A postglacial plant macrofossil record of vegetation and climate change in southern Saskatchewan

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Abstract: Plant macrofossil analyses and ¹⁴C ages from a small, closed-drainage basin on The Missouri Coteau are used to reconstruct six phases of postglacial environmental change in southern Saskatchewan. Fossil remains of 41 taxa of vascular and nonvascular plants have been recognized and are illustrated.

Sparse macrofossils recovered from the basal diamicton (phase 1) are likely redeposited. Abundant fossils indicate establishment of an open, white spruce forest by ca. 10 200 BP (phase 2), followed by development of a pond and replacement of the spruce forest by deciduous parkland vegetation (phase 3) that persisted until ca. 8800 BP. The pond shallowed at the end of this period. Prairie fires are evident between ca. 8800 and 7700 BP (phase 4). Water levels rose between ca. 7700 and 5800 BP, and a semipermanent prairie pond was established (phase 5). After 5800 BP, this wetland became ephemeral (phase 6) and no longer conducive for fossil preservation.

Résumé: Des analyses de macrofossiles végétaux et des datations au ¹⁴C dans un petit bassin hydrographique fermé sur le coteau du Missouri ont été utilisées pour reconstituer six phases de changements environnementaux postglaciaires dans le sud de la Saskatchewan. Les vestiges fossiles de 41 taxons de plantes vasculaires ont été reconnus et sont illustrés.

Les rares macrofossiles prélevés dans le diamicton de base (phase 1) sont vraisemblablement redéposés. La présence de fossiles abondants indique qu’une forêt claire d’épinettes blanches s’était implantée dès environ 10 200 BP (phase 2), après quoi il y a eu développement d’un étang et remplacement de la forêt d’épinettes par une végétation de forêt-parc à feuilles caduques (phase 3) qui a persisté jusqu’à environ 8 800 BP. À la fin de cette période, l’étang est devenu moins profond. L’action des feux de prairies est manifestée d’environ 8 800 à 7 700 BP (phase 4). Le niveau de l’eau a monté entre environ 7 700 et 5 800 BP et un étang de prairie semi-permanent est apparu (phase 5). Après 5 800 BP, ces terres humides sont devenues éphémères (Phase 6) et défavorables à la conservation des fossiles.

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INTRODUCTION

Meteorological records for the Canadian Prairies are available for only the last century (Gullett and Skinner, 1992) and provide insufficient evidence to distinguish between climate change and meteorological variability. Therefore, numerous sites with detailed environmental records spanning the past several millennia have been investigated within this region by participants in the Palliser Triangle Global Change Project, in order to identify long-term trends in regional climate (Lemmen et al., 1993; Last, 1994; Vreeken, 1994; Vance and Last, 1994; Yansa, 1995; Beaudoin, 1996; Vance, 1997; Wilson et al., 1997).

Reconstruction of past vegetation provides valuable information concerning changes in climate and other environmental factors. Fossil pollen studies have been used to reconstruct past regional vegetation; however, long-distance dispersal and poor taxonomic control limit the resolution of such interpretations (Paegri et al., 1989; Vance et al., 1994). Alternatively, accurate information on past local vegetation assemblages and environments may be provided by the study of plant macrofossils, including wood, leaves, seeds, and fruits, because most macrofossil remains of Holocene age can be identified to the species level, and the majority of seeds and other plant remains are autochthonous and paraautochthonous (Birks and Birks, 1980; Bateman, 1991; Vance and Mathewes, 1994).

Coring of lake sediments is the most common method of collecting plant fossil remains; however, suitable lakes are uncommon on the dry northern Great Plains (Barnosky et al., 1987; Vance et al., 1993). Nevertheless, the available lake data do furnish a good regional paleovegetation record for the last 5000-6000 years (Mott, 1973; Last and Slezk, 1988) and, in a few cases, for the last 9000-10,000 years (Vance and Last, 1994; Vance, 1997). A number of recent studies in the Palliser Triangle region of southern Saskatchewan and southeastern Alberta indicate that significant paleoenvironmental data can also be obtained from postglacial sediments that fill small (30-80 m diameter) kettle depressions in hummocky and ice-thrust moraine (Beaudoin, 1992; Klassen, 1994; Yansa, 1998). The sediments that accumulated in these kettle basins have often been preserved plant and animal remains that provide a record of floral, climatic, and hydrological changes from late-glacial to mid-Holocene time. The fossil records obtained from kettle-fills sites, therefore, complement the paleoenvironmental interpretations provided by lake records from this region (e.g. Last and Sleze, 1986; Sauchyn and Sauchyn, 1991; Vance and Last, 1994; Vance, 1997).

Data on kettle-fill sites were first reported in Saskatchewan by Dew (1959), Kupsch (1960), Devries (1963), Ritchie and DeVries (1964), Ritchie (1966), and Mott and Christiansen (1981); and in North Dakota by Moir (1957), Thompson (1962), McAndrews et al. (1967), Cvancara et al. (1971), and Malo (1988). These studies were largely preliminary with poor chronological control. A number of kettle-fill deposits have been recently investigated by Klassen (1994) in southwestern Saskatchewan and by Beaudoin (1992, 1996) in southeastern Alberta, but chronostratigraphic resolution of these studies was also limited.

This study provides a history of the local vegetation and climate change following deglaciation on The Missouri Coteau upland of southern Saskatchewan, from ca. 10 200-5800 BP, based on plant macrofossils from a kettle fill. High-resolution sampling, species-level determinations, and several radiocarbon ages have allowed determination of the time and duration of the local vegetational, climatic, and environmental changes, and allow for comparison with other sites in the region.

SETTING

The Andrews site (lat. 50°20'N, long. 105°52'W; elev. 720 m a.s.l.), located on The Missouri Coteau upland about 100 km southwest of Regina, Saskatchewan (Fig. 1), is typical of the closed-drainage kettles of that region.

Geology

The Missouri Coteau upland (Fig. 1) is a northwest-trending band of predominantly hummocky moraine, averaging 50 km in width and extending nearly 1300 km from south-central South Dakota to west-central Saskatchewan (Acton et al., 1960; Clayton, 1967). Bedrock, mainly nonmarine deposits of the Paleocene Ravenscrag Formation, is overlain by up to 100 m of Pleistocene sediments (Christiansen, 1961; Klassen, 1992). The surficial glacial sediments on much of The Missouri Coteau were deposited during a period of ice stagnation, forming the characteristic 'knob-and-kettle' hummocky terrain seen throughout most of this upland (Clayton, 1967). The closed drainage of these kettles makes them ideal traps for lacustrine, eolian, and colluvial sediments (Hubbard and Linder, 1986).

Vegetation

The Andrews site is situated within the northern mixed-grass prairie region (Stipa-Bouteloua association), which in Canada extends as an arc from southern Alberta through Saskatchewan to Manitoba (Risser et al., 1981). Eighty percent of the vegetation of this region consists of associations dominated by Agropyron (wheatgrass), Stipa (needle grass), and Bouteloua (grama grass) species (Barker and Whitman, 1988). Woody species such as Salix spp. (willow) and Populus spp. (poplar) occur along riverbanks, coulees, and moist depressions. Small stands of Populus tremuloides (aspen poplar) are found near the bottom of a few kettles in the immediate vicinity of the study site, indicating that groundwater seepage is locally sufficient to support some trees on an otherwise treeless landscape.
Climate
The present regional climate is strongly continental, with extreme differences between summer and winter temperatures and low annual precipitation. Evapotranspiration rates throughout this area are high, with an annual moisture deficit greater than 300 mm (Winter, 1989). It is not surprising, therefore, that extended periods of dry weather or droughts are common on the northern Great Plains in Canada. The closest meteorological station is at Moose Jaw, located 22 km east of the Andrews site, which reports an average frost-free period of 105 days, January mean temperature of -14.2°C, July mean temperature of +19.7°C, and mean annual precipitation of 357 mm (Environment Canada, 1993).

Hydrology
Each closed kettle within the hummocky moraine is dependent upon snowmelt runoff, which accumulates as standing water and slowly recharges the underlying aquifer from spring to mid-summer through the poorly permeable clay-rich surficial sediments (Lissey, 1971). This groundwater recharge-dominated regime results in kettle water chemistry being fresh to slightly brackish. Analysis by Christiansen (1961) of water samples collected about 4 m below the water table from three test holes near our study site indicated that total dissolved solids (TDS) ranged from 880 to 1360 mg·L⁻¹. The areal extent of surface waters expands and contracts seasonally and varies considerably with annual changes in precipitation and temperature. Today, many kettles on the Missouri Coteau are ephemeral ponds; however, the plant macrofossil record from the Andrews site suggests that water levels were higher and perennial in the past.

METHODS
Field sampling
Sediment samples were collected from a 5.8 m section where well preserved trunks of Picea glauca (white spruce) were found in situ after excavation for a livestock watering-hole (Fig. 2). Samples were taken at 5 cm intervals and stored in labelled plastic bags at 4°C to prevent microbial and fungal decomposition prior to processing (Warner, 1990; Gale and Hoare, 1991). Sixty-seven samples from the plant macrofossil-bearing beds (3.1–5.1 m) and the underlying diamicton (5.1–5.8 m) form the basis for this study (Fig. 3) and are late Pleistocene to mid-Holocene in age. Samples collected from the upper 3.05 m of the section lacked identifiable plant macrofossils (Fig. 3).

Sample preparation and analysis
A subsample of 50 cm³ of sediment from each sample was processed for macrofossils. Each was treated with approximately 900 mL of distilled water and 20 mL of Quaternary
O™ detergent. The mixture was gently heated to 40°C and agitated for 2 h on an oscillating hot plate to deflocculate the clay minerals, then washed with water through nested screens of 1 mm, 250 µm, and 125 µm mesh sizes. Following the methods of A. Beaudoin (pers. comm., 1994), the fossils were stored in labelled glass vials filled with a 1:1:1 mixture of 95% ethanol, distilled water, and glycerine to which three drops of a dilute phenol solution were added to prevent fungal and microbial decomposition. Samples are stored in the University of Saskatchewan Paleobotanical Collection (USPC), Department of Geological Sciences, University of Saskatchewan, Saskatoon.

Fossil seeds and fruits were identified with the aid of keys and published reports (Martin and Barkley, 1961; Montgomery, 1977; Levesque et al., 1988). Species identifications were confirmed by comparison with a modern seed and fruit collection prepared for this study and presently housed in the

Figure 2.
Photographs of the Andrews study site: A) dragline excavation of site for a livestock watering-hole; GSC 1999-044A B) 5.8 m section sampled along one wall of the dugout at the Andrews site; field assistants (indicated by arrow) for scale; GSC 1999-944B C) close-up of the 3.8 m long trench seen in the lower part of Figure 2B, showing buried plant macrofossil-bearing layers; in situ trunks of Picea glauca overtime roots that penetrate the diamicton; white arrow points to the contact between the lacustrine sediments (zone III) and overlying charcoal-rich sandy clay (zone IV) at 400 cm; trowel in lower right corner for scale. GSC 1999044C. Photographs by C.H. Yansa.
Fraser Herbarium, University of Saskatchewan. Identifications of nonvascular plants were provided by R. Belland, Devonian Botanic Gardens, Edmonton, Alberta.

Fossil fruits, seeds, and vegetative organs were mounted on scanning electron microscope (SEM) stubs with double-sided tape and coated with gold. Specimens were viewed and photographed on a Philips 505 SEM at 30 kV. Conifer leaves with cuticle were first soaked in Calgon™-softened water (sodium hexametaphosphate solution) for 48 h, oxidized for up to one minute in household bleach (6% sodium hypochlorite) until clear, and then flushed with Calgon™-softened water (method of J. Skog, as cited in LePage and Basinger (1995)). The cuticle was easily separated from mesophyll using insect pins, and examined and photographed under an SEM.

The relative abundance of leaves, mosses, and charcoal was estimated using a scale of 0 to 5, as proposed by Birks and Birks (1980) and Warner (1990), whereas seeds and fruits were counted. These abundance numbers were then plotted (Fig. 4) using Tilia™ and Tilia.graph™ (Grimm, 1992).

Six 14C ages for the Andrews site were obtained from uncharred Picea wood using conventional dating methods, and from nonaquatic seeds, charcoal flakes, and plant fragments using accelerator mass spectrometry (AMS) techniques (Table 1). Samples were selected from layers where significant plant macrofossil and stratigraphic changes were noted (Fig. 3). Two of the wood samples were from trunks buried in laminated sediments, and the third was from an in situ Picea root penetrating a litter layer into diamicton (Fig. 2C; Table 1). The seeds and plant remains selected for AMS 14C age determinations showed no signs of abrasion. Preparation of these fossils included rinsing with distilled water (neither Quaternary O™ nor heating was used in sample processing). The radiocarbon ages (Table 1) have been corrected for δ13C fractionation (R. McNeely, pers. comm., 1995).

**Table 1. Radiocarbon ages (corrected for δ13C fractionation) of significant plant macrofossil–bearing levels of the Andrews site.**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dating lab—sample #</th>
<th>14C age (± BP)</th>
<th>Materials dated</th>
</tr>
</thead>
<tbody>
<tr>
<td>310–315</td>
<td>TO-5018</td>
<td>5770 ± 80; AMS</td>
<td>Charcoal flakes and plant roots</td>
</tr>
<tr>
<td>390–395</td>
<td>TO-4780</td>
<td>7670 ± 80; AMS</td>
<td>Charcoal flakes and plant roots</td>
</tr>
<tr>
<td>405–410</td>
<td>TO-6019</td>
<td>8790 ± 140; AMS</td>
<td>Cheno podium salinum seeds and Salix americanus fruits</td>
</tr>
<tr>
<td>445–450</td>
<td>AECV-2048C</td>
<td>10 200 ± 140; conventional</td>
<td>Picea wood (trunk)</td>
</tr>
<tr>
<td>490–495</td>
<td>GSC-5822</td>
<td>10 200 ± 80; conventional</td>
<td>Picea wood (trunk)</td>
</tr>
<tr>
<td>500–505</td>
<td>AECV-2047C</td>
<td>10 230 ± 140; conventional</td>
<td>Picea wood (root)</td>
</tr>
</tbody>
</table>

Age-dating laboratories: TO, IsoTrace Laboratory, University of Toronto; AECV, Alberta Environmental Centre–Vegreville; GSC, Geological Survey of Canada–Ottawa.

**Figure 3.** Stratigraphic column of the Andrews site, illustrating the vegetation zones, 14C ages, lithology, and fossils.
RESULTS

The results of this study enable reconstruction of the environmental setting and local vegetation, from the time of establishment of vegetation following deglaciation to the mid-Holocene. Based on changes in plant macrofossil assemblages, five zones were recognized (Fig. 3, 4). These zones are associated with $^{14}$C ages and often correlate with changes in lithology.

Zone I – reworked fragments; diamicton (580–510 cm)

The base of the section consists of a very dark grey (5Y 3/1, Munsell™ Colour Chart) diamicton composed of a calcareous clay loam with striated cobbles (Fig. 3). Rare and poorly preserved plant macrofossils were recovered (Fig. 4), although these remains are likely reworked. Abrasive degradation of most of the specimens indicates transport, while those taxa identified as aquatics are not typical of an early succession vegetational assemblage.

Zone II – Picea; litter and laminated silty clay (510–445 cm)

In situ Picea sp. roots (Fig. 2C), which penetrate a 10 cm thick litter layer (Fig. 3, 4) containing abundant spruce macrofossils and the seeds and fruits of shrubby and herbaceous angiosperms, indicate the establishment of a spruce forest by ca. 10 200 BP (Table 1). Cone and seed-wing morphology were used to identify Picea glauca (white spruce) as the dominant constituent of this forest (Appendices A, B). No identifiable macrofossils of P. mariana (black spruce) were recovered. An open forest is indicated by macrofossils of Rubus idaeus (wild raspberry), Shepherdia canadensis (Canada buffaloberry), Fragaria virginiana (smooth wild strawberry), Rorippa cf. R. truncata (blunt-fruited yellow cress), Chenopodium cf. C. berlandieri (false lamb’s-quarters), and Mentha arvensis var. villosa (field mint), which are all light-demanding shrubs and herbs (Fig. 4).

Overlying the root and litter layer are 55 cm of dark olive grey (5Y 3/2, Munsell™) silty clay, which constitute the uppermost part of zone II (Fig. 3). These sediments are laminated and contain several large (18–30 cm in diameter, >1.5 m long) Picea trunks (Fig. 2B, 2C, 3). Other Picea macrofossils are also found in these fine-grained sediments, but are less abundant than those from the underlying litter layer (Fig. 4). One piece of charred wood was recovered 10 cm above the litter layer and is associated with a peak in charcoal abundance (Fig. 4). The laminated silty clay (Fig. 5A) and the remains of molluscs and arthropods, including Coleoptera (Appendix A, Pl. A-7, fig. 5–9), suggest that a perennia pond had developed, and that water depth was at least 1.8 m (e.g. McAndrews et al., 1967) and perhaps more than 3 m (e.g. Last, 1989).

Figure 4. Summary plant macrofossil diagram for the Andrews site showing the 41 taxa identified. Analysis by C.H. Yansa. All fossils are seeds or fruits, unless otherwise indicated. These plant macrofossils are illustrated in Appendix A and described in Appendix B.
The macrofossil flora from the pond deposits of zone II indicate that the vegetation was species rich (Fig. 4), representing a diversity of microhabitats. Two cm thick organic layers composed almost entirely of the moss Drepanocladus polycarpus (Bland. ex Voit) Roth (= Drepanocladus aduncus (Hedw.) Warnst.) occur near the base of these deposits (Fig. 4, 5A). This sedge-branch moss can either be emergent or shallowly submerged and is a good indicator of open, wet, alkaline, calcareous habitats (Crum and Anderson, 1981).

Emergent plants fringing the pond included Epilobium cf. E. ciliatum (northern fireweed), Typha latifolia (common cat-tail), Scirpus americanus (three-square bulrush), Carex cf. C. rostrata (beaked sedge), and Carex cf. C. atherodes (awned sedge). Aquatic plants included Wolffia arrhiza (water-meal), Myriophyllum verticillatum var. pectinatum (whorled water-milfoil), Potamogeton filiformis (thread-leaved pondweed), P. natans (floating-leaved pondweed), P. obtusifolius (blunt-leaved pondweed), Hippuris vulgaris (mare’s-tail), and Lemma trisulca (ivy-leaved duckweed). All of these species are indicative of quiet, pH neutral to alkaline, nutrient-rich waters. The presence of Rorippa cf. R. truncata, Mentha arvensis var. villosa, Ranunculus sceleratus (celery-leaved buttercup), and Chenopodium cf. C. berlandieri indicate that the soils in the vicinity of the pond were slightly alkaline and nonsaline.

Species such as Geranium cf. G. bicknellii (Bicknell’s geranium), Cirsium cf. C. muticum, and Aster cf. A. novae-angliae (New England aster) probably occupied the pond edges. Juniperus communis (low juniper) was likely to be found on the more open, well drained knolls or south-facing slopes. Due to the lack of preserved grasses, except for one vegetative fragment (Appendix A, Pl. A-3, fig. 8), it is not known if they were a significant component of this vegetational assemblage.

Near the top of zone II, the sediments grade from gyttja to marl. This transition is accompanied by the first appearance of leaves and buds of Populus balsamifera (balsam poplar) and P. tremuloides (aspen poplar) and the last appearance of Picea wood (Fig. 3, 5B).

**Zone III — Populus, Betula; laminated silty clay (445–400 cm)**

With the exception of the uppermost 5 cm, the marly sediments of zone III are laminated. Deposition of this unit occurred between ca. 10 200 BP on spruce trunks, which may be somewhat older than the sediments) and ca. 8800 BP (Fig. 3; Table 1). The AMS 14C age of 8800 BP was obtained from seeds collected 5 cm below the top of this unit; the uppermost sediments of zone III are not laminated and contain poorly preserved plant macrofossils. An undulating contact occurs between zone III sediments and the overlying charcoal-rich sandy clays of zone IV (Fig. 2C, 3). These lithological changes suggest a general shallowing of the pond during deposition of zone III sediments. The plant macrofossils from zone III (Fig. 4) also indicate shallowing of

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*Figure 4. (cont.)*
Figure 5. A) Cross-section of laminated lacustrine sediments of zone II containing the upper of two Drepanoclados polycarpos (sickle-branch) moss layers; sample from 480–495 cm; scale bar = 1 cm; GSC 1999-044D. B) Plan view of leaves of Populus balsamifera (balsam poplar, Pb) and P. tremuloides (aspen poplar, Pt) preserved in lacustrine silty clay; sample from 445 cm; scale (on left end of sample) = 1 cm. GSC 1999-044E. Photographs by C.H. Yansa.
the pond within a parkland setting. *Subularia aquatica* (water awl-wort), *Eleocharis palustris* (creeping spike-rush), and *Typha latifolia* are common constituents of shallow-water and shoreline environments (Thompson, 1992). Poplar macrofossils, as well as *Betula* cf. *B. occidentalis* (river birch) fruits, are common throughout zone III sediments (Fig. 4).

The marly sediments indicate a significant increase in dissolved carbonate. Abundant lime-encrusted shoots and oogonia of *Chara* sp. (stonewort algae; Appendix A, Pl. A-1, fig. 1, 2) indicate that the water was warm, shallow, and carbonate rich. Reduction in the number of *Hippuris vulgaris*, *Myriophyllum verticillatum* var. *pectinatum*, and *Lemma trisulca* macrofossils, and increases in *Scirpus americanus* seeds and *Zannichellia palustris* var. *palustris* (horned pondweed) fruits indicate a shift in the water chemistry toward more alkaline and brackish conditions (Fig. 4). Increased abundance of *Chenopodium salinum* (saline goosefoot) throughout zone III and the first appearance of *Rumex maritimus* var. *fueginus* (golden dock) provide evidence of brackish and alkaline soils (Fig. 4). The plant macrofossils of zone III, therefore, suggest the development of alkaline and brackish conditions in a shallow pond.

**Zone IV – Charcoal; sandy clay (400–390 cm)**

Zone IV consists of a 10 cm thick black (5Y 2.5/1, Munson*) sandy clay containing abundant charcoal, rootlets, and a few charred seeds (Fig. 2C, 3, 4). The carbonaceous remains were used to obtain an AMS 14C age of 7670 BP (Table 1). Abundant charcoal indicates that a major fire, or recurring fires, swept the area during deposition of zone IV sediments. The occurrence of sand may be attributed to sloughwash and/or deposition ofolian sediment.

**Zone V – Typha, Ranunculus; nonlaminated sandy clay (390–310 cm)**

The dark olive grey (5Y 3/2, Munson*) sandy clay sediments of zone V are nonlaminated, probably due to bioturbation or wave action (e.g. Last, 1989). Pulmonate gastropods suggest that water depth in zone V was shallower than in zones II (lacustrine phase) and III (with a branchiopod fauna) (Appendix A, Pl. A-7, fig. 5, 6; Thompson, 1962; McAndrews et al., 1967). Macrofossils of the few aquatic and emergent plant species recovered also indicate that water levels were intermediate between the high-water stand of zones II and III and the ephemeral conditions seen today (Fig. 4). Abundant carbonate nodules and *Chara* sp. macrofossils indicate that the water was carbonate rich.

Fossils from this zone indicate formation of a semipermanent pond in a grassland setting. The only emergent plant of this zone, *Typha latifolia*, is known for its capacity to produce abundant seeds in disturbed habitats, and to quickly revegetate when water levels drop (Stewart and Kantrud, 1972; Thompson, 1992). Fluctuating water levels may account for the abundance of wet- meadow species well adapted to disturbance and for an increase in seed production and species diversity in the surrounding area (Fig. 4). *Ranunculus seleratus*, in particular, is a good indicator of drying pond beds, while *Rumex maritimus* var. *fueginus* and *Chenopodium salinum* indicate that the soil conditions were brackish and alkaline.

Increasing fungal and microbial degradation of the fossil remains near the top of zone V (Appendix A, Pl. A-3, fig. 2, 3), and decreasing species diversity and abundance (Fig. 4), indicate that this wetland was becoming ephemeral to the point that fossil preservation was deteriorating. The disappearance of fossils correlates with the change from a sandy clay to a silty clay at a depth of 3.1 m (Fig. 3, 4).

**INTERPRETATION**

The zones of paleoenvironmental change that have just been described are interpreted below and depicted as a sequence of phases in Figure 6.

**Phase 1 – late glacial**

The top 70 cm of zone I sediments were sampled for plant macrofossils to determine whether a pioneer herbaceous community could be recognized, for such a vegetation has yet to be identified from other fossil deposits in the Canadian Prairie region (Ritchie, 1976, 1987). However, the rare fossils recovered from this deposit are likely reworked. Based on available evidence, this phase is shown in Figure 6 as a nonvegetated surface.

**Phase 2 – open white spruce forest (ca. 10 200 BP)**

**Phase 2a – forest development**

In situ *Picea* sp. roots (Fig. 2C), which penetrate the 10 cm thick litter layer (zone II) into diamicton (Fig. 3), indicate development of a white spruce forest at the Andrews site by ca. 10 200 BP. The timing for appearance of this forest at the Andrews site (Table 1) lags significantly behind the estimated retreat of the Laurentide Ice Sheet from this area at ca. 11 700–11 300 BP (Clayton and Moran, 1982). Nevertheless, based on geomorphological evidence, Clayton (1967) proposed that, on The Missouri Coteau of North Dakota, it took 1000–3000 years after ice sheet retreat for buried stagnant ice to melt. This interpretation, combined with evidence from the Andrews site for existence of a well drained spruce forest habitat at a site that would later become a pond, suggests that initial development of a forest in this area occurred on a thick blanket of till overlaying stagnant ice, and that the landscape subsequently experienced inversion (Fig. 6, phase 2a).

The Andrews site record is consistent with other studies from north-central North America that have reported *Picea glauca* as a dominant component of early postglacial vegetation (Ritchie and MacDonald, 1986; Ritchie, 1987; Grimm, 1995). Like these other studies, the assemblage reconstructed for phase 2a at the Andrews site appears to lack a precise modern analogue. While most taxa of the Andrews site spruce forest presently are found in the mixed-grass prairie region, taxa such as *Caltha palustris* (marsh-marigold) and *Cirsium nuticum* (swamp thistle) are constituents of the aspen.
parkland and southern boreal forest, while *Picea glauca* is a constituent of the Cypress Hills and southern boreal forests. Climatic conditions supporting *P. glauca* forests in the southern boreal forest region of Saskatchewan today include lower mean summer temperature (18°C) and higher mean annual precipitation (390 mm) than is currently found at the Andrews site (Ritchie and Harrison, 1993).

**Phase 2b – surface collapse**

The *Picea glauca* forest occupied a site that was not initially water filled, as indicated by the preserved forest soils of lower zone II, and the preference of this species for well drained soils. Eventually, the continued melting of buried stagnant ice would have resulted in subsidence of the surface until the water table intersected the base of the newly formed depression, creating a pond at the Andrews site (landscape inversion; Fig. 6, phase 2b). This gradual process of melting of buried ice and collapse of the forest-covered till surface to create the present knob-and-kettle terrain has been proposed for similar deposits in North Dakota (Clayton, 1967) and the Great Lakes region (Warner et al., 1991). A gradual depression and inundation to form a closed basin with ponded water is supported by the basal, intact soil litters and by the progressive increase in the diversity and abundance of aquatic plant and animal fossils recovered from the bottom to the top of the *P. glauca*–dominated zone II (Fig. 4).

**Phase 2c – pond development**

It is unclear from the fossils and lithology whether the spruce forest at the Andrews site persisted long after pond development. The continued presence of *Picea glauca* in the lacustrine sediments of zone II may have resulted from addition of long-dead debris and thus predated the pond. Equally plausible is that spruce trunks found buried at various levels within the laminated lacustrine sediments may be remains of a drowned forest, the tangle of submerged woody stems resisting decay for centuries before finally being buried. The latter scenario is more consistent with the uniform 14C ages attributed to the woods found below and within the lacustrine sediments of zone II, as aerial exposure is unlikely to preserve dead wood for more than decades.

**Phase 3 – deciduous parkland (10 200–8800 BP)**

From 10 200 to 8800 BP there occurred a change in the flora at the Andrews site, from open spruce forest (zone II) to deciduous parkland (zone III) dominated by *Populus balsamifera*, *P. tremuloides*, and *Betula* cf. *B. occidentalis* (Fig. 3, 4, 5B, 6; phase 3). This change probably occurred in response to regional warming and/or drying, which would have favoured the growth of broad-leaved angiosperms over evergreen conifers. Charred wood and abundant charcoal recovered from the laminated sediments of zone II (Fig. 4) suggest that fire, perhaps associated with increasing aridity, may have contributed to elimination of spruce. On a regional scale, Ritchie (1976) attributed the elimination of *Picea glauca* from late-glacial environments to increased aridity. General circulation model (GCM) simulations and pollen spectra data for north-central North America indicate that temperature in western Canada was about 2°C warmer than present during the Hypsithermal, a warm and dry interval that persisted from ca. 10 000–9000 BP until at least 6000 BP and was associated with summer insolation greater than today (Ritchie et al., 1983; Kutzbach and Webb, 1991, 1993; MacDonald, 1993; Vance et al., 1994). Under these conditions, as Szeicz and MacDonald (1994) have shown, *P. glauca* is unable to regenerate.

Although evidence indicates that the area became increasingly arid and water levels declined near the end of phase 3, deep-water conditions nevertheless persisted throughout most of this phase, and sufficient moisture was available to support diverse aquatic, emergent, and wet-meadow plants within a deciduous broadleaf forest. All of the taxa recovered from zone III, except for *Aster* cf. *A. novae-angliae* and *Subularia aquatica*, occur in the mixed-grass prairie region today. These two exceptions are indicative of a cooler and moister climate, although hummocky moraine has been found by Zoltai (1988) to contribute to microclimate diversity conducive to persistence of such taxa in an otherwise arid environment.

The transition from laminated to nonlaminated sediments 5 cm below the top of zone III indicates shallowing (e.g. Last, 1989). The undulating contact between sediments of zones III and IV (Fig. 2C) is interpreted as a load-contorted contact between the saturated fine-grained pond deposits of zone III and the overlying coarser grained sediments of zone IV, a

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**Figure 6. Schematic reconstruction of phases 1–6 of late-glacial to mid-Holocene paleoenvironmental change at the Andrews site.**

**LEGEND**

- White spruce tree
- Mudflat plant
- Deciduous tree
- Aquatic plant
- Shrub
- Emergent plant
- Root
- Cobble
- Grass/forb
- White spruce trunk
Table 2. Kettle-fill sites on the northern Great Plains that provide records of early Holocene revegetation. Only 14C ages obtained from wood and AMS 14C ages obtained from seeds are listed. Locations of sites that are in the Palliser Triangle are shown in Figure 1.

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>14C age (a)</th>
<th>Materials dated</th>
<th>Depth (cm)</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hatchuck</td>
<td>50°20'N, 105°52'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Ritchie and DeVries (1964)</td>
</tr>
<tr>
<td>Kyle</td>
<td>50°53'N, 107°50'W</td>
<td>10 300 ± 90 (GSC-5622)</td>
<td>Pine wood</td>
<td>ca. 400</td>
<td>Yanis (1995)</td>
</tr>
<tr>
<td>Beecly</td>
<td>50°55'N, 107°40'W</td>
<td>10 300 ± 90 (GSC-5931)</td>
<td>Pine wood</td>
<td>ca. 400</td>
<td>Yanis (1995)</td>
</tr>
<tr>
<td>Herbert</td>
<td>50°22'N, 107°15'W</td>
<td>10 200 ± 300 (S-41)</td>
<td>Same sample</td>
<td>330</td>
<td>Kupsch (1969)</td>
</tr>
<tr>
<td>Crestwynd</td>
<td>49°52'N, 105°39'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Ritchie (1966)</td>
</tr>
<tr>
<td>Scenic</td>
<td>49°46'N, 105°11'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Dew (1959), DeVries (1963)</td>
</tr>
<tr>
<td>Wusen</td>
<td>49°55'N, 107°40'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>DeVries (1963)</td>
</tr>
<tr>
<td>Seabold</td>
<td>47°03'N, 99°11'W</td>
<td>9750 ± 140 (J-4537)</td>
<td>Wood (unidentified)</td>
<td>ca. 400</td>
<td>Ovancara et al. (1971)</td>
</tr>
<tr>
<td>Woodworth</td>
<td>47°17'N, 98°53'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>McAndrews et al. (1967)</td>
</tr>
<tr>
<td>Tappen</td>
<td>46°46'N, 99°35'W</td>
<td>11 480 ± 300 (W-542)</td>
<td>Pine wood</td>
<td>—</td>
<td>Moir (1957)</td>
</tr>
<tr>
<td>Cass</td>
<td>46°46'N, 97°40'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Malo (1988)</td>
</tr>
<tr>
<td>McIntosh</td>
<td>46°14'N, 99°22'W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Thompson (1962)</td>
</tr>
<tr>
<td>Val Marie</td>
<td>49°03'N, 107°41'W</td>
<td>9900 ± 80 (TO-1711)</td>
<td>Seeds (AMS)</td>
<td>600</td>
<td>Klassen (1994)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9880 ± 80 (TO-2212)</td>
<td>Seeds (AMS)</td>
<td>1100</td>
<td>Klassen (1994)</td>
</tr>
<tr>
<td>Horseman</td>
<td>49°13'N, 109°10'W</td>
<td>9500 ± 80 (GSC-4098)</td>
<td>Wood (unidentified)</td>
<td>400-500</td>
<td>Klassen (1994)</td>
</tr>
<tr>
<td>Jenner</td>
<td>50°44'N, 110°47'W</td>
<td>10 050 ± 110 (AECV-1594C)</td>
<td>Populus wood</td>
<td>ca. 400</td>
<td>Beaudoin (1992)</td>
</tr>
<tr>
<td>Webb</td>
<td>51°06'N, 111°05'W</td>
<td>10 150 ± 140 (AECV-1596C)</td>
<td>Populus wood</td>
<td>415</td>
<td>Beaudoin (1992)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9890 ± 120 (AECV-1597C)</td>
<td>Same sample</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Hampton</td>
<td>52°42'N, 112°45'W</td>
<td>10 200 ± 130 (AECV-1396C)</td>
<td>Populus wood</td>
<td>ca. 400</td>
<td>Beaudoin (1992)</td>
</tr>
</tbody>
</table>

1 indicates that 14C age has been corrected for δ13C fractionation

feature consistent with shallowing. This is similar to the interpretation presented for the Fletcher site in southeastern Alberta (Fig. I, Table 2) by Vickers and Beaudoin (1989). It is significant that the water table remained sufficiently high throughout this time and the remainder of the Holocene to have preserved the underlying fossils and laminated sediments of zones II and III within a continuously saturated subsurface environment.

**Phase 4 – prairie fires (8800–7700 BP)**

It is difficult to ascertain fire frequency during deposition of the 10 cm thick layer of charcoal-rich sandy clays that make up zone IV. The rarity of uncharred seeds and plant fragments may indicate that this deposit represents a single, intense fire. Accumulation of organic matter during a more humid climatic regime may have made the region vulnerable to conflagration during increasing drought. Alternatively, if a more open grassland vegetation was present during phase 4, then frequent fires may have consumed most of the litter and left little uncharred fossil evidence. In either case, phase 4 represents a significant change in fire regime that is likely attributed to increasing aridity. Nevertheless, the pond at no time dried out during this interval.

Removal of surface vegetation as a result of fire apparently resulted in intense slope-wash and/or eolian transport of sand into the pond. This explanation has been invoked for occurrence of sandy sediment in kettles elsewhere in Saskatchewan and in North Dakota (e.g., Moran et al., 1976; Vreeken, 1994).

**Phase 5 – semipermanent prairie pond (ca. 7700–5800 BP)**

The plant macrofossils, gastropods, and sedimentology indicate that water levels during phase 5 were intermediate between the highstand that occurred during phases 2c and 3 and the ephemeral conditions seen today. The depth of the Andrews pond is interpreted to decrease continually through phases 3, 4, and 5. Water levels were sufficiently high throughout phase 5 to sustain a semipermanent prairie pond vegetation. At no time during deposition of zone V sediments did the basin dry long enough for plant remains in the sediments to decay or oxidize, and there is no evidence for the formation of a soil.

Precipitation during phase 5 may have been variable, because the Andrews site plant macrofossil record suggests that water levels may have fluctuated (Fig. 4). On the basis of comparison with modern semipermanent prairie ponds (Stewart and Kanrud, 1972), it is proposed that a mudflat environment expanded from the shoreline toward the centre of the basin whenever the water table lowered, whereas the fringe of cattails would expand at the expense of mud flats when the water level rose. Eventually, the water level fell low enough, and the sediment surface was exposed long enough, to prevent plant fossil preservation.
Phase 6 – ephemeral pond

About 5800 BP, the Andrews site pond became ephemeral and preservation of macrofossils was precluded (Fig. 6, phase 6). Paleoclimate reconstructions indicate that a climate more arid than at present prevailed in western Canada at that time (Vance et al., 1994). While aridity likely contributed to the cessation of fossil preservation at the Andrews site, additional factors may have been involved. It may be that, by the mid-Holocene, the Andrews site and perhaps most other kettle basins within the region were filled with enough sediment to reduce the water-holding capacity of these basins, and thus restrict fossil preservation to below the water table. As well, fluctuations in local groundwater supply may have altered the water table at this and other sites in this region (e.g. Last and Slezak, 1986), thus limiting the extent to which fossils could be preserved. Therefore, climate, sedimentological processes, and local hydrology may all have contributed to the discontinuation of the Andrews site fossil record at ca. 5800 BP.

CONCLUSIONS

The Andrews site provides one of the most complete records of earliest postglacial vegetation currently available in the northern Great Plains region, including remains of an in situ Picea glauca forest litter and underlying diamicton. The record of the Andrews site, in the context of other sites known of the northern Great Plains, contributes to local and regional paleoenvironmental interpretation.

Picea glauca forests occupied North Dakota at ca. 12 000 BP, and extended into southern Saskatchewan by ca. 10 200 BP at the Andrews site and about the same time (ca. 10 300 BP) at the Kyle and Becchy sites (Fig. 1; Table 2; Moir, 1957; Klassen, 1994; Grimm, 1995). To the southwest, open grassland has apparently existed in Montana over the past 12 000 years, with spruce being conspicuously absent (Barnosky, 1989). In southeastern Alberta, Populus was present, but Picea apparently absent (Table 2; Beaudoin, 1992, 1996).

On The Missouri Coteau throughout North Dakota and southern Saskatchewan, spruce forests are interpreted to have been growing on a blanket of tilled overlying stagnant ice (Clayton, 1967; Yansa, 1998). Melting of buried ice caused collapse of the land surface to form the knob-and-kettle terrain that characterizes this upland (Clayton, 1967; Yansa, 1998). Spruce forests likely persisted on the slopes and knobs surrounding the ponds.

The spruce forests in northern North Dakota were apparently replaced by grassland vegetation at ca. 10 000 BP (Grimm, 1995). Data from the Andrews site indicates that spruce forests in southern Saskatchewan were succeeded by deciduous parklands prior to establishment of open prairie. Balsam poplar, aspen poplar, and river birch became established at some time after 10 200 BP, and persisted until at least 8800 BP.

The moist climate and deep ponds of the Andrews area are consistent with early Holocene records reported for a number of kettles and lakes in southern Saskatchewan and southern Alberta (Last, 1990; Klassen, 1994; Beaudoin, 1996). Beaudoin et al. (1996) suggested that high water levels throughout the region at that time resulted from the influx of meltwater into aquifers from the melting of buried stagnant ice. Such a source of water may have buffered the local environments against increasing warmth and dryness of the early Holocene Hypsithermal, and contributed to the apparent delay in the effects of early Holocene aridity in this region.

A floral shift toward plants tolerant of shallow, alkaline, and brackish water occurred in the upper part of zone III at the Andrews site (Fig. 6, phase 3), and has also been noted in other kettle-fill and lake studies from the region (Sauchyn and Sauchyn, 1991; Beaudoin, 1992; Klassen, 1994; Wilson et al., 1997). The increase in aridity, identified in phase 3, intensified during phase 4 at the Andrews site, indicating the onset of Hypsithermal effects at the Andrews site sometime between ca. 8800 and 7700 BP. Delay in the appearance of peak Holocene aridity until the mid-Holocene has also been reported from the American Midwest, where it has been identified as time transgressive and corresponding to the retreat of the Laurentide Ice Sheet across north-central North America (Wright, 1976; Winkler et al., 1986; Baker et al., 1992; Dean et al., 1996). Evidence from the Mackenzie Delta, central Alberta, and Montana, however, reveals that dry lake basins and drought-tolerant taxa were common from 10 000 to 8000 BP (Ritchie et al., 1983; Barnosky, 1989; Schweger and Hickman, 1989). Thus, in addition to protracted release of water from subsurface ice, the delay in appearance of Hypsithermal drought at the Andrews site could be attributed to a lag in deglaciation in this region.

Water levels in the Andrews site pond appear to have continually decreased, with minor fluctuations, through to about 5800 BP, when the pond become ephemeral and preservation of macrofossils ceased. Reconstruction of an interval of fluctuating water levels from ca. 7700 to 5800 BP, within a long-term climatic drying trend, agrees with the interpretation by Vance et al. (1992), based on the Chappie Lake record of southeastern Alberta, of brief moist intervals occurring during a largely arid period between 7300 and 6000 BP. Vance et al. (1992) suggested that the regional climate between 6000 and 4000 BP was more arid than at present, which is consistent with the termination of the Andrews site fossil record at about 5800 BP. Although a lacustrine environment persisted throughout the Holocene in some basins, such as Chappie Lake (Vance et al., 1992, 1993), the vast majority of ponds in the region dried and vanished, as was the case at the Andrews site.

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APPENDIX A

This appendix contains SEM micrographs of the 41 plant macrofossil taxa, plus associated animal fossils, identified at the Andrews site. See Appendix B for descriptions and remarks.
PLATE A-1

Figure 1. Chara sp. (stonewort algae) oogonium. Scale bar = 0.5 mm.

Figure 2. Chara sp. shoot fragments. Scale bar = 1.0 mm.

Figure 3. Picea glauca (white spruce) cone. Abundant seeds (as in fig. 4) were contained in cone. Scale bar = 5.0 mm.

Figure 4. Picea glauca winged seed. Scale bar = 1.0 mm.

Figure 5. Picea glauca needle. Scale bar = 1.0 mm.

Figure 6. Juniperus communis (low juniper) leaf. Scale bar = 1.0 mm.

Figure 7. Typha latifolia (common cattail) achene. Scale bar = 0.5 mm.

Figure 8. Potamogeton filiformis (thread-leaved pondweed) drupe. Scale bar = 0.5 mm.

Figure 9. Potamogeton natans (common floating-leaved pondweed) drupe. Scale bar = 0.5 mm.
PLATE A-2

Figure 1. Modern *Picea glauca* (white spruce) inner cuticle showing anticlinal walls. Scale bar = 50 μm.

Figure 2. Modern *Picea glauca* outer cuticle showing stomatal complexes. Scale bar = 0.1 mm.

Figure 3. Modern *Picea mariana* (black spruce) inner cuticle showing anticlinal walls. Scale bar = 50 μm.

Figure 4. Modern *Picea mariana* outer cuticle showing stomatal complexes. Scale bar = 0.1 mm.

Figure 5. Fossil *Picea glauca* inner cuticle showing anticlinal ridges. Scale bar = 50 μm.

Figure 6. Fossil *Picea glauca* outer cuticle showing stomatal complexes. Scale bar = 0.1 mm.
PLATE A-3

Figure 1. Cross-sections of *Potamogeton filiformis* (thread-leaved pondweed) drupes: fossil (left); and modern (right). Scale bar = 1.0 mm.

Figure 2. Fungal and microbial destruction of *Potamogeton* sp. drupes in zone V, where more testas are also found. Scale bar = 1.0 mm.

Figure 3. Close-up (at arrow in fig. 2) of *Potamogeton* sp. drupe, showing in situ fungi. Scale bar = 0.5 μm.

Figure 4. *Potamogeton obtusifolius* (blunt-leaved pondweed) drupe. Scale bar = 0.5 mm.

Figure 5. *Potamogeton pectinatus* (sago or fennel-leaved pondweed) drupe. Arrow at persistent attachment of drupe, which is a feature characteristic of this species. Scale bar = 0.5 mm.

Figure 6. *Potamogeton vaginatus* (sheathed pondweed) drupe. Scale bar = 0.5 mm.

Figure 7. *Zannichellia palustris* var. *palustris* (horned pondweed) drupe. Scale bar = 0.5 mm.

Figure 8. Gramineae (grass) glumes and awn. Scale bar = 0.5 mm.
PLATE A-4

Figure 1. Carex cf. C. atherodes (awned sedge) achene. Scale bar = 0.5 mm.

Figure 2. Carex cf. C. rostrata (beaked sedge) achene. Scale bar = 0.5 mm.

Figure 3. Eleocharis palustris (creeping spike-rush) achene. Scale bar = 0.5 mm.

Figure 4. Scirpus americanus (three-square bulrush) achene. Scale bar = 0.5 mm.

Figure 5. Scirpus cf. S. validus (great bulrush) achene with basal bristles. Scale bar = 0.5 mm.

Figure 6. Lemna trisulca (ivy-leaved duckweed) thallus. Scale bar = 1.0 mm.

Figure 7. Wolffia arrhiza (water-meal) thallus. Scale bar = 0.5 mm.

Figure 8. Populus balsamifera (balsam poplar) bud scale. Scale bar = 1.0 mm.

Figure 9. Populus tremuloides (aspen poplar) bud scale. Scale bar = 0.5 mm.
PLATE A-5

Figure 1. *Betula cf. B. occidentalis* (river birch) samara (wings not preserved). Scale bar = 0.5 mm.

Figure 2. *Rumex maritimus var. fueginus* (golden dock) achene. Scale bar = 0.5 mm.

Figure 3. *Rumex maritimus var. fueginus* perianth segments. Scale bar = 0.5 mm.

Figure 4. *Chenopodium cf. C. berlandieri* (false lamb's-quarters) seed. Scale bar = 0.5 mm.

Figure 5. *Chenopodium salinum* (saline goosefoot) seed. Scale bar = 0.5 mm.

Figure 6. *Caltha palustris* (marsh-marigold) seed. Scale bar = 0.5 mm.

Figure 7. *Ranunculus sceleratus* (celery-leaved buttercup) achene. Scale bar = 0.5 mm.

Figure 8. *Rorippa cf. R. truncata* (blunt-fruited yellow cress) seed. Scale bar = 0.5 mm.

Figure 9. *Subularia aquatica* (water awl-wort) seed. Scale bar = 0.5 mm.
PLATE A-6

Figure 1. *Fragaria virginiana* (smooth wild strawberry) achene. Scale bar = 0.1 mm.

Figure 2. *Lemna* sp. (Duckweed) achene. Scale bar = 0.1 mm.

Figure 3. *Rubus idaeus* (wild red raspberry) endocarp. Scale bar = 0.5 mm.

Figure 4. *Geranium* cf. *G. bicknellii* (Bicknell’s geranium) seed. Scale bar = 0.5 mm.

Figure 5. *Shepherdia canadensis* (Canada buffaloberry; soapberry) achene. Scale bar = 0.5 mm.

Figure 6. *Epilobium* cf. *E. ciliatum* (northern fireweed) seed. Scale bar = 0.5 mm.

Figure 7. *Hippuris vulgaris* (mare’s tail) seed. Scale bar = 0.5 mm.

Figure 8. *Myriophyllum* sp. (water-milfoil) mericarp. Scale bar = 0.5 mm.

Figure 9. *Myriophyllum verticillatum* var. *pectinatum* (whorled water-milfoil) bract. Scale bar = 0.5 mm.
PLATE A-7

Figure 1. *Lycopus americanus* (water-horehound) nutlet. Scale bar = 0.5 mm.

Figure 2. *Mentha arvensis* var. *villosa* (field mint) nutlet. Scale bar = 0.5 mm.

Figure 3. *Aster* cf. *A. novae-angliae* (New England aster) achene. Scale bar = 0.5 mm.

Figure 4. *Cirsium* cf. *C. maticum* (swamp thistle) achene. Scale bar = 0.5 mm.

Figure 5. Gastropoda (branchiate gastropod) shell. Scale bar = 0.5 mm.

Figure 6. Gastropoda (pulmonate gastropod) shell. Scale bar = 0.5 mm.

Figure 7. *Pisidium* sp. (clam) shell. Scale bar = 0.5 mm.

Figure 8. Coleoptera (beetle) elytron. Scale bar = 0.5 mm.

Figure 9. Arthropoda (insect), unidentified. Scale bar = 0.5 mm.
APPENDIX B

This appendix provides descriptions and remarks on the 41 plant macrofossil taxa, plus associated animal fossils, identified at the Andrews site. See Appendix A for illustrations.

<table>
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<tr>
<td>Chara sp. L. (stonewort algae)</td>
<td>Pl. A-1, fig. 1, 2</td>
<td>Elliptical oogonia, 0.9–1.1 mm long, 1.0–1.3 mm in diameter, with helicoidal ridges. Shoots up to 4.4 mm long and 0.8–1.0 mm in diameter. Both oogonia and shoots may be encrusted with CaCO₃.</td>
</tr>
<tr>
<td>Picea glauca (Moench) Voss (white spruce)</td>
<td>Pl. A-1, fig. 3–5; Pl. A-2, fig. 1, 2, 5, 6</td>
<td>Seed cones, 27.0–41.0 mm long, 11.0–15.0 mm wide. Seeds, 3.2–3.4 mm long, 1.7–1.8 mm wide. Features of cones, scales, and seeds fall within range of living Picea glauca, and differ from those of P. mariana (Miller) B.S. &amp; P. (black spruce). External morphological features of needles cannot be used to distinguish between these two species; however, cuticle micromorphology is diagnostic. Inner cuticle of fossil needles (Pl. A-3, fig. 1) compares favourably to that of modern P. glauca (Pl. A-2, fig. 3) and differs from that of P. mariana (Pl. A-2, fig. 5). Wood of Picea is not identifiable to species, but presumed to be that of P. glauca based on the association.</td>
</tr>
<tr>
<td>Juniperus communis L. (low juniper)</td>
<td>Pl. A-1, fig. 6</td>
<td>Leaves narrowly awl shaped, subulate, apex acute, base truncate and jointed, 5.0–5.6 mm long, 0.8–0.9 mm wide, 0.7–0.9 mm thick.</td>
</tr>
<tr>
<td>Typha latifolia L. (common cattail)</td>
<td>Pl. A-1, fig. 7</td>
<td>Achenes minute, 1.0–1.1 mm long, 0.30–0.33 mm wide, 0.27–0.30 mm thick; elliptoidal, apex narrow, truncate with the micropy/ł operculum appearing mucronate. Seed coat has a finely areolate texture.</td>
</tr>
<tr>
<td>Potamogeton filiformis Pers. (thread-leaved pondweed)</td>
<td>Pl. A-1, fig. 8; Pl. A-3, fig. 1</td>
<td>Drupes obvoid, asymmetrical, 2.4–2.7 mm long, 1.5–1.6 mm wide, 1.0–1.1 mm thick. Style short, up to 0.4 mm long. Dorsal germination valve extending from base and nearly reaching the style, lateral faces of drupe flattened with central depression. Drupe single-seeded, seed curved around prominent conicle, embryo campylotropous (Pl. A-3, fig. 3). Seed coat is smooth. Drupes of this species are significantly smaller than those of other species of this genus.</td>
</tr>
<tr>
<td>Potamogeton natans L. (floating-leaved pondweed)</td>
<td>Pl. A-1, fig. 9</td>
<td>Drupes obvoid to obliquely elliptic, asymmetrical, 3.3–3.6 mm long, 2.0–2.4 mm wide, 1.0–1.2 mm thick. Dorsal margin rounded with low spines, lateral faces flattened with central depression. Dorsal germination valve extending from base and nearly reaching the style. Drupe single seeded, seed strongly hook shaped and curved around prominent conicle, embryo campylotropous. Seed coat areolate.</td>
</tr>
<tr>
<td>Potamogeton obtusifolius Mert. &amp; Koch. (blunt-leaved pondweed)</td>
<td>Pl. A-3, fig. 4</td>
<td>Drupes obovate, asymmetrical, 3.4–3.6 mm long, 2.1–2.4 mm wide, 0.9–1.2 mm thick. Dorsal margin prominent with sharply corrugated edge, lateral faces flattened with pronounced external and central depression. Germination valve extending entire length of fruit. Drupe single seeded. Seed coat areolate.</td>
</tr>
<tr>
<td>Potamogeton pectinatus L. (sago pondweed or fennel-leaved)</td>
<td>Pl. A-3, fig. 5</td>
<td>Drupes obliquely obovate to nearly circular, asymmetrical, 3.5–3.8 mm long, 2.5–3.1 mm wide, 1.6–1.9 mm thick. Germination valve extends only one-half to two-thirds the length of the rounded dorsal margin and is not in contact with the base of the slender style. Drupe single seeded, seed U-shaped and curved around prominent conicle, embryo campylotropous. Fossil drupes are superficially comparable to those of Potamogeton vaginatus Turcz. achenes (Pl. A-3, fig. 8), but differ in that they are more circular and bear a persistent attachment (Pl. A-3, fig. 7).</td>
</tr>
<tr>
<td>Potamogeton vaginatus Turcz. (sheathed pondweed)</td>
<td>Pl. A-3, fig. 6</td>
<td>Fruits obliquely obovate, asymmetrical, 2.9–3.3 mm long, 2.2–2.6 mm wide, 1.4–1.8 mm thick. Germination valve extends only two-thirds the length of the rounded dorsal margin and is not in contact with the base of the slender style. Large seed strongly hook shaped and curved around conicle, seed slightly smaller than locule. Seed coat smooth.</td>
</tr>
<tr>
<td>Zannichellia palustris L. var. palustris (horned pondweed)</td>
<td>Pl. A-3, fig. 7</td>
<td>Drupes oblong and curved, 2.0–2.1 mm long, 0.7–1.0 mm wide, 0.3–0.4 mm thick, with persistent pedicel and style. Spine-like projections along margin on one side of drupes are unique to this species.</td>
</tr>
<tr>
<td>Incertae sedis (grass)</td>
<td>Pl. A-3, fig. 8</td>
<td>Identification of this grass material is restricted to the family level as only one vegetative fragment was recovered and diagnostic organs are absent.</td>
</tr>
<tr>
<td>Carex cf. C. atherodes Sprong. (awned sedge)</td>
<td>Pl. A-4, fig. 1</td>
<td>Achenes narrow ovoid in shape, trigonous, 2.1–2.7 mm long, 1.0–1.3 mm wide, 1.2–1.4 mm thick, sides slightly concave. Maximum width is midway between centre of achene and base. Although a number of important features are not preserved, comparison of fossil achenes with those of the living species indicates that the fossils most closely resemble Carex atherodes.</td>
</tr>
<tr>
<td>Carex cf. C. rostrata Stokes (beaked sedge)</td>
<td>Pl. A-4, fig. 2</td>
<td>Achenes small, wide obovate, trigonous, 1.4–1.7 mm long, 1.0–1.3 mm wide, 0.8–1.3 mm thick. Base acute with remnants of a stalk present, sides concave, margins rounded. Greatest width near the style. Style attached to seed and angled, curved like a corkscrew, 1.8–1.9 mm long, 0.1–0.2 mm wide. Style morphology and seed shape and size of the fossil are best compared to that of Carex rostrata achenes.</td>
</tr>
<tr>
<td>Eleocharis palustris (L.) R. &amp; S. (creeping spike-rush)</td>
<td>Pl. A-4, fig. 3</td>
<td>Achene obovate, lenticular, 1.9 mm long, 1.0 mm wide, 0.5 mm thick. Seed broadest below tubercle and narrowing toward base. Tubercle conical, longer than broad. Perianth composed of bristles of varying length; bristles with retrorse barbs.</td>
</tr>
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<tr>
<td><em>Scolpus americanus</em> Pers. (three-square bulrush)</td>
<td>Pl. A-4, fig. 4</td>
<td>Achenes wide obovate, lenticular, 2.9–3.3 mm long, 2.0–2.3 mm wide, 1.0–1.1 mm thick. Seeds broadest and thickest in upper third near style; style base short, apiculate; achene base sharply acut.</td>
</tr>
<tr>
<td><em>Scirpus cl. S. validus</em> Vahl. (great bulrush)</td>
<td>Pl. A-4, fig. 5</td>
<td>Achenes wide obovate, lenticular, 1.7–2.1 mm long, 1.3–1.5 mm wide, 0.7–0.9 mm thick. Base of seed broadly acute, base of style apiculate. Faint longitudinal furrows on outer surface of seed coat; epidermal cells isodiametric, arranged in longitudinal rows, surface slightly textured. The identification of these fossil seeds was difficult as the fossils are superficially similar in morphology to the seeds of <em>Scolpus americanus</em> Muilh. Based on size, they are tentatively assigned to <em>S. validus</em>.</td>
</tr>
<tr>
<td><em>Lemma trisulca</em> L. (ivy-leaved duckweed)</td>
<td>Pl. A-4, fig. 6</td>
<td>Thalius elliptic to oblanceolate, flattened, 6.0–5.3 mm long, 1.5–2.1 mm wide; stipule 1.8–3.1 mm long. Venation faint, three veins visible; margin finely serrate towards apex.</td>
</tr>
<tr>
<td><em>Wolffia arrhiza</em> (L.) Wimm. (water-meat)</td>
<td>Pl. A-4, fig. 7</td>
<td>Thalius ovate to globose, free floating, rosette, 0.3–0.6 mm long, 0.3–0.5 mm wide. Distinctive border of flattened, thick-walled epidermal cells. Young fronds of <em>Wolffia arrhiza</em>, produced from a basal cleft in mature thalli, are also found preserved (Pl. A-4, fig. 9).</td>
</tr>
<tr>
<td><em>Populus balsamifera</em> L. (balsam poplar)</td>
<td>Pl. A-4, fig. 8 (see also Fig. 5B)</td>
<td>Single terminal bud scale elongate, slender, up to 100 mm long, 2.4–2.7 mm wide, apex acute, margins ciliate, surface smooth. Leaves ovate to ovate-lanceolate, tapering to an acute to acuminate to attenuate apex, base broadly obtuse to cuneate to subcordate, 73.0–79.0 mm long, 56.0–60.0 mm wide. Venation pinnate reticulocormous. Margins minutely crenulate to subentire.</td>
</tr>
<tr>
<td><em>Populus tremuloides</em> Michx. (aspen poplar)</td>
<td>Pl. A-4, fig. 9 (see also Fig. 5B)</td>
<td>Terminal bud scale slender, conical, 4.5–4.7 mm long, 2.4–2.8 mm wide, apex acuminate, margins not ciliated. Leaves broadly ovate to nearly circular, 33.0–53.0 mm long, 32.0–48.0 mm wide, apex acuminate, base truncate to subcordate. Margins finely crenate to serrate to subentire. Venation reticulate acinodiromous. Petiole flattened and longer than blade.</td>
</tr>
<tr>
<td><em>Betula cf. B. occidentalis</em> Hook. (river birch)</td>
<td>Pl. A-5, fig. 1</td>
<td>Samaras elliptic to ovoblate, flattened, 1.1–1.2 mm long, 0.5–0.6 mm wide, lateral wings not preserved. Styles two. Assignment to either <em>Alnus</em> or <em>Betula</em> is complicated by poor preservation. Tentatively assigned to <em>B. occidentalis</em> on the basis of size, because samaras of <em>A. crispa</em> are considerably larger than those of <em>B. occidentalis</em> and the fossils.</td>
</tr>
<tr>
<td><em>Rumex maritimus</em> L. var. <em>fuegicus</em> (Phil.) Dusen (golden dock)</td>
<td>Pl. A-5, fig. 2, 3</td>
<td>Achenes elliptic, symmetrical, sharply trigonous, 1.1–1.2 mm long, 0.5–0.6 mm wide, 0.4–0.6 mm thick, with long marginal bristles; tuberolos acute, 3.3–3.6 mm long, 2.1 mm wide, 2.0 mm thick. Closely resembles those of <em>R. maritimus</em> var. <em>fuegicus</em> seeds. Identification supported by recovery of associated perianth segments with spinous margins (Pl. A-5, fig. 5), considered characteristic of this species.</td>
</tr>
<tr>
<td><em>Chenopodium cf. C. berlandieri</em> Moquin (false lamb's-quarters)</td>
<td>Pl. A-5, fig. 4</td>
<td>Achenes broadly ovate to nearly circular, asymmetrical, 1.0–1.2 mm long, 0.9–1.1 mm wide, 0.4–0.7 mm thick. On each side of the seed a shallow furrow extends radially from the centre to the hilum. Seed coat has a reticulate pattern with occasional wart-like papillae. Morphology of the fossil seeds is superficially similar to those of <em>C. pratericola</em> Rydb. and <em>C. hians</em> Standley. However, <em>C. pratericola</em> seeds are smaller and more irregular in shape than the fossil seeds. Seeds of <em>C. hians</em> are circular and symmetrical, whereas the micropylar end of the seed protrudes slightly in both the fossil and <em>C. berlandieri</em> seeds. Fossil seeds therefore tentatively identified as <em>C. berlandieri</em>. Recently, <em>C. berlandieri</em> has been recognized as a separate sp. and a native counterpart of <em>C. album</em>.</td>
</tr>
<tr>
<td><em>Chenopodium saltinum</em> Standley (saline goosefoot)</td>
<td>Pl. A-5, fig. 5</td>
<td>Achenes very wide ovate, asymmetrical, 0.7–0.6 mm long, 0.6–0.7 mm wide, 0.2–0.3 mm thick. Sides slightly convex, seed margin distinct. An indistinct furrow extends one-third the length of the seed from the hilum towards its centre. Seed coat texture slightly waxy to smooth. Seeds of <em>C. rubrum</em> L. var. rubrum are similar in size and shape to the fossil seeds; however, they differ in being ovate in cross-section and having a very smooth surface.</td>
</tr>
<tr>
<td><em>Caltha palustris</em> L. (marsh-marigold)</td>
<td>Pl. A-5, fig. 6</td>
<td>Seed significantly abraded, elliptic, nearly symmetrical, 2.7 mm long, 1.5 mm wide, 0.8 mm thick. Distinct fold on one margin, apex truncate, margins entire, hilum swollen. Surface texture reticulate.</td>
</tr>
<tr>
<td><em>Ranunculus sceleratus</em> L. (calcareous buttercup)</td>
<td>Pl. A-5, fig. 7</td>
<td>Achenes very wide ovate, elliptic in cross-section, flat, nearly symmetrical, 0.9–1.0 mm long, 0.8–0.9 mm wide, 0.3–0.4 mm thick. Margin entire, slight furrow surrounding periphery of seed visible, depression near hilum, and outer keel obtuse with longitudinal groove. Surface texture faintly areolate. All other species of <em>Ranunculus</em> have achenes that are significantly larger than the fossil and living <em>R. sceleratus</em>.</td>
</tr>
<tr>
<td><em>Rorippa cf. R. truncata</em> (Jepson) Studley (blunt-fruiting yellow cress)</td>
<td>Pl. A-5, fig. 8</td>
<td>Seeds nearly circular, elliptic in cross-section, asymmetrical, 0.8 mm long, 0.6–0.7 mm wide, 0.3–0.4 mm thick. Slight cleft between radicle and cotyledon near hilum. Surface texture reticulate to rugose. Seeds of <em>Rorippa palustris</em> (Oeder) Borbas (= <em>R. Islandica</em> (Oeder) Borbas) are closely comparable to fossil and living <em>R. truncata</em> seeds and may easily be confused. However, <em>R. truncata</em> seeds are consistently nearly circular in shape and possess rounded margins, whereas those of <em>R. palustris</em> are irregularly shaped and have sharply ridged margins.</td>
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### Appendix B (cont.)

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<tr>
<td><em>Subularia aquatica</em> L. (water awl-wort)</td>
<td>Pl. A-5, fig. 9</td>
<td>Seed narrow ovate, elliptic to oblong in cross-section, flattened, symmetrical, 0.8–1.0 mm long, 0.4–0.5 mm wide, 0.3 mm thick. Apex distinctly notched, broadest part of seed near middle. Longitudinal primary groove between radicle and cotyledons centrally placed. Seed coat glabrous, slightly textured.</td>
</tr>
<tr>
<td><em>Fragaria virginiana</em> Done. (smooth wild strawberry)</td>
<td>Pl. A-6, fig. 1</td>
<td>Achenes ovate, obovate in cross-section, asymmetrical, 1.2–1.3 mm long, 0.8–1.0 mm wide, 0.5–0.7 mm thick. Apex acute, slightly hooked adaxially. Faint striations radiating from hilum apparent on adaxial surface. Surface texture smooth. This species of strawberry was identified at the Andrews site during the floral survey.</td>
</tr>
<tr>
<td><em>Lemma sp.</em> (duckweed)</td>
<td>Pl. A-6, fig. 2</td>
<td>Achenes ovate to orbiculate, elliptic in cross-section, symmetrical, 0.7–0.8 mm long, 0.5–0.6 mm wide, 0.4–0.5 mm thick. Prominent indentation at one end and surface texture faintly areolate with prominent longitudinal ribs are distinctive of this taxa.</td>
</tr>
<tr>
<td><em>Rubus idaeus</em> L. (wild red raspberry)</td>
<td>Pl. A-6, fig. 3</td>
<td>Endocarps elliptic to suborbiculate, elliptic in long-section, asymmetrical, 1.8–2.4 mm long, 1.2–1.6 mm wide, 0.9–1.0 mm thick. Features characteristic of this species include distinct suture line between two halves, apex beak-like, and surface texture deeply areolate with series of Anastomosing ridges.</td>
</tr>
<tr>
<td><em>Geranium</em> cf. <em>G. bicknellii</em> Britton. (Bicknell's geranium)</td>
<td>Pl. A-6, fig. 4</td>
<td>Seeds narrow elliptic, circular in cross-section, symmetrical, 1.6 mm long, 0.5 mm wide, 0.5 mm thick. Faint protuberances at both ends. Surface reticulate to rugose. Poor preservation of this material made the identification of these fossil seeds difficult. However, the morphology of the fossil seeds most closely resembles the seeds of <em>G. bicknellii</em>.</td>
</tr>
<tr>
<td><em>Shepherdia canadensis</em> (L.) Nutt. (Canada buffaloberry)</td>
<td>Pl. A-6, fig. 5</td>
<td>Achenes ovate, asymmetrical, wide elliptic in cross-section, 3.1–4.1 mm long, 2.0–3.0 mm wide, 0.8–0.9 mm thick. Prominently lobed on one side with longitudinal groove extending from base to apex. Surface appearing smooth to slightly textured.</td>
</tr>
<tr>
<td><em>Epilobium cf. E. ciliatum</em> Raf. (northern fireweed)</td>
<td>Pl. A-6, fig. 6</td>
<td>Seeds narrow elliptic, transversely elliptic in cross-section, symmetrical, 1.0 mm long, 0.8 mm wide, 0.2 mm thick. Apex prominent. Based on surface texture, which appears longitudinally striate, and the presence of an opening in the hilum, the fossil seeds are tentatively identified as those of <em>E. ciliatum</em>.</td>
</tr>
<tr>
<td><em>Hippuris vulgaris</em> L. (mare’s-tail)</td>
<td>Pl. A-6, fig. 7</td>
<td>Seeds oblong-cylindric to elliptic, circular in cross-section, symmetrical, 2.0–2.2 mm long, 1.1–1.2 mm wide, 1.0–1.1 mm thick. Faint groove extending from base to apex. Large opening, up to 0.5 mm in diameter at apex. Fruit wall thick and woody; surface texture areolate.</td>
</tr>
<tr>
<td><em>Myriophyllum sp.</em> (water-milfoil)</td>
<td>Pl. A-6, fig. 8</td>
<td>Mericarps oblong to elliptic, oblong in cross-section, symmetrical, 2.1 mm long, 1.0 mm wide, 1.2 mm thick. Apex truncated to slightly emarginate; base rounded. Margins slightly rounded and bearing small tooth-like processes. Identification of fossil mericarps to the specific level is not possible.</td>
</tr>
<tr>
<td><em>Myriophyllum verticillatum</em> L. var. sectinatum Wolf. (whorled water-milfoil)</td>
<td>Pl. A-6, fig. 9</td>
<td>Bract palmate, broadly obovate, 1.6–1.7 mm long, 1.1–1.3 mm wide, is diagnostic of only this species and variety.</td>
</tr>
<tr>
<td><em>Lycopodium americanum</em> Muell. (water-horehound)</td>
<td>Pl. A-7, fig. 1</td>
<td>Nutlets oblate to orbiculate, obliquely triangular in cross-section, symmetrical, 1.1–1.3 mm long, 0.8–0.9 mm wide, 0.4–0.5 mm thick. Central region of nutlet raised and surrounded by thick marginal flange, which is characteristic of this species. Surface texture coarse.</td>
</tr>
<tr>
<td><em>Menispermum virgatum</em> var. villosa (Benth.) S. R. Stewart (field mint)</td>
<td>Pl. A-7, fig. 2</td>
<td>Nutlets suborbiculate, elliptic in cross-section, symmetrical, 0.7–0.9 mm long, 0.5–0.6 mm wide, 0.4–0.6 mm thick. Apex rounded; base wedge shaped and occluded. Surface texture faintly areolate. The floral survey at the study area indicates that this species presently grows there.</td>
</tr>
<tr>
<td><em>Aster cf. A. novae-angliae</em> L. (New England aster)</td>
<td>Pl. A-7, fig. 3</td>
<td>Achenes narrow oblong, elliptic in cross-section, flattened, symmetrical, 1.3–1.4 mm long, 0.3–0.4 mm wide, 0.1–0.2 mm thick. The longitudinally ribbed, densely pubescent fossil achenes most closely resemble those of <em>Aster novae-angliae</em>. The only feature which is not well preserved in the fossil achenes is the pappus rim.</td>
</tr>
<tr>
<td><em>Cirsium cf. C. muticum</em> Michx. (swamp thistle)</td>
<td>Pl. A-7, fig. 4</td>
<td>Achenes oblong to elliptic, elliptic and compressed in cross-section, symmetrical, 2.2–2.5 mm long, 0.6–0.7 mm wide, 0.5–0.6 mm thick. Prominent longitudinal ribs and fine longitudinal striations. Seed body tapers to rounded base. Apex with prominent cup-shaped cartilaginous pappus rim surrounding remnant of style. Although the pappus bristles are poorly preserved, other features of the achenes are diagnostic of living <em>C. muticum</em> achenes.</td>
</tr>
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