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Résumé de l'article

La Formation de Muir Point, dans le sud-ouest de la Colombie-Britannique, date probablement du dernier interglaciaire et de l'optimum climatique du Pleistocène supérieur. Elle comprend cinq lithofaciès: estuarien, de plaine d'inondation, fluviale, de cône de déjection et de coulée boueuse. La partie inférieure à découvert offre un magnétisme normal et a probablement été formée au cours du chrono de polarité normale de Brunhes (<790 ka BP). En raison de la similitude de la polarité, de la palynologie, de la lithologie et de la position stratigraphique, la Formation de Muir Point a été corrélée avec la Formation de Whidbey du nord-ouest de l'état de Washington. Elle correspond probablement aussi à la Formation de Highbury, localisée sur le continent, sous les basses terres du Fraser. Ces formations sont peut-être les vestiges de hauts fonds, composés de matériel sédimentaire, qui ont bordé les paléo-bassins du détroit de Géorgie et de Puget il y a plus de 100 ka, mais qui ont en grande partie été détruits au cours des glaciations subséquentes; le niveau marin était alors peut-être de 10 m supérieur à celui d'aujourd'hui. L'unité médiane de plaine d'inondation comprend cinq zones polliniques dont les différences s'expliquent surtout par le déplacement des méandres que décrivaient des fleuves. Les données révèlent que le pollen du pin de Douglas est plus abondant que maintenant à proximité des sites à l'étude, ce qui indique que le climat était au moins aussi chaud et aussi sec qu'aujourd'hui.

# LAST INTERGLACIAL MUIR POINT FORMATION, VANCOUVER ISLAND, BRITISH COLUMBIA

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**ABSTRACT** The Muir Point Formation probably represents the last interglacial and climatic maximum of the Late Pleistocene in southwest British Columbia. It comprises estuarine, floodplain, fluvial, alluvial fan, and debris flow lithofacies. The lower exposed part of the formation is normally magnetized and probably formed during the Brunhes Normal Polarity Chron (<790 ka BP). On the basis of similar polarity, palynology, lithologies, and stratigraphic position, the Muir Point Formation is correlated with the Whidbey Formation of northwest Washington State. It probably also correlates with the Highbury Formation under the Fraser Lowland of mainland British Columbia. These formations may be remnants of shallow marine or subaerial sediment shelves which once rimmed ancestral Strait of Georgia and Puget basins over 100 ka, but were mostly removed by later glaciations. During this time sea level may have been 10 m higher than today. The middle floodplain unit contains five pollen zones whose differences can be explained mainly by shifts in a meandering tidal stream. Throughout most of this record Douglas fir pollen is more abundant than in modern pollen rain around the study sites which indicates that paleoclimate was at least as warm and dry as present.

**RÉSUMÉ** La Formation de Muir Point du dernier interglaciaire, île de Vancouver, Colombie-Britannique. La Formation de Muir Point, dans le sud-ouest de la Colombie-Britannique, date probablement du dernier interglaciaire et de l'optimum climatique du Pléistocène supérieur. Elle comprend cinq lithofaciès: estuarien, de plaine d'inondation, fluviale, de cône de déjection et de coulée boueuse. La partie inférieure à découvert offre un magnétisme normal et a probablement été formée au cours du chrono de polarité normale de Brunhes (<790 ka BP). En raison de la similitude de la polarité, de la palynologie, de la lithologie et de la position stratigraphique, la Formation de Muir Point a été corrélée avec la Formation de Whidbey du nord-ouest de l'état de Washington. Elle correspond probablement aussi à la Formation de Highbury, localisée sur le continent, sous les basses terres du Fraser. Ces formations sont peut-être les vestiges de hauts fonds, composés de matériel sédimentaire, qui ont bordé les paléo-bassins du détroit de Georgie et de Puget il y a plus de 100 ka, mais qui ont en grande partie été détruits au cours des glaciations subséquentes; le niveau marin était alors peut-être de 10 m supérieur à celui d'aujourd'hui. L'unité médiane de plaine d'inondation comprend cinq zones polliniques dont les différences s'expliquent surtout par le déplacement des méandres que décrivaient des fleuves. Les données révèlent que le pollen du pin de Douglas est plus abondant que maintenant à proximité des sites à l'étude, ce qui indique que le climat était au moins aussi chaud et aussi sec qu'aujourd'hui.

**ZUSAMMENFASSUNG** Die Muir Point Formation vom letzten Interglazial, Vancouver Island, British Columbia. Die Muir Point Formation bezeugt wahrscheinlich das letzte Interglazial und klimatische Maximum des späten Pleistozän im Südwesten von British Columbia. Sie umfasst Mündungs-, Überschwemmungsebene-, Fluss-, Alluvialfächer- und Schlammstrom-Lithofazies. Der untere ausgesetzte Teil der Formation hat eine normale Magnetisierung und wurde wahrscheinlich während des Normal-Polarität-Chron von Brunhes (790 ka v.u.Z.) gebildet. Aufgrund ähnlicher Polarität. Pollen- und Fossilvorkommen, Gesteinszusammensetzung und stratigraphischer Position wird die Muir Point Formation mit der Whidbey Formation im Nordwesten vom Staat Washington in Verbindung gebracht. Wahrscheinlich stimmt sie auch mit der Highbury Formation auf dem Festland von British Columbia unter dem Tiefland von Fraser überein. Diese Formationen sind möglicherweise Überbleibsel von seichten Meeres- oder Hochgrund Sediment, welche ehemals vor über 100 ka die Paläobecken der Meerenge von Georgia und Puget säumten, dann aber durch spätere Vereisungen fast ganz zerstört wurden. Während dieser Zeit war das Meeresniveau wohl 10 m höher als heute. Die mittlere Schwemmland-Einheit enthält fünf Pollen-Zonen, deren Unterschiede vor allem durch Veränderungen in den Windungen eines Gezeitenflusses erklärt werden können. Fast in dem gesamten Beleg findet man mehr Douglas-Tannen-Pollen als in dem modernen Pollen-Vorkommen um die untersuchten Gebiete, was anzeigt, dass das Paläoklima mindestens genauso warm und trocken wie das gegenwärtige war.

## INTRODUCTION

The Muir Point Formation is a Pleistocene interglacial sequence which underlies two major glacial formations. It was named by Hicock (1980), and formalized by Hicock and Armstrong (1983) who established its holostratotype at Muir Point, west of Victoria, and its parastratotype at Cordova Bay, north of Victoria, along the southern shore of Vancouver Island (Fig. 1). Later Alley and Hicock (1986) documented the palynology of the formation and concluded that it was deposited under climatic conditions at least as warm as present. However, the age of the Muir Point Formation remained elusive and correlation with sediments in adjacent northwestern Washington State was inconclusive. This paper briefly summarizes current knowledge of the Muir Point Formation and discusses the significance of recent paleomagnetic information showing that the lower part of the formation has normal polarity (E. Irving and J. J. Clague, Geological Survey of Canada, oral communication, 1988).

## LITHOSTRATIGRAPHY AND FACIES

The Muir Point Formation is sandwiched unconformably between glacial formations and contains five units with conformable contacts between them (Hicock and Armstrong, 1983; Alley and Hicock, 1986). At the base is cross-bedded deltaic and (or) channel rusty gravel (Fig. 2) containing lenses of



FIGURE 1. Location map showing southwest British Columbia and northwest Washington State. MP: holostratotype at Muir Point; CB: parastratotype at Cordova Bay.

Carte de localisation montrant le sud-ouest de la Colombie-Britannique et le nord-ouest de l'état de Washington. MP: holostratotype de Muir Point; CB: parastratotype de Cordova Bay.

organic-rich silt and casts of logs and branches. This is overlain by a floodplain sequence of interbedded organic-rich silt and sand, with detrital peat, scattered gravel lenses, and abundant plant macrofossils (Fig. 3). In the middle of this sequence is 1-2 m of compact woody autochthonous peat (Fig. 4). Alluvial fan sandy gravel with lenses of coarse gravel and debris flow diamicton overlies the organic unit (Fig. 4). This is capped by fluvial sand.

Similar stratigraphic position and lithologies suggest that the Muir Point Formation correlates with Highbury Sediments buried under Fraser Lowland (Hicock and Armstrong, 1983), but dating control and pollen studies are lacking for Highbury Sediments. If the correlation is correct a floodplain — coastal plain — marine facies sequence may have developed from either side of the ancestral Strait of Georgia basin (Fig. 1). These formations may have formed shallow marine or subaerial shelves rimming the basin, whose sediment was removed by later glaciations. If sediment filled the basin it may have supported an extensive interglacial ecosystem.

## PALYNOSTRATIGRAPHY AND PALEOECOLOGY

Five pollen zones are recognized within the organic-rich floodplain unit of the Muir Point Formation (Fig. 5) and represent mainly changes in edaphic conditions resulting from tidal river meander shifts (Alley and Hicock, 1986). Zone 1, based on one sample of peaty sand, is characterized by Douglas fir (*Pseudotsuga menziesii*). Zone 2 (peaty silt) is dominated by grass (Gramineae), Douglas fir, and western red cedar (*Thuja plicata*) which imply grassy floodplain near the upstream end of a tidal channel or flat (as indicated by rare marine dinoflagellate cysts). Douglas fir and cedar probably grew on adjacent uplands and in stands scattered across the floodplain. This is followed by zone 3 (organic-rich silt) of mainly alder (*Alnus*), cedar, Douglas fir, and grass representing a shift of the estuarine channel and the establishment of a swampy floodplain ecosystem. Douglas fir, cedar, western hemlock (*Tsuga heterophylla*), alder, maple (*Acer*), and aquatic plants characterize zone 4 (autochthonous peat) which represents a swamp that formed on the floodplain.



FIGURE 2. Lowest unit of cross-bedded channel sand and gravel at Cordova Bay (pick is 43 cm long).

Unité inférieure de sable et de gravier à stratification entrecroisée à Cordova Bay (le pic mesure 43 cm).



FIGURE 3. Macrofossils in interbedded organic-rich silt, sand and gravel of the floodplain unit at Muir Point (knife is 20 long).

*Macrofossiles dans le silt, sable et gravier interstratifié riche en matière organique de l'unité de plaine d'inondation à Muir Point (le couteau mesure 20 cm).*



FIGURE 4. Compact, fissile autochthonous peat of a floodplain swamp (layered dark material in middle) between interlayered organic-rich floodplain silt and sand (below), and mixed alluvial fan gravel and debris flow diamicton (lighter sediment, above) at Muir Point (knife at centre is 20 cm long).

*Tourbe autochtone fissile et compacte d'un marécage de plaine d'inondation (matériel lité foncé au centre) entre un silt et un sable interlités de plaine d'inondation riche en matière organique (en-dessous) et un gravier de cône de déjection et un diamicton issu de coulée boueuse (sédiments plus clairs au-dessus) à Muir Point (le couteau au centre mesure 20 cm).*

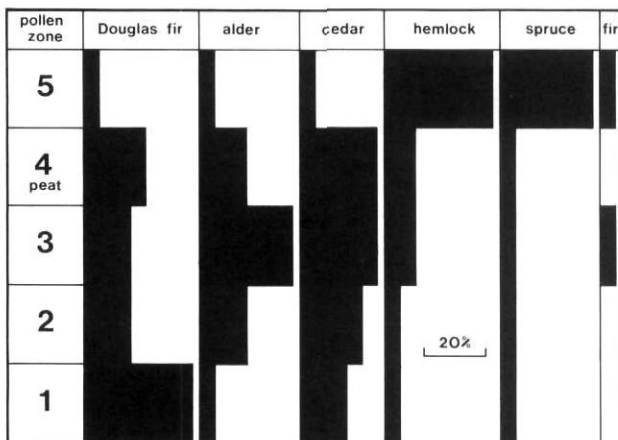


FIGURE 5. Tree pollen of the Muir Point Formation. Abundances of key types have been visually averaged (to nearest 5% from curves in Alley and Hicock, 1986) for five pollen zones within the floodplain unit. Bar scale represents 20% of total pollen counted for each zone (excluding aquatics, semi-aquatics, and spores). No vertical scale.

*Le pollen arboréen de la Formation de Muir Point. On a fait la moyenne à l'œil de l'abondance des types clés (à 5% près des courbes de Alley et Hicock, 1986) de cinq zones polliniques à l'intérieur de l'unité de plaine d'inondation. L'échelle graphique représente 20% de la totalité des grains de pollen comptés dans chaque zone (excluant les plantes aquatiques et semi-aquatiques et les spores).*

Zone 5 (mud) is dominated by spruce (*Picea*), western hemlock, and fir (*Abies*), with marked declines in Douglas fir, cedar, and alder. This zone, in contrast to the others, represents a major change in forest structure which suggests a climatic shift to moister and (or) cooler conditions.

### REGIONAL CORRELATION AND AGE

Similar stratigraphic position and lithologies suggest that the Muir Point Formation correlates with the Whidbey Formation of northwest Washington State (Hicock and Armstrong, 1983). Palynological correlation, on the other hand, is equally valid with either the Whidbey Formation or one of the earlier inter-

glacial formations of that area (Alley and Hicock, 1986). Amino acid ratios on wood from the Muir Point Formation do not aid correlation because they vary greatly and are considered invalid (Hicock and Rutter, 1986).

Recent paleomagnetic studies offer additional information. The lowest exposed interbedded sandy silt and silty sand (below peat) in the Muir Point Formation were analyzed along the base of the holostatotype section by E. Irving and J. J. Clague of the Geological Survey of Canada. Irving (oral communication, 1988) issued the following statement: "The magnetizations at three sites in the Muir Point Formation, spanning 250 m between 1-10 m above beach level, have normal polarity. They are single component magnetizations with a mean direction coincident with a geocentric axial dipole field and hence no inclination erratics are present." This indicates that they were formed within the Brunhes Normal Polarity Chron (790 ka BP to present; Johnson, 1982) unless sediments above the peat are reversely magnetized, which is unlikely.

In adjacent Puget Lowland all pre-Whidbey Formation interglacial sediments have reversed polarity, indicating that they belong to the Matuyama Reversed Polarity Chron (2.48-0.79ma BP; Easterbrook, 1986, 1987a, 1987b; Easterbrook *et al.*, 1981, 1988; Westgate *et al.*, 1987). In con-



trast, the Whidbey Formation is normally magnetized. Therefore, unless there are other, unrecognized interglacial formations in northern Puget Lowland, the Muir Point and Whidbey formations are probably correlative based on: similar polarities, palynology, lithofacies, stratigraphic position, and their ages exceeding the range of radiocarbon dating. However, it is still possible that the Whidbey and Muir Point formations are of different ages within the Bruhnes Normal Polarity Chron.

Amino acid ratios on marine shells from the Whidbey Formation suggest an age of about 100 ka BP (Easterbrook and Rutter, 1981, 1982; Easterbrook, 1986, 1987a, 1987b). The actual age, however, is critically dependent on temperature and pH histories of the fossils analysed, which are poorly known in this area (Rutter *et al.*, 1985). Considering this, the age estimate could be minimum and, therefore, could assign the Whidbey (and Muir Point) formations to the last interglaciation and to marine oxygen isotope stage 5.

### PALEOCLIMATIC RECONSTRUCTION

The abundance of Douglas fir (a poor pollen producer) in the four lower pollen zones of the Muir Point Formation indicates an interglacial climate at least as warm and dry as present on the southern end of Vancouver Island (Alley and Hicock, 1986). Similarly, Heusser (1977) and Heusser and Heusser (1981) concluded that the Douglas fir-alder maxima of the Whidbey Formation represent conditions of warmth comparable to western Washington State today. The occurrence of marine dinoflagellate cysts within the Muir Point Formation suggest that interglacial sea level could have been higher (10 m relative to the land) than at present, if the assumption is made that negligible tectonic uplift has occurred since the last interglaciation.

The Muir Point Formation sections occur within the Coastal Douglas fir vegetation zone with a mean July temperature of 16-19°C (Krajina, 1969). High abundances of Douglas fir and alder pollen at several levels in the Muir Point Formation (even higher than in modern pollen rain at the study sites; Alley and Hicock, 1986) imply that mean July paleotemperature was also similar to present, probably 19°C or more during some time intervals represented by the sediments. Following the warm interval, the uppermost pollen zone indicates that climate became wetter and/or cooler, perhaps signalling the onset of glaciation.

### CONCLUSIONS

The Muir Point Formation is probably the stratigraphic equivalent of the interglacial Whidbey Formation of northwest Washington State. It was probably formed during the last interglacial and climatic maximum of the Late Pleistocene in southwest British Columbia under conditions at least as warm and dry as present. Mean July paleotemperature at the southern end of Vancouver Island may have exceeded 20°C at times. The Muir Point Formation may have formed a sediment shelf along the western side of an ancestral Strait of Georgia. Actual age determination of the formation will probably depend on thermoluminescence dating of its mineral grains.

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