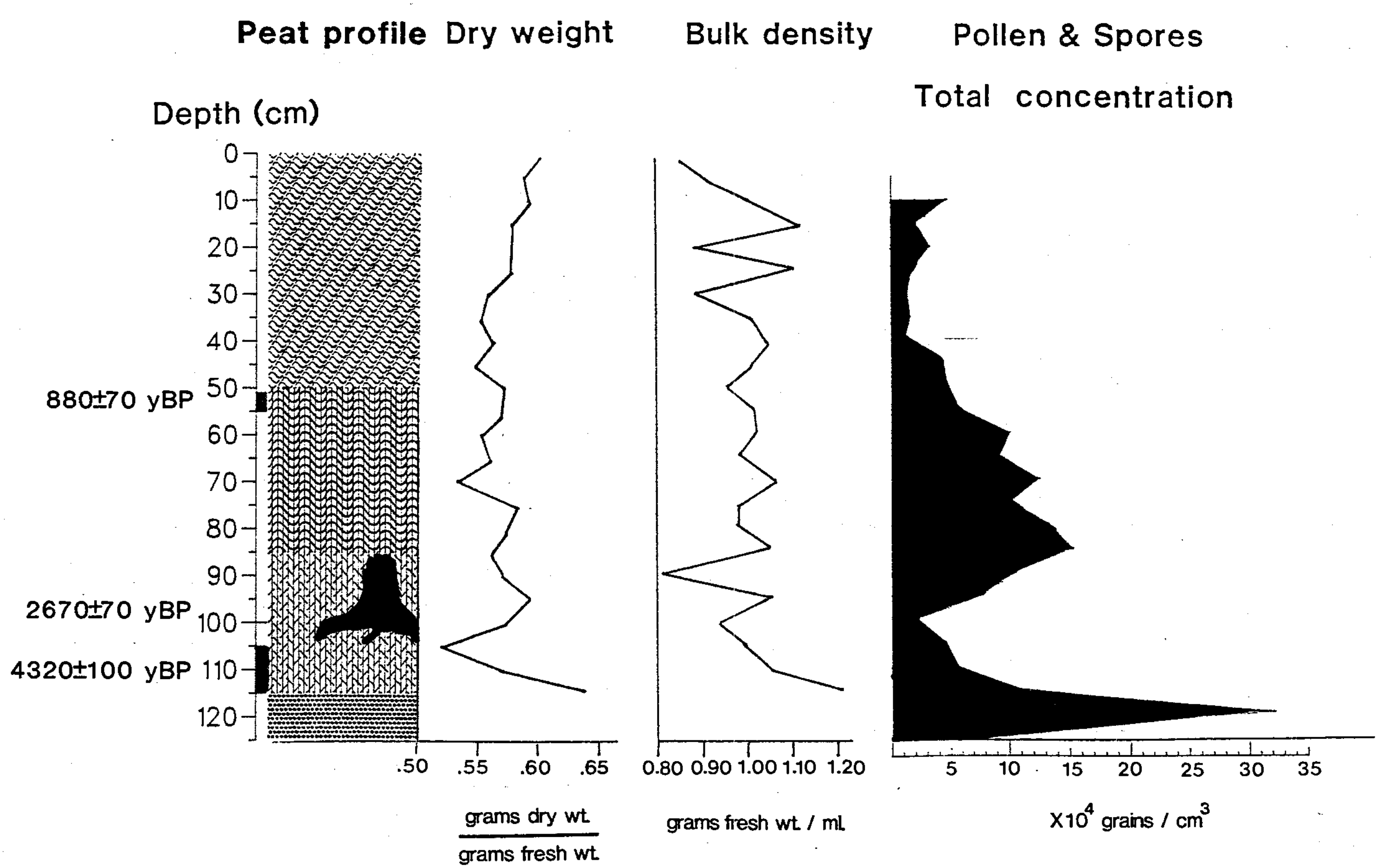


FIGURE 11: Drizzle Pit macrofossils, scale in cm.

a. *Tsuga heterophylla* cone (zone DP I),
b. *Taxus brevifolia* seed (zone DP I),
c. *Juniperus communis* needle leaves (zone DP I, DP II & DP III),
d. *Carex obnupta* seeds (zone DP I) and
e. *Thuja plicata* scale leaves (zone DP II).

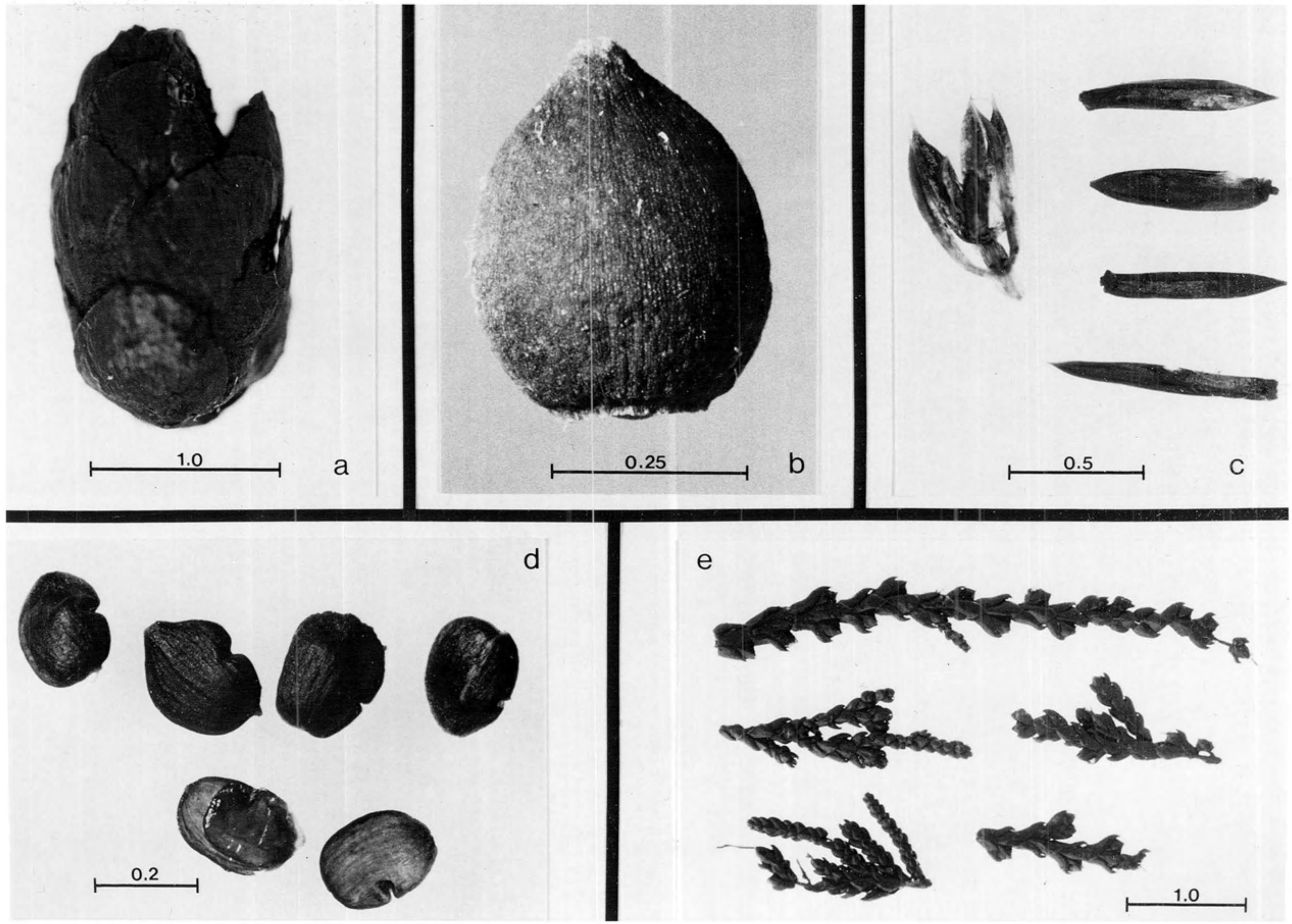
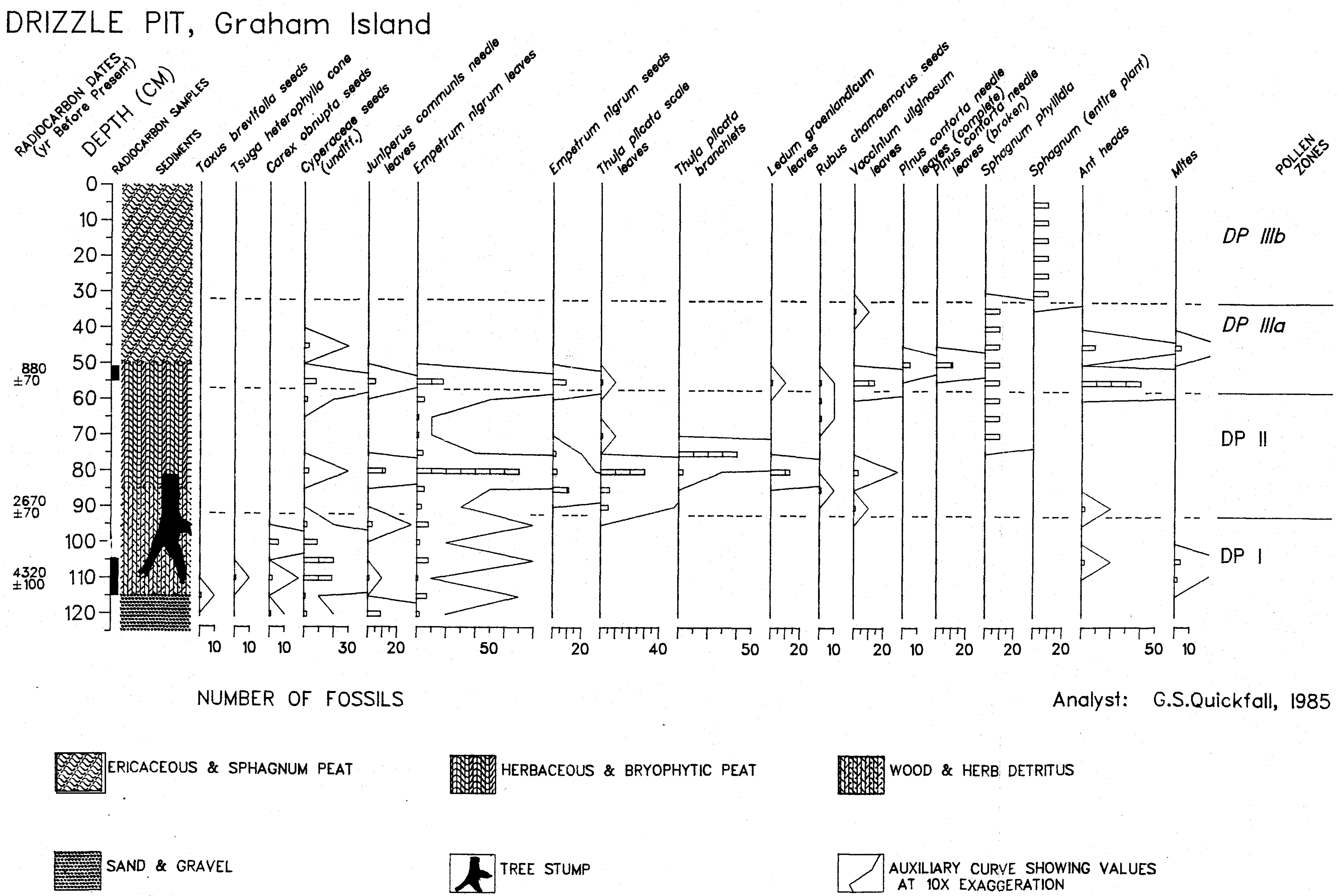

1.0
a
0.25
b
0.5
c
d
0.2
e
1.0

FIGURE 12: Drizzle Pit macrofossil diagram (raw counts).


DRIZZLE PIT, Graham Island
RADIOCARBON DATES (yr Before Present)
DEPTH (CM)
RADIOCARBON SAMPLES
SEDIMENTS
Taxus brevifolia seeds
Tsuga heterophylla cone
Carex obnupta seeds
Cyperaceae seeds (undiff.)
Juniperus communis needle leaves
Empetrum nigrum leaves
Empetrum nigrum seeds
Thuja plicata scale leaves
Thuja plicata branchlets
Ledum groenlandicum leaves
Rubus chamaemorus seeds
Vaccinium uliginosum leaves
Pinus contorta needle leaves (complete)
Pinus contorta needle leaves (broken)
Sphagnum phyllidia
Sphagnum (entire plant)
Ant heads
Mites
POLLEN ZONES
880 ±70
2670 ±70
4320 ±100
0
10
20
30
40
50
60
70
80
90
100
110
120
DP IIIb
DP IIIa
DP II
DP I
NUMBER OF FOSSILS
Analyst: G.S.Quickfall, 1985
ERICACEOUS & SPHAGNUM PEAT
HERBACEOUS & BRYOPHYTIC PEAT
WOOD & HERB DETRITUS
SAND & GRAVEL
TREE STUMP
AUXILIARY CURVE SHOWING VALUES AT 10X EXAGGERATION

ZONE: DP II (93-53cm)

PICEA-CYPERACEAE-SPHAGNUM assemblage zone

The peat in this zone is dark brown and well humified. It is mainly composed of a fine matrix of ericaceous fragments and mosses, predominantly *Sphagnum*. Pollen of *Alnus*, *Pinus contorta*, and spores of *Pteridium aquilinum*, *Polypodium vulgare* and undifferentiated Filicales all decrease dramatically at the DP I - DP II transition. Concentrations also decrease, varying between 126,000grains cm^{-3} (60cm) and 78,000grains cm^{-3} (85cm). Ericales and *Sphagnum* both show large increases in percentage as does Cyperaceae. *Thuja plicata* scale leaves and branches were found in this zone (figs. 11e & 12).

SUBZONE: DP IIIa (53-33cm)

TSUGA-CYPERACEAE assemblage zone

A recurrence surface was encountered at 53cm and dated at 880±70 yBP. From 53cm to the surface a *Sphagnum*-ericaceous peat predominates. Pollen of *Tsuga heterophylla* and Cyperaceae reach their highest percent values in this zone, however, it is the marked decrease in Ericales and *Sphagnum* values which distinguish this as a subzone. Concentrations are slightly lower than DP II reaching a high of 101,000grains cm^{-3} (50cm) and a low of 42,000grains cm^{-3} (35cm). Leaves of *Ledum groenlandicum*, *Vaccinium uliginosum*, *Pinus contorta*, *Empetrum nigrum* and seeds of *Empetrum* and *Rubus chamaemorus* are among the macrofossils found just prior to and above this peat transition (Fig. 12 & 13a-e).

<u>SUBZONE:</u> DP IIIb (33-5cm)

PINUS-ERICALES-SPHAGNUM assemblage zone

The peat type has not varied from DP IIIa, however, the pollen and spore percentages shift dramatically at 33cm. Ericales and *Sphagnum* percentages rise again from lows reached in DP IIIa. *Pinus contorta*, Cyperaceae and *Picea sitchensis* also increase slightly, however, pollen and spore concentrations reach their lowest values in this zone with a high of 48,000grains cm^{-3} (0cm) and a low of 12,000grains cm^{-3} (30cm). Entire *Sphagnum* plants and ericaceous root fragments have replaced all other macrofossils.

Kunghit Island bog (K3)

<u>ZONE:</u> KU I (210-175cm)

ALNUS-POLYPODIUM-FILICALES assemblage zone

At the base, K3 changes from the sandy-peat (5090±70 yBP) to a dark woody peat. This basal zone parallels those in AH I and DP I by containing the highest pollen and spore concentrations found in the core, 264,000grains cm^{-3} (Fig. 14 & 15). A stump of *Picea sitchensis* buried in life position on the basal sandy-peat was dated at 4650±70 yBP. Pollen of *Alnus*, spores of *Polypodium vulgare* and undifferentiated Filicales are all present in high percentages in the basal spectra but all fall to <5% values

FIGURE 13: Drizzle Pit macrofossils, scale in cm.

a. *Ledum groenlandicum* leaves (zone DP II),
b. *Vaccinium uliginosum* leaves (zone DP II & DP IIIa),
c. *Empetrum nigrum* leaves (zone DP I, DP II & DP IIIa),
d. *Empetrum nigrum* seeds (zone DP II & DP IIIa),
e. *Rubus chamaemorus* seeds (zone DP II & DP IIIa).

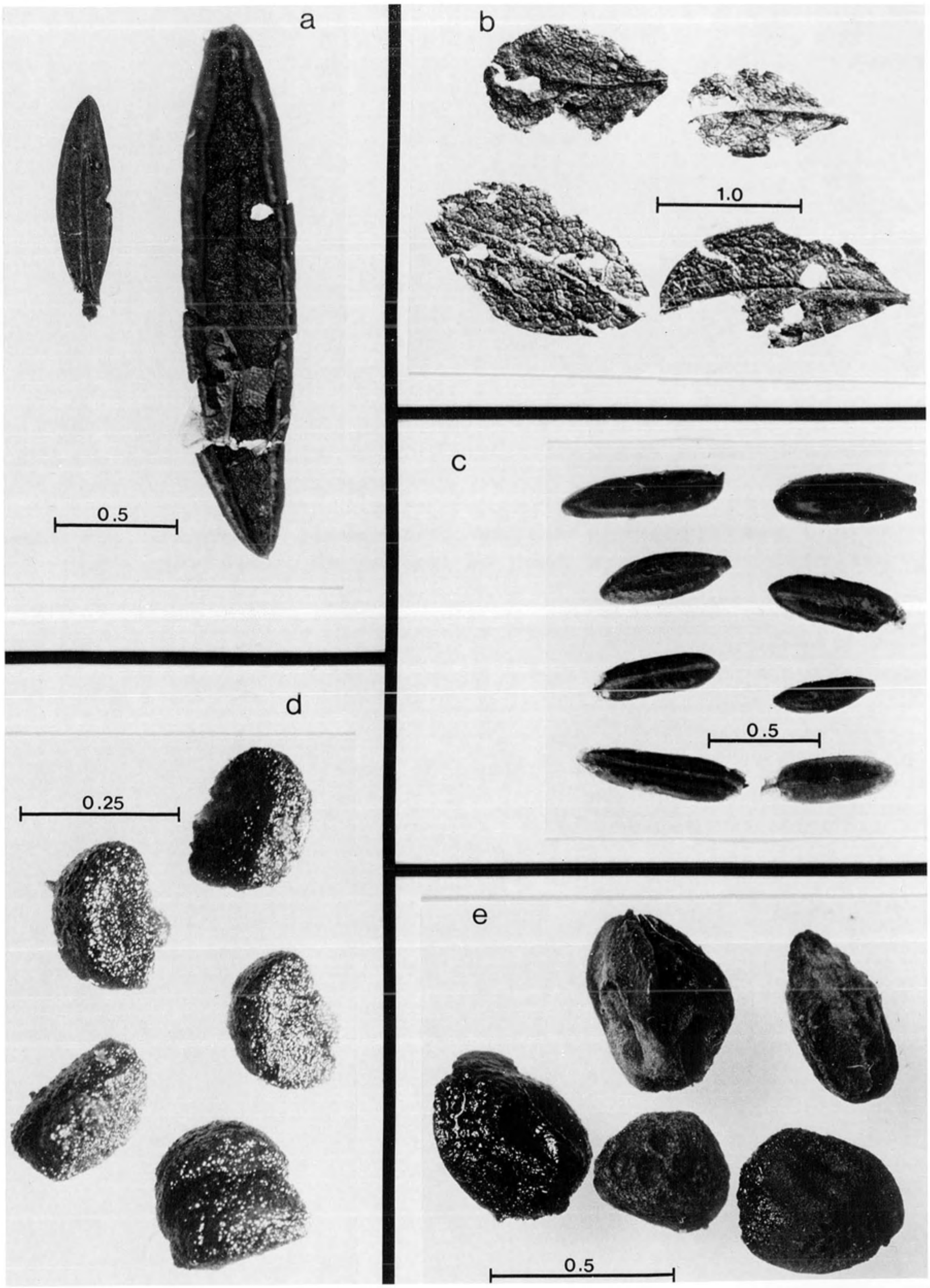

a
0.5
b
1.0
c
0.5
d
0.25
e
0.5

FIGURE 14: Kunghit Island total pollen concentration & peat profile. For a key to peat symbols see Fig. 15.

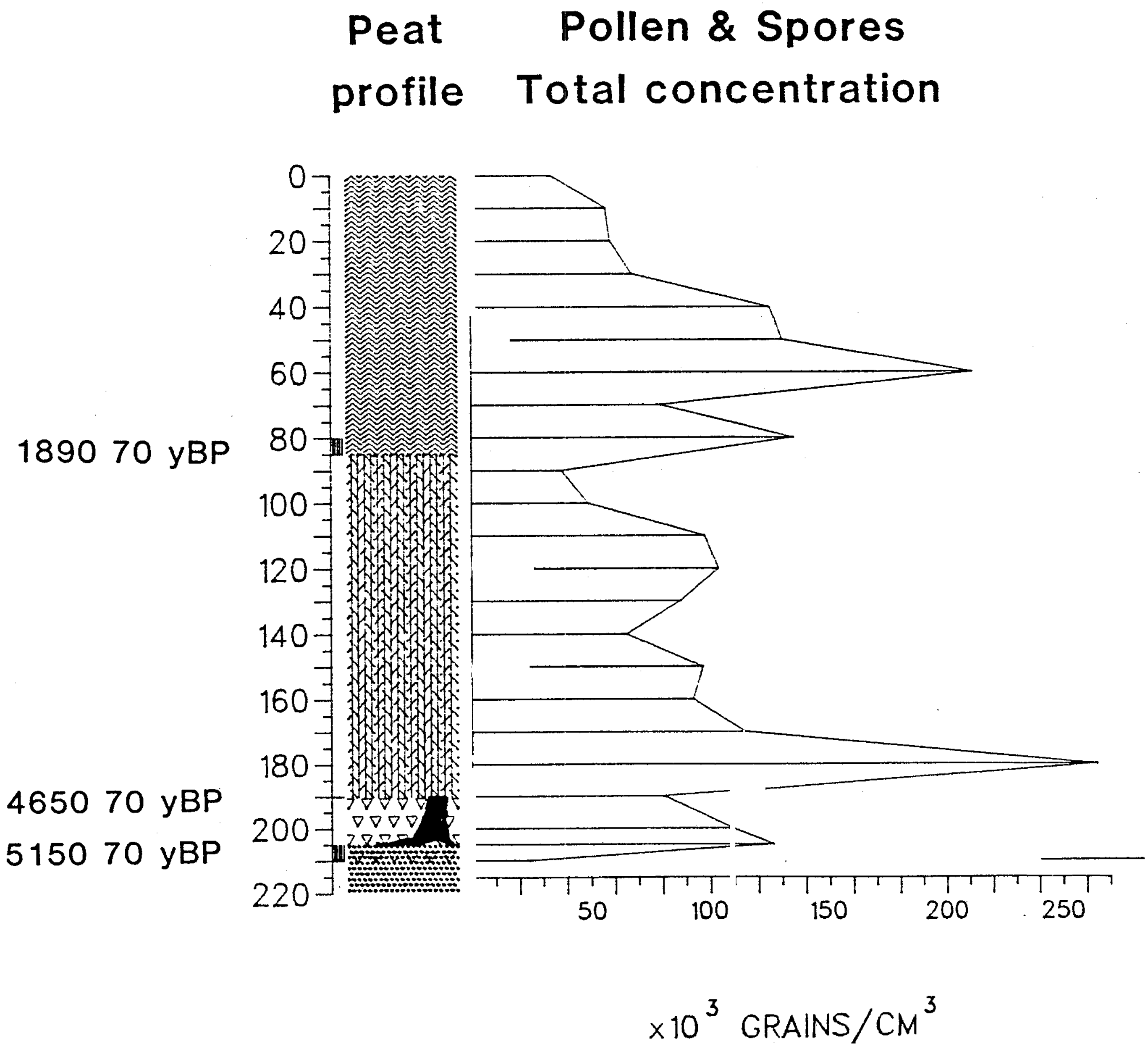
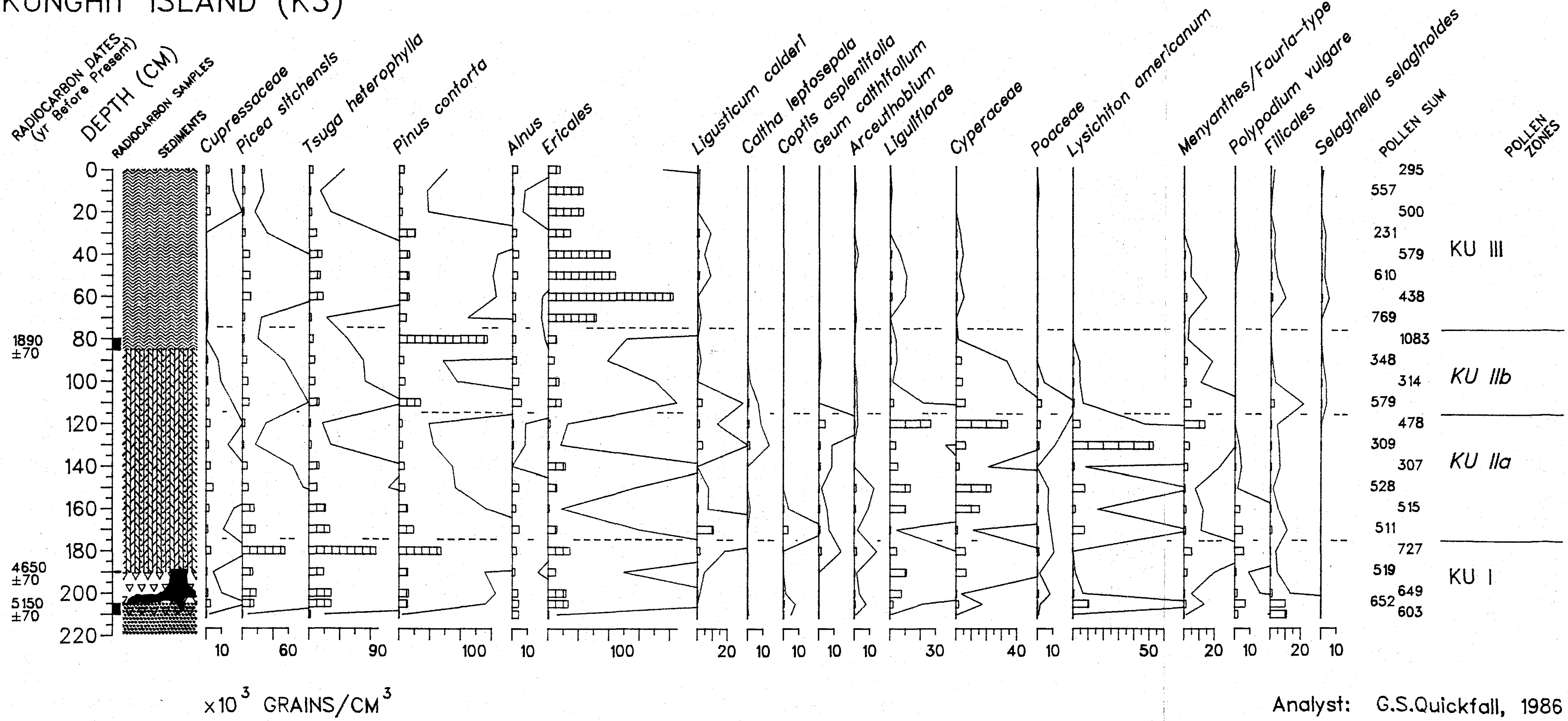

Peat
profile
Pollen & Spores
Total concentration
1890 70 yBP
4650 70 yBP
5150 70 yBP
0
20
40
60
80
100
120
140
160
180
200
220
50
100
150
200
250
x10^3 GRAINS/CM^3

FIGURE 15: Kunghit Island concentration diagram.

KUNGHIT ISLAND (K3)



Analyst: G.S.Quickfall, 1986

ERICACEOUS PEAT

WOOD & HERB DETRITUS

WOODY PEAT

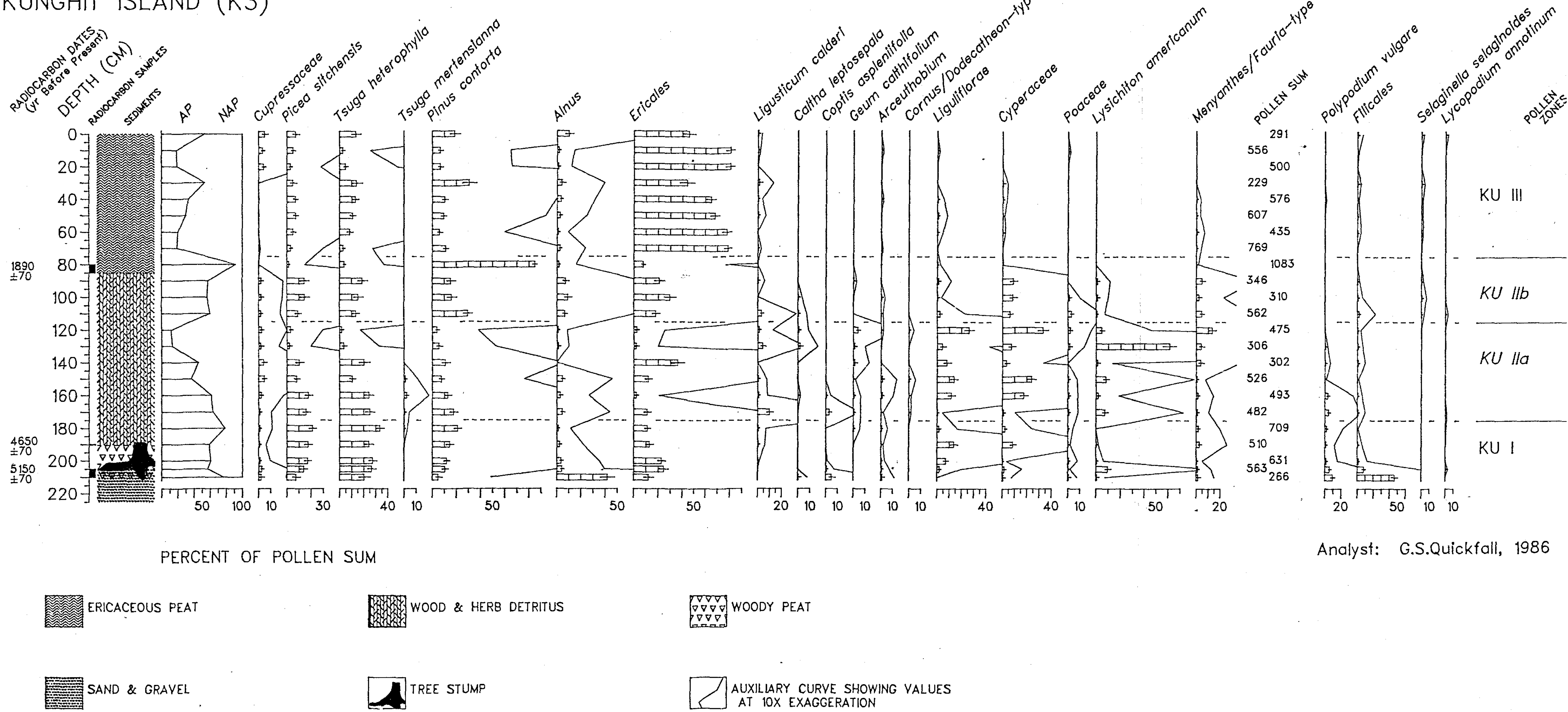
SAND & GRAVEL

TREE STUMP

AUXILIARY CURVE SHOWING VALUES AT 10X EXAGGERATION

FIGURE 16: Kunghit Island percent pollen diagram.

KUNGHIT ISLAND (K3)



above 200cm (Fig. 16). *Lysichiton americanum*, Ericales, *Gentiana douglasiana*, Liguliflorae and Cyperaceae all rise slowly during the middle of this zone and then decrease while *Picea sitchensis*, *Tsuga heterophylla* and *Pinus contorta* all peak prior to the transition to KU IIa.

<u>SUBZONE:</u> KU IIa (175-120cm)

ERICALES-LIGULIFLORAE-CYPERACEAE-LYSICHITON assemblage zone

The peat found in this subzone is well humified, dark brown containing herbaceous remains and woody fragments, <5mm in size. Pollen concentrations are lower than the previous zone never exceeding 114,000grains cm^{-3} (170cm) and not falling below 63,000grains cm^{-3} (140cm). Pollen of Ericales, Liguliflorae, Cyperaceae and *Lysichiton americanum* all rise in the middle of this zone. Arboreal pollen decrease towards the transition of KU IIa and KU IIb.

<u>SUBZONE:</u> KU IIb (120-75cm)

PINUS-ERICALES-LIGULIFLORAE-CYPERACEAE assemblage zone

Peat in this zone is the same as that in KU IIa and is composed of wood and herb detritus. Pollen increasing in this zone are *Picea sitchensis*, *Tsuga heterophylla* and *Pinus contorta*. Ericales, Liguliflorae and Cyperaceae all increase, then decrease by the end of the zone. *Menyanthes/Fauria*-type peak in this subzone. Pollen concentrations vary from a high of 135,000grains cm^{-3} (80cm) to a low of 37,000grains cm^{-3} (90cm).

ZONE: KU III (75-0cm)

ERICALES assemblage zone

The peat composition changes in this zone to a fibrous ericaceous peat. Approaching the surface of the bog the ericaeous component of the peat increases and is of a recent origin in the form of roots and root fragments. A high concentration of 212,000grains cm^{-3} (60cm) is reached in this zone in contrast to the concentrations of the other spectra, which are relatively low (33,000grains cm^{-3}, 0cm). Ericales becomes the most predominant pollen type in this layer and probably represents an almost pure *Empetrum* heath similar to that at the site today.

CHAPTER V

MID TO LATE HOLOCENE PALUDIFICATION

Part 1: Vegetation Change and Paludification

One or more Holocene paludification events have occurred in many areas across North America. Depending on the study, it appears climatic deterioration commonly occurs between 6000-2000 yBP. Evidence for neoglacial cooling in the form of the advance of alpine glaciers has also been discovered. Clague (1981) stated that such advances occurred around 4000 - 5000 and 2300 - 3100 yBP in the Cordillera of Western North America. This investigation was undertaken to compile data for the existence and timing of paludification events in peatlands of the Queen Charlottes. How might a climatic deterioration manifest itself in a palynological study? It has been suggested that bog climax vegetation is ultimately dependent on climate (Moore and Bellamy 1974, Aaby 1976, Barber 1981, Banner et al. 1983a, 1983b). Therefore, synchronous changes in the floristic composition of the study bogs through time, together with recurrence surfaces, should reflect climatic changes rather than local hydrological effects.

Argonaut Hill Bog

Argonaut Hill Bog spans 7970±100 yBP and overlies a mineral sediment. Prior to bog formation, a forest of *Picea sitchensis* and *Tsuga heterophylla* with a fern understory appears to have occupied the site. The high concentration of spores characteristic to many of the basal peat zones of Queen Charlotte pollen and spore profiles is not due to climatic influences. This is indicated by the time transgressive nature of these peaks. The basal peat accumulation rate is low, 0.0131cm/yr (Table 3), allowing for a natural concentration of pollen and spores. The overrepresentation of spores is further compounded by their good preservation in mineral soils (Fægri and Iversen 1975, Banner et al. 1983a). Pollen and spore concentrations may also increase above an iron hardpan which prevents their further migration downward. The presence of a hardpan, however, was not detected at Argonaut Hill Bog. All these qualities serve to reduce the interpretive importance of high values of fern spores, although ferns were an important component of the understory. The *Picea-Tsuga-Alnus-Lysichiton*-fern assemblage, zone AH I is indicative of a moist, nutrient rich environment. A recurrence surface dated at 5230±80 yBP is followed by a four fold increase, 0.0490cm/yr, in the peat accumulation rate. This recurrence surface is coincident with a sudden decrease in arboreal and increase in Ericales pollen percentages and concentrations.

Argonaut Hill bog after 5230±80 yBP exhibits increasingly boggy conditions. Accompanying the increase in peat accumulation is a decrease in *Lysichiton americanum* and fern percentages. As peat accumulates, the *Lysichiton americanum*-fern assemblage are

TABLE 3: Peat accumulation rates for the Argonaut Hill, Drizzle Pit and Kunghit Island K3 bog sites.

SITE	DEPTH (cm)	PEAT ACCUMULATION RATE (cm/yr)
Argonaut Hill Bog	0-72	0.0261
	72-152	0.0490
	152-232	0.0131
Drizzle Pit Bog	0-53	0.0597
	53-110	0.0167
Kunghit Island Bog K3	0-83	0.0437
	83-200	0.0383

further removed from the mineral substrate causing decreased vigour and declining populations. The Ericales maximum after 5230±80 yBP follows the *Lysichiton americanum* peak and subsequent decline. Heusser (1955, 1960) discovered similar *Lysichiton*-Ericales relationships. He interpreted the *Lysichiton* peak and subsequent decline as a response to the late-postglacial climatic fluctuation favouring new peat growth. *Sphagnum* for the first time exhibits continued presence in subzone AH IIa. *Menyanthes/Fauria* type also rises, further indicating boggy conditions.

Paludification seems to have occurred at Argonaut Hill Bog around 5230±80 yBP between AH I and AH IIa, as indicated by the following:

1. rise in the peat accumulation rate,
2. presence of a recurrence surface,
3. appearance of typical bog species and
4. declines of some arboreal species.

A marked difference between subzones AH IIa and AH IIb is the disappearance of *Coptis aspleniifolia*, *Trientalis*-type and *Cornus/Dodecatheon*-type. *Menyanthes/Fauria*-type becomes scarce while *Sphagnum* increases slightly and *Selaginella selaginoides* micro and megaspores appear for the first time. The decrease in species richness is interpreted to be due to a loss in nutrient availability. *Selaginella selaginoides* and *Sphagnum* have high moisture requirements and are found in nutrient poor environments (Peteet 1986) consistent with ombrotrophic peatlands of the Islands (Banner et al 1983b).

Nearing the end of AH IIb the Cupressaceae and Cyperaceae curves rise, also consistent with abundant moisture. The source of the Cupressaceae pollen on the Islands may come from the following species; *Chamaecyparis nootkatensis*, *Thuja plicata* and *Juniperus communis*. *Chamaecyparis nootkatensis* is a montane-subalpine species which favours moist, base rich substrata (Krajina et al. 1982). It grows on Argonaut Hill today, so it may have been a minor contributor to the Cupressaceae count. *Thuja plicata* is a lowland to montane species of moist soils, which presently are co-dominant with *Tsuga heterophylla* around Argonaut Hill Bog. The main population expansion of this tree on Graham Island appears to begin around 3000 yBP, although it may have been present as early as 5800 yBP (Hebda and Mathewes 1984, Warner 1984). Prior to about 3000 yBP, the Cupressaceae curve probably represents a mixture of *Chamaecyparis* and *Thuja*, as well as *Juniperus* shrubs, which are presently common on bog surfaces. In the absence of macrofossils, the meaning of the Cupressaceae curve cannot be further resolved at Argonaut Hill.

Changes in the pollen and spore spectra of zone AH II appear to be due to autogenic succession rather than climatic change. Species richness and pollen concentrations of bog species decline as peat buildup continues. Since precipitation is the only source of nutrients for ombrotrophic bogs (Moore and Bellamy 1974, Banner et al. 1983b, Moore and Webb 1983, Wells and Pollett 1983), declining nutrient availability can be expected to favour fewer and more acid tolerant species with time (Wells and Pollett 1983, Banner et al. 1986).

A second peat recurrence surface is dated at 2780±80 yBP. Maximum Cupressaceae values (probably *Thuja*) and rising *Selaginella selaginoides* and *Sphagnum* spores indicate high moisture levels and bog expansion. Pollen zone AH III, occurring after a recurrence horizon and dominated by bog plants and upland Cupressaceae, suggests a wet climate and cool temperatures to the present day. The strength of an argument based on climate control will depend on a comparison with the results from the Drizzle Pit and Kunghit Island studies.

Drizzle Pit Bog

A *Picea-Tsuga-Pinus-Alnus*-fern assemblage, indicative of a forest, is present at the base of zone DP I, 4320±100 yBP. A similar assemblage existed at Argonaut Hill 7970±100 yBP, further exhibiting its time-transgressive nature. Paludification of the site is indicated by the presence of *Carex obnupta* seeds, a typical rich fen species (Banner et al. 1983b), *Lysichiton* pollen, *Sphagnum* spores and macro remains. An interesting inclusion in the basal pollen spectrum is the high percentage of *Pteridium aquilinum* spores. *Pteridium* is generally considered to be a woodland species due to the detrimental effects of strong winds and frost (Watt 1976), both of which are reduced under a forest canopy. Well drained, acid sandy soils also contribute to vigorous *Pteridium* growth. This does not preclude the presence of *Pteridium* on the edges of wetlands, but indicates that it may prefer more mesic forest habitats. The environment envisioned involves a clearing composed of fen and bog plants. The fen component of the clearing is evidenced by the presence of *Carex obnupta* seeds while the bog plants present include *Gentianna douglasiana*, *Sanguisorba officinalis*, Ericales and *Sphagnum*. Also found on the peat will be stunted *Pinus contorta*, which increase in abundance and vigor as they approach the edge of the clearing. Next, a ring of *Alnus* surrounds the fen. The surrounding forest is composed of *Picea sitchensis*, *Tsuga heterophylla*, *Taxus brevifolia* and *Pinus contorta* with an understory component of *Pteridium aquilinum*, *Polypodium vulgare* and Filicales ferns.

A transition from zones DP I to DP II is marked by a dramatic decrease in pollen concentrations of some of the arboreal species as well as *Pteridium aquilinum*, *Polypodium vulgare* and undifferentiated Filicales, accompanied by increases in Ericales, Liguliflorae (probably *Microseris borealis*), Cyperaceae and *Sphagnum* concentrations. A tree stump found in life position is dated at 2670±70 yBP and identified as *Tsuga heterophylla*. *Tsuga* is more sensitive to soil saturation than *Picea sitchensis*, *Pinus contorta* and *Thuja plicata* (Krajina et al. 1982) and flooding is the probable cause of death. *Carex obnupta* seeds, discovered in the previous zone, do not occur above 93cm, while other Cyperaceae seeds and pollen continue through the transition to zone DP II. Ericales and *Sphagnum* increases, combined with dramatic decrease of *Alnus*, *Pteridium*, *Polypodium* and Filicales spores, also mark the DP I to DP II transition.

The following evidence was used to interpret the local vegetation at the DP I to DP II transition:

1. presence of a forest-fen complex composed of:

    a. *Tsuga* (tree stump, cone and pollen),
    b. *Taxus* (seed and pollen),
    c. *Picea* (pollen),
    d. *Pinus* (wood and pollen),
    e. *Carex obnupta* (seeds),
    f. *Pteridium* (spores).

2. replacement of forest-fen with bog

    a. decrease in arboreal component,
    b. absence of *Carex obnupta*,
    c. decrease in *Pteridium*,
    d. increases in Ericales and *Sphagnum*.

These observations point to a paludification event, most likely in response to climatic change. An iron hardpan, however, was discovered at the base of zone DP I. The hardpan may have changed the local hydrological conditions causing a buildup of water leading to peat expansion, independent of climate (Ugolini and Mann 1979). The test of a climatic influence versus a local hydrological change causing paludification will again depend on whether or not these episodes of peat accumulation are synchronous at all three sites.

The transition between zone DP II and subzone DP IIIa is marked by a prominent recurrence surface. The peat accumulation rate increases from 0.0167 to 0.0597cm/yr (Table 3) suggesting climatic conditions favouring rapid growth of peat forming plants. The change coincides with large decreases in *Sphagnum* spores and a smaller decline in Ericales pollen percentages. It is difficult to discern any specific reason for the pollen and spore declines since the peat makeup suggests that conditions favoured *Sphagnum* and Ericales growth. The date obtained at this recurrence surface (880±70) exemplifies one problem when dealing with peat deposits. Root penetration from recent plants growing on the surface of the peat may have contaminated the 53cm-deep sample, producing too young a date. This recurrence surface may mark the same possible climatic deterioration that occurred at Argonaut Hill Bog (2789 yBP) and Kunghit Island Bog (1860 yBP).

Subzone DP IIIb is marked by a decrease in *Tsuga heterophylla*, *Gentianna douglasiana*, *Sanguisorba officinalis*, Cyperaceae and *Pteridium aquilinum*. Ericales and *Sphagnum* increase to high percentages. The changes from subzone DP IIIa to subzone DP IIIb appear to be successional in nature, reflecting the *Empetrum* heath, *Sphagnum* bog found at the site today. As with zone AH II, the changes in zone DP III may be caused by precipitation being the only source of nutrients for ombrotrophic bogs (Moore and Bellamy 1974, Banner et al. 1983b, Moore and Webb 1983, Wells and Pollett 1983). Accompanying the nutrient decline is a decrease in species richness and pollen concentrations of bog species.

Kunghit Island Bog

Initial peat accumulation occurred 5090±70 yBP in zone KU I. A *Picea sitchensis* and *Tsuga heterophylla* forest community was present just prior to bog formation. This forest is similar to the forest communities present in zones AH I and DP I. The time transgressive nature of the *Picea-Tsuga-Alnus-Lysichiton*-fern assemblage is again demonstrated by its presence at all three sites during different time periods. Graphic evidence of the presence of a forest is a buried stump of *Picea sitchensis* sitting on the basal sandy peats. The stump is dated at 4650±70 yBP and its death is probably a result of drowning. Coincident with the presence of the forest species are a number of bog species; *Gentiana douglasiana, Ligusticum calderi, Caltha leptosepala*, Liguliflorae (probably *Microseris borealis*) and Ericales, all attesting to the presence of boggy conditions about 5000 yBP.

The transition of zone KU I to subzone KU IIa is marked by a decrease in some arboreal species. The initial peat accumulation rate is high, 0.0383cm/yr (Table 3) indicating conditions conducive for paludification were present 5090±70 yBP. Coincident with the arboreal decrease at the zone KU I and subzone KU IIa transition is the presence of the seepage indicator *Lysichiton americanum* and the bog indicator, Ericales. *Sphagnum* spores were absent in the profile, however, sufficient caulidia and phyllidia were observed indicating its presence at the site. A paludification event is interpreted as occurring near the transition of the zone and subzone, probably close in age to that of the tree stump, 4650±70 yBP.

Subzone KU IIb exhibits an increase in some arboreal taxa. *Pinus contorta* exhibits the most interesting curve with extremely high values in some spectra. The *Pinus* increase is interpreted as real and is not due to an inclusion of some staminate cones in the samples. Samples for pollen analysis were removed from two different sections of the bulk sample and two separate runs were produced. The count results were almost identical and the high counts were discovered to cover five different spectra. Fire horizons or charcoal were not found and the interpretation applied here is that *Pinus contorta* was growing directly at the site in conditions conducive to high pollen production. Bog plants are still present but not as abundant as in subzone KU IIa. The interpretation for the subzone change is, as with subzones AH IIa - AH IIb and DP IIa - DP IIb, due to non climatic successional changes. Low nutrient regimes in ombrotrophic peats are interpreted as the cause of reduced species abundance as there is a definite reduction in the number of bog flora present.

Zone KU III is marked by a recurrence surface at 1890±70 yBP. An increase in peat accumulation rate from 0.0383 to 0.0437cm/yr (Table 3) accompanies the recurrence surface. The floristic change is indicative of a paludification event. *Lysichiton americanum* decrease, followed by an Ericales increase, occurs at the subzone KU IIb, zone KU III transition.

This relationship, alluded to earlier in the zone AH I to subzone AH IIa transition, is interpreted as being a response to cooler temperatures (Heusser 1955, 1960). The high Ericales concentrations probably represent an almost pure *Empetrum nigrum* heath found at the site today. *Sphagnum* spores are still lacking, although, some macrofossil remains suggest that it was present during zone KU III as it is today. The lack of spores is probably due to a predominantly vegetative means of reproduction (Schofield 1986). Arboreal taxa remain relatively constant throughout the zone suggesting that the initial forest was present in the surrounding area. A summary of the evidence for a second paludification episode at Kunghit Island Bog around 1890± yBP include:

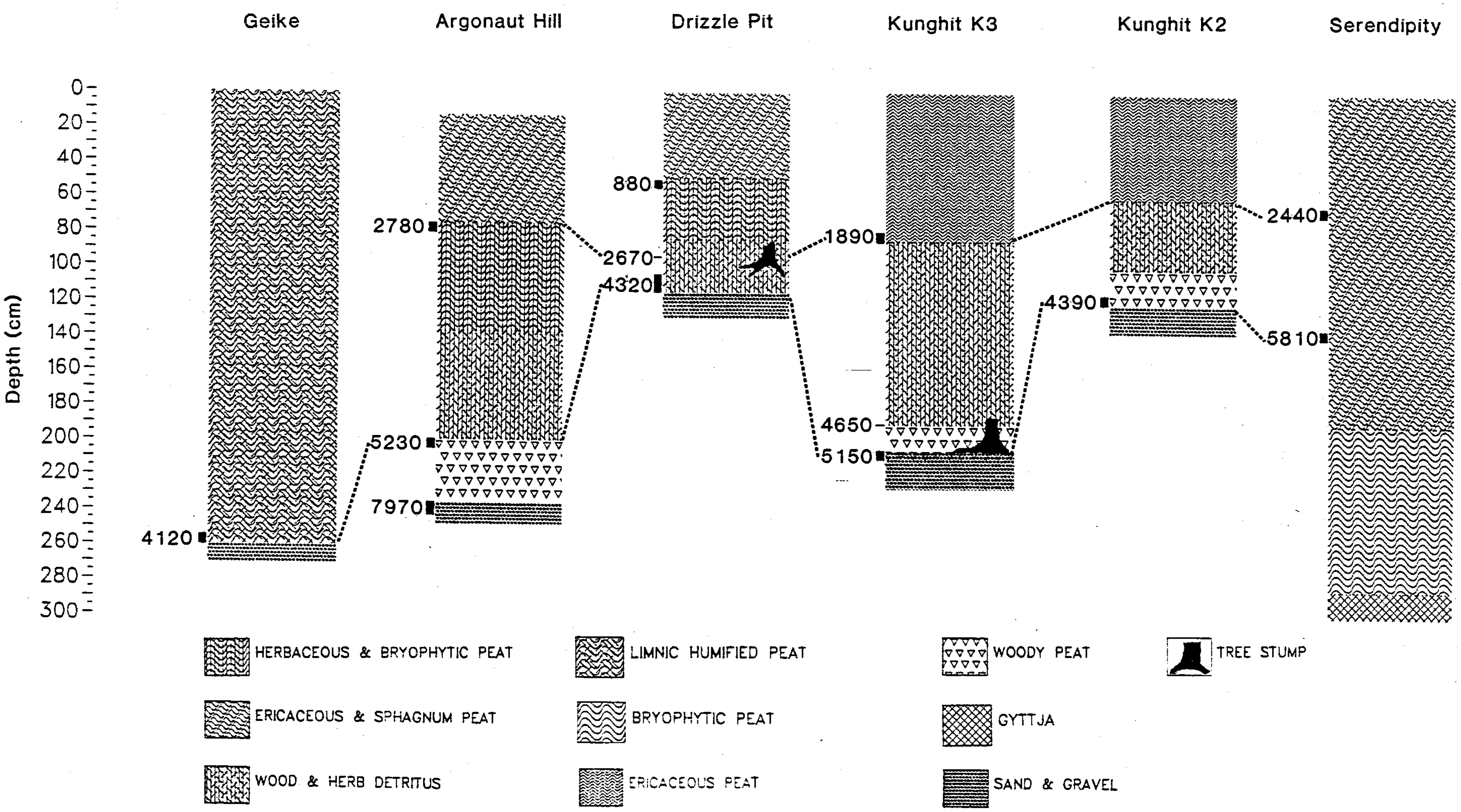
1. presence of recurrence surface,
2. arboreal pollen decrease and
3. Ericales increase following a *Lysichiton americanum* decrease.

Part 2: Climatically Influenced Paludification

If paludification events are a response to climatic rather than local hydrological changes then one would expect to find regional, synchronous peat production episodes. With this framework in mind, are the episodes of paludification described earlier, regionally synchronous?

The three study sites sampled (Fig. 17) combined with other dated bogs seem to indicate roughly coincident events of peat initiation or paludification. There appear to be two temporally

FIGURE 17: Possible synchronous peat initiation and paludification events from sites on the Queen Charlotte Islands. Serendipity Bog Lake dates from Warner (1984).



Geike
Argonaut Hill
Drizzle Pit
Kunghit K3
Kunghit K2
Serendipity
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
4120
2780
5230
7970
880
2670
4320
1890
4650
5150
4390
2440
5810
HERBACEOUS & BRYOPHYTIC PEAT
LIMNIC HUMIFIED PEAT
WOODY PEAT
TREE STUMP
ERICACEOUS & SPHAGNUM PEAT
BRYOPHYTIC PEAT
GYTTJA
WOOD & HERB DETRITUS
ERICACEOUS PEAT
SAND & GRAVEL

different episodes of peat expansion. The first occurs between 5810 and 4120 yBP (fig 17) and includes:

1. Geike, 4120 yBP, peat initiation,
2. Argonaut Hill, 5230 yBP, recurrence surface,
3. Drizzle Pit, 4320 yBP, peat initiation,
4. Kunghit Island K3, 5150 yBP, peat initiation,
5. Kunghit Island K2, 4390 yBP, peat initiation,
6. Serendipity, 5810 yBP, recurrence surface

and the second, which falls between 2780 and 1890 includes:

1. Argonaut Hill, 2780 yBP, recurrence surface,
2. Drizzle Pit, 2670 yBP, death of the tree, possibly due to drowning,
3. Kunghit Island K3, 1890 yBP, recurrence surface,
4. Kunghit Island K2, recurrence surface probably coincident with the 1890 yBP recurrence surface at Kunghit Island K3.
5. Serendipity, 2440 yBP, pollen change indicating increasingly boggy conditions.
6. Cape Ball, 2810 yBP, peat initiation.

The first group of peat building events spans 1790 ^{14}C years and the second group, 920 ^{14}C years. They are separated by 1340 ^{14}C years and indicate different events at the <0.001 level of significance (Appendix 2). The implication is that the two groups reflect two temporally separate deteriorations of the climate. Is it reasonable, however, to suggest that the individual peat production episodes within each group are synchronous responses to the same climatic deterioration?

Today, local climatic averages vary between sites (Table 1) and these differences are a response to local topography, and location of each climatic station. Compounding the different effect that a regional climatic shift may have at any site is the surficial geology, which would affect local hydrology. Ombrotrophic peat initiation or production would therefore differ temporally between sites due to any one or a combination of the following:

1. topography affecting local climate,
2. location, inland versus exposed coast and
3. surficial geology affecting local hydrology.

Hadden (1975) presented a climatic deterioration which resulted in an hemlock maximum about 4200 yBP at Folly Bog, Nova Scotia while the same hemlock peak occurred at Canoran Lake, Nova Scotia, 3300 yBP, 900 ^{14}C years later. Decreased precipitation and warmer temperatures, due to its inland location, are given as reasons for the delayed hemlock peak at Carnoran Lake.

Davis (1984) stated that the ombrotrophic peatlands of Newfoundland respond to differences in climate at varying rates due to large- and small-scale morphologies. Slope bog morphologies are determined by topography and substrate type. As with many of the bogs in Newfoundland, the formation of some peat deposits on the Queen Charlottes occurs long after deglaciation has exposed substrates of fluvioglacial nature. It is argued that the process of peat accumulation on such a surface would occur at different times at differing sites, even in response to a single climatic event (Wells and Pollett 1983, Davis 1984). The peat initiation lags would be due to the different rates of pedogenic formation of hardpans or impermeable soil horizons. The formation rates of hardpans and whether the hardpan forms prior to paludification or after paludification is not fully understood. For southeastern Alaska, Ugolini and Mann (1979) implied that paludification followed the formation of iron hardpans. Only Drizzle Pit, in this study, provided any evidence that a hardpan existed and the initiation date for peat formation is coincident with the other peat events present in group one.

The large variation between the dates of the first episode around 5000 yBP may be due to the differing rates at which peat formation occurs. Therefore, the initial accumulation of peat on any site is quite variable and it would not be unreasonable to argue that a climatic deterioration triggered the six paludification events listed in group one. The second six paludification events refer to four recurrence surfaces, one tree death and one peat initiation. The date of 2670 yBP applied to the tree, is used to indicate paludification at Drizzle Pit rather than the recurrence surface dated at 880 yBP. The latter date is deemed to be unreliable for reasons stated earlier. The range and deviation (appendix 2) between the dates for the second group of paludification events is much narrower. This would be expected, since peat stratigraphy and pollen are much more responsive to climatic change than initial peat formation

(Ogden 1960, Aaby 1976 1979, Wells and Pollett 1983, Davis 1984).

CONCLUSION

It seems that peat growth and spread on the Queen Charlotte Islands can be divided into two episodes centred around 4800 and 2500 yBP. The episodes appear to be distinct responses too two separate, climatic deteriorations during the past 8000 yBP. The possible role of pedogenesis in the initial formation of the Islands peatlands is still not understood, although it is thought that the formation of the Drizzle Pit Bog hardpan was initiated by climatic influences.

Drizzle Pit Bog, Geike Bog and Kunghit Island Bogs formed approximately 4800 yBP, probably in response to reduced temperatures and/or increased precipitation, which is also indicated by synchronous recurrence surfaces at Argonaut Hill Bog and Serendipity Bog Lake. Around 2500 yBP a second climatic deterioration caused another synchronous response in peat production. Recurrence surfaces at Argonaut Hill Bog, Kunghit Island Bogs, and Serendipity Bog Lake, as well as a paludification event at Drizzle Pit (marked by the probable drowning of the tree) and peat bog formation at Cape Ball, are broadly synchronous events reacting to the second climatic shift to lower temperatures and/or increased precipitation. The argument for climatic control is strengthened by the independent evidence of neoglacial ice advances in the Cordillera. Clague (1981) identifies 4000 - 5000 and 2300 - 3100 yBP as periods of alpine glacier advance. The two episodes of peat bog initiation and expansion on the Queen Charlottes also fall within these two intervals.

APPENDIX 1

COMMON AND LATIN NAMES REFERRED TO IN THE TEXT[1]

LATIN NAME	COMMON NAME
ARBOREAL	
Abies lasiocarpa	Alpine fir
Alnus rubra	Red alder
Chamaecyparis nootkatensis	Yellow cedar
Picea mariana	Black spruce
Picea sitchensis	Sitka spruce
Pinus contorta	Lodgepole pine
Taxus brevifolia	Western yew
Thuja plicata	Western redcedar
Tsuga canadensis	Eastern hemlock
Tsuga heterophylla	Western hemlock
Tsuga mertensiana	Mountain hemlock
SHRUBS	
Empetrum nigrum	Black crowberry
Gaultheria shallon	Salal
Juniperus communis	Ground juniper
Kalmia microphylla	Western swamp kalmia
Ledum groenlandicum	Common Labrador tea
Vaccinium caespitosum	Dwarf blueberry
Vaccinium oxycoccos	Bog cranberry
Vaccinium uliginosum	Bog blueberry
Vaccinium vitis-idaea	Mountain cranberry
HERBS	
Caltha leptosepala	Two-flowered white marsh-marigold
Carex obnupta	Slough sedge
Coptis aspleniifolia	Spleenwort-leaved goldthread
Cornus unalaschkensis	Western cordilleran bunchberry
Dodecatheon jeffreyi	Jeffrey's shooting star
Drosera rotundifolia	Round-leaved sundew
Eleocharis	Spike rush

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[1] Taxonomic nomenclature for vascular plants follows that of Taylor & McBryde (1977) and for Bryophytes, Schofield (1969).

Eriophorum angustifolium	Narrow-leaved cotton-grass
Fauria crista-galli	Deer cabbage
Gentiana douglasiana	Swamp gentian
Geum calthifolium	Caltha-leaved avens
Juncus	Rush
Ligusticum calderi	Calder's lovage
Luetkea pectinata	Luetkea
Lysichiton americanum	American skunk cabbage
Menyanthes trifoliata	Buck bean
Microseris borealis	Apargidium
Nuphar lutea	Pond water lily
Pinguicula vulgaris	Common butterwort
Rubus chamaemorus	Cloudberry
Sanguisorba officinalis	Great burnet
Sparganium minimum	Small bur-reed
Tolfieldia glutinosa	Sticky false asphodel
Trientalis europaea	Northern starflower
Veratrum viride	Green hellebore

CRYPTOGAMS

Blechnum spicant	Deer fern
Lycopodium annotinum	Stiff club moss
Polypodium vulgare	Licorice fern
Polystichum munitum	Imbricate sword fern
Pteridium aquilinum	Braken
Selaginella selaginoides	Mountain moss

MOSSES

Hylocomium splendens	Step moss
Polytrichum juniperinum	Hairy cap moss
Rhacomitrium canescens	Rock moss
Rhytidiadelphus loreus	
Sphagnum species	Peat moss

APPENDIX 2

ANOVA OF PEAT INITIATION AND PEAT EXPANSION TIMES ON 7 QUEEN CHARLOTTE ISLAND BOGS

SITE	GROUP ONE (yBP)	GROUP TWO (yBP)
GEIKE BOG	4120	
ARGONAUT HILL BOG	5230	2780
DRIZZLE PIT BOG	4320	2670
KUNGHIT ISLAND BOG K3	5150	1890
KUNGHIT ISLAND BOG K2	4390	
SERENDIPITY BOG LAKE	5810	2440
CAPE BALL		2810
sum =	29020	12590
mean =	4837	2518
standard deviation =	660	380

ANOVA TABLE

	sum of squares	df	mean sum of squares	F
treatments	14662405	1	14662405	47.85
error	2757813	9	306424	
total	17420218	10		

$F_{(0001)}(1,9) = 28.0$ F(calc) = 47.85

null hypothesis $\sigma_1{}^2 = \sigma_2{}^2$
alternate hypothesis $\sigma_1{}^2 \neq \sigma_2{}^2$

Fcalc > Ftab

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