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THE STRATIGRAPHY, PALYNOLOGY AND CLIMATIC SIGNIFICANCE OF PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, SOUTHERN VANCOUVER ISLAND, BRITISH COLUMBIA.

GEOLOGICAL SURVEY

by

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The stratigraphy, palynology and climatic significance of Pre-Middle Wisconsin Pleistocene sediments, southern Vancouver Island, British Columbia.

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CONTENTS

TABLES

FIGURES

4.	Bedded organic-rich silt and sand with darker peat layers in Unit 3 at Muir Point. Two macrofossils of wood branches are arrowed.	photo
5.	Stratigraphy of pre-Wisconsin Pleistocene sediments at Cordova Bay.	84-130
6.	Relative pollen and spore frequencies for Unit 3 and 4 of the Muir Point Formation at Muir Point. See Figure 3 for location.	84-131
7.	Relative pollen and spore frequencies for Unit 6 of the Cowichan Head Formation at Muir Point. See Figure 3 for location.	84-133
8.	Relative pollen and spore frequencies for Unit 3 of the Muir Point Formation at Cordova Bay. See Figure 5 for location.	84-134

ABSTRACT

Palynological investigations of organic-rich sediments from Muir Point Formation and basal Cowechan Head Formation on southernmost Vancouver Island have determined six pollen zones. A study of modern pollen spectra from the extant vegetation in southwestern British Columbia was undertaken to aid in interpreting paleoenvironments from the fossil pollen assemblages. Six of the pollen zones (MP-1, MP-2, MP-3, MP-4, CB-3 and CB-4) are from the Muir Point Formation and are beyond the range of ^{14}C dating. They record evidence of vegetation and climate during either the penultimate interglacial or last interglacial when conditions were at first warmer and/or drier than present, then succeeding to cooler and/or moister conditions. The sixth and youngest pollen zone (MP-5) provides evidence of subalpine to near treeline vegetation growing in cool/cold conditions just prior to 43 000 years age during the early Olympia non-glacial interval. These pollen zones and interpretations are in part correlative with established zones from adjacent Washington and eastern Vancouver Island.

INTRODUCTION

Pre-Wisconsin Pleistocene sediments occur at only a few sites on southern Vancouver Island (Hicock and Armstrong 1983) and infrequently in surface exposures, tunnels and boreholes in the Fraser Lowland (Armstrong 1975, 1977, 1984; Hicock and Armstrong 1983). In adjacent Washington State, however, evidence for the sediments is more commonplace and their lithostratigraphic characteristics are better known (Armstrong et al. 1965; Crandell 1965; Easterbrook 1969; Easterbrook et al. 1967; Easterbrook et al. 1981). Palynological investigations in the latter area have greatly extended knowledge of palaeoecology and paleoclimates during the Pre-Wisconsin interval (Easterbrook et al. 1967; Hansen and Mackin 1949; Heusser 1977; Heusser and Heusser 1981; Leopold and Crandell 1957).

Recently Hicock and Armstrong (1983) examined Pre-Wisconsin interglacial sediments in southwestern coastal British Columbia. They tentatively correlated the Muir Point Formation on Vancouver Island with Highbury Sediments in the Fraser Lowland because of their relative stratigraphic positions in relation to the Early Wisconsin Dashwood and Semiahmoo Drifts (Table 1). By similar argument these authors proposed that it is also possible that the interglacial sediments are correlative with the Whidbey Formation of last (Sangamon) interglaciation age in the Puget Lowland.

Preliminary palynological evidence from Muir Point Formation was used to suggest that climate during deposition of the unit was at least as warm as present (Hicock and Armstrong, 1983). For this reason, and because of their relative stratigraphic positions, Muir Point Formation and Highbury Sediments were tentatively assigned a Sangamon Interglacial age.

Uncertainty persists, however, about the age of the Muir Point Formation and whether it is correlative with the Highbury Sediments in the Fraser Lowland or with the Whidbey Formation in the Puget Lowland. The purpose of this paper is largely two fold: 1) to determine the palynostratigraphy of Muir Point Formation on southernmost Vancouver Island and attempt correlation with the established palynostratigraphic framework in western Washington, and 2) to determine the details of paleoclimate during deposition of the formation. In doing this it is hoped that new light might be thrown on the age of the bounding sediments and geological history of the sites investigated. The sediments investigated include those exposed in the sea cliff at Muir Point, the holostratotype of the Muir Point Formation, and sediments in the coastal slope at Cordova Bay, the parastratotype (Fig. 1).

METHODS

To aid in the paleoecological interpretations from palynological evidence, 23 surface samples were analysed from a variety of sites in the five major vegetation zones of southwestern British Columbia.

Particular attention, however, was paid to samples from contemporary deposits such as floodplain and lacustrine sediments, bog and fen peats and estuarine deposits, that are likely to correspond most closely with those preserved in the stratigraphic record. Where this was not possible, moss polsters were sampled. The modern spectra from the above samples and from published information elsewhere in the Pacific Northwest form the bases for the paleoecological interpretations.

At Muir Point the peat of Unit 4 was sampled at 10 cm intervals and the organic-rich silts of Unit 3 at 25 cm intervals. The latter sampling method, however, frequently led to the sampling of silts containing few or no palynomorphs. Thus, thin peats and organic-rich silts were sampled in preference. In Unit 6 only thin peat lenses and organic-rich beds were sampled. Systematic sampling of Unit 3 at Cordova Bay was not attempted. Silts underlying the peat were sampled but proved barren of palynomorphs; the peat was sampled at 10 cm intervals of which the second highest sampled was barren. Thin, organic-rich beds contained by the overlying laminated silty-clays were sampled at approximately 50 cm intervals, but only the four lowest samples contained sufficient pollen for counting.

Because of their lignitic character it was found that treatment of the Pleistocene samples with a modified acetolysis procedure, involving the addition of a seven minute treatment with Schulze's solution to oxidize the humic material and a final very brief wash in 1% K_2CO_3 produced the best results. Following this the samples underwent differential centrifugation and then the residue was stained with Safranin O and mounted in polyvinyl alcohol. All the modern surface samples, however, were treated with the traditional laboratory procedure of Faegri and Iversen (1975), but the residue was mounted in polyvinyl alcohol.

Counts of 300 grains of pollen were attempted for all samples, but could not be achieved in some of the Pleistocene silts where sparser assemblages were encountered. Relative percentage frequencies of the pollen were calculated exclusive of aquatics, semi-aquatics and spores. Identification of pollen and spores was undertaken by reference to a modern collection from British Columbia.

The number of taxa shown for the modern pollen spectra (Fig. 2) has been reduced to include only those considered to have some bearing on the paleoecological interpretations, the remaining taxa recorded during counting are totalled in the numbered 'other' columns. Spectra from Vancouver Island have been reported previously (Alley, 1979). However, these data have been recalculated by the method outlined earlier and replotted thus allowing the significance of the regional pollen rain to be determined more easily and make the diagrams consistent with traditional presentation methods. Results from six additional samples from higher parts of the Coast Mountains are also shown to complete the range of spectra likely to be encountered in southwestern British Columbia and to increase confidence in the general paleoclimate interpretations.

MODERN VEGETATION AND CLIMATE

The extant vegetation of Vancouver Island largely comprises three major vegetation zones (Table 2): 1) the Coastal Douglas Fir Zone occupying the drier eastern Vancouver Island coastal lowland, 2) the Coastal Western Hemlock Zone occurring along the wetter western part of the island and the lower/middle slopes of the Vancouver Island Mountains, and 3) the Subalpine Mountain Hemlock Zone which extends to the edge of the treeline (Krajina, 1969). At highest elevations in the central Vancouver Island Mountains climatic conditions are severe enough to produce small, scattered areas of Alpine Tundra.

Samples for analysis of modern pollen spectra were taken from all four of the above vegetation zones, although, because of poor accessibility on Vancouver Island, samples from higher parts of the Subalpine Mountain Hemlock and the Alpine Tundra Zones were obtained from high parts of the Coast Mountains in the Mount Waddington area. With regard to samples from the Alpine Tundra Zone, a few sites lay adjacent to the Subalpine Engelmann Spruce-Subalpine Fir Zone and since some transport of pollen from here into the Alpine Tundra may have occurred, a brief reference to dominant tree species in the latter zone are made below.

The Coastal Douglas Fir plant community extends from sea level on the eastern slopes of the island up to an altitude of approximately 450 m along the eastern slopes of the Vancouver Island Mountains. Apart from the dominant trees and their associates (Table 2) common seral species include broadleaf maple (Acer macrophyllum) and red alder (Alnus rubra). Lodgepole pine (Pinus contorta) occurs sporadically on coastal bogs or as a seral species on drier sites, and western white pine (Pinus monticola) is found at higher elevations.

Along the western side of the island, the Coastal Western Hemlock Zone ranges from the coast to over 1000 m elevation, but is found above 450 m along the drier eastern slopes of the Vancouver Island Mountains. The zone is divided into the drier Douglas Fir-Western Hemlock Subzone and an upper wetter Pacific Silver Fir-Western Hemlock Subzone (Krajina 1969). Maple is again common along streambanks throughout the zone.

Douglas fir (Pseudotsuga menziesii) is the principal tree in the drier subzone where it is commonly associated with western hemlock (Tsuga heterophylla), grand fir (Abies grandis) and western red cedar (Thuja plicata) whereas Sitka spruce (Picea sitchensis) is very common along the coast. In the wetter subzone these taxa are associated with Pacific silver or lovely fir (Abies amabilis) which is the dominant climax species.

The Subalpine Mountain Hemlock Zone occurs between 900 and 1500 m elevation on wetter western slopes of the mountains of southern Vancouver Island, but on the drier eastern slopes rises to 1100-1800 m or even higher. In the northern part of the Vancouver Island Mountains the vegetation zone may be found as low as 300-900 m a.s.l.

Dominant coniferous trees in the zone are mountain hemlock (Tsuga mertensiana), Alaska cedar (Chamaecyparis nootkatensis) and Pacific silver fir. Western hemlock and western red cedar are common associate species at lower elevations. Stunted specimens of alpine fir (Abies lasiocarpa) and whitebark pine (Pinus albicaulis) make rare appearances near treeline. In this upper part of the vegetation zone, subalpine parkland predominates, in which clumps of coniferous trees are separated by extensive heather (Ericaceae) communities.

Harsh climatic conditions in the Alpine Tundra Zone ensure that only a few stunted conifers and woody deciduous plants survive in the most favourable sites. At lowest elevations subalpine fir, whitebark pine and mountain hemlock may occur in the krummholz form. A few modern pollen sites in the Mount Waddington area lie adjacent to the Subalpine Engelmann Spruce-Subalpine Fir Zone. Dominant trees in this zone are the conifers, engelmann spruce (Picea engelmannii) and subalpine fir, which often occur in association with the lodgepole and whitebark pines.

MODERN POLLEN SPECTRA

Coastal Douglas Fir Zone

Pollen spectra in this zone are characterized by high frequencies of arboreal taxa comprised largely of *Alnus* (dominantly *A.rubra*). *Alnus* is a common seral species in the Coastal Douglas Fir Zone and its pollen is thus overrepresented at the expense of pollen from the conifers, in particular, the dominant extant species *Pseudotsuga menziesii*, *Abies grandis* and *Thuja plicata* (Alley 1979). Diploxylon pine pollen in this zone and all other vegetation zones is largely contributed by *Pinus contorta*. In the Vancouver Island samples, pollen of *Picea* is entirely from *P.sitchensis* whereas the high elevation samples from the Coast Mountains would contain a high proportion of *P.engelmannii*. The pollen grouped as Cupressaceae in both the Coastal Douglas Fir and the Coastal Western Hemlock Zones is largely contributed by *Thuja plicata* with minor amounts of *Juniperus* (juniper) and *Chamaecyparis nootkatensis*.

The one significant occurrence of grass (Gramineae) pollen occurs in the Coast Douglas Fir Zone, obtained from a sample on a sparsely treed meadow bordering an estuary a few kilometres east of Muir Point.

Coastal Western Hemlock

Apart from the one site at which *Myrica* is overrepresented, the pollen in this zone is almost entirely comprised of arboreal types of which *Tsuga heterophylla*, *Thuja* and *Alnus* are important elements.

Relatively low frequencies of pollen from Picea and Pinus make appearances at a few sites, but Pseudotsuga pollen is again underepresented even though this tree is locally important in drier parts of the vegetation zone and is well represented at a number of sample sites.

Subalpine Mountain Hemlock

Although arboreal pollen again remains predominant in this zone, nonarboreal types, in particular from the Ericaceae are locally important. The latter probably results from the preponderance of Ericaceous taxa in the understory and open areas of the Subalpine Mountain Hemlock parkland.

Pollen of a number of arboreal species are well represented including Pinus (diploxylon type), Picea, Tsuga heterophylla, and Alnus whereas Tsuga mertensiana for the first time occurs in significant frequencies in higher parts of the zone.

Pollen from Valeriana sitchensis, is found at most sample sites in this zone and the higher Alpine Tundra Zone. Pollen of Valeriana recorded on the river estuary, however, is not from V. sitchensis but from some unidentifiable lowland species.

Alpine Tundra

Pollen spectra from this zone show that there is considerable deposition of arboreal pollen from lower zones. It is interesting to note that the frequency of Pinus and Picea pollen is higher than in any of the lower zones. Considerable pollen was probably being contributed from stunted specimens of Pinus contorta and P. albicaulis growing near the sample sites. Of the nonarboreal spectra, pollen from the Compositae are dominant at one site and up to 4% Artemisia was recorded at two other sites.

LITHOSTRATIGRAPHY

Muir Point

Eight separate units are recognized on the basis of lithological differences and their relative stratigraphic positions (Fig. 3). This paper is concerned with Units 1 to 6.

a) Unit 1 - Basal till

Exposed at the base of the cliff at its north-western extremity is at least 10 m of compact till characterized by abundant large clasts set in a gritty matrix (sand 51%, silt 49%). Clasts are dominantly of local origin but the presence of a low percentage of pink granite and garnetiferous schist suggests that the ice which transported them was of Cordilleran provenance. Tensional fractures, till wedges, shear planes, and clast fabrics (long axes), all formed at the same time as till deposition (mainly by lodgement), indicate that ice movement was to the northwest along Juan de Fuca Strait (Hicock 1980; Hicock and Dreimanis in press).

b) Units 2, 3, 4 and 5 - Muir Point Formation

A succession of partly fossiliferous non-glacial fluvial sediments (with lenses of diamicton in Unit 5) unconformably overlie the till. These units comprise the holostratotype for the Muir Point Formation (Hicock and Armstrong, 1983). The beds pinch out to the northwest against the basal till and the much younger Vashon Till, which, in this part of the cliff, makes unconformable contact with both the basal till and Muir Point Formation (Fig. 3).

The lowermost unit of the formation (Unit 2) is a compact ferruginous gravel with lenses of oxidized organic-rich silt, and limonite casts of former small logs and branches. The thickness of the gravel is unknown since its base lies below sea level along the eastern part of the section.

Unit 3 consists of organic-rich, fluvial silts and sands intercalated with abundant allochthonous peat layers, wood and occasional gravel lenses (Fig. 4). Current and rhythmic bedding up to 5-10 cm in amplitude is common. The lower 2-3 m of the beds comprises medium-grained, slightly weathered sands from which no palynomorphs were recovered, although larger plant fragments occur. The organic-rich beds grade upwards into compact woody autochthonous peat (Unit 4) which passes laterally into peaty silt and minor sand.

Conformable on Unit 4 is up to 10 m of sandy gravel (Unit 5) containing a large lens of coarser gravel and gravelly diamicton. The latter is interpreted as a mudflow or fan deposit rather than a till because, although a low percentage of Coast Mountains lithologies are present (probably reworked from older glacial sediments), no glacially polished, faceted or striated clasts were observed. Extensive searches for plant material in Unit 5 were unsuccessful and analysis of lenses of fine sand or rare silt revealed the sediments to be barren of palynomorphs.

Plant macrofossils ranging from grasses, sedges, needles and cones of conifers, leaves of deciduous trees, twigs, branches and logs are common throughout Units 3 and 4. These remains include abundant leaves of *Salix* sp. and *Alnus* sp., needles of *Pseudotsuga menziesii* and cones of *P. menziesii*, *Picea sitchensis* and *Thuja plicata*.

A portion of a log of *Thuja plicata* recovered from Unit 4 was dated at >40 000 yr. B.P. (I-8449), thus the age of the organic-rich beds cannot be determined directly.

c) Unit 6 - Organic-bearing fluvial sediments

Unit 5 is succeeded by a sequence of organic-rich silt, peat lenses, sands and gravel (Unit 6) reaching a maximum thickness of approximately 6 m. These fluvial sediments are truncated by Vashon Till deposited during the Fraser Glaciation; the same till in the northwestern part of the cliff also makes unconformable contact with Units 1, 3, 4 and 5 (Fig. 3). Although plant megafossils occur throughout the unit, only the lower two metres yielded palynomorphs.

Radiocarbon dates on peat produced an age of >40 300 (GSC-358); and on wood, ages of >40 000 (I-9443), >41 000 (GSC-2774) and 43 600 ± 660 (GSC-3295), the latter analysis being undertaken at high pressure. A branch of Abies sp. produced the date for GSC-2774 and the log producing GSC-3295 was possibly Tsuga sp.

Cordova Bay

Five pre-Dashwood Drift units are recognized at the western end of Cordova Bay (Fig. 5). These form the subject of this paper since the overlying sediments have been adequately described by Alley (1979) and Hicock and Armstrong (1983).

a) Unit 1 - Basal till

Overlying bedrock at the westernmost edge of the Bay are a few metres of fissile, silty sand lodgement and layered undermelt till. The orientation of striae and grooves on the surface of bedrock roche moutonnées indicate that the ice which deposited the till moved from north to south (Hicock 1980). Larger clasts are dominated by Vancouver Island and local lithologies with about 9% granite and 3% high grade metamorphic types being derived from the Coast Mountains.

b) Units 2, 3, 4 and 5 - Muir Point Formation

The till is unconformably overlain by up to 6 m of compact, ferruginous cross-bedded pebble gravel and medium sand containing limonite casts of wood and oxidized wood fragments (Unit 2). Conformable on this gravel unit are 5 m of plant-bearing silt, clay, peat beds and lenses, wood, and minor sand and mud (Unit 3). The thickest peat bed is an autochthonous deposit and produced the microfloral assemblages presented later, but only four levels in the plant-bearing silt and clay contained adequate pollen. The latter levels are allochthonous accumulations of leaf litter, fine organic debris and abraded wood particles.

Unit 3 is overlain by: 2-5 m of non-fossiliferous interbedded silt, coarse sand and gravel (Unit 4); up to 10 m of medium to coarse sand (Unit 5); and then unconformably by Dashwood Drift. Although there is no clear evidence to indicate whether Units 4 and 5 are part of the Muir Point Formation, or a proglacial facies of the Dashwood Drift, they are placed with the former since they appear to lie conformably on Unit 3.

The age of the organic-bearing beds cannot be determined directly because dates from a glaciomarine facies of the overlying Dashwood Drift are infinite (Alley 1979; Hicock and Armstrong 1983).

STRATIGRAPHIC PALYNOLOGY

Muir Point

Comparative pollen frequencies for sedimentary units 3, 4 and 6 at Muir Point are shown in Figures 6 and 7. Although the other non-till units underlying unit 6 were also systematically sampled, laboratory analyses showed them to be barren of palynomorphs. Five pollen assemblage zones can be recognized from the pollen diagrams.

Pollen Zone MP-1 consists of one sample between 6.3 m and 6.9 m where the highest frequency (65%) of pollen of Pseudotsuga found in the Muir Point Formation is recorded. Unfortunately the poor preservation of pollen from underlying sediments prevented the determination of the lower boundary of MP-1.

Pollen Zone MP-2 occurs between 6.9 m and 8.4 m and is defined on the basis of the preponderance of pollen of the Gramineae, reaching a maximum of 57% in one level. No other zone at Muir Point or Cordova Bay displays such high frequencies.

Significant percentages of Pseudotsuga and the Cupressaceae are present also, although these occur consistently through Zones MP-2 to MP-4. Notably rare to infrequent arboreal taxa are Pinus, Picea and Abies.

The boundary between Pollen Zone MP-3 and Zone MP-2 is drawn on the basis of an upsurge in Alnus which remains an important component of the pollen comprising the Zone, but which declines near the top. Other important elements of the Zone are the arboreal taxa Cupressaceae and Pseudotsuga and the nonarboreal Gramineae, although the latter decline significantly in Zone MP-3. Other minor characteristics of the Zone are low frequencies of Pinus, Picea and Abies. Several taxa not used in the calculation of the pollen frequencies but which are commonly encountered are the Cyperaceae and spores of the Polypodiaceae which peak strongly in the upper part of the Zone. Low frequencies of marine dinoflagellates occur in levels 14 and 16.

Rises in Pseudotsuga, the Cupressaceae and Tsuga heterophylla characterize Zone MP-4. Other aboreal taxa associated with this Zone are Alnus and the normally greatly underrepresented Acer. Nonarboreal associates are significant percentages of pollen from the Gramineae, Lysichiton, the Rosaceae and the Compositae. Significant peaks in the Cyperaceae and spores of the Polypodiaceae also occur.

Pollen Zone MP-5 (Fig. 7) incorporates only the bottom two metres of sedimentary Unit 6 because the upper few metres to the contact with the Vashon Till are too oxidized and no palynomorphs were recovered. Although this Zone is characterized by a high frequency of arboreal pollen, these assemblages stand in marked contrast to those of the lower zones. Zone MP-5 is dominated by pollen of Pinus (mainly diploxylon type), Picea sitchensis and Abies with only low percentages of Tsuga, the Cupressaceae and Alnus, whereas Pseudotsuga makes only a rare appearance in the three lowest sample levels. A low percentage of Tsuga mertensiana is found near the top of the Zone. Pollen of non-arboreal taxa are poorly represented in the Zone and consist largely of the Gramineae, Rosaceae and Compositae (including Artemisia), with minor but consistent occurrences of Valeriana sitchensis. During pollen counting, a few cysts of marine dinoflagellates were encountered in sample levels 5, 8 and 9.

Cordova Bay

Identifiable pollen could only be recovered from the autochthonous peat and lower part of the overlying plant-bearing silts and clays. The pollen assemblages are divided into two zones designated CB-3 and CB-4 (Fig. 8) this designation being employed so as to avoid confusion with Zones CB-1 and CB-2 defined for part of the overlying Late Pleistocene sediments (Alley 1979).

Pollen Zone CB-3 is defined on the basis of the high frequency of the Cupressaceae *Alnus*, *Pseudotsuga* the Gramineae and *Lysichiton*. *Pseudotsuga* reaches its maximum (34%) along with a strong peak in the Gramineae (27%) low in the Zone. Higher in the Zone *Pinus* (largely haploxylon type) and *Picea sitchensis* increase but with concurrent declines in *Pseudotsuga* (min. 4%) and the Gramineae (min. 1%).

The lower boundary of CB-4 is marked by upsurges in the frequency of *Picea* (max. 38%) and *Tsuga heterophylla* (37%) in conjunction with an increase in the percentage of *Abies*. Parallel with these increases are marked declines in the frequencies of *Pseudotsuga*, the Cupressaceae and *Alnus* to less than a few percent at the top of the zone. Nonarboreal pollen is poorly represented in the zone and at no level does the frequency of any of the taxa rise above two percent.

AGE AND CORRELATION

Southern Vancouver Island

All radiocarbon dates from the Muir Point Formation have been infinite (Hicock and Armstrong 1983) and thus determination of the chronostratigraphy in this paper relies on correlation by palynology.

At Muir Point, a radiocarbon date of 43 600 ± 660 years BP (GSC-3295) from Unit 6 suggests that these organic-bearing sediments correlate with the Mid Wisconsin Cowichan Head Formation of the Olympia nonglacial interval (Hicock and Armstrong 1983), whose age probably extends back about 65 000 years B.P. (Gascoyne et al. 1981). The high frequencies of pollen of Pinus (in particular, diploxylon type), Picea, Abies, Tsuga heterophylla and the rarity of Pseudotsuga menziesii in conjunction with the presence of marine dinoflagellates suggests a correlation with pollen assemblages from the early Olympia nonglacial interval on eastern Vancouver Island (Alley 1979). The marine dinoflagellates also show that, locally, relative sea level was 28 m higher than present.

At approximately the same time as the interval represented by MP-5, palynofloras from Lynn Canyon in the Fraser Lowland were dominated by Picea and Tsuga mertensiana (Hebda et al. 1983) and in adjacent western Washington by Tsuga heterophylla, Picea and Pinus (upper Zone 5 of Heusser 1977).

Hicock and Armstrong (1983) correlated Units 2, 3, 4 and 5 at Cordova Bay with Units 2, 3, 4 and 5 at Muir Point on the basis of similar lithologies and stratigraphic positions. This correlation is supported by our palynological evidence: CB-3 probably correlates with MP-3 because of high frequencies of *Pseudotsuga menziesii*, Cupressaceae and *Alnus* and significant percentages of Gramineae. CB-3 is unlikely to correlate with MP-2 which has a marine aspect whereas CB-3 is entirely terrestrial, or to correlate with MP-1 which has very high frequencies of Gramineae. CB-4 has no palyno-stratigraphic correlative at Muir Point, although the fluvial aspect of the beds in which the pollen assemblages occur suggests that they may be correlative with the fluvial gravels of Unit 5 at Muir Point.

The fact that the Muir Point Formation underlies Dashwood Drift at Cordova Bay is an indication that the formation is at least pre-Wisconsin in age. Although the correlative units at Muir Point directly underlie the Cowichan Head Formation, palynological evidence indicates that the beds are not an older part of the latter formation. Pollen assemblages from the Cowichan Head Formation are characteristically lacking in the *Pseudotsuga menziesii*, the arboreal spectra being dominated by *Picea* and *Pinus* (Alley 1979; Hicock and Armstrong 1983). Because of the abundance of *Pseudotsuga* in the Muir Point Formation, its stratigraphic position at Cordova Bay, and its possible correlative (Highbury Sediments) in the Fraser Lowland, Hicock and Armstrong (1983) suggest a correlation with the last interglaciation. The underlying tills at Muir Point and Cordova Bay are thus regarded by them as correlatives of the Westlynn drift in Fraser Lowland (Armstrong 1975), or some older glacial deposits.

The above correlations are acknowledged as being tentative and conclusive dating will rely on the results of investigations currently in progress, including amino acid and thermoluminescence studies. The correlations we make below suggest that the Muir Point Formation may correlate with or predate the last major interglaciation.

Adjacent Areas

The Muir Point Formation in southwestern British Columbia is correlated with the nonmarine Whidbey Formation of Easterbrook et al. (1967) and Easterbrook (1969) in northwestern Washington (Hicock and Armstrong 1983). Recent amino acid dating of wood from the Whidbey Formation shows that it is of Whidbey Interglacial (Sangamon) age (Easterbrook and Rutter 1981, 1982; Easterbrook et al. 1981).

The correlation of the Muir Point Formation (in particular, units 3 and 4) with the Whidbey Formation seems compelling since the lithostratigraphy of the formations and of bounding sediments is similar (see Easterbrook 1969 and Easterbrook et al. 1967). An identical succession of sediments commonly occurs in the central and northern Puget Lowland (Easterbrook personal communication 1983). If the above correlation is correct then units 1 and 5 at Muir Point and Cordova Bay may be equivalents of the Double Bluff Drift and Possession Drifts, respectively (Interpretation 1,

Table 3). Paleontological evidence for correlating Unit 5 with Possession Drift is lacking and the interpretation that units 2 to 5 at both Muir Point and Cordova Bay are all part of the Muir Point Formation (Hicock and Armstrong 1983) is preferred.

Palynological evidence also supports a correlation between the Muir Point Formation and Whidbey Formation. At the Useless Bay type section the largest part of the Whidbey Formation is characterized by high frequencies of Pseudotsuga (Heusser and Heusser 1981) and thus is similar to parts of the Muir Point Formation. The abundance of Pseudotsuga in conjunction with Alnus and the Gramineae (UB-4, UB-6 and UB-7 of Heusser and Heusser 1981) suggests a correlation with MP-1 to 4 and CB-3, although the Cupressaceae are also important in the latter assemblage zones. The association of significant amounts of Pseudotsuga and Tsuga heterophylla in UB-2 and CB-4 is also similar, although Alnus is also important in the former and Picea sitchensis in the latter assemblage zones. Palynological evidence from Muir Point, however, indicates that part of the Muir Point Formation is of marine origin whereas Whidbey Formation is regarded as wholly nonmarine (Easterbrook et al. 1967; Easterbrook 1968; Heusser and Heusser 1981).

A comparison of the pollen zones from Muir Point and Cordova Bay with interglacial assemblages from northwestern Washington, however, suggests that a correlation with sediments of penultimate interglacial age may also be appropriate. Currently the geochronology of Pleistocene stratigraphic units in northwest Washington is being re-investigated (see Easterbrook *et al.* 1981). Until this review is completed the stratigraphic correlation of the classical units of southern Puget Lowland (Crandell *et al.* 1958) to others elsewhere in North America will remain unknown or, at best, tentative. Thus, the old names are avoided in this paper.

Apart from one zone (9-A) at the type locality near Alderton (Heusser 1977), and at the Zenith locality (Leopold and Crandell 1957), last interglacial pollen assemblages elsewhere in northwestern Washington record only low frequencies of *Pseudotsuga* or it is absent. On the other hand, a palynological examination of peat from the Alderton type section for the penultimate interglacial revealed uniformly high frequencies of *Pseudotsuga* in association with high *Alnus* and significant *Abies* (Zone 11 of Heusser 1977). Therefore, pollen assemblage zones MP2, MP3 and CB3 from the Muir Point Formation could well be correlated with Zone 11 on the basis of the striking similarities in their arboreal spectra. Pollen Zones MP1 and CB4 are older and younger respectively than Zone 11. If this correlation is acceptable, then Muir Point Formation could be of penultimate interglaciation age and the underlying tills of the preceding glaciation age or older (Interpretation 2, Table 3).

PALEOECOLOGY

Comparison of the above fossil pollen with modern pollen spectra presented earlier, and with modern and Quaternary pollen spectras in adjacent areas, forms the basis upon which the following paleo-environmental interpretations are made.

Muir Point Formation

Pollen Zone MP-2

Since Pollen Zone MP-1 consists of only one level no interpretations are made here apart from acknowledging that locally Douglas-fir was by far the most important forest tree probably with minor stands of western hemlock growing in moister sites.

The association of high frequencies of Douglas-fir and grass pollen in Pollen Zone MP-2 has no modern counterpart in the pollen spectra of the coastal areas of the Pacific Northwest. Heusser and Heusser (1981), however, record high frequencies of Douglas-fir and grass pollen in assemblages from the Whidbey Formation at Useless Bay. They interpret the association of these pollen as an open grassland, possibly on a floodplain or estuary, with large amounts of Douglas-fir pollen being transported from adjacent uplands by streams to be deposited in the lowlands. Work elsewhere strongly suggests that considerable volumes of arboreal pollen is transported and deposited in sedge or grass dominated floodplains and deltas by streams (Hebda 1977).

Clearly Douglas-fir was the dominant tree and, for a greater part of the interval represented by MP-2, was more important than it is in the extant vegetation of the Coastal Douglas Fir vegetation zone (Fig. 2). Pseudotsuga menziesii is a very poor producer of pollen and even the presence of a few percent of this taxon in the pollen sum indicates that it formed a substantial part of the extant vegetation (Alley 1979; Heusser 1978a, 1978b; Heusser and Heusser 1981; Mack et al. 1978; Mack et al. 1979).

Only at the river estuary site in the Coastal Douglas Fir vegetation zone, do pollen of grass and Douglas-fir from important elements of the modern spectra. Unlike Pollen Zones MP-1 and MP-2, the modern pollen spectra at this site are dominated by Alnus (as is all of the Coastal Douglas Fir Zone), reflecting the importance of alder as a seral plant following the clearing of the forests by logging and other disturbances.

Thus, Pollen Zone MP-2 could be interpreted as a broad grassy floodplain bounded by dry hills on which almost pure stands of Douglas-fir were growing, whereas moist areas may have supported smaller stands of western red cedar. An alternative interpretation, however, may be related to the influence that changes in river channel position and valley-floor sedimentation had on plant growth. For example, sedimentary units 2, 3 and 4 could represent a fining upward sequence characteristic of valley alluviation: Unit 2 a channel deposit succeeding to sands and then silts of Unit 3 as the channel moved away from the site, and finally to a peat bog in Unit 4. The occurrence of rare dinoflagellates in a few levels in Unit 3 is evidence of minor marine influence, with sedimentation taking place possibly near the upstream limit of a tidal channel or flat. Stands of Douglas-fir scattered across a grassland may have been growing on the well-drained gravels of Unit 2 and sands of Unit 3, whereas western red cedar survived in the wetter sloughs of the developing floodplain. This interpretation is probably the most acceptable because the sediments were fluvially transported and are more likely to be dominated by pollen from the floodplain elements of the vegetation rather than from adjacent hills. This interpretation is supported by the presence of cones of *Pseudotsuga menziesii* and *Thuja plicata* along with *Picea sitchensis* in Unit 3. The occurrence of the latter is interesting in view of the low frequency of *Picea* pollen, since, although a number of sample sites chosen for analysis of modern pollen spectra were in proximity to stands of Sitka spruce, it is poorly represented in the spectra. This is probably a reflection that the species is a relatively low pollen producer (Hebda, 1983) rather than other factors related to transportation and preservation.

Pollen Zone MP2

Douglas-fir remains prominent in the fossil pollen spectra of Pollen Zone MP-3; generally the pollen exceed 10% of the total in each level and reaches a maximum of 26% near the top of the zone. The zone, however, is characterized by significant increases in alder and western red cedar pollen along with minor increases in spruce and fir and up to 12% of western hemlock pollen. In these respects, the spectra are similar to those found in the Coastal Western Hemlock Zone (Fig. 2), although western hemlock is lower and Douglas-fir pollen in the fossil spectra.

Clearly the site of the present Muir Point was not occupied by closed forest during MP-3, although forest may have existed adjacent to the site. The presence of wetland meadow is suggested by several lines of evidence : 1) significant percentages of grass (max. 26%) and sedge (max. 27%) pollen occur; 2) macrofossils of grass and sedges (some in growth position) are common in the sediments encompassed by Zone MP-3; and 3) the sediments are fluvial, whereas the presence of rare marine dinoglagellate cysts (at levels 14 and 16) indicates that for a time, tidal or estuarine conditions prevailed. The latter implies that sea level was at least 10 m higher than present during the interval represented by MP-3.

It is probable that the character of vegetation represented by Pollen Zone MP-3 is more closely related to edaphic conditions peculiar to the upper part of an estuarine plain that experienced changes in channel position rather than in general climatic change. For example, the expansion of alder is probably a result of the changes in the plain as the channel migrated laterally near to the site, the latter also producing an environment in which Sitka spruce and the sedges expanded (lower MP-3) but in which the grasses declined. As the channel meandered from the site and a floodplain formed (upper MP-3), the swamp environment enhanced the growth of western red cedar (at the expense of alder) and it reached its maximum near the top of the zone. Expansion of grassy flats adjacent to the channel may be the possible cause of a brief peaking of the Gramineae in upper MP-3. Throughout Pollen Zone MP-3, however, Douglas-fir must have remained the most prominent tree on drier sites on the floodplain and in the forests adjacent to it.

Pollen Zones MP-4 and CB-3

The return of freshwater to boggy conditions in Zones MP-4 and CB-3 is suggested by the presence of pollen of cat-tail (Typha), pond weed (Potamogeton), yellow pond lily (Nuphar) and coast myrtle (Myrica). Although there are no modern correlatives of these zones, it is possible that western red cedar and western hemlock expanded along boggy parts of the floodplain, an interpretation supported by the presence of significant amounts of pollen of skunk cabbage (Lysichiton) commonly found in such stands. Douglas-fir remained an important tree probably both on drier parts of the floodplain and in adjacent forests, as suggested by a significant increase in the frequency of its pollen (reaching 40% in two levels).

Changes in the structure of the floodplain vegetation, perhaps as a result of a meandering channel, can be inferred from nonsynchronous fluctuations in the major components of the arboreal and of the nonarboreal pollen.

Pollen Zone CB-4

A significant change in the forest structure occurred in this zone with new conditions favouring the spread of spruce and western hemlock at the expense of Douglas-fir, western red cedar and alder. In these respects, the pollen spectra bear some resemblance to modern spectra either in lower elevations of the Coastal Western Hemlock vegetation zone or in the Subalpine Mountain Hemlock zone. The fossil assemblages are also similar to modern spectra from the coastal lowland forests of western Olympic Peninsula (Florer 1972; Heusser 1978) and found in the fossil spectra of the early part of pollen Zone 8 or in the middle part of pollen Zone 2 from western Washington (Heusser 1977). Arboreal spectra found in Middle Holocene assemblages (BC-4A of Hebda 1983) at Bear Cove on northeastern Vancouver Island are very similar to CB-4.

It is unlikely that the spruce in Zone CB-4 is <u>Picea engelmannii</u>, which is the main contributor to modern spectra in the Subalpine Mountain Hemlock vegetation zone, because this spruce is a Cordilleran

Subalpine species not currently found near sea level in coastal British Columbia (Krajina, 1969). Engelmann spruce, however, did grow in the coastal lowlands of the Pacific Northwest during the Fraser Glaciation (Barnosky, 1981, 1984; Hicock et al., 1982). These studies show that the Engelmann spruce was associated with significant frequencies of pine, fir (alpine fir), mountain hemlock and Pacific yew (*Taxus brevifolia*) along with sage, grass and alpine herbaceous taxa. In CB-4 the spruce is associated with high frequencies of western hemlock and Douglas-fir, but the taxa recorded in the Fraser Glaciation assemblages are rare or absent. Thus, the spruce in CB-4 is probably *Picea sitchensis*, which thrives in moist coastal situations. The fossil spectra are correlatives of spectra in lower elevations of the Coastal Western Hemlock vegetation zone an interpretation agreeing with that from similar assemblages of Middle Holocene age at Bear Cove, northeastern Vancouver Island (Hebda, 1983). Such an interpretation suggests a climatic shift to cooler and/or moisture conditions from those of MP-4 and CB-3 since the site at Cordova Bay currently lies in the driest part of Coast Douglas-fir plant community.

Heusser (1977) interprets the microflora of his pollen Zones 8 and 2 as representing spruce and western hemlock forests growing in refugia on western Olympic Peninsula during the penultimate and last glaciations, respectively. Although there was a significant change in climate during Pollen Zone CB-4 on Vancouver Island, the presence of a few percent of Douglas-fir pollen indicates that it is unlikely that subalpine forests prevailed.

Cowichan Head Formation

Pollen Zone MP-5

Just prior to 43 000 years B.P. higher frequencies of diploxylon (lodgepole) pine type pollen, spruce and fir, along with sporadic occurrences of subalpine mountain hemlock and the herbaceous alpine/subalpine indicator *Valeriana sitchensis*, occurred. The spectra in MP-5 have modern counterparts in present Subalpine Mountain Hemlock to near Alpine Tundra vegetation zones (Fig. 2).

During approximately the same interval of time represented by MP-5, pollen assemblages in the Fraser Lowland show that forests dominated by spruce and mountain hemlock were growing in cool moist conditions (Hebda *et al.* 1983). Forests similar to the above grew concurrently in the Queen Charlotte Islands along the central coast of British Columbia where subalpine vegetation elements may have been depressed by at least 400 m (Warner *et al.* 1984). At the same time forests dominated by spruce and western hemlock with significant fir, mountain hemlock and pine were growing in a treeline ecotone or subalpine forest conditions on western Olympic Peninsula (Heusser 1972, 1977).

The pollen assemblages in MP-5 are also similar to early Fraser Glaciation spectra (pollen Zone CB1) reported from Cordova Bay (Alley 1979) and late Fraser Glaciation spectra (pollen zones ML2 and SL1) from the southwestern Coast Mountains of British Columbia (Mathewes 1973). In the latter study, however, considerable alder pollen was also present, but these form only a small portion of the arboreal spectra in MP-5. Late Fraser Glaciation spectra on western Olympic Peninsula are also characterized by high frequencies of pine, spruce and fir along with western hemlock and subalpine mountain hemlock (Heusser 1977).

Peats of Whidbey Interglacial age at Enumclaw and Zenith in Washington are also characterized in part by similar arboreal spectra (pollen Zone B at both sites, Leopold and Crandell 1957). These pollen assemblages are regarded as spectra derived from the colder parts of montane forests growing in cold and possibly moist conditions.

PALEOCLIMATE

Throughout the intervals represented by the five oldest pollen zones (MP-1, MP-2, MP-3, MP-4 and CB-3) there is no compelling evidence to suggest that changes in vegetation structure, as interpreted from the pollen spectra, were the result of general climatic changes. Rather, the vegetation changes can be viewed mainly in terms of seral vegetation assemblages produced by changes in edaphic conditions, resulting from shifts in tidal river channel position by meandering.

However, the presence of the pollen of the xerophytic Douglas-fir in large quantities throughout all four pollen zones is indicative of a climate much warmer and/or drier than Muir Point and Cordova Bay currently experience. Significant percentages of Douglas-fir pollen in the early to middle Holocene sediments of Saanich Inlet (Heusser 1983), Bear Cove (Hebda 1983) and Fraser Lowland (Mathewes 1973) were used to infer the presence of warm/dry conditions of the Hypsithermal. The Saanich Inlet data, however, include relatively large quantities of oak pollen, whereas only sporadic occurrences are found in the Muir Point and Cordova Bay assemblages.

The higher temperatures and/or drier conditions of the Hypsithermal Interval in adjacent western Washington are also reflected by the presence of significant frequencies of Douglas-fir pollen (Hansen 1938; Hansen and Easterbrook 1974; Heusser 1973, 1974, 1977). Reconstructions of average July temperatures for the Interval (Heusser 1973, 1977; Heusser et al. 1980; Mathewes and Heusser 1981) suggest that they may have been almost 2 to 3°C higher than present. Heusser (1977) and Heusser and Heusser (1981), in commenting on pollen spectra from the Alderton type section and the Whidbey Formation at Useless Bay, note that the maxima of Douglas-fir and alder pollen are higher than in all other pre-Holocene deposits studied in western Washington and imply unparalleled conditions of warmth. We draw the same conclusions about the fossil spectra contained in the four oldest pollen zones at Muir Point and in CB-3 at Cordova Bay.

The younger pollen zone (CB-4) at Cordova Bay, however, is interpreted as a climatic change to cooler and/or moister conditions, particularly in view of the great decline in the frequency of Douglas-fir pollen. The interpretation earlier that CB-4 represents a vegetation assemblage currently found in lower elevations of the Coastal Western Hemlock zone would imply a lowering of temperature by a few degrees. This could have resulted in an increase in effective moisture availability, or the decrease in average temperature may have been accompanied by an increase in precipitation.

It is unknown whether the climatic deterioration represents the onset of a glaciation or whether it was a cooler and/or moister phase during an interglaciation (Table 3). We conclude that the latter applies since the sediments overlying the bedded silt and clay of pollen Zone CB-4 (unit 3) have been interpreted as part of the Muir Point Formation (Hicock and Armstrong 1983). It is possible that the climatic change also resulted in altered stream regimes and thus a change in environment of deposition, producing the coarser sediments of units 4 and 5 at Cordova Bay and unit 5 at Muir Point.

The pollen assemblages in Zone MP-4 are regarded as having been derived from plants growing in subalpine to near-treeline forests. This implies that conditions during the early Olympia nonglacial interval were at least cool or cold with significantly more moisture than Muir Point currently experiences. Average July temperatures are likely to have been 3-5°C cooler and average annual precipitation considerably greater (Table 2).

CONCLUSIONS

Pollen assemblages from the Muir Point Formation are the oldest Pleistocene microfloras yet described from British Columbia. From a stratigraphic viewpoint the pollen assemblages have a significant bearing on the interpretation of the geological history at Muir Point and Cordova Bay. Should the Muir Point Formation be of last (Whidbey) interglacial age then the Early Wisconsin Dashwood Drift is absent at Muir Point and an unconformity occurs between Units 5 and 6 (Table 3). If, as may equally be the case, the Muir Point Formation is of penultimate interglacial age, then sediments related to two major glaciations (Early Wisconsin and an earlier glaciation) and the Whidbey (Sangamon) Interglaciation are not represented at Muir Point and a considerable hiatus is represented by the unconformity between Units 5 and 6. In the latter scenario, at Cordova Bay only sediments of Whidbey (Sangamon) interglacial age and an earlier glaciation would not be represented.

Interpretation of paleoclimate from the fossil pollen assemblages from Units 3 and 4 at Muir Point and Unit 3 at Cordova Bay record an interglacial climate that was at first much warmer and drier than southern Vancouver Island currently experiences, bearing a striking similarity to the paleoclimate interpreted for the penultimate interglaciation and the Whidbey Interglaciation in western Washington (Heusser, 1977; Heusser and Heusser, 1981).

Although there can be reasonable confidence placed on the paleoclimatic interpretations outlined above, as yet there is no certainty in dating by correlation with similar palynological assemblages in adjacent Washington. Thus, the establishment of the age of the Muir Point Formation and its bounding sediments awaits dating by independent means; either at the type section, at para-stratotypes on southern Vancouver Island and Fraser Lowland or of correlatives in the Pacific Northwest.

Neville F. Alley
Biostratigraphy

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CAPTIONS

Figures

1. Map showing location of sites mentioned in the text.
2. Modern pollen spectra from the major vegetation zones in southwestern British Columbia.
3. Stratigraphy of Pleistocene sediments at Muir Point.
4. Bedded organic-rich silt and sand with darker peat layers in Unit 3 at Muir Point. Two macrofossils of wood branches are arrowed.
5. Stratigraphy of pre-Wisconsin Pleistocene sediments at Cordova Bay.
6. Relative pollen and spore frequencies for Unit 3 and 4 of the Muir Point Formation at Muir Point. See Figure 3 for location.
7. Relative pollen and spore frequencies for Unit 6 of the Cowichan Head Formation at Muir Point. See Figure 3 for location.
8. Relative pollen and spore frequencies for Unit 3 of the Muir Point Formation at Cordova Bay. See Figure 5 for location.

Tables

1. Geologic-event units and possible lithostratigraphic equivalents in southwestern British Columbia and Puget Lowland.
2. Summary of important tree types and their main climatic requirements from the four major vegetation zones on Vancouver Island (source: Krajina 1969).
3. Correlation chart for pre-Middle Wisconsin Pleistocene sediments in northwestern Washington and southern Vancouver Island.

TABLE 1

Geologic-event units of the Pacific Northwest (Easterbrook et al. 1981)	Lithostratigraphic equivalents (pre-Wisconsin correlations are speculative)			Appr equi stra in t recc
	Southern Vancouver Island (Alley 1979; Armstrong & Clague 1977; Hicock & Armstrong 1983)	Fraser Lowland (Armstrong 1975, 1977; Armstrong & Clague 1977; Hicock & Armstrong 1983)	Puget Lowland (Crandell 1965; Easterbrook et al. 1967; Easterbrook 1969; Easterbrook et al. 1981)	
Fraser Glaciation	Fraser glacial deposits	Fraser glacial deposits	Vashon drift	Late Sub
Olympic nonglacial interval	Cowichan Head Formation	Cowichan Head Formation	Quadra Sediments	Mid Sub
penultimate glaciation	Dashwood Drift	Semiahmoo Drift	Possession Drift	Earl Sub
last interglacial	Muir Point Formation?	Highbury Sediments?	Whidbey Formation	Sanç
glaciation	older glacial and	Westlynn drift	Double Bluff Drift	Illi
penultimate inter-glaciation	nonglacial sediments	older drift and sediments	un-named sediments	?
glaciation			older drift	?

TABLE 2

Vegetation Zone	Dominant Trees	Common Associate Trees	Av. Annual Precip. (mm)	Mean Monthly Temps. (°C) January	July
COASTAL DOUGLAS HEMLOCK	*Pseudotsuga menziesii*, *Abies grandis* *Thuja plicata*	*Picea sitchensis* (coast) *Quercus garryana*, *Arbutus menziesii*, *Tsuga heterophylla*.	660 - 1520	1 to 4	16 to 19
COASTAL WESTERN FIR	*Pseudotsuga menziesii*, *Tsuga heterophylla*, *Thuja plicata*.	*Abies grandis*, *Picea sitchensis*, *Abies amabilis*, *Pinus monticola*, *Pinus contorta*.	1650 - 6650	-4 to 5	13 to 18
SUBALPINE MOUNTAIN HEMLOCK	*Tsuga mertensiana*, *Abies amabilis*, *Chamaecyparis nootkatensis*.	*Tsuga heterophylla*, *Thuja plicata*	1780 to 4320	-9 to -1	11 to 13
ALPINE TUNDRA	At lowest elevations only: *Tsuga mertensiana*, *Abies lasiocarpa*, *Pinus albicaulis*.	None	700 - 2800	-18 to -7	7 to 11

3461

Table 3

GEOLOGIC-CLIMATE UNITS OF THE PACIFIC NORTHWEST	POSSIBLE LITHOSTRATIGRAPHIC EQUIVALENTS		
	Puget Lowland	Interpretation 1 (Vancouver Island)	Interpretation 2 (Vancouver Island)
penultimate glaciation	Possession Drift	Dashwood Drift (Cordova Bay) Unit 5 (Muir Point and Cordova Bay)	Dashwood Drift (Cordova Bay)
last interglacial	Whidbey Formation	Muir Point Formation	
glaciation	Double Bluff Drift	lowermost till (Muir Point and Cordova Bay)	
penultimate interglacial	unnamed sediments		Muir Point Formation
glaciation	older drift		lowermost till (Muir Point and Cordova Bay)

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PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.

CORRELATION CHART FOR PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS IN NORTHWESTERN WASHINGTON AND SOUTHERN VANCOUVER ISLAND

COMPILED N.A.
DRAWN M.B.
DATE Mar '84
CHECKED
C.D.O. DATE 26.6.85
SCALE
PLAN NUMBER 84-129

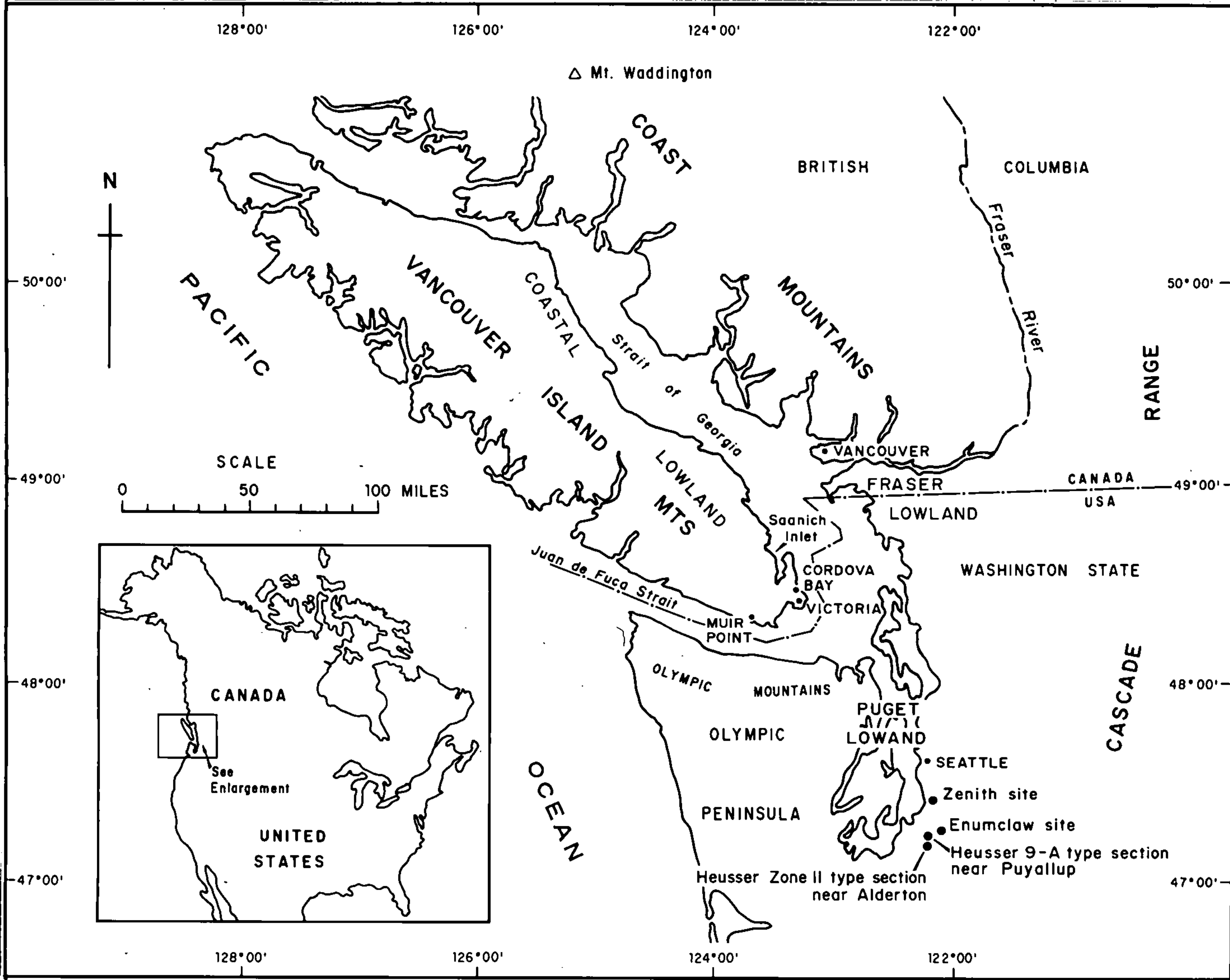

Fig. 1

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PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.

LOCALITY PLAN

COMPILED N. A.	C.D.O 26·6·85 DATE
DRAWN M.B.	SCALE AS SHOWN
DATE APR '84	PLAN NUMBER
CHECKED	84-140

3461

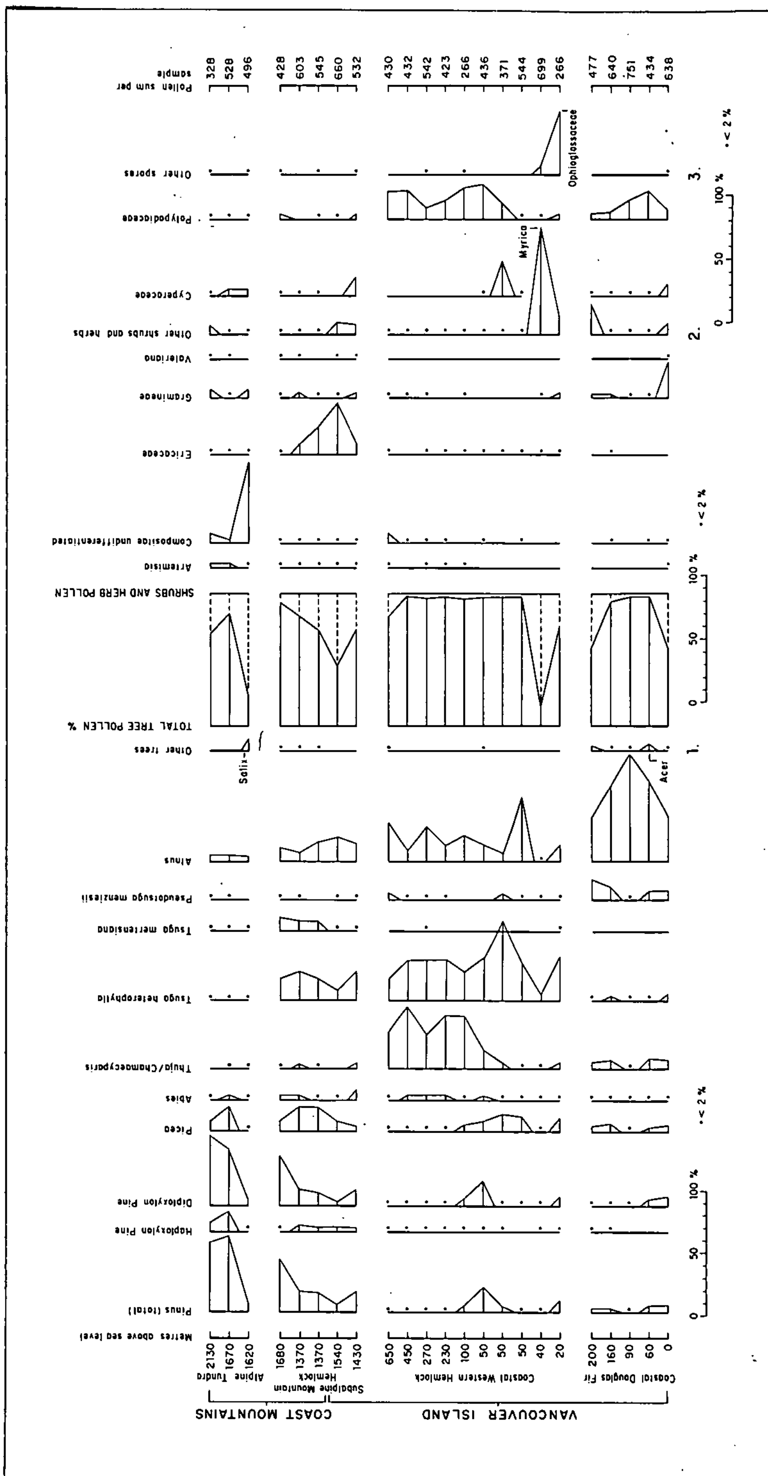

Fig. 2

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SOUTH AUSTRALIA

PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.
MODERN POLLEN SPECTRA FROM THE MAJOR VEGETATION ZONES IN SOUTHWESTERN BRITISH COLUMBIA

COMPILED N.A.	UR - 26·6·85 C.D.O. DATE
DRAWN M.B.	SCALE
DATE Mar '84	PLAN NUMBER
CHECKED	84-132

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.
STRATIGRAPHY OF PLEISTOCENE SEDIMENTS AT MUIR POINT

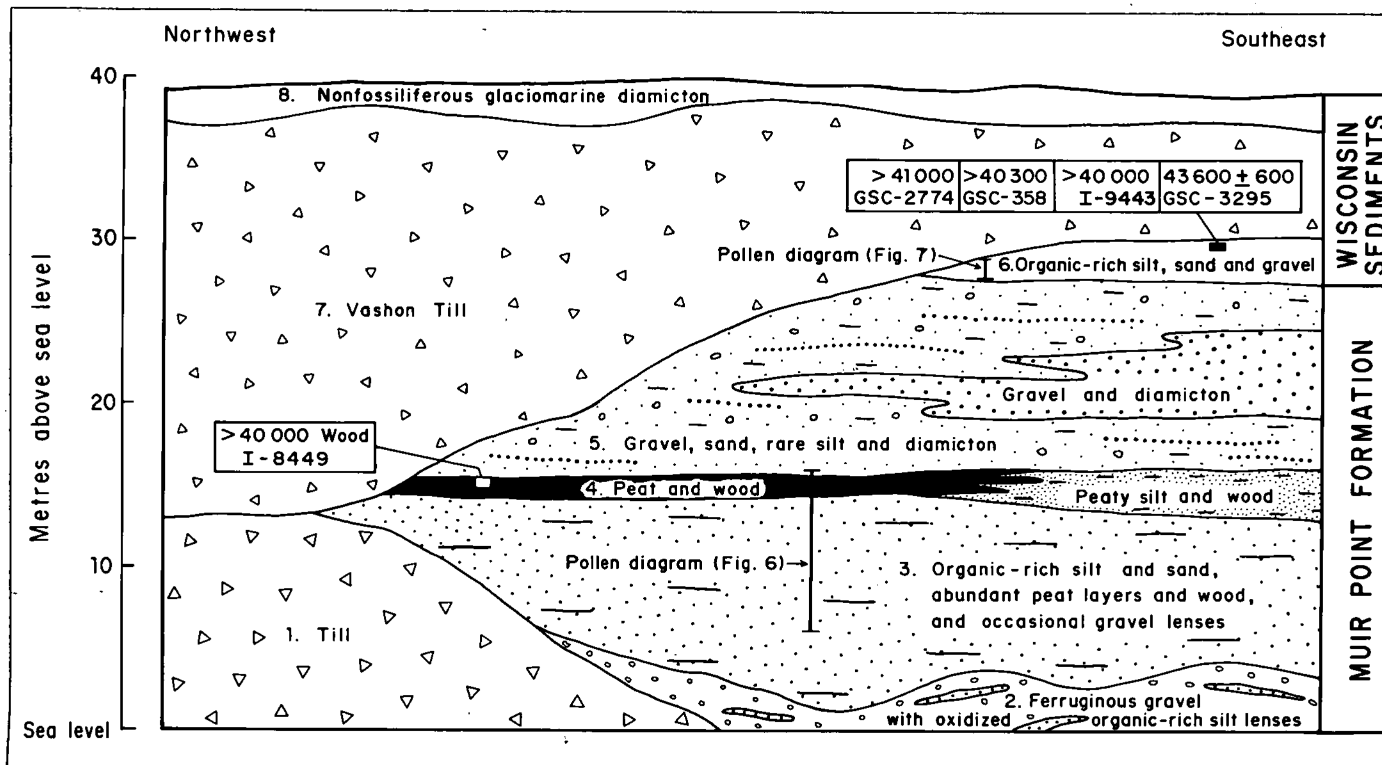

Fig. 3

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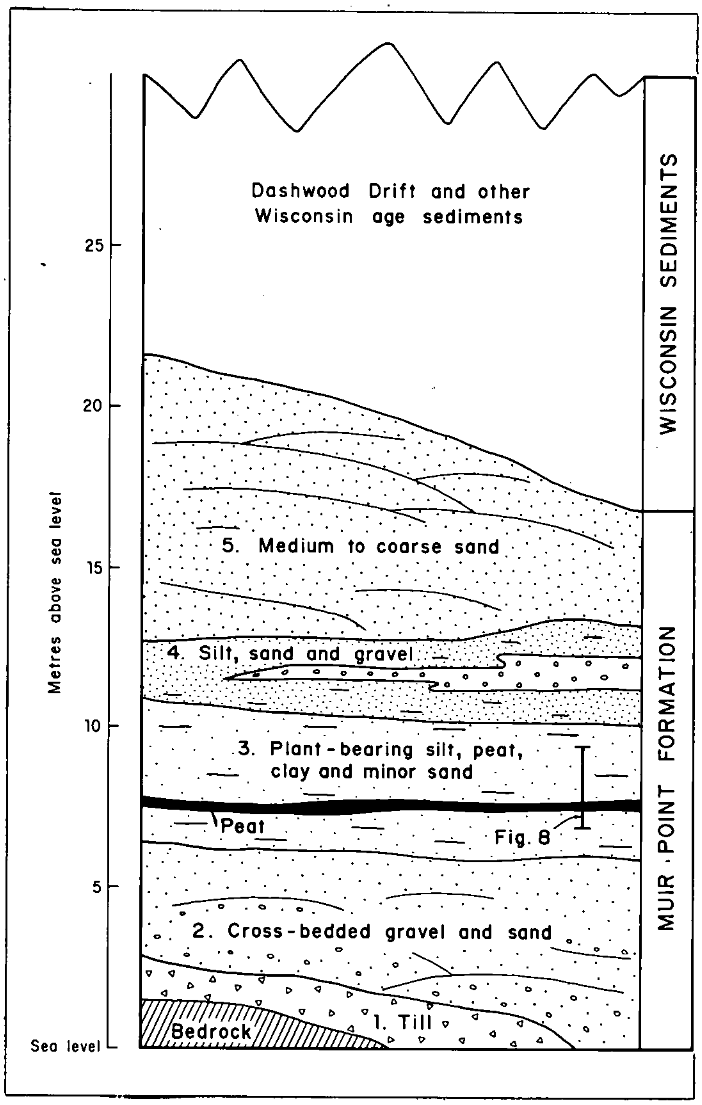

Fig. 5

DEPARTMENT OF MINES AND ENERGY
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PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.

STRATIGRAPHY OF PRE-WISCONSIN PLEISTOCENE SEDIMENTS AT CORDOVA BAY

COMPILED N. A.	C D O 26·6·85 DATE
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PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.
RELATIVE POLLEN AND SPORE FREQUENCIES FOR UNIT 3
AND 4 OF THE MUIR POINT FORMATION AT MUIR POINT

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COMPILED N.A.	CDO 26·6·85 DATE
DRAWN M.B.	SCALE
DATE Mar '84 CHECKED	PLAN NUMBER 84 - 131

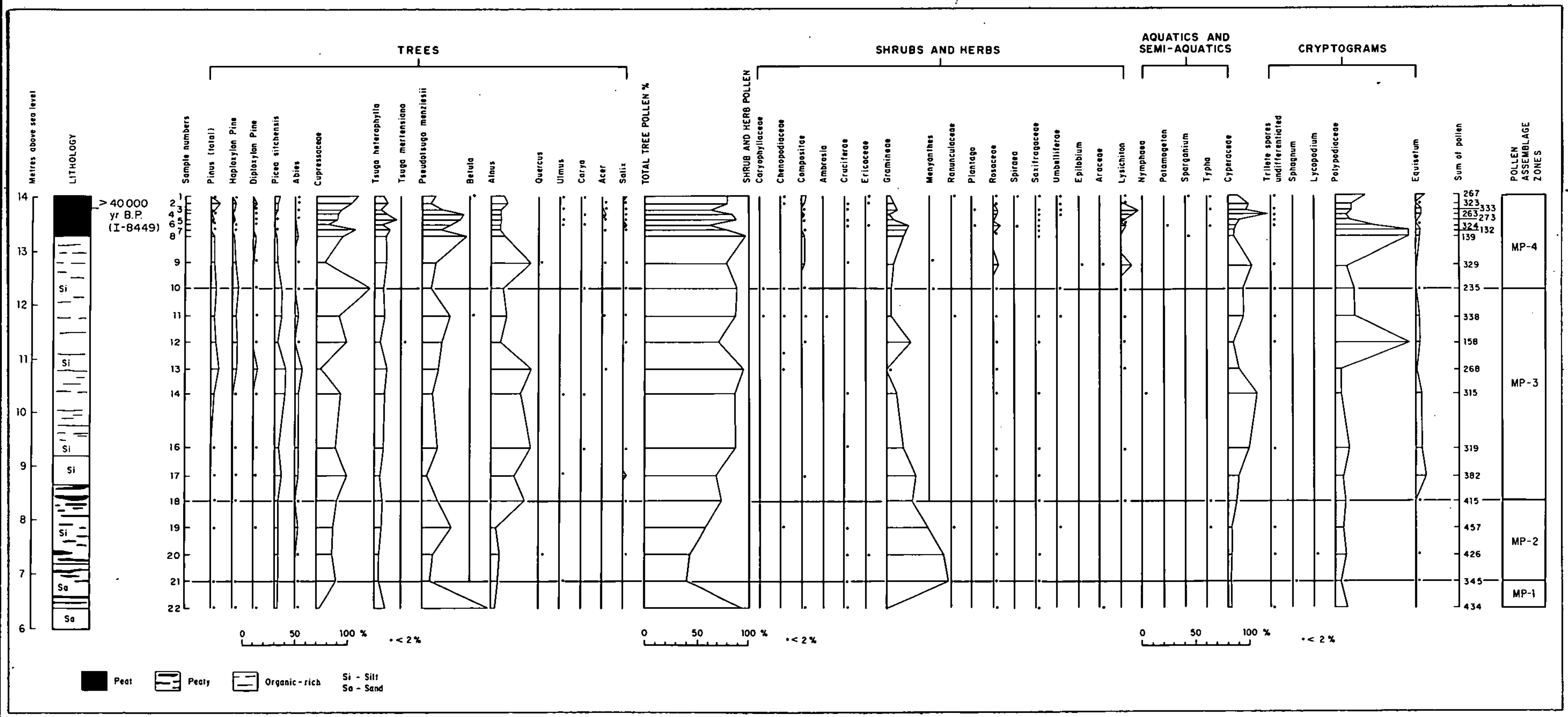

Fig. 6

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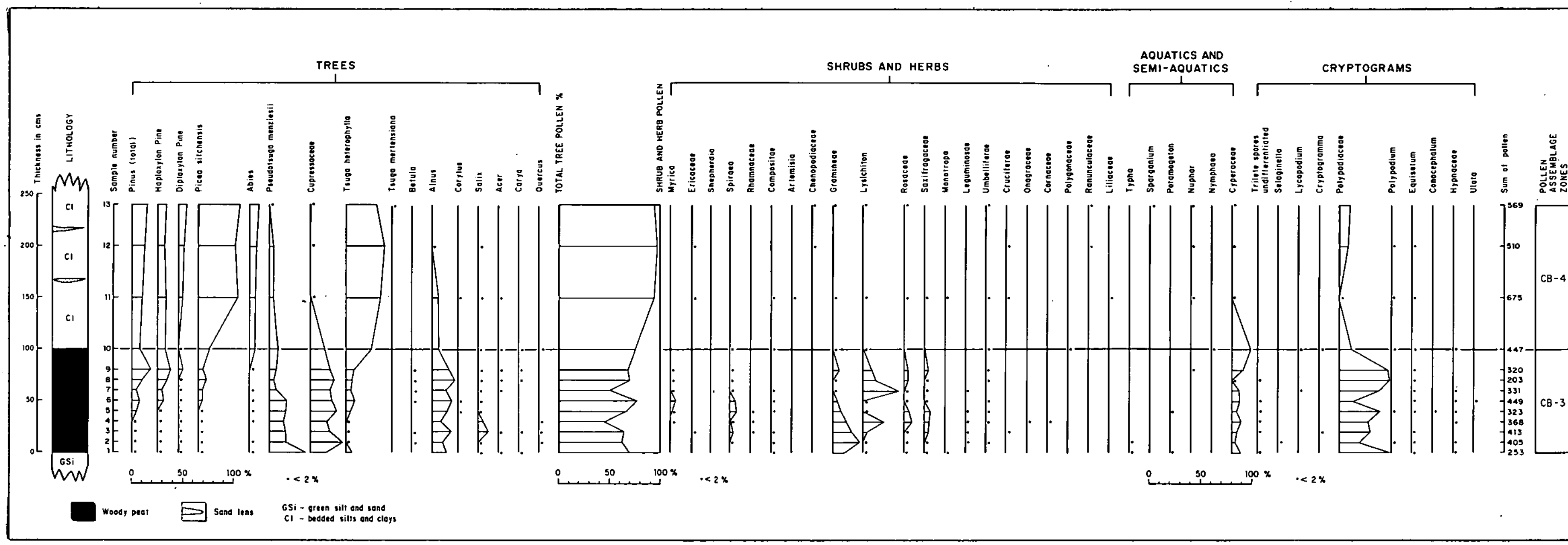

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.
RELATIVE POLLEN AND SPORE FREQUENCIES FOR UNIT 6
OF THE COWICHAN HEAD FORMATION AT MUIR POINT

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Fig. 7

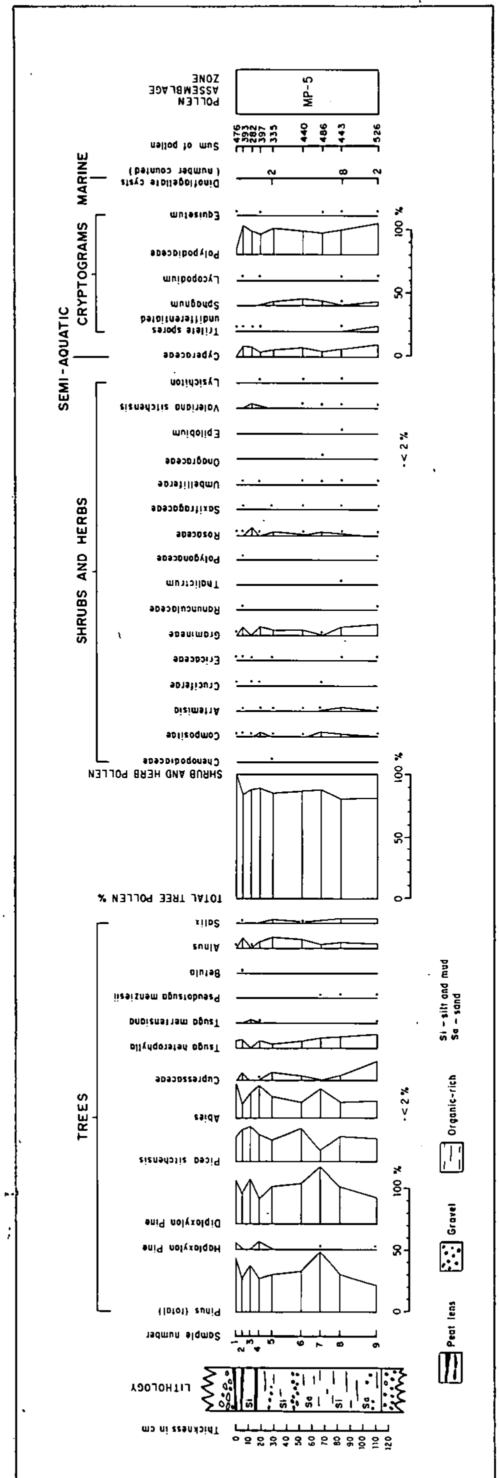

Fig. 8

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

PRE-MIDDLE WISCONSIN PLEISTOCENE SEDIMENTS, VANCOUVER IS.
RELATIVE POLLEN AND SPORE FREQUENCIES FOR UNIT 3
OF THE MUIR POINT FORMATION AT CORDOVA BAY

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