A diverse late-glacial (Mackinaw Phase) biota from Leamington, Ontario

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Abstract: A sand pit at Leamington, Ontario, in southeastern Essex County in the southernmost part of Canada, has yielded many taxa of fossil animals and plants that are dated over 13 000 BP. The fossils are of both terrestrial and freshwater origin, and comprise a surprisingly diverse but coherent assemblage of molluscs, ostracodes, Chironomidae, Coleoptera, Turbellaria, Trichoptera, and a few fish bone fragments. This is the oldest known postglacial occurrence in Ontario for all animal groups. Paleoenvironments indicated by the taxa range from boreal forest to tundra; taxa are an in situ assemblage with little transport or reworking. Although this site has yielded the richest fossil record of this age yet found in Ontario, previous finds at a few sites on the north edge of the eastern Erie basin and in the southern Huron basin indicate plants were well established in southwestern Ontario by the time of the Mackinaw Phase interstadial when lowered lake levels likely facilitated their arrival from land areas to the south. This discovery greatly improves the prospects of finding fossils of this age even though the known record is still extremely limited. The site represents fortuitous preservation and discovery, and amply demonstrates that glacial lakes of this time, when much of the last ice sheet was still in existence, were far from barren of life and that the migration of biota into the area was quite rapid during ice retreat.

Résumé : De nombreux taxons d'animaux et de plantes fossiles datant de plus de 13 000 ans avant le présent ont été trouvés dans une carrière de sable à Leamington, en Ontario, dans le sud-est du comté d'Essex, dans la partie la plus méridionale du Canada. Les fossiles ont des origines terrestres et d'eau douce et ils comprennent un assemblage étonnamment diversifié mais cohérent de mollusques, d'ostracodes, de chironomes, de coléoptères, de turbellariés, de trichoptères et de quelques fragments d'os de poissons. Cet endroit constitue la plus ancienne occurrence postglaciaire en Ontario de tous les groupes d'animaux. Les paléoenvironnements signalés par la plage des taxons varient de la forêt boréale à la toundra; les taxons constituent un assemblage in situ très peu déplacé ou retravaillé. Bien que ce site ait produit le plus riche profil fossile de cet âge trouvé à ce jour en Ontario, des découvertes antérieures à quelques sites à la bordure nord de l'est du bassin du lac Érié et dans le sud du bassin du lac Huron indiquent que des plantes étaient bien établies dans le sud-ouest de l'Ontario à l'époque de l'interstadiaire Mackinaw alors que les niveaux abaissés des lacs ont sans doute facilité leur arrivée en provenance de territoires plus au sud. Cette découverte améliore grandement les perspectives de trouver des fossiles de cet âge même si les données sont encore très limitées. Le site représente une conservation et une découverte fortuites et démontre de manière significative que les lacs glaciaires de cette époque, alors que la dernière nappe glaciaire existait encore, étaient loin d'être stériles et que la migration du biote dans la région s'est effectuée assez rapidement lors du retrait de la glace.

[Traduit par la Rédaction]

Introduction

We report on a fossiliferous site that reveals a diverse biota from the earliest known postglacial habitat in Ontario. We conclude that the establishment of thriving aquatic communities along the ice margin was quite rapid.

Morris et al. (1993) described sediments, plants (pollen and macrofossils), ^{14}C dates (13 150 – 13 410 BP), and a shrub-ox bone (cf. *Eucatherium* sp.) from sand and gravel pit exposures (Bondi Pit) near Leamington, Ontario (Fig. 1). In their description, mention of molluscs ("with shells", "shell-rich", p. 2437) drew attention to their presence, but

Received 4 June 2006. Accepted 18 October 2006. Published on the NRC Research Press Web site at http://cjes.nrc.ca on 20 April 2007.

Paper handled by Associate Editor J. Desloges.

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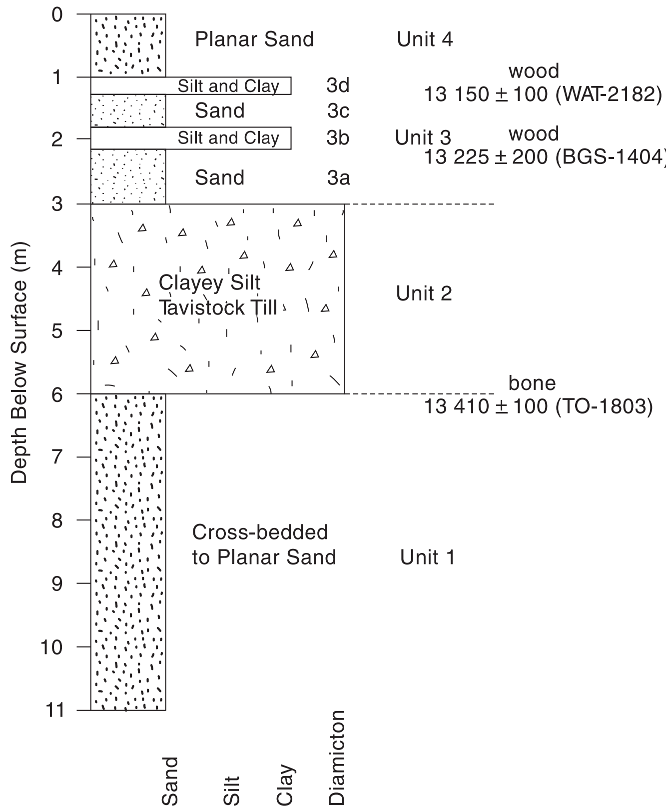
 doi:10.1139/E06-116

Fig. 1. Location of study site at Bondi pit (×). Hatched area northwest of Leamington is Leamington Island.

Fig. 2. Composite sketch of stratigraphy at Bondi pit, Leamington, Ontario (after Morris et al. 1993) showing studied units and positions of dated samples.



they were not further identified. Here we report a rich assemblage of other biotic remains and provide paleoecological interpretations to supplement that provided by Morris et al. (1993). Special interest is taken in this site because it has yielded the oldest dated postglacial biotic (animal and plant) assemblages so far known in Ontario.

The Bondi Pit is situated on NTS sheet 40 J/2b (Kingsville, 1 : 25 000 scale) at latitude 42°05′17″N and longitude 82°38′40″W on a broad hill (crest elevation 229 m) northwest of the town of Leamington in southeastern Essex County, Ontario. This location is in the southernmost part of Canada north of western Lake Erie. The hill formed a temporary island (here called Leamington Island, Fig. 1) in the declining water levels of a succession of Erie basin glacial lakes (Arkona, Whittlesey, Warren). The topography is apparently palimpsest, with a glaciofluvial subaquatic fan forming the core of the hill mantled by later glacial and glaciolacustrine sediments. The deposit was formed just north of the interlobate zone between the southbound Lake Huron ice lobe and the westbound Lake Erie ice lobe (Morris 1994).

Sediments in the pit were divided by Morris et al. (1993) into four superimposed units (Fig. 2): (1) a lower sand of glaciofluvial subaquatic fan origin, (2) Huron–Georgian Bay lobe Tavistock Till and proglacial outwash sand and gravel, (3) fossiliferous sand interbedded with fossiliferous laminated silt and clay, and (4) stratified sand; the latter two units are associated with lake-level fluctuations in the Erie basin. Unit 3 was described as consisting of subunits here designated from bottom up as 3a, disturbed sand; 3b, laminated silt and clay with plants and shells; 3c, shell-rich massive sand; and 3d, laminated silt and clay with plants; an unknown amount has been removed at the surface of overlying unit 4 sands by pit operations. The shrub-ox bone was found at the contact between units 1 and 2 at the west side of the pit. The fossiliferous sediments of unit 3 over till were only present in the eastern part of the pit and are no longer (as of November 2001) accessible, having been covered by slump, fill, and landscaping, but active excavation continues in the north and west parts of the pit.

Methods

Fossils were recovered from two unit 3 subunits (3b, 3c). A unit 3c grab sample (ca. 1 L) was collected in 1988 during Quaternary geology mapping (the shell-rich sand) and a large (about 30 L) bulk sample of unit 3b was collected in 1995 of laminated silt and clay in which molluscs were much sparser. The 3b sample (clay and silt) proved difficult to disaggregate with dispersing agent, but alternating drying and washing proved effective. The sediment samples were washed through 10 (2000 µm), 35 (500 µm), and 60 (250 µm) mesh sieves for concentration of fossils. From dried residual concentrates, all identifiable fossils were picked under a low-power (10×–40×) binocular microscope with a moist paint brush. Identification of molluscs was aided by Walter and Burch (1957), Clarke (1981), Jokinen (1992), and Mackie et al. (1980). La Rocque (1966–1970), Clarke (1973), and Jokinen (1992) provided paleoecological data. While recovering the molluscs, a variety of other fossils was recovered as well.

Paleontology

The fossil list (Table 1) is mostly new for the Bondi site and is described later in the text by taxonomic group. Sediments and radiocarbon dates (Table 2) indicate the depositional time span was short.

Plants

Spores of *Isoetes lacustris* (quillwort) were abundant (scores to hundreds) in units 3b and 3c. This aquatic plant lives in shallow, clear water on a clastic, sandy to silty substrate. Birks (2001) describes this plant as a non-pioneering species arriving after such plants as *Nymphaea* and *Potamogeton*; seeds of the latter are abundant at this site. Its presence indicates some maturity and soil formation in the landscape. *Isoetes* inhabits sparsely vegetated, shallow marsh, sandy substrates that are susceptible to wave action. Also present were fungi imperfecti sclerotia, which are widespread forms that provide little ecological information.

Numerous plant macrofossils, mainly seeds, were recovered from the samples. These were examined to check for additional species beyond those reported by Morris et al. (1993). All of the short list is shown in Table 1 because the original list was not specifically attributed to separate sediment subunits. Two taxa, *Betula glandulosa* and *Hippuris vulgaris*, are newly reported. This floral list is consistent with tundra.

Platyhelminthes: Turbellaria

More than one type of flatworm egg capsules were present (Turbellaria), but little is known about their ecology let alone their paleoecology (Warner 1989). Flatworms have no hard parts so they are not preserved, but they are abundant and widespread in a wide range of fresh waters. They are most abundant in very shallow waters near the shore, and live at the substrate surface or just below, commonly sheltered from light (Kolasa 1991).

Mollusca

The presence of visible, but unidentified, mollusc shells was the impetus for undertaking additional work on fossils at the Bondi site. Even though the unit 3b sample was much larger, the molluscs in unit 3c were more numerous and somewhat more diverse. Overall, the mollusc fauna comprises few taxa; two of the total of nine taxa were found only in unit 3c (*Stagnicola elodes*, a single specimen only, and *Pisidium milium*). Some taxa, such as *Pisidium casertanum*, *Gyraulus parvus*, and *Stagnicola elodes*, occupy a wide range of northern habitats and are widespread. *G. parvus*, *Valvata lewisi*, *P. milium*, and *S. elodes* prefer shallow water, muddy bottoms, and the presence of aquatic vegetation. *V. lewisi* is considered by Clarke (1981) to be a form of *Valvata sincera*, but most malacologists (e.g., LaRocque 1966–1970; Turgeon 1998) consider it to be a separate species. *Stagnicola* is found in calcareous environments and eutrophic water. Except for *P. milium*, which is uncommon anywhere, other taxa are common. *P. milium* nevertheless has widespread distribution geographically and ecologically.

The greater diversity and numbers of unit 3c molluscs could reflect their later deposition as taxa were spreading into the area, or it could simply reflect a more favourable sedimentary environment or sampling bias. It was evident in the field that unit 3c was more fossiliferous (i.e., for molluscs) than unit 3b, however the trend reversed in unit 3d where no molluscs were evident but plants were abundant.

Trichoptera

Trichoptera (caddisfly) mandibles were identified from two families; based only on mandibles, identification only to family was possible. The two families represented, together with the lack of other families, indicate the environment was a pond or lake rather than a river or stream. The families present tend to be northern, but extend well south into the USA (N.E. Logan, written communication, 2004).

Diptera: Chironomidae

Among microfossils recovered from the +60 mesh fraction were 14 taxa of Chironomidae (Table 1). The relatively coarse lower sieve used did not retain the smaller species so most of the assemblage was lost and diversity is lower than usual. As cold water taxa tend to be smaller, the recovered assemblage is biased. Nevertheless, the sample suggests a relatively warm, shallow environment. *Dicrotendipes*, *Glyptotendipes*, and *Polypedilum* are all littoral taxa and are rare or absent north of tree line (Oliver and Roussel 1983; Walker 1991; Walker and MacDonald 1995). The only cold stenotherm is *Sergentia*, which probably indicates that the lake was deep enough to thermally stratify.

Coleoptera

Well-preserved beetle fragments belonging to several different orders were extracted from dried residues from site levels 3b and 3c. The identifications are grouped collectively in Table 1, and the discussion later in the text refers to the assemblage as a single unit. The small fauna extracted consists predominantly of Coleoptera representing carabid beetles, a short-nosed weevil, and several small water scavenger beetles. True bugs were also present but indeterminate.

Although the identified taxa are few, they are of interest and present a coherent ecological story. *Bembidion balli* is only known today from western Canada, specifically on the Clearwater (tributary to the Athabasca), and North and South Saskatchewan River valleys. It is found on bare mud flats near backwaters of the main river (Lindroth 1963). David Maddison has probably collected the most specimens, and his collecting records indicate that *B. balli* is found “virtually exclusively in wetter areas (e.g., around little pools in sand flats) where soil was wet sand and clay”, or “commonest on flat sand/silt areas”. Most collecting sites appear to have *Equisetum* and small mosses nearby with *Salix* along the river banks. Occasionally, *B. balli* was collected from under riverbank detritus.

A single well-preserved head was identified by Henri Goulet as belonging to the *Elaphrus americanus* lineage. There are two subspecies in North America, *E. americanus americanus* Dejean and *E. americanus sylvanus* Goulet. The former has a broadly transcontinental northern distribution in boreal regions, but does not reach the Pacific coast; the latter is an extreme western species ranging along the Pacific coast and east to Colorado and southwestern Alberta (Goulet 1983). Both are found on wet beaches along slow meandering

Table 1. Fossils in units 3b and 3c, Bondi Pit, Leamington, Ontario.

	Unit 3b(ca. 1 L)	Unit 3c (ca. 30 L)
Plant macrofossils		
Ranunculus (Batrachium)	100	300
Potamogeton filiformis (similar to *P. vaginatus*)	20	300
Betula glandulosa bract	2	—
Betula glandulosa seed	1	—
Hippuris vulgaris	—	10
Dryas leaf	—	10
Isoetes lacustris megaspores	Numerous	Numerous
Unknowns	20	50
Platyhelminthes		
Turbellaria (flat worms)	Numerous	Numerous
Mollusca (snails and clams)		
Valvata lewisi	101	413
Fossaria galbana	6	13
Fossaria parva	1	5
Stagnicola elodes	—	1
Gyraulus parvus	31	—
Gyraulus sp.	—	6
Pisidium casertanum[a]	52	90
P. milium[a]	—	6
P. ventricosum[a]	10	11
Hemiptera (bugs)		
scutellum and indet. fragments	5 fragments	—
Trichoptera (caddisflies)		
Phryganeidae	12	8
Limnephilidae	8	6
Diptera		
Chironomidae (midges)		
Chironomus	224.0	253.5
Cryptochironomus	6.0	21.5
Dicrotendipes	92.0	97.0
Glyptotendipes	6.0	10.0
Sergentia	5.0	2.0
Stictochironomus	—	1.0
Polypedilum	1.0	—
Micropsectra	2.0	—
Tanytarsina spp.	12.0	17.0
Cricotopus–Orthocladius	8.0	6.0
Limnophyes?	—	0.5
Psectrocladius subgenus *Psectrocladius*	8.0	5.0
Zalutschia	1.5	—
Procladius	2.0	1.0
Unidentified fragments	0.5	9.5
Coleoptera (beetles)		
Carabidae (ground beetles)		
Bembidion balli (Lindroth)	1LE, 1RE, 1PR	1LE
Bembidion sp.1	1LE, 1HD	—
Bembidion sp.2	1RE, 1HD	—
Elaphrus americanus Kirby	1HD	—
Patrobus cf. *septentrionis* Dejean	1PR	—

Table 1 (*concluded*).

	Unit 3b(ca. 1 L)	Unit 3c (ca. 30 L)
Curculionidae (weevils)		
1 species indet.	—	1LE, 1HD
Hydrophilidae (water scavenger beetles)		
Potomanectes sp.	4 fragments	—
Ostracoda[a]		
Candona candida	236	142
Candona caudate	18	36
Candona cf. *neglecta*	183	124
Candona	2	—
Candona juveniles	92	257
Cyclocypris ampla	15	82
Cyclocypris ovum	—	11
Cypridopsis vidua	2	14
Heterocypris incongruens	—	4
Heterocypris sp.	1	—
Limnocythere herricki	11	10
Vertebrata		
Pungitius cf. *P. pungitius*	—	1

Note: LE, left elytron, RE, right elytron; HD, head; PR, pronotum; indet., indeterminate.
[a]Number of valves.

Table 2. Radiocarbon dates.

Site	Date (BP)	Laboratory #	Material	Reference
Bondi, unit 3c	13 150±100	WAT-2182	Wood	Morris et al. 1993
Bondi, unit 3b	13 225±200	BGS-1404	Wood	Morris et al. 1993
Bondi, unit 1/2	13 410±100	TO-1803	Bone collagen	Morris et al. 1993
Ridgetown, Ont.	12 660±440 (deemed too young)	S-31	*Larix*	Dreimanis 1966
Vanderven, Ont.	13 360±440	BGS-929	*Dryas*	Warner and Barnett 1986
Highland Glen, Ont.	13 100±110	GSC-2213	*Picea*	Gravenor and Stupavsky 1976
Riverside, Mich.	13 470±130	ISGS-1378	Conifer wood	Monaghan and Hansel 1990
Nichols Brook, N.Y.	12 320±240	WAT-844	Wood	Fritz et al. 1987
Kitchener, Ont.	11 900±140	GSC-4371	Wood	Karrow and Warner 1988
Kitchener, Ont.	12 000±90	WAT-1685	Wood	Karrow and Warner 1988
Woodstock, Ont.	12 150±90	WAT-2917	Wood	Krzyszkowski and Karrow 2001
Hawkesville, Ont.	12 135±75	BGS-2478	Wood	Bajc and Karrow 2004
Brampton, Ont.	11 970±150	BGS-550	Peat	Motz and Morgan 2001
Brampton, Ont.	12 320±360	BGS-551	*Picea glauca* cones	Terasmae and Matthews 1980
Brampton, Ont.	12 770±200	BGS-707	Cones, twigs	Motz and Morgan 2001
Georgetown, Ont.	11 700±90	WAT-1758	Wood	Warner et al. 1991
Columbus, Ohio	13 125±470	OWU-177	Wood	Garrison 1967
Columbus, Ohio	12 695±240	OWU-177A	Wood	Garrison 1967
Columbus, Ohio	13 200±480	OWU-197	Peat	Garrison 1967
Fenske mammoth, Wis.	13 470±50	CAMS-36642	Bone	Overstreet 1998; Holman 2001
Mud Lake mammoth, Wis.	13 440±60	CAMS-36643	Bone	Overstreet 1998; Holman 2001

Note: BGS, Brock University; CAMS, Lawrence Livermore National Laboratory; GSC, Geological Survey of Canada; ISGS, Illinois State Geological Survey; OWU, Ohio Weslayan University; S, Saskatchewan Research Council; TO, Isotrace, University of Toronto; WAT, University of Waterloo.

creeks or on clay beaches in the saturated portion. The surfaces are often sun exposed.

Patrobus septentrionis Dejean was tentatively identified from one half of a pronotum. Again, this species has a transcontinental disjunct distribution, ranging from Newfoundland to Quebec and then from Alberta to western Alaska. It is recorded in northern Michigan (Lindroth 1961). Lindroth (p. 184) describes the species as occurring “at the borders of lakes, ponds and slow streams on more or less clayish ground with grass and *Carex* vegetation and little moss”. He also notes that it is “not found on the true tundra”. Habitat records for this species in the University of Waterloo collection are all northern or high-altitude collecting sites “under stones on mud beside treeline pond” (Colorado, unplublished); “streamside in saturated short sedges and grasses” and “among sparse grass, near shore, shaded by 2 m *Salix*” (Nunavut, unplublished); “at treeline, beach site 1–2 m from lake edge” (northern Quebec, Morgan 1989, pp. 30–31.).

The presence of water at the site is confirmed by small aquatic beetles and caddis jaw fragments. These could indicate small pools or a far larger water body.

Ostracoda

The ostracode assemblages from units 3b and 3c (Table 1) share a common group of eight species indicative of cool, shallow wetland or lakeshore conditions linked to very dilute groundwater discharge. These species are all extant, living today with mid-latitude to arctic distributions. The dominance of *Candona candida* and *Candona* cf. *neglecta* indicates groundwater discharge; these species are often found in ponds and streams connected to permanent springs (Meisch 2000; Smith et al. 2003). Published accounts of modern distributions of *Candona candida* and *Cyclocypris ampla* in North America indicate that the total concentration of the water in which these microcrustaceans lived was <500 mg/L total dissolved solids (Delorme 2001; Forester et al. 2005). *Cyclocypris ampla*, *Cyclocypris ovum*, and *Cypridopsis vidua* are strongly associated with nearshore aquatic plants, and *Limnocythere herricki* and *Heterocypris incongruens* are associated with wetlands (Smith et al. 2003). Overall, the assemblage indicates that the water was dilute (<500 mg/L total dissolved solids) and ranged in bottom temperature from ~7 to 15 °C.

Vertebrates

Of three small bone fragments, all fish, one was unidentifiable and the other two were joinable pieces of the same right frontal bone of ninespine stickleback, *Pungitius* sp. cf. *P. pungitius*, catalogued as ROM 55681 in the paleobiology collections (K.L. Seymour, written communication, 2005). This incomplete bone was compared with examples of all five eastern North American species of stickleback and the bubbly but not strutted texture of the frontal bone best matches *Pungitius*. This small fish is commonly found in the shallow vegetated bays of lakes, but may also be found in slow streams and ponds (Coad 1995). Scott (1968) gives its distribution as eastern Canada and the Great Lakes in the south, but in smaller lakes in the north including salt water pools along the shore of Hudson Bay. It does not occur in the Lake Erie basin today, being of slightly more northerly distribution (Lee et al. 1980).

Several other types of fossil remains encountered in the concentrates remain unidentified.

Discussion

As the southernmost of the Great Lakes basins, the Lake Erie basin was the first of these basins to be deglaciated. This occurred for the first time since the last glacial maximum during the Erie Phase about 16 000 BP. The subsequent Port Bruce Phase readvance refilled the basin with ice for the last time; the ice expanded onto adjacent lands about 15 000 BP and covered nearly all of southwestern Ontario. This advance deposited the Tavistock Till identified in the eastern, now covered, Bondi pit exposures. Final deglaciation commenced with retreat of the Port Bruce Phase ice during the Mackinaw Phase (Karrow et al. 2000), and a succession of lowering glacial lakes followed—including Maumee, Arkona, and a low-level Ypsilanti with eastward drainage—as the ice retreated into the Lake Ontario basin (Calkin and Feenstra 1985). Dreimanis (1966) reported a date of 12 660 ± 440 BP (S-31, Table 2) related to the Arkona–Whittlesey transition from gravels near Ridgetown (75 km northeast of Leamington), which he considered to have been slightly contaminated, yielding too young an age. Morris et al. (1993) postulated that it was during the time of Mackinaw Phase low water and expanded land areas that animals and plants spread into southern Ontario from the USA. Plant fossils indicated the establishment of spruce forest – tundra by about 13 200 BP (Table 2) at the Bondi site and at the eastern Erie basin Vanderven site (Warner and Barnett 1986; Morris et al. 1993). Diverse plant assemblages are recorded at several eastern Erie basin sites at that time (Barnett 1998); these assemblages were recovered from outwash deltaic settings and probably transported some distance from more northerly sources. None of these, however, yielded the diversity of animal remains now known from the Leamington site. During the ensuing Port Huron Phase ice readvance into the eastern Erie basin (Barnett 1979), glacial lakes Whittlesey and Warren and subsequent lakes recorded their water levels on Leamington Island (MacLachlan 1939; Chapman and Putnam 1984; Morris 1994). A single date on *Picea* sp. wood of 13 100 ± 110 BP (GSC-2213) indicates the presence of spruce trees offshore from the present shoreline and lowered water levels in the Lake Huron basin (Gravenor and Stupavsky 1976); one of these trees was incorporated into St. Joseph till deposited by the Port Huron advance of the Huron lobe, later to be discovered in shorecliff exposures south of Grand Bend, Ontario (Table 2). On the southeastern shore of Lake Michigan, which for most of its history has shared water levels conjoined with Lake Huron, conifer wood dated at 13 470 ± 130 BP (ISGS-1378) and near present lake level similarly indicates lowered lake levels and the presence of plants about the same time (Table 2).

It is probably significant that the relatively old Bondi and Vanderven sites are located so far south and were part of the early deglaciation of the region. Farther inland to the northeast, the oldest wood dates are about 12 000 BP (Table 2). Morris et al. (1993) also referred to the Nichols Brook site in western New York as a fossil site of similar age. Dating of that site remains uncertain (Calkin and McAndrews 1980; Fritz et al. 1987); only the oldest wood date is shown in Table 2. Several dates on poplar and spruce wood and plant detritus from glacial Lake Iroquois range from 12 000 to 12 600 BP and clearly demonstrate the presence of trees in the Ontario basin at that time (Karrow 1987).

All modern ecological data suggest that the Bondi fossil Coleoptera once resided on the margins of water, likely on a clay or sandy substrate, probably with small *Carex* species and grasses nearby, and perhaps with *Salix* close by. However, there are significant absences of species that should occur in the habitat reconstruction. Staphylinid beetles are absent, particularly *Bledius* and the often associated carabid *Dyschirius*; this suggests that the collecting and (or) sorting methods missed these species. The indeterminate short-nosed weevil is likely a root feeder and is frequently found hiding under plant detritus.

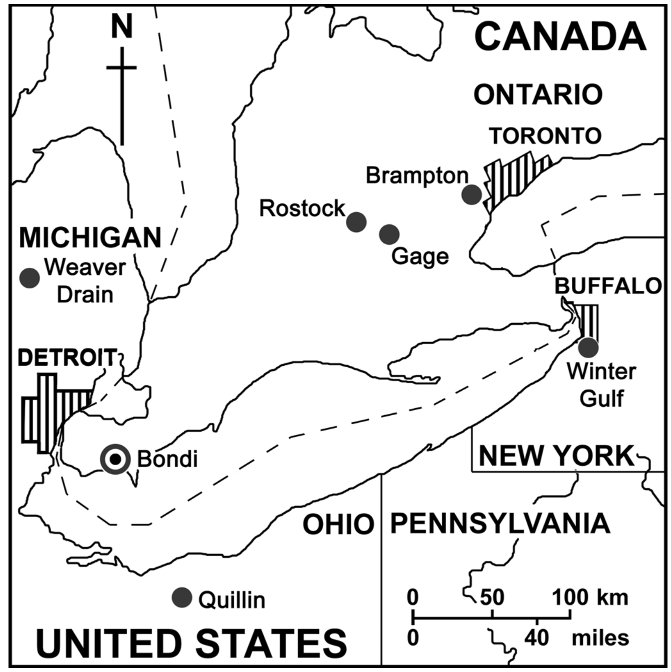
The question of climate would probably be best answered by looking at the modern beetle distributions. The "best fit" would likely be mean July temperatures of 16–18 °C and mean minimum January temperatures of ca. −20 to −25 °C. This is not a "tundra" assemblage, but it is one that could be found close to tree line or at least on open ground areas within the boreal zone. The mean annual temperature would be about 3–0 °C. The seeming peculiarity of "western" beetles being present in the late-glacial of southern Ontario is not at all unusual, and sites with many different Coleoptera with exclusively "western" modern distributions have been described from the region (Morgan 1987).

The time frame represented by the Bondi Site is about 13 200 ± 200 years, an episode of rapidly changing climate and the end of a short-lived permafrost regime that was geographically widespread in the region north and east of Leamington. The Bondi site is of interest because it fills a void on the late-glacial fossil beetle climate curve for the southern Great Lakes region. The "open-ground" landscape that followed ice retreat was colonized by plants and by animals. Many of the plant assemblages can be interpreted as "tundra" communities, but animals, particularly fossil Coleoptera (beetles), appear to indicate that the term "open-ground" rather than "tundra" might be a better descriptive term. Morgan (1987) has pointed out that there are differences in the interpretation of climatic figures between plant assemblages and beetle communities. True northern tundra beetle assemblages, representative of species found today north and west of Churchill, Manitoba, were extirpated at the low-elevation margins of the retreating Laurentide Ice Sheet commencing about 16 500 BP, although some species persisted in the higher elevations of the Appalachians minimally as late as 11 000 BP. Beetles that recolonized the deglaciated eastern low-elevation areas of the continent, although present up to tree line and present in open areas of the boreal forest, are not true "tundra" forms.

A short review of climatic conditions reconstructed from fossil beetle sites in the region around the Bondi Site (Fig. 3) shows July temperatures were warm enough for trees to grow. It seems, therefore, that the matter of soil maturation, soil stability, and colonization were greater impediments to tree arrival than the changing late-glacial climate.

At Quillin, Ohio (~100 km south of Bondi), a basal "litter layer" in a kettle produced a date of 14 500 ± 150 BP on woody detritus. Phytophagous tree-eating scolytids and other beetles from the same horizon have distributional ranges today that would place mean July temperatures at ~15 °C. By contrast, the Weaver Drain site, in Michigan, (140 km north of Bondi) dated at 13 770 ± 210 BP has open ground "tundra" plants (*Vaccinium uliginosum, Dryas integrifolia, Salix herbacea*) with an "open ground" to boreal beetle assemblage that has an estimated mean July temperature of ~11 °C. The solitary scolytid indicates that trees were not far away, and

Fig. 3. Fossil insect sites referred to in the text.



other beetles present in this site normally occupy open areas in the northern boreal forest. The mean July temperature could have been as high as 14 to 15 °C. Given the proximity of the retreating ice margin, winter winds and even summertime katabatic winds would create a very steep thermal climate gradient away from the ice margins. As indicated earlier in the text, the Bondi insects at ~13 200 BP indicate mean July temperatures of 16 to 18 °C.

Rostock, Ontario, and Winter Gulf, New York, (north and east of Bondi, respectively) are believed to be slightly younger than Bondi (perhaps 13 000 and 12 700 BP, respectively). Rostock (Pilny et al. 1987) is altitudinally higher than Winter Gulf (Schwert and Morgan 1980) with July mean temperatures of ~12 to 14 °C at Rostock and 16 °C at Winter Gulf. Finally, the Gage site in Kitchener (Schwert et al. 1985) and the Brampton Site, near Toronto (Motz and Morgan 1997), have beetles recovered from basal samples ~12 500 BP that indicate July mean temperatures of 15–17 °C.

The Coleoptera recovered from all of these sites point to common factors, namely that although there are "tundra" plants present in many areas, the July temperatures away from the ice margins were warm enough for tree growth had trees been able to colonize these "open" environments. Even in close proximity to the retreating ice and at higher elevations, the minimum July temperatures do not indicate "tundra" conditions in terms of what we see today as true northern tundra.

Mean annual temperatures are more difficult to calculate because the only parameters that we have for estimating mean temperatures are the abundant ice wedges described from the Ontario Island by Morgan (1972, 1982) and more recently by Gao (2005). Ice wedges will not form unless the average mean temperature is below −3.5 °C. It appears that ice wedges further north and east of the Bondi site formed until approximately 13 000 BP, and Morgan (1987) has pointed out that the conditions peculiar to their formation might have been because of the ice front configuration. Once the major horseshoe-shaped front of the ice vanished with retreat of the Huron and Ontario–Erie lobes, coupled with rapidly rising insolation, the mean annual temperature rose rapidly to +2 °C in as little as 500 to 700 years by 12 500 BP. In the Bondi area, it is likely that the lake water, coupled with a lower altitudinal setting, might never have allowed permafrost to take hold.

About the same time as the Bondi deposits were laid down, beaver (*Castor canadensis*) activity has been described from Columbus, Ohio, just beyond the Erie basin (Garrison 1967). Although most dated mastodon and mammoth sites of the Great Lakes region are between 10 000 and 12 000 BP, two mammoth sites in Wisconsin, also just at or beyond the Lake Michigan drainage divide, are of similar age to the Bondi site (Holman 2001). The time when diverse mammal assemblages succeeded in penetrating “Ontario Island” (the high interior of southwestern Ontario isolated by the retreating ice lobes and extensive proglacial lakes) remains to be determined, but it would appear to have been after the retreat of Port Huron ice, i.e., after 13 000 BP.

The similarity of the three Bondi radiocarbon dates on two types of materials (bone, wood) from three different ^{14}C dating laboratories (Isotrace, Brock, Waterloo) in proper stratigraphic sequence, with oldest at the bottom and youngest at the top, provides support for their validity. However, stratigraphically, the bone date is incongruous. Its stratigraphic position in the Bondi pit sequence indicates it precedes the arrival of Tavistock (Port Bruce) ice. The distribution and occurrence of Tavistock Till in Ontario (Karrow 1984; Karrow and Occhietti 1989; Morris 1994) places its age early in the Port Bruce Phase and significantly older than the Port Huron advance of about 13 000 BP. Its age is likely 14 000 – 15 000 BP, suggesting that the bone collagen ^{14}C date is too young. There is experience with bone collagen dates that indicates they tend to be too young (Meltzer and Mead 1983; Lepper et al. 1991; Higham et al. 2006). The living conditions and where and how the animal died remain unanswered questions.

As for molluscs, Erie basin glacial lakes have yielded little record. This is in contrast to later glacial lakes of other basins, such as Iroquois (Ontario basin, Karrow et al. 1972) and Algonquin (Huron basin: Karrow et al. 1975, 1995; Miller et al. 1985). Mentions of molluscs from Lake Warren deposits near Hamilton (Erie basin, Karrow 1963) and Lake Schomberg (Georgian Bay basin, Gwyn 1972) were not followed up because those occurrences could not later be relocated. The existing biotic records and widespread discovery of rhythmite (varve) bedding plane trace fossils (Banerjee 1973; Gibbard and Dreimanis 1978) clearly show that glacial lakes were not barren of life, but fossil occurrences in the Erie basin remain rare. Thus, these occurrences near Leamington are a unique and significant discovery, and should stimulate alertness to the possibility of further discoveries. This exceptional discovery has to be appreciated in terms of its chance preservation (as so far known, unique), chance exposure by aggregate extraction 1988–1995 (not exposed by 2001), and chance examination by a geologist in the course of routine geological mapping of Essex County in 1988. The timely recovery and reporting of a single bone drew the attention of scientists to the site.

Conclusions

Fortuitous discovery of fossiliferous sediments in a sand pit at Leamington, southern Ontario, has yielded a diverse assemblage of animal and plant remains. Dated as >13 000 BP, the assemblage includes plant macrofossils, flatworm egg cases, molluscs, bugs, caddisflies, midges, beetles, ostracodes, and fish; it is the oldest late-glacial fossil animal assemblage known in Ontario and supports the conclusion that plants were well established in southern Ontario by that time. Fossils indicate climate was cooler than present and boreal woodland to open-ground environments were present. The various fossil groups are very consistent in indicating depositional environments were shallow with near-shore waters and adjacent, low-lying wet parts of near-shore land. The highly coherent fauna and flora indicate an essentially in situ assemblage that experienced little transport or reworking, attributes that further enhance its uniqueness, i.e., taxa lived at the site. The site, far from the mainland to the south or from ice and glacial lake-isolated Ontario Island to the north, had to have been colonized quickly by its typical early successional aquatic biota after deglaciation. (see also Dieffenbacher-Krall and Jacobson 2001). Around that time, glacial lakes were extensive and surprisingly rich in life while most of the Laurentian ice sheet was still active. This discovery greatly improves the prospect of discovering other fossil sites of equal or greater age. Such fossil assemblages are the only opportunities to learn about the earliest biotic inhabitants because traditional coring methods used in lakes and wetlands do not allow sampling of such materials.

Acknowledgments

Laboratory processing (washing, picking) of the bulk sample was carried out by M. Battler, C. Jermyn, and C. Ma, funded by the University of Waterloo – Ontario Work Study Program. Help with identification of fossils and paleoecological interpretation by G.L. Mackie, University of Guelph, Guelph, Ontario, on Sphaeriidae and Gastropoda, D.R. Barton, University of Waterloo, Waterloo, Ontario, on Chironomidae, N.E. Logan, Sault Ste. Marie, Ontario, on Trichoptera, K.L. Seymour, Royal Ontario Museum, Toronto, on vertebrates, and B.G. Warner, University of Waterloo and N.G. Miller, New York State Museum, Albany, N.Y., on various unknowns, is greatly appreciated. Thanks are also due to Henri Goulet and Yves Bousquet for confirming the *Elaphrus* and *Bembidion* identifications. David Maddison, Danny Shepley and Keith Roper also provided additional ecological and location data for *B. balli*. We thank B.G. Warner, S.R. Hicock, P.J.H. Richard, and J.R. Desloges for reading the manuscript and providing comments that improved the presentation. Field work expenses were partly funded by a Natural Sciences and Engineering Research Council operating grant to P.F. Karrow, and partly by a self-funded grant through the University of Waterloo. Figures 1 and 2 were prepared by B. Levely, University of Waterloo.

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