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EVIDENCE OF MIDDLE WISCONSINAN CLIMATE FROM THE PURCELL TRENCH, SOUTH CENTRAL BRITISH COLUMBIA

GEOLOGICAL SURVEY

by

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Evidence of Middle Wisconsinan climate from the Purcell Trench, south central British Columbia

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ABSTRACT

A paleosol and organic-rich horizons exposed in Bessette Sediments near Meadow Creek, south central British Columbia, were investigated to determine the nature of Middle Wisconsin climate. The paleosol is at least 42 000 years old and formed on a paleoslope adjacent to some precursor to Meadow Creek. On higher parts of the paleoslope, soil development occurred under locally dry conditions and regular influxes of eolian material. This part of the paleocatena is similar to modern Luvisolic or Chernozenic soils in warmer/drier parts of British Columbia. Lower on the paleoslope the paleosol resembles a regosol that formed near the base of a slope marginal to a floodplain.

Palynomorph assemblages from the organic-rich horizons are grouped into two assemblage zones. MC 1 is approximately 42 000 years old and is dominated by arboreal pollen, mainly Picea. MC 2 (approximately 34 000 years old) has a preponderance again of Picea but in conjunction with significant amounts of Tsuga heterophylla. Palaeoclimatic implications of the assemblages are that conditions at 42 000 years ago were at least 3°C cooler than present but by 34000 years ago had ameliorated to similar to or only slightly cooler than present.

INTRODUCTION

Sediments of Olympia nonglacial interval age are exposed in a borrow pit on the east side of Meadow Creek, a tributary to Duncan River in the Purcell Trench of south central British Columbia (Fig. 1). These sediments (Bessette Sediments) were first described by Fulton (1968) who correlated them with other deposits in the Pacific Northwest of Olympia "Interglaciation" age and deposits elsewhere in North America which are of Middle Wisconsinan age (Table 1).

The stratigraphy of the site (here referred to as Meadow Creek site) is well known and the Middle Wisconsinan age of the Bessette Sediments is clearly demonstrated by radiocarbon dates on the enclosed abundant organic materials. It is the purpose of this paper to derive evidence of Middle Wisconsinan climate in south central British Columba through pollen analysis of the organic-rich beds and by analysis of the pedological characteristic of a paleosol developed on a till underlying the Bessette Sediments.

CLIMATE, VEGETATION AND SOILS

Meadow Creek site is situated on the western edge of the Purcell Trench at an elevation of approximately 600 m, with the Purcell and Selkirk Mountains rising steeply to more than 3 000 m on either side. These dramatic changes in relief have a significant influence on the character of climate, vegetation and soils over relatively short distances.

Extant vegetation in the Purcell Trench belongs to the Interior Western Hemlock Biogeoclimatic Zone, in which western hemlock (*Tsuga heterophylla*) is the climax species (Krajina 1969). The zone extends from valley bottom to altitude 1 200 m, above which the Engelmann Spruce/Subalpine Fir followed by the Alpine Tundra Biogeoclimatic Zones occur. The dominant conifers and their associates for these zones and two other neighbouring zones are summarized in Table 2 along with precipitation and average July temperatures.

Deciduous trees commonly occurring along streams and other moist sites in the study area are paper birch *(Betula papyrifera)*, Sitka alder *(Alnus sinuata)*, Douglas maple *(Acer glabrum)*, and poplars including aspen *(Populus tremuloides)*, black cottonwood *(P. trichocarpa)* and balsam poplar *(P. balsamifera)*. Patches of grassland are found along the floodplains of Meadow Creek and the adjacent Duncan River. In these areas sedges (Cyperaceae) and grasses (Gramineae) are locally dominant, whilst grasses and sage *(Artemisia* sp.) are common on dry, south-facing slopes of the river terraces.

The predominant soil in the vicinity of Meadow Creek is a Humo-Ferric podzol resulting from high effective precipitation, acid forest litter and coarse, textured parent materials. At lower elevations in the Interior Western Hemlock Zone, Dystric

Brunisols prevail (Wittneben and Lacelle 1978). Gleysols and Humic Regosols are common along poorly drained parts of the floodplains.

STRATIGRAPHY

The stratigraphy of the Pleistocene sediments at Meadow Creek is summarized in Figure 2. Since the lithology and age of these sediments has been reported previously (Fulton 1968, 1975b) we concentrate here on the environments of deposition and soil formation, and on the age relationships between the various facies of the Bessette Sediments.

The oldest deposits exposed at the site are the till (unit 1, Fig. 2) and gravel belonging to the Okanagan Centre Drift. Next in the succession are about 10 m of interstratified autochthonous woody peat, silt, sand and gravel (units 2, 3 and 4), although only the upper 5 m of sediments were exposed at the time of sampling. On the basis of their lithology and the presence of current bedding and cut and fill structures the units are regarded as the overbank and channel deposits of an aggrading floodplain. The phase of deposition of unit 2 commenced before 43 800 ± 800 yr BP (GSC - 740) and deposition of unit 4 ended after 42 300 yr BP (Fulton 1968).

Humic colluvium (unit 5) mantling the paleoslope adjacent to the old channel interfingers with the muds and peats forming unit 4. This stratigraphic continuity is borne out by a date of 41 800 ± 600 yr BP (GSC - 716) obtained on a stump rooted in the colluvium. The latter unit merges further up the relict slope with a paleosol (unit 6) and 20-30 cm of brown, eolian silty sand (unit 7).

The paleosol, here named the Meadow Creek Paleosol, is exposed along about 120 m of the face in the borrow pit and is developed largely in the upper colluvially modified part of the Early Wisconsinan till. From a high point the paleoslope descends to the north and south, local slopes being as high as 4.5° on the south and 6° on the north. The southern slope is the longest (70 m) producing an asymmetrical slope profile. Altitude falls southwards about 3.5 m from the high point and northwards approximately 3 m.

Roots in the paleosol were dated at 41 900 ± 600 yr BP (GSC - 733) providing a minimum age for the soil and demonstrating that it was also forming in conjunction with the humic colluvium and alluvial unit 4. The eolian silty sand is regarded as part of the paleosol since it is partly oxidized and intermixed with the upper part of unit 6. Soil-forming processes probably affected the eolian deposit as it accumulated and as it buried the underlying soil. Although the source of the eolian material is not known it could have been blown up from an adjacent, seasonally bare, braided channel bottom that was partly bordered by a swampy floodplain in which muds and peats (unit 4) were being deposited.

These floodplain sediments, the humic colluvium and part of the paleosol are overlain by gravel that grades vertically into sand (unit 8). The latter unit is interpreted as the topset sequence of a delta fan that was possibly built at the mouth of a western tributary to Meadow Creek sometime after 41 800 ± 600 yr BP (GSC - 716).

Laterally the sandy facies of unit 8 intertongues with intercalated sand, silt and gravel (unit 9) containing leaf litter layers and thin allocthonous peats. Duncan Lake Tephra, dated at approximatley 34 000 yr BP (Westgate and Fulton 1975) occurs in the lower part of the unit. Unit 9 is interpreted as swampy floodplain deposit developed where drainage of the valley was impeded by fan deposition. Radiocarbon dates indicate that deposition continued until after 32 710 ± 800 yr BP (GSC - 493). The disturbance of bedding of this deposit and the presence of several wedge-shaped casts suggest that periglacial conditions prevailed after deposition of this unit.

In an exposure elsewhere in the borrow pit unit 9 is overlain by a few metres of gravel (unit 10) that contained wood dated 25 840 ± 320 yr BP (GSC - 715). Overlying this unit is the Kamloops Lake Drift of Late Wisconsinan age (unit 11). The genetic relationship between unit 10 and the deposits above and below it is unknown.

In summary, deposition of the Bessette sediments commenced prior to 43 800 yr B.P. and continued until sometime after 32 700 yr B.P., an interval of time correlative with the Olympia nonglacial interval (Fulton 1975a; Fulton and Smith 1978). Based on the stratigraphic evidence and dates, the paleosol and humic colluvium formed on a valley side adjacent to a floodplain in which unit 4 was deposited and in which units 2 and 3 had been laid down. The eolian silty sand, perhaps blown up out of the channel early during formation of unit 8, was deposited on the valley side and incorporated into the soil. Continued aggradation filled the channel and sand and gravel spread across the adjacent slope, burying the soil and eolian deposit. Advance of the Late Wisconsinan glaciers eroded part of the Bessette Sediments and deposited the Kamloops Lake Drift.

METHODS

Pollen

Complete systematic sampling of the Bessette Sediments for pollen analysis was prevented by the occurrence of several major beds of gravel and coarse sand in the middle portion of the section. The peat dated at 43 600 ± 700 yr B.P. in unit 2 (Fig. 2) was not accessible for sampling. Thus, only the Ah horizon of the paleosol and units 4, 5, 7 and 9 were sampled as potential pollen-bearing beds.

Sixteen surface samples were collected from moss polsters and open bogs in the five major vegetation zones occurring nearest to Meadow Creek site. Modern pollen spectra were obtained from the samples to aid in interpreting paleoclimate from the fossil spectra.

All Pleistocene samples were systematically treated with a modified laboratory procedure of Faegri and Iversen (1964). This includes treatment with HF to remove silicates, boiling in 10% KOH, followed by acetolysis. The method was modified slightly by the addition of a 7 minute treatment with Schulze Solution ($KClO_3$ in conc. HNO_3) to oxidize the humic material, and a final wash in 1% K_2CO_3 for not longer than 30 seconds (Alley 1979). After differential centrifuging, the residue was stained with Safranin O and mounted in polyvinyl alcohol. Treatment of the surface samples followed the unmodified laboratory procedure. Pollen identification was facilitated by reference to a modern collection from British Columbia.

In the calculation of the relative pollen frequencies (Figures 3 and 4) the cryptograms and aquatic and semi-aquatic pollen (including Cyperaceae) are omitted from the pollen sum. Exclusion of the Cyperaceae serves to reduce the effect of over-representation of the local sedge-bog communities on the regional pollen frequencies.

Paleosol

The paleosol was described at eleven intervals along the section. Two profiles (Fig. 2) were chosen for detailed study so that some estimate of the range of soil development could be obtained. Profile 1 is near the highest exposure of the soil, and is a potentially well-drained ridge crest profile; profile 2 is the lowest and potentially wettest part of the paleocatena that was accessible.

Analyses of all the apparent soil horizons were made following methods by McKeague (1976): pH in 0.01 M $CaCl_2$; total carbon by dry combustion in a LECO induction furnace; nitrogen by the macro-Kjeldahl method; cation exchange capacity (CEC) and exchangeable cations in NH_4OAc at pH7; Fe and Al using the sodium pyrophosphate method; and particle size by pipette analysis. Thin sections of the same horizons for soil micromorphology studies were prepared according to Dalrymple (1957).

CHARACTERISTICS AND DEVELOPMENT OF THE PALEOSOL

Analyses

Morphological evidence of soil development in profile 1 includes the presence of dark humic layers, fine roots, blocky structure and clay skins on ped faces and on coarse fragments and general decalcification (Table 3). Dark humic layers, fragments of charcoal, stumps and roots in place, gley colours and some decalcification provide some evidence in profile 2.

Chemical and physical analyses (Table 4) do not illustrate soil development as clearly as the field evidence. Particle size analyses of the fine fraction largely reflect sedimentological differences in the parent materials rather than being a consequence of pedogenic differences. For example, layers 1-3 in profile 1 and layers 3-4 in profile 2 have developed in silt, whereas the lower layers have a much higher sand content. Thus, the sedimentological changes make horizon comparisons difficult.

Generally, however, the chemical analyses provide only limited evidence of pedological changes down the profiles. In profile 1 there are slight decreases in percentages of C, N and Fe and in C.E.C. from layer 1 to 4. Layer 5 has a high pH and a Ca content as a consequence of $CaCO_3$ lenses. Profile 2 displays only minor decreases in percentages of C and Fe from layer 3 to 6.

Micro-fabric data indicate that, apart from traces of organic matter, layers 1-3 (profile 1) have little pedological modification, since there are no structural aggregates and little weathering/reorganization of the clay fraction. On the other hand, layer 4 is characterized by illuviation cutans, reorganized clay matrix, well weathered rock clasts and a fabric similar to a soil B horizon. Secondary deposits of $CaCO_3$ in the voids of layer 5 probably resulted from decalcification of layer 4, although the fabric of layer 5 is generally that of an unleached C horizon.

The micro-fabric of profile 2 shows little evidence of soil development since the material is dense with very few voids, structural aggregates are absent and there is little evidence of the reorganization of the clay fraction.

Soil Formation

Layers 1-5 (profile 1) have been given tentative soil horizon designations (Table 3). The Ah horizon, however, is not well expressed, either because of postburial change due to pressure or immature soil development in an eolian deposit that was quickly buried.

The Btj and Cca horizons of profile 1 are similar to those of modern Luvisolic or Chernozemic soils. The nearest modern soil analogue to this profile in British Columbia would be those soils occurring in the forest-grassland transition zones in the drier central interior of the Province. Such an interpretation is supported by the presence of the eolian silty sand in the A horizon.

Layers 3 to 6 of profile 2 are also assigned soil horizon names (Table 3), but this profile bears little resemblance to a subaerially developed soil. Although roots and woody plants are present in the upper layers the field morphology, physical analyses and micro-fabric show that the material more closely resembles a colluvial/alluvial sediment than a soil which is consistent with the sedimentological interpretation. Profile 2 is thus regarded as a regosol formed on the margin of a floodplain, or at the base of a slope marginal to the floodplain, when sedimentary unit 4 was being laid down.

Because of its better development, soil profile 1 is used for reconstructing environmental conditions. Modern soils in the Meadow Creek area have Podzolic or Brunisolic profiles related to the presence of dense forest cover with subhumid to humid moisture regimes. The paleosol, however, is similar to Luvisolic or Chernozemic soils in the warmer/drier parts of British Columbia where subhumid to semiarid moisture conditions prevail. It is unlikely, however, that this evidence alone would imply that the climate approximately 41 900 yr B.P. and earlier in the Meadow Creek area was drier and possibly warmer than present. The deposition of eolian silty sand on the sunny south-facing paleoslope probably induced locally drier conditions and thus the paleosol is unlikely to be representative of regional soil and climatic conditions. This interpretation is supported by palynological evidence presented below.

PALYNOLOGY

Modern Pollen Spectra

Modern pollen rain for sixteen sites within the five major vegetation zones is presented in Figure 3. These spectra reveal a number of regional relations: (1) Arboreal spectra are highest and dominant in the Interior Douglas-fir, Interior Western Hemlock and Engelmann Spruce/Subalpine Fir Zones; (2) *Picea* (both *P. engelmannii* and *P. glauca*) is best represented in the upper three zones and reaches a maximum in the Engelmann Spruce/Subalpine Fir Zone; (3) Pine is present in all zones but is best represented in the lowest and the two uppermost zones; (4) *Tsuga heterophylla* reaches a maximum in the Interior Douglas-fir and the Interior Western Hemlock Zones; (5) *Pseudotsuga* is under-represented throughout, even though it is an important tree in the lower three zones, a conclusion that accords with Alley (1979), Baker (1976) and Mack *et al*. (1978a, 1978b, 1978d, 1979); (6) Arboreal pollen from lower zones is transported into the Alpine Tundra.

Non arboreal pollen types are generally not well represented in any of the zones, although are locally important in the Ponderosa Pine/Bunchgrass Zone, where the Gramineae and *Artemisia* are very important at some sites. Mack *et al*. (1978a) also find the association of high pine and grass pollen in the *Pinus ponderosa* - *Festuca idahoensis* and *P. ponderosa* - *Agropyron spicatum* plant associations in eastern Washington and northern Idaho.

The above data, in particular the high percentage of arboreal pollen of most taxa in all vegetation zones and the transport of this pollen into the Alpine Tundra Zone, make interpretation of the fossil spectra in mountainous areas problematic. This would be especially true for fossil sites in the current treeline and alpine areas. Indications are, however, that sites in valley bottoms may not be unduly complicated by pollen transported from higher vegetation zones since wind movements are largely upslope and thus the spectra generally record the local vegetation (Markgraf 1980). The fossil spectra at Meadow Creek may also reflect a measure of the regional vegetation because both allochthonous and autochthonous peats were sampled. Even the latter may be expected to contain some long distance pollen that were deposited during periods of flooding in the spring thaw.

Several key taxa or assemblages in the modern spectra may serve as general climatic indicators. Relatively high percentages (10%) of *Pseudotsuga/Larix* pollen occurring in conjunction with high amounts of *Artemisia* and Gramineae pollen may be indicative of the warmer/drier conditions found in the Ponderosa Pine/Bunchgrass Zone. Significant amounts (30%) of *Tsuga heterophylla* pollen in association with low frequencies of *Pseudotsuga/Larix* and *Thuja/Juniperus* types are characteristic of the two samples from the Interior Douglas-fir Zone. Moister climatic conditions than occurring in the latter vegetation zone may be indicated by relatively high amounts (20-40%) of *Tsuga heterophylla* pollen, significant *Thuja/Juniperus* and very low *Pseudotsuga/Larix* pollen types found in the Interior Western Hemlock Zone. High percentages of pine and spruce pollen and low frequencies of other arboreal taxa appear to be characteristic of the Engelmann Spruce/Subalpine Fir Zone and thus indicate cooler and moist conditions. Although no arboreal pollen assemblages can be readily used to infer cold climatic conditions occurring in the Alpine Tundra Zone, the presence of pollen of *Valeriana sitchensis* by itself may do so.

Fossil Pollen Spectra

Pollen recovery from all but the peaty layers in units 4 and 9 was poor. Highly degraded pollen occurred in the colluvium of unit 5 and the Ah horizon of the paleosol, but, only parts of the more resistant grains such as *Picea, Pinus, Alnus* and *Artemisia* could be recognized. Thus no counts were attempted in these units.

The remaining fossil spectra are divided into two assemblage zones designated MC1 and MC2 (Fig. 4). The earliest zone commences before 42 300 ± 700 and extends to just after 42 000 years ago. The spectra in this assemblage will in part reflect plants growing on the adjacent paleoslope since it was demonstrated earlier that units 4, 5 and 7 are contemporaneous. The age of pollen assemblage zone MC2 is approximately 34 000 yr B.P.

Pollen assemblage zone MC1 is dominated by arboreal pollen of which *Picea* is the most important, reaching 74% of the total in lower levels although there is considerable variability elsewhere in the zone. The normally overrepresented *Pinus* is relatively low and reaches only 24% in the lower part of the zone whereas other coniferous taxa are very poorly represented, with *Pseudotsuga/Larix* the most consistently occurring of these but reaching a maximum of only 5% of the base. *Salix* is important in the upper part of the zone but exhibits strong fluctuations in frequency.

Nonarboreal pollen form a relatively unimportant part of MC1 with pollen of *Artemisia* and the Cruciferae, the Gramineae and the Rosaceae being the most significant. It is interesting to note that increases in the frequency of *Artemisia* and the Gramineae parallel increases in *Salix* and decreases in *Picea*. Although pollen of the Cyperaceae are omitted from the calculation of the pollen frequencies they are the most significant element of the nonarboreal pollen. Peaks in the frequency of the Cyperaceae are generally coincident with those in *Salix* and *Artemisia*.

Pollen of *Picea* remains the dominant arboreal type in pollen assemblage zone MC2 although *Tsuga heterophylla* is also well represented and forms almost 20% of the total in the lowermost part of the zone. Apart from *Pinus*, which forms 5% or less thoughout the zone, other arboreal taxa are virtually absent. Of the nonarboreal pollen, only the Gramineae are significant, but these generally form less than 10% of the assemblage.

DISCUSSION

Paleocological Implications of the Fossil Spectra

In view of the alluvial origin of the pollen-bearing beds, interpretation of the significance of the pollen assemblages at Meadow Creek is complicated by the likely presence of pollen transported from upper parts of the drainage basin and by pollen recycled from older sediments. This problem is compounded by the inability of present palynological methods to determine species of the genera *Pinus*, *Picea* and *Artemisia* which are important components of the pollen assemblages at Meadow Creek. These genera have considerable ecological amplitudes in British Columbia ranging from the relatively warm, dry Ponderosa Pine/Bunchgrass Zone to the cold Alpine Tundra Zone and into the arctic steppe tundra.

The fossil spectra in MC1 and MC2 are not replicated in the modern spectra. The frequency of *Picea* pollen is anomalously high, for not even in the Engelmann Spruce/Subalpine Fir Zone where spruce is an important tree does pollen of this genus dominate the spectra (Fig. 3). It is possible that pollen of *Picea* is overrepresented since it can be easily identified even when badly degraded (Matthews 1974); the same is true of *Artemisia* which has a thick, resistant exine. The possibility that weathering of the pollen has occurred is borne out by the degraded condition of many pollen of the coniferous taxa, especially *Pseudotsuga/Larix, Tsuga, Thuja* and *Picea,* examined during the counting. This factor alone, however, is not sufficient to explain the predominance of *Picea* in the pollen assemblages. Other explanations may be that the pollen assemblages were derived from vegetation associations not occurring in the extant vegetation of the Canadian Cordillera or that they are similar to modern spectra from extant vegetation associations not examined by this or other studies in the Pacific Northwest.

The association of *Picea, Artemisia,* the Gramineae and haploxylon pine in Postglacial pollen assemblages of the Columbia Basin south of the study area, is interpreted as a vegetation mosaic of stands of conifers interspersed with open areas of grass and sage growing in steppe-tundra conditions (Mack *et al.* 1976). Although both haploxylon and diploxylon pine occur at Meadow Creek, the grains are too weathered to determine their individual frequencies. In view of the presence of more temperate arboreal types such as *Pseudotsuga/Larix, Tsuga heterophylla* and *Acer* in Pollen Zone MC1 the above interpretation is not appropriate for these spectra. Alpine to treeline conditions are not implied, because MC1 is not replicated in the modern spectra from the Alpine Tundra Zone (Fig. 3), nor have similar assemblages been reported from the alpine of nearby areas (Heusser 1973).

An explanation for the significant percentages of *Artemisia* and the Gramineae in MC1 would be to interpret the assemblages in terms of warm/arid conditions such as encountered in the Ponderosa Pine Bundgrass Zone of adjacent areas. However, modern pollen spectra from this plant association (Fig. 3) and from similar associations in nearby areas show that although significant frequencies of pollen of *Pinus* occur with *Artemisia* and the Gramineae, pollen of *Picea* is very low or absent (Mack and Bryant 1974; Alley 1976).

Any interpretation would need to take account of the set of geomorphological and edaphic conditions operating during the interval represented by pollen Zone MC1. Evidence presented above indicates that a floodplain lay adjacent to a valley-side slope (possibly a terrace escarpment) and that conditions on the floodplain were dry enough that silt could be blown up on to the developing soil. Deposition of the eolian silty sand and relative aridity on the floodplain may have favoured the periodic expansion of grasses and sagebrush; at other times conditions on the floodplain favoured the spread of spruce. Such variations are supported to some extent by the out of phase peaking between *Artemisia*/Gramineae and *Picea* in pollen Zone MC1.

The spruce species represented by the *Picea* pollen is unknown although the pollen assemblage and the geomorphic setting suggests several interpretations:

(1) the treed areas of the site were dominated by Engelmann spruce which is a common component of the forested valleysides today and which is well established on alluvial floodplains where cones and seeds are brought in by floods (Krajina 1969);

(2) white spruce (*Picea glauca*) was common since this establishes more readily in submontane and lowland habitats, especially where frost pockets occur, or on floodplains which are flooded with cold water mixed with ice. In these areas it may mix with Engelmann spruce, but the latter is the dominant species (Krajina 1969); and

(3) pollen of black spruce (*Picea mariana*) may be present in conjunction with white spruce, growing together in a pocket of the Boreal White and Black Spruce vegetation Zone, intrusions of which today occur south of the 50°N parallel of latitude in the adjacent Rocky Mountain Trench (Krajina 1969). In such an association Engelmann spruce is unlikely to have been present because it usually does not grow in the Boreal White and Black Spruce Zone.

In view of the presence of pollen of *Tsuga heterophylla*, *Thuja plicata* and *Acer*, interpretation 3 is unlikely since these trees do not grow in association with black spruce. Either (1) or (2) is possible, although in view of the floodplain setting, a mixture of both interpretations is more likely. Western red cedar (*Thuja plicata*) is a probable associate to spruce since it enjoys a floodplain habitat and the presence of minor amounts of its pollen is indicative of stands of cedar (Mack *et al.* 1978a).

Although *Pseudotsuga/Larix* pollen occur consistently in pollen Zone MC1, but only forming less than 5% of the total pollen count, they may be significant to the paleoecological and paleoclimatic interpretations. It was impossible to differentiate the pollen of *Pseudotsuga* from *Larix* using a conventional light microscope. However, if the pollen in zone MC1 is *Larix*, then the contributors could have been western larch (*Larix occidentalis*), subalpine larch (*L. lyallii*) or tamarack (*L. laricina*). The latter species presently grows in the Boreal White and Black Spruce and Sub-boreal Spruce vegetation zones and for the reasons given for discounting the presence of black spruce in MC1, pollen of tamarack is also unlikely to have been present in the pollen zone. Subalpine larch is restricted to the upper parts of the Engelmann Spruce Subalpine Fir vegetation zone where it grows well on calcareous lithosols and rendzina soils, particularly in the Rocky Mountains (Krajina 1969). The presence of pollen from this species is also unlikely in pollen Zone MC1 because of the lack of "alpine" aspect to the microflora and the lack of its preferred soils on valley bottom and valley sides in the study area.

The above discussion suggests that the *Pseudotsuga/Larix* pollen present in pollen Zone MC1 is *Pseudotsuga menziessii* and/or *Larix occidentalis*. It is interesting to note that the distribution of western larch in the extant vegetation is in the Interior Douglas-fir Zone, drier parts of the Interior Western Hemlock Zone and moister parts of the Ponderosa Pine-Bunchgrass Zone in all of which Douglas-fir is an important tree. Although the two species occur together in these three vegetation associations, Douglas-fir extends into the Englemann Spruce Subalpine Fir and the Cariboo Aspen-Lodgepole Pine-Douglas-fir zones, where western larch does not. The low frequency of pine pollen in MC1 suggests that if the pollen is from Douglas-fir then it was not growing in the Cariboo vegetation association since this produces pollen spectra heavily dominated by *Pinus* (Bassett and Crompton 1967).

The most satisfactory ecological interpretation for pollen Zone MC1 is one that takes account of plants that locally could tolerate floodplain conditions and others that tolerated relatively drier soils on the adjacent terrace slope. It is possible that spruce dominated the floodplain and Douglas-fir and/or western larch formed stands on the drier adjacent slopes subject to regular inundations of eolian silt. Larch, however, does not tolerate dry habitats nor is it likely to be associated with sagebrush. Douglas-fir was probably the edaphic climax on the drier sites even though its pollen frequency is very low, whereas the floodplain and distant valley sides were dominated by spruce, perhaps growing in a plant association similar to that of the Engelmann Spruce Subalpine Fir zone.

Spruce continued to be an important tree in pollen Zone MC2, although the upsurge in pollen of western hemlock (*Tsuga heterophylla*) indicates that a significant change occurred in forest structure. Studies south of Meadow Creek show that even where western hemlock is the dominant tree cover, its pollen forms a minor part of the pollen fall out (Mack *et al*. 1978a, 1978b, 1978c), although in coastal areas much higher frequencies are encountered (Alley 1979). Thus, western hemlock also must have formed a significant part of the forest structure.

Modern pollen spectra (Fig. 3) show that pollen of western hemlock is best represented in the Interior Douglas-fir and Interior Western Hemlock vegetation zones where the tree is the climax species. Hemlock, however, is adapted to a long vegetative season and thus grows poorly in the Engelmann Spruce/Subalpine Fir vegetation zone where spruce is the dominant tree (Krajina 1969) and where its pollen is highest in the modern pollen spectra. In view of its very low nutritional requirements, western hemlock is unlikely to have been growing on the floodplain during the interval occupied by MC2, since seepage and other mobile waters would have contained more nutrients than the trees could tolerate (Krajina 1969). It is thus possible that a vegetation association similar to the present prevailed with hemlock growing along valley bottom above flood-plain level and spruce occupying adjacent higher valley sides and the floodplain. In the latter area spruce may have formed large stands growing amongst extensive grassed areas as suggested by significant amounts of pollen of the Gramineae which dominate the nonarboreal pollen in MC2.

Correlation

It was shown earlier that the Bessette Sediments were deposited during the Middle Wisconsinan Olympia nonglacial interval and thus have lithostratigraphic correlatives in southwestern British Columbia and adjacent Washington. The sediments are also correlative with unnamed clay and silt deposited approximately 43 000 yr B.P. near Babine Lake in central British Columbia (Harington *et al*. 1973).

Little information is available for the age and character of paleosols in western Canada. However, the age of the Meadow Creek Paleosol suggests a possible correlation with unnamed paleosols formed during the Olympia nonglacial interval:

(1) South of Sweetsbridge on the Salmon River where a brown paleosol is developed on angular colluvium underlying Fraser Glaciation till (Fulton 1975a),
(2) Near Okanagan Centre a brown chernozomic soil developed in eolian sand underlies Kamloops Lake Drift and overlies Okanagan Centre Drift (Fulton 1975a; Fulton and Smith 1978),
(3) A paleosol dated at approximately 35 000 yr B.P. is formed in Cowichan Head Formation (Middle Wisconsinan) at Cowichan Head (Fulton and Halstead 1972) and another dated at more than 39 000 yr B.P. developed on Dashwood Drift (Early Wisconsinan) at Dashwood (Alley 1979), both sites on Vancouver Island.

Unfortunately no analytical study has been made of the above paleosols and thus the environments in which they formed are unknown.

Fossil pollen spectra from the Bessette Sediments at Meadow Creek have ages of approximately 42 000 yr B.P. (MC1) and 34 000 yr B.P. (MC2). The older pollen zone is thus correlative with pollen assemblage zone DW1 on Vancouver Island (Alley 1979), Zone 5 in western Washington (Heusser 1977) and is roughly the same age as a pollen assemblage from the unnamed clay and silt near Babine Lake (Table 5). Pollen assemblage zone MC2 is approximately the same age as DW2 on Vancouver Island and the boundary between Zones 3 and 4 in western Washington. There are significant differences between the character of assemblages at

Meadow Creek and their time equivalents elsewhere in British Columbia and western Washington. These differences, in the case of the coastal areas, undoubtedly relates to topographic and climatic controls over vegetation associations, similar to the conditions prevailing today. However, the contrast between Meadow Creek and Babine Lake assemblages may reflect a set of climatic conditions that were peculiar to central British Columbia during the Olympia nonglacial interval (see below).

Paleoclimate

Evidence from the Meadow Creek site suggests the following:

(1) For an unknown interval before and after approximately 42 000 yr B.P., climate was cooler and/or moister than present. If the pollen assemblages in MC1 imply that a vegetation association similar to the present Engelmann Spruce-Subalpine Fir vegetation zone grew along valley bottom then average July temperatures may have been approximately 3°C cooler (Table 2). Geologic/pedologic and palynologic evidence strongly suggest that localized aridic soil conditions also prevailed; and

(2) By approximately 34 000 yr B.P. conditions had ameliorated to the extent that a vegetation association, in which western hemlock was an important element, was able to grow along valley bottom. In this respect vegetation may have had similarities with, but by no means was identical to, extant valley bottom vegetation. This could be interpreted in terms of an increase in average July temperatures by a few degrees above that inferred from pollen Zone MC1.

In general this supports the evidence previously derived for climate during the Olympia nonglacial interval. Fulton (1975a) and Fulton and Smith (1978) conclude from the character of sediments and plant and invertebrate remains that, for at least part of the interval in south central British Columbia, climate was similar to present. In southwestern coastal British Columbia, palynological assemblages have been used to infer that climate particularly around 32 000 yr B.P. may have been similar to that prevailing today (Pollen Zones DW-2 and DW-3; Alley

1979). Paleotemperatures derived by oxygen isotopic analysis of speleothems from a cave on Vancouver Island agrees with estimates of temperature from pollen spectra, although for the term of the Olympia nonglacial interval it is suggested that gradual cooling occurred from between 65 000 and 30 000 yr B.P. (Gascoyne *et al.* 1980).

These conclusions agree only in part with palynological evidence from western Washington. Heusser (1977) finds that at approximately 42 000 yr B.P. (upper Zone 5) climate was probably a few degrees cooler than present, but by 34 000 yr B.P. conditions were substantialy cooler, with average July temperatures 6 to 7°C lower than present. This was followed by a brief interval (Zone 3 of Heusser, 1977) when average July temperatures were again similar to upper Zone 5. More recent analysis of Quaternary pollen spectra from the northwestern coast of North America shows that relatively warm intervals (similar to present) occurred around approximately 60 000 yr B.P. and 30 000 yr B.P., with temperatures for the intervening interval generally a few degrees lower (Heusser *et al.* 1980).

Evidence from Babine Lake in northcentral British Columbia, however, indicates that shrub tundra conditions similar to alpine areas or the northern part of the Province may have prevailed approximately 43 000 yr B.P. (Harington *et al.* 1974). Babine Lake lies within the Sub-Boreal Spruce vegetation zone (Krajina 1969) and thus the presence of shrub tundra vegetation at that time would imply a significant departure (5-6°C) from present climatic conditions. It is possible that northern British Columbia recovered more slowly from the Early Wisconsinan glacial conditions than did the south and that near periglacial conditions may have persisted as far south as Babine Lake as late as approximately 43 000 yr B.P.

ACKNOWLEDGEMENTS

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N.F. Alley

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CAPTIONS

Tables

1. Major Wisconsinan lithostratigraphic units in south central British Columbia and their geologic-climate and time-stratigraphic equivalents

2. Dominant conifers and their associates in the major biogeoclimatic zones of south central British Columbia (source: Krajina 1969)

3. Generalized description of soil profiles examined in Meadow Creek paleosol. Location of soil profiles shown on Figure 2. Soil descriptions follow Canada Soil Survey Committee (1978)

4. Chemical and physical analyses of profiles 1 and 2 in Meadow Creek paleosol. Terminology after the Canada Soil Survey Committee (1978)

5. Correlation of Middle Wisconsinan pollen zones at Meadow Creek site with established zones in adjacent areas

Figures

1. Location of sites referred to in the text

2. Stratigraphy of Wisconsinan sediments at Meadow Creek site.

3. Modern pollen spectra from the major vegetation zones in south central British Columbia

4. Fossil pollen spectra from Bessette Sediments at Meadow Creek site

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YEARS B.P.	SOUTH CENTRAL BRITISH COLUMBIA	COASTAL BRITISH COLUMBIA	MID – CONTINENT OF U.S.A.
	Lithostratigraphic Units (Fulton, 1975a)	Geologic - climate Units (modified after Armstrong, 1984)	Time – Stratigraphic Units
	POSTGLACIAL SEDIMENTS	POSTGLACIAL	HOLOCENE
10	KAMLOOPS LAKE DRIFT	FRASER GLACIATION	LATE WISCONSINAN
20		26 000	
30	BESSETTE SEDIMENTS	OLYMPIA NON – GLACIAL INTERVAL	MIDDLE WISCONSINAN
40			
50	> 43800	> 62 000	
	OKANAGAN CENTRE DRIFT	SEMIAHMOO GLACIATION	EARLY WISCONSINAN

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

MAJOR WISCONSIN LITHOSTRATIGRAPHIC UNITS
IN SOUTH CENTRAL BRITISH COLUMBIA

COMPILED N.A.	C.D.O.	DATE
DRAWN M.B.	SCALE	
DATE Dec '84	PLAN NUMBER	
CHECKED	85–5	

Table...1

BIOGEOCLIMATIC ZONE, APPROXIMATE ELEVATION, PRECIPITATION AND AVERAGE JULY TEMPERATURES	DOMINANT CONIFERS (FIRST IS MOST IMPORTANT)	ASSOCIATES, OCCURRENCE USUALLY EDAPHICALLY CONTROLLED
Ponderosa Pine / Bunchgrass 270 - 750 m Precip. 190 - 360 mm Temp. 18 - 22° C	Ponderosa pine (*Pinus ponderosa*) Douglas - fir (*Pseudotsuga menziesii*)	Western red cedar (*Thuja plicata*) Western larch (*Larix occidentalis*)
Interior Douglas - fir 300 - 1350 m, depending on aspect Precip. 360 - 560 mm Temp. 17 - 21° C	Douglas - fir Ponderosa pine Western white pine (*P. monticola*) Western larch	Western red cedar White spruce (*Picea glauca*) Lodgepole pine (*Pinus contorta*) Grand fir (*Abies grandis*) Engelmann spruce (*Picea engelmannii*) Subalpine fir (*Abies lasiocarpa*) Western hemlock (*Tsuga heterophylla*)
Interior Western Hemlock 360 - 1260 m, depending on aspect Precip. 560 - 1700 mm Temp. 15 - 21° C	Western hemlock Douglas - fir Western larch Western red cedar Western white pine Lodgepole pine	Grand fir White spruce Engelmann spruce Subalpine fir Ponderosa pine Whitebark pine (*Pinus albicaulis*)
Engelmann Spruce / Subalpine Fir 1260 - 2250 m Precip. 410 - 1830 mm Temp. 12 - 16° C	Engelmann spruce Subalpine fir Lodgepole pine Western white pine Whitebark pine	Western hemlock Douglas - fir Western red cedar Mountain hemlock (*Tsuga mertensiana*) Limber pine (*Pinus flexilis*) Alpine larch (*Larix lyallii*)
Alpine Tundra Above 2250 m Precip. 700 - 2800 mm Temp. 7 - 11° C	Trees only in krummholz form include: Engelmann spruce Subalpine fir Whitebark pine Alpine larch	

TABLE 2

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

DOMINANT CONIFERS AND THEIR ASSOCIATES IN THE MAJOR BIOGEOCLIMATIC ZONES OF SOUTHCENTRAL BRITISH COLUMBIA (Source: KRAJINA, 1969)

COMPILED N. A.
DRAWN M.B.
DATE Nov '84
PLAN NUMBER 85-6
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Sedimentary Unit	Soil layer * (Horizon)	Soil description depth cm (below base of sedimentary unit 9)	
Soil profile 1			
7. Brown silty sand	1 (Ah 1)	0-3	Dark yellowish brown silt; friable with platy structure and fine roots and pores.
	2 (Ah 2)	3-13	Yellowish brown silt; firm with platy structure and fine roots and pores.
	3 (Ah 3)	13-23	Dark yellowish brown silt; firm and structureless with about 5 % fine gravel and fine roots and pores.
6. Oxidized diamicton	4 (IIBtj)	23-65	Yellowish brown sandy loam; friable with blocky structure, about 10 % gravel and thin clay skins.
1. Unoxidized diamicton	5 (IICca)	65-100+	Greyish brown silt loam; friable with blocky structure, about 10 % gravel and lenses of calcium carbonate.
Soil profile 2			
5 and 7. Brown silty sand	1 (-)	0-1	Chestnut red iron pan; hard and brittle.
	2 (-)	1-10	Grey stratified silt; traces of carbonized organic matter, strong effervescence.
	3 (Ah 1)	10-23 (in pockets)	Dark grey silt; very firm and structureless with fine charcoal particles and stumps and roots in place.
	4 (Ah 2)	10-28	Dark brown silt loam; very firm and structureless with fine charcoal particles and stumps and roots in place.
6. Weakly oxidized diamicton	5 (IIBg)	28-70	Dark greenish grey gravelly loam; very firm and structureless with some roots; weak effervescence.
	6 (IIICg)	70-100+	Olive grey gravelly, loamy sand; friable and structureless; weak effervescence.

* Soil layers with horizon designation given in brackets are used because in some cases they do not fit precisely with definitions used in the Canadian Soil Classification System (1978).

TABLE 3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

GENERALISED DESCRIPTION OF SOIL PROFILES EXAMINED IN MEADOW CREEK PALEOSOL. LOCATION OF SOIL PROFILES SHOWN ON FIGURE 2. SOIL DESCRIPTIONS FOLLOW CANADA SOIL SURVEY COMMITTEE (1978)

COMPILED N. A.
DRAWN M. B.
DATE Dec '84

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Layer (Horizon)	pH ($CaCl_2$)	C%	N%	C.E.C. me/100g	Exch. Ca	cations Mg	me/100g K	Na	Fe% (pyrophosphate ext)	Al% (pyrophosphate ext)
Profile 1										
1 (Ah1)	7·3	0·4	0·04	12·0	10·5	1·0	0·2	–	0·10	0·04
2 (Ah2)	7·1	0·1	0·02	10·1	9·4	0·9	0·3	0·1	0·12	0·04
3 (Ah3)	7·0	0·1	0·02	9·9	9·2	0·8	0·2	–	0·08	0·03
4 (IIBtj)	7·2	0·1	0·02	5·0	6·0	0·5	0·1	0·1	0·04	0·03
5 (IICca)	7·8	0·2	0·02	2·7	54·2	0·6	0·1	–	0·03	0·02
Profile 2										
3 (Ah1)	6·0	0·8							0·12	0·04
4 (Ah2)	5·1	0·4							0·08	0·04
5 (IIBg)	6·3	0·2							0·06	0·02
6 (IIICg)	6·7	0·1							0·04	0·02

	Sand % 2 – 0·05 mm	Silt % 0·05 – 0·002 mm	Clay % < 0·002 mm	Fine Clay % < 0·2 u
Profile 1	10·7	82·7	6·6	1·3
	8·3	83·6	8·1	0·8
	8·2	86·5	5·2	0·1
	61·7	33·8	4·5	0·7
	41·2	55·6	3·2	–
Profile 2	5·8	86·3	7·9	2·5
	14·6	78·1	7·3	2·1
	43·3	49·6	7·1	2·2
	77·2	22·1	0·7	0·6

TABLE 4

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

CHEMICAL AND PHYSICAL ANALYSES OF PROFILES 1 AND 2 IN MEADOW CREEK PALEOSOL. TERMINOLOGY AFTER THE CANADA SOIL SURVEY COMMITTEE (1978)

N. A.

M. B.

Dec '84

85–8

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

CHART SHOWING APPROXIMATE CORRELATIONS BETWEEN POLLEN ZONES AT MEADOW CREEK AND THE PACIFIC NORTHWEST

TABLE 5

N.A. | M.B. | Nov '84 | 85-9

MID CONTINENT OF U.S.A.	SOUTH CENTRAL BRITISH COLUMBIA				VANCOUVER ISLAND	WESTERN WASHINGTON	BABINE LAKE
TIME - Stratigraphic Units	^{14}C age	Geologic - climate Units	Pollen Zones	Paleosol	Pollen Zones (Alley, 1979)	Pollen Zones (Heusser, 1977)	Harington et al, (1974)
LATE WISCONSINAN		Fraser Glaciation					
	20				SF 1 & 2		
					CB 2	2	
					CB 1		
					DW 4		
MIDDLE WISCONSINAN	30	Olympia non - glacial interval			DW 3	3	
	33		MC 2		DW 2		
	42		MC 1	(hatched)	DW 1	4	? unnamed pollen assemblage ?
	>43 800 yr B.P.					?	
EARLY WISCONSINAN		Okanagan Centre Glaciation				5	

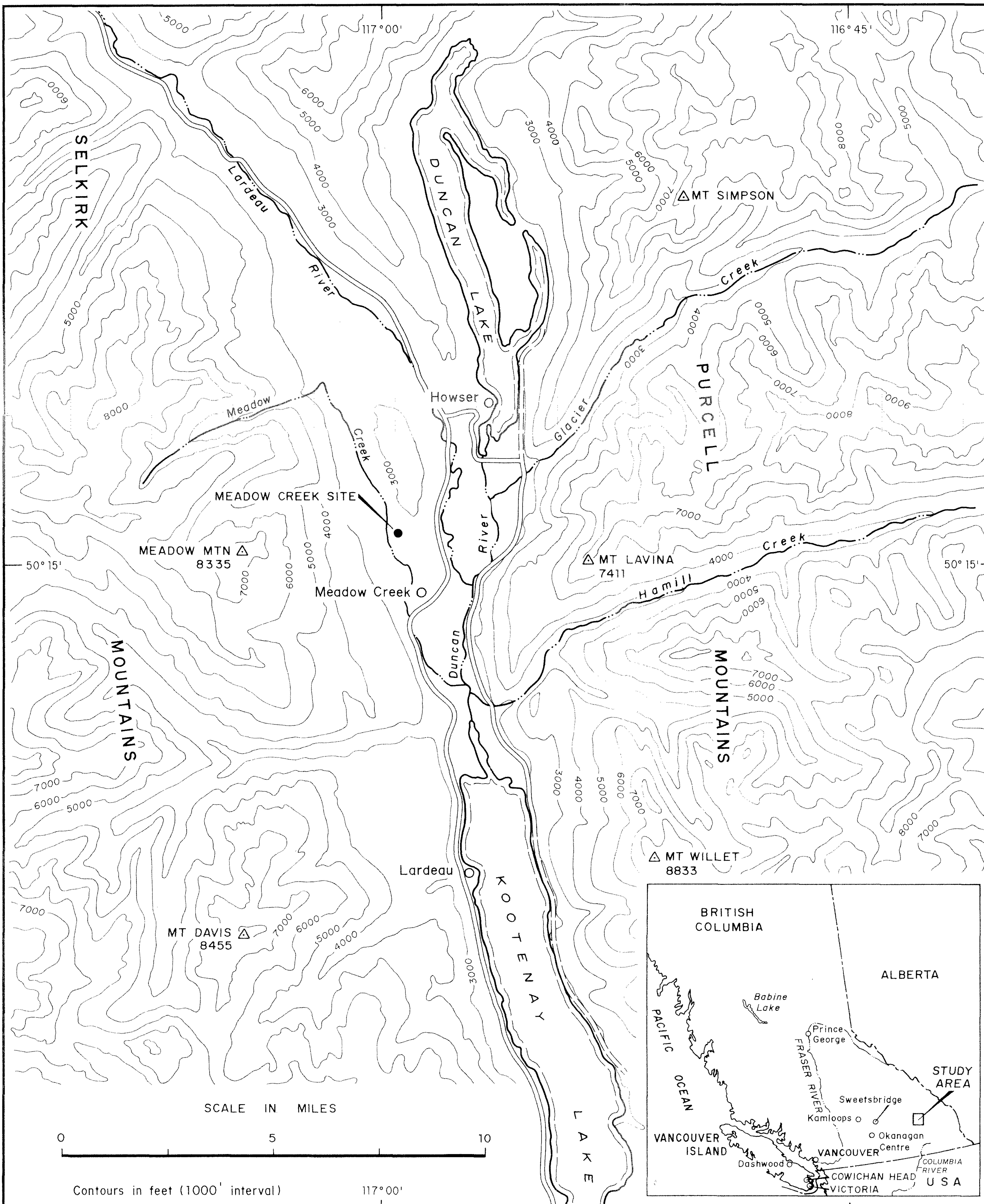

FIG. 1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED N.A.	
MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA	DRAWN M.B.	SCALE As shown
LOCALITY PLAN	DATE Dec '84	PLAN NUMBER 85-1

3697

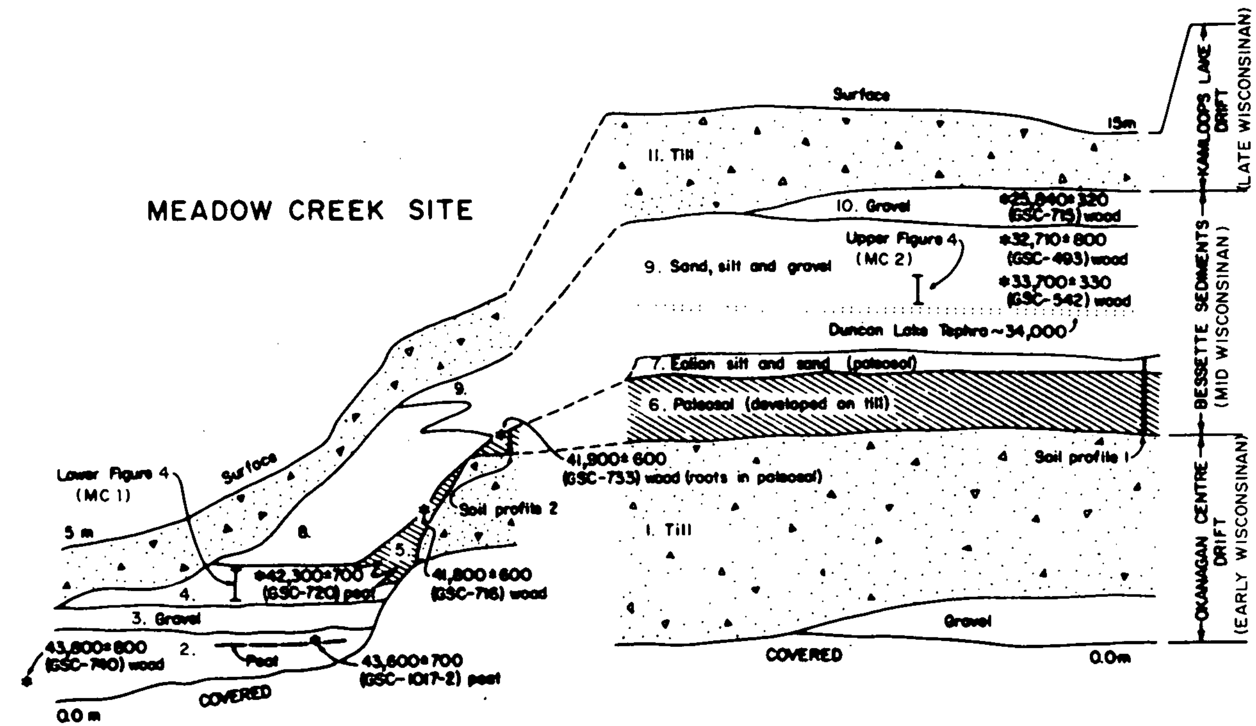

FIG. 2

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

STRATIGRAPHY OF MEADOW CREEK SITE

COMPILED N.A.	CDD	DATE
DRAWN M.B.	SCALE	
DATE Dec '84	PLAN NUMBER	85-2
CHECKED		

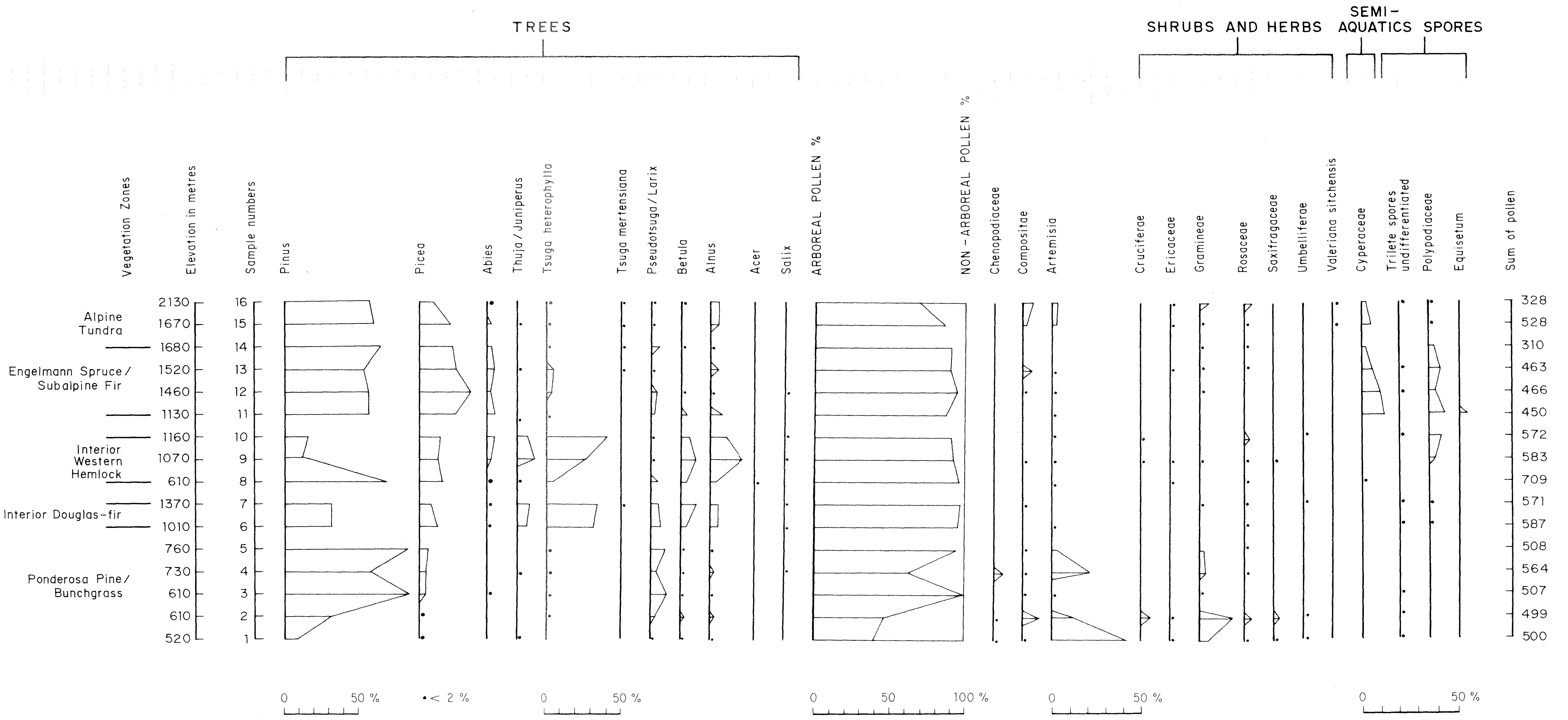

FIG. 3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

MODERN POLLEN SPECTRA

N. A.

M. B.

Dec '84

85-3

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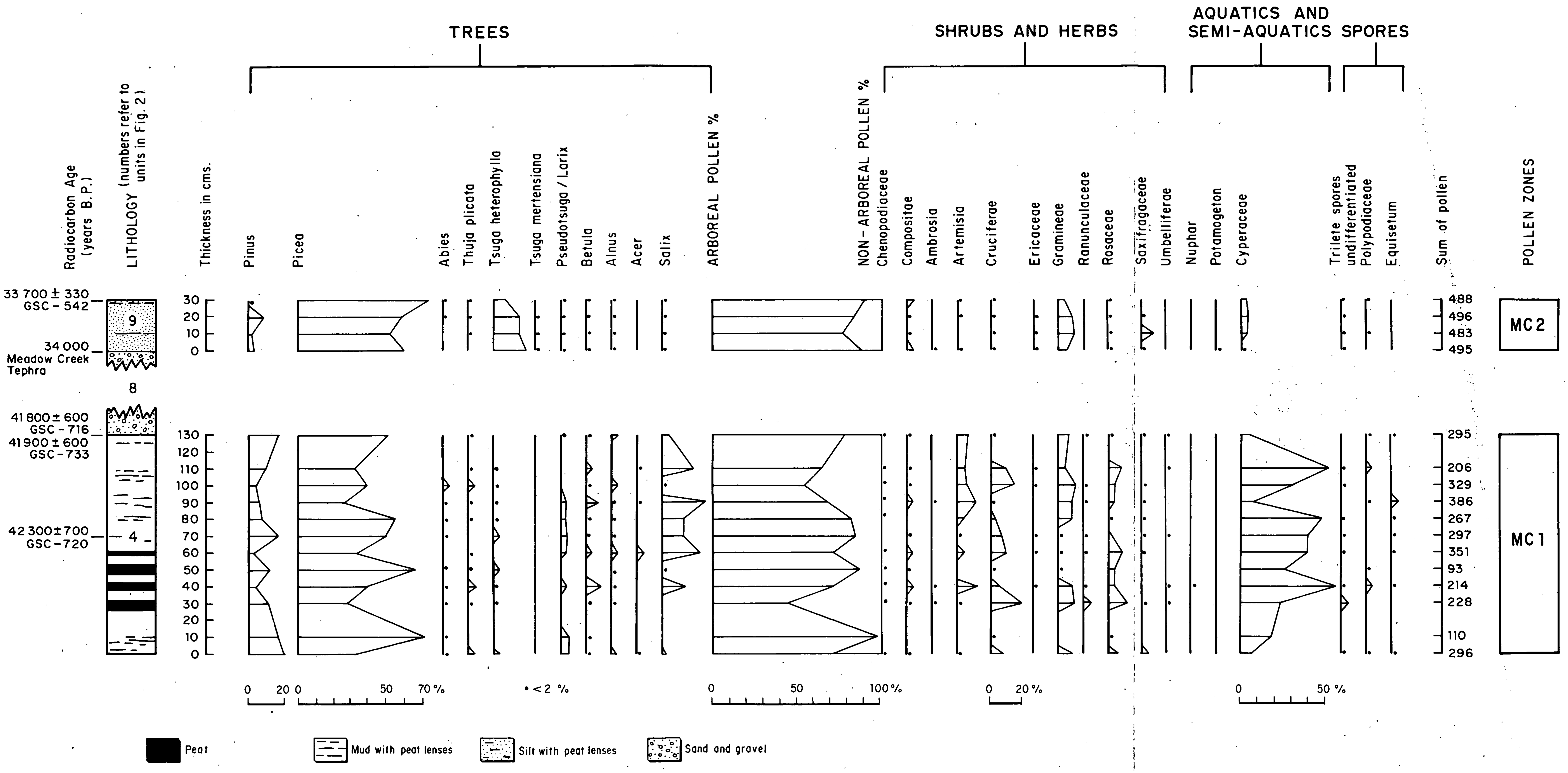

FIG. 4

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MIDDLE WISCONSIN CLIMATE, BRITISH COLUMBIA

FOSSIL POLLEN SPECTRA

COMPILED N.A.	D.D.O. DATE
DRAWN M.B.	SCALE
DATE Dec '84	PLAN NUMBER 85–4
CHECKED	

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