Cave infill and associated biotic remains as indicators of Holocene environment in Gatineau Park (Quebec, Canada)

B. Lauriol, E. Deschamps, L. Carrier, W. Grimm, R. Morlan, and B. Talon

Abstract: A rich sedimentary deposit reaches a depth of more than 4 m in a cave located on the Eardley Escarpment in the Gatineau Park. Analysis shows that the infilling started during the last Ice Age. Following the deglaciation and the Champlain Sea retreat, terrestrial sedimentation began. Radiocarbon dating of wood charcoal indicates that around 9200 ± 110 years BP trees and shrubs were starting to grow on the Eardley Escarpment. A fauna, with boreal affinity, including the Ungava collared lemming (*Dicrostonyx hudsonius*), was living in vegetation dominated by jack pine. After 8170 ± 60 years BP, the boreal forest was replaced by a mixed forest dominated by white pine, oak, and red maple. The faunal assemblage was enriched at that time by woodland vole (*Microtus pinetorum*) and *Strobilops aenea*, a terrestrial mollusk. These two species are presently living in the Carolinian Life Zone south of the Great Lakes. By around 5742 ± 120 years BP these two species had left the site, and the modern fauna was established with mammals, such as the black bear and the white-tailed deer. Holocene infilling of the cave was gravity driven and unassisted, except for an episode just before 8170 ± 60 years BP when a sand layer was deposited by water coming from the surface.

Résumé : Une riche séquence sédimentaire de 4 m d'épaisseur est présente dans une caverne située sur l'Escarpement d'Eardley, dans le Parc de la Gatineau. Son étude montre que la sédimentation terrestre continentale a commencé après la déglaciation et le retrait de la mer de Champlain. D'après l'analyse des charbons de bois, les arbres et les arbustes poussaient sur l'Escarpement d'Eardley vers 9200 ± 110 années BP. Une faune, avec des affinités boréales, incluant le lemming d'Ungava (*Dicrostonyx hudsonius*), vivait dans cette végétation dominée par le pin. Après 8170 ± 60 années BP la forêt boréale a été remplacée par une forêt mixte dominée par le pin blanc, le chêne et l'érable à sucre. L'assemblage faunistique a été enrichi en même temps par un mammifère, le campagnol sylvestre (*Microtus pinetorum*) et un mollusque terrestre: *Strobilops aenea*. Ces deux espèces vivent actuellement dans la Zone Carolinienne localisée au sud des Grands Lacs. Vers 5742 ± 120 années BP, elles ont disparu du site et la faune moderne s'est établie, avec notamment des espèces comme l'ours noir et le chevreuil de Virginie. La sédimentation a été de type gravitaire, pendant tout l'Holocène sauf un peu avant 8170 ± 60 années BP, où un ruissellement venant de la surface a mis en place une couche de sable.

Introduction

Caves are among terrestrial sites that have recorded both abiotic and biotic change during the Holocene and the Pleistocene. Their location is favorable for the preservation of plant and animal remains (Emslie 1998). They are often used as reliable proxies for past climate change (Miskovsky 1987; Cogeoenvironment [IUGS] Working Group on Geo-indicators 1996). This article presents the results of the excavated site, "Caverne de la Mine" (Fig. 1). The site occurs on Grenville (Precambrian) marble outcrop (Hogarth 1970), near the eastern limit of the Canadian Shield, in the Gatineau–Ottawa region (Fig. 2). It was probably developed by subglacial melt water flowing from the Laurentide Ice Sheet. During deglaciation, the site was submerged ~20 m below the surface of the Champlain Sea, an arm of the Atlantic Ocean that extended along the lower St. Lawrence River valley into the isostatically depressed lower Ottawa and upper St. Lawrence valleys. The marine submersion occurred around 12 ka BP in the Gatineau–Ottawa region (Rodrigues and Richard 1985). After the sea's retreat, terrestrial sediments began to fill in the cave, a process that still continues. The study of the cave infill allows a reconstruction of the mammalian faunal assemblage and its environment dur-

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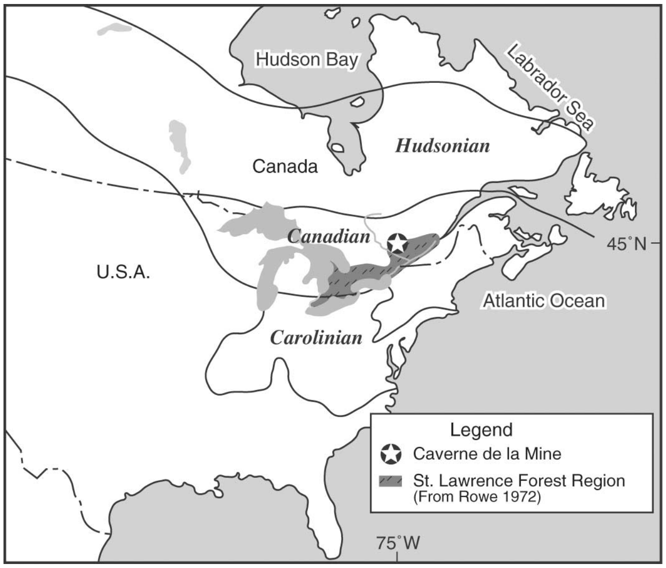


Fig. 1. Location of Caverne de la Mine and the Biotic Life Zones in northeastern North America.

ing the Holocene. The results supplement regional-scale reconstructions of past climate of this period from lake sediments and from other paleontological sites in the Canadian Shield and St. Lawrence Lowlands.

Study site

Caverne de la Mine lies on the Eardley Escarpment within the Gatineau Park limits in southern Quebec (45°28′18′′N, 75°51′01′′W; Fig. 2). This escarpment is 40 km long and 150–200 m high and probably formed by a fault at the contact between the St. Lawrence Lowlands and the Canadian Shield (Hogarth 1970). The cave consists of a rock shelter and a vertical shaft comprising two pits (Fig. 3). The first pit leads to a small room at 4 m below the entrance. A narrow opening in the floor of this room leads to the second pit where the studied material was collected.

The cave is located in a region characterized by large seasonal temperature variations and relatively high precipitation. The mean annual air temperature at the Ottawa airport is 5.5°C, and the area receives annually a total of 955.8 mm of precipitation (Environment Canada 1993). January is the coldest month and July the warmest with monthly averages of –11.5°C and 20°C, respectively. The southern exposure of the Eardley Escarpment induces a microclimate: the temperature near the cave entrance is 2°C to 3°C warmer than the surrounding plateaus and plain (Gagnon and Bouchard 1981).

The park's mixed deciduous and coniferous vegetation is characteristic of the middle Ottawa zone of the Great Lakes – St.Lawrence Forest Region (Rowe 1972). Its vegetation is described in detail by Grandtmer (1966). The forest cover surrounding the cave entrance consists of hardwoods, such as red maple, sugar maple, red oak, beech, basswood, and white ash. Butternut was abundant near the cave entrance until a few years ago, as can be deduced from the presence of its fruit in the modern surface infill. On the Escarpment, some species (butternut, bur oak, white ash, black cherry, and red cedarwood) are at their northern limits (Gagnon and Bouchard 1981).

Table 1. Most common mammal taxa of local fauna (Adapted from Sankey 1997).

Species	Common name
Sorex cinereus	Common shrew
Blarina brevicauda	Short-tailed shrew
Myotis lucifugus	Little brown bat
Eptesicus fuscus	Big brown bat
Sylvilagus floridanus	Eastern cottontail
Lepus americanus	Snowshoe hare
Tamias striatus	Eastern chipmunk
Sciurus carolinensis	Gray squirrel
Microtus pennsylvanicus	Meadow vole
Marmota monax	Woodchuck
Peromyscus leucopus	White-footed mouse
Erethizon dorsatum	Porcupine
Ursus americanus	Black bear
Procyon lotor	Raccoon
Odocoileus virginianus	White-tailed deer

Unlike the vegetation, the local faunal composition may be difficult to assess because of mobility and the crepuscular lifestyle of certain species. A complete list of mammalian taxa naturally occurring in the Ottawa region was produced by Rand (1945) and revised by Sankey (1997). According to Sankey, 53 taxa presently occur in the region in varying population sizes (Table 1). The terrestrial mollusk fauna of the region consists of 46 species (Oughton 1948).

Objectives and methodology

The main objective of the study was to analyze mammalian remains present in Caverne de la Mine and to determine the environmental conditions reflected by their formation and conservation. All the sediment confined between the cave walls was removed in 5-cm increments following procedures reviewed by Djindjian (1987) and Lévêque (1987). The material was excavated using a garden towel and packaged in labeled “Ziploc” bags. All excavated material was brought to the lab for bulk sieving. Bones, teeth, land snails and wood charcoal were recovered from the sieved matrix with the help of forceps, and often with the help of a Lietz binocular microscope (×50) or a standard laboratory magnifying glass. For each level sampled, a bag containing approximately 500 g of sediment was reserved for abiotic sediment analysis. Carrier (1989) studied the material from the first metre (the upper infill). Lauriol, from 1990 to 1995, excavated the intermediate section which is 2 m thick. Deschamps (2001) studied the material from the last metre (the lower infill). Mammal bones, mollusk shells and wood charcoal were identified to the species level by E. Deschamps, L. Carrier, and B. Lauriol, assisted by R. Morlan and C.R Harington (bones), W. Grimm (shells), and B. Talon (charcoal).

Cave infill and environmental conditions

Causes of the cave's infill might be various. First, chunks from the walls could have fallen in with material located near the rock shelter. Second, material could have been brought

Fig. 2. Bedrock geology and main patterns of Late Wisconsinian ice flow in the Gatineau–Ottawa region. Adapted from Fulton et al. (1987).

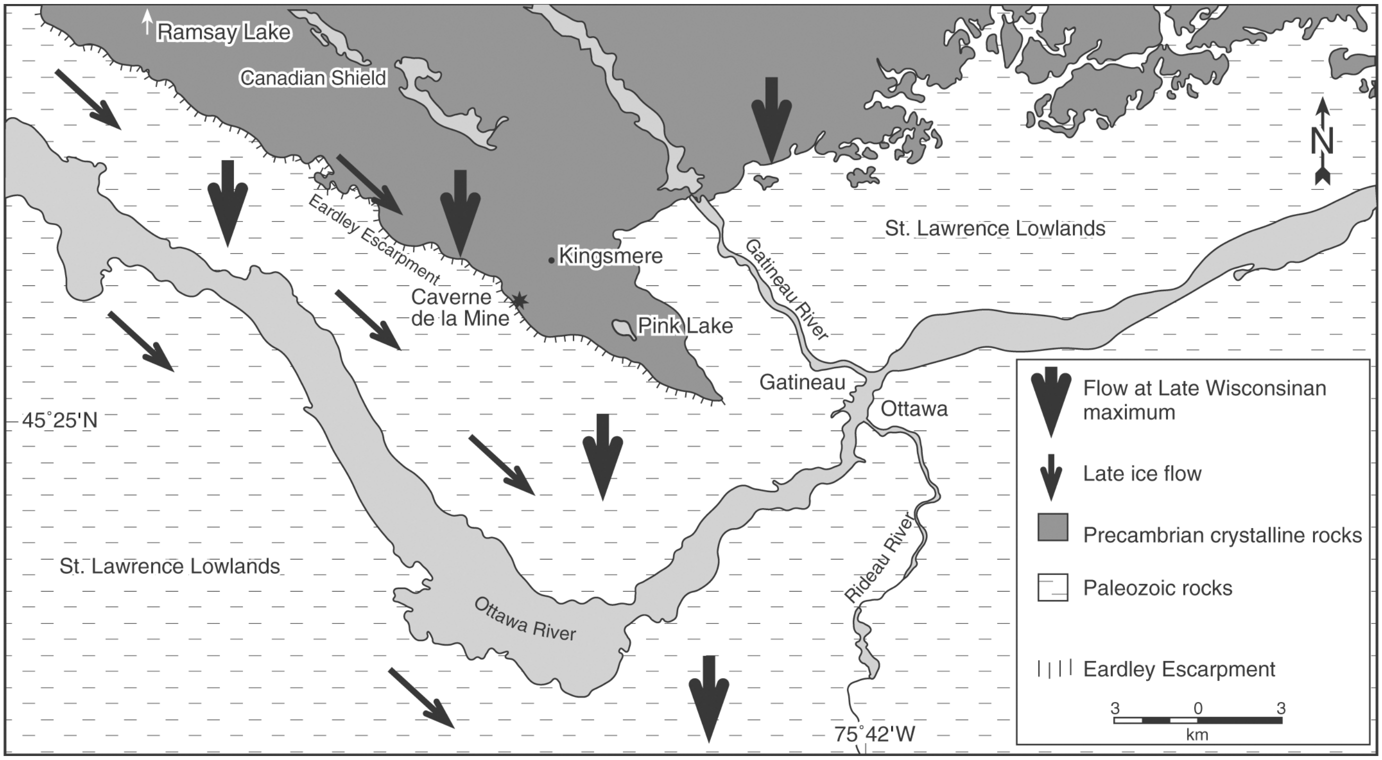
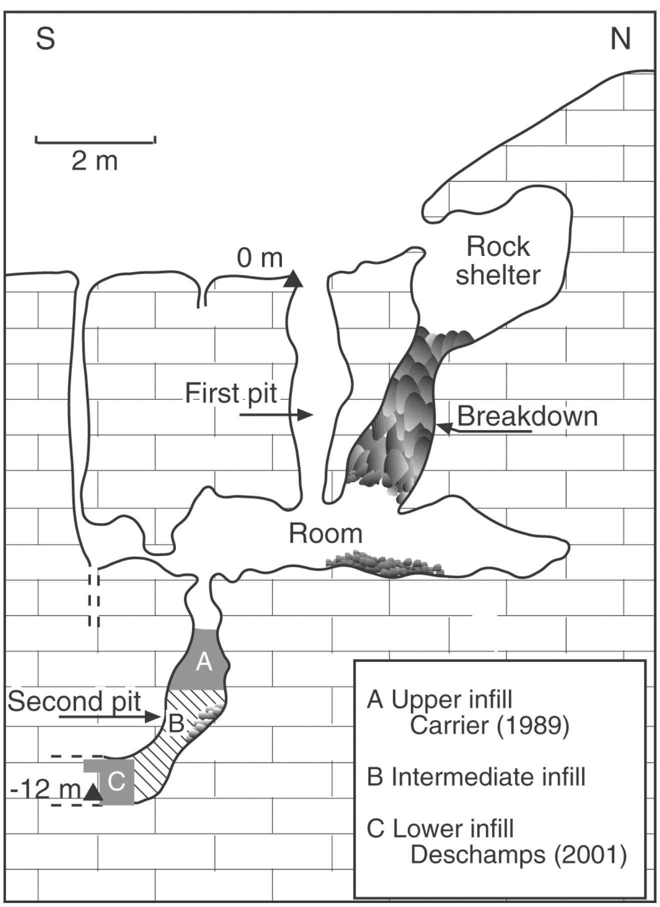


Fig. 3. Cross section of Caverne de la Mine showing location of excavations.



in by surface runoff. Third, during the last glaciation, till or fluvio-glacial sediment could have been injected into the cave. Fourth, marine sediment could have been deposited in the cave since the entrance is located below the marine limit of the Champlain Sea.

One of the objectives of the study was to determine the origin of the sediment in the second pit. The lithology of the gravel, grain-size analysis, sediment colour, and pH of the fine sediment for each 5-cm interval sample was analyzed. To establish a chronology of the infill, eight charcoal samples were radiocarbon dated and converted to calendar years (Stuiver et al. 1998).

Palynological, anthracological (study of charcoal), and malacological analyses were carried out on sampled material to infer the environmental conditions characterizing the Eardley Escarpment at the time the mammals lived. Since the sediments are aerobic, only pollen grains with thick exine were preserved. In total, nine samples of sediment have been analyzed for their content of pollen and spores. Three samples come from the lower infill and six from the intermediate and upper infill. Only 100 grains per sample have been examined because of the difficulty of analysis. Normal procedure requires the identification of a minimum of 200 grains for each level.

The methodology followed for charcoal identification is that described by Talon et al. (1998). Only samples larger than 2 mm from the lower infill were studied. A percentage count of conifers versus hardwoods for each stratum was performed. A more precise identification was done for wood charcoal collected in three levels. Except for the Rosaceae, all the charcoals were identified to genus or species level. The wood charcoal comes essentially from forest fires in the immediate area of the entrance, and was brought into the cave by surface runoff or gravity. Leaves and pieces of unburned wood could have fallen into the cave, but unlike the wood charcoal, they would have decomposed and contributed to the accumulation of organic matter.

The sampled mollusks could have been introduced from the entrance where they lived in the soil, or from the walls. In a few cases, they may be derived from animal droppings. The main sources for the mollusk identification are Pilsbry (1940, 1946, 1948), Oughton (1948), Canadian Museum of Nature, and F.W. Grimm collections. Mollusks are good indicators of climate sensu lato, as well as providing specific climatic signals corresponding to environmental factors, such as temperature, precipitation, and moisture (Rousseau et al. 1992; Lauriol et al. 2002).

Mammal remains

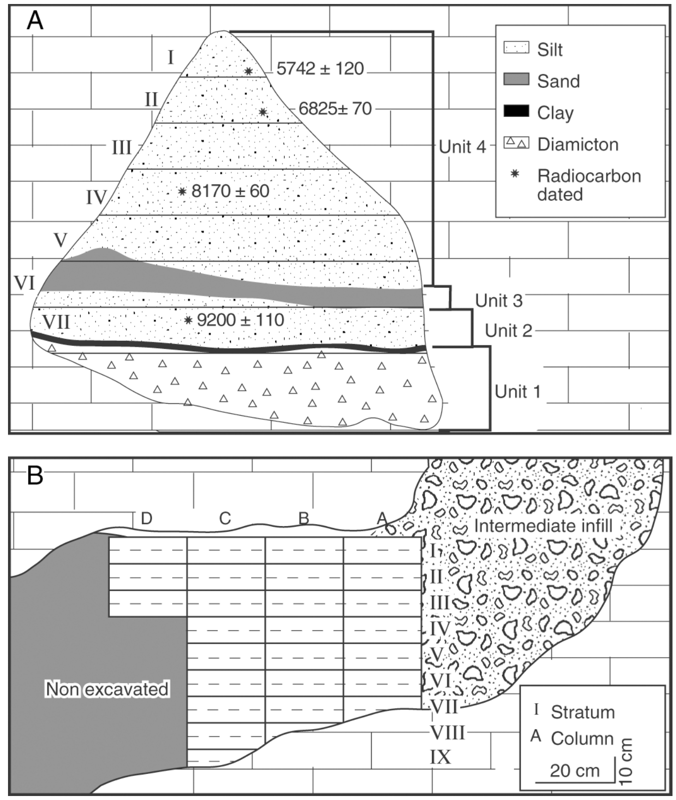
The accumulation of mammal remains in caves is normally derived from various sources, which include the remains of animals frequenting or living in caves, the remains of animals trapped in caves, the remains of predators' prey, and bones transported to the cave (Emslie 1998). Several of these sources may simultaneously contribute to forming the fossil fauna of a particular site, some of them leaving distinctive physical markings on bones and teeth (Mellett 1974; Dodson and Wexlar 1979; Korth 1979; Andrews and Nesbit Evens 1983; Andrews 1990). During identification, the cranial material was examined for evidence of breakage, pitting, and corrosion were recorded that might indicate the nature of the accumulation and any post-depositional alterations. Since time was lacking to study the post-cranial material, the observations cannot support a detailed taphonomic analyses, such as that of Andrews (1990). However, we can suggest aspects of a taphonomic history that would account for the remains found in the cave.

Techniques used for vertebrate and microvertebrate fossil recovery were those explained by Churcher and Wilson (1990). Only mammalian cranial elements (i.e., maxillae, mandibles, and teeth) were identified. These elements are usually well represented in fossiliferous deposits because of their resistant nature, which makes them quite useful in assessing the number of individuals present (Lyman 1994*a*, 1994*b*). Taxonomic identifications were done by direct comparison with the reference collections at the Canadian Museum of Civilization. Identification keys and guides for mammals (Glass 1973; Kurta 1993), for rodents (Chomko 1980), and for insectivores and bats (van Zyll de Jong 1983*a*, 1983*b*) were also useful.

Tabulation: NISP and MNI

Two commonly used indices were computed to summarize the data of mammal species: the number of identified specimens (NISP) and the minimum number of individuals (MNI). NISP, an observational unit, is "the number of identified specimens per taxon in which the taxon may be a subspecies, species, genus, family or higher taxonomic category" (Lyman 1994*a*: p.100). Grayson (1984: p.16) defines a specimen as "a bone or tooth, or fragment thereof". Cranial specimens are the only ones considered in this study. MNI is a derived unit, which expresses "the minimum number of individual animals necessary to account for some analytically specified set of identified faunal specimens" (Lyman 1994*a*: 100), for example, the third right maxillary molar. MNI values were calculated based on identified material for each stratum of the lower deposit. Strata sampled at 5-cm intervals were aggregated

Fig. 4. Caverne de la Mine lower infill excavation grid: (A) frontal view; (B) lateral view.



into 10-cm strata to obtain a greater number of specimens per stratum. Such level aggregations are valid since only slight differences appear in taxon rank orders between the most divided approach (NISP) and the aggregated (MNI_{10cm}) approach (see Grayson 1984). A significant Spearman's rank order coefficient ($r_s = 0.954$) confirms this. Although the use of NISP and MNI as counting units has many weaknesses (Morlan 1983; Grayson 1984), they are, by far, the most often used measures of faunal abundance.

Paleoenvironmental conditions

Chronostratigraphy

The lower infill in the second pit of Caverne de la Mine consists of four units (Fig. 4). Unit 1 is composed of a compact diamicton located at the base of the infill. It contains small calcareous erratics from the Paleozoic rocks of the Ottawa Valley. Their occurrence suggests that the material was injected into the cave by the latest ice flow, which was toward the southeast in the region (Fig. 2). A small gray clay bed (<1 cm thick) exists in the upper part of the diamicton. It is hypothesized that it was deposited when the cave was submerged by the Champlain Sea. Since sampling was done at 5-cm intervals, it is not possible to detect whether fish fossils, a few millimetres in length, were in situ in the clay horizon or were introduced from surrounding horizons. In fact, other fish fossils were found in overlying horizons. However, they were probably remains introduced by other animals, such as raccoons (*Procyon lotor*). The likelihood that they were introduced by flowing water is slight. Actually,

Table 2. Caverne de la Mine lower infill sediment analysis.

Strata	Age: ^{14}C BP (sample)	Calendar age	pH	Colour code	Gravel (%)	Sand (%)	Fines (%)
I	5020 ± 70 (TO-6854)	5742 ± 120	7.77	10YR2/2	23	66	11
Il	6020 ± 70 (TO-6855)	6825 ± 70	7.59	10YR2/2	19	67	13
III	—	—	7.65	10YR2/2	13	72	14
IV	7280 ± 60 (TO-7767)	8170 ± 60	7.17	10YR2/2	23	42	35
V	—	—	6.37	10YR2/2	13	52	34
VI	—	—	6.81	5YR2/2	9	71	20
VII	8230 ± 80 (TO-6858)	9200 ± 110	7.19	10YR2/2	3	48	49

Note: All dates are on wood charcoal.

streams with minnows can be found on the higher plateau no less than a kilometre away.

Unit 2 is composed of 10–15 cm-thick, very compact dark-coloured sediments (stratum VII, very dark brown: 10YR 2/2; Table 2). It is constituted of 3% gravel, 48% sand, and 49% fine. The pH is 7.2. Unit 2 contains some bones, mollusks, and charcoal. A radiocarbon date on wood charcoal gave an age of 9200 ± 100 years BP (TO-6858).

A sand layer constitutes unit 3. The band's thickness is about 5 cm across most of the deposit and increases to 12 cm at a protuberance near the right cave wall. This natural stratum was encountered at the same depth throughout sections A, B, and C (section D was not excavated to that depth) suggesting that the buildup of the lower infill occurred along a level horizontal plane. Its pinkish colour (stratum VI, dark reddish brown: 5YR 2/2), due to its richness in marble and syenite, differs from the other deposits in the cave.

Unit 4 extends from the sand layer up to the ceiling of the cave passage. The sediments consist mainly of silt and sand of a brownish colour (very dark brown: 10YR 2/2) with a pH between 7.5 and 8. A change in sediment size occurs between strata IV and III when the percentage of fine particles drops from 35% to 14%. Fossils become more numerous in the deposit as one approaches the ceiling. A total of 1351 mammalian fossils were identified; snake remains were also found. Amphibian fossils (*Bufo americanus*) and mollusk shells are also very abundant. Three radiocarbon dates were obtained from pieces of charcoal: 8170 ± 60 years BP (TO-7767), 6825 ± 70 years BP (TO-6855) and 5742 ± 120 years BP (TO-6854). These dates indicate on average accumulation rate of 2 cm per century for the upper 40 cm of the lower infill.

The sediments in the upper infill are coarse with a brownish colour, a pH between 7 and 7.5, and a dominance of sandy material. High pH values (near 8) characterize the intermediate infill. Over 7000 fossils, consisting mostly of amphibians, bats, and raccoons, were collected from this section but were not thoroughly analyzed. Radiocarbon dates on wood charcoal are 2951 ± 200 years BP (UQ-1652) at 50 cm, 4855 ± 110 years BP (GSC-5352) at 90 cm, 3383 ± 140 years BP (UQ-1958) at 110 cm, and 7635 ± 40 years BP at 250 cm (Beta-93668).

Table 3. Percentage of charcoal wood in strata from the Caverne de la Mine lower infill.

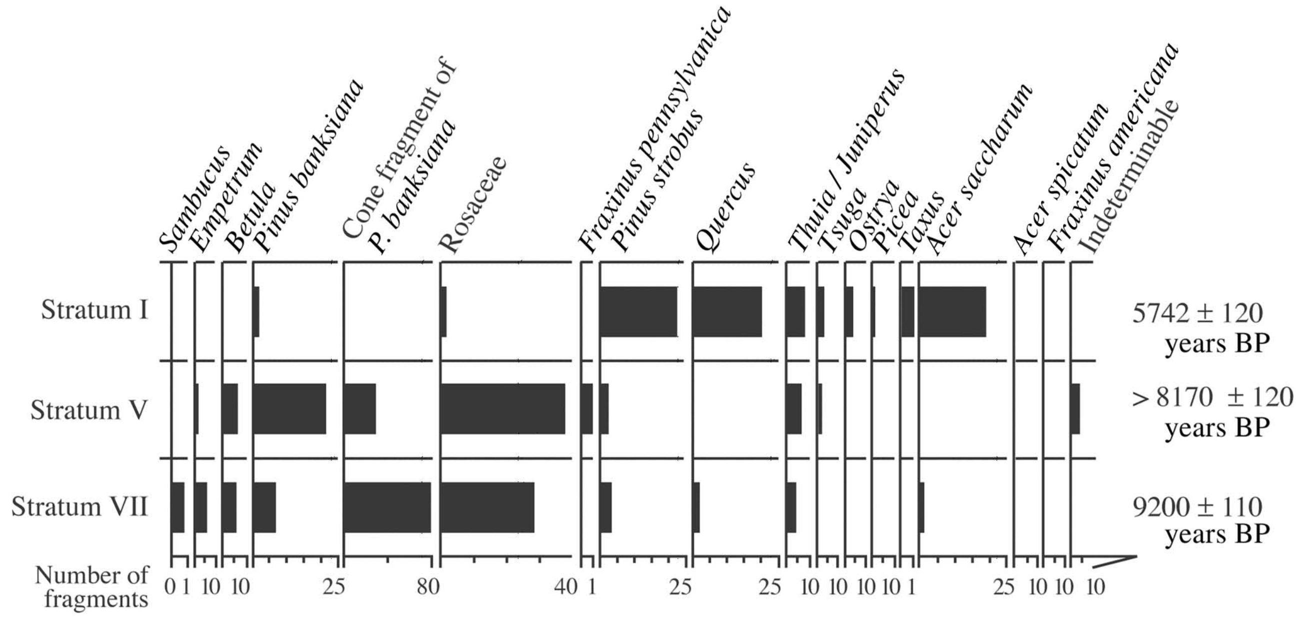
Strata	% Conifers	% Hardwoods
I	39	61
II	No data	No data
III	48	52
IV	47	53
V	56	44
VI	64	36
VII	67	33

Abiotic deposit origin

Carrier (1989) performed in-depth granulometric, morphoscopic, and petrographic analyses of infill from caves of the Eardley Escarpment (1989). His results have shown that the bulk of the fine sediments in the infill are comparable to sediments found on the surface. Consequently, he concluded that the cave sediments were mostly derived from the surface and likely correspond to an admixture of till. Rain and snow meltwater likely permitted surface material to infiltrate through fissures in the rock and be deposited inside the cave. The occurrence of some speleothems and angular material within the deposit also suggest that mechanical and chemical degradation of the parent rock inside the cave also contributed to the formation of the infill. Undoubtedly, such processes are also responsible for the formation of the lower infill in Caverne de la Mine.

As for the occurrence of the reddish brown sand layer in unit 3 (stratum VI), it appears that a distinct event took place sometime during the formation of lower infill. While several hypotheses could be proposed to explain the origin of this material, Carrier (1989) attributed the occurrence of sandy material in three nearby caves to fluvial processes. Likewise, it is imaginable that sometime between about 9000 and 8000 years BP, some material may have been washed inside the cave via one or several of its many openings. Whether this occurred as a result of a widespread climatic event during the early Holocene (Alley et al. 1997) or as a result of a localized event, such as an intense rainstorm, it appears that the factors that contributed to the incorporation of the material of unit 3 were relatively short-lived.

Fig. 5. Charcoal wood diagram from Caverne de la Mine lower infill.



Vegetation

Pollen preservation is very poor in Caverne de la Mine. Two of three pollen spectra, from the lower infill, dated respectively at 9200 ± 110 years BP and 8170 ± 60 years BP are dominated by pine (*Pinus*: 40%), birch (*Betula*: 35%) and have some sagebrush (*Artemisia*). The third pollen spectrum, dated at 5742 ± 120 years BP, holds mainly pine (*Pinus* sp.: 25%), birch (*Betula*: 40%), elm (*Ulmus*: 10%), and oak (*Quercus*) grains. In the intermediate and upper infill, it is also possible to observe a dominance of pine (*Pinus*), spruce (*Picea* sp.), and birch (*Betula*) species from the spectra contemporaneous and older than 7635 ± 40 years BP and the presence of linden (*Tilia*), oak (*Quercus*), and elm (*Ulmus*) in spectra younger than 7635 ± 40 years BP. All spectra contain abundant spores, probably originating from ferns and mosses located in the first pit.

Floral change occurred gradually. The increase of hardwood taxa is less than 10% from one stratum to another in the lower infill (Table 3). Hardwood taxa range from 33% in stratum Vll to 61% in the stratum I. In more detail, the 9200 ± 110 years BP and 8170 ± 60 years BP charcoal samples are similar as they contain the same taxa in comparable quantities (Fig. 5). Charcoal of jack pine (*Pinus banksiana*) is abundant along with Rosaceae and birch (*Betula*). The charcoal assemblage of 5742 ± 120 years BP differs from the lower strata by its abundance of white pine (*Pinus strobus*), sugar maple (*Acer saccharum*), and oak (*Quercus*), with very little jack pine (*P. banksiana*) and Rosaceae.

The assemblages of wood charcoal can, therefore, be subdivided into two zones according to the visible contrast between the upper and two lower strata. The lower strata suggest that the regional forest cover from 9200 ± 110 years to 8170 ± 60 years BP was mainly comprised of jack pine, birch and Rosaceae. The presence of crowberry near the base of the infill suggests an open and dry environment. The second zone which consists of the charcoal assemblage of the upper stratum, shows a replacement of jack pine by the white pine and increasing importance of hardwood species.

Table 4*a*. Mollusks identified from the Caverne de la Mine lower infill (strata I, II, and III, Holocene).

Species	N.	Species	N.
Discus ruderatus	345	*Gyraulus* sp.	5
Helicodiscus parallelus	272	*Carychium exile*	4
Strobilops labyrinthica	216	*Strobilops affinis*	4
Nesovitrea binneyana	174	*Gastrocopta similis*	3
Zonitoides arboreus	135	*Helicodiscus shimeki*	3
Euconulus fulvus	44	*Anguispira alternata*	2
Lymnaeidae	29	*Gastrocopta corticaria*	1
Cochlicopa lubrica	26	*Gastrocopta tappaniana*	1
Paravitrea multidenta	25	*Vertigo ventricosa*	1
Neohelix alborabris	25	*Vertigo bollesiana*	1
Vallonia gracilicosta	21	*Vertigo arthuri* group	1
Mesomphix inornatux	13	*Columella columella*	1
Glyphyalinia indentata	13	*Striatura milium*	1
Euchemotrema fraternum	13	*Striatura ferrea*	1
Euconulus polygartus	11	*Glyphyalinia solida*	1
Discus catskillensis	11	*Cochlicopa nitens*	1
Striatura exigua	10	*Aplexa hyponorum*	1
Vertigo cristata	9	*Hawaiia minuscula*	1
Glyphyalinia rhoadsi	8	*Pomatiopsis lapidaria*	1
Nesovitrea electrina	8	*Physa* sp.	1
Gastrocopta pentodon	6	*Planorbula armigera*	1
Gastrocopta contracta	6		
Strobilops aenea	6		
Strobilops (Fragments)	5		
TOTAL			1467

Note: N., number of samples.

Our pollen and wood charcoal analyses agree well with the regional vegetation records provided by Mott and Farley-Gill (1981) from the analysis of pollen in two sediment cores at Pink and Ramsay lakes in Gatineau Park (Fig. 2).

Molluscan fauna

The molluscan assemblage from the lower infill, in the second pit, comes from the material in strata I to III. The amount of sediment examined represents ~120 kg. These samples contained 1467 specimens representing 44 species, of which five are aquatic (Table 4*a*). The main species are *Discus ruderatus*, *Helicodiscus parallelus*, *Strobilops labyrinthica*, *Nesovitrea binneyana*, and *Zonitoides arboreus*. This assemblage is characteristic of a mesic environment. Of particular interest is *H. parallelus* since it lives usually in the soil, mainly in deciduous forest, rarely in the coniferous forest. Some of the species, such as *Strobilops aenea*, with six specimens, may also provide evidence of a warmer climate than today since they live presently in the Carolinian Life Zone (Fig. 1). The presence of species that are amphibian (Lymnaidae) or hygrophilus (*Pomatiopsis lapidaria*, *Fossaria*, *Physa* sp., *Planorbula amigera*, *Gyraulus* sp.) indicates wetter environment with probably the occurrence of occasional standing water near Caverne de la Mine around 6000 and 7000 years BP. The material below stratum III supplied only some *D. ruderatus*. Differences above and below stratum may be linked to differences in preservation conditions and the type of vegetation cover. In fact, it is around stratum III that the transition from a boreal forest to a mixed forest is observed. The boreal forest has an acidic soil, which is unfavorable to the preservation of mollusks.

The modern assemblage is composed of 808 specimens and 27 species extracted from material collected in the rock shelter and outside, on the Eardley Escarpment (Table 4*b*). It is different from the lower infill. Two hard shelled species (*D. ruderatus* and *Vallonia gracilicosta*) are dominant. *Neohelix alborabris*, the largest land snail in the region, is also common where it lives under the soil foliage. All the species of the modern assemblage are generally common to the deciduous forest but rare in the coniferous forest. *H. parallelus*, abundant in the lower infill, is now absent from the rock shelter. It is presently observed in some more shaded and humid sites on the Eardley Escarpment.

It appears from these mollusk assemblages that climatic conditions in the middle Holocene on the Eardley Escarpment were probably wetter and warmer than now. An increase in humidity between 8170 ± 110 and 5742 ± 120 years BP, inferred from shell remains, agrees with the regional environmental records from sediment cores collected in lakes and swamps by Lavoie and Richard (2000*a*, 2000*b*) and in peatlands by Bhiry and Filion (1996), in the Montreal region. Higher precipitation around this time in eastern Canada was possibly caused by increased meridional circulation as the influence of the Laurentide Ice Sheet waned, as was the case in the northeastern United States (Newby et al. 2000; Shuman et al. 2001).

Table 4***b***. Mollusks identified from the rock shelter and Eardly Escarpment.

Rock shelter (Modern)		Eardley Escarpment (Modern)	
Species	N.	Species	N.
Discus ruderatus	240	*Discus ruderatus*	40
Vallonia gracilicosta	90	*Gastrocopta pentodon*	39
Caryculum exile	45	*Gastrocopa holzingeri*	27
Strobilops labyrinthica	38	*Strobilops affinis*	23
Nesovitrea binneyana	31	*Anguispira alternata*	20
Vertigo cristata	29	*Vallonia costata*	17
Anguispira alternata	25	*Strobilops labyrinthica*	15
Vallonia costata	20	*Vertigo bollesiana*	7
Gastrocopta pentodon	15	*Vertigo cristata*	6
Zonitoides arboreus	15	*Neohelix alborabris*	5
Discus catskillensis	10	*Helicodiscus parallelus*	4
Gastrocopta contracta	7	*Striatura exigua*	3
Gastrocopta holzingeri	5	*Euchemotrema fraternum*	3
Cochlicopa lubrica	3	*Discus catskillensis*	2
Euconulus fulvus	3	*Novisuccinea chittenangoensis*	2
Columella columella	1	*Glyphyalinia solida*	2
Cochlicopa nitens	1	*Glyphyalinia rhoadsi*	2
		Glyphyalinia indentata[a]	2
		Euconulus fulvus	2
		Strobilops (Fragments)	2
		Carychium exile	2
		Nesovitrea binneyana	2
		Cochlicopa lubrica	1
		Punctum minutissimum	1
		Vitrina limpida	1
TOTAL	578		230

Note: N., number of samples.
[a]This species is a collective composed of several undescribed species.

Mammalian fauna in the lower infill

NSIP and MNI

The lower infill in Caverne de la Mine provided a total of 2630 mammal specimens, half of which (NISP: 1351) were identified to some extent (Fig. 6). They represent 25 species and a minimum of 510 individuals when the entire bat assemblage is considered (Table 5). Two species, the woodland vole (*Microtus pinetorum*) and the Ungava collared lemming (*Dicrostonyx hudsonius*), are not currently found in the area (Fig. 7).

Small mammals are the most prominent taxa of the fossil assemblage both in terms of specimens and individuals. According to mammal body size categories (Dyck and Morlan 1995), 16 of the 25 identified taxa in the lower infill belong to the lowest rank, which represents animals normally weighing less than 100 g while alive (Table 6). The high proportion of small mammals recorded may be attributed to their striking majority in the surrounding fauna.

The taphonomic history of the deposit appears to be somewhat complex, but it cannot be reconstructed without a detailed analysis of the post-cranial remains. Some of the cranial specimens are relatively complete with little post-mortem alteration, presumably representing animals that lived and died in the cave or that tumbled in and perished there. Other specimens are fragmented, and a few exhibit slight degrees of corrosion. These probably represent animals that were consumed by avian predators roosting above the cave and regurgitating pellets that fell into the deposits. No tooth-marks were observed that would suggest predation by mammalian carnivores and deposition in their scats. Some breakage may have been caused by sediment compaction and excavation of the deposit.

Bats rank first in terms of abundance in the infill, overshadowing all the other taxa (Table 5). Bats alone represent more than half (66%) of all identified specimens of the lower infill fossil assemblage and three quarters (74%) of identified individuals. Their abundance may indicate that the cave was inhabited by a large number of bats during the period of its infilling, perhaps even supporting an important colony at one time. Today only a few bats (4–5) can be seen wintering in the cave. A variety of rodents, including squirrels, mice, and voles, also contributed significantly to the fossil assemblage. Among those, the mice (*Peromyscus* sp.) and the red-backed vole (*Clethrionomys* cf. *gapperi*) are the most

Fig. 6. Photographs of some fossil mammal specimens from Caverne de la Mine lower infill. (A) *S. cooperi* (medial view, left mandibule with teeth). (B) *C. gapperi* (medial view, right mandibule, with teeth). (C) *Sorex* sp. (medial view, left mandibule with teeth). (D) *P. lotor* (medial view, left mandibule, one tooth missing). (E) *M. pennsylvanicus* (dorsal view; skull). (F) *B. brevicauda* (dorsal view). (G) *M. lucifugus* (dorsal view). (H) *M. pinetorum* (medial view, right mandibule, with teeth).

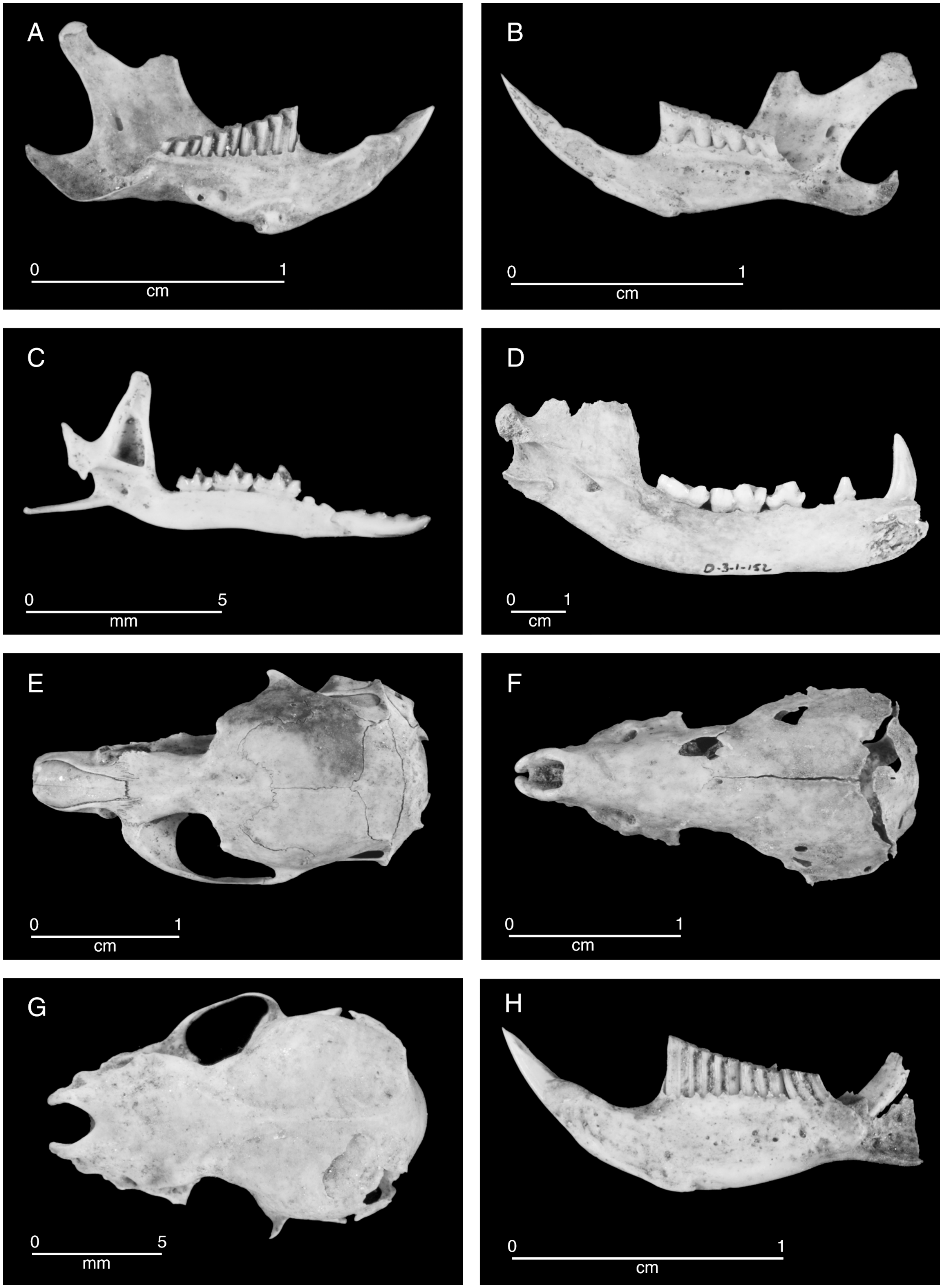


Table 5. Taxonomic abundance per mammal family, Caverne de la Mine lower infill.

Family	Species	NISP	NISP (%)	MNI	MNI (%)
Soricidae	Sorex fumeus, *Sorex* sp.	13	0.96	7	1.37
	Blarina brevicauda	18	1.33	12	2.35
	Total	31	2.29	19	3.72
Talpidae	*Parascalops breweri*	5	0.37	3	0.59
	Condylura cristata	8	0.59	7	1.37
	Total	13	0.96	10	1.96
Vespertilionidae	*Myotis septentrionalis*[a], *Myotis lucifugus*, *Lasionycteris noctivagans*	774	57.29	329	64.51
	Eptesicus fuscus	115	8.51	49	9.61
	Total	889	65.80	378	74.12
Leporidae	*Leporidae* spp.	5	0.37	3	0.59
	Total	5	0.37	3	0.59
Sciuridae					
	Tamias striatus	8	0.59	2	0.39
	Tamiasciurus hudsonicus	3	0.22	2	0.39
	Glaucomys cf. *sabrinus*	2	0.15	2	0.39
	Total	13	0.96	6	1.18
Cricetidae	*Peromyscus* sp.	78	5.77	26	5.10
	Total	78	5.77	26	5.10
Arvicolidae	*Clethrionomys* cf. *gapperi*	78	5.77	21	4.12
	Synaptomys cooperi	10	0.74	6	1.18
	Synaptomys sp.	12	0.89		
	Dicrostonyx hudsonius	1	0.07	1	0.20
	Ondatra zibethicus	5	0.37	3	0.59
	Microtus cf. *pinetorum*	27	2.00	9	1.76
	Microtus pennsylvanicus	19	1.40	8	1.57
	Microtus cf. *chrotorrhinus*	2	0.15	2	0.39
	Microtus sp.	23	1.70		
	Total	177	13.10	50	9.80
Erethizontidae	*Erethizon dorsatum*	5	0.37	3	0.59
	Total	5	0.37	3	0.59
Canidae	*Canis* cf. *latrans*	8	0.59	3	0.59
	Total	8	0.59	3	0.59
Procyonidae	*Procyon lotor*	132	9.77	12	2.35
	Total	132	9.77	12	2.35
	Total all species	1351	100	510	100

Note: NISP, number of identified specimens; MNI, minimum number of individuals.
[a]Tabulation includes *Myotis* sp., and *Chiroptera* spp. type A fossil specimens.

abundant taxa, represented by 26 and 21 individuals respectively (Table 5). With the exception of bats, the lower infill fossil assemblage suggests that these two taxa were among the most numerous mammals of the local fauna during the period in question. The other taxa, including larger species, such as the raccoon, are represented by less than a dozen individuals and account for only a small portion of the fossil fauna.

Community analysis and habitats

The area of maximum sympatry of the lower infill mammals extends throughout the northern portions of the Great Lakes basin and the Appalachians and is largely limited to the eastern section of the Laurentian Mixed Forest (Fig. 8). Here, the distributions of northerly occurring species (e.g., Star-nosed mole, American red squirrel, Gapper's red-backed vole) overlap those of southern-ranging species (e.g., smoky shrew, hairy-tailed mole, eastern chipmunk) and those of widespread range (e.g., northern long-eared bat, muskrat, coyote).

The Caverne de la Mine fossil fauna can be subdivided into community associations. Based on their distribution and habitat preferences, Graham (1976) sorted several small mammals according to the faunal units they represent, in which members of the small mammal assemblage of the Caverne de la Mine lower infill fossil assemblage are found (Table 7). Widespread species were not included. Among the 14 small mammal taxa recovered from the lower infill that figure in Graham's list, 11 are boreal taxa while three are deciduous or southern taxa. Accordingly, the small mammal fossil assemblage dated between 9200 ± 110 and 5742 ± 120 years BP in Caverne de la Mine is principally made up of taxa associated with boreal environments. Southern taxa do not occur before 8170 ± 60 years BP and progressively increase until 5742 ± 120 years BP, while proportions of boreal taxa remain relatively constant throughout most of the lower deposit (Table 8).

Different habitats are represented by the small mammal

Fig. 7. Drawing of occlusal surfaces of two left first mandibular molars with unusual cusp patterns thought to belong to *M. pinetorum* and drawing showing the occlusal surface of a left maxillary molar of *D. hudsonius* recovered from Caverne de la Mine lower infill. Catalogue number (B-8-4-1) consists of an infill section letter, an excavation level number, a skeletal element number, and a specimen number.

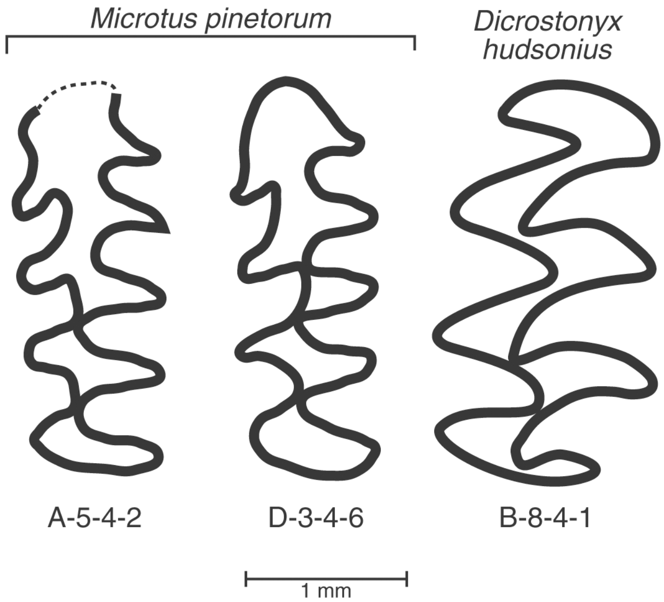


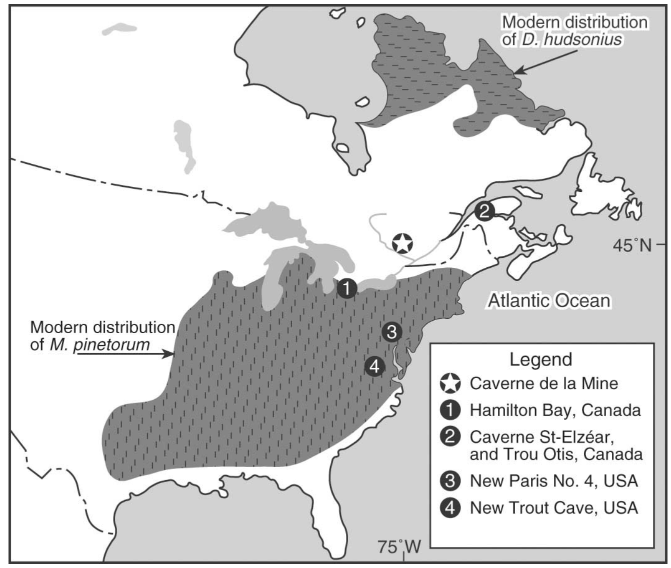
Fig. 8. Map showing area of sympatry for mammalian taxa recovered from Caverne de la Mine lower infill.

fossil fauna. These include forest, moist grassland, wetland and shoreline, and tundra habitats (Table 9). While most taxa are not confined to any one particular habitat, they have been assigned to those that are most characteristic. The fossil fauna of the Caverne de la Mine shows varying habitat affinities, yet, the majority of the taxa favor forested habitats.

Extirpated taxa

The Ungava Bay collared lemming (*Dicrostonyx hudsonius*)

Fig. 9. Map showing modern distribution of *M. pinetorum* and *D. hudsonius* and location of fossil sites referred to in the text.



does not presently live in the St. Lawrence valley. It is today restricted to the cold environment of the Labrador – Ungava Bay peninsula (Fig. 9). A single specimen belonging to this species was recovered from the material, which was dated at 8170 ± 60 years BP. To date, only four other fossil sites yielding remains of collared lemming are known outside the species' present range: New Paris No. 4 (Guilday et al. 1964), New Trout Cave (Grady and Graton 1981), Caverne St-Elzéar (LaSalle and Guilday 1980; LaSalle 1984), and Trou Otis (Harington 1980). The geographic distribution of collared lemming fossil records suggested that the species once occurred only east of and throughout the Appalachians Mountains (Woodman 1982; Mead and Mead 1989). The specimen recovered from the Caverne de la Mine deposit is the first known record recovered west of the Appalachians. Special importance has been given to fossil sites containing either of the two North American species of lemming, as they are often believed to be indicators of tundra environments (Guilday et al. 1964; Guilday 1971; Lundelius et al. 1983). However, Mead and Mead (1989) cautioned against using lemming as a strict tundra indicator in paleoenvironmental reconstructions. They pointed out that fossil faunas that contain lemmings are commonly constituted of species that do not share the same habitats today, including tundra, boreal forest, steppe, and even deciduous forest, and that the reconstructions may represent "a variety of possibilities, from tundra transition to boreal forest" (Mead and Mead 1989: 329). The unusual association of collared lemming with species that do not share the same habitat today creates associations known as "disharmonious faunas," which are suggestive of contrasting environmental conditions (Graham 1976, 1985*a*, 1985*b*; Graham and Mead 1987). The fossil assemblage of Caverne de la Mine is no exception. Stratum IV also yielded other species not characteristic of tundra environments (Table 10), most of them associated with boreal environments and one, short-tailed shrew, is considered a deciduous inhabitant. Furthermore, short-tailed shrew (*Blarina brevicauda*) and big

Table 6. Mammal body sizes, Caverne de la Mine lower infill.

Body size category	Animal weight	N.	Taxa
1	<100 g	16	*S. fumeus*, *B. brevicauda*, *P. breweri*, *C. cristata*, *M. septentrionalis*, *M. lucifugus*, *L. noctivagans*, *E. fuscus*, *T. striatus*, *Peromyscus* sp., *C. gapperi*, *S. cooperi*, *D. hudsonius*, *M. pinetorum*, *M. pennsylvanicus*, *M. chrotorrhinus*
2	100–700 g	2	*G. sabrinus*, *T. hudsonicus*
3	700–5000 g	2	Leporidae spp., *O. zibethicus*
4	5–25 kg	3	*E. dorsatum*, *C. latrans*, *P. lotor*
5	25–200 kg	0	N/A
6	200–700 kg	0	N/A
7	>700 kg	0	N/A

Note: N., number of samples; N/A, not available.

Table 7. Small mammal faunal units in Caverne de la Mine. Modified from Graham (1976).

Faunal units	Taxa		
Boreal			
	Sorex arcticus	*Martes americana*[a]	*Phenacomys intermedius*
	Sorex cinereus[a]	Mustela erminea[a]	***Microtus pennsylvanicus***[a, b]
	Sorex dispar	*Mustela nivalis*	*Microtus xanthognathus*
	Sorex fumeus[a, b]	***Tamiasciurus hudsonicus***[a, b]	***Microtus chrotorrhinus***[a, b]
	Sorex palustris[a]	***Glaucomys sabrinus***[a, b]	*Zapus hudsonicus*[a]
	Sorex vagrans	*Neotoma cinerea*	*Napeozapus insignis*[a]
	Sorex hoyi[a]	***Dicrostonyx hudsonius***[b]	***Erethizon dorsatum***[a, b]
	Condylura cristata[a, b]	***Synaptomys cooperi***[a, b]	*Lepus americanus*[a]
	Parascalops breweri[a, b]	*Synaptomys borealis*	*Thomomys talpoides*
	Martes pennanti[a]	***Clethrionomys gapperi***[a, b]	
Deciduous (southern)			
	Didelphis virginiana	*Sciurus carolinensis*[a]	*Peromyscus leucopus*[a]
	Blarina brevicauda[a, b]	*Sciurus niger*	*Neotoma floridana*
	Cryptotis parva	*Glaucomys volans*[a]	*Oryzomys palustris*
	Scalopus aquaticus	Reithrodontomys humulis	*Sigmodon hispidus*
	Mormota monax[a]	*Peromyscus gossypinus*	***Microtus pinetorum***[b]
	Tamias striatus[b]	*Peromyscus nuttali*	*Sylvilagus floridanus*[a]

[a]Taxa part of the modern local fauna.
[b]Taxa present in the Caverne de la Mine lower infill fossil fauna in bold.

brown bat (*Eptesicus fuscus*) do not occur with the collared lemming today.

Fossil records of pine vole (*M. pinetorum*) are virtually non-existent north of its present range, which makes this the most northerly known occurrence for this species (Fig. 9). Twenty-seven specimens belonging to this species were recovered from strata III through I. Today, the vole is found in hardwood forests in the Carolinian Life Zone. Its closest known modern locality is approximately 175 km south of Caverne de la Mine in Lewis County, northern New York (Hall and Cockrum 1952). The vole was recorded in southern Ontario as part of the Hamilton Bay vertebrate fossil fauna (Wetmore 1958; Churcher and Karrow 1963), which is the closest known fossil record. The Hamilton Bay deposit is located within the northernmost limits of the species' current range. The occurrence of pine vole in the Caverne de la Mine deposit may reflect conditions warmer than now. A northward displacement of vegetation zones, initiated by a warmer climate during the middle Holocene (McAndrews 1980; Liu 1990; Anderson 1995), may have prompted the vole to expand its range northward into this region.

Mammalian fauna in the upper and intermediate infill

In total, more than 3000 remains were collected from the upper infill (Carrier 1989). Of them, 1677 fossils were identified, representing 14 species and a minimum of 47 individuals (Table 11). The majority of the species are similar to those of the lower infill. Among those most frequently encountered are the big brown bat, the American toad and the raccoon. In addition to the faunal material recovered from the deposit, there are two etched and polished raccoon ulnae near the surface of the infill, making Caverne de la Mine a possible archaeological site.

Small-sized mammals dominate the upper infill. More than half weigh less than 100 g alive, but larger mammals (between 25 and 200 kg) are more abundant than in the

Table 8. Stratigraphic abundance of boreal and southern taxa. Caverne de la Mine lower infill.

Faunal units	Taxa	Strata (MNI)						
Boreal								
		I	II	III	IV	V	VI	VII
	Sorex fumeus	1	—	—	—	—	—	—
	Condylura cristata	2	4	1	—	—	—	—
	Parascalops breweri	1	1	1	—	—	—	—
	Tamiasciurus hudsonicus	—	1	—	1	—	—	—
	Glaucomys sabrinus	1	—	—	1	—	—	—
	Dicrostonyx hudsonicus	—	—	—	1	—	—	—
	Clethrionomys gapperi	6	9	2	1	1	—	—
	Synaptomys cooperi	—	4	2	—	—	—	—
	Microtus pennsylvanicus	2	2	1	1	1	—	—
	Microtus chrotorrhinus	—	1	—	—	1	—	—
	Erethizon dorsatum	1	1	1	—	—	—	—
	Number of species/individuals	7/14	8/23	6/8	5/5	3/3	0	0
Southern								
	Blarina brevicauda	6	3	2	1	——	—	
	Tamia striatus	—	1	1	—	—	—	—
	Microtus pinetorum	5	3	1	—	—	—	—
	Number of species/individuals	2/11	3/7	3/4	1/1	0	0	0

Table 9. Habitats represented by the Caverne de la Mine lower infill small

Habitats	Taxa
Forest	
	Sorex fumeus
	Blarina brevicauda
	Parascalops breweri
	Tamia striatus
	Tamiasciurus hudsonicus
	Glaucomys sabrinus
	Clethrionomys gapperi
	Microtus pinetorum
Moist grassland	
	Microtus chrotorrhinus
	Synaptomys cooperi
	Microtus pennsylvanicus
Wetland and shoreline	
	Condylura cristata
	Ondatra zibethicus
Tundra	
	Dicrostonyx hudsonicus

lower infill. In fact, the faunal assemblage contains remains of a black bear and a white-tailed deer. These two animals are also abundant at the Île Morrison archeological site dated between 4620 ± 40 ^{14}C BP (Beta-88725) and 4860 ± 50 ^{14}C BP (Beta-89851), where remains of a moose (*Alces alces*) and two caribous (*Rangifer tarandus*) are also present (Clermont and Chapdelaine 1998). The occurrence of the caribous in the Ottawa–Gatineau region during the middle Holocene is a relict of the cold period of the early Holocene. The faunal assemblage of the upper infill, in the second pit of Caverne de la Mine, suggests that the terrestrial regional fauna has not changed since the mid-Holocene.

Conclusions

The preceding results allow a reconstruction of the Holocene mammalian fauna and its environment on the Eardley Escarpment. The oldest natural event to be recorded in the cave is the accumulation of glacial sediments (unit 1). These sediments were transported on to the Escarpment and into the entrance of the cave by southeasterly glacial flow and were injected into the cave by ice. The calcareous fragments found in the cave indicate that the ice lobe had a minimum thickness of 120 m, since the cave is located 200 m above sea level (asl) and the plain is 110 m asl. Southeasterly flow developed after the major glacial flow, which came from the north. The glacial period ended with the invasion of marine waters of the Champlain Sea. Fossils suggest that small fishes lived near the cave when it was inundated.

The Champlain Sea left the cave site and the Eardley Escarpment at the end of the Pleistocene. Terrestrial sedimentation then began (unit 2). Analysis of wood charcoal indicates that around 9200 years BP, trees and shrubs were starting to grow near the cave. They included birch and jack pine, a tree adapted to cold climate, now living mainly on the plateau of Gatineau Park. The presence of Rosaceae suggests an open environment, and that of crowberry, a marine influence. In fact, crowberry presently grows mainly in littoral regions.

After 9200 years BP, gravity sedimentation ended and was replaced by surface runoff, which left a sand and silt layer in the cave 5–12 cm thick (unit 3). Fossils are rare in this horizon, mollusks absent, but wood charcoal abundant. The cause of this flooding is unknown. We propose that it consisted of a episode of surface runoff associated with heavy rainfall — the effect amplified by the destruction of the vegetation cover by forest fires. However, perhaps a cooler, more humid period prevailed around this time (Alley et al. 1997).

Gravity sedimentation resumed before 8000 years BP (unit 4, strata V and IV). The accumulating material was

Table 10. Mammalian species occurring in stratum IV alongside *Dicrostonyx hudsonius*, Caverne de la Mine lower infill.

Taxa	MNI (stratum IV)	Associated environment	Sympatric
Blarina brevicauda	1	Deciduous forest	No
Eptesicus fuscus	2	Widespread	No
Leporidae spp.	1		
Tamiasciurus hudsonicus	1	Boreal forest	Yes
Glaucomys sabrinus	1	Boreal forest	Locally
Peromyscus sp.	1		
Clethrionomys gapperi	1	Boreal forest	Yes
Microtus pennsylvanicus	1	Widespread	Yes

Table 11. Caverne de la Mine upper infill fossil taxa in order of fossil abundance.

Species	Common name	NISP	MNI
Eptesicus fuscus	Big brown bat	300	13
Bufo americanus	American toad	216	7
Procyon lotor	Raccoon	216	7
Peromyscus leucopus	White-footed mouse	26	5
Ursus americanus	Black bear	22	1
Sciurus carolinensis	Grey squirrel	11	1
Ondatra zibethicus	Muskrat	9	1
Microtus pennsylvanicus	Meadow vole	8	1
Odocoileus virginianus	White-tailed deer	8	1
Marmota monax	Woodchuck	6	1
Tamias striatus	Chipmunk	5	1
Erethizon dorsatum	Porcupine	4	2
Sorex cinereus	Masked shrew	4	2
Condylura cristata	Star-nosed mole	1	1
Total		1677	47

dark coloured and fine grained with many wood charcoal fragments, but few mollusks. The vegetation was still dominated by jack pine, Rosaceae, and birch. The fauna had a boreal affinity with the presence of species, such as red squirrel, northern flying squirrel, red-backed vole, Ungava collared lemming, meadow vole and rock vole.

After 8000 years BP, numerous changes were observed in the sediments (unit 4, strata III and II). The pH became more basic and the sediment coarser. The most drastic change occurred in the fauna and flora. The conifers were replaced by deciduous trees (sugar maple, white pine) and animals linked to a warmer climate were present (i.e., woodland vole, gray squirrel, white-tailed deer), while several boreal taxa (lemming, southern red-backed vole, rock vole) disappeared from the region. These changes can be explained by warming climate during this time. The presence of the mollusk *Strobilops aenea* is also indicative of a warmer climate while the occurrence of six hydrophile–aquatic–amphibian mollusks can be related to a wetter climate.

At 5742 ± 120 years BP (unit 4, stratum I) the climate was cooling, and southern species such as woodland vole disappeared. The modern fauna was established, with mammals such as the black bear and white-tailed deer. Results from other sites in the area, particularly the Late Archaic archaeological site of Morrison Island (Clermont and Chapdelaine 1998), agree well with the upper infill mammalian fauna record of Caverne de la Mine.

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