HOLOCENE LAKE-LEVEL CHANGE AND SUBMERGED ARCHAEOLOGICAL SITE POTENTIAL OF RICE LAKE, ONTARIO

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ABSTRACT:

Isostatic rebound and climatic changes throughout the Holocene have resulted in several periods of lowered water-levels in the Great Lakes watershed. The Early Holocene lowstand phase corresponds with the Paleoindian period in the Great Lakes Region (11,000-9000 YBP), and subsequent water-level rise has inundated Paleoindian archaeological sites. This research sought to reconstruct the water-level history of Rice Lake (located north of Lake Ontario) in order to identify areas of high potential for submerged prehistoric sites.

Over 750 line km of detailed geophysical data (single-beam bathymetry) and 16 sediment cores were collected over a 30 km^2 area of Rice Lake. Sediment cores were visually logged and analyzed for particle size, microfossils and microdebitage. Water-level reconstructions accounting for sediment infill and isostatic rebound of the lake record a post Lake Iroquois (after 12 ka BP) Early Holocene lowstand (~10-12 m below present level (bpl)) (EH-1). At 10 ka BP, gradually rising water-levels and establishment of wetlands as indicated by thecamoebian assemblages coincide with a newly discovered Paleoindian occupation of the McIntyre basin, where quartz microdebitage was found. Water-level continued to rise to almost 2 m bpl until 6.5 ka BP, when warmer and drier temperatures caused a sudden drop in water-levels as recorded by a pollen hiatus. After 4 ka BP, water-levels quickly recovered and stabilized as shown by rapid recovery of pre-hiatus thecamoebian biofacies and the establishment of wild rice stands.

The small number of known, well-preserved Great Lakes Paleoindian sites has limited analysis of Early Holocene population densities, migration patterns, cultural diffusion, or the chronology of settlement. The method of modelling water-level fluctuations and associated archaeological potential developed in this thesis represents a substantial advance in our understanding of Early Holocene archaeology in the Great Lakes. These methods will have broader application to exploration of submerged terrestrial landscapes elsewhere in the Great Lakes and will allow for future regional synthesis of archaeological site distribution and characteristics.

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Chapter 1: Introduction

1.1 Introduction

Until recently, archaeological research on Quaternary prehistoric settlement patterns (ca. 25 to 1 ka BP) has been focused largely on the record available from terrestrial archaeological sites. The study of these sites has greatly expanded understanding of the adaptation of prehistoric humans to terrestrial and coastal habitats, their subsistence strategies and their migration and settlement patterns (Bailey 2004; Kraft et al. 2005). Archaeological sites on land, however, do not provide a complete record of human adaptation in these environments, as large tracts of prehistoric coastlines and adjacent terrestrial landscapes were inundated during the last 25,000 years by rising post-glacial sea levels (Fedje and Josenhans 2000; Faught 2002). During the last glacial maximum global sea levels were more than 120 m below present and extensive areas of the world's continental shelf (extending seaward up to 100 km from the modern shoreline in some areas) were sub-aerially exposed landmasses. In the area of Haida Gwaii, on the northwest coast of British Columbia, at least 100 km^2 of continental shelf would have been exposed (Fedje and Christensen 1999). These now submerged landscapes are of tremendous archaeological importance, as well-preserved evidence of early human migration, settlement patterns and subsistence strategies exists in these contexts (Bailey and Flemming 2008).

The importance of understanding submerged landscapes in the archaeological record has only recently been recognized (Bailey 2004; Bailey and

Flemming 2008). The discovery and investigation of more submerged archaeological sites provides increasing evidence of the importance of marine resources for prehistoric subsistence. The increased rate of development in many countries has adversely affected the preservation potential of many terrestrial sites; submerged archaeological sites have provided better preservation, particularly of Mesolithic and Paleolithic sites in Europe, Asia and Africa. In some areas, now indundated coastal landscapes may have provided prehistoric peoples and animals with unique and productive conditions that may not have been available elsewhere on land (Bailey and Flemming 2008).

It has been long known from the terrestrial archaeological record that coastlines, inland lakes and river valleys were a major locus for prehistoric settlement. Using landscape geomorphology as a guide, land archeologists have been successful in locating prehistoric sites associated with relict high level shorelines and river terraces exposed by changing sea levels or tectonic uplift (Brown 1997). In the Great Lakes, for example, many Paleoindian sites are located in close proximity to relict glacial lake strandlines and river terraces raised by postglacial isostatic uplift (Jackson et al. 2000; Karrow 2004). A similar predictive geomorphic approach has only recently been attempted in the search for submerged prehistoric sites. Previously, it was often considered too costly and too difficult to locate underwater sites, and it was often assumed that the preservation potential of archaeological materials was likely to be low (Bailey 2004). Recent advances in remote sensing technologies and the increasing adaptation and integration of geoarchaeological and paleoenvironmental data within archaeological investigations have made archaeological reconnaissance and exploration of prehistoric underwater sites much more feasible (Fedje and Christensen 1999; Fischer 2004; Kelley et al. 2010).

The first large-scale, systematic investigations of underwater prehistoric sites were conducted in Europe in the 1980s, and led to the discovery of important submerged sites in Denmark (Grøn and Skaarup 2004), the Netherlands (Verhart 2004) and the North Sea of the United Kingdom and Ireland (Flemming 2004; Momber 2004). Much of the survey work in the North Sea began as cultural resources inventories conducted prior to offshore oil development (Firth 2004). Because of the large areas requiring exploration, there was an impetus to use more efficient survey methods including side-scan and multi-beam sonars, which provide detailed images of sea bed relief (Dean and Frazer 2004; Mayer et al. 2004). The application of these sonar techniques led to the discovery of prehistoric relict shorelines and river valleys on the European shelf and further stimulated the search for prehistoric underwater sites using predictive modeling. In Denmark and Ireland, predictive modeling using geoarchaeological and geophysical data has been used widely to generate paleogeographic reconstructions of submerged landscapes and their archaeological potential (Fischer 2004; Grøn and Skaarup 2004). These models integrate sea level and shoreline reconstructions, paleoenvironmental proxies and swath bathymetry mapping to identify the areas of highest archaeological probability, which are then ground-truthed by diver survey (Westley et al. 2010). This approach has led to the discovery of well-preserved underwater prehistoric sites with fire pits, stone tools, and burials (Flemming 2004; Glimmerveen et al. 2004). Many of these sites exhibit excellent preservation, including the organic materials that are not often preserved in terrestrial sites.

Most studies conducted to date in North America have relied largely on paleoshoreline mapping for site prediction and have not incorporated other paleoenvironmental or geoarchaeological data. Fedje and Christensen (1999) for example, identified Holocene prehistoric sites in intertidal and offshore areas of British Columbia using paleoshorelines identified in multi-beam sonar images. The sonar images identified paleobeaches and a delta floodplain, where a single stone tool and well-preserved tree stumps were discovered in 53 m of water. The sites provide important evidence for occupation of the coast by prehistoric peoples during the late Pleistocene and early Holocene, and support the coastal migration hypothesis (Fladmark 1979; Dillehay 1991). On the east coast of North America, geophysical surveys have led to discovery of early Holocene submerged archaeological sites in Florida (Faught 2002), Maine (Kelley et al. 2010) and to the mapping of areas of archaeological potential on the coast of Newfoundland (Bell and Renouf 2003).

The Great Lakes and surrounding watershed areas (Fig. 1.1) have high potential for submerged archaeology due to considerable water level changes during deglaciation and as a result of Holocene climate change (Yu and

McAndrews 1994). The Holocene period in Ontario (ca. last 12,000 years) was marked by several phases of drier climate and low lake levels (lowstands)

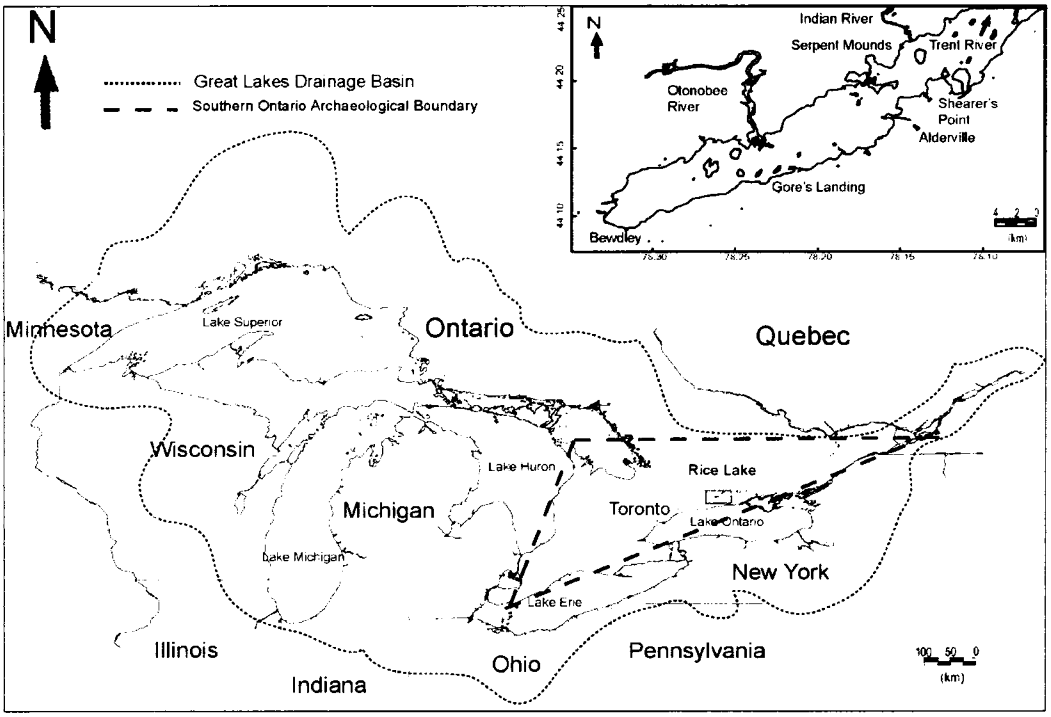

Figure 1.1: Map of the Great Lakes Drainage Basin, including the Southern Ontario Archaeological area as defined by Ellis (1990). Inset shows Rice Lake and major tributaries.

including a major event at ca. 9.9 to 7.5 ka BP recorded in sediments in Lake Huron and Georgian Bay (Lake Hough and Lake Stanley lowstands) (Yu et al. 1997; Drzyzga 2007; Lewis et al. 2007). During the Lake Stanley phase (10-8 ka BP) water levels in the Lake Huron Basin were up to 70-100 m below present and large areas of the lake bed were exposed terrestrial landscapes. Recent investigations of Lake Huron have identified potential archaeological features in 40-60 m of water (O'Shea and Meadows 2009). During the Admiralty Phase of Lake Ontario (11.7-11.4 ka BP), lake levels were up to 40 m below present

(Coakley and Karrow 1994), and it has been estimated that up to $10{,}000^2$ km of lake plain would have been available for human habitation (Jackson et al. 2000). It has been postulated that lake level rise following these lowstand events may have inundated terrestrial archaeological sites during the Paleoindian and early Archaic phases of Great Lakes archaeology (Lovis et al. 1994; Janusas et al. 2004). The Paleoindian phase is known as having a sparse archaeological record in the Great Lakes (Ellis 2006; O'Gorman and Lovis 2006), which may in part be explained by inundation of coastal occupation sites as water levels recovered rapidly from early Holocene lowstands.

While there is considerable evidence that well-preserved submerged sites may exist in the Great Lakes, there has been little attempt to systematically locate and study them (Lovis et al. 1994; Stevens 2002). Much prehistoric archaeology in Ontario has focused on the land record from long-occupied areas such as Rice Lake (Fig. 1.1). Located on the Trent-Severn Waterway, near Peterborough, Ontario, Rice Lake has been continuously occupied since the end of the last glaciation (Jackson 1998) and has long been speculated to have potential for submerged archaeology. Most of the known prehistoric sites are clustered around the modern shoreline, along raised relict Pleistocene glacial strand lines, river terraces, and on drumlin islands in the lake (Fig. 1.2) (Johnston 1968; Jackson et al. 2000; Jackson 2004).

Previous coring and palynological investigations at Rice Lake have identified the existence of a low water level phase ca 10 ka BP and between 6.5

and 4 ka BP and the presence of submerged terrestrial deposits on the lake bed (Yu and McAndrews 1994). The timing of the lowstands and their causes are not well understood, but likely corresponds with immediate post-glacial low water levels (e.g. Admiralty Phase in Lake Ontario) and a mid-Holocene dry climate phase (the Climatic Optimum) that is recorded elsewhere in the Great Lakes (Yu

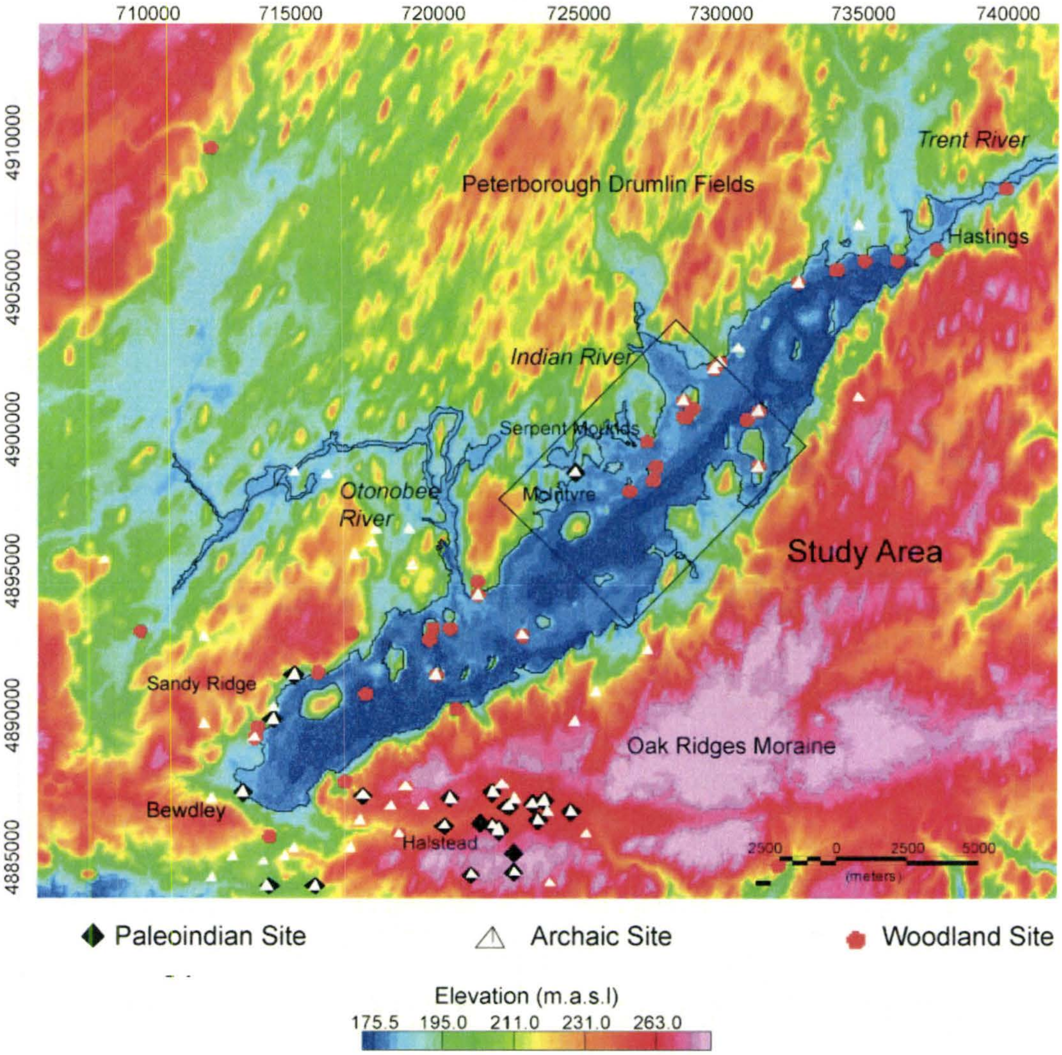

Figure 1.2: Digital elevation model, known archaeological sites and study survey area of Rice Lake

et al. 1997). These events occurred during the Paleoindian and Archaic periods, which are notably underrepresented in the archaeology of Rice Lake (Johnston 1984), and raises the potential for finding Paleoindian and Archaic sites on the drowned terrestrial landscape on the lake bed. The location of the early and mid-Holocene lowstand shorelines have been estimated using available low-resolution navigational charts (Jackson et al. 2000) and limited sonar survey in the early 1990's (Jackson 1998) but these methods did not provide sufficient resolution or accuracy for underwater search or predictive modeling purposes. Detailed geophysical survey, including high-resolution bathymetry and side-scan surveys need to be conducted prior to archaeological survey in order to establish the paleogeography of the drowned landscape. This work would include detailed mapping of submerged relict shorelines, former beaches, stream outlets, river paleochannels, paleodeltas, drumlin islands and identification of areas and features of potential archaeological interest (i.e. occupation sites, middens, hearths).

Rice Lake is an ideal locale to investigate submerged prehistoric sites, as there is an abundance of terrestrial archaeological sites and the lake water depth (< 10 m) and bottom sediment conditions are conducive to coring and geophysical survey work. The pollen data and radiocarbon dates available from a single previous study (Yu and McAndrews 1994) also provide an important basis for comparison with new paleoenvironmental data in this study (e.g. thecamoebian diversity, grain size). While there are a few scattered Paleoindian and early

Archaic terrestrial sites at Rice Lake, they are considerably less well represented compared to later Archaic and Woodland sites (after ca. 4 ka BP) (Fig. 1.2). The known Paleoindian and Archaic sites elsewhere in southern Ontario are often small, highly disturbed multi-component sites with poor organic preservation (Johnston 1984; Jackson 1998; Ellis 2006). There is a need to locate larger, undisturbed single-component sites in order to gain a better understanding of Paleoindian and early Archaic subsistence strategies and settlement patterns (Ellis 2006). A fundamental starting point in the search for these sites is the reconstruction of the paleogeography, geomorphology and paleoenvironmental conditions that would have had a large influence on prehistoric settlement patterns. Based on the distribution of known sites in the Rice Lake area, the location of shorelines and paleo-river channels was one of the most important environmental variables in determining site locations (Jackson et al. 2000). It should be noted however, that the numerous sites discovered in proximity to a paleo-river valley may be partially due to archaeological sampling bias (Jackson 2004).

1.2 Research Objectives

The overall objective of this thesis is to document changes in the Early to Mid-Holocene water-levels and other paleoenvironmental changes at Rice Lake, and to evaluate how these changes influenced prehistoric (Paleoindian and Archaic Period) settlement patterns in the littoral zone. The research will employ multi-proxy geoarchaeological methods, including geophysical survey, sediment coring and paleoshoreline reconstruction to identify areas with high potential for submerged prehistoric sites. This approach has been employed successfully on a limited basis on land but has not been utilized to its full potential for underwater archaeology, particularly in the North American context. The specific objectives of the research are:

1) to evaluate the use of microdebitage in submerged contexts as an indicator of prehistoric settlements (Chapter 2)
2) to determine the paleoenvironmental changes associated with the early Holocene lowstand (i.e. changes in wetland ecology, habitats, vegetation) based on detailed analysis of core data, microfauna and other core physical properties (grain size, magnetic susceptibility, microfossils, sediment composition) (Chapter 3)
3) to better resolve the timing and extent of Holocene lowstand events in Rice Lake, including detailed mapping of the location of submerged shorelines, river channels and the paleogeography of the drowned Holocene landscape (Chapter 4)
4) to integrate paleoenvironmental and paleogeographic data (objectives 1,2 and 3) within an archaeological potential map that identify areas with the likelihood for discovery of new prehistoric sites (Chapter 4).

The systematic survey and paleogeographic reconstruction of submerged landscapes proposed here, while not uncommon in Europe (Firth 2004; Westley et al. 2010), is a relatively underdeveloped research approach in North American archaeology (Kelley et al. 2010). By underutilizing submerged sites, a substantial portion of the archaeological record of prehistoric settlement is unknown. The discovery of submerged coastal prehistoric sites in Europe is changing interpretations of settlement patterns of Paleolithic and Neolithic peoples (Flemming 2004; Bailey and Flemming 2008). If this approach is applied to submerged shorelines in the Great Lakes, there is the potential for a much better understanding of prehistoric settlement patterns and subsistence strategies.

1.3 Study Area

Rice Lake is located 50 km south of Peterborough, Ontario, on the Trent-Severn Waterway (Fig. 1.1). The lake is about 26 km in length, 3-4 km in width and has a maximum water depth of about 10 m (Fig. 1.2). The current lake level (187 m.a.s.l) was established in the 1830s by construction of the Trent-Severn canal system and the Hastings Dam (Yu and McAndrews 1994)(Fig. 1.2). The flooding raised water levels by about 1.8 metres and greatly increased the lake surface area. The present study examines the prehistoric archaeology of a 30 km^2 area of the lake bed in eastern Rice Lake (Fig. 1.2). This location was selected because of the high density of land archaeological sites, including a well-studied

Paleoindian and Archaic-age site (McIntyre site) and the Woodland-age Serpent Mounds complex (Johnston 1968; Johnston 1984) (Fig.1.2).

1.3.1 Geological Setting

The surficial geology of the Rice Lake area reflects the repeated advances and retreats of Late Wisconsin ice sheets and the development of post-glacial lakes during the past 30,000 years (Barnett 1992). The narrow lake basin was formed by glacial erosion and widening of a pre-glacial river valley, which was flooded and became an embayment of glacial Lake Iroquois (Fig. 1.2). The topography around the lake is defined by south-east trending drumlins up to 50 m in relief that define the southern extent of the Peterborough drumlin field (Figure 1.2). A number of partially submerged drumlin islands are present within the lake and are associated with Archaic and Woodland-age occupation sites and burial complexes (Johnston 1968). The southern shore of the lake borders the west-east trending Oak Ridges interlobate moraine (Gorrell and Brennand 1997). The surficial sediment cover consists mainly of sandy till, coarse-grained kame moraine and outwash deposits and thin postglacial river and lacustrine sediments (Barnett 1992)(Fig. 1.3). The sediments reach a maximum thickness of over 150 m within the Oak Ridges Moraine and rest on Ordovician limestone bedrock (Gravenor 1957; Gorrell and Brennand 1997).

1.3.2 Water Level History

Rice Lake was formed during deglaciation (ca. 12.5 ka BP) as rising water levels in glacial Lake Iroquois inundated low lying glacial valleys to the south of Peterborough (Muller and Prest 1985). As water levels dropped in the Ontario basin glacial Lake Algonquin drained into the Ontario basin via the Fenelon Falls outlet (Karrow 2004), releasing large volumes of meltwater and sediment. The Otonobee and Indian Rivers (Fig. 1.2) are the remnants of glacial flood water channels formed during the Nipissing flood phase. As both glacial Lake Algonquin and Iroquois receded, the southwestern end of Rice Lake was

Figure 1.3: Surficial Geology of the Rice Lake area (adapted from The Ontario Geological Survey, 2003).

gradually flooded by isostatic uplift of the eastern outlet at the mouth of the Trent River (Yu and McAndrews 1994; Jackson et al. 2000).

During the Holocene water levels in Rice Lake fluctuated under the influence of regional climatic changes that have been documented by McAndrews (1984) and Yu and McAndrews (1994) in sediment and pollen records. These studies analyzed pollen zones and radiocarbon dated sediment cores from the southwestern and central basins (McIntyre site) in Rice Lake. They identified a generalized stratigraphy consisting of an uppermost gyttja unit (4 ka BP to present) overlying marl (6-8 ka BP) and detrital muds (>8 ka BP) with a distinctive pollen hiatus between 6 and 4 ka BP. Water-level reconstruction based on stratigraphy, radiocarbon dating and pollen analysis indicates at least two lowstand phases at ca 10 ka BP (8 m below current levels) and 6-4 ka BP (4 m below current levels) (Fig 1.4). The timing and cause of these events is not clearly understood, but the 6-4 ka BP event is likely linked to a mid-Holocene phase of drier climate that affected most of central and eastern parts of North America (Yu et al. 1997). It is unclear whether this Holocene dry period was one long climatic event, or a series of climatic oscillations (Dean et al. 1996).

The construction of the Hastings Dam in the 1830s raised water levels an additional ~2 m. There have been some recoveries made from this post-1830 flooding depth, including near-shore dredged Holocene caribou bones (Jackson and McKillop 1988), and partially submerged potential Paleoindian sites that extend into the water (Jackson, pers. comm.). Sedimentation rates remained relatively stable (except during the hiatus) until about 1850 when European settlement, deforestation and flooding of the lake from the Hastings Dam (1838) increased the sedimentation rate dramatically (Yu and McAndrews 1994). According to elders from the Hiawatha Reserve (Serpent Mounds), prior to dam construction,

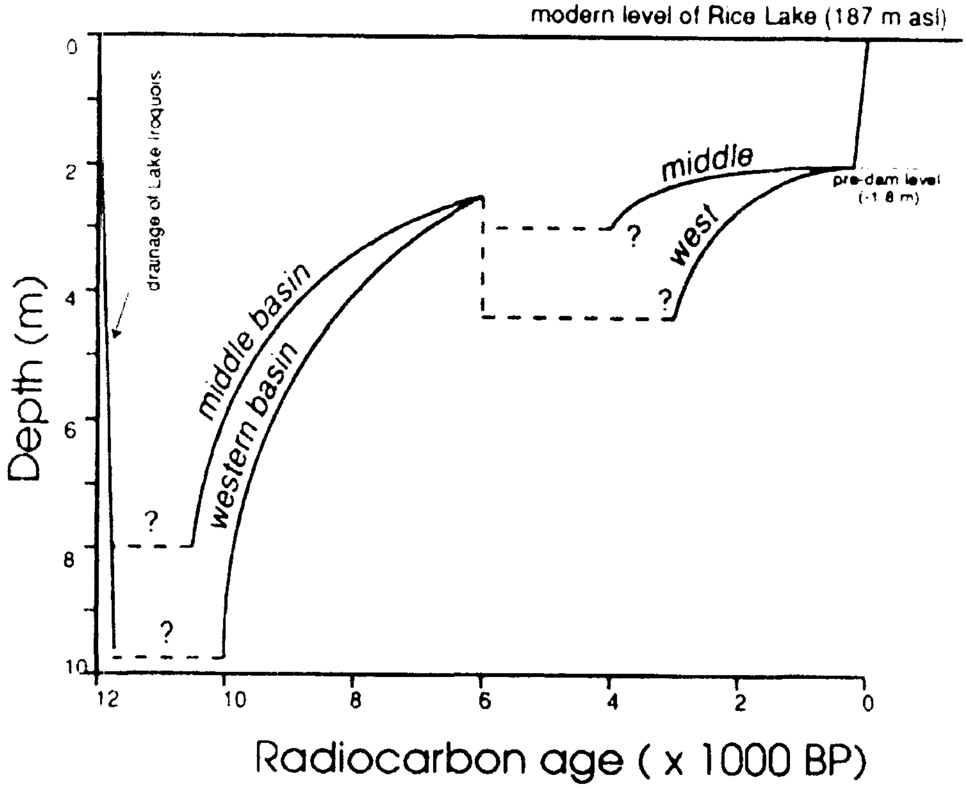

Figure 4.1: Yu and McAndrews' (1994) water-level reconstruction for Rice Lake.

the lake was almost entirely surrounded by wild rice plants, which is also supported by palynology (Yu and McAndrews 1994). Now, very few patches of the rice remain, and are cultivated for mostly commercial purposes (Stonechild, pers. comm.).

1.3.3 Settlement History

Paleoindian peoples began to colonize the Rice Lake area about 11 ka BP, possibly following the migration routes of herds of caribou along the shore of Early Lake Ontario (Jackson 1998). Palynological studies indicate large stands of boreal pine forests and abundant wetlands surrounding the lake, providing suitable habitat for caribou and other large game (Yu and McAndrews 1994). Paleoindian peoples are most often characterized as big-game hunters using distinct fluted projectile points (Mason 1981; Jackson 2004), however, recent discoveries indicate that Paleoindian peoples were also actively exploiting wetland resources as well (Chapter 3). Excavation of Paleoindian sites around Rice Lake has revealed both residential and logistical sites occupied by small, highly mobile task groups (Jackson 1998).

At about 9 ka BP notched projectile points indicate the appearance of Archaic peoples in Rice Lake (9-3 ka BP). Archaic cultures were characterized by a larger variety of tools, and exploitation of a much broader resource base than the Paleoindians (Ellis et al. 1990; Kuehn 1998). It has been proposed that Archaic peoples may have gathered in larger groups near waterways during the summer months, and moved inland during the winter months as smaller family units to hunt large game (Lovis et al. 2005). During this long period of settlement Archaic peoples would have lived during substantial shifts in climate and water-levels

(Lovis et al. 1994). By 3 ka BP, the emergence of pottery signaled the end of the Archaic period. Woodland peoples settled in the area around 2.9 ka BP, and the Middle Woodland period is when many of the burial mounds at Rice Lake were created (Johnston 1968). At about 1 ka BP, Iroquoian (Cayuga) peoples moved into the area bringing horticulture with them, and by the time of European contact, much of the area was already cultivated. The Cayuga however, were eventually driven out due to conflict with other groups. By the late 17th century, more nomadic Mississauga (Ojibwa) peoples had settled in the area, and are the immediate ancestors of the modern Ojibwe who now live in the area. The European colonization of the area began in the early 19th century and was documented in literary portrayals of Susannah Moodie (*Roughing it in the Bush*) and Catharine Parr Traill (*The Backwoods of Canada*). The first permanent settlements were established in the 1850's, when the canal construction stimulated logging and new Crown lands became available for private ownership (Martin et al. 1986) .

In the 20th century, Rice Lake became a popular recreation destination and is increasingly under pressure for residential and recreational development. These developments have resulted in a reduction in water quality and decline in game fish and other native species (Ferguson and Metcalfe 1989). The increasing development of the shorelines and potential destruction and loss of archaeological sites has prompted Parks Canada, the federal agency which operates the Trent-Severn Waterway, to undertake a Submerged Cultural Resources Inventory (SCRI) of the canal system, including portions of Rice Lake (Stevens 2002). As Rice Lake is only a very small part (~ 30 km) of the Trent-Severn waterway, the inventory work was limited to compilation of existing data and diver reconnaissance of known underwater sites.

1.4 Background and Previous Work

1.4.1 Archaeology

The Southern Ontario region has been defined archaeologically by Ellis et al. (1990) as encompassing the area south of Ottawa to the east, and the Bruce peninsula to the west and includes Lakes Erie, Huron and Ontario (Fig. 1.1). It has a varied and abundant archaeological record spanning the Holocene and ranging from ephemeral Paleoindian and Archaic sites to extensive Woodland burial mound complexes and Iroquoian villages. Many recent site discoveries in Ontario are a result of archaeological reconnaissance that is now required as part of the assessment process for development (Ellis 2006).

Rice Lake is the locale of well-studied Paleoindian and Archaic archaeological sites. Jackson (1998) published a monograph of the Sandy Ridge and Halstead Paleoindian sites (Fig. 1.2), which details the finds at these two Gainey phase locations. Gainey is an Early Paleoindian culture (11.2-10.8 ka BP) distinguished by distinctive fluted projectile points and the hunting of migratory mammals such as caribou. Jackson was utilizing lithic tool technology and attributes from these sites to identify the regional boundaries of Gainey phase groups in Southern Ontario (Jackson 1998).

The McIntyre site (Figs. 1.2, 1.5) has been investigated since the 1960's by Richard Johnston (Johnston 1984). The site has an extensive surface collection, and was excavated in the 1970's. These excavations led to the discovery of several stone lined pits below the plow-zone; however, a majority of the material recovered from the site was plant and animal specimens from these features. As with many sites in Ontario, the McIntyre site was highly disturbed, however, the examination of subsistence material from features preserved beneath the plow zone allowed for a much broader investigation which included plant macrofossils, palynology and zooarchaeology (Johnston 1984).

1.4.2 Paleoenvironmental Reconstruction

Geoarchaeological and geophysical techniques are now used widely to locate and investigate archaeological sites, especially when sites are hard to access, excavation time is limited and/or few diagnostic artifacts remain. Geoarchaeology in Southern Ontario has primarily focused on shoreline mapping to locate Paleoindian sites (Jackson et al. 2000), or mapping of floodplains to identify areas exploited by early horticulturalists (Walker et al. 1997). There is little evidence in the literature that geoarchaeological techniques are being utilized to their full potential in Southern Ontario archaeology, particularly in regards to paleoenvironmental reconstruction of archaeological sites. Non-invasive geophysical methods are well established for use in submerged landscape archaeology in Europe and other parts of North America (Fedje and Christensen 1999; Fischer 2004). However, there are other examples within the Great Lakes of the effective use of both geophysical and geoarchaeological techniques for identification and paleoenvironmental reconstruction of archaeological sites (Julig 2002; Boyd 2007; Karrow et al. 2007).

Multi-proxy paleolimnological methods have been used successfully to determine trophic and environmental changes in lake sediments due to natural and anthropogenic influences (Last 2001; Reinhardt et al. 2005). In this study, particle size, magnetic susceptibility, loss on ignition (organic, carbonate and silicate content) and microfossil (thecamoebians) analysis in conjunction with previously published pollen data will be used to delineate water level and trophic changes, local ecology, anthropogenic influences, and sedimentation rates. While most of these techniques are used frequently in paleolimnology studies, they are seldom utilized in Southern Ontario archaeology.

1.5 Methods

1.5.1 Remote Sensing

Bathymetry data were acquired using a Knudsen 320 BP single-beam echosounder and side-scan sonar with a 200 kHz transducer (Fig. 1.5). The surveys were undertaken in the spring and fall of 2007 and 2008 across a 30 km^2 area of the lake. The bathymetry data were acquired with 100 m nominal line spacing with orthogonal tie lines at 150 m (Fig. 1.6). Side scan sonar lines were collected at 175 m with a 100 m swath to ensure 25% overlap, however, the excessive weed growth in Rice Lake did not allow for an accurate representation of the lake bottom. Post-processing of bathymetry followed protocols outlined in Sonnenburg and Boyce (2008) to create a detailed digital bathymetric model (DBM). The DBM is the basis for identifying and mapping relict shorelines and the submerged paleogeography of Rice Lake (Chapter 4).

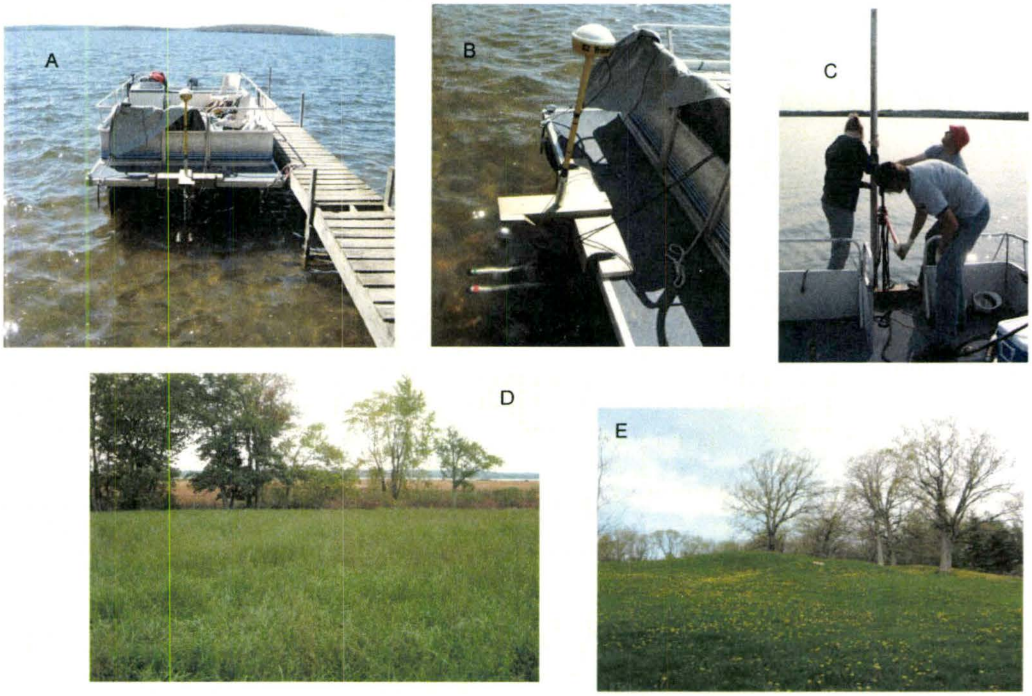

Figure 1.5: Examples of survey equipment and archaeological site areas from Rice Lake. A) Survey boat. B) DGPS, single beam and side scan sonar transducers front-mounted to boat. C) Sediment coring. D) View from McIntyre Site looking south toward Rice Lake. E) View of Serpent Mounds looking northeast.

In order to accurately model the water-level fluctuations of Rice Lake, isostatic rebound must be taken into account. Previous work has identified almost 30 m of uplift between the eastern and western sections of the lake basin (Yu and

McAndrews 1994). A isostatic uplift curve has been calculated (Coakley and Karrow 1994) in order to take into account the effects of rebound on water-level changes throughout the Holocene. The importance of modelling isostatic uplift in

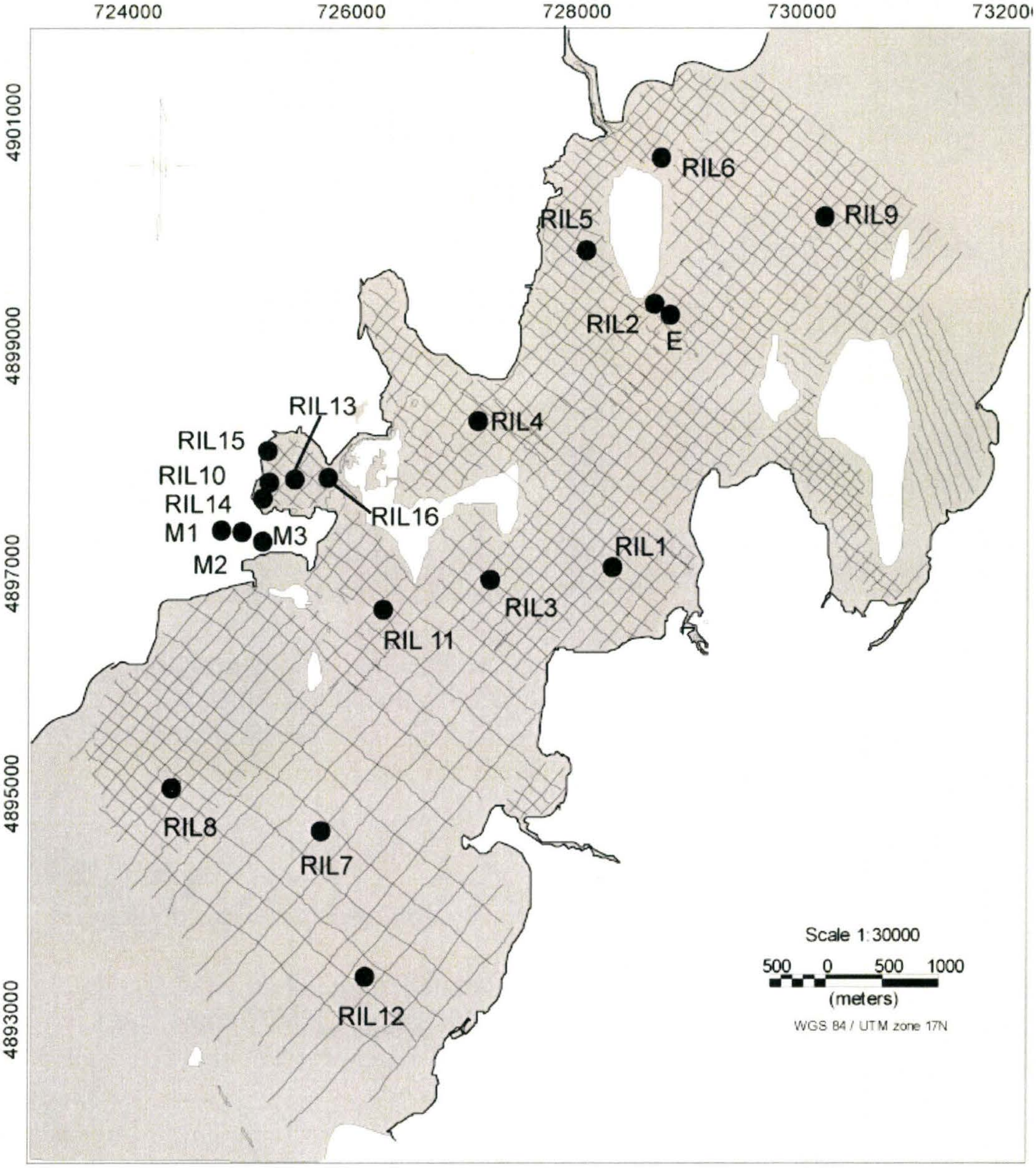

Figure 1.6: 30 km^2 detailed study area of Rice Lake with core locations and bathymetry survey lines.

order to accurately map submerged landscapes in coastal areas for archaeological potential modeling is well-established in Europe and North America (Fedje and Christensen 1999; Bailey and Flemming 2008; Kelley et al. 2010; Westley et al. 2010), but has yet to be applied to inland waters in North America (Chapter 4).

1.5.2 Sediment Coring

A total of 11, 4-6 m long sediment cores were extracted from the survey area in the main basin, and 5 cores were extracted from the McIntyre basin (Fig. 1.6) using a vibrocoring system (Figure 1.5). Core lithofacies, texture and colour changes were logged in detail and downcore magnetic susceptibility measured following procedures outlined in Sandgren and Snowball (2001). Volume magnetic susceptibility was measured using the Bartington MS2E probe, with a sensitivity of 2.0 x 10^{-6} SI. Detailed results are available in Fallon (2009).

Two cores were chosen for high-resolution grain size and microfossil analysis. RIL2 was chosen from the main basin, as it was taken close to Core E from Yu and McAndrews' (1994) study. Comparison of the radiocarbon dates and pollen analysis of Core E was useful in assisting with the paleoenvironmental reconstruction of the Main basin. RIL 10 was chosen from the McIntyre basin as microdebitage was located in the core (Chapter 2, 3).

1.5.3 Particle Size Analysis

Samples for particle size analysis were taken at 1 cm intervals, pre-treated to remove organics, carbonates and diatoms according to procedures outlined in Matthews (1991) and Conley and Schelske (2001) and measured on LS230

Beckman-Coulter particle size analyzer (Last 2001). A second group of samples were also measured without pre-treatment. The high resolution particle size data were logged and gridded in Geosoft Oasis Montaj™ to determine seasonal variations (van Hengstum et al. 2007). Loss on ignition samples were conducted to determine changes in sediment organic content and were prepared according to Heiri et al. (2001) (Chapter 3).

1.5.4 Microdebitage Analysis

Microdebitage, or lithic flakes smaller than 1 mm, were first defined by Fladmark (1982) as having use in archaeological settings. These small stone fragments can be produced in large quantities at lithic knapping sites, and have potential for being utilized to identify submerged sites (Fladmark 1982). Samples were treated according to Fladmark (1982), and initial samples were taken at lithologic boundaries in RIL2 and 4 from the main basin and all five cores from the McIntyre basin. Microdebitage was not recovered in any cores from the main basin, but three cores in the McIntyre basin (RIL 10, 14 and 16) yielded several fragments from a peat/sand boundary (Fig. 1.3). Quartz fragments from these samples were also classified according to roundness in order to determine if these fragments occurred through non-anthropogenic processes. Finally, additional samples from both RIL-2 and RIL-10 were investigated for microdebitage; however none was recovered (Chapter 2).

1.5.5 Micropaleontology

Thecamoebians are not often used in archaeological site investigation, however they have great potential in archaeological site reconstruction (Gearey and Caseldine 2006). In this study, thecamoebians were used to identify water-level and trophic changes within Rice Lake. Samples were split and counted until 200-300 specimens were reached for each sample (Patterson and Fishbein 1989; Scott and Hermelin 1993). Identification of species was based on Kumar and Dalby (1998) and Scott et. al (2001) and statistically analyzed using Q-mode cluster analysis in the PAST program (Hammer et al. 2001; Davis 2002) (Chapter 3).

1.5.6 Geochronology

In order to constrain water-level fluctuations in Rice Lake throughout the Holocene, radiocarbon dates were obtained on cores. All ^{14}C dating was conducted at Beta Analytic, Inc. using accelerated mass spectroscopy (AMS). A total of 6 radiocarbon dates were obtained from cores in the main basin (RIL 1,2,8,11) and 4 were obtained from cores in the McIntyre basin (RIL 10,14,16) (see Chapter 3 for full details). In prior studies of Rice Lake, Yu and McAndrews (1994) and McAndrews (1984) acquired 9 radiocarbon dates from 3 different cores (one located in the southeastern basin, one in the marsh adjacent to the McIntyre site, and one at Sugar Island) (Fig. 1.2) to determine the chronology of water level fluctuations. These additional radiocarbon dates were employed to help constrain the timing and nature of water-level fluctuations in Rice Lake.

1.5.7 Thesis Format

The thesis consists of 3 papers in a 'sandwich' format, with a total of 5 chapters including introduction and summary. A brief summary of the papers, their purpose, author contributions and the intended journal of submission are outlined below.

Paper 1: **Quartz flakes in lakes: microdebitage evidence for submerged Great Lakes prehistoric (Late Paleoindian-Early Archaic) tool-making sites**
E.P. Sonnenburg, J.I. Boyce and E.G. Reinhardt

This paper is an analysis of microdebitage and its usefulness in locating submerged Paleoindian archaeological sites. Microdebitage recovered from cores in the McIntyre basin were analyzed and compared to naturally occurring sediments. This research is unique because it is the first evidence of human activity in a submerged context located by microdebitage. E. Sonnenburg wrote all initial drafts and collected and analyzed data. J.I. Boyce assisted with data collection, identification of microdebitage and editing of the manuscript. E.G, Reinhardt assisted with data collection, microfossil analysis and manuscript editing. Submission to the journal *Geology* is planned, as the journal has previously published work on submerged archaeological site location using geoarchaeological methods. The article will also be of interest to earth scientists as a means of identifying differences in natural and anthropogenically modified quartz fragments.

Paper 2: **Multi-proxy lake sediment record of Prehistoric (Paleoindian-Archaic) archaeological paleoenvironments at Rice Lake, Ontario, Canada**

Authors: Elizabeth P. Sonnenburg, Joseph I. Boyce, Eduard G. Reinhardt, Nicole Fallon

Previous work has demonstrated the usefulness of multi-proxy methods for reconstructing submerged landscapes (Sonnenburg et al. 2009). This paper focuses on utilizing similar techniques at a much higher resolution in conjunction with previously published pollen data to gain a better understanding of environmental changes due to water-level fluctuations throughout the Holocene. The utilization of testate amoebae to identify hydrologic and environmental changes in submerged landscapes is unique in North American archaeology. E. Sonnenburg wrote the initial drafts, collected and analyzed data and identified and counted all microfossils. J. Boyce assisted with data collection and edited manuscripts. E. Reinhardt assisted with data collection, microfossil identification and manuscript editing. N. Fallon assisted with data collection and completed all magnetic susceptibility data. The intended journal of submission is Quaternary Science Reviews. This journal publishes interdisciplinary studies of all aspects of Quaternary sciences, including geoarchaeology. This article will be of interest to QSR readers as it utilizes both novel and well-established methods to answer questions about early Holocene environments and the potential impacts on Paleoindian peoples.

Paper 3: **Holocene paleoshorelines, water levels and submerged prehistoric site archaeological potential of Rice Lake, Ontario, Canada**

Authors: Elizabeth P. Sonnenburg, Joseph I. Boyce and Philip Suttak

The purpose of this paper is to describe the process of creating paleogeographic maps of Rice Lake using available paleoenvironmental and remotely sensed data. These maps can then be used to identify areas of archaeological interest at different time periods throughout the Holocene. This research is unique as it not only models paleoshorelines, but also includes the effects of sedimentation and isostatic uplift on water-level reconstruction. This model identifies several areas of archaeological interest in Rice Lake that can be subjected to further study. This is the first model of its kind applied to submerged landscape in the Great Lakes watershed. E. Sonnenburg wrote the initial manuscript, collected and processed all geophysical data and created the final paleogeographic maps. J. Boyce assisted in the collection and processing of geophysical data and creation of paleogeographic maps. P. Suttak created the tilt-corrected Digital Elevation Models. The intended journal of submission is Journal of Archaeological Sciences. This is the most well-known journal dealing with archaeological sciences, and this paper will be of interest to specialists in the field of submerged landscapes, as it highlights new ways of understanding past landscapes.

1.6 Summary

Submerged landscapes are a relatively new area of archaeology in North America. The submerged landscapes of the Great Lakes are a potentially large archaeological resource that is not yet explored. Previous studies of submerged landscapes in Europe and the coasts of North America have provided valuable insights into the settlement patterns and lifeways of prehistoric peoples. The relative scarcity of Paleoindian sites in the Great Lakes regions causes problems for archaeologists to understand the timing and extent of Paleoindian settlement of the area. The discovery of new sites in submerged contexts will not only provide additional settlement information, but may also provide well-preserved sites with organic remains, which is a rarity in Great Lakes Paleoindian archaeology. These additional sites will provide important insights into the adaptations of these peoples to a rapidly changing environment. In addition, the modern development of many of the Great Lakes shorelines may destroy much of the underwater archaeological record if these sites remain undiscovered.

In this study, integration of multi-proxy paleoenvironmental analysis, geophysical data, paleogeographic reconstruction, as well as knowledge of current terrestrial sites and aboriginal cultural knowledge can create a useful visual aid for identifying areas of archaeological potential in Rice Lake, Ontario. The multi-disciplinary approach adopted in this work is innovative and of importance, as it leads to significant insights into Paleoindian littoral zone settlement history and Holocene paleoenvironmental change in central Ontario. The methods and techniques developed also have wider application to investigations in the Great Lakes basin and other lakes in Canada, which are host to significant archaeological resources. The data collected is shared with Parks Canada in order to facilitate cultural resource management of Rice Lake and Trent-Severn Waterway; however, the research methodology outlined here can then be used by other organizations looking to find submerged sites for the purposes of cultural resource management and archaeological research. Archaeologists will be able to effectively investigate a large portion of the archaeological record that until now has been missing.

References

Bailey, G. (2004). The wider significance of submerged archaeological sites and their relevance to world prehistory. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol. 141: 3-11.

Bailey, G. N. and N. C. Flemming (2008). Archaeology of the continental shelf: marine resources, submerged landscapes and underwater archaeology. Quaternary Science Reviews 27: 2153-2165.

Barnett, P. J. (1992). Quaternary geology of Ontario. Geology of Ontario. J. B. Thurston, H. R. Williams, R. H. Sutcliffe and G. M. Scott (eds.), Sudbury, Ontario Geological Survey. Vol. 4 Part 2: 1011-88.

Bell, T. and M. A. P. Renouf (2003). Prehistoric cultures, reconstructed coasts: Maritime Archaic Indian site distribution in Newfoundland. World Archaeology 35(3): 350-370.

Boyd, M. (2007). Early postglacial history of the southeastern Assiniboine Delta, glacial Lake Agassiz basin. Journal of Paleolimnology 37: 313-329.

Brown, A. G. (1997). Alluvial Geoarchaeology. Cambridge, UK, University of Cambridge Press.

Coakley, J. P. and P. F. Karrow (1994). Reconstruction of post-Iroquois shoreline evolution in western Lake Ontario. Canadian Journal of Earth Science 31: 1618-1629.

Conley, D. J. and C. L. Schelske (2001). Biogenic Silica. Tracking Environmental Change Using Lake Sediments. J. P. Smol, H. J. B. Birks and J. P. Last (eds.), Dortrecht, Kluwer Academic Publishers. Vol. 3: 281-293.

Davis, J. C. (2002). Statistics and Data Analysis in Geology. New York, John Wiley and Sons.

Dean, M. and J. Frazer (2004). The application of high resolution multibeam sonar to the investigation of archaeological sites. The Application of Recent Advances in Underwater Detection and Survey Techniques to Underwater Archaeology, Bodrum, Turkey, Uluburun Publishing.

Dean, W. E., T. S. Ahlbrandt, R. Y. Anderson and J. P. Bradbury (1996). Regional aridity in North America during the middle Holocene. The Holocene 6(2): 145-155.

Dillehay, T. D. (1991). The Great Debate on the First Americans. Anthropology Today 7(4): 12-13.

Drzyzga, S. A. (2007). Relict shoreline features at Cockburn Island, Ontario. Journal of Paleolimnology 37: 411-417.

Ellis, C. (2006). A preliminary report on the 2006 test excavations at the Davidson site: an archaic 'Broad Point' component. Kewa 06(7): 1-16.

Ellis, C., I. T. Kenyon and M. W. Spence (1990). The Archaic. Archaeology of Southern Ontario to A.D. 1650. C. Ellis and N. Ferris (eds.), London, Ontario Archaeological Society. Vol.: 65-124.

Fallon, N. (2009). Magnetic susceptibility of sediments in Rice Lake. School of Geography and Earth Sciences. Hamilton, McMaster University. Honours Bachelor of Science.

Faught, M. K. (2002). Submerged Paleoindian and Archaic Sites of the Big Bend, Florida. Journal of Field Archaeology 29(3/4): 273-290.

Fedje, D. W. and T. Christensen (1999). Modeling paleoshorelines and locating early Holocene coastal sites in Haida Gwaii. American Antiquity 64(4): 635-652.

Fedje, D. W. and H. Josenhans (2000). Drowned forests and archaeology on the continental shelf of British Columbia, Canada. Geology 28: 99-102.

Ferguson, M. L. and C. D. Metcalfe (1989). Distribution of PCB congeners in sediments of the Otonabee River-Rice Lake system, Peterborough, Canada. Chemosphere CMSHAF 19(8/9): 1321-1328.

Firth, A. (2004). Prehistory in the North Sea: questions for development-led archaeology. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol.: 89-94.

Fischer, A. (2004). Submerged Stone Age- Danish examples and North Sea potential. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol.: 21-37.

Fladmark, K. (1979). Routes: Alternative Migration Corridors for early Man in North America. American Antiquity 44(1): 55-69.

Fladmark, K. (1982). Microdebitage analysis: Initial considerations. Journal of Archaeological Science 9(2): 205-220.

Flemming, N. C. (2004). The prehistory of the North Sea floor in the context of Continental Shelf archaeology. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol.: 11-21.

Gearey, B. R. and C. J. Caseldine (2006). Archaeological applications of testate amoebae analyses: a case study from Derryville, Co. Tipperary, Ireland. Journal of Archaeological Science 33: 49-55.

Glimmerveen, J., D. Mol, K. Post, J. W. F. Reumer, H. van der Plicht, J. de Vois, B. van Geel, G. van Reenan and J. P. Pals (2004). The North Sea project: first palaeontological, palynological, and archaeological results. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol. 141: 43-52.

Gorrell, G. and T. A. Brennand (1997). Surficial Geology of the Rice Lake Area, MTS 31D/1, southern Ontario, Geological Survey of Canada Open File 3332.

Gravenor, C. P. (1957). Surficial geology of the Lindsey-Peterborough area, Ontario, Victoria, Peterborough, Durham and Northumberland counties, Ontario, Geological Survey of Canada. 288: 60.

Grøn, O. and J. Skaarup (2004). Submerged Stone Age coastal zones in Denmark investigation strategies and results. Submarine Prehistoric Archaeology in the North Sea: research priorities and collaboration with industry. N. C. Flemming (eds.), York, English Heritage/Council for British Archaeology. Vol.: 53-56.

Hammer, O., D. A. T. Harper and P. D. Ryan (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 1-9.

Heiri, O., A. F. Lotter and G. Lemcke (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25: 101-110.

Jackson, L. J. (1998). The Sandy Ridge and Halstead Paleo-Indian sites. Ann Arbor, Museum of Anthropology, University of Michigan.

Jackson, L. J. (2004). Changing our view of late Palaeo-Indian in Southern Ontario. The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early Holocene

Environments. L. J. Jackson and A. Hinshelwood (eds.), Ottawa, Canadian Museum of Civilization. Vol. 165: 25-56.

Jackson, L. J., C. Ellis, A. V. Morgan and J. H. McAndrews (2000). Glacial lake levels and eastern Great Lakes Palaeo-Indians. Geoarchaeology 15(5): 415-440.

Jackson, L. J. and H. McKillop (1988). Ontario fossil cervids: neglected data and dating. Orono, Main, Center for the Study of Early Man, University of Maine.

Janusas, S. E., S. M. Blasco, S. McClellan and J. Lusted (2004). Prehistoric drainage and archaeological implications across the submerged Niagara Escarpment north of Tobermory, Ontario. The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments. L. J. Jackson and A. Hinshelwood (eds.), Ottawa, Canadian Museum of Civilization. Vol.: 303-314.

Johnston, R. B. (1968). Archaeology of Rice Lake, Ontario. Ottawa, Department of the Secretary of State.

Johnston, R. B. (1984). McIntyre Site: Archaeology, Subsistence and Environment. Ottawa, ON, Archaeological Survey of Canada.

Julig, P. (ed) (2002). The Sheguiandah Site: Archaeological, geological and paleobotanical studies at a Paleoindian site on Manitoulin Island, Ontario. Ottawa, Canadian Museum of Civilization.

Karrow, P. F. (2004). Ontario geological events and environmental change in the time of the late Palaeo-Indian and early Archaic cultures (10,500 to 8,500 B.P.). The Late Palaeo-Indian Great Lakes; Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments. L. J. Jackson and A. Hinshelwood (eds.), Ottawa, Canadian Museum of Civilization. Vol. 165: 1-24.

Karrow, P. F., E. C. Appleyard and A. L. Endres (2007). Geological and Geophysical evidence for pre-Nipissing (>5,000 years BP) transgression infilled valleys in the Lake Huron basin, Ontario. Journal of Paleolimnology 37: 419-434.

Kelley, J. T., D. F. Belknap and S. Claesson (2010). Drowned coastal deposits with associated archaeological remains from a sea-level "slowstand": Northwestern Gulf of Maine, USA. Geology 38(8): 695-698.

Kraft, J. C., G. A. Rapp, J. A. Gifford and S. E. Aschenbrenner (2005). Coastal change and archaeological setting in Elis. Hesperia 74(1): 1-39.

Kuehn, S. R. (1998). New evidence for late Paleoindian-early Archaic subsistence behaviour in the western Great Lakes. American Antiquity 63(3): 457-476.

Kumar, A. and A. P. Dalby (1998) Identification key for Holocene lacustrine arcellacean (thecamoebian) taxa. Palaeontologia Electronica 1(1): 39.

Last, W. M. (2001). Textural Analysis of Lake Sediments. Tracking Environmental Change Using Lake Sediments. Volume 2: Physical and Geochemical Methods. W. M. Last and J. P. Smol (eds.), Dortrecht, Kluwer Academic Publishers. Vol. 2: 41-81.

Lewis, C. F. M., C. W. Heil, J. B. Hubney, J. W. King, T. C. Moore Jr. and D. K. Rea (2007). The Stanley unconformity in Lake Huron basin: evidence for a climate driven closed lowstand about 7900 ^{14}C BP, with similar implications for the Chippewa lowstand. Journal of Paleolimnology 37: 435-452.

Lovis, W. A., R. E. Donahue and M. B. Holman (2005). Long-distance logistic mobility as an organizing principle among northern hunter-gatherers: a Great Lakes middle Holocene settlement system. American Antiquity 70(4): 669-693.

Lovis, W. A., M. B. Holman, G. W. Monaghan and R. K. Skowronek (1994). Archaeological, geological and paleoecological perspectives on regional research design in the Saginaw Bay Region of Michigan. Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties. R. I. MacDonald (eds.), Waterloo, Quaternary Sciences Institute. Vol.: 81-94.

Martin, N., C. Milne and D. S. McGillis (1986). Gore's Landing and the Rice Lake Plains. Cobourg, Heritage Gore's Landing.

Mason, R. J. (1981). Great Lakes Archaeology. New York, Academic Press.

Matthews, M. D. (1991). The effect of pretreatment on size analysis. Principles, Methods and Application of Particle Size Analysis. J. P. M. Syvitski (eds.), New York, Cambridge University Press. Vol.: 34-42.

Mayer, L., B. Calder, J. S. Schmidt and C. Malzone (2004). Exploring the third dimension: high-resolution multibeam sonar as a tool for archaeological investigations-an example for the D-Day beaches of Normandy. The Application of Recent Advances in Underwater Detection and Survey

Techniques to Underwater Archaeology, Bodrum, Turkey, Uluburun Publishing.

McAndrews, J. H. (1984). Late Quaternary vegetation history of Rice Lake, Ontario, and the McIntyre archaeological site. The McIntyre Site: Archaeology, Subsistence and Environment. R. B. Johnston (eds.), Ottawa, National Museums of Canada. Vol. 126: 161-189.

Momber, G. (2004). The inundated landscapes of the western Solent. Submarine Prehistoric Archaeology of the North Sea: research priorities and collaborations with industry. N. C. Flemming. York, English Heritage/Council for British Archaeology: 37-42.

Muller, E. H. and V. K. Prest (ed) (1985). Glacial lakes in the Ontario Basin. Quaternary Evolution of the Great Lakes. St.John's, Geological Association of Canada.

O'Gorman, J. A. and W. A. Lovis (2006). Before removal: an archaeological perspective on the southern Lake Michigan basin. Midcontinental Journal of Archaeology 31(1): 21-56.

O'Shea, J. M. and G. A. Meadows (2009). Evidence for early hunters beneath the Great Lakes. PNAS 106: 10120-10123.

Patterson, R. T. and E. Fishbein (1989). Re-examination of the statistical methods used to determine the number of point counts needed for micropaleontological quantitative research. J Paleontol 63(2): 245-248.

Reinhardt, E. G., M. Little, S. Donato, D. Findley, A. Krueger, C. Clark and J. I. Boyce (2005). Arcellacean (thecamoebian) evidence of land-use change and eutrophication in Frenchman's Bay, Pickering, Ontario. Environmental Geology 47: 729-739.

Sandgren, P. and I. Snowball (2001). Application of mineral magnetic techniques to paleolimnology. Tracking Environmental Changes Using Lake Sediments. Volume 2: Physical and Geochemical Methods. J. P. Last and J. P. Smol (eds.), Dordrecht, Kluwer Academic Publishers. Vol. 2: 504.

Scott, D. B. and J. O. R. Hermelin (1993). A device for precision splitting of micropaleontological samples in liquid suspension. J Paleontol 67(1): 151-154.

Scott, D. B., F. S. Medioli and C. T. Schafer (2001). Monitoring in Coastal Environments Using Foraminifera and Thecamoebian Indicators. Cambridge, UK, Cambridge University Press.

Sonnenburg, E. P. and J. I. Boyce (2008). Digital bathymetric model and integrated side-scan as a base for archaeological inventory of submerged landscapes in the Rideau Canal (Ontario, Canada). Geoarchaeology 23(5): 654-674.

Sonnenburg, E. P., J. I. Boyce and E. G. Reinhardt (2009). Multi-proxy environmental record of Colonial land-use change in the lower Rideau Canal System (Colonel By Lake), Ontario, Canada. Journal of Paleolimnology 42: 515-532.

Stevens, W. (2002). Underwater archaeology and the future of submerged cultural resources on the Trent-Severn Waterway. Ontario Archaeology 73: 76-78.

van Hengstum, P. J., E. G. Reinhardt, J. I. Boyce and C. Clark (2007). Changing sedimentation patterns due to historical land-use changes in Frenchman's Bay, Pickering, Canada: evidence from high-resolution textural analysis. Journal of Paleolimnology 37(4): 603-618.

Verhart, L. (2004). The implications of prehistoric finds on and off the Dutch Coast. Submarine prehistoric archaeology of the North Sea: research priorities and collaboration with industry. N. C. Flemming. York, English Heritage/Council for British Archaeology. 141: 57-64.

Walker, I. J., J. R. Desloges, G. W. Crawford and D. G. Smith (1997). Floodplain formation processes and archaeological implications at the Grand Banks site, Lower Grand River, southern Ontario. Geoarchaeology 12(8): 865-887.

Westley, K., R. Quinn, W. Forsythe, R. Plets, T. Bell, S. Benetti, F. McGrath and R. Robinson (2010). Mapping submerged landscapes using multibeam bathymetric data: a case study from the north coast of Ireland. International Journal of Nautical Archaeology.

Yu, Z. and J. H. McAndrews (1994). Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen, and plant macrofossil evidence. Holocene 4(2): 141-152.

Yu, Z., J. H. McAndrews and U. Eicher (1997). Middle Holocene dry climate caused by change in atmospheric circulation patterns: Evidence from lake levels and stable isotopes. Geology 25(3): 251-254.

Chapter 2
Quartz flakes in lakes: microdebitage evidence for submerged Great Lakes prehistoric (Late Paleoindian-Early Archaic) tool-making sites

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Abstract

The exploration for submerged prehistoric archaeological sites in the Great Lakes is a major challenge due to the difficulty in locating scant cultural artifacts (e.g. stone tools, pottery) in lake-bottom sediments. Stone tool micro-fragments ('microdebitage';< 1 mm) are abundant (> 10^6 per tool) and widely dispersed around tool-making sites but have not been identified previously in an underwater context. To evaluate their use as a submerged site indicator, microdebitage analysis was conducted on five lake sediment cores from a shallow basin adjacent to a long-occupied prehistoric site (McIntyre Site, Rice Lake, Ontario). 155 microdebitage fragments were identified within a distinctive muddy peat horizon (2-2.5 m depth) using light microscopy and SEM methods. The microdebitage consisted of angular to very angular quartz grains (400-1000 μm) with characteristic conchoidal fractures and flake scars produced by mechanical percussion. The microdebitage horizon had a distinctive bi-modal particle size peak and contained a low-diversity soil thecamoebian assemblage (*Phryaginella*, *Bullinularia* sp.) indicative of a wetland environment that formed during an Early Holocene shoreline transgression. AMS ^{14}C dating of wood fragments yielded ages of 9470-8760±50 BP (11070-9560 cal BP), indicating a Late Paleoindian-Early Archaic age for the tool-making site. Results demonstrate that coring and microdebitage analysis are effective tools in the search for underwater prehistoric materials and can be employed more broadly in the exploration of submerged landscapes in the Great Lakes basins.

Keywords: Paleoindians, Great Lakes, microdebitage, lake sediments, SEM

2.1 Introduction

The arrival of the first Paleoindian hunter-gatherers in the lower Great Lakes (ca. 11.5-11 ka BP) coincided with major changes in Early Holocene lake levels, vegetation and climate (Eren, 2009; Jackson et al., 2000). In the Lake Ontario basin, Paleoindian settlement occurred during a major lowstand event (Admiralty Phase; Fig. 2.1) following the drainage of high-level Lake Iroquois between 11.7-11.4 ka BP (Anderson and Lewis, 1985; Coakley and Karrow, 1994). Water levels during this phase were > 100 m below present and more than half the area of the modern lakebed (approx. 10,000 km^2) was an exposed lake plain with extensive coastal wetlands. The open lake plain environment was highly attractive to Paleoindian hunter-gatherers, providing access to a variety of food resources (e.g. caribou, fish, aquatic plants) and a transportation corridor for migration (Jackson et al., 2000). No underwater Paleoindian sites have yet been documented in Lake Ontario but it has been speculated that large numbers of occupation sites were rapidly inundated by rising Holocene lake levels. Several well-studied terrestrial sites 40 km to the north at Rice Lake (Fig. 2.2) provide evidence for Paleoindian presence with small task groups living in logistical (e.g. seasonal hunting camps) and residential sites (Jackson, 1998). Based on the site density at Rice Lake (approx. 0.12/ km^2) Jackson et al. (2000) speculated that more than 1000 Paleoindian sites may be preserved on the drowned lake plain in Lake Ontario (Fig. 2.1).

Submerged prehistoric landscapes have also been documented in Lake Huron and Lake Michigan (Hunter et al., 2006) associated with Early Holocene (10-7.5 ka BP) lowstand events (Lake Stanley-Hough and Lake Chippewa respectively) (Lewis et al., 2007). In Lake Huron, side-scan and multi-beam sonar mapping of the lakebed has found evidence for caribou drive lanes and hunting blinds (O'Shea and Meadows, 2009). These features indicate that prehistoric peoples were occupying and utilizing the resources on the exposed lake plain and highlight the need for more systematic exploration of submerged landscapes using remote sensing and sediment coring (Sonnenburg and Boyce, 2008; Westley et al., 2010).

Despite the tremendous archaeological potential, the search for underwater prehistoric sites is a major challenge due to the difficulty in locating cultural materials underwater. Paleoindian nomadic peoples left few cultural materials other than stone tools and a few built structures (e.g. firepits, caribou drive lanes) (O'Shea and Meadows 2009). Where present, such artifacts are likely to be buried and surface finds occur only where non-deposition or erosion has removed the overlying Holocene sediment cover. Chance finds of archaeological materials in sediment cores have been documented (e.g. hand tools) (Stanley et al., 2008) but coring has a low likelihood of retrieval of single lithic artifacts unless sampled on a very dense grid-work. Multi-beam and side-scan sonar mapping of drowned geomorphic features (e.g. relict strandlines, river terraces) can assist in defining areas with high archaeological potential, but discovery of individual sites with dimensions of a few 10's or 100's of m^2 has a low likelihood using remote sensing or by direct diver survey (O'Shea and Meadows, 2009; Quinn et al., 2008; Sonnenburg and Boyce, 2008).

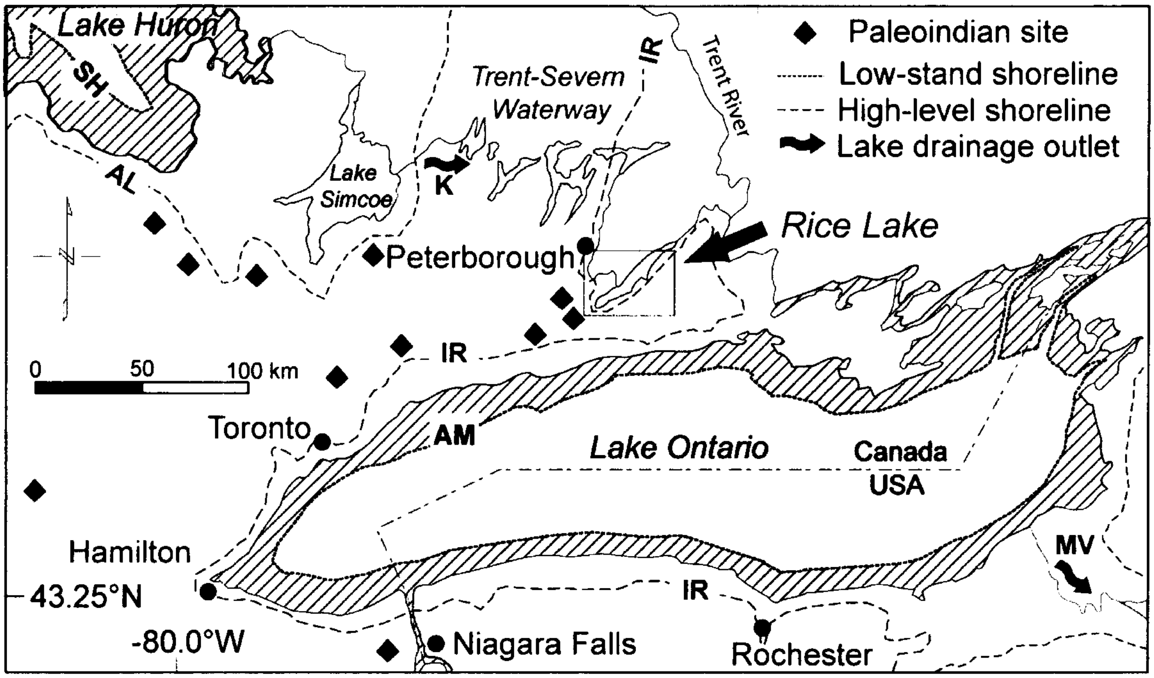

Figure 2.1. Location of Rice Lake in southern Ontario with distribution of selected terrestrial Paleoindian sites and post-glacial lake shorelines. AL = Main Lake Algonquin (11.2-10.4 ka BP), IR = Lake Iroquois (12.5-12 ka BP), SH=Stanley-Hough lowstand (10 ka BP), AM=Admiralty lowstand (11.7-11.4 ka BP), MV =Mohawk Valley Outlet (13.5-13.1 ka BP), K= Kirkfield Outlet (11.7-11.2 ka BP). Hatching indicates area of modern lakebed (approx. 10,000 km^2) exposed during AM lowstand when water levels were > 100 m bpl.

An alternate approach is to look for the presence of widely distributed stone tool micro-artifacts or 'microdebitage' as part of the microscopic analysis of sediment core properties (e.g. particle size and morphology, microfossil analysis). Microdebitage are small microscopic stone flakes (<1 mm) produced by stone tool knapping. These small lithic fragments are much more numerous and more widely dispersed than their larger parent flakes; experimental studies have shown that the production of 1 stone tool distributes more than 1 million particles of less than 1 mm over a 2-3 m radius (Fladmark, 1982). Microdebitage is easily extracted from sediment samples using conventional sieving methods and identified under light microscope by its high angularity, presence of conchoidal fractures and anomalous particle size (Dragovich and Susino, 2001; Fladmark, 1982). Fladmark (1982) noted that the method could be employed for investigation of submerged sites but it has not previously been applied in underwater archaeology.

In this paper, we report on the discovery of submerged Paleoindian tool-making fragments at Rice Lake, Ontario using microdebitage analysis of lake sediment cores (Fig. 2.2B). Microdebitage was identified with light and scanning electron microscopy (SEM) using the criteria developed by Fladmark (1982) and Dragovich and Susino (2001). Our results identify a distinctive quartz-microdebitage layer within the basin that dates to the Late Paleoindian-early Archaic period (ca. 9.5-8.7 ka BP ^{14}C). This discovery represents the first-documented evidence of human activity in a submerged context using microdebitage analysis, and confirms the high archaeological potential for underwater prehistoric sites at Rice Lake (Jackson et al., 2000; Chapter 4). The technique is rapidly conducted on lake sediment cores and integrated with a range of other paleoenvironmental indicators (e.g. thecamoebians, particle size, pollen analyses), providing an effective strategy for identifying and reconstructing Great Lakes submerged prehistoric sites.

2.2 Study Site and Archaeological Setting

Rice Lake, located 40 km to the north of Lake Ontario, contains one of the largest concentrations of prehistoric sites (> 300) in the Great Lakes (Fig. 2.2). The lake basin

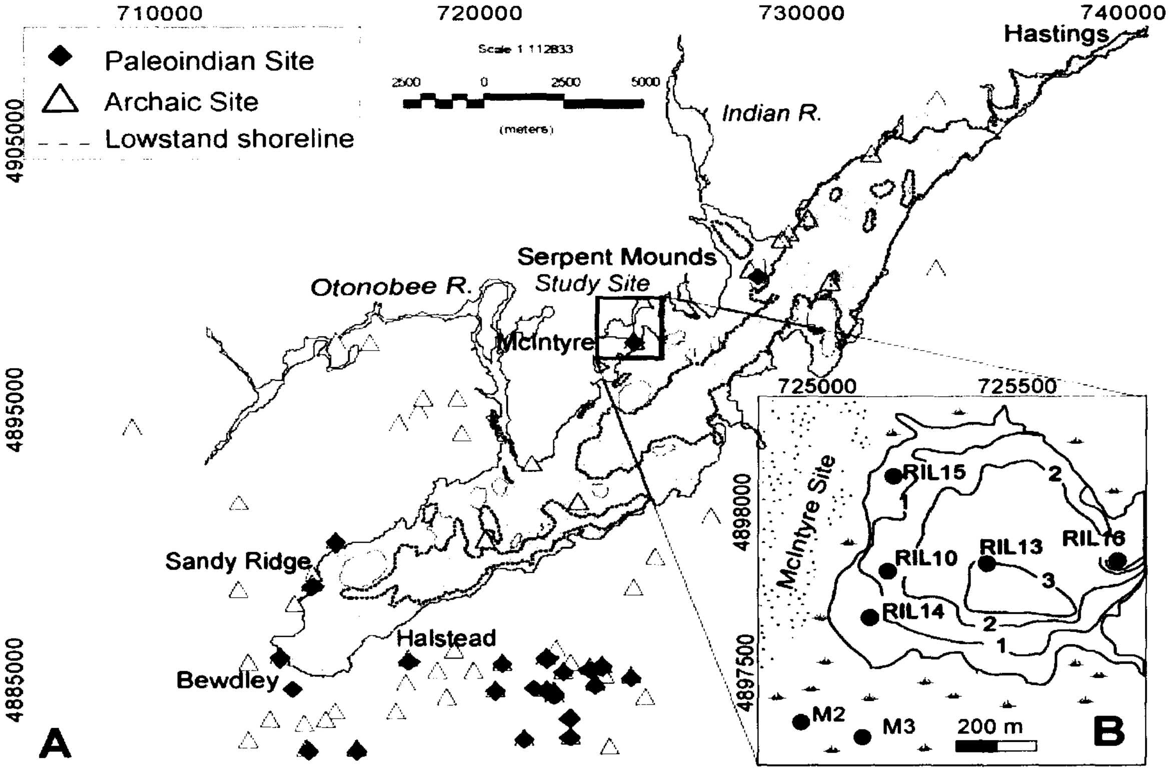

Figure 2.2. A. Rice Lake study area showing locations of Paleoindian and Archaic sites and Early Holocene (ca. 11 ka BP) lowstand paleoshoreline (approx. 8 m bpl). The lowstand was synchronous with Admiralty lowstand in Lake Ontario basin. B. McIntyre basin coring site.

was formed after 12.5 ka BP by flooding of a pre-glacial river valley by glacial Lake Iroquois (Fig. 1). Following the drainage of Lake Iroquois (ca. 11.7 ka BP) water levels dropped dramatically and a large area of the lakebed was sub-aerially exposed (Chapter 4) (Yu and McAndrews, 1994). The Early Holocene lowstand lake level was more than 11 m below present and the open water area was restricted to the northeast portion of the Rice Lake basin (Fig. 2.2A). By the time of Paleoindian settlement (ca. 11 ka BP) water levels had begun to rise due to isostatic uplift of the eastern lake outlet and extensive wetlands and marshes had developed around the margins of the lake as recorded by organic mud and peat overlying Lake Iroquois deposits (Fig. 2.3) (Yu and McAndrews, 1994; Chapter 3). Several Paleoindian occupation sites have been documented above the modern shoreline at the southwestern end of the lake (Halstead and Sandy Ridge sites; Fig. 2.3) but sites are conspicuously absent elsewhere compared to the large number of Late Archaic and Woodland-age sites (Fig. 2.3). The low archaeological visibility of Paleoindian sites at Rice Lake may be attributed to Holocene shoreline transgression, but to date, few submerged sites have been documented (Jackson, 2004).

Coring investigations were focused on a small (1-km^2) basin that borders the long-occupied McIntyre prehistoric site (Fig. 2.2). The main McIntyre site occupation was in the Late Archaic Period (ca. 4.4-3.6 ka BP) (Johnston, 1984) with scattered lithic finds from an earlier Paleoindian presence (Jackson, 1998). Microdebitage analysis was conducted on basin cores with the objective of identifying submerged Paleoindian sites from this earliest phase of settlement. The semi-enclosed basin has a maximum water depth of about 3.5 m, providing an ideal location for accumulation of a continuous Holocene sediment record, as fewer destructive processes such as wave action affect sedimentation (Figs. 2.2B, 2.3).

2.3 Methods

Five vibrocores were extracted from the McIntyre basin (Fig. 2.2), stratigraphically logged and sampled for microdebitage and particle size analysis. For microdebitage analysis 20 g samples were extracted at 5 cm intervals using the methods outlined by Fladmark (1982). 20 g sediment samples were sieved and separated into <500, and <250 μm fractions and pre-treated with peroxide to remove organics. The samples were air-dried and 1 g placed in a gridded petrie dish for identification under a light microscope. Lithic microdebitage was identified using the following criteria: 1) high angularity, 2) particle geometry (flat or blade-like grains with triangular, sub-rectangular, trapezoidal shapes), 3) presence of conchoidal fractures, ridges and flake scars typical of mechanical percussion, 4) mean grain size larger than surrounding matrix (Fladmark, 1982). Microdebitage shape was classified using Powers (1953) roundness index (Table 2.1) and imaged using SEM to assist in differentiating naturally-occurring angular quartz grains from lithics (Dragovich and Susino, 2001).

High-resolution particle size analysis was performed on a single core (RIL-10) on a LS230 Coulter Counter at 1 cm and microfossil analysis (testate amoebae) at 5 cm intervals (Fig. 2.4). Particle size analysis was completed on both bulk (unprocessed) and processed samples (organics, carbonates and diatoms removed). Testate amoebae (thecamoebians) are sensitive indicators of changes in lake environments, trophic status and water-levels (Gearey and Caseldine, 2006; Reinhardt et al., 2005; Sonnenburg et al., 2009) and were identified and 200-300 counted under light microscope at 80 x magnification (Table 2.2) (Kumar and Dalby, 1998; Scott et al., 2001).

2.4 Results

2.4.1 Basin Stratigraphy

Six distinctive lithostratigraphic units were recognized based on lithology, grain size and thecamoebian assemblages (Units A-F; Figs. 2.3, 2.4). A lowermost coarsening-up sequence of Lake Iroquois laminated mud and sand (Units A, B) was overlain by a light-coloured (10YR 3/1) thick silty mud or darker peaty mud (10YR 2/2) (Unit C) with abundant plant and wood fragments and rooted horizons extending into Unit B. The peaty

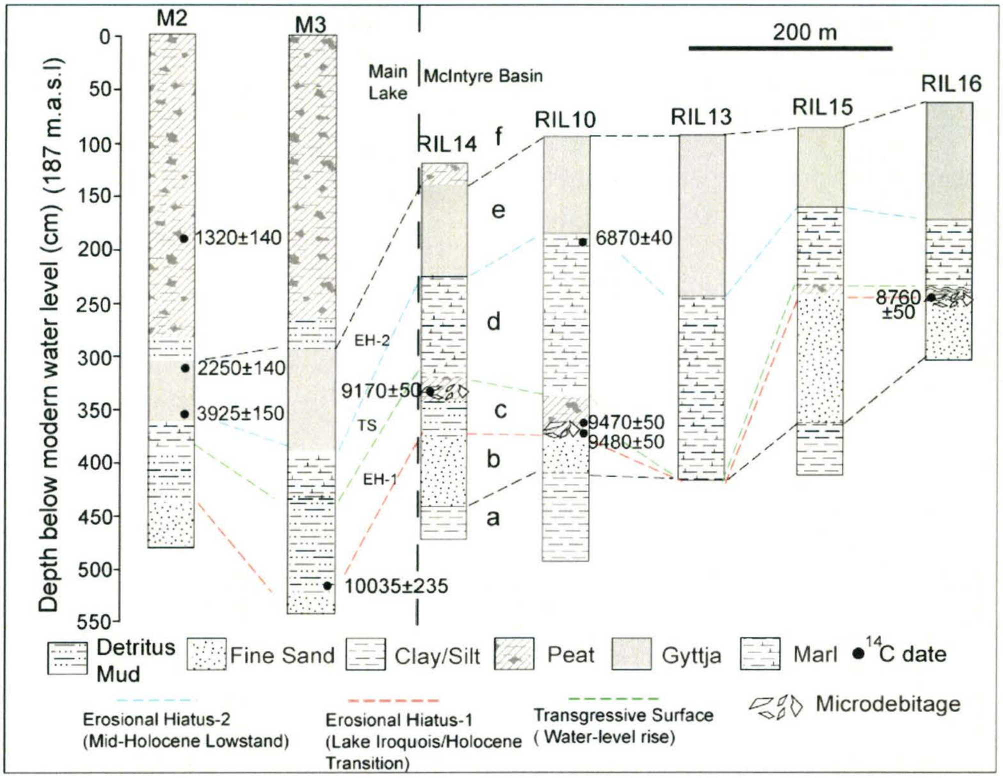

Figure 2.3. McIntyre basin lithostratigraphy and ^{14}C chronology. All ^{14}C dates are conventional radiocarbon ages BP. Microdebitage was identified in three cores within an organic-rich silty mud layer (Unit C). Unit C was deposited in a wetland environment and records the development of marshes following the recovery of water levels from the Early Holocene lowstand in Rice Lake. ^{14}C dates (9480-8760±50 BP) indicate a Late Paleoindian to Early Archaic age for the tool-making sites. Cores M2, M3 ^{14}C dates from McAndrews (1984).

mud contained a low-diversity thecamoebian assemblage (*Phryaginella* and *Bullinularia* sp.; Fig. 2.4, Table 2.2) typical of soils and wetland environments (Asada and Warner, 2009; Booth, 2008; Scott et al., 2001; Swindles et al., 2009). AMS ^{14}C dating of seeds and wood fragments from Unit C peat yielded an Early Holocene age (ca. 9480-8760 ±50 BP; Fig. 2.3). Unit C records the establishment of marshes and soil formation following drainage of Lake Iroquois (Chapter 3). Unit D is a well-laminated, carbonate-rich (>40-

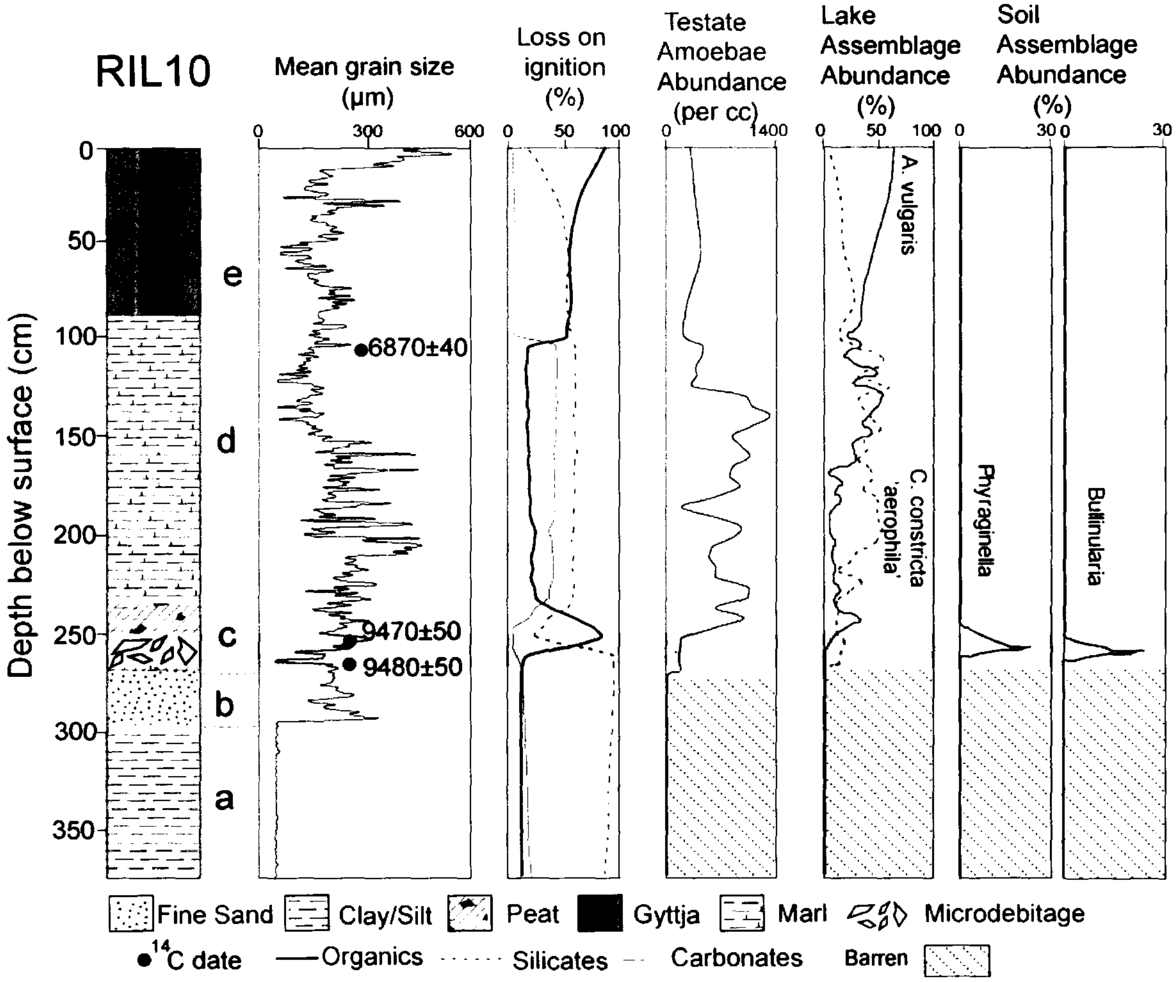

Figure 2.4. Core RIL-10 lithofacies, mean grain size, composition from loss-on-ignition (LOI) and thecamoebian abundances. Note shift from lake-based thecamoebian assemblages (*Arcella vulgaris*, *C. constricta* 'aerophila') to soil/wetland assemblages (*Phyraginella*, *Bullinularia* sp.) at 250 cm in Unit C. The Unit C/D contact is a transgressive surface recording the flooding of wetland by rising lake levels.

50%) marl containing abundant mollusk fragments and abundant *Arcella vulgaris* and *Centropyxid* species (Fig. 4) representing a shift to an open water lake environment. The Unit D marls are erosionally truncated by 1-3 m thick sequence of organic-rich mud (gyttja) and peat (Units E, F; Fig. 2.3). ^{14}C dates immediately above and below the marl-gyttja transition indicate a major erosional hiatus (6870±40 to 3925±150 BP) (EH-2) that formed during a mid-Holocene lowstand event in Rice Lake (Yu and McAndrews, 1994) (Chapter 3).

2.4.2 Microdebitage

Microdebitage analysis was conducted on samples from all 6 lithostratigraphic units in the basin cores, but all were barren of lithic fragments except in lithologic Unit C. Further analysis of additional sediment samples of RIL 10 at 5-cm intervals was also barren of microdebitage. The microdebitage recovered from Unit C ranged in size from 1mm to 400 μm. SEM of identified microdebitage and unmodified quartz particles revealed key differences (Fig. 2.5A-F). Features evident on the SEM images were not visible under light microscope, such as thinned edges, flake scars and lack of weathering (Fig. 2.5A-D). Weathering and striations oriented in multiple directions visible in the natural particles did not occur in the microdebitage. Fine, delicate edges that distinguish microdebitage are completely missing from natural quartz particles (Fig. 2.5E, F).

Another feature of microdebitage is its larger size and abundance of angular particles relative to the surrounding matrix (Fig. 2.5G). Analysis of the 249-250 and 269-270 cm fraction show a normal distribution of particle size, however the 256-257 cm interval displays bi-modal distribution (100 and 400 μm). Evaluation of roundness of quartz particles (see Table 2.1) show a trend towards high angularity of quartz particles in the 257 cm interval, where 42% of particles were classified as very angular and angular, and 50% of all grains counted were classified as microdebitage. In the 270 cm fraction, only 14 % of grains were classified as very angular or angular, and no microdebitage was identified. No quartz grains were found in the 250 cm interval. Particle size analysis (Fig. 2.4) reveals a small, 5 cm sub-unit (255-260 cm) of finer grained silt in which microdebitage was recovered, and radiocarbon dates from this unit (9470-9480 ± 50 BP) place it within the Paleoindian time period (ca. 11,000-9,000 YBP).

A

Interval	256.5 cm		258 cm		270.5 cm	
Roundness Class	Count	%	Count	%	Count	%
Very Angluar	15	3.9	17	15.3	5	0.5
Angluar	55	14.1	30	27	137	13.74
Subangular	140	37	32	28.8	486	48.75
Subrounded	150	38.6	26	23.4	337	33.8
Rounded	25	6.4	6	5.4	32	3.2
Well rounded	0	0	0	0	0	
Total grains counted	389		111		997	
Total microdebitage	17	4.4	56	50.45	0	0

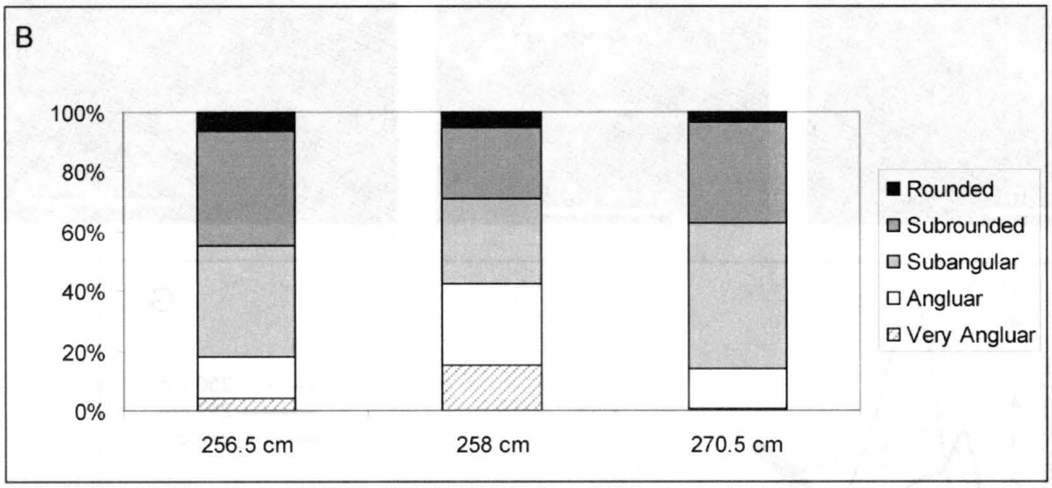

Table 2.1. Point counts of quartz grain roundness from three intervals in core RIL-10. A. Quartz grain and microdebitage roundness. B. Total quartz grain roundness.

2.5 Discussion

Microdebitage recovered from Rice Lake supports previous studies indicating Paleoindian sites in Southern Ontario are submerged beneath higher Holocene water-levels (Jackson, 2004; Jackson et al., 2000). This represents the first use of microdebitage in locating evidence of human activity in submerged sediments, and the first submerged

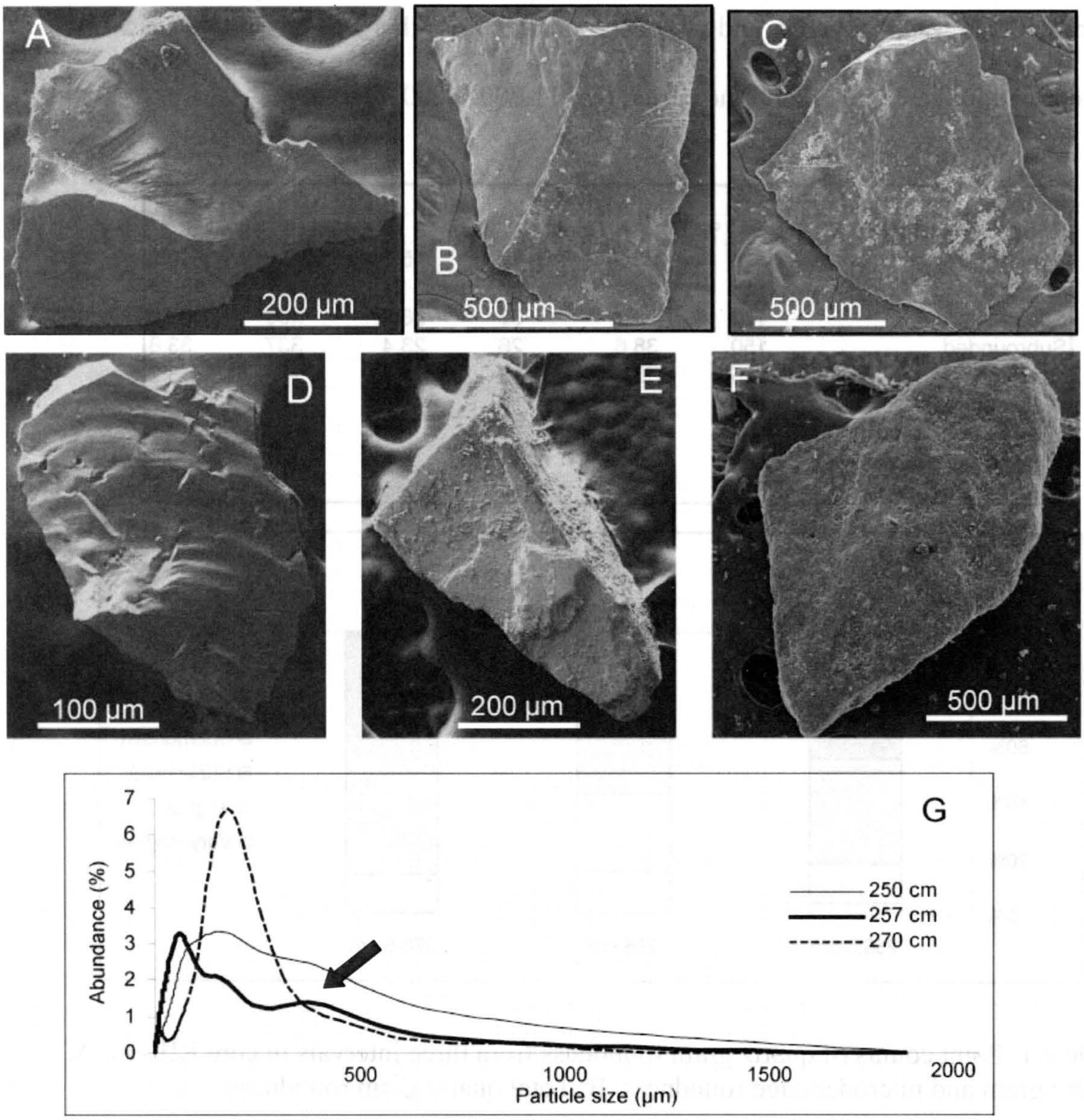

Figure 2.5. SEM images and particle size data of selected microdebitage and naturally occurring quartz grains. A-C Microdebitage from core RIL 10. D. Quartz microdebitage from McIntyre site. E-F. Naturally occurring angular grains from RIL 10. Note weathered surfaces, lack of conchoidal fractures and flake scars. G. Particle size plots of sediments above, within and below microdebitage layer in RIL 10. Note the bimodal distribution at 257 cm (black arrow), denoting the coarser microdebitage within the silty-clay matrix.

tool debris from the Paleoindian period to be found in the Lake Ontario watershed. Lithic fragments from cores RIL 10, 14 and 16 exhibit evidence of anthropogenic manufacture including flake scars, lack of weathering, high angularity, geometric shapes and larger particle sizes. While mechanical crushing, spalling and frost-heave of quartz boulders may also create angular grains (Mahaney, 2002), these fragments would be spread throughout all recovered cores. RIL10 was examined at 5 cm intervals for microdebitage, and no microdebitage was recovered outside of Unit C. Since microdebitage is restricted to this unit, and occurs in only 3 of the 5 cores, it is unlikely that natural processes are responsible for the characteristic features of the microdebitage recovered.

Secondary deposition of microdebitage from overland flooding of adjacent archaeological sites, fluvial inputs, aeolian processes, thawing ice or accidental discard may have transported material from other locations and the vegetation within the wetland would act as a sediment trap for any upland terrestrial or fluvial material. However, the restriction of microdebitage to specific intervals and cores, larger particle size, tightly constrained radiocarbon dates, microfossil evidence of a stable soil surface and lack of erosional structures, strongly suggest that the microdebitage was a primary deposit as a result of direct human activity. Microdebitage was located in RIL 10, 14 and 16; while RIL 10 and 14 are adjacent to an existing archaeological site where materials could be transported from, RIL 16 is not. In addition, no microdebitage was recovered from RIL 15, despite having similar sedimentary characteristics to RIL 10, 14 and 16 (Fig. 2.3). Particle sizes of less than 250 um are more likely to be transported by aeolian and fluvial processes (Mahaney, 2002); the larger size of the McIntyre microdebitage (<400 um) may have prevented more long-distance transport. The tightly constrained radiocarbon dates of Unit C from the microdebitage layer in RIL 10, 14 and16 indicate a gradual transgression of the shoreline, burying deposits intact as water-levels rose. The dominance of soil inhabiting testate amoebae species from 250-257 cm in RIL 10 indicates the development of a stable surface that was gradually flooded and inhabited by lake-based species. The Unit C/D transition has no evidence of erosional surfaces or channelized contacts, as root horizons extend into the underlying Unit D,

RIL10									
Core depth (cm)	**1.5**	**25.5**	**50.5**	**75.5**	**90.5**	**95.5**	**100.5**	**105.5**	**110.5**
Total specimens counted (per cc)	189	264	327	139.5	102	363	345.5	266	276.75
Total number of species	13	15	13	10	11	15	7	10	9
Species									
Arcella vulgaris	65.87	60.79	48.31	36.55	33.33	23.00	35.45	19.17	29.47
Centropyxis constricta 'aerophila'	7.40	14.39	17.58	27.59	15.19	15.15	31.40	53.57	47.73
Bullinularia	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0

RIL10									
Core depth (cm)	**115.5**	**120.5**	**125.5**	**130.5**	**135.5**	**140.5**	**145.5**	**150.5**	**155.5**
Total specimens counted (per cc)	209.5	928	1020	1272	1024	760	880	984	772
Total number of species	7	3	7	5	3	5	7	12	11
Species									
Arcella vulgaris	52.27	27.59	55.29	53.77	44.14	37.37	45	28.05	29.53
Centropyxis constricta 'aerophila'	30.79	59.91	31.76	34.28	44.53	51.58	36.82	38.62	30.57
Bullinularia	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0

RIL10									
Core depth (cm)	**160.5**	**165.5**	**170.5**	**175.5**	**180.5**	**185.5**	**190.5**	**195.5**	**200.5**
Total specimens counted (per cc)	724	852	760	880	984	772	724	852	450
Total number of species	8	12	5	7	12	11	8	12	12
Species									
Arcella vulgaris	29.83	5.63	17.36	11.39	15.95	8.68	6.18	5.83	11.55
Centropyxis constricta 'aerophila'	43.09	43.19	35.84	48.4	48.25	49.77	53.09	47.08	30.22
Bullinularia	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0

RIL10									
Core depth (cm)	**205.5**	**210.5**	**215.5**	**220.5**	**225.5**	**230.5**	**235.5**	**240.5**	**245.5**
Total specimens counted (per cc)	536	532	980	964	534	916	494	62.5	57
Total number of species	13	13	15	12	11	11	13	11	9
Species									
Arcella vulgaris	8.20	9.77	11.42	9.95	16.1	10.48	14.57	35.6	19.65
Centropyxis constricta 'aerophila'	24.25	13.53	34.28	22.82	11.61	13.97	11.33	12	17.9
Bullinularia	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0

RIL10									
Core depth (cm)	**250.5**	**255.5**	**256.5**	**260.5**	**275.5**	**300.5**	**325.5**	**350.5**	**374.5**
Total specimens counted (per cc)	41.75	60.25	52.25	0	0	0	0	0	0
Total number of species	10	12	11	0	0	0	0	0	0
Species									
Arcella vulgaris	8.38	0.82	0.95	0	0	0	0	0	0
Centropyxis constricta 'aerophila'	15.56	14.1	8.61	0	0	0	0	0	0
Bullinularia	0	16.18	24.88	0	0	0	0	0	0
Phyraginella	5.38	14.10	19.61	0	0	0	0	0	0

Table 2.2: Testate amoebae data, including relative abundances (%) of selected species

which also suggests the microdebitage layer was deposited on a stable surface and remained undisturbed.

Most large stone tools found in the area are made from exotic cherts (source >200 km from Rice Lake); the source of the glacially-derived quartz material is from 30-60 km north of Rice Lake. Quartz material from this source were found at the Sandy Ridge site in the form of scrapers and flakes, which has been interpreted as a logistical camp (Jackson, 1998). The site is located on the northwestern shore of the lake, and would have been near wetland resources similar to the McIntyre site (Chapter 4). The microdebitage located in the McIntyre basin may represent a similar type of site; possibly as part of a tool-making area of a seasonal encampment, with the main occupation area at the terrestrial McIntyre site. The microdebitage could also be remnants of a tool created or sharpened on the spot during a hunting/gathering foray, as small quartz cobbles were likely readily available in the area.

The recovery of microdebitage in RIL 14 and 16 at successively higher elevations and later dates indicates that the basin was likely used over a 1000 year period and may have extended into the Early Archaic. The date of 8760±50 BP from the microdebitage layer in RIL 16 suggests that wetland resources continued to be exploited as the shoreline of the basin gradually transgressed. It is unclear whether the microdebitage from RIL 16 may represent Early Archaic rather than Late Paleoindian resource procurement. Further analysis of the materials and methods of microdebitage production is required before determining which cultural affiliation (if any) can be ascribed to the microdebitage from RIL 16.

Microdebitage offers a reliable method for discovering areas of archaeological interest. Microdebitage is ubiquitous in archaeological sites, represents a larger proportion of stone tool manufacture and is dispersed over a larger area than single tools (Fladmark, 1982). Microdebitage is easy to extract and requires only a light microscope for preliminary identification; it could also be easily integrated into existing microscopic sediment core and paleoenvironmental analysis of archaeological sites. Microdebitage could be utilized as an effective and efficient means of locating archaeological sites in areas that are not easily accessible and have an ephemeral archaeological record Microdebitage may be particularly effective for studies of Pleistocene North American migration, where evidence of these peoples may be located on the now submerged continental shelves of North America. There have only been a few recoveries of small amounts of material from these contexts, often from fishermen or sport divers (Kelley et al., 2010). While geophysical surveys of these areas have identified landscape features that may have high archaeological potential, archaeological materials are often buried or are too small to be identified by geophysical methods (Faught, 2002; Fedje and Josenhans, 2000; Kelley et al., 2010). Microdebitage offers a quantitative method to narrow search parameters of long stretches of coastline for sparsely scattered archaeological materials. Archaeological and associated paleoenvironmental surveys could be maximized using a gridwork of cores, which are then examined for microdebitage. While much future work needs to be completed to refine methodologies for characterization and analysis of microdebitage, this method has proven to be extremely useful for locating submerged prehistoric archaeological sites.

REFERENCES CITED

Anderson, T.W., and Lewis, C.F.M., 1985, Postglacial water-level history of the Lake Ontario basin, *in* Karrow, P.F., and Calkin, P.E., eds., GAC Special Paper, Volume 30: St. John's, Geological Association of Canada, p. 231-253.

Asada, T., and Warner, B.G., 2009, Plants and testate amoebae as environmental indicators in cupriferous peatlands, New Brunswick, Canada: Ecological Indicators, v. 9, p. 129-137

Booth, R.K., 2008, Testate amoebae as proxies for mean annual water-table depth in *Sphagnum*-dominated peatlands of North America: Journal of Quaternary Science, v. 23, p. 43-57

Coakley, J.P., and Karrow, P.F., 1994, Reconstruction of post-Iroquois shoreline evolution in western Lake Ontario: Canadian Journal of Earth Science, v. 31, p. 1618-1629

Dragovich, D., and Susino, G.J., 2001, Identification of experimental quartz microdebitage from rock engravings: Earth Surface Processes and Landforms, v. 26, p. 859-868

Eren, M., 2009, Paleoindian stability during the Younger Dryas in the North American Lower Great Lakes, *in* Shea, J.J., and Lieberman, D.E., eds., Transitions in Prehistory: Essays in honour of Ofer Bar-Yosef: Oxford, Oxbow Books, p. 389-422.

Faught, M.K., 2002, Submerged Paleoindian and Archaic sites of the Big Bend, Florida: Journal of Field Archaeology, v. 29, p. 273-290

Fedje, D.W., and Josenhans, H., 2000, Drowned forests and archaeology on the continental shelf of British Columbia, Canada: Geology, v. 28, p. 99-102

Fladmark, K., 1982, Microdebitage analysis: initial considerations: Journal of Archaeological Science, v. 9, p. 205-220

Gearey, B.R., and Caseldine, C.J., 2006, Archaeological applications of testate amoebae analyses: a case study from Derryville, Co. Tipperary, Ireland: Journal of Archaeological Science, v. 33, p. 49-55

Hunter, R.D., Panyushkina, I.P., Leavitt, S.W., Wiedenhoeft, A.C., and Zawiskie, J., 2006, A multiproxy environmental investigation of Holocene wood from a submerged conifer forest in Lake Huron, USA: Quaternary Research, v. 66, p. 67-77

Jackson, L.J., 1998, The Sandy Ridge and Halstead Paleo-Indian sites: Ann Arbor, Michigan, Museum of Anthropology, University of Michigan, 165 p.

—, 2004, Changing our view of late Palaeo-Indian in Southern Ontario, *in* Jackson, L.J., and Hinshelwood, A., eds., The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments, Volume 165: Mercury Series Archaeology Paper: Ottawa, Canadian Museum of Civilization, p. 25-56.

Jackson, L.J., Ellis, C., Morgan, A.V., and McAndrews, J.H., 2000, Glacial lake levels and eastern Great Lakes Palaeo-Indians: Geoarchaeology, v. 15, p. 415-440

Kelley, J.T., Belknap, D.F., and Claesson, S., 2010, Drowned coastal deposits with associated archaeological remains from a sea-level "slowstand": Northwestern Gulf of Maine, USA: Geology v. 38, p. 695-698

Kumar, A., and Dalby, A.P., 1998, Identification key for Holocene lacustrine arcellacean (thecamoebian) taxa: Palaeontol Electron, v. 1, p. 1-39

Lewis, C.F.M., Heil, C.W., Hubney, J.B., King, J.W., Moore Jr., T.C., and Rea, D.K., 2007, The Stanley unconformity in Lake Huron basin: evidence for a climate driven closed lowstand about 7900 ^{14}C BP, with similar implications for the Chippewa lowstand: Journal of Paleolimnology, v. 37, p. 435-452

Mahaney, W.C., 2002, Atlas of Sand Grain Surface Textures and Applications: New York, NY, Oxford University Press, 237 p.

McAndrews, J.H., 1984, Late Quaternary vegetation history of Rice Lake, Ontario, and the McIntyre archaeological site, *in* Johnston, R.B., ed., The McIntyre Site: Archaeology, Subsistence and Environment, Volume 126: National Museum of Man Mercury Series: Ottawa, National Museums of Canada, p. 161-189.

O'Shea, J.M., and Meadows, G.A., 2009, Evidence for early hunters beneath the Great Lakes: PNAS, v. 106, p. 10120-10123

Quinn, R., Dix, J., and Dean, M., 2008, Geophysical and remote sensing surveys, *in* Bowens, A., ed., Archaeology Underwater: The NAS Guide to Principles and Practice, Wiley-Blackwell, p. 103-113.

Reinhardt, E.G., Little, M., Donato, S., Findlay, D., Krueger, A., Clark, C., and Boyce, J.I., 2005, Arcellacean (thecamoebian) evidence of land-use change and eutrophication in Frenchman's Bay, Pickering, Ontario: Environ Geol, v. 47, p. 729-739

Scott, D.B., Medioli, F.S., and Schafer, C.T., 2001, Monitoring in Coastal Environments Using Foraminifera and Thecamoebian Indicators: Cambridge, United Kingdom, Cambridge University Press, 177 p.

Sonnenburg, E.P., and Boyce, J.I., 2008, Digital bathymetric model and integrated side-scan as a base for archaeological inventory of submerged landscapes in the Rideau Canal (Ontario, Canada): Geoarchaeology, v. 23, p. 654-674

Stanley, J.-D., Jorstad, T.F., Bernasconi, M.P., Stanford, D., and Jodry, M., 2008, Predynastic human presence discovered by core drilling at the northern Nile delta coast, Egypt: Geology, v. 36, p. 599-602

Swindles, G.T., Charman, D.J., Roe, H.M., and Sansum, P.A., 2009, Environmental controls on peatland testate amoebae (Protozoa: Rhizopoda) in the North of Ireland: Implications for Holocene palaeoclimate studies Journal of Paleolimnology, v. 42, p. 123-140

Westley, K., Quinn, R., Forsythe, W., Plets, R., Bell, T., Benetti, S., McGrath, F., and Robinson, R., 2010, Mapping submerged landscapes using multibeam bathymetric data: a case study from the north coast of Ireland: International Journal of Nautical Archaeology doi:10.1111/j.1095-9270.2010.00272.x.

Yu, Z., and McAndrews, J.H., 1994, Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen and plant macrofossil evidence: Holocene, v. 4, p. 141-152

Chapter 3

Multi-proxy lake sediment record of prehistoric (Paleoindian-Archaic) archaeological paleoenvironments at Rice Lake, Ontario, Canada

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Abstract

The arrival of Paleoindian peoples in the lower Great Lakes ca. 11 ka years ago coincided with a phase of lowstand lakes and rapid environmental change in southern Ontario. At Rice Lake, an archaeologically-rich area to the north of Lake Ontario, Early Holocene lake levels were up to 11 m below present, but little is known about the paleoenvironmental conditions or the extent and types of lake habitats encountered by Paleoindians. In order to better understand these archaeological paleoenvironments and the water level history at Rice Lake, a detailed multi-proxy analysis was conducted on two 4-metre vibrocores extracted from the open lake (Middle Basin) and a smaller sheltered bay (McIntyre lagoon) adjacent to an Archaic-era archaeological site (ca. 4 ka BP). The cores were analyzed for particle size, testate amoebae, magnetic susceptibility and presence of microdebitage to determine changes in water levels, habitat types and lake trophic status. Core lithostratigraphy consists of organic rich muds (gyttja) overlying carbonate rich marls, followed by layers of detritus muds and peats. The basal units represent sands and clays of Glacial Lake Iroquois. The Early (EH-1) and Mid-Holocene (EH-2) lowstand events are clearly defined by sudden shifts in grain sizes and testate amoebae (thecamoebian) assemblages. The dominant thecamoebian species in the main lake basin, *Arcella vulgaris* and *Centropyxis constricta* 'aerophila' occur throughout most

of the lake's history, indicating the trophic status of the lake has remained stable throughout the Holocene. In the McIntyre basin, the Early Holocene lowstand is associated with unique bog and wetland species (*Bullinaria* and *Phyraginella* sp.) along with the recovery of microdebitage, indicating that Paleoindian peoples were likely exploiting wetland resources. This study shows that the study of lake paleoenvironments using a multi-proxy approach provides additional information for areas of archaeological analysis including, settlement patterns and resource procurement strategies of Paleoindian and Archaic peoples in Southern Ontario.

3.1 Introduction

The arrival of the first Paleoindians (ca. 11 ka BP) and settlement of the lower Great Lakes by Archaic peoples (ca. 9-3 ka BP) coincided with a period of rapidly changing Holocene environments (Jackson et al., 2000). The Early to Mid-Holocene period was marked by several phases of drier climate and low lake levels (lowstands) including major events between ca. 11 ka (EH-1) and 6 ka (EH-2) BP. These lowstand events have been recognized by erosion surfaces ('hiatuses') in lake cores and in seismic data from lakes Ontario, Huron and Michigan (Kincare, 2007; Lewis et al., 2007; Muller and Prest, 1985; Yu et al., 1997). During the Lake Stanley phase (ca. 10 ka BP) water levels in the Lake Huron Basin were up to 70-100 m below present (Fig. 3.1A) and large areas of the lake bed were exposed terrestrial landscapes (Karrow et al., 2007). In the Lake Ontario basin, the maximum lowstand (Admiralty Phase) occurred at ca. 11.5 ka BP

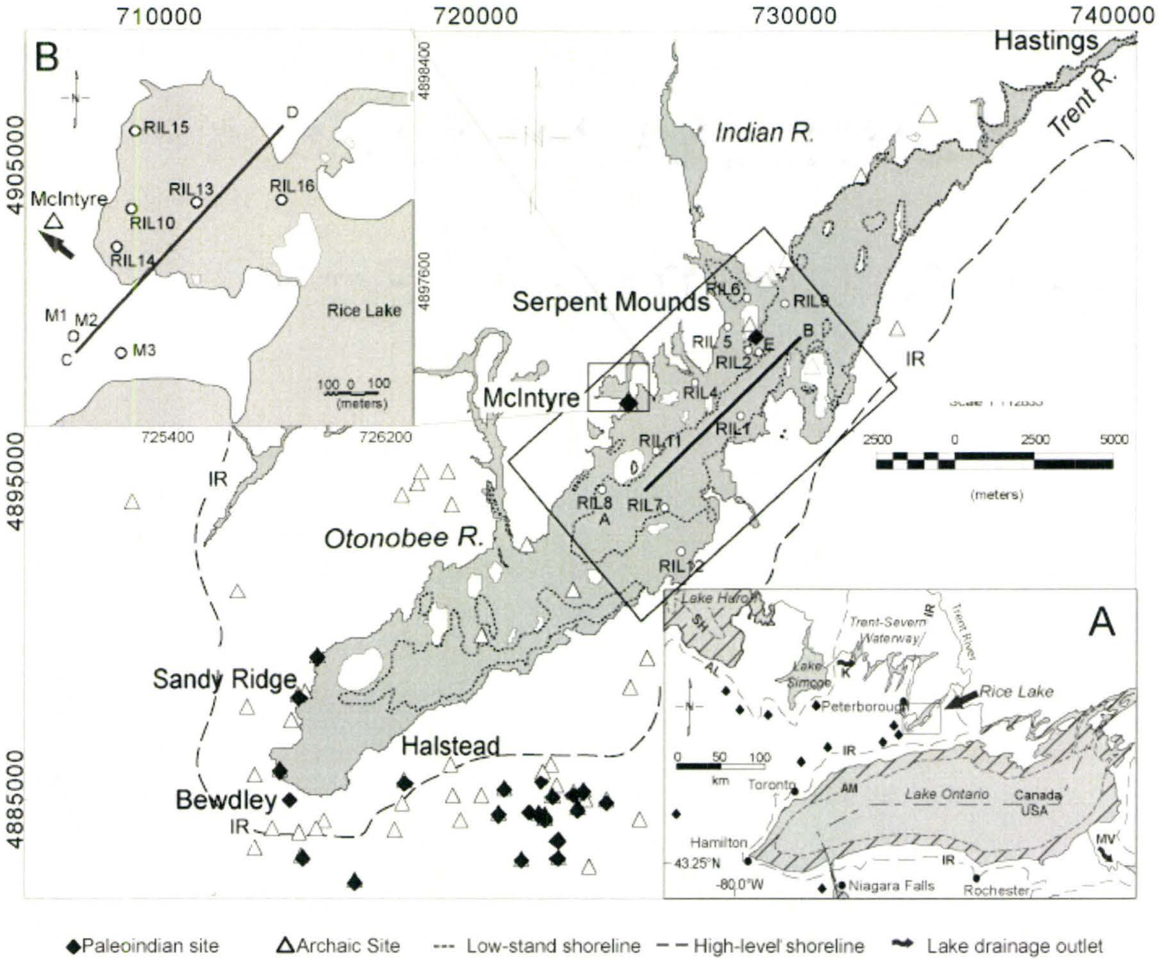

Figure 3.1: Study area map of Rice Lake including survey area, core locations, early Holocene highstand and lowstand shorelines and known terrestrial archaeological sites. Inset A shows glacial lake boundaries and drainages. Inset B shows the McIntyre basin with core locations.

with lake levels more than 100 m below present (Anderson and Lewis, 1985). It has been estimated that more than 10,000 km^2 of terrestrial and coastal habitats exposed during this phase were subsequently inundated by the rising levels in Lake Ontario (Jackson et al., 2000). Recent discoveries in Lake Huron (O'Shea and Meadows, 2009) and near Lake Ontario (Chapter 2) provide evidence that prehistoric humans were exploiting these now submerged landscapes.

While palynological and sedimentological work has greatly expanded understanding of regional changes in Holocene paleoclimate and water levels in the Great Lakes, few studies have examined the environmental constraints they placed on prehistoric settlement patterns (Jackson, 2004). It is widely recognized that prehistoric sites are closely associated with former shorelines and wetlands but detailed reconstruction of these archaeological paleoenvironments is often difficult based on only a single environmental indicator (e.g. pollen analysis). While pollen analysis has greatly expanded knowledge of terrestrial paleoenvironments of archaeological sites in Southern Ontario (McAndrews, 1984; McAndrews, 1994), pollen does not always reflect water body trophic status changes or water-level fluctuations in littoral zones. Taphonomic issues such as rate and amount of dispersion of pollen, differential preservation, recycling of spores and the available source area can lead to misinterpretations of paleoenvironments (Birks and Birks, 2000; McCarthy et al., 1995).

Testate amoebae (thecamoebians) have been used to complement pollen analysis for more robust paleoclimatic reconstructions in lake basins (e.g. (Lamentowicz and Obremska, 2010; McCarthy et al., 2007). Testate amoebae are ubiquitous and abundant in freshwater environments. Their tests are commonly preserved even in low pH environments, and can be used as indicators of lake trophic status, bottom and surface water conditions, paleohydrology and salinity changes through time (Booth, 2008; Reinhardt et al., 2005; Swindles et al., 2009; Van Hengstum et al., 2008). Testate amoebae have been shown to be very sensitive to subtle environmental changes and may react to climate shifts more quickly than pollen (McCarthy, et al., 1995).

While testate amoebae have been successfully used to reconstruct paleoenvironmental changes in lake basins in Southern Ontario, their application in archaeology is still limited and has focused primarily on peatlands in Europe (Gearey and Caseldine, 2006; Plunkett et al., 2009). Past paleoenvironmental work in the Great Lakes has also emphasized lake basins as large-scale homogenous environments, when the available terrestrial archaeological record indicates that specific areas of lakes were used to exploit a wide variety of resources in very defined locales (Ellis et al., 1998; Kuehn, 1998).

A fundamental starting point in the understanding of submerged landscapes and associated archaeological sites is to reconstruct the paleogeography, geomorphology and paleoenvironmental conditions that influence settlement patterns of ancient peoples. Rice Lake, located within the Great Lakes watershed, south of Peterborough, Ontario (Fig. 3.1) has evidence of continuous human occupation since deglaciation. Paleoindian peoples began to colonize the Rice Lake area about 11 ka BP, possibly following the migration routes of herds of caribou along the shore of glacial Lake Iroquois/early Lake Ontario (Jackson, 1998). Palynological studies indicate large stands of boreal pine forests and abundant wetlands surrounding the lake, providing suitable habitat for caribou and other large game (Yu and McAndrews, 1994).

Previous coring and palynological investigations at Rice Lake have identified the existence of a low water level phase before 10 ka BP and the presence of submerged marsh/wetland deposits on the lake bed (Yu and McAndrews, 1994). The timing of the lowstand and its cause are not well understood, but it was likely synchronous with the Admiralty lowstand in Early Lake Ontario (Fig. 3.1A) (Muller and Prest, 1985). The lowstand shorelines in Rice Lake have been estimated from available low-resolution bathymetric charts (Jackson, et al., 2000) and limited sonar data collected in the early 1990's (Jackson, 1998). Detailed geophysical survey, including high-resolution bathymetry and side-scan surveys (see Chapter 4) and more in-depth paleoenvironmental analysis needs to be conducted prior to archaeological survey in order to establish the paleogeography of the drowned landscape.

Rice Lake is an ideal locale to investigate submerged prehistoric sites, as there is an abundance of terrestrial sites; the lake water depth (< 10 m) and bottom sediment conditions are conducive to coring and preservation of sediments. The pollen data and radiocarbon dates available from a single previous study (Yu and McAndrews, 1994) also provide an important basis for comparison with new environmental indicators employed in this study (e.g. thecamoebian diversity, grain size).

A number of partially submerged drumlin islands are present within Rice Lake and are associated with Archaic and Woodland-age occupation sites and burial complexes (Johnston, 1968; Johnston, 1984) (Fig. 3.1). The McIntyre site is a well-documented Archaic terrestrial site located on the northwest shore of the lake. The site was extensively excavated in the 1970's and yielded large numbers of stone tools, faunal remains, hearths and radiocarbon dates (ca. 4000 BP) (Johnston, 1984). The decision to focus on the McIntyre basin for detailed coring was based on a number of factors. Initial bathymetry (Chapter 4) indicates the area was a possible kettle lake, which offers potentially better preservation and a more complete sediment record, as the hydrologically-closed area is more conducive to accumulation of a continuous sediment record. An investigation of the water-level changes and associated environmental changes over the time-period of the McIntyre occupation (and earlier) may offer additional insights in regards to landscape interactions and resource procurement compared to the larger main lake basin.

3.2 Regional Setting

Rice Lake is located 50 km south of Peterborough, Ontario, on the Trent-Severn Waterway. The lake is about 26 km in length, and 3-4 km in width (Fig. 3.1) with a maximum water depth of about 10 m. The topography around the lake is defined by south-east trending drumlins up to 50 m in relief that define the southern extent of the Peterborough drumlin field (Barnett, 1992). The southern shore of the lake borders the west-east trending Oak Ridges interlobate moraine.

After deglaciation, Rice Lake was part of the Fenelon Falls (Kirkfield) outlet which drained Lake Algonquin into Lake Iroquois (Fig. 3.1) (Jackson, et al., 2000). During the Holocene water levels in Rice Lake fluctuated under the influence of isostatic rebound and regional climatic changes (Yu and McAndrews, 1994; Yu, et al., 1997). The current lake levels were established in the 1830's by construction of the Trent-Severn canal system and the Hastings Dam (Fig. 3.1). The historic flooding raised water levels by about 1.8 metres, greatly increasing the lake surface area and destroying stands of wild rice which are considered culturally important to the local aboriginal population (Yu and McAndrews, 1994). Currently, Rice Lake is known as a recreation destination, and is increasingly under pressure from recreational and residential development. These developments have resulted in a reduction in water quality and decline in game fish and other native species (Ferguson and Metcalfe, 1989). Surveys completed during 2007 and

2008 observed heavy weed growth in the lake, likely due to nutrient input from agricultural runoff (Smol, 1992).

3.2.2 Geological Setting

The surficial geology of the Rice Lake area (Chapter 1, Fig. 1.3) reflects the repeated advances and retreats of Late Wisconsin ice sheets and the development of post-glacial lakes during the past 30,000 years (Barnett, 1992). The narrow lake basin was formed by glacial erosion and widening of a pre-glacial river valley, which was subsequently infilled by sediment and flooded by isostatic uplift of the eastern drainage outlet. The surficial sediment cover consists mainly of sandy till, coarse-grained kame moraine and outwash deposits and thin postglacial river and lacustrine sediments (Barnett, 1992). The sediments reach a maximum thickness of over 150 m within the Oak Ridges Moraine and rest on Ordovician limestone bedrock (Gorrell and Brennand, 1997; Gravenor, 1957).

3.2.3 Water Level History

Rice Lake was formed during deglaciation (ca. 12.5 ka BP) as rising water levels in glacial Lake Iroquois inundated low lying glacial valleys to the south of Peterborough (Muller and Prest, 1985). As water levels dropped in the Ontario basin glacial Lake Algonquin drained into the Ontario basin via the Fenelon Falls outlet and through Rice Lake (Karrow, 2004), releasing large volumes of meltwater and sediment. As both glacial Lake Algonquin and Iroquois receded, the southwestern end of Rice Lake was gradually flooded by isostatic uplift of the eastern outlet at the mouth of the Trent River. The Otonobee and Indian Rivers (Fig. 3.1) are the remnants of glacial flood water channels formed as part of the Kirkfield outlet during the Algonquin flood phase (Gravenor, 1957; Jackson, et al., 2000; Yu and McAndrews, 1994).

During the Holocene water levels in Rice Lake fluctuated under the influence of regional climatic changes that have been documented by McAndrews (1984) and Yu and McAndrews (1994) in sediment and pollen records. These studies analyzed pollen zones and radiocarbon dated sediment cores from the southwestern and central basins (McIntyre site) in Rice Lake (Fig. 3.1). They identified a generalized stratigraphy consisting of an uppermost gyttja unit (4 ka BP to present) overlying marl (6-8 ka BP) and detrital muds and peats (>8 ka YBP) with a distinctive pollen hiatus between 6 and 4 ka BP (Fig. 3.2). The pollen hiatus was interpreted as evidence for a mid-Holocene lowstand phase with water levels as much as 4 m below current lake level (Chapter 4). The timing and cause of the lowstand is not clearly understood, but is likely linked to a mid-Holocene phase of drier climate that affected most of central and eastern parts of North America (Yu, et al., 1997). It is unclear whether this Holocene dry period was one long climatic event, or a series of climatic oscillations (Dean et al., 1996).

The construction of the Hastings Dam in the 1830s raised water levels an additional 2 m. There have been some recoveries made from this post-1830 flooding depth, including Holocene caribou bones from near shore dredging (Jackson and McKillop, 1988), and potential partially submerged Paleoindian sites that extend into the water (Jackson, pers. comm.). Sedimentation rates remained relatively stable (except during the hiatus) until about 1850 when European settlement, deforestation and flooding of the lake from the Hastings Dam increased the sedimentation rate dramatically according to estimates

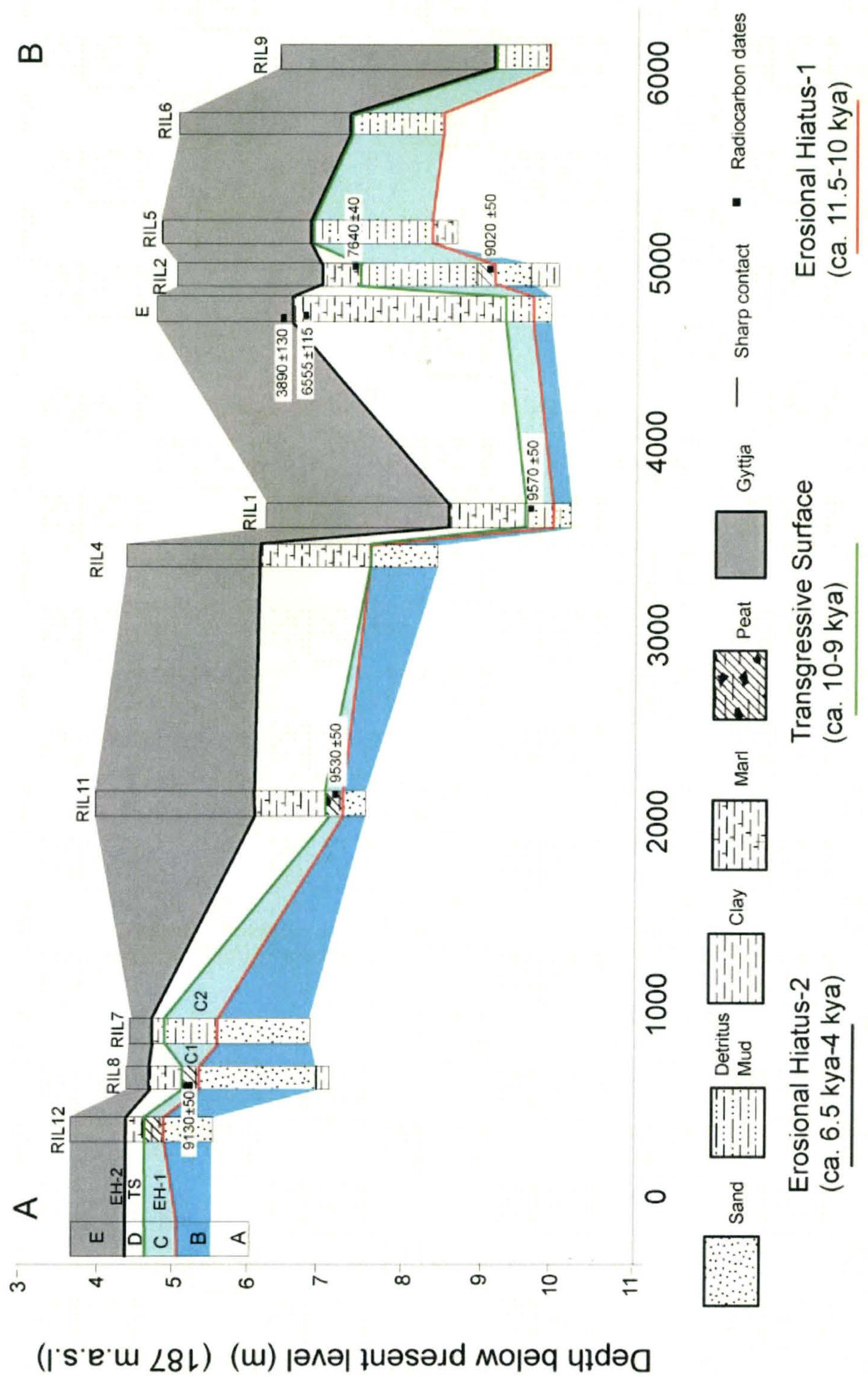

Figure 3.2: Tilt-corrected sediment stratigraphy (10 ka BP) of main Rice Lake basin

from Yu and McAndrews (1994). According to elders from the Hiawatha Reserve (near Serpent Mounds), prior to dam construction, the lake was almost entirely surrounded by wild rice plants, which is also supported by palynology (McAndrews, 1984). Now, very few patches of the rice remain, and are cultivated for mostly commercial purposes (Stonechild, pers. comm.).

3.3 Materials and Methods

Multi-proxy paleolimnological methods have been used successfully to determine trophic and environmental changes in lake sediments due to natural and anthropogenic influences (Last, 2001; Reinhardt, et al., 2005). In this study, particle size, magnetic susceptibility, loss on ignition (organic, carbonate and silicate content), microfossil (testate amoebae) and microdebitage analysis in conjunction with previously published pollen data will be used to delineate water level and trophic changes, local ecology, anthropogenic influences, and sedimentation rates.

3.3.1 Sediment Coring

A total of 16 cores were extracted using a vibrocoring system with 3" aluminum core tubes (Fig. 3.2). 11 cores were extracted from the middle basin (open lake) and 5 of these cores were extracted in the McIntyre basin (Fig. 3.3). The cores were cut into 1-metre lengths for transportation and then split, logged and stored in a refrigerator to reduce microbial growth.

3.3.2 Particle Size Analysis

High-resolution particle size analysis was performed on cores RIL 10 and RIL 2 at 1 cm intervals on a LS230 Coulter Counter particle size analyzer (Figs. 3.4 and 3.5).

These cores were chosen as representative of the open lake environment (RIL 2) and more restricted lagoonal microenvironment.(RIL 10). Core RIL 2 was extracted close to the location of Core E from Yu and McAndrews (1994) allowing comparison with their pollen data and radiocarbon dates. Two sets of samples from each core were analysed;

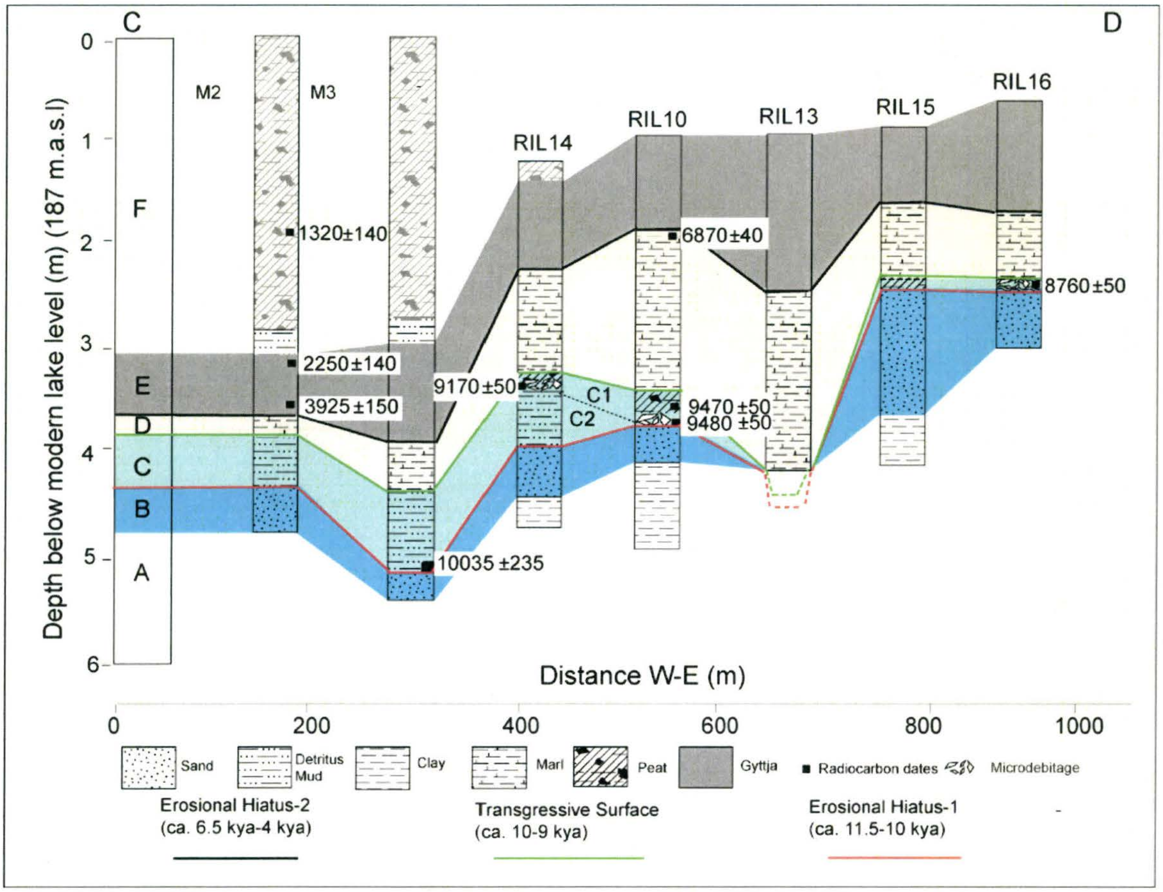

Figure 3.3: Sediment stratigraphy of McIntyre Basin

one was treated with 10% dilute HCl to remove carbonates (Murray, 2002), 40% peroxide to remove organic materials, and finally 1% sodium hydroxide to remove diatoms (processed) (Conley and Schelske, 2001), the other was not (bulk). The use of both processed and bulk methods has the advantage of determining the influence of organic matter and diatoms on particle size. The average particle sizes (µm) were plotted versus core depth (Blott and Pye, 2006) to determine downcore changes in sediment texture (van Hengstum et al., 2007) (Figs. 3.4 and 3.5). Moisture, organic, carbonate and silicate content were determined using the loss on ignition (LOI) method described by Heiri et al., (2001). Volume magnetic susceptibility was measured on core RIL10 using the Bartington MS2E probe, with a sensitivity of 2.0 x 10^{-6} SI (Fallon, 2009). Sedimentation rates were determined using interpolated values based on sediment thickness for interval rates, while cumulative rates were determined using available radiocarbon dates (Table 3.1).

3.3.3 Microdebitage Analysis

Microdebitage, or lithic flakes smaller than 1.0 mm, were first defined by Fladmark (1982) as having use in archaeological settings. These small stone fragments can be produced in large quantities at lithic knapping sites (Fladmark, 1982) and can provide a useful indicator of tool-making sites in lake sediments (Chapter 2) to identify submerged sites. Samples extracted from cores RIL 2, 4, 8, 11, 10, 14 and 16 were dried and split into 1/8 samples for analysis. Lithic identification was assisted by microdebitage sampled from the Archaic McIntyre site by the author and from experimental obsidian microdebitage from Mt. Garibaldi in British Columbia courtesy of Rudy Reimer. Scanning Electron Microscopy (SEM) was utilized to determine microdebitage from the glacially-derived surrounding matrix (Chapter 2).

3.3.4 Microfossils

Testate amoebae are not often used in archaeological site investigation but have great potential for reconstruction of archaeological paleoenvironments (Gearey and Caseldine, 2006; Plunkett, et al., 2009). Thecamoebians were used to identify water-level and trophic changes within Rice Lake (Figs. 3.6, 3.7 and 3.8). Samples were taken from cores RIL 2 and RIL 10 at 25 cm intervals in the uppermost gyttja and lower glacial sediments, and every 5 cm mid-core (1-4 meters). Samples were split and counted until 200-300 specimens were reached (Patterson and Fishbein, 1989; Scott and Hermelin, 1993). Identification of species was based on Kumar and Dalby (1998) and Scott et. al (2001). Standard error was calculated to determine which species were statistically significant, and subsequent cluster analysis used Ward's method in both Q and R-mode analyses in the PAST program (Davis, 2002; Hammer et al., 2001). Q-mode analysis determined similarities between samples, and R-mode analysis determined the similarities in species (Fig. 3.6). Diversity was calculated using the Shannon-Weaver Diversity Index in the PAST program (Hammer, et al., 2001). Pollen data analyzed by McAndrews (1984) and Yu and McAndrews (1994) will be utilized for comparison with

Unit	Interval Sedimentation Rates		Unit	Cumulative Sedimentation Rates		
	Main Basin	McIntrye Basin		Main Basin	McIntyre	
B	0.098	0.112	C	0.030	0.025	
C	0.028	0.013	D	0.028	0.015	
D	0.030	0.033	E	0.037	0.088	
E	0.038	0.087				

Table 3.1: Interval and cumulative sediment rates ($cmyr^{-1}$) for the main basin and McIntyre basin of Rice Lake

the thecamoebian data. Cores from the McIntyre marsh M2 and M3 are compared with RIL 10 (Fig. 3.4), and Core E is compared with RIL 2 (Fig. 3.3).

3.3.5 Geochronology

A total of 10 radiocarbon dates were determined on core organics (seeds, woody fragments)(Table 3.2). ^{14}C dating was performed using accelerated mass spectroscopy (AMS) at Beta Analytic, Inc. In prior studies of Rice Lake, Yu and McAndrews (1994) and McAndrews (1984) acquired 9 radiocarbon dates from 3 different cores (one located in the southeastern basin, two in the marsh adjacent to the McIntyre site, and one at Sugar Island) (Figs. 3. 2 and 3.3) to determine the chronology of water level fluctuations.

3.4. Results

3.4.1 Core Stratigraphy

Main Basin

The stratigraphy of the main Rice Lake basin is divided into 6 distinctive sedimentary facies based on lithology, chronology (all dates in ^{14}C yrs) and textural analysis (particle size, organic content, magnetic susceptibility) including thecamoebian abundances (Figs. 3.2 and 3.4). One core (E) extracted near Sugar Island and RIL 2 (McAndrews, 1984) is included for comparison. Average sedimentation rates were calculated for individual units and the entire core (cumulative) by age (Table 3.1). Cumulative sedimentation rates were reasonably consistent throughout the basin (~0.3 cm/yr).

Lab #	Sample Core/Depth (cm)	Type	Material	Conventional Age (BP)	1δ calibration (Cal BP)	2 δ calibration (Cal BP)	Median Age (Cal BP)
Beta256580	RIL10 259-260	AMS	Wood	9480±50	10604-11060	10582-11070	10826±244
Beta256579	RIL 10 254-255	AMS	Wood	9470±50	10589-11050	10574-11069	10821±248
Beta256578	RIL 10 101-103	AMS	Seed	6870±40	7663-7746	7619-7790	7704±86
Beta274139	RIL1D-323-324	AMS	Wood	9570±50	10767-11077	10722-11125	10923±202
Beta274140	RIL2C-213.5-215.5	AMS	Peat	7640±50	8367-8509	8376-8542	8459±83
Beta274141	RIL2D-381.5-383.5	AMS	Plant	9020±50	10178-10235	9933-10254	10363±161
Beta274142	RIL8B-95.5-96.5	AMS	Peat	9130±50	10228-10374	10204-10478	10341±137
Beta274143	RIL 11D-325.5-326.5	AMS	Peat	9530±50	10716-11069	10682-11091	10886±205
Beta274144	RIL14C-222.5-225.5	AMS	Wood	9170±50	10247-10391	10234-10490	10362±128
Beta274145	RIL16B-168.5-169.5	AMS	Wood	8760±50	9677-9888	9555-10114	9834±280
BGS1531	*B295-302*	*Bulk*	*Gyttja (Organic)*	*3070±120*	*3079-3436*	*3558-2949*	*3253±304*
BGS1533	*B306-321*	*Bulk*	*Marl (Organic)*	*5900±360*	*6324-7163*	*5943-7472*	*6707±765*
BGS1534	*B565-570*	*Bulk*	*Sandy detritus (Organic)*	*8610±240*	*9328-10125*	*9032-10231*	*9631±600*
I-7222	*E140-150*	*Bulk*	*Gyttja*	*3890±130*	*4097-4516*	*3928-4806*	*4367±439*
I-7223	*E183-200*	*Bulk*	*Marl*	*6555±115*	*7331-7570*	*7257-7653*	*7455±198*
GX-5290	*M2190-200*	*Bulk*	*Peat*	*1320±140*	*1071-1345*	*958-1517*	*1237±280*
GX-5291	*M2295-305*	*Bulk*	*Detritus mud*	*2250±140*	*2008-2450*	*1934-2706*	*2320±386*
GX-5292	*M2340-350*	*Bulk*	*Gyttja*	*3925±150*	*4099-4569*	*3981-4821*	*4401±420*
GX-5293	*M3495-505*	*Bulk*	*Detritus mud*	*100035±235*	*11241-11982*	*10800-12519*	*11659±860*

Table 3.2: Radiocarbon dates for Rice Lake. Italicized dates are from Yu and McAndrews (1994). Calibrations were calculated using Calib 6.0.1 (Stuiver and Reimer, 2010).

Unit A consists of laminated and massive silty clay with high silicate (>85%) and low organic (<10%) content; the samples in this unit contained no thecamoebians. Unit B is a fine to medium sand (100-600 μm) with low thecamoebian abundances (<200 per cc). There is a sharp transition to Unit C (EH-1) as indicated by the sudden shift to higher organic (~50%) and lower silicate content (~50%)(Fig. 3.4). Unit C is a layer of organic rich silty mud (~25-200 μm) and is dated to between 9570±50 and 9020±50 (Fig. 3.2). There are differences in thecamoebian abundances throughout Unit C; with fluctuations ranging from 50-1000 specimens per cc. There is a gradual transition (TS) to Unit D consisting of well-laminated, higher-carbonate marl (~25%). The oscillating particle size and thecamoebian values (Fig. 3.4) indicate seasonal 'varves' or rhythmites. There is a sharp transition from Unit D to the overlying Unit E (EH-2), a gyttja layer, consisting of organic-rich silty mud (<100 μm) There is a sharp increase in coarser particles (seen in the bulk sample) and decrease in thecamoebian abundances from over 1200 to less than 400 specimens per cc in the uppermost 50 cm of the unit (Fig. 3.4).

McIntyre Basin

While the lithology of the McIntyre Basin (Fig. 3.3) is similar to the main Rice Lake basin (Fig. 3.2), there are some minor differences which impact the potential for locating areas of archaeological interest. Textural analysis for RIL 10 includes magnetic susceptibility (Fig. 3.5), which was not completed on RIL 2; bulk magnetic properties were measured and results are discussed in Fallon (2009) Sedimentation rates also differ

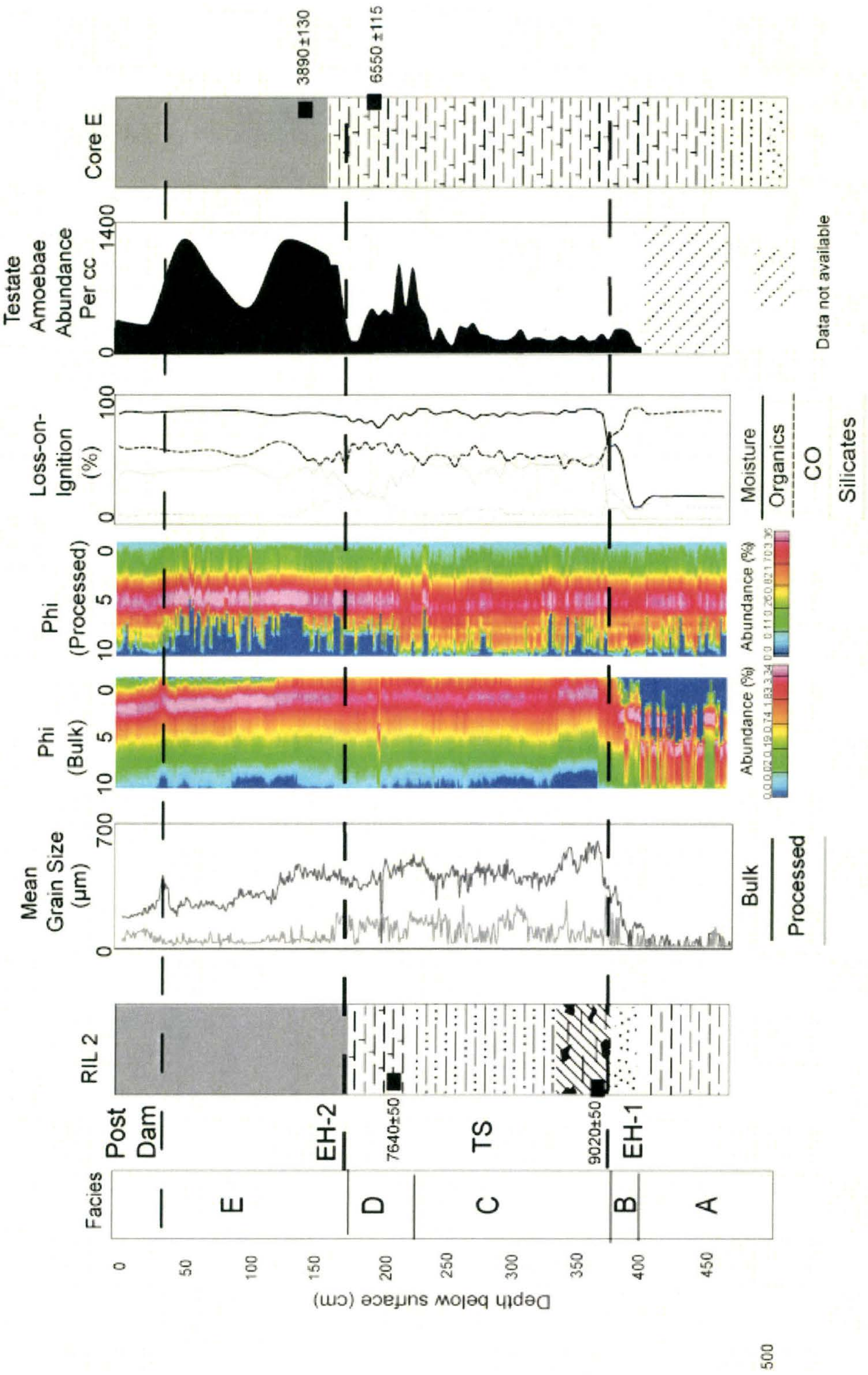

Figure 3.4: RIL 2 core log (main basin) showing lithofacies, mean grain size, particle size plots (Phi units), organic content, and testate amoebae abundances. Core E from Yu and McAndrews (1994)

from the main basin, as cumulative rates are much lower for Units C, D and E and increase rapidly for Unit F (Table 3.1). Units A and B are similar sedimentologically to the main basin; however no testate amoebae were recovered in these units. Magnetic susceptibility is high in both these units (~500 x 10^{-6}) (Fig. 3.5). Unit C is also a fine-grained silty mud (> 250µm) organic-rich (>50%) layer and surrounds the basin, and is the unit where microdebitage was recovered in RIL 10, 14 and 16. Unit C may have been deposited earlier in the McIntyre basin (10035±235) than in the main basin (9570±50) (Figs. 3.2, 3.3). This unit shows small oscillations in the magnetic susceptibility values, likely related to the oscillations in particle size that occur in this unit due to the presence of microdebitage (Fig. 3.5). The marl (Unit D) and gyttja (Unit E) seem consistent sedimentologically and chronologically with the main basin (ca. 8-4 ka BP). Marl deposition is much thicker in the McIntyre basin and the thecamoebian abundances are much higher in the marl (400- 1000 per cc) and decrease in the gyttja unit (<300 per cc). Magnetic susceptibility remains constant to the most recent sediments (~50 x 10^{-6} SI); Unit F is a marsh facies, and is only evident in RIL 14, as it is the nearest core to the present-day marsh. This facies represents the majority of sedimentation in M2 and M3 (Fig. 3.3).

3.*4.2 Microdebitage*

155 pieces of microdebitage from 3 cores (RIL 10, 14, 16) were identified under light microscope and SEM (Chapter 2). No microdebitage was recovered from the main basin cores (RIL 2, 4, 8 and 11). Based on previous studies comparing experimental, archaeologically derived and natural quartz samples, the following criteria were used to positively identify anthropogenically modified microdebitage; high angularity, irregular

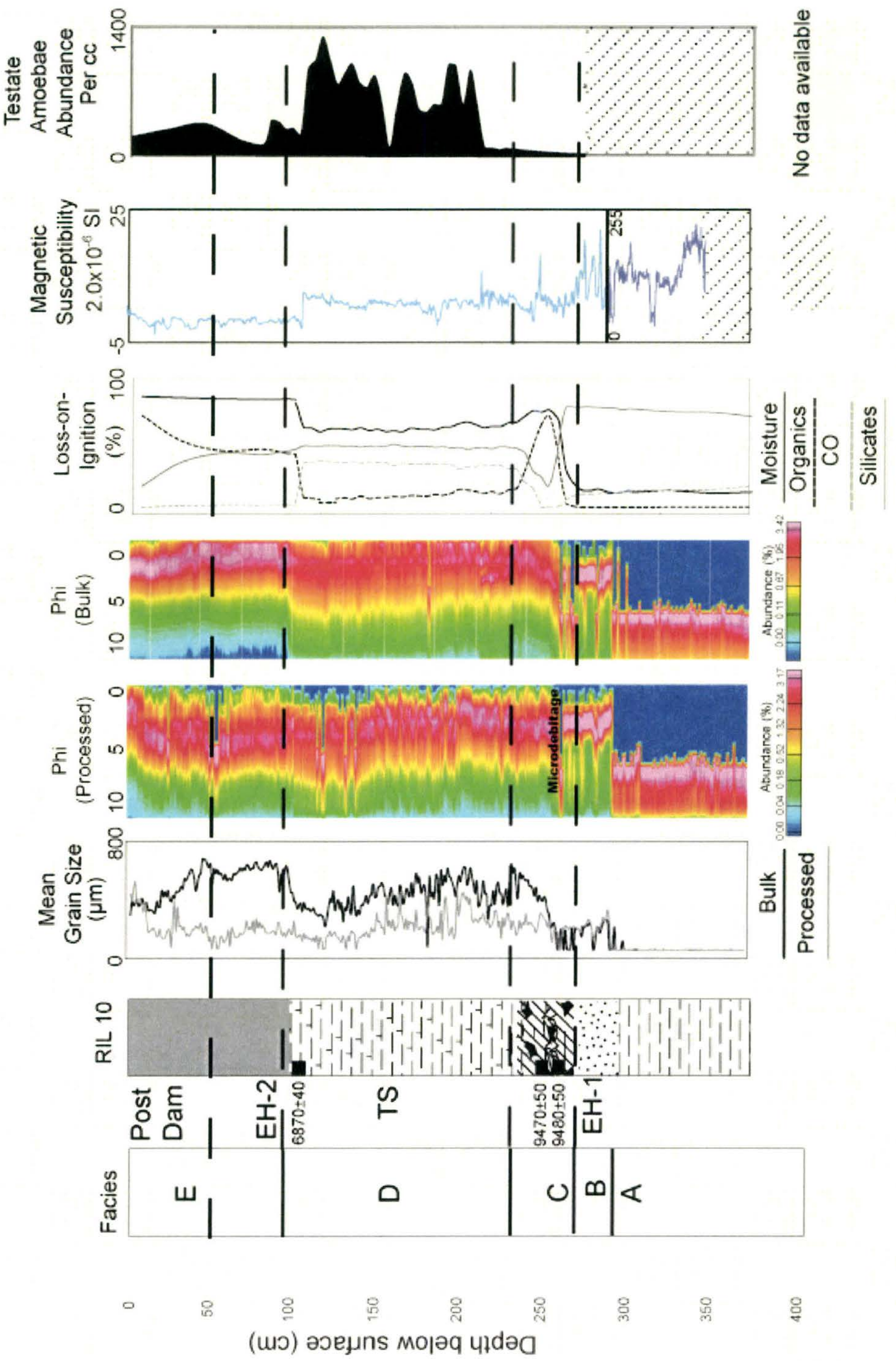

Figure 3.5: Lithofacies, mean grain size, particle size plots (Phi units) organic content, magnetic susceptibility and testate amoebae abundances for core RIL 10 from the McIntyre Basin. Note distinct changes in all parameters in Unit C where microdebitage was recovered.

surfaces, conchoidal fractures and breakage blocks (Dragovich and Susino, 2001). The microdebitage identified was composed of quartz and ranged in size from 1000 to 400 µm. All microdebitage came from the same sedimentary unit (C), which is identified as a wetland facies. In RIL10, the microdebitage was found between 257 and 259 cm, and in RIL 16, between 171 and 173 cm below surface. Additional samples were taken from RIL 10 to determine if the microdebitage was spread throughout the unit or isolated to a small section. Samples examined at 5 cm increments downcore and at 260-262 cm and 253-254 cm depth did not yield any microdebitage. Further examination of the particle size data indicates a small five centimeter sub-unit within the wetland facies of finer-grained sediment, which is concurrent with the location of the microdebitage (Fig. 3.5)(Chapter 2). Three samples for radiocarbon dating were taken from RIL10, below the gyttja-marl transition (Units D-E, 101-103 cm) and bracketing the microdebitage layer in Unit C (254-255 cm, and 259-260 cm) (Figs. 3.3 and 3.4). The dates (^{14}C years) taken from the microdebitage layer were 9470 and 9480 ± 50 respectively (Fig. 3.4), and are consistent with the hypothesis of lower water levels during the early Paleoindian period in Southern Ontario (Jackson, et al., 2000)

3.4.3 Microfossils

Testate Amoebae Biofacies

Several distinct biofacies were determined based on textural characteristics, Q-mode cluster analysis (Figs. 3.6, 3.7) and pollen zones (Fig. 3.8). These biofacies are: Main Basin Shallow Water (MBS), Main Basin Deep Water (MBD), McIntyre Basin Shallow Water (MIS) and McIntyre Basin Deep Water (MID) and Bog/Wetland (BW). Samples from the two cores clustered separately except for sediments from Unit E and samples from zones of water-level fluctuations (eg. EH-1) (Fig. 3.6). The R-mode cluster analysis (Fig. 3. 6) identifies *Arcella vulgaris* and *Centropyxis constricta* 'aerophila' as the dominant species. These species are associated with eutrophic and highly stressed environments and are often the dominant species in boggy arctic ponds (Dallimore et al., 2000). *A. vulgaris* are also found in low pH lakes, due to the erosion of heavy minerals from the surrounding glacial till (Kumar and Patterson, 2000), contaminated and polluted waters (Reinhardt et al., 1998), and also those with strong water bottom currents (Medioli and Brooks, 2003) or acidic soils from nearby wetlands being washed into the lake (Asada and Warner, 2009). *Curcurbitella tricuspis*, *Difflugia oblonga* (strains combined), *Difflugia globulus* and *Difflugia proteiformis* 'amphorialis' are all closely related. These species are generally indicative of nutrient and organic-rich, eutrophic environments (Reinhardt, et al., 2005). *Centropyxis aculeata* strains ('aculeata' and 'discoides'), along with wetland-associated species of *Heliopera sphagni*, *Nebela colaris* and *Euglypha* also cluster closely together, along with *Bullinaria indicta*, *Phyringenella* sp., *Difflugia urens*, *D. fragosa* and *D. proteiformis* strains ('claviformis' and 'proteiformis') to these wetland species. The bottom of both cores (Unit A) was barren.

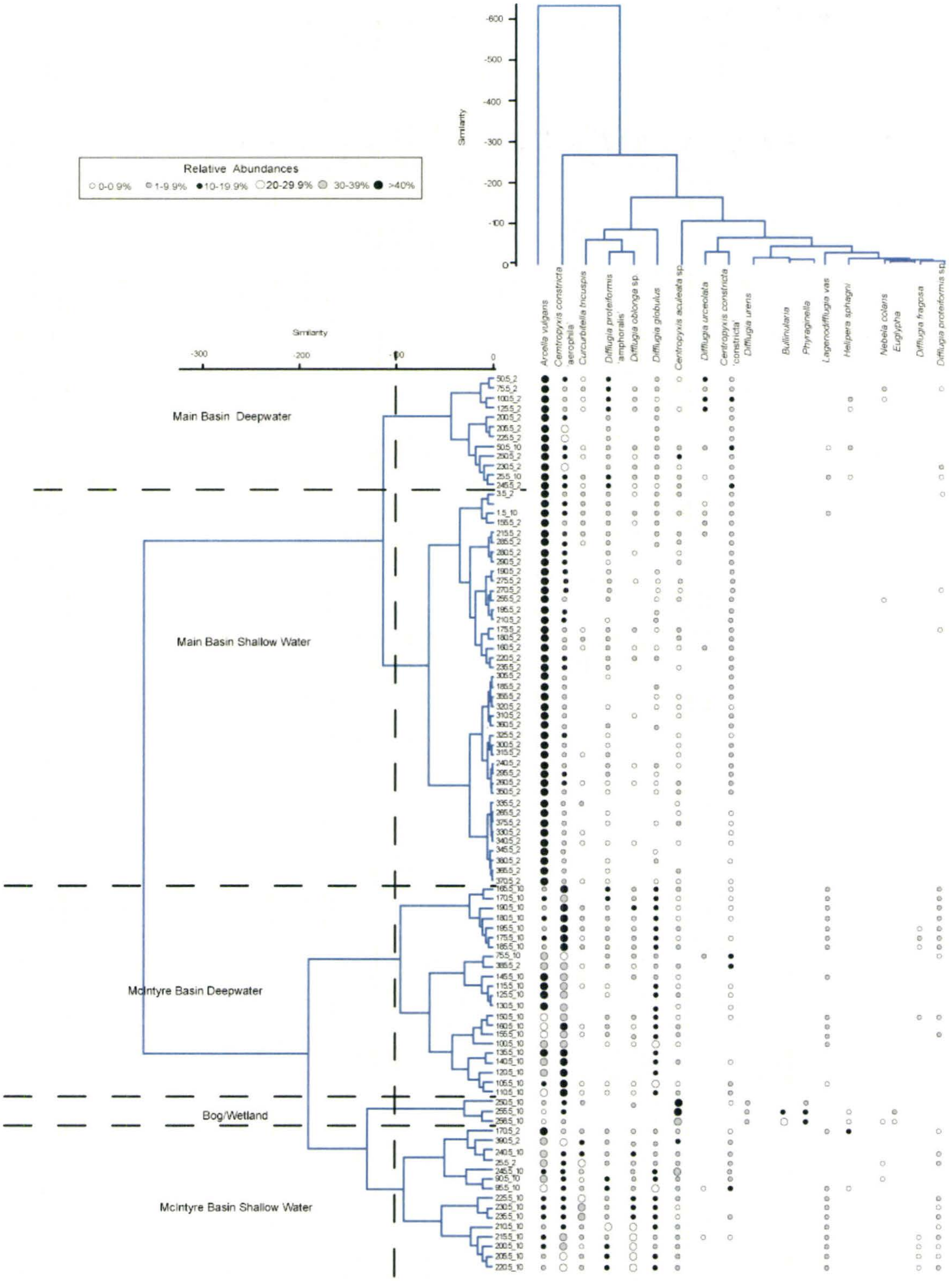

Figure 3.6: Q and R-mode Cluster analysis and species abundances of RIL 2 and 10. Similarity (Euclidean Distance) was measured using Ward's method.

Main Basin Shallow Water (MBS)

This biofacies consists of the top 25 cm of RIL 2 and 10 and Unit C of RIL 2 (Fig. 3.6). The dominant species are *Arcella vulgaris* which comprises an average of 78% of the assemblage (Table 3.3), and in some samples reach as high as 95% (Fig. 3.7). The rest of the assemblage is dominated by *Centropyxis constricta* 'constricta' (~10%), *Difflugia globulus* and *Difflugia proteiformis* 'amphoralis'(<3%). The lack of *Curcurbitella tricuspis*, *Difflugia oblonga* sp. and low diversities (average <1) indicate a shallow water, low nutrient, stressed environment. The assemblage is similar to thecamoebians recovered from low-nutrient arctic lakes (Dallimore, et al., 2000; McCarthy, et al., 1995), and high acidic, low pH polluted lakes (Kumar and Patterson, 2000; Reinhardt, et al., 1998). The waters may have a lower pH at this time due to lowered water-levels following the drainage of Lake Iroquois (Yu and McAndrews, 1994; Chapter 4) and the establishment of acidic peat bogs (Asada and Warner, 2009); plant macrofossils recovered from similar lithologic units are of shallow water and marginal marsh taxa (McAndrews, 1984). Run-off from acidic forest litter would also increase acidity, as the dominant tree species during this time was pine (McAndrews, 1984) (Fig. 3.8) which promotes soil acidity (Jeffries et al., 2010). The presence of the Indian River adjacent to RIL 2 (Fig. 3.1) would also contribute acids from high-silicate glacial sediment run-off (Jeffries et al., 2010). The modern samples, while having higher numbers of specimens, are subject to strong currents in the lake which contribute to a lack of diverse assemblages; other studies have shown that high-energy environments also have low testate amoebae diversities (Holcovà, 2007; Medioli and Brooks, 2003).

Biofacies	**Main Basin Shallow**		**Main Basin Deep**		**McIntyre Basin Shallow**		**Bog/Wetland**		**McIntyre Deep**	
Sample	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Specimens per cc	298.08	285.76	515.83	378.11	189.86	319.16	51.42	9.28	624.95	353.40
Diversity	0.62	0.29	1.28	0.20	1.84	0.13	1.48	0.18	1.39	0.28
A. vulgaris	83.57	8.66	59.24	5.62	21.86	13.12	3.39	4.32	28.72	15.89
C. constricta 'aerophila'	8.67	4.19	14.95	7.15	17.97	7.65	12.76	3.67	42.06	9.04
C. tricuspis	0.77	2.20	0.56	0.57	12.49	11.69	0.40	0.69	0.42	0.67
D. prot. 'amphoralis'	1.59	2.03	7.54	4.53	9.22	6.35	0.00	0.00	3.49	4.06
D. globulus	1.04	1.47	2.18	1.59	11.77	5.29	0.00	0.00	14.30	5.68
D. oblonga	0.23	0.55	1.37	1.65	13.78	8.16	0.40	0.69	3.34	4.06
Bullinaria sp.	0.00	0.00	0.00	0.00	0	0.00	13.69	12.63	0	0.00

Table 3.3: Summary statistics for testate amoeba biofacies including fractional abundance (relative to total abundance of all species) and standard deviations.

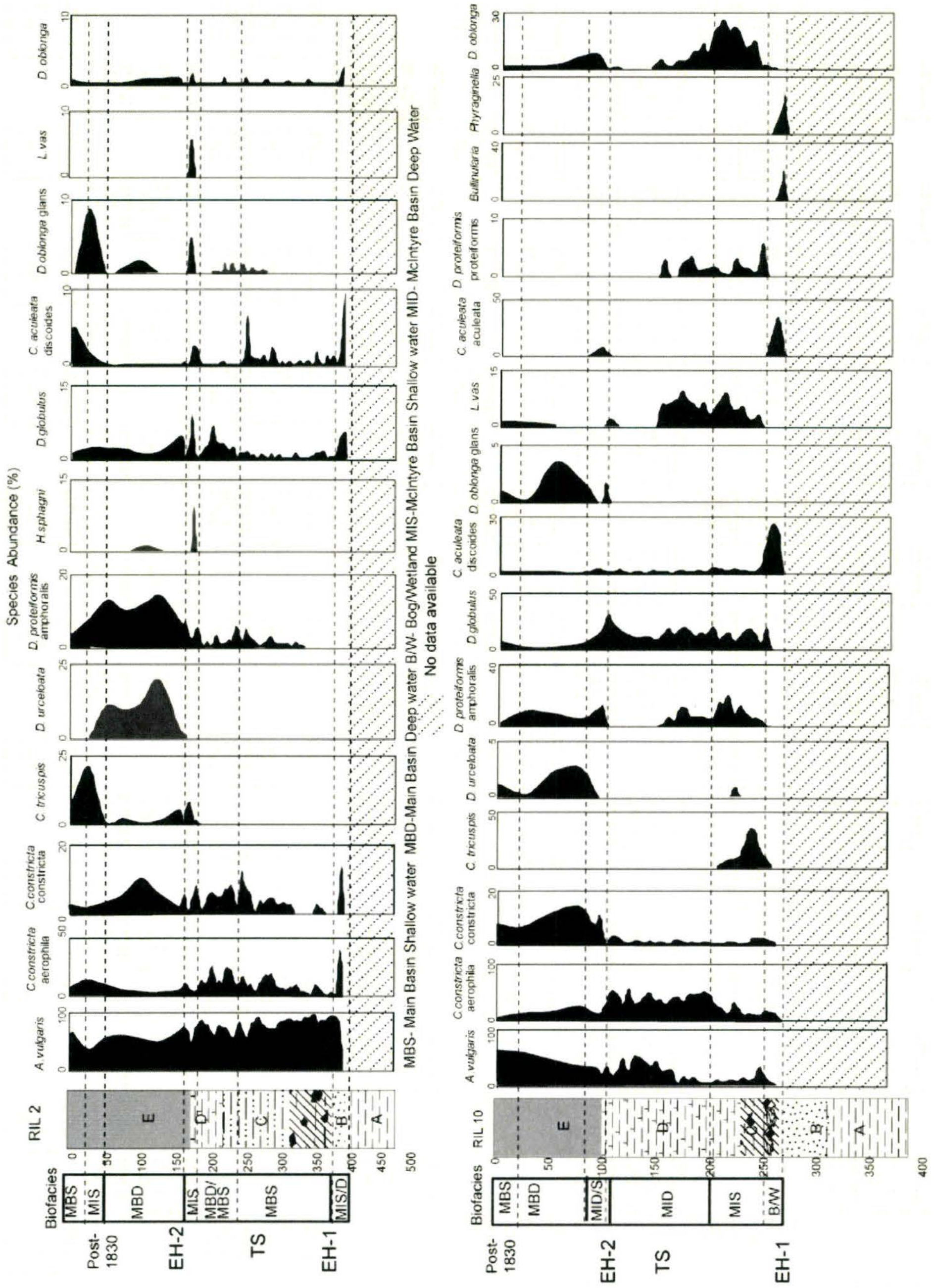

Figure 3.7: Testate amoebae species abundances and associated biofacies based on cluster analysis and sedimentary facies. Note unique species (Bog/Wetland Assemblage) occurring at microdebitage layer in RIL 10.

Main Basin Deepwater (MBD)

This assemblage occurs primarily in the post-hiatus (EH-2) Unit E of both the Main and McIntyre basins, and in the marl deposition of the main basin (Figs. 3.6, 3.7) reflecting higher water-levels. Plant macrofossil and pollen show submerged aquatic weeds in the marls of Unit D, transitioning to aquatic grasses such as wild rice in Unit E (McAndrews, 1984). This assemblage is characterized by higher average abundances (~515 per cc), and less dominance by *Arcella vulgaris*, although it is still almost 60% of the assemblage (Table 3.3). Other species are *C. constricta* aerophila (~15%), *Difflugia proteiformis* 'amphoralis' and *Difflugia globulus* (~15%) (Table 3.3). In RIL 2 Unit C, the assemblage is interspersed with shallow-water assemblages, reflecting decadal or even seasonal water-level fluctuations in the basin that are synchronous with fluctuations pollen abundances and particle sizes (Fig 3.8).

Bog/Wetland (BW)

The taxa in this assemblage are completely different from species found in other units. The addition of *Bullinaria indica* and *Phyraginella* sp. as dominant species (Figs. 3.6 and 3.7), low abundances (50 per cc) (Table 3.3) and very few *A. vulgaris* and other lake-based species indicate a wetland/bog environment. Shallow-water plant and marsh taxa also appear in the adjacent marsh cores (McAndrews, 1984) and this assemblage occurs at the Spruce/Pine pollen transition (Zone 1/2), where emergent marshes appeared after the drainage of Lake Iroquois (Yu and McAndrews, 1994; Chapter 4). *B. indica* has been identified as belonging to drier areas of modern peatlands, whereas *Phyraginella* sp. is associated with wetter areas (Booth, 2008). It is possible that these species represent seasonal fluctuations in the water-table, or simply wetter and drier areas of the same bog (Booth, 2008).

This assemblage only occurs in three samples from the McIntyre basin, which correlates to Unit C and dates to 9570-80 ± 50 BP (Fig. 3.3). This is also the unit where microdebitage was recovered, indicating that this wetland environment may have been exploited by Paleoindian peoples. Wetland and bog environments have been extensively exploited by Paleolithic and Mesolithic peoples in Europe, and would have provided a large diversity of resources for procurement (Gearey and Caseldine, 2006).

McIntyre Basin Shallow Water (MIS)

This assemblage occurs immediately after the wetland/bog lowstand in RIL 10, and at lithologic boundaries (units C/D and D/E) in both basins (Figs. 3.7 and 3.8). Higher numbers of *C. tricuspis* (~12%) and *D. oblonga* (~14%) along with the highest diversity of all assemblages (~1.8) indicate a more nutrient-rich environment (Table 3.3). This assemblage correlates with water-level (EH-1,2 and post-dam) and pollen zone changes in the cores (Fig. 3.8) and may be recording flooding. The sudden water-level rises after the two hiatuses and the building of the Hastings Dam would be accompanied by sudden inputs of nutrients and sediments as illustrated by increased numbers of *D. globulus* (Table 3. 3, Fig. 3.7). *D. globulus* has also been noticed in flooding surfaces in Chile (Reinhardt et al., 2010).

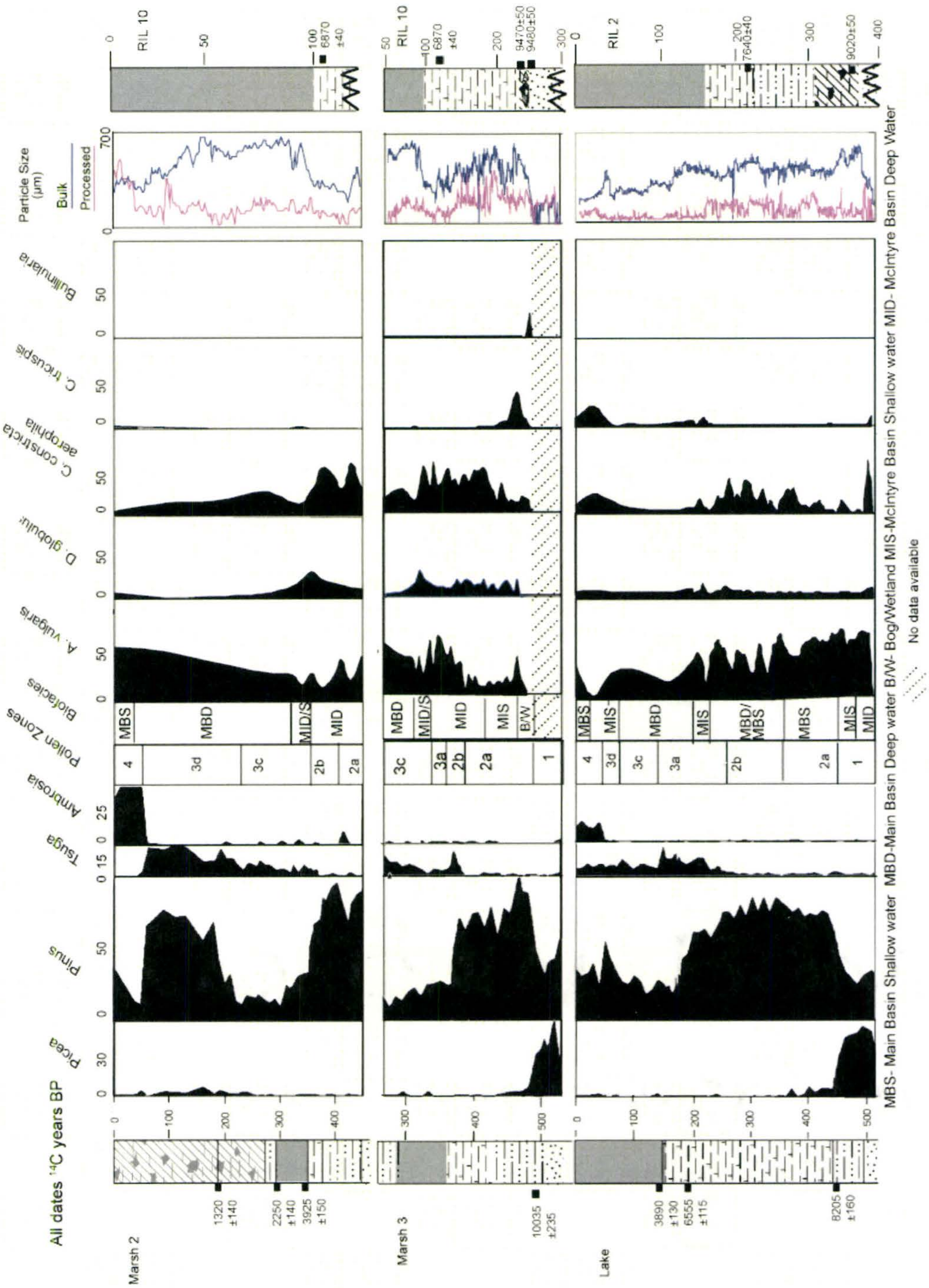

Figure 3.8: Key pollen species representing southern Ontario pollen zones (adapted from McAndrews 1984) compared with testate amoebae biofacies. Note synchronous fluctuations in pollen and testate amoebae abundances and grain size.

McIntyre Basin Deep Water (MID)

The deepwater assemblage for the McIntyre basin occurs throughout the upper 100 cm of Unit D. Like the deep water assemblage in the main basin, this assemblage has high abundances (~625 per cc) and medium diversity (~1.39). The assemblage precedes the change from pollen sub-zone 2a to 2b and ends at the mid-Holocene lowstand (EH-2). The main difference between the deepwater and shallow water assemblages in the McIntyre basin is the decreased presence of higher nutrient species such as *C. tricuspis* and *D. oblonga* in the deep water assemblage. Pollen and plant macrofossils from the marl in the adjacent marsh cores show submerged aquatic vegetation (*Najas*) which replaced shallow water and marsh species such as bulrush (McAndrews, 1984). Like the deepwater assemblage in the main basin, synchronous changes in pollen and thecamoebian abundances and grain sizes indicate seasonal or decal water-level fluctuations. This assemblage also occurs at the base of RIL2 (Fig. 3.7, 3.8), perhaps indicating higher water levels immediately prior to the drainage of Lake Iroquois.

3.5 Discussion

Environmental differences between the main lake and McIntyre basin were particularly evident in the microfossil analysis. Cluster analysis of RIL 2 and RIL 10 have the cores clustering almost completely separately, with the modern sediments being the most closely related (Fig. 3.6). The main characteristic of thecamoebian assemblages in the main lake basin are extremely low diversity and dominance of *Arcella vulgaris* (Fig. 3.6). The modern trophic status of the lake has been described as eutrophic due to large amounts of aquatic plant growth and high phosphorous (P) levels (Ferguson and

Metcalfe, 1989), and *Arcella vulgaris* has been associated with high P levels (Roe et al., 2010). However, other species associated with eutrophic conditions, notibly *C. tricuspis* and *D. oblonga* sp., are almost completely absent except in modern and post-dam sediments. The reason for the lack of *C. tricuspis* throughout the basin is unclear; there may be other more aggressive benthic species that are in competition for food resources, or that the algae (*spirogyra* mats) that is the main food source of *C. tricuspis* (Reinhardt, et al., 2005) is absent.

In the McIntyre basin, the dominant species are still *A. vulgaris* and Centropyxids, but the samples have a much higher diversity (~1.4-1.8) (Table 3.3) and additional dominant species include those associated with more eutrophic and nutrient rich environments such as Difflugids and *C. tricuspis*. The more eutrophic nature of the basin may be due to groundwater input and carbonate-rich macrophytes (Canada Parks Service, et al., 1994) having a larger influence on a smaller basin. In addition, recent water-level reconstructions indicate that the McIntyre basin was hydrologically isolated from the main basin until after 4 ka BP. The isolation of the McIntyre basin is supported by the testate amoebae assemblages; the separate clustering of samples from the basins; the unique Bog/Wetland Biofacies (ca 9.5 ka BP) that is only found in the McIntyre basin despite a similar lithologic unit in the main basin (C); and the biofacies that are the same between the basin and the main lake when water-levels rose after the mid-Holocene lowstand (EH-1).

3.5.1 *Main Lake Basin Macroenvironment*

Initial post-Iroquois higher water-levels in the basal sediments in RIL 2 is recorded by the appearance of the MID assemblage. Rapidly lowered water-levels of the

Admiralty phase of Lake Ontario is indicated by the quick succession of a more eutrophic shallow water assemblage (MIS). The change from spruce to pine (Zone 1 to 2) at ca 10 ka BP is marked by shallow water plant taxa and the establishment of the dominant species in the lake (*A. vulgaris*, Centropyxids). The MBS assemblage reflects gradually rising waters and transgressing shorelines (TS) after the Early Holocene lowstand (EH-1). Seasonal or decadal water-level fluctuations are recorded in the initial appearances of deepwater biofacies (MBD). Oscillations in particle size and pollen abundances are synchronous with changes in shallow and deepwater assemblages (Fig. 3.8). The final establishment of the deepwater assemblage coincides with marl deposition. The Mid-Holocene lowstand (EH-1) is marked by a sudden shift to a more eutrophic shallow water assemblage (MIS) and occurs prior to the missing pollen sub-zone 3b due to differences in the elevations of RIL 2 (testate amoebae samples) and E (pollen samples) (Figs. 3.2, 3.8). The immediate re-appearance of deepwater biofacies (MBD) after the shallow water assemblage indicates rapid recovery of water-levels and trophic status after the lowstand.

It has been postulated that wild rice growth came with the stabilization of water-levels after 4 ka BP (EH-2) (McAndrews, 1984). Water-level reconstructions indicate the basin may have been hydrologically closed until after 4 ka BP, as water-levels dropped below the bedrock sill at Hastings (185 m.a.s.l) (Chapter 4). The isolation of the basin may have led to the recovery and stabilization of post-hiatus water-levels as indicated by the rapid re-establishment of pre-hiatus assemblages (MBD).

The MBD biofacies is replaced in the upper 50 cm by a shallow eutrophic assemblage (MIS), reflecting the water-level and environmental changes that occurred when the Hastings Dam was built in 1838. Also appearing at this time is the onset of pollen associated with land clearance activities (Ragweed; Zone 4). The combination of increased sediment and nutrient input from deforestation associated with early European agriculture and flooding from the dam likely increased eutrophication of the basin. The upper sediment sample shows the lake has returned to pre-dam trophic conditions, but has much higher overall abundances.

Despite major changes in water-levels, environment and vegetation, the trophic status of the lake has remained relatively stable, with rapid re-establishment of the 'natural' assemblages (dominated by *A. vulgaris* and Centropyxids) after major water-level events. This re-establishment of trophic conditions despite water-level fluctuations also occurs in other lakes in the Great Lakes watershed that have been investigated using a variety of multi-proxy techniques (Christie and Smol, 1996; Forrest et al., 2002; Little and Smol, 2000; Sonnenburg et al., 2009).

3.5.2 McIntyre Basin Microenvironment

Unlike the main basin sample, no thecamoebians were recovered in the immediate post-Iroquois phase (Pollen Zone 1). The lack of testate amoebae in these samples may be a result of the area being completely dry during the lower water levels of Lake Admiralty Phase (Chapter 4). The first thecamoebian specimens recovered record the onset on rising water-levels and the spruce/pine transition (Zones 1 and 2) after the Early Holocene Lowstand (EH-1). After 10 ka BP, the appearance of *Buillinaria* and *Phyraginella* sp. are indicative of boggy soils and wetlands that surrounded the basin where microdebitage was recovered (Figs 3.5, 3.7). The wetland transgressed eastwards (Chapters 2, 4) and these rising water-levels record the establishment of the 'natural' assemblages associated with the McIntyre basin. The shallow water assemblage in the basin (MIS) is the most diverse of the biofacies and like the shallow water assemblages in the main basin, shallow water plant macrofossils are also found in adjacent cores. The shift to deeper water assemblages (MID) starts slightly before the transition from sub-Zone 2a (jack pine) to 2b (white pine) (Fig 3.8) and submerged aquatic weeds (*Najas*). Like the main basin, the mid-Holocene lowstand (EH-1) can be seen by the appearance of the more eutrophic shallow water biofacies (MIS), followed by a 'recovery' to the pre-hiatus biofacies (MID). However this recovery is short-lived, as increasing water-levels eventually connect the McIntyre basin to the main basin as is shown by the shift to the less nutrient-rich *A. vulgaris* dominated biofacies (MBS) (Fig. 3.7). Unlike the main basin, the rise in water-levels following the construction in 1838 of the Hastings dam does not show a transitional phase of increased nutrients and sediment input, but immediately shifts to the post-dam biofacies (MBS).

3.5.3 Archaeological Implications

Paleoindian Phase (~11-9 kya)

Based on the results of this study utilizing microfossil, previous pollen analysis, and known archaeological sites, a much clearer picture of Paleoindian lifeways can be visualized. When the first Paleoindian peoples came to the Rice Lake area, they would have found a dense pine dominated forest, similar to the modern Boreal forest (McAndrews, 1984). The climate would have been cooler and drier, and the lake would have been much lower than modern levels. Fringing marshland and small isolated kettle lakes surrounded by wetlands would have surrounded the lake (Chapter 4). Besides the large herds of caribou that followed the shoreline of the main lake, waterfowl, aquatic grasses and fish from the surrounding marshes and kettle lakes would have also provided potentially important resources for Paleoindian peoples.

The traditional view of Paleoindian resource procurement and settlement strategies is of small, highly mobile groups hunting large game along shorelines with distinct, large projectile points made from exotic materials (Mason, 1981). More recent studies have determined that this model is far too simplistic, however, most studies of Paleoindians in the Great Lakes still focus on sites located along former strandlines of glacial lakes (Ellis, et al., 1998; Jackson, 1998; Jackson, 2004). Previous pollen studies indicate that Rice Lake during the Paleoindian time period would have closely resembled the modern Boreal Forest (Yu and McAndrews, 1994). The addition of thecamoebian biofacies provides a more specific paleoenvironmental picture. These biofacies indicate that Rice Lake was not a homogenous environment but a collection of microenvironments. These microenvironments, such as the wetlands of the McIntyre basin would have provided a wide variety of resources for human exploitation. The recovery of quartz microdebitage in the wetland facies of the McIntyre basin implies that Paleoindian peoples were utilizing this important resource, and using specific stone tool technology to acquire wetland resources (Chapter 2). Most studies of littoral zones and Paleoindian archaeological sites have a tendency to assume a uniform resource procurement of large game along shorelines without considering smaller microenvironments that would have contained considerable resources, perhaps on a seasonal scale (Ellis, et al., 1998; Kuehn, 1998). These resources, while not as visible in the archaeological record compared to large faunal remains, nonetheless could have been an important part of the diet of Paleoindians.

Archaic Phase (9-3 kya)

As the water-levels gradually rose after 8.5 ka BP, the climate warmed and caribou moved further north, the Archaic peoples who now inhabited Rice Lake became more reliant on a wider variety of resources. During this time period, the vegetation shifted to a more mixed deciduous forest, with several successions of dominant tree species (McAndrews, 1984). While the climate gradually became warmer and wetter, a sudden shift to drier and warmer temperatures (1-2° warmer than present) (Dean, et al., 1996) occurred around 6 ka BP, dramatically lowering water levels. It is unclear how Archaic people adapted to this sudden shift in climate and subsequent changes in resource availability. However, after water levels recovered around 4 ka BP, we start to see larger settlements, burials and the utilization of wild rice which colonized the lake after 4 ka BP.

The reasons for the establishment of wild rice in the lake after 4 ka BP which became a resource of fundamental importance to the Lake Archaic and Woodland peoples are unclear. McAndrews (1984) postulates that the absence of hemlock and the transition to less coniferous species produced less acid litter and subsequent decrease in lime leached into the lake sediments. The calcium-poor soil led to the establishment of more organic-rich mud needed for wild rice. While the abundance of low pH tolerant *Arcella vulgaris* in the lake basin indicates that plenty of acid litter was still leaching into the lake, the isolation of the basin during the mid-Holocene lowstand may have changed the hydrological regime to favour the establishment of more organic-rich sediments.

While it is unclear whether the Archaic peoples were the same group as Paleoindian peoples or replaced them in the area, what is known is that there is a gradual shift in technology with regards to stone tool manufacturing. Stone tools become smaller, more diversified and used local materials. It has been theorized that changing environments during the early Archaic period led to a more diverse resource procurement strategy (Ellis et al., 1990), however, major environmental shifts continued to take place within the 5-6000 years of Archaic occupation in Southern Ontario. A rise, and sudden major drop in water levels would have forced Archaic peoples to adapt quickly to changing environments. Thecamoebian assemblages indicate that despite water-level fluctuations and shifts in vegetation, the trophic status of the lake remained relatively constant. This consistency may have allowed for continued occupation of the area with only minor changes in settlement and resource procurement strategies.

3.6. Conclusion

This is the first time that testate amoebae have been used to reconstruct submerged archaeological landscapes and identify areas of archaeological potential in North America. Testate amoebae are underutilized in archaeology; comparison of testate amoebae with pollen data from Rice Lake shows that the two data sets are synchronous and respond to the same shifts in environmental conditions. The combination of the two datasets provides a more robust and site-specific paleoenvironmental reconstruction. While pollen was able to determine vegetation changes related to climate changes, the thecamoebians detected water-level fluctuations associated with changes in pollen assemblages, identifying the Early Holocene lowstand event (EH-1) ca. 10 ka BP, which was less discernable in the pollen record.

In this study, testate amoebae were able to determine differences in water-levels between the main and McIntyre basins, demonstrating the subtle differences in environment that may exist in a lake basin. In the McIntyre basin, thecamoebians were able to identify a previously unknown submerged wetland area that was used for resource procurement ca. 9.5 ka BP (Chapter 2). Previous palynological data from cores adjacent to this area were unable to determine the extent of lowered water-levels, and widely dispersed pollen from trees and grasses did not identify a nearby small (< $1km^2$) isolated basin and fringing wetland.

This research also highlights the importance of wetland environments as a location for archaeological materials. While prehistoric archaeological sites in wetlands have been extensively investigated in Europe, wetlands are often neglected in North America as areas of archaeological interest. The discovery of microdebitage in a lithologic unit that was identified as a wetland through testate amoebae analysis, demonstrates that wetland environments played a more important role in the resource strategy of Paleoindian peoples than previously thought (Jackson, 1998; Mason, 1981). Previous studies have focused on the importance of large game as the primary resource of Paleoindian peoples, with later Archaic peoples exploiting a wider variety of resources (such as fish and wild rice) (Ellis and Deller, 1990; Ellis, et al., 1990). The identification of wetland habitats through testate amoebae analysis with archaeological material from the Paleoindian time period provides compelling evidence that these peoples were exploiting a wide variety of resources. The identification of Early Holocene wetlands in the paleoenvironmental record may be an important key to discovering additional Paleoindian sites in the Great Lakes.

References

Anderson, T.W. and Lewis, C.F.M., 1985. Postglacial water-level history of the Lake Ontario basin. In: P. F. Karrow and P. E. Calkin (Eds.), GAC Special Paper, 30, pp. 231-253. Geological Association of Canada, St. John's.

Asada, T. and Warner, B.G., 2009. Plants and testate amoebae as environmental indicators in cupriferous peatlands, New Brunswick, Canada Ecological Indicators 9, 129-137.

Barnett, P.J., 1992. Quaternary geology of Ontario. In: J. B. Thurston, H. R. Williams, R. H. Sutcliffe and G. M. Scott (Eds.), Geology of Ontario, 4 Part 2, pp. 1011-1088. Ontario Geological Survey, Sudbury.

Birks, H.H. and Birks, H.J.B., 2000. Future uses of pollen analysis must include plant macrofossils Journal of Biogeography 27 (1), 31-35.

Blott, S.J. and Pye, K., 2006. Particle size distribution analysis of sand-sized particles by laser diffraction: an experimental investigation of instrument sensitivity and the effects of particle shape Sedimentology 53, 671-685.

Booth, R.K., 2008. Testate amoebae as proxies for mean annual water-table depth in *Sphagnum*-dominated peatlands of North America Journal of Quaternary Science 23 (1), 43-57.

Christie, C.E. and Smol, J.P., 1996. Limnological effects of 19th century canal construction and other disturbances on the trophic state history of upper Rideau Lake, Ontario Lake Reserv Manage 12, 448-454.

Conley, D.J. and Schelske, C.L., 2001. Biogenic silica. In: J. P. Smol, H. J. B. Birks and W. M. Last (Eds.), Tracking Environmental Change Using Lake Sediments: Volume 3: Terrestrial, Algal and Siliceous Indicators, 3, pp. 281-293. Springer, Dordrecht.

Dallimore, A., Schroder-Adams, C.J. and Dallimore, S.J., 2000. Holocene environmental history of thermokarst lakes on Richard Island, Northwest Territories, Canada: thecamoebians as paleolimnological indicators Journal of Paleolimnology 23, 261-283.

Davis, J.C., 2002. Statistics and Data Analysis in Geology. John Wiley and Sons, New York, 638p.

Dean, W.E., Ahlbrandt, T.S., Anderson, R.Y. and Bradbury, J.P., 1996. Regional aridity in North America during the middle Holocene The Holocene 6 (2), 145-155.

Dragovich, D. and Susino, G.J., 2001. Identification of experimental quartz microdebitage from rock engravings Earth Surface Processes and Landforms 26, 859-868.

Ellis, C. and Deller, D.B., 1990. Paleo-Indians. In: C. Ellis and N. Ferris (Eds.), Archaeology of Southern Ontario to A.D. 1650, pp. 37-63. Ontario Archaeological Society, London.

Ellis, C., Goodyear, A.C., Morse, D.F. and Tankersley, K.B., 1998. Archaeology of the Pleistocene-Holocene transition in eastern North America Quaternary International 49/50 (151-166).

Ellis, C., Kenyon, I.T. and Spence, M.W., 1990. The Archaic. In: C. Ellis and N. Ferris (Eds.), Archaeology of Southern Ontario to A.D. 1650, pp. 65-124. Ontario Archaeological Society, London.

Ferguson, M.L. and Metcalfe, C.D., 1989. Distribution of PCB Congeners in Sediments of the Otonabee River-Rice Lake System, Peterborough, Canada Chemosphere CMSHAF 19 (8/9), 1321-1328.

Fladmark, K., 1982. Microdebitage analysis: Initial considerations Journal of Archaeological Science 9 (2), 205-220.

Forrest, F., Reavie, E.D. and Smol, J.P., 2002. Comparing limnological changes associated with 19th century canal construction and other catchment disturbances in four lakes within the Rideau Canal system, Ontario, Canada J Limnol 61 (2), 183-197.

Gearey, B.R. and Caseldine, C.J., 2006. Archaeological applications of testate amoebae analyses: a case study from Derryville, Co. Tipperary, Ireland Journal of Archaeological Science 33, 49-55.

Gorrell, G. and Brennand, T.A., 1997. Surficial Geology of the Rice Lake Area, MTS 31D/1, southern Ontario. Geological Survey of Canada Open File 3332.

Gravenor, C.P., 1957. Surficial geology of the Lindsey-Peterborough area, Ontario, Victoria, Peterborough, Durham and Northumberland counties, Ontario. In: M. a. T. Surveys (Ed.), 288, p. 60. Geological Survey of Canada.

Hammer, O., Harper, D.A.T. and Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis Palaeontol Electron 4 (1), 1-9.

Heiri, O., Lotter, A.F. and Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results J Paleolimnol 25, 101-110.

Holcovà, K., 2007. Thecamoebians from the Upper Vltava River (šumava) Mountains, Czech Republic): species composition of assemblages vs. environment in streams J Foramin Res 37 (4), 287-299.

Jackson, L.J., 1998. The Sandy Ridge and Halstead Paleo-Indian sites. Museum of Anthropology, University of Michigan, Ann Arbor, 165p.

Jackson, L.J., 2004. Changing our view of late Palaeo-Indian in Southern Ontario. In: L. J. Jackson and A. Hinshelwood (Eds.), The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments, 165, pp. 25-56. Canadian Museum of Civilization, Ottawa.

Jackson, L.J., Ellis, C., Morgan, A.V. and McAndrews, J.H., 2000. Glacial Lake Levels and Eastern Great Lakes Palaeo-Indians Geoarchaeology 15 (5), 415-440.

Jackson, L.J. and McKillop, H., 1988. Ontario fossil cervids: neglected data and dating. Center for the Study of Early Man, University of Maine, Orono, Main, 73-75p.

Jeffries, D.S., Semkin, R.G., Gibson, J.J. and Wong, I., 2010. Recently surveyed lakes in northern Manitoba and Saskatechewan, Canada: characteristics and critical loads of acidity Journal of Limnology 69 (1), 45-55.

Johnston, R.B., 1968. Archaeology of Rice Lake, Ontario. Department of the Secretary of State, Ottawa, 49p.

Johnston, R.B., 1984. McIntyre Site: Archaeology, Subsistence and Environment, 126, p. 190. Archaeological Survey of Canada, Ottawa, Ontario.

Karrow, P.F., 2004. Ontario Geological Events and Environmental Change in the Time of the Late Palaeo-Indian and Early Archaic Cultures (10,500 to 8,500 B.P.). In: L. J. Jackson and A. Hinshelwood (Eds.), The Late Palaeo-Indian Great Lakes; Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments, 165, pp. 1-24. Canadian Museum of Civilization, Ottawa.

Karrow, P.F., Appleyard, E.C. and Endres, A.L., 2007. Geological and geophysical evidence for pre-Nipissing (>5, 000 years BP) transgression infilled valleys in the Lake Huron basin, Ontario Journal of Paleolimnology 37, 419-434.

Kincare, K., 2007. Response of the St. Joseph River to lake level changes during the last 12,000 years in the Lake Michigan basin Journal of Paleolimnology 37, 383-394.

Kuehn, S.R., 1998. New evidence for late Paleoindian-early Archaic subsistence behaviour in the western Great Lakes American Antiquity 63 (3), 457-476.

Kumar, A. and Dalby, A.P., 1998. Identification key for Holocene lacustrine arcellacean (thecamoebian) taxa Palaeontol Electron 1 (1), 1-39.

Kumar, A. and Patterson, R.T., 2000. Arcellaceans (thecamoebians): new tools for monitoring long- and short-term changes in lake bottom acidity Environmental Geology 39 (6), 689-697.

Lamentowicz, M. and Obremska, M., 2010. A rapid response of testate amoebae and vegetation to inundation of a kettle hole mire Journal of Paleolimnology 43 (3), 499-511.

Last, W.M., 2001. Textural Analysis of Lake Sediments. In: W. M. Last and J. P. Smol (Eds.), Tracking Environmental Change Using Lake Sediments. Volume 2: Physical and Geochemical Methods, 2, pp. 41-81. Kluwer Academic Publishers, Dortrecht.

Lewis, C.F.M., Heil, C.W., Hubney, J.B., King, J.W., Moore Jr., T.C. and Rea, D.K., 2007. The Stanley unconformity in Lake Huron basin: evidence for a climate driven closed lowstand about 7900 ^{14}C BP, with similar implications for the Chippewa lowstand Journal of Paleolimnology 37, 435-452.

Little, J.L. and Smol, J.P., 2000. Changes in fossil midge (Chironomidae) assemblages in response to cultural activities in a shallow, polymictic lake Journal of Paleolimnology 23, 207-212.

Mason, R.J., 1981. Great Lakes Archaeology. Academic Press, New York, New York, 425p.

McAndrews, J.H., 1984. Late Quaternary vegetation history of Rice Lake, Ontario, and the McIntyre archaeological site. In: R. B. Johnston (Ed.) The McIntyre Site: Archaeology, Subsistence and Environment, 126, pp. 161-189. National Museums of Canada, Ottawa.

McAndrews, J.H., 1994. Pollen diagrams for southern Ontario applied to archaeology. In: R. I. MacDonald and B. G. Warner (Eds.), Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties, pp. 179-195. Quaternary Sciences Institute, Waterloo.

McCarthy, F., McAndrews, J., Blasco, S. and Tiffin, S., 2007. Spatially discontinuous modern sedimentation in Georgian Bay, Huron Basin, Great Lakes Journal of Paleolimnology 37 (3), 453-470.

McCarthy, F.M.G., Collins, E.S., McAndrews, J.H., Kerr, H.A., Scott, D.B. and Medioli, F.S., 1995. A comparison of postglacial arcellacean ("thecamoebian") and pollen succession in Atlantic Canada, illustrating the potential of Arcellaceans for paleoclimatic reconstruction J Paleontol 69 (5), 980-993.

Medioli, B.E. and Brooks, G.R., 2003. Diatom and thecamoebian signatures of Red River (Manitoba and North Dakota) floods: Data collected from the 1997 and 1990 spring freshets Journal of Paleolimnology 29, 353-386.

Muller, E.H. and Prest, V.K., 1985. Glacial lakes in the Ontario Basin. In: P. F. Karrow and P. E. Calkin (Eds.), Quaternary Evolution of the Great Lakes, Special Paper 30, pp. 213-229. Geological Association of Canada, St. John's.

Murray, M.R., 2002. Is laser particle size determination possible for carbonate-rich lake sediments? Journal of Paleolimnology 27 (2), 173-183.

O'Shea, J.M. and Meadows, G.A., 2009. Evidence for early hunters beneath the Great Lakes PNAS 106, 10120-10123.

Patterson, R.T. and Fishbein, E., 1989. Re-examination of the statistical methods used to determine the number of point counts needed for micropaleontological quantitative research J Paleontol 63 (2), 245-248.

Plunkett, G., Whitehouse, N.J., Hall, V.A., Charman, D.J., Blaauw, M., Kelly, E. and Mulhall, I., 2009. A multi-proxy investigation of the findspot of an Iron Age bog body from Oldcroghan, Co. Offaly, Ireland Journal of Archaeological Science 36, 265-277.

Reinhardt, E.G., Dalby, A., Kumar, A. and Patterson, R.T., 1998. Arcellaceans as pollution indicators in mine tailing contaminated lakes near Cobalt, Ontario, Canada Micropaleontology 44, 131-148.

Reinhardt, E.G., Little, M., Donato, S., Findlay, D., Krueger, A., Clark, C. and Boyce, J.I., 2005. Arcellacean (thecamoebian) evidence of land-use change and eutrophication in Frenchman's Bay, Pickering, Ontario Environ Geol 47, 729-739.

Reinhardt, E.G., Nairn, R.B. and Lopez, G.I., 2010. Recovery estimates for the Rio Cruces after the May 1960 Chilean earthquake Marine Geology 269, 18-33.

Roe, H.M., Patterson, T. and Swindles, G.T., 2010. Controls on the contemporary distribution of lake thecamoebians (testate amoebae) within the Greater Toronto Area and their potential as water quality indicators Journal of Paleolimnology 43 (4), 955-975.

Scott, D.B. and Hermelin, J.O.R., 1993. A Device for Precision Splitting of Micropaleontological Samples in Liquid Suspension Journal of Paleontology 67 (1), 151-154.

Scott, D.B., Medioli, F.S. and Schafer, C.T., 2001. Monitoring in Coastal Environments Using Foraminifera and Thecamoebian Indicators. Cambridge University Press, Cambridge, UK, 177p.

Smol, J.P., 1992. Paleolimnology: an important tool for effective ecosystem management Journal of Aquatic Ecosystem Health 1, 49-58.

Sonnenburg, E.P., Boyce, J.I. and Reinhardt, E.G., 2009. Multi-proxy environmental record of Colonial land-use change in the lower Rideau Canal System (Colonel By Lake), Ontario, Canada Journal of Paleolimnology 42, 515-532.

Stuiver, M. and Reimer, P.J., 2010. Calib Radiocarbon Calibration Program.

Swindles, G.T., Charman, D.J., Roe, H.M. and Sansum, P.A., 2009. Environmental controls on peatland testate amoebae (Protozoa: Rhizopoda) in the North of Ireland: Implications for Holocene palaeoclimate studies Journal of Paleolimnology 42, 123-140.

Van Hengstum, P.J., Reinhardt, E.G., Beddows, P.A., Huang, R.J. and Gabriel, J.J., 2008. Thecamoebians (testate amoebae) and foraminifera from three anchialine cenotes in Mexico: low salinity (1.5-4.5 psu) faunal transitions Journal of Foraminiferal Research 38 (4), 305-317.

van Hengstum, P.J., Reinhardt, E.G., Boyce, J.I. and Clark, C., 2007. Changing sedimentation patterns due to historical land-use changes in Frenchman's Bay, Pickering, Canada: evidence from high-resolution textural analysis Journal of Paleolimnology 37 (4), 603-618.

Yu, Z. and McAndrews, J.H., 1994. Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen and plant macrofossil evidence Holocene 4 (2), 141-152.

Yu, Z., McAndrews, J.H. and Eicher, U., 1997. Middle Holocene dry climate caused by change in atmospheric circulation patterns: Evidence from lake levels and stable isotopes Geology 25 (3), 251-254.

Chapter 4
Holocene paleoshorelines, water levels and submerged prehistoric site archaeological potential of Rice Lake (Ontario, Canada)

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Abstract

Rice Lake, located in the Lake Ontario watershed, has been continuously occupied for over 12,000 years and has a high density of prehistoric (Paleoindian-Archaic age) terrestrial sites. It has been speculated that a large number of submerged sites are present on the lakebed, as lake levels have risen about 9 m since the arrival of Early Paleoindian peoples at Rice Lake about 11 ka BP. In order to better understand the submerged landscape and its archaeological potential, a detailed bathymetric survey and sediment coring program was conducted across a 30-km^2 area of northeastern Rice Lake. Changes in Holocene water levels and shoreline positions were reconstructed by integrating core data with a digital elevation and bathymetric model (DEBM) that accounted for differential isostatic uplift and basin sedimentation. The DEBM was used to generate a series of paleogeographic maps showing paleoshoreline positions, water depths and areas of prehistoric archaeological potential.

The basin stratigraphy consists of a 3-5 m thick sequence of Holocene mud, marl and gytjja overlying glacial Lake Iroquois (ca. 12.5 ka BP) sand and clay deposits. Erosional hiatuses at the base of the Holocene sequence and at the mid-Holocene (ca. 6.5-4 ka) marl-gytjja boundary provide a low water level datum for construction of a water level curve. The isostatic uplift of the eastern basin outlet (> 30 m) had a dramatic influence on water levels and shoreline positions since the inception of Rice Lake (ca. 12

ka BP). During the Early Paleoindian occupation phase (ca. 11-10.5 ka BP), water levels were at a maximum lowstand (10 m bpl) and much of the present lakebed was an exposed lake plain with extensive wetlands. At the time of the Late Paleoindian/Early Archaic occupation of the McIntyre basin (9.5-8.7 ka BP), the lake was about half its modern extent and the basin was separate from the open lake. During a second lowstand phase after 6.5 ka BP, water levels dropped to > 4 m bpl and the lake was hydrologically closed. After 4 ka BP water levels began to recover and the lake approached its modern extents. Sedimentation rates remained relatively constant (0.01-0.03 cmyr^{-1}) during the Early to Mid-Holocene and increased dramatically during the last 170 years due to post-European land use changes. An archaeological potential map based on the reconstructed paleoshorelines identified four areas with archaeological potential: these include drowned river mouths, submerged wetlands and an area of uplifted Early Holocene lakebed in northeast Rice Lake. The approach can be applied more broadly to other basins within the Great Lakes watershed to locate paleoshoreline positions and to assess prehistoric site archaeological potential.

Keywords: prehistoric sites, submerged landscapes, paleoshorelines, Rice Lake, archaeological potential

4.1. Introduction

The Great Lakes and surrounding watershed areas (Fig. 4.1A) have a high potential for submerged prehistoric archaeology due to large water level fluctuations during the Holocene (Ellis et al., 1998; Jackson et al., 2000; Yu and McAndrews, 1994). It has been postulated that a large number of prehistoric occupation sites were inundated by rising water levels following the Paleoindian and Early Archaic phases (ca. 11-8 ka BP) of Great Lakes archaeology (Jackson, et al., 2000; Janusas et al., 2004; Lovis et al., 1994). The Paleoindian period, in particular, has a sparse terrestrial archaeological record in the Great Lakes (Fig. 4.1A) (Jackson, 2004), which may in part be explained by inundation of littoral and wetland sites as water levels rose from Early Holocene lowstand lake phases (Muller and Prest, 1985). In the Lake Ontario basin for example, it has been estimated that up to 10,000 km^2 (Jackson, et al., 2000) of the modern lakebed was sub-aerially exposed and available for prehistoric settlement during the Admiralty Phase lowstand (ca. 11.4-11.7 ka BP; Fig. 4.1A) when lake levels were more than 100 m below present (Anderson and Lewis, 1984; Coakley and Karrow, 1994). Following the lowstand, water levels recovered rapidly, submerging paleo-landscapes and potentially preserving a large number of prehistoric sites (Jackson, et al., 2000).

Submerged landscapes with prehistoric archaeological potential have been documented in other Great Lakes basins (Coleman, 2008; Janusas, et al., 2004; Karrow, 2004; Lovis, et al., 1994; O'Shea and Meadows, 2009) and in other smaller lakes inundated by rising Holocene water levels and dam construction (Sonnenburg and Boyce, 2008; Sonnenburg et al., 2009; Yu and McAndrews, 1994). Rice Lake, located 40 km

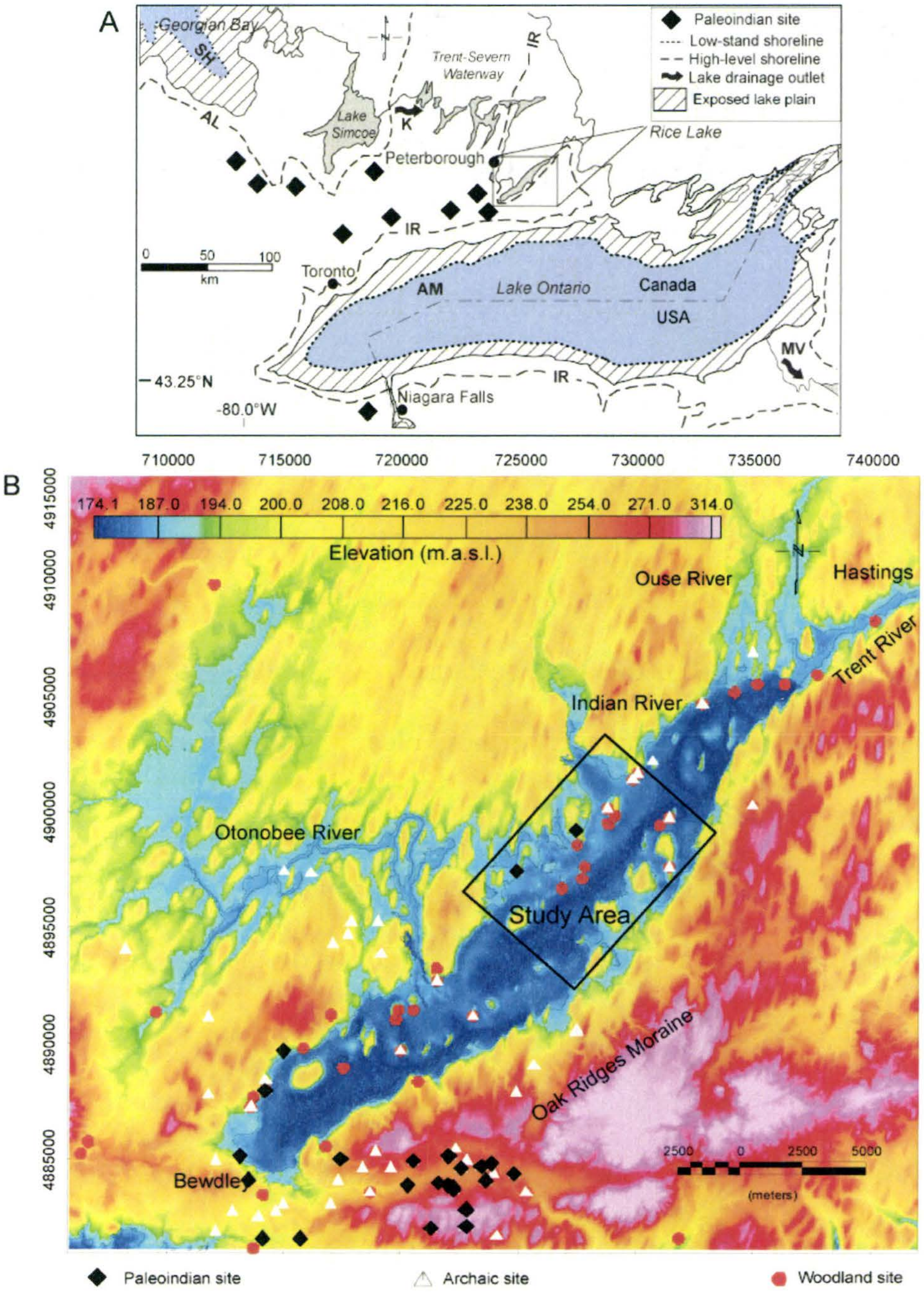


Figure 4.1: A) Map of Lake Ontario basin showing extents of glacial lakes, drainage outlets and Early Holocene lowstand shorelines. Location of known terrestrial Paleoindian sites also shown. During Admiralty lowstand phase (ca. 11.7-11.4 ka BP) in Lake Ontario more than 10,000 km^2 of the modern lakebed was exposed and available for prehistoric human occupation. B) Digital elevation and bathymetric model (DEBM) and of Rice Lake with locations of known prehistoric archaeological sites. Topographic data from 1:10,000 Ontario Base Map series. Detailed study area (30-km^2) includes the McIntyre Paleoindian-Archaic age archaeological site.

north of Lake Ontario (Fig. 4.1) has long been recognized as a location with high probability for submerged prehistoric archaeology (Jackson, 1998; McAndrews, 1984). The area around the lake has been continuously occupied since the Early Holocene and has a large density of prehistoric terrestrial archaeological sites (~0.22/km^2). More than 200 sites have been documented (Ontario Ministry of Culture 2010), including the well-studied Halstead and Sandy Ridge Paleoindian sites (Gainey Phase; ca. 11.2-10.8 ka BP)(Jackson, 1998) and the Archaic-age McIntyre site (ca. 4.7-3.6 ka BP) (Fig. 4.1B)(Johnston, 1976; Johnston, 1984). The majority of prehistoric sites at Rice Lake date to the Woodland phase (< 2.9 ka BP) (Johnston, 1968) and few Paleoindian and Archaic-age sites (ca. 11.5-2.9 ka BP) have been discovered in the vicinity of the modern shoreline (Fig. 4.1B). The largest cluster of these older sites occurs on an Oak Ridges Moraine river to the southeast of Rice Lake (Fig. 1B) (Jackson, 1998).

The small number of Paleoindian and Early Archaic-age (11-8 ka BP) sites around the modern shoreline at Rice Lake (Fig. 4.1B) is conspicuous, and it has been proposed that many submerged sites may be present on the lakebed (Jackson, et al., 2000). The water level history of Rice Lake includes at least two lowstand phases when lake levels were up to 10-12 m below present level (bpl). The lake basin formed about 12.5 ka BP when glacial Lake Iroquois expanded northward of Lake Ontario, creating a northeast-trending embayment (Fig. 4.1). Following the drainage of Lake Iroquois at 12-11.8 ka BP, water levels fell rapidly to a maximum lowstand (ca. 11.5 ka BP), exposing a large area of the lakebed (Yu and McAndrews, 1994). By the time of arrival of Early Paleoindian peoples (ca. 11 ka BP), water levels in Rice Lake had begun to rise as a result of the isostatic uplift of the eastern lake outlet at Hastings (Fig. 4.1B). The transgression of the Early Holocene shoreline is recorded in the basin sediments by a distinctive organic-rich ‘detritus-mud’ overlying Lake Iroquois deposits (McAndrews, 1984; Chapter 3). The detritus-mud contains shallow-water plant macrofossils and a distinctive soil thecamoebian assemblage that records the establishment of wetland environment on the former Lake Iroquois lake plain (Yu and McAndrews, 1994; Chapter 3). A second phase of low water-levels was attained in Rice Lake during the mid-Holocene (6.5-4 ka BP). This event is marked by a basin-wide sediment hiatus in cores and missing pollen zones that record a period of drier climate with reduced water levels (~ -4 bpl) and erosion of the lakebed (Yu and McAndrews, 1994; Chapter 3).

Despite the high archaeological potential of Great Lakes submerged landscapes (e.g. Fig. 4.1A) there have been few systematic attempts to locate and study them (Lovis, et al., 1994; Stevens, 2002). The water level history of the lower Great Lakes (i.e. Ontario, Erie, Huron) has been well documented (Holcombe et al., 2003; Karrow and Calkin, 1985; Kincare, 2007; Lewis et al., 2007; Muller and Prest, 1985) but few studies have attempted to reconstruct paleoshorelines at a level of detail sufficient for archaeological potential mapping. In a pioneering study in western Lake Ontario, Coakley and Karrow (1994) reconstructed the post-Iroquois shoreline configurations using a computer model that accounted for both basin isostatic effects and sediment erosion and deposition. They combined available sediment core, sub-bottom seismic and bathymetric data with water level curves to determine the Early Lake Ontario shoreline positions from 11.4 ka BP to present. A key component in that model was a correction for

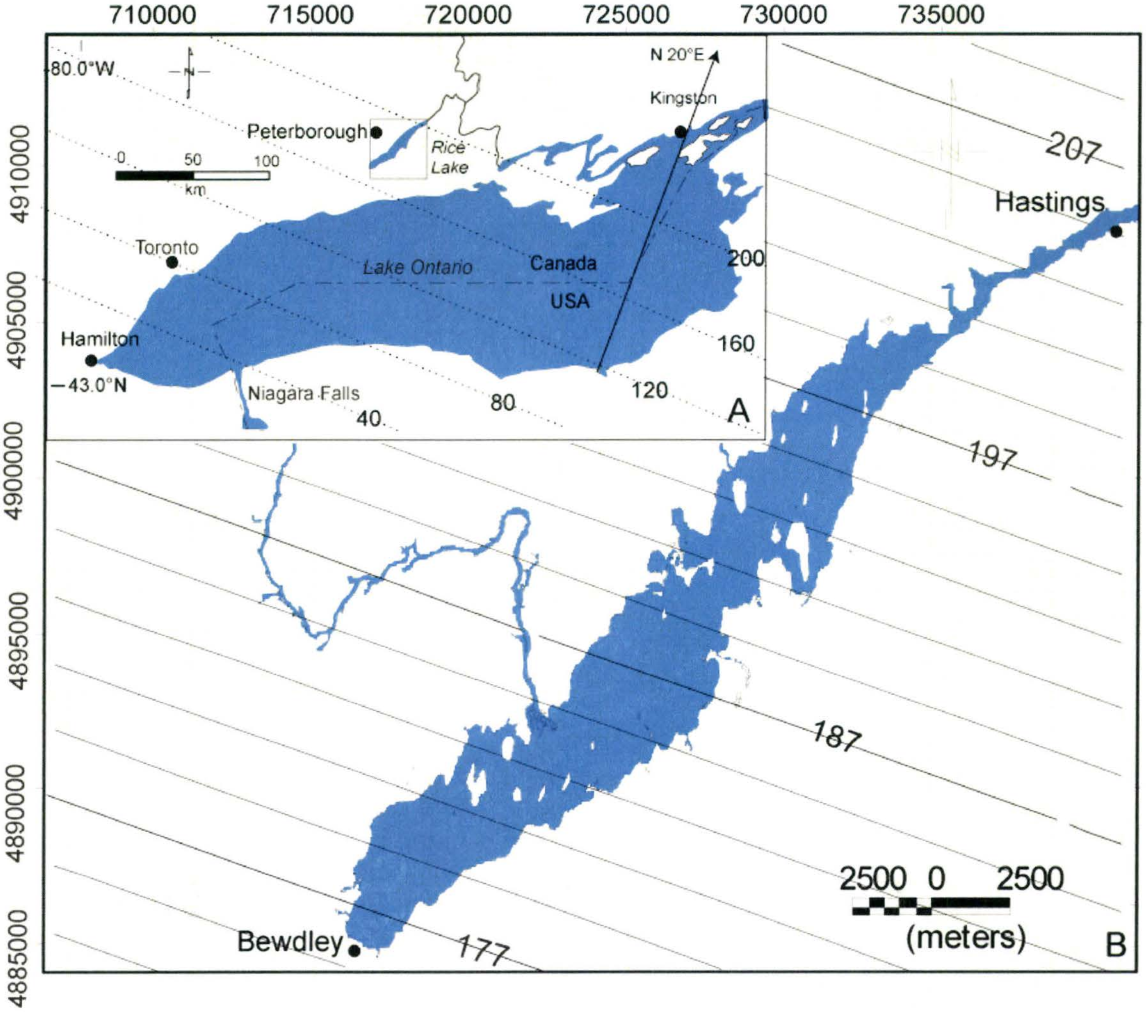


Figure 4.2: A) Isobase map (m.a.s.l) for the Lake Iroquois water plane at ca. 12.5 ka BP (adapted from Anderson and Lewis, 1984). Axis of maximum isostatic uplift is N20°E. B) Isobase map (m.a.s.l) for Rice Lake based on best-fit linear interpolation of Lake Iroquois shoreline elevations (data from Mirynech 1962; Yu and McAndrews 1994). Differential iostatic uplift of eastern outlet of Rice Lake is more than 30 m over 12 ka. The current lake level (187 m .a.s.l.) is maintained by dam at Hastings.

differential isostatic uplift and tilting of the Lake Ontario basin (Fig. 4.2A). Uplift of the lake outlet at Kingston has resulted in a water level rise of more than 100 m since the inception of Early Lake Ontario. The maximum direction of isostatic uplift is approximately N20°E with the hinge line (zero isobase) located to the southwest of Lake Ontario (Fig. 4.2A) (Anderson and Lewis 1985).

At Rice Lake, isostatic rebound effects have been even more pronounced, as the lake basin axis lies approximately parallel with the maximum direction of isostatic uplift (Fig. 4.2). The total differential uplift over the 30 km length of the lake has been about 30 m over the past 12 ka. Isostatic uplift of the eastern basin outlet at Hastings (Fig. 4.2B) resulted in the rapid transgression of the shoreline following the Early Holocene lowstand (ca. 11.5 ka BP) and coupled with mid-Holocene climate-driven water level changes, has resulted in a very complex water level history (Yu and McAndrews, 1994). In two previous studies the location of the postglacial lowstand shorelines at Rice Lake were estimated using low-resolution navigational charts and limited sonar survey data, but these did not take into account isostatic rebound or basin sedimentation (Jackson, 1998; Yu and McAndrews, 1994). The exploration for submerged prehistoric sites at Rice Lake, and in other Great Lakes submerged landscapes (e.g. Fig. 4.1A), requires a more detailed understanding of changes in shoreline positions and water levels during the Holocene; this can only be achieved through detailed reconstructions of the lake basin paleogeography that account for basin sedimentation and isostatic effects (e.g. Coakley and Karrow 1994).

In this study, we investigated the detailed water level history and changes in Holocene shoreline positions at Rice Lake with the objective of predicting the locations of underwater prehistoric sites (Fig. 4.3). Detailed paleogeographic reconstructions of the Early to mid-Holocene lake environments were constructed by integrating core

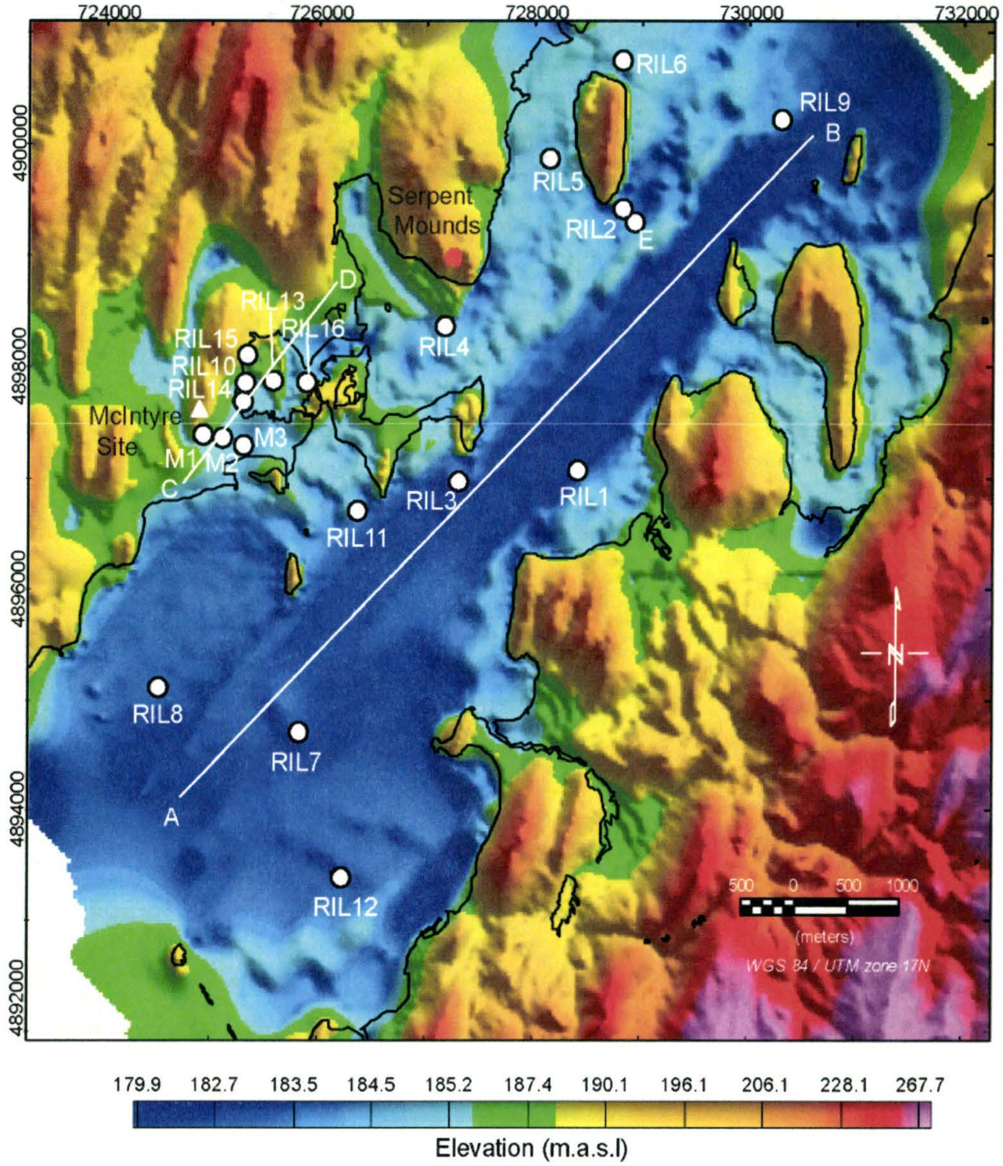


Figure 4.3: Digital elevation and bathymetric model (DEBM) for detailed study area (location shown in Fig. 1 inset) showing location of cores and McIntyre and Serpent Mounds archaeological sites.

stratigraphic data with a digital elevation and bathymetric model (DEBM) for the lake basin. The DEBM was corrected for isostatic uplift effects using a grid subtraction method and the Holocene sediment thickness calculated and back-stripped using the cumulative sedimentation rates obtained from the available core data and radiocarbon chronology (Chapter 3). The detailed configuration of the shoreline and changes in water depth were also examined within a 30-km^2 area of northeastern Rice Lake, which includes recently discovered submerged Late Paleoindian-Early Archaic tool deposits (McIntyre basin) (Fig. 4.1B) (Chapter 2). The paleogeographic maps were then used to identify areas of archaeological potential for the Paleoindian to Late Woodland time periods (ca. 11.5 ka BP to 170 BP). The archaeological potential maps demonstrate that large areas of the modern lakebed were sub-aerially exposed during the Paleoindian and Early Archaic periods and host to rich wetland habitats. Because of rapid, isostatically-controlled flooding of the wetlands, the submerged landscapes at Rice Lake have very high potential for preservation of prehistoric occupation sites. The approach demonstrated in this paper can be adapted for exploration of much larger tracts of submerged landscapes in the Lake Ontario basin (Fig. 4.1A) and elsewhere in the Great Lakes.

4.2 Study Area

4.2.1 Physical and Geologic Setting

Rice Lake (125 km^2) is part of the Trent-Severn Waterway system connecting Georgian Bay with Lake Ontario (Fig. 4.1A). The lake is about 30-km in length and has a maximum water depth of about 10 m. The modern lake level (187 m above sea level) is maintained by a dam at Hastings constructed in 1838. The dam raised the lake levels by about 1.8 m and significantly increased the lake surface area (Yu and McAndrews, 1994). Prior to dam construction, water levels in the lake were controlled by a limestone bedrock sill near Hastings with an elevation of ~185 m a.s.l.

Rice Lake is situated at the southern margin of the Peterborough Drumlin Field and bordered to the south by the uplands of the Oak Ridges interlobate moraine (Barnett, 1992)(Fig. 4.1B). The lake basin occupies a glacially over-deepened and sediment infilled valley that became an embayment of high-level glacial Lake Iroquois during deglaciation, about 12.5 ka BP (Gravenor, 1957; Mirynech, 1962). At that time, Lake Iroquois drained southward through the Mohawk Valley into upper New York state (Fig. 4.1A) (Muller and Prest, 1985). As water levels receded and outlets changed due to isostatic uplift, Rice Lake became part of the Kirkfield drainage outlet, which for a time drained Lake Algonquin into Lake Iroquois (Fig. 4.1A). After the opening of the St. Lawrence (ca. 12-11.8 ka BP) water-levels in Lake Iroquois dropped to more than 40 m below modern sea level and the Rice Lake basin was sub-aerially exposed (Fig. 4.1A) (Yu and McAndrews, 1994; (Coakley and Karrow, 1994).

Previous coring and palynological investigations at Rice Lake have identified the existence of two low water level phases: a maximum lowstand at ca. 12-11.5 ka BP following the drainage of Lake Iroquois, and a mid-Holocene event at ca. 6.5-4 ka BP that is recorded by a major erosional hiatus in Holocene sediments (Yu and McAndrews, 1994). The Early Holocene lowstand event was likely synchronous with low water levels in Ontario basin (e.g. Admiralty Phase; Coakley and Karrow 1994) and is recorded in cores by an organic-rich peaty mud layer (termed 'detritus mud' by Yu and McAndrews, 1994) overlying Lake Iroquois lacustrine deposits (Fig. 4.4). The timing and cause of mid-Holocene lowstand event is not well known, but was likely related to a mid-Holocene dry climate phase (the Climatic Optimum) that is recorded elsewhere in the Great Lakes (Yu et al., 1997). The Early Holocene lowstand event coincided with the

Paleoindian and Early Archaic periods, which are notably under-represented in the archaeology of Rice Lake (Johnston, 1984) and raises the potential for finding prehistoric sites of these ages on the drowned terrestrial landscape on the lake bed.

4.2.2 Archaeological Context

Rice Lake boasts a rich and complex archaeological record that spans the entire Holocene (Jackson, 1998; Johnston, 1968). The area is host to several well-studied and archaeologically significant Paleoindian and Archaic-age sites (Fig. 4.1). The Halstead and Sandy Ridge Paleoindian sites, located at the western end of the lake, are some of the earliest sites in Ontario (Gainey Phase; ca. 11 ka BP) (Jackson, 1998). The McIntyre Site, located on the northeastern shore of Rice Lake (Fig. 4.1) is a multi-component Archaic campsite with evidence of earlier Paleoindian occupation (Jackson, 1998) and has been the subject of extensive excavation and previous paleoenvironmental studies (Johnston, 1984; McAndrews, 1984). Recent coring work in the basin adjacent to the site (McIntyre basin) has identified lithic microdebitage in lake sediments, providing new evidence for Late Paleoindian-Early Archaic tool-making sites (Chapter 2). Serpent Mounds, located near the mouth of the Indian River, is the most well-known Rice Lake archaeological site, comprising a large Woodland burial complex (Johnston, 1968). Other important clusters of Paleoindian and Early Archaic sites have been documented to the south of Rice Lake, on the Oak Ridges Moraine (Figure 4.1B)(Jackson, 1998). In addition to its abundant and important terrestrial record, Rice Lake is an ideal locale to investigate submerged prehistoric sites, as the lake water depth (< 10 m) and bottom sediment conditions are conducive to coring and geophysical survey work.

4.3. Methods and Database for Paleogeographic Reconstruction

4.3.1 Bathymetry Data

A detailed bathymetric survey was conducted across a 30-km^2 area of Rice Lake in 2007 and 2008 (Fig. 4.1B) using a Knudsen 320BP single-beam echosounder and 200 kHz transducer. The transducer was front-mounted to a 5.5 m pontoon boat, allowing for shallow water mapping in water depths < 1 m (Sonnenburg and Boyce, 2008). Survey positioning was recorded using differential-GPS (Trimble Ag132) with an update rate of 10 Hz and positioning accuracy of 1-2 m. A total of 750-line km of bathymetry data were acquired with nominal line spacings of 100 m and orthogonal tie lines at 150 m. Bathymetry data were processed using the methods outlined by Sonnenburg and Boyce (2008). The processing flow included corrections for transducer draft, multi-path echoes, and intermittent backscatter from weeded areas on the lake bottom. The processed depths were then tie-line leveled (Luyendyk, 1997) and gridded at a 2 m cell size using a minimum curvature algorithm (Fig. 4.3) (Briggs, 1974).

The generalized bathymetric contours for the remainder of the lake basin were digitized from Canadian Hydrographic Service (CHS) hydrographic charts and incorporated into the basin-scale digital elevation and bathymetric model (DEBM) (see section 4.3.3).

4.3.2 Sediment Coring and Stratigraphic Analysis

A total of 16 sediment cores (4-5 m length) were extracted using a vibrocoring system with 15-cm diameter aluminum core tubes (Fig. 4.3). Core locations were selected to target paleoshorelines and other geomorphic features indicated in bathymetry maps (Fig. 4.3). Five cores were collected in McIntyre basin to determine the water level changes and paleoenvironmental conditions during the Paleoindian occupation phase (Fig. 4.3) (Chapters 2, 3). The cores were cut into 1 m lengths, split, sampled at regular intervals for textural and paleoenvironmental analysis (microfossils, organic content, composition by loss on ignition) and the sedimentary facies logged in detail (see Chapter 3 for paleoenvironmental results).

The cores were subdivided into 5 distinctive lithostratigraphic units (Fig. 4.4) based on sediment lithofacies and textural data and corrections applied for sediment compaction using the methods outlined by Sonnenburg (2006). The elevations of sediment cores were measured relative to the modern lake level (187 m a.s.l.) during core extraction and corrected for basin isostatic tilt by subtraction of the estimated isostatic uplift (i.e. at 6.5 ka and 10 ka BP) from each core top elevation (Figs. 4.5, 4.6). The magnitude of the rebound at each core location was obtained from a first-order trend surface fit to the Lake Iroquois shoreline elevations compiled from various sources (Gravenor 1957; Mirynech 1962; Yu and McAndrews 1994). The interpolated Lake Iroquois water plane is shown in Figure 4.2B as an isobase map. This shows that the cumulative differential isostatic uplift since 12 ka BP is > 30 m from the western terminus of the lake at Bewdley to the outlet at Hastings.

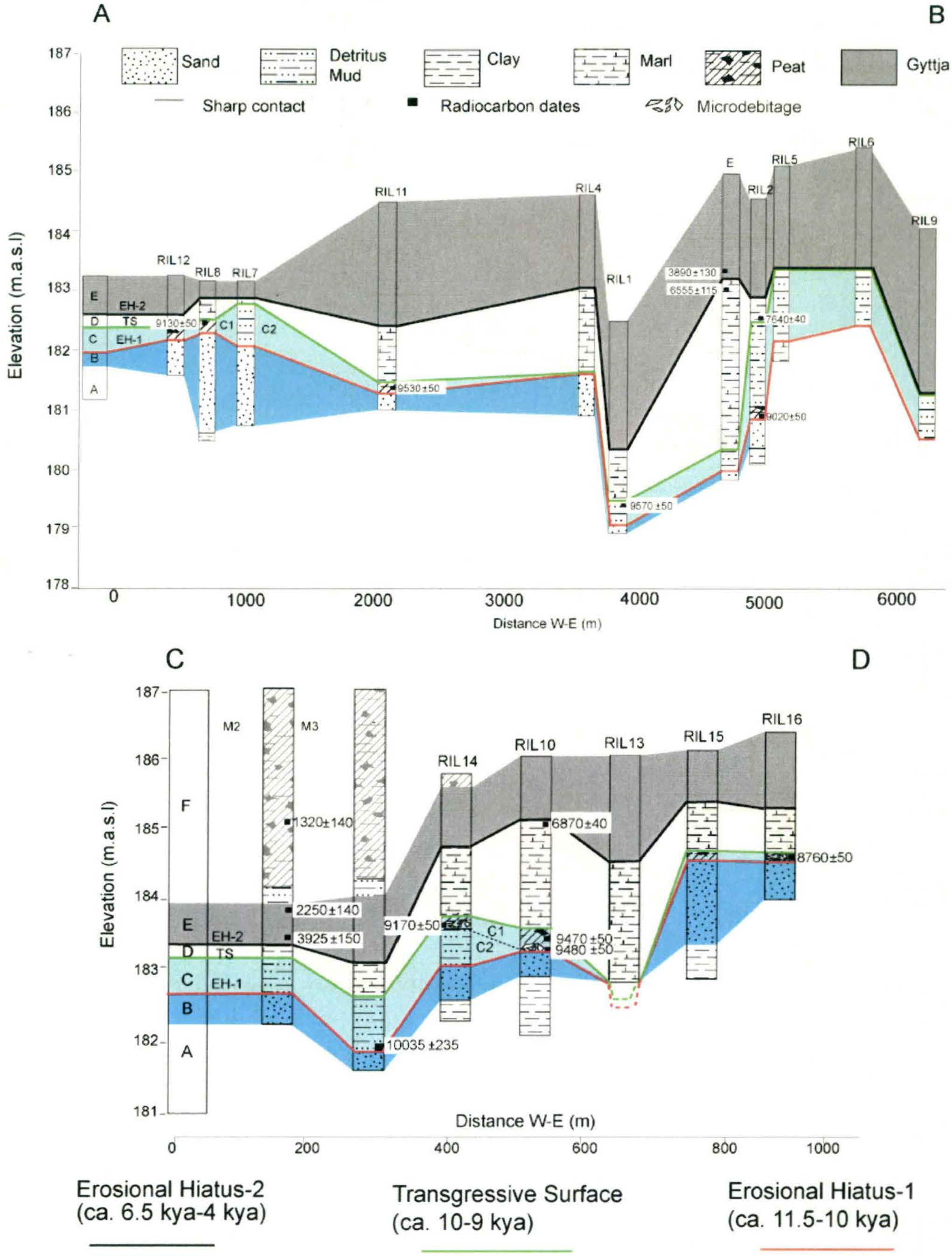


Figure 4.4: Lithostratigraphic profiles for open lake (A-B) and McIntyre basin (C-D) without corrections for isostatic tilt. Two major lowstand phases are indicated by erosional hiatuses (EH-1, EH-2) at base of Holocene sequence (Unit B/C boundary; ca. 11.5-10 ka) and at the mid-Holocene marl-gyttja contact (Unit D/E boundary; ca. 6.5-4 ka). The Early Holocene recovery in water levels, following the EH-1 lowstand, is recorded by a transgressive surface (TS) at the Unit C/D contact. Note the difference in thickness and elevations of top of marl (Unit D) in basin cores versus open lake cores (M2, M2 and RIL-11). All ^{14}C dates are conventional radiocarbon ages BP.

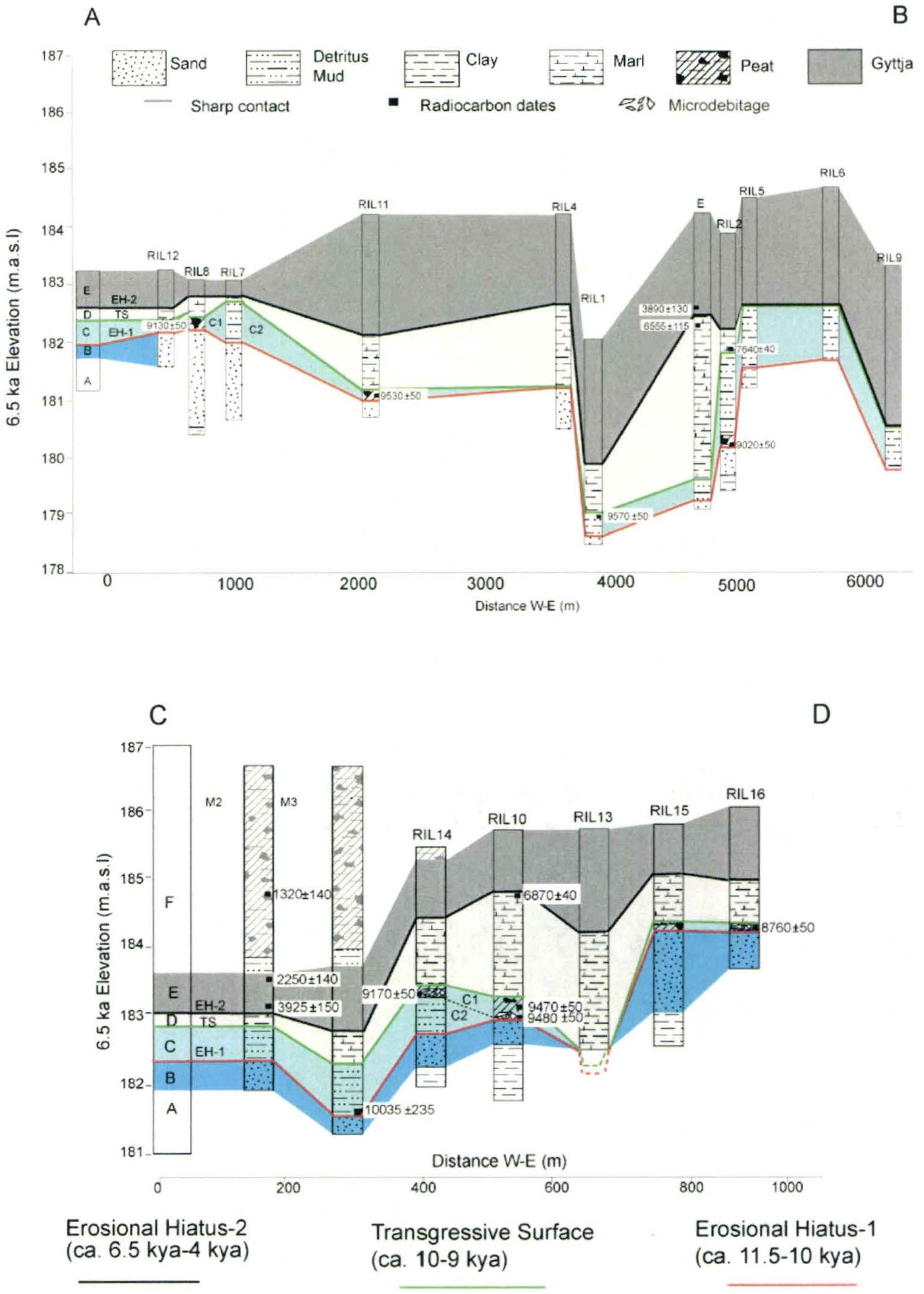


Figure 4.5: Isostatic tilt-corrected lithostratigraphic profiles for the open lake (A-B) and McIntyre basin (C-D) at 6.5 ka BP. Prior to 6.5 ka BP, the basin was connected with the open lake and subsequently became a hydrologically closed 'kettle lake' during the mid-Holocene lowstand. The marl (Unit D) was selectively preserved within the basin during the hydrologically closed phase. All ^{14}C dates are conventional radiocarbon ages BP.

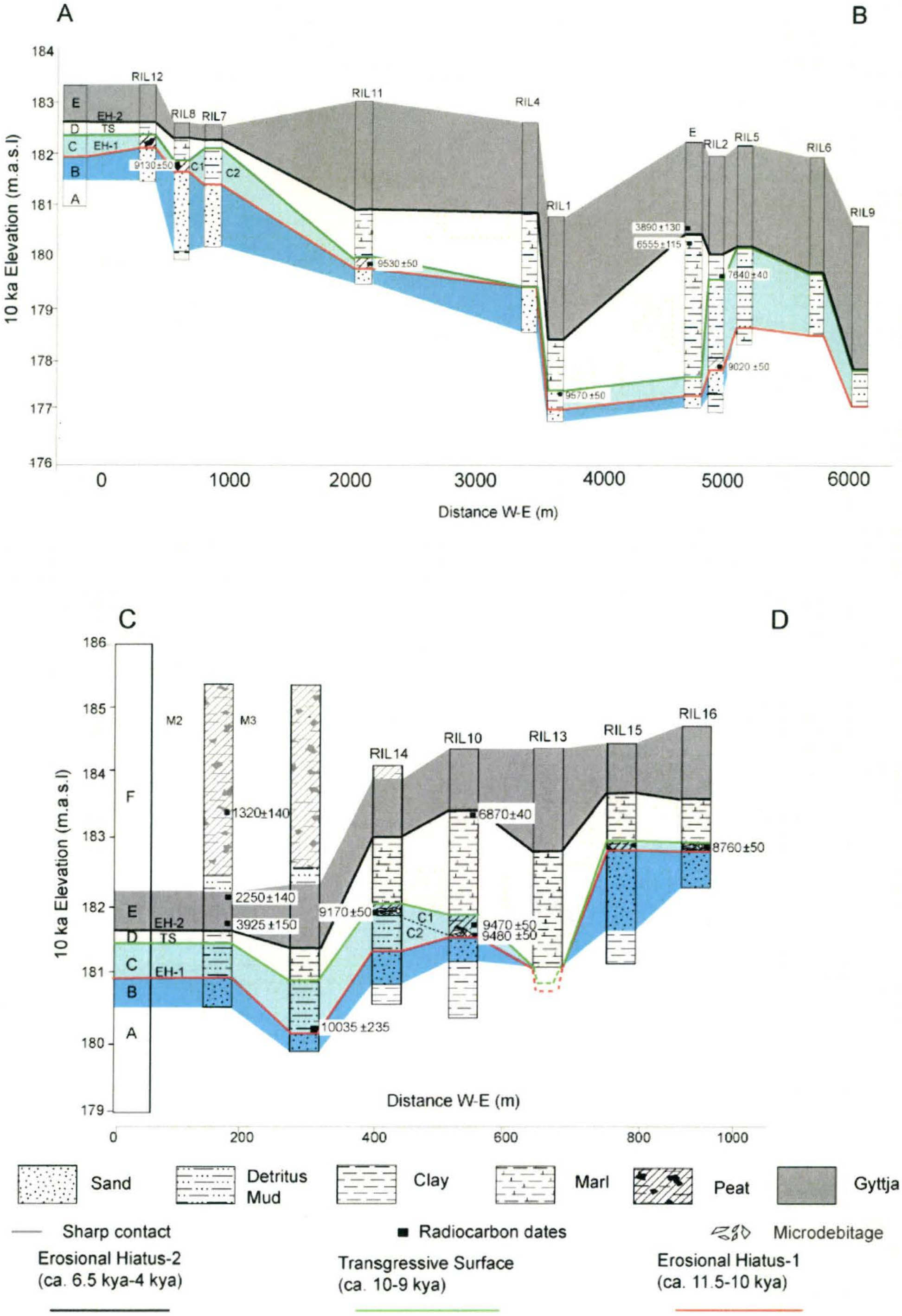


Figure 4.6. Isostatic tilt-corrected lithostratigraphic profiles for the open lake (A-B) and McIntyre basin (C-D) at 10 ka BP. Note dramatic change in elevation of cores in the eastern part of the basin (e.g. RIL-9) as a result of a differential uplift of more than 4 m (Fig. 4.4). All ^{14}C dates are conventional radiocarbon ages BP.

The zero metre isobase indicates the intersection between the modern lake surface at 187 m a.s.l. and the tilted Lake Iroquois water plane (Fig. 4.2). The area of modern lakebed that lies to the northeast of the zero isobase was formerly at a lower elevation than the Lake Iroquois water plane, and would have been inundated during the expansion of the glacial lake. The zero isobase, which is equivalent to the dam-controlled modern lake level (187 m a.s.l.), provides a convenient reference datum for reconstruction of past Holocene water levels and is used in this study as a datum for the tilt-corrected core elevations (Figs. 4.5, 4.6).

Sedimentation rates were calculated using core stratigraphic data and radiocarbon chronology from 10 new AMS ^{14}C dates and 6 bulk ^{14}C dates from two previous studies (McAndrews 1984; Yu and McAndrews 1994). The sedimentation rates were calculated for each lithostratigraphic interval as well as the cumulative rate for the entire core (Table 4.1). The interval sedimentation rates were based on individual unit thicknesses and bracketing radiocarbon ages where available.

4.3.3 Water Level Curves

Water level curves were constructed for the open lake and McIntyre basin using available ^{14}C dates and selected lithostratigraphic boundaries that are indicators of either *low water levels* or *shoreline transgression* (Figs. 4.5, 4.6, 4.7). Two major low water level phases (lowstands) are indicated in the core by sediment erosional hiatuses (Figs. 4.4, 4.5, 4.6): one at the base of the Holocene sequence (EH-1) and a second in mid-core (EH-2), recording a mid-Holocene phase of lower lake levels and sub-aerial erosion of the lakebed after 6.5 ka BP (Yu and McAndrews 1994; Chapter 3).

Unit	Interval Sedimentation Rates		Unit	Cumulative Sedimentation Rates	
	Main Basin	McIntrye Basin		Main Basin	McIntyre
B	0.098	0.112	C	0.030	0.025
C	0.028	0.013	D	0.028	0.015
D	0.030	0.033	E	0.037	0.088
E	0.038	0.087			

Table 4.1: Interval and cumulative sedimentation rates ($cmyr^{-1}$) for open lake (Main Basin) and McIntyre basin.

The EH-1 boundary is identified in cores by a distinctive peat and silty, organic-rich mud layer (Units C_1, C_2 respectively) that overlies Lake Iroquois laminated mud and sand (Unit A, B) across a sharp, erosive contact (Figs. 4.4, 4.5, 4.6). Radiocarbon dates were not obtained on the Lake Iroquois sediments but these deposits can be inferred to be ca. 12.5-12 ka old based on previous ^{14}C age determinations (Coakley and Karrow, 1994; Jackson, et al., 2000). The ^{14}C dating of the silty muds (Unit C_2) just above the EH-1 contact yielded early Holocene ages (10,035±235-9020±50 BP) indicating a ~2 ka period of erosion following the drainage of Lake Iroquois. The maximum low water level during the EH-1 lowstand (~ 10 m bpl; Fig. 4.7) was estimated from the tilt-corrected down-core depth to the Unit B/C boundary in cores RIL-1, and RIL-9 (Fig. 4.6).

The EH-2 erosional hiatus is marked by a sharp transition from laminated marl (Unit D) to organic-rich gytjja (Unit E) in all cores (Figs. 4.4, 4.5, 4.6). Bracketing ^{14}C ages above and below the EH-2 boundary (6870±40 and 3890±120 BP) indicate an extended period of erosion (~ 3 ka) that corresponds with a mid-Holocene period of warmer, drier climate in southern Ontario (Bartlien and Webb, 1985; Edwards and Fritz, 1988; Yu and McAndrews, 1994). The marl deposits contain abundant seeds of submerged aquatic plants (*Najas flexilis;* section 4.4.1) and were deposited in a lake environment with water depths of at least 1-2 m (Yu and McAndrews, 1994). Accordingly, the lake water levels during the pre-hiatus phase of marl accumulation (ca. 7.5-6.5 ka BP) were estimated using available ^{14}C dates for the marl and assuming a minimum water depth of 2 m for accumulation of marl sediment with *Najas flexilus* seeds (Fasset et al., 2000). These provide only a minimum water depth estimate, as the total vertical thickness of marl removed by erosion during the EH-2 lowstand is unknown. For the EH-2 lowstand phase (6.5 to 4 ka BP) the water level curve assumes that the marl was sub-aerially exposed prior to the deposition of the Unit E gytjja (Fig. 4.6). The available ^{14}C dates from cores M3 and E (Figs. 4.4, 4.5) suggest that the EH-2 lowstand water levels were between 4 and 6.5 m bpl by 4 ka BP.

A third water level indicator is provided by a transgressive surface (TS) that occurs at the gradational contact between the peat and silty-mud (Units C_1 and C_2) and overlying marls (Unit D). The silty-mud/peat is of Early Holocene age (ca. 9570±50-8760±50 BP) and contains plant macrofossils and soil thecamoebian assemblages that are characteristic of wetland environments (see section 4.4.1)(McAndrews, 1984; Chapter 2, 3). The transition from the shallow water/wetland facies (Unit C) to the deeper water marl sequence (Unit D) signals a basin-wide rise in water levels and inundation of wetlands established on the Iroquois lake plain after 12 ka BP (Chapter 3). The transgression of the wetland shoreline can be seen clearly in both the open lake and in the basin cores in

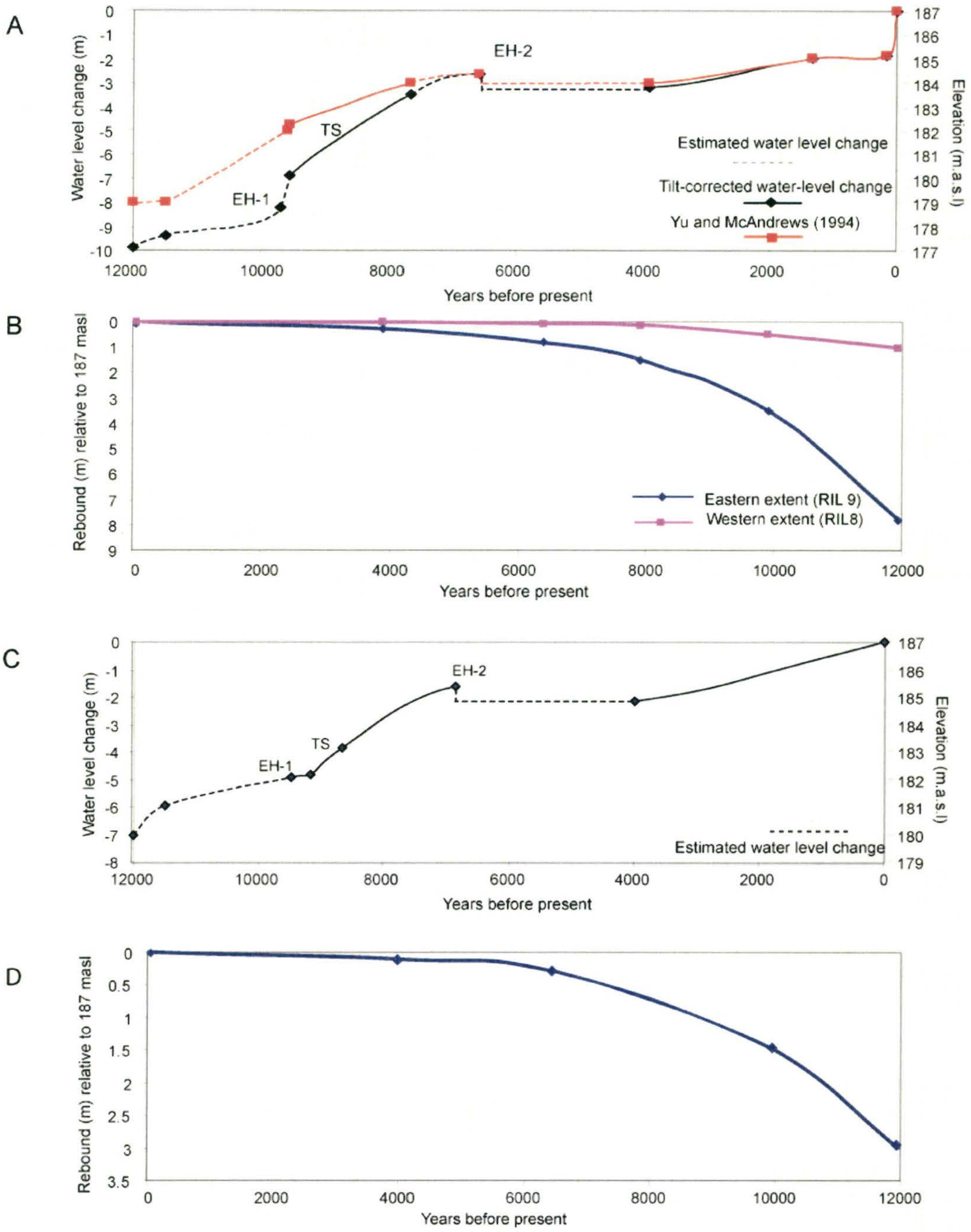


Figure 4.7: A) Tilt-corrected water level curve for the main basin with water levels of Yu and McAndrews (1994) for comparison. Water levels are shown as the change in water plane elevation in metres relative to modern lake level (187 m a.s.l.). Note declining differences in the two curves due to decay in isostatic rebound. B) Isostatic rebound curve for main basin of Rice Lake calculated using exponential decay model (Anderson and Lewis, 1985; Coakley and Karrow, 1994). C) Water level curve for McIntyre basin. D) Isostatic rebound curve for McIntyre basin.

the declining age of the peat deposits at higher elevations. In the open lake for example, the peat has an age of 9530±50 BP at 7.2 m bpl (RIL-11) and further up basin slope is 9130±50 BP at a depth of 5.4 m bpl (RIL-8) (Fig. 4.6). A similar trend is seen in the McIntyre basin, where the shoreline transgressed 1 m between 9470±50 BP (RIL-10) and 8760±50 BP (RIL-16) (Fig. 4.6).

4.3.3. Digital Elevation and Bathymetric Models

Digital elevation and bathymetric models (DEBM's) were created at three different scales to permit detailed modeling of paleoshoreline positions and paleogeographic reconstruction at site- to basin-wide scales (Figs. 4.1, 4.8, 4.9, 4.10). The DEBM's for the 30-km^2 detailed survey area and McIntyre basin were constructed using available digital topographic data (Ontario Base Map, 1:10,000) and newly acquired single-beam bathymetric data (Fig. 4.1B). The topographic and bathymetry data were integrated as a point database in Oasis Montaj^{TM} software and gridded and interpolated using a minimum curvature algorithm with 2 m grid cells (Briggs, 1974). For the basin-scale DEBM (Figs. 4.1, 4.10) the digitized generalized bathymetric contours from the navigation chart were combined with 1:10,000 digital elevation data and gridded at a 10 m resolution using minimum curvature gridding algorithm (Briggs, 1974).

Corrections for isostatic tilt of the Rice Lake basin were applied to all DEBM's using a grid subtraction method modified from Coakley and Karrow (1994). As a first step, the cumulative isostatic rebound was calculated at three different time steps (10-9 ka BP, 7.5-6.5 ka BP, 4 ka BP) using an exponentially decaying uplift model developed by for the Lake Ontario basin (Anderson and Lewis, 1985) given by:

$$U_{(t)} = U_{tot}\, e^{-k(T-t)}$$

where $U_{(t)}$ is the uplift remaining at time (t), U_{tot} is the total uplift since reference time (T), and (k) is a relaxation coefficient representing the time required for the total uplift to be reduced to 1/e or 2.71 of its original value (Coakley and Karrow, 1994). U_{tot} in this study represents the total cumulative isostatic uplift since 12.5 ka BP and is equivalent to the titled Lake Iroquois water plane in Figure 4.2B. A relaxation coefficient (k) of 0.404 determined for the Lake Ontario (Anderson and Lewis, 1985) was used in this study. The tilt-corrected DEBM was created for each time step by grid subtraction of the estimated rebound value (m) for every node in the input (uncorrected) DEBM grid.

A sediment back-stripping correction was applied to each tilt-corrected DEBM grid to account for the thickness of sediment that has accumulated since each Holocene time interval. Sediment accumulation rates determined from core data (Table 4.1) were employed to calculate an average sediment thickness, which was then subtracted from the bathymetric grid nodes (lake-bottom) in each DEBM grid. The final back-stripped and tilt-corrected grids thus provide an estimate of the *paleobathymetry* of the lake basin at each time interval (Figs. 4.8, 4.9).

In a final step, the paleoshoreline positions were plotted on the tilt-corrected DEBM's for each time step using the water depth curves (Fig. 4.7). The shoreline elevations were calculated for both a minimum and maximum water plane elevation by subtraction of the estimated water depths from the modern lake level (187 m a.s.l.) (Figs.

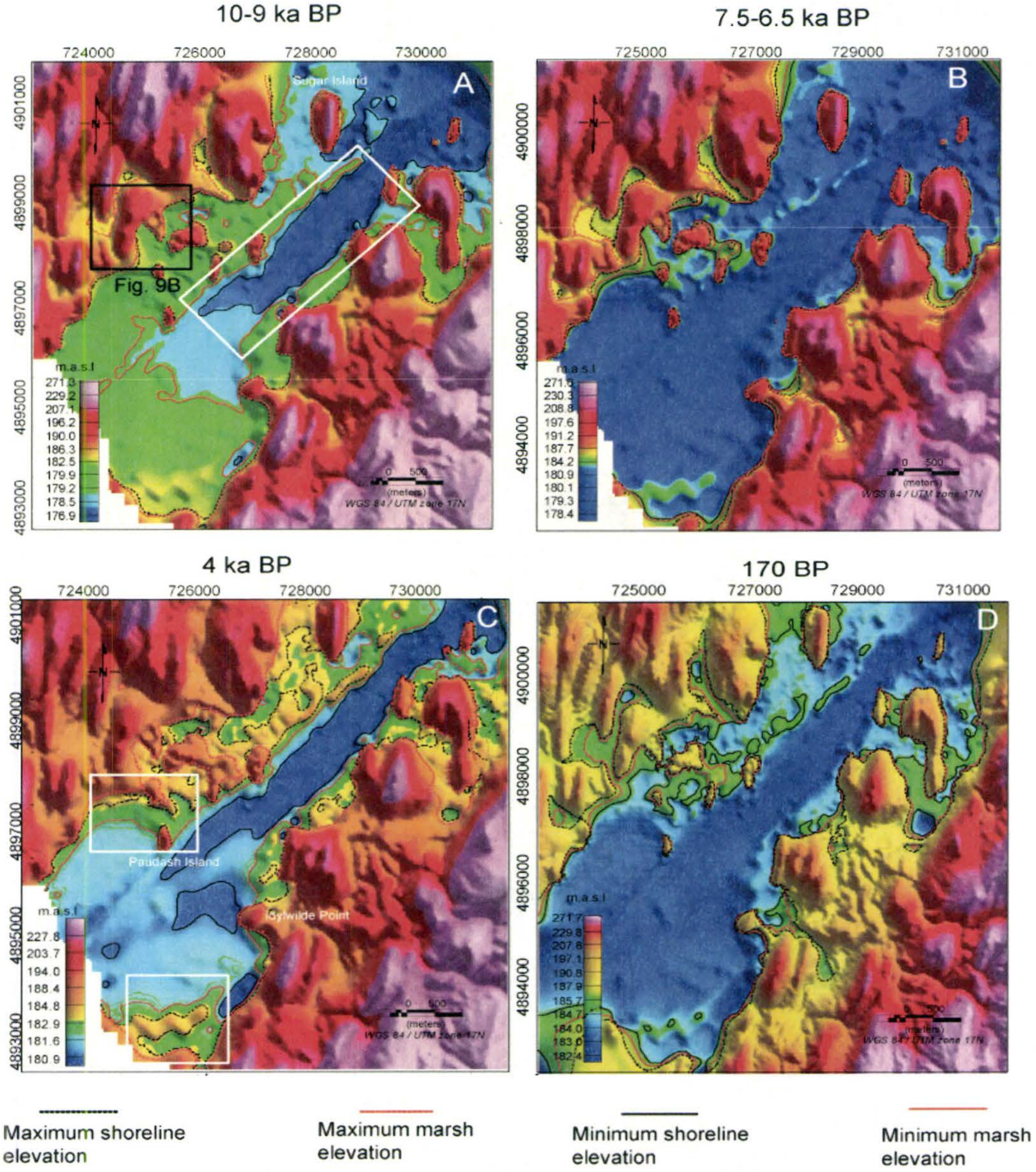


Figure 4.8: Paleogeographic maps showing changes in shoreline positions and extent of wetlands for 30-km^2 detailed study area. A) 10-9 ka BP, B) 7.5-6.5 ka BP, C) 4 ka BP, D) 170 BP (pre-dam). Note changes in lake and wetland extents due to isostatic uplift. White boxes indicate locations of paleoshoreline features. Small black box at 10 ka BP shows the location of the McIntyre basin (Fig. 4.9B). Note the McIntyre basin is hydrologically-closed and separate from the main lake during the Early Holocene (10-9 ka BP) and mid-Holocene lowstand events (4 ka BP). The maximum and minimum shoreline and marsh elevations show the change in water levels and wetland extents for each time step.

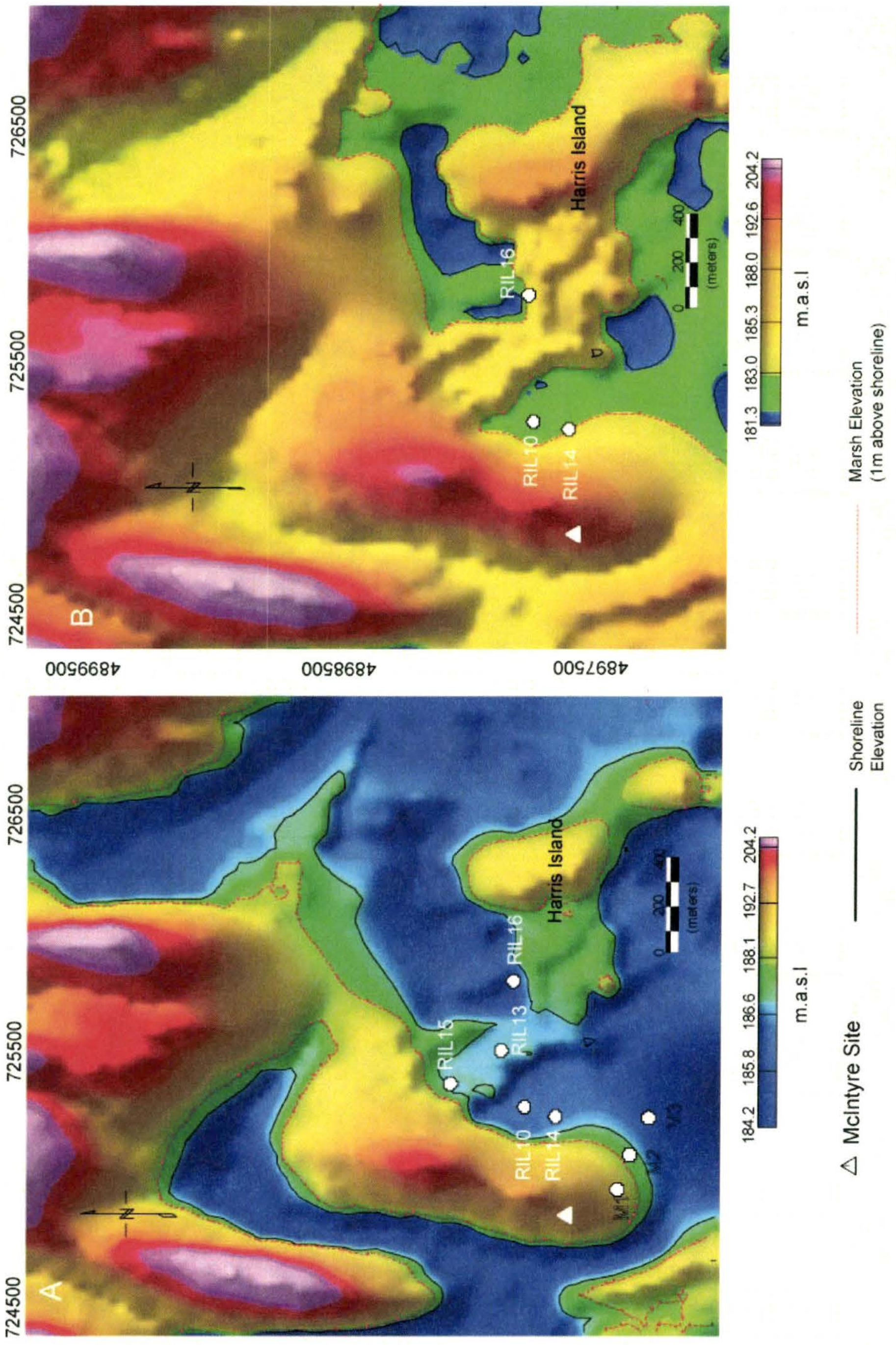


Figure 4.9: DEBM for McIntyre basin showing A) modern shoreline and B) 10 ka BP paleoshoreline. Note at 10 ka BP the basin was hydrologically-close, separate from the main lake basin with fringing marshes.

4.8, 4.9). The extent of low-lying wetland areas around shoreline was also estimated as the area of the DEBM's lying at elevations up to 1 m above the maximum water plane.

4.4 Results

4.4.1 Basin Stratigraphy

The cores were sub-divided into 5 distinctive lithostratigraphic units based on lithology and particle size data (Figs. 4.4, 4.5, 4.6; Chapter 3). Units A and B at the base of the cores consist of a coarsening-upward sequence of laminated silty clay and sands with low organic content. These units are barren of thecamoebians and plant macrofossils and are interpreted as glacial Lake Iroquois sediments deposited prior to 12 ka BP. Above Unit B is a sharp transition to an organic-rich muddy silt with abundant woody fragments (Unit C) previously described as 'detritus mud' by Yu and McAndrews (1994). In a number of cores (RIL-14, 15, 16) Unit C silty muds are capped by a 20-40 cm thick peat layer allowing subdivision into to two sub-units (Units C_1, C_2)(Fig. 4.4). Unit C contains shallow water plant macrofossils (Yu and McAndrews 1994) and bog/wetland testate amoebae species that are indicative of shallow wetland environment (Chapter 3). The average sedimentation rate in Unit C in the main basin was 0.028 $cmyr^{-1}$ and 0.12 $cmyr^{-1}$ in the McIntyre basin (Table 4.1). The tilt-corrected stratigraphic profiles show that Unit C is thickest around the basin edges, and is thin or absent in the deeper parts of the basin, consistent with deposition in a shallow-water fringing wetland (Fig. 4.4).

Unit C is overlain by a well-laminated, silt to sandy marl (Unit D) with high carbonate content. Oscillations in the grain size and thecamoebian abundances in Unit D indicate seasonal varves or rhythmite deposition (Chapter 3). Unit D contains abundant shallow water plant macrofossils (e.g. *Najas flexilis*) and thecamoebian assemblages characteristic of an open water oligotrophic lake environment (Chapter 3). The marl units record an increase in water levels and drowning of fringing marshes (Unit C) after ca. 8.5 ka BP. Unit D is truncated erosively by Unit E organic-rich silty mud ('gyttja') that was deposited after 4 ka BP (Fig. 4.4). The gytjja contains shallow water plant taxa and thecamoebians indicating deposition in a shallow eutrophic lake environment. The sedimentation rate during the Unit D marl deposition was on average 0.03 cmyr^{-1} and increased to 0.038-0.088 cmyr^{-1} during deposition of the Unit E gyttja (Table 4.1). In the McIntyre basin, an additional unit (F) consisting of uppermost muddy peat is recognized in cores RIL-14, M2 and M3) closest to the McIntyre archaeological site. Unit F represents the recent accumulation of marsh deposits after 1.3 ka BP (Fig. 4.4) (McAndrews 1984).

Shoreline elevation (m.a.s.l)			
Main Basin	**10-9 ka**	**7.5-6.5 ka**	**4 ka**
Maximum	178	182	181
Minimum	182.5	185	183
McIntyre Basin	**10-8.5 ka**		
Maximum	182		
Minimum	183		

Table 4.2: Estimated water-levels (m.a.s.l) used to reconstruct paleoshorelines. Radiocarbon dates used to determine depths are included in brackets.

4.4.2 Water Levels

The reconstructed water depth curves are shown in Figure 4.7A with the water depth estimates of Yu and McAndrews (1994) for comparison. The two curves show a similar pattern of water level changes but the Yu and McAndrews (1994) data underestimate the water depths between 12-6.5 ka BP due to uncompensated isostatic effects (Fig. 4.7A, B). After 4 ka BP, the curves converge as the isostatic component of water level rise is negligible. The estimated water levels for the 6.5-4 ka lowstand BP are lower in this study because they assume that the levels dropped to the EH-2 boundary (Fig. 4.7A). Both curves show rapid recovery of water-levels after 4 ka BP and an increase of 1.8 m in water-levels at 170 years BP, due to the construction of the Hastings dam in 1838 (Fig. 4.7A).

4.4.3 Paleogeographic Reconstructions

Paleogeographic maps showing the paleoshoreline positions for five selected time periods (12 ka, 10-9 ka, 7.5-6.5 ka, 4 ka and 170 BP) are shown in Figures 4.8, 4.9, and 4.10. The shoreline reconstructions for each time period represent the maximum and minimum estimated paleoshoreline elevations relative to modern lake level (187 m a.s.l.)

4.4.4 Post-Iroquois drainage (12 ka BP)

The drainage of Lake Iroquois after 12 ka BP lowered water levels in the Rice Lake basin to about 10-12 m bpl (Figure 4.7A). Due to isostatic depression of the eastern outlet, the lake was much more limited in extent than present and restricted to the northeastern portion of the Rice Lake basin (Fig. 4.10). The lake surface area was approximately 40 km^2 with a maximum water depth of about 6 m. The wetland area surrounding the low level lake was approximately 45 km^2. Because of the isostatic downwarp of the eastern end of the lake basin, a large area of the Trent River and Ouse River valley in northeastern Rice Lake were inundated (Figure 4.10).

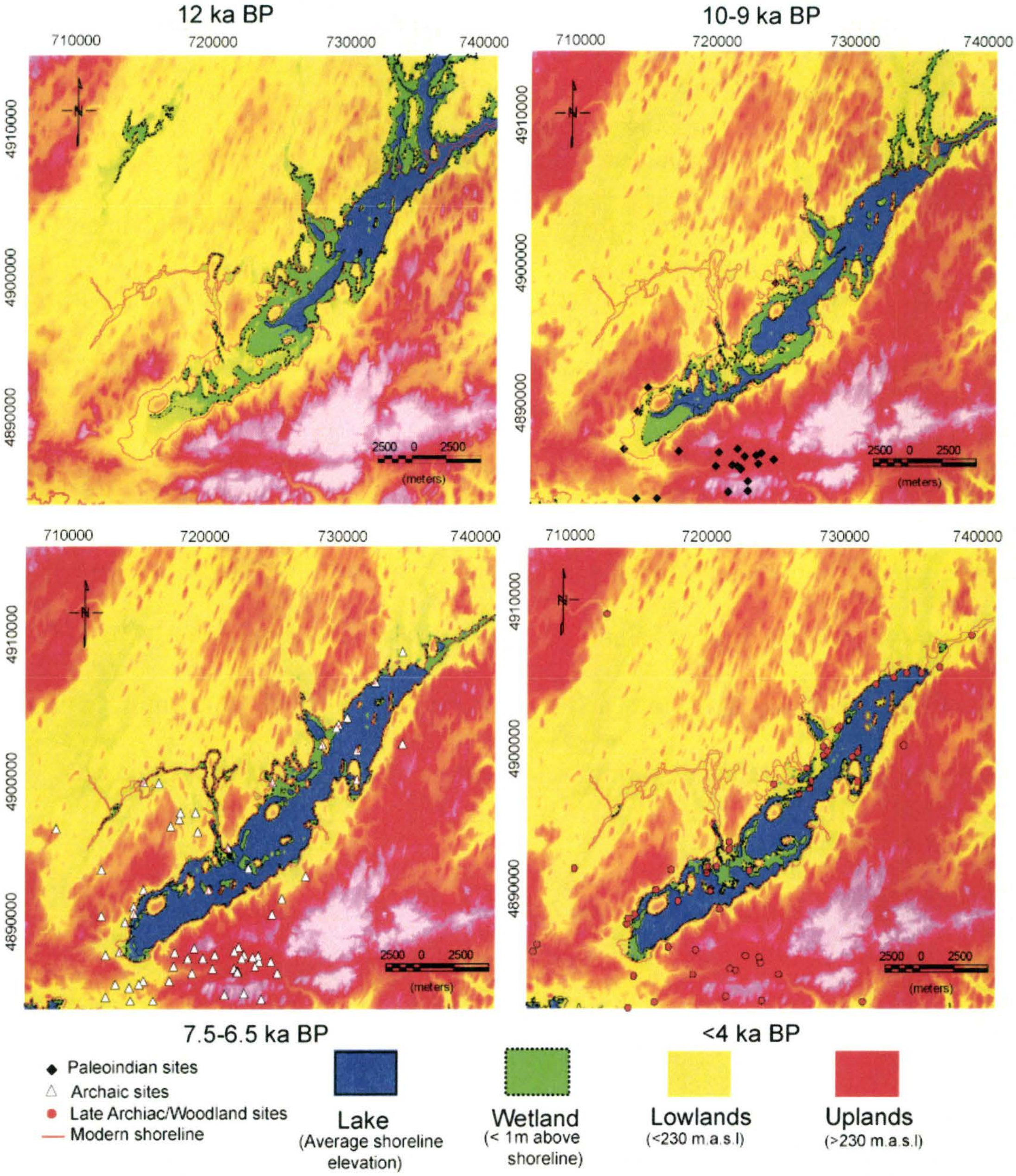


Figure 4.10: Paleogeographic maps showing Holocene shoreline positions and extent of wetlands, lowlands and upland areas. Location of known archaeological sites for each time period also shown. Note greatly reduced lake surface area and extensive wetlands between12-9 ka BP. These wetland areas are now submerged below modern lake levels and are areas with high archaeological potential.

4.4.5 Early Holocene Water Level Recovery (10-9 ka BP)

After 10 ka BP, water-levels had begun to rise in response to isostatic uplift of the basin outlet and the lake basin expanded westward (Fig. 4.7). Water levels were about 7 m lower than present and sections of the southeastern shoreline were still above the modern lake level (Fig. 4.10). Isostatic uplift of (~ 4 m) of the outlet (Fig. 4.7B) caused the paleoshoreline to shift almost 5 km southwestward and increased water levels to ~ 9 m bpl at the western end of the basin. The lake surface area had expanded to >50 km^2 and new wetland areas (35 km^2) had developed to the southwest as the preglacial river valley flooded (Figure 4.10).

The detailed 30-km^2 DEBM (Fig.4.8) shows further details as to water-level changes and paleoshorelines. At 10 ka BP the lake was a narrow (< 1 km) northeast-trending basin with well-defined shorelines and steep basin side slopes. The maximum lowstand shoreline (~ 9 m bpl at 10 ka) during this phase is delineated by a linear strandline feature to the south of East Sugar Island (Fig. 4.8A). The narrow lowstand lake basin is an expression of the original glacially-over-deepened valley that underlies Rice Lake (Gravenor, 1957). By 9 ka BP, the shoreline had quickly transgressed as a result of rapid water level rise of about ~ 3 m in 1 ka (Fig. 4.7A).

During this phase the McIntyre basin was a separate, closed basin lying at elevation of about 2 m above the Rice Lake paleoshoreline (Fig. 4.9B). The water depth was less than 1 m based on the abundance of peat deposits (Unit C; RIL-10, 14, 16; Fig. 4.4) and the basin was divided by a spit connected to Harris Island (Fig. 4.9A). The ages of Unit C peat deposits clearly indicate transgression of the basin shoreline between 9.5-8.6 ka BP. The Unit C_1 peat contains microdebitage, indicating that Paleoindian/Early

Archaic peoples had utilized the McIntyre basin for resource procurement. The testate amoebae assemblages from the McIntyre basin (Chapter 3) are distinctive from the open lake and support the existence of a terminal lake, separate from the main basin.

4.4.5 Highstand (7.5-6.5 ka BP)

By 7.5 ka BP, water-levels in the main basin had gradually increased due to continued isostatic uplift and a shift to cooler, wetter climate (the Younger Dryas) (Yu, 1997). (Figs. 4.7A, B). The rise in lake levels during this period is recorded by marl deposition over wetland peat deposits (TS) (Fig. 4.5). The paleoshoreline elevation during this phase was about 2 m below present and the lake had a surface area of approximately 100 km^2, which is close to modern open water area (125 km^2) of Rice Lake. The expansion of the lake during the highstand decreased the available wetland habitat to < 16 km^2 (Fig. 4.10).

Core data indicate that marl was accumulating in the McIntyre basin during the highstand but the thecamoebian data and elevations of the Unit D/E boundary suggest that the basin was still isolated from the main lake. The top of the marl/gytjja contact in the McIntyre basin is at a higher elevation (185 m a.s.l.) than nearby main lake cores (M2, M3; 184 m a.s.l.) (Figs. 4.4, 4.5) supporting the presence of higher water levels and terminal lake in the McIntyre basin.

4.4.6 Mid- Holocene Lowstand (< 6.5-4 ka YBP)

The erosional hiatus (EH-2) marks a period of dramatically lowered water-levels (6.8-3.7 m bpl; Fig. 4.7A) that coincides with a phase of drier, warmer mid-Holocene climate in southern Ontario (Yu and McAndrews, 1994; Yu, et al., 1997). The minimum elevation of the paleoshoreline can only be estimated assuming that water levels dropped to the EH-2 boundary, as regressive shorelines recording falling water levels are not evident in the bathymetry. Based on the EH-2 datum, the lake shoreline elevation was approximately 184 m a.s.l., about one metre below the outlet sill at Hastings (185 m a.s.l.) and the main lake had entered a hydrologically-closed phase (Fig. 4.10). The lake had an open water surface area of about 62 km^2 and the extent of wetlands had increased to over 20 km^2 (Fig. 4.10). As a result of the water level decline, several islands in the middle portion of the lake were connected to the mainland via a narrow peninsula extending southeastward from the Otonabee River to Idylwilde Point. The detailed paleogeographic reconstruction also shows a number of smaller peninsulas extending from the shoreline, including a spit at Paudash Island (Fig. 4.8C). A large portion of the Indian River mouth and delta was also exposed during this phase.

4.4.7 Post-dam Construction

Water-levels after 4 ka BP gradually rose an additional 2 m reaching the level of the eastern bedrock sill and re-establishing lake outflow between 1-2 ka ago (Fig. 4.7A). Water levels were maintained at this level until 1838, when the dam built at Hastings rapidly increased water-levels 1.8 m above the bedrock sill to the modern level (187 m.a.s.l) (Figs. 4.1, 4.7A). Prior to dam construction, the shallow water areas of the lake were host to extensive stands of wild rice, a plant adapted to annual water-level fluctuations; the stabilization of water-levels after dam construction destroyed many of these stands (Yu and McAndrews, 1994).

4.5. Discussion and Archaeological Implications

The paleogeographic reconstructions demonstrate that the prehistoric landscapes encountered by the first Paleoindian settlers and Archaic peoples were substantially different from the modern landscape (Figs 4.8, 4.9). Rapid changes in the Early Holocene water levels resulted in dramatic changes in the configuration of paleoshorelines and the distribution of wetland areas at Rice Lake. The transgression of the shoreline between 10-9 ka BP was particularly dramatic (Fig. 4.7A), and would have placed important constraints on prehistoric settlement and resource procurement strategies. These archaeological implications are discussed in the following sections and areas with high archaeological potential for underwater prehistoric sites are identified with reference to Figure 4.11.

4.5.1 Paleoindian Settlement (11-9 ka BP)

When the first Paleoindians settled at Rice Lake, the area was a series of ponds and small rivers, surrounded by fringing marsh and boreal forest (Fig. 4.10) (Chapter 3). All known terrestrial Paleoindian sites cluster almost exclusively around the western basin and south of the Oak Ridges Moraine; the only other known Paleoindian sites are located at McIntyre and East Sugar Island (Fig. 4.10). The reason for the lack of Paleoindian sites in the eastern section of the basin and the general paucity throughout the rest of the Rice Lake area is due to inundation of sites during the Early Holocene transgression (such as the McIntyre basin), but also that sites may have actually been sited away from the modern shoreline (e.g. Halstead). Since isostatic uplift has raised the eastern portion of the basin (Fig. 4.10), there may be the possibility of locating uplifted marsh and shoreline sites. As demonstrated by the finds at the McIntyre basin, Paleoindian peoples were likely exploiting wetland resources along with large game.

Early Paleoindian (ca. 11 ka BP) sites along the western extent (see Fig. 4.10) of the lake are representative of near-basin processing sites (Sandy Ridge), far basin residential sites (Halstead) and isolated butchering sites at the basin's western extent (Jackson 1998)(Fig. 4.10). The Sandy Ridge site, located near wetland resources, may represent wetland and aquatic resource extraction, such as fishing, aquatic plant gathering and waterfowl in addition to large mammal processing. Core RIL-10 which contained evidence of occupation from the Late Paleoindian period (ca. 9.5 ka BP) is located at the edge of a spit-like feature surrounded by small ponds and marsh. The McIntyre terrestrial site has been interpreted as a residential/logistical site (Johnston, 1984) with the scattered microdebitage finds in the basin itself possibly representing nearby logistical sites of wetland resource procurement.

4.5.2 Archaic Settlement (9-3 ka BP)

Based on known archaeological finds, it is unclear whether Archaic peoples were a different group that migrated to the area, or whether they are related to earlier Paleoindian peoples (Ellis et al., 1990). What is clear is a change in lithic technology from large well-formed projectile points made of exotic materials to a locally derived generalized tool-kit. It is has been speculated that this change in technology is due in part to environmental change (Ellis, et al., 1990; Mason, 1981). Water-level and paleogeographic reconstructions of this time period clearly indicate that these peoples were faced with a constantly changing environment.

While Early Archaic sites are better represented in Rice Lake than Paleoindian sites, the number of sites and site types is still relatively low compared with Late Archaic and Woodland sites. While this may be a result of archaeological visibility (many of the late Archaic and Woodland sites are simply larger and have more material to recover), the lack of sites may also be partially due to rising water-levels. Many of the known Mid to Late Archaic sites are on higher ground (Fig. 4.10), as water-levels rose and possibly drowned previous shoreline occupations. After 6500 YBP, when water-levels dropped, it is possible that some Archaic people would have exploited the increased marsh areas that were now available (Figs. 4.8, 4.10). However, the sedimentological, palynological and radiocarbon records indicate that any sites located in the lake basin between 6.5 and 4 ka BP have likely been destroyed by erosion during this lowstand period.

4.5.3 Late Archaic/Early Woodland Settlement (< 4 ka BP)

The reestablishment of higher and more stable water-levels after 4 ka BP (Fig. 4.7A) may partially explain the large number and extent of sites that have been discovered from this time period (Fig. 4.10). The main occupation of the McIntyre site dates from this time period. Woodland terrestrial sites are typically on lower ground, clustered around river mouths and along the shoreline. More sites are found at the eastern extent of the basin, possibly because of their visual proximity to Serpent Mounds (Dillane, 2010, pers.comm.) (Fig.4.1). The re-establishment of higher water-levels and larger areas of marsh are also conducive to the establishment of wild rice. This was an extremely important resource (and where the lake gets its name) until 1838, when the raised water-levels from the Hastings dam destroyed many of the wild rice stands (McAndrews, 1984).

4.5.4 Areas of Archaeological Potential

Figure 4.11 shows a compilation of the reconstructed paleoshorelines for the main settlement time periods (10, 6.5 and 4 ka BP) with areas of archaeological potential indicated. During the Paleoindian time period, the eastern portion of the Rice Lake basin was flooded to a level above the modern shoreline. Any settlements in this area would now be raised in elevation due to differential isostatic uplift of the basin outlet. Sites with high potential for Paleoindian sites include uplifted terraces and marsh deposits to the northeast of the modern shoreline (Fig. 4.11A). Other areas to be investigated would include the now flooded mouths of the Indian and Otonobee Rivers, which were open wetlands during the Paleoindian and Early Archaic phases (Fig.4.11B, D) and the submerged areas of the modern lakebed between the Paleoindian (green) and Archaic (red) shorelines. These areas would have been wetland environments with abundant resources. The area surrounding the McIntyre site, which has already yielded archaeological evidence, may also have provided small ponds and wetlands for resource extraction (Fig. 4.11B). Some of these ponds are semi-enclosed depressions that began as spring-fed kettle lakes (Chapter 3).

More existing terrestrial sites (50+) are located along the north shore of Rice Lake compared to the south shore (~20) ((Fig. 4.1). These include sites located on drumlin uplands and sites adjacent to the modern shoreline. The higher site density on the north shore may be due to a number of different factors; more development on the north shore has unearthed more sites, the focus of archaeological survey has been on the north shore (following Lake Iroquois strandlines amongst numerous other reasons) or that the environmental conditions were more favourable on the north shore. On the south

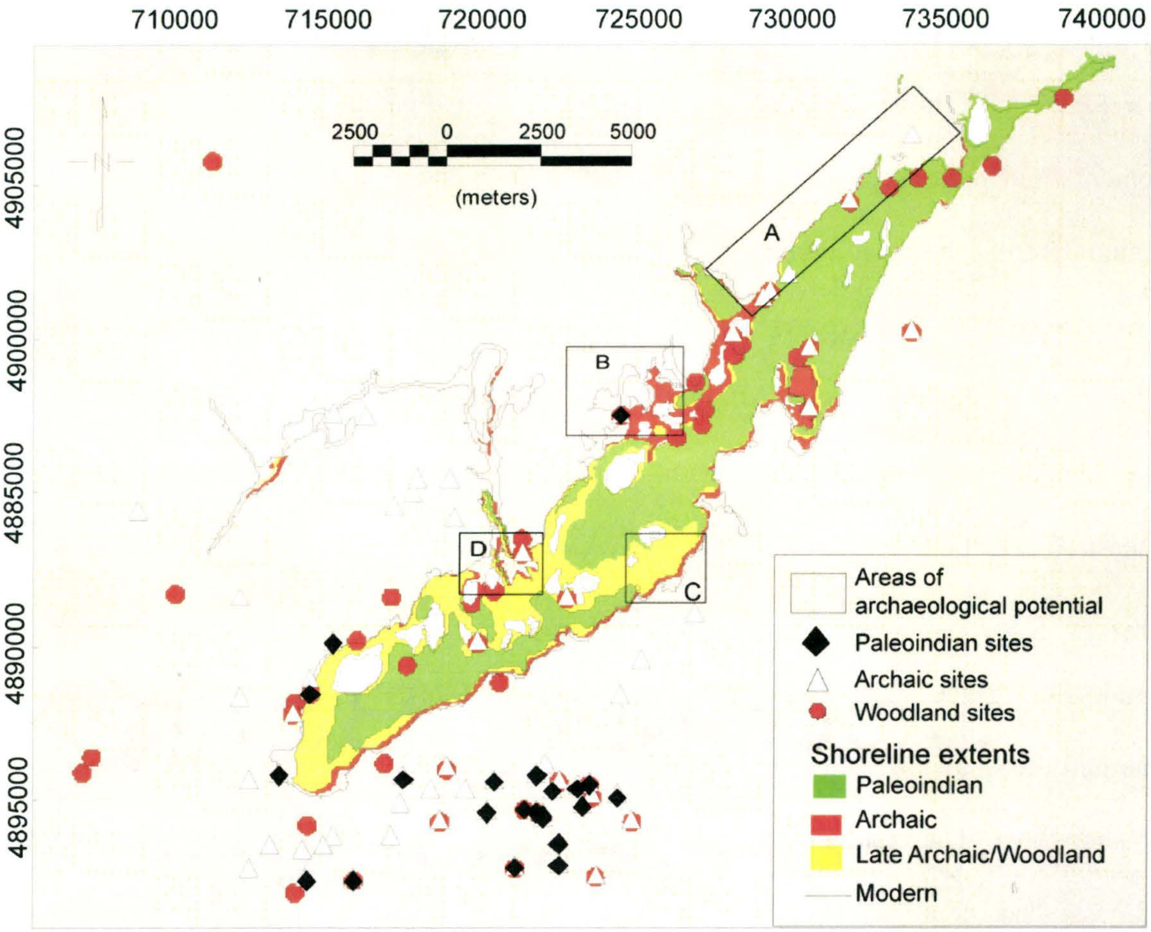


Figure 4.11: Shoreline extents, known terrestrial sites and areas of archaeological potential of Rice Lake. A. Area of potential uplifted Paleoindian sites. B. Area of archaeological potential based on proximity and environmental similarity to the McIntyre site. C. Area of southern shore that has not been adequately surveyed previously. D. Mouth of the Otonobee River, which may also include Late Archaic sites.

shoreline there are a number of areas that meet the criteria for archaeological potential near the few existing Archaic sites (Fig. 4.11C). This area, besides including the boundaries of paleoshorelines, also may have had small ponds and isolated wetlands associated with the edge of the former shorelines. More intensive investigations of a 50 km^2 area to the south of the Oak Ridges Moraine discovered 2 dozen Paleoindian and Archaic sites (Jackson 1998). A similar program of intensive investigation in the area to the northeast of the moraine may yield additional sites as well. This area should be explored more fully to investigate whether the lack of sites is based on fewer archaeological surveys or possible environmental reasons such as poor soils or less available resources.

While evidence of Archaic submerged sites may no longer be visible due to erosion of sediments during the lowstand, the area immediately adjacent to the Otonobee River has potential to have both Paleoindian and Late Archaic sites (Fig. 4.11D). This is the only area that remained exposed during both these time periods; it may be possible that submerged sites exist in this area, buried under sediment from the mouth of the Otonobee. Some early Woodland sites may also be located in this area, as several sites are clustered close to the mouth of the river and on adjacent drumlin islands (Fig. 4.11D).

4.6. Conclusion

While there has been much discussion in the Great Lakes region regarding the potential of submerged landscapes to yield prehistoric archaeological sites (Jackson, et al., 2000; Lovis, et al., 1994), very few detailed surveys have been conducted to locate these sites (O'Shea and Meadows, 2009; Sonnenburg and Boyce, 2008). Previous attempts to map prehistoric shorelines have been hindered by the lack of high-resolution data, as shoreline reconstructions are based on existing low-resolution navigation charts (Jackson, et al., 2000). The other problems that have not been addressed widely are the effects of isostatic movements and basin sedimentation on the location of paleoshorelines. While it has long been acknowledged that isostatic effects greatly affect the water-levels in Great Lakes (Coakley and Karrow, 1994) and also on continental shelf areas (Fedje and Josenhans, 2000; Westley et al., 2010), isostatic and local tectonic effects (i.e. sediment compaction, subsidence) have been largely ignored in paleoshoreline reconstructions. The method of shoreline reconstructions outlined in this paper is the first attempt to combine high-resolution bathymetry data with corrections for isostatic rebound and sediment infill to identify areas of archaeological potential in the Great Lakes.

The 10-9 ka BP paleogeographic reconstruction of Rice Lake shows that large areas of lake basin (ca. 40 km^2) may have been available for human habitation during the Paleoindian period, with up to 36 km^2 of wetland habitat for resource exploitation (Fig. 4.10). The reconstruction of water-levels in Rice Lake and microdebitage finds in Unit C the McIntyre basin clearly shows that many Paleoindian sites could be located under 2-4 m of water and up to 5 m of sediment (Figs 4.2, 4.4). These sites are likely to have good preservation, as wetland testate amoebae assemblages (Unit C) and the lack of erosional features at the TS boundary (Fig. 4.4) all point to rapid burial of intact sub-aerial surfaces. The potential for preservation of organic material of submerged Paleoindian sites in Rice Lake is of particular importance, as preserved organic remains at sites of this time period are extremely rare (Jackson, 1998).

The paleogeographic reconstructions and DEBM's created for this study can be used to create a more detailed archaeological predictive model for Rice Lake based on the approach developed for Boreal forest sites (Dalla Bona, 1994). This approach employs both inductive and deductive modelling methods to allow for integration of environment factors, with cultural variables that may have influenced settlement patterns (i.e. access to resources and cultural/spiritual reasoning). It also uses statistical methods as a means of both discovering and evaluating the association between environmental and cultural variables and potential site locations (Dalla Bona, 1994; Kvamme, 1990). This model is suitable for Rice Lake because of the similarities in the ephemeral nature of the sites being modeled.

Available baseline environmental data and the paleogeographic maps created for this research provide an important fist step for creating a predictive model. The next step would involve creating both inductive and deductive models by identifying variables using statistical methods and existing archaeological knowledge, assigning weighted values and combining them into one predictive model with areas of high, medium and low probability (Dalla Bona, 1994). In order to prove the effectiveness of this approach, ground-truthing needs to be undertaken within Rice Lake to verify the presence of archaeological sites. A series of cores could be collected using a Livingstone piston corer in a closely spaced grid pattern, as is done in preliminary test surveys in terrestrial archaeology (Stein, 1991). The short cores would be sub-sampled at 5-10 cm intervals and screened for lithic fragments (microdebitage) and other archaeological materials (e.g. charcoal, bone). The relative concentration of microdebitage and other materials would be gridded using a Kriging algorithm (Davis, 2002; Fladmark, 1982) to produce a map showing density of cultural finds which could be compared by overlay with the predicted site locations.

This example of the potential approach for creating predictive models for submerged sites in Rice Lake could be applied elsewhere in the Great Lakes. Predictive models for submerged landscapes in the Great Lakes combining detailed geophysical and paleoenvironmental data have not been attempted. The use of these multiple techniques for reconstructing paleoenvironments and areas of archaeological potential in the Great

Lakes can provide key information such as the location of submerged sites, localized wetlands and more accurate shoreline reconstructions. The Great Lakes region has a vast untapped archaeological record that is now underwater. The methods proposed in this study provide new means of investigating these largely unexplored areas. The lack of Early Holocene archaeological sites has greatly hindered understanding of prehistoric resource procurement and settlement strategies. The results of this study provide a much more comprehensive view of the environmental changes and new ways of exploring the submerged archaeological potential of the Great Lakes.

References

Anderson, T.W. and Lewis, C.F.M., 1984. Postglacial water-level history of the Lake Ontario basin. In: P. F. Karrow and P. E. Calkin (Eds.), GAC Special Paper, 30, pp. 231-253. Geological Association of Canada, St. John's.

Briggs, I.C., 1974. Machine contouring using minimum curvature Geophysics 39, 39-48.

Coakley, J.P. and Karrow, P.F., 1994. Reconstruction of post-Iroquois shoreline evolution in western Lake Ontario Canadian Journal of Earth Science 31, 1618-1629.

Coleman, D., 2008. Sinkholes in Lake Huron and the possibility for early human occupation on the submerged Great Lakes shelf. In: R. Ballard (Ed.) Archaeological Oceanography. Princeton University Press, Princeton.

Dalla Bona, L., 1994. Volume 4: A predictive model of prehistoric activity location for Thunder Bay District, OntarioCultural Heritage Resource Predictive Modeling Report, p. 98. Centre for Archaeological Resource Prediction, Lakehead University, Thunder Bay, Ontario.

Davis, J.C., 2002. Statistics and Data Analysis in Geology. John Wiley and Sons, New York, 638p.

Ellis, C., Goodyear, A.C., Morse, D.F. and Tankersley, K.B., 1998. Archaeology of the Pleistocene-Holocene transition in eastern North America Quaternary International 49/50 (151-166).

Ellis, C., Kenyon, I.T. and Spence, M.W., 1990. The Archaic. In: C. Ellis and N. Ferris (Eds.), Archaeology of Southern Ontario to A.D. 1650, pp. 65-124. Ontario Archaeological Society, London.

Fasset, N.C., Hellquist, C.B. and Crow, G.E., 2000. Aquatic and wetland plants of northeastern North America: a revised and enlarged edition of Norman C. Fasset's A manual of aquatic plants. University of Wisconsin Press, Madison.

Fedje, D.W. and Josenhans, H., 2000. Drowned forests and archaeology on the continental shelf of British Columbia, Canada Geology 28, 99-102.

Fladmark, K., 1982. Microdebitage analysis: Initial considerations Journal of Archaeological Science 9 (2), 205-220.

Gravenor, C.P., 1957. Surficial geology of the Lindsey-Peterborough area, Ontario, Victoria, Peterborough, Durham and Northumberland counties, Ontario, 288, p. 60. Geological Survey of Canada.

Holcombe, T.L., Taylor, L.A., Reid, D.F., Warren, J.S., Vincent, P.A. and Herdendorf, C.E., 2003. Revised Lake Erie postglacial lake level history based on new detailed bathymetry Journal of Great Lakes Research 29 (4), 681-704.

Jackson, L.J., 1998. The Sandy Ridge and Halstead Paleo-Indian sites. Museum of Anthropology, University of Michigan, Ann Arbor, Michigan, 165p.

Jackson, L.J., 2004. Changing our view of late Palaeo-Indian in Southern Ontario. In: L. J. Jackson and A. Hinshelwood (Eds.), The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early

Holocene Environments, 165, pp. 25-56. Canadian Museum of Civilization, Ottawa.

Jackson, L.J., Ellis, C., Morgan, A.V. and McAndrews, J.H., 2000. Glacial lake levels and eastern Great Lakes Palaeo-Indians Geoarchaeology 15 (5), 415-440.

Janusas, S.E., Blasco, S.M., McClellan, S. and Lusted, J., 2004. Prehistoric Drainage and Archaeological Implications Across the Submerged Niagara Escarpment North of Tobermory, Ontario. In: L. J. Jackson and A. Hinshelwood (Eds.), The Late Palaeo-Indian Great Lakes: Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments, pp. 303-314. Canadian Museum of Civilization, Ottawa.

Johnston, R.B., 1968. Archaeology of Rice Lake, Ontario. Department of the Secretary of State, Ottawa, Ontario, 49p.

Johnston, R.B., 1976. Preliminary report of the archaeological investigation of the McIntyre Site in 1975. Ministry of Culture and Recreation, Peterborough, ON.

Johnston, R.B., 1984. McIntyre Site: Archaeology, Subsistence and Environment, 126, p. 190. Archaeological Survey of Canada, Ottawa, Ontario.

Karrow, P.F., 2004. Ontario geological events and environmental change in the time of the late Palaeo-Indian and early Archaic cultures (10,500 to 8,500 B.P.). In: L. J. Jackson and A. Hinshelwood (Eds.), The Late Palaeo-Indian Great Lakes; Geological and Archaeological Investigations of Late Pleistocene and Early Holocene Environments, 165, pp. 1-24. Canadian Museum of Civilization, Ottawa.

Karrow, P.F. and Calkin, P.E., 1985. Quaternary Evolution of the Great LakesGAC Special Paper 30, 30. Geological Association of Canada.

Kincare, K., 2007. Response of the St. Joseph River to lake level changes during the last 12,000 years in the Lake Michigan basin Journal of Paleolimnology 37, 383-394.

Kvamme, K., 1990. One-sample test in regional archaeological analysis: new possibilities through computer technique. American Antiquity 55 (2), 367-381.

Lewis, C.F.M., Heil, C.W., Hubney, J.B., King, J.W., Moore Jr., T.C. and Rea, D.K., 2007. The Stanley unconformity in Lake Huron basin: evidence for a climate driven closed lowstand about 7900 ^{14}C BP, with similar implications for the Chippewa lowstand Journal of Paleolimnology 37, 435-452.

Lovis, W.A., Holman, M.B., Monaghan, G.W. and Skowronek, R.K., 1994. Archaeological, geological and paleoecological perspectives on regional research design in the Saginaw Bay Region of Michigan. In: R. I. MacDonald (Ed.) Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties, pp. 81-94. Quaternary Sciences Institute, Waterloo.

Luyendyk, E., 1997. Processing of airborne magnetic data AGSO Journal of Australian Geology and Geophyscis 17, 31-38.

Mason, R.J., 1981. Great Lakes Archaeology. Academic Press, New York, New York, 425p.

McAndrews, J.H., 1984. Late Quaternary vegetation history of Rice Lake, Ontario, and the McIntyre archaeological site. In: R. B. Johnston (Ed.) The McIntyre Site: Archaeology, Subsistence and Environment, 126, pp. 161-189. National Museums of Canada, Ottawa.

Mirynech, E., 1962. Pleistocene geology of the Trenton-Campbellford map-area, OntarioGeology, PhD. University of Toronto, Toronto.

Muller, E.H. and Prest, V.K., 1985. Glacial lakes in the Ontario Basin. In: P. F. Karrow and P. E. Calkin (Eds.), Quaternary Evolution of the Great Lakes, Special Paper 30, pp. 213-229. Geological Association of Canada, St. John's.

O'Shea, J.M. and Meadows, G.A., 2009. Evidence for early hunters beneath the Great Lakes PNAS 106, 10120-10123.

Sonnenburg, E.P., 2006. Paleoenvironmental reconstruction of submerged landscapes in Colonel By Lake using geoarchaeological and geophysical techniquesSchool of Geography and Earth Sciences, M.Sc., p. xv+118. McMaster University, Hamilton, Ontario.

Sonnenburg, E.P. and Boyce, J.I., 2008. Digital bathymetric model and integrated side-scan as a base for archaeological inventory of submerged landscapes in the Rideau Canal (Ontario, Canada) Geoarchaeology 23 (5), 654-674.

Sonnenburg, E.P., Boyce, J.I. and Reinhardt, E.G., 2009. Multi-proxy environmental record of Colonial land-use change in the lower Rideau Canal System (Colonel By Lake), Ontario, Canada Journal of Paleolimnology 42, 515-532.

Stein, J.K., 1991. Coring in CRM and Archaeology: A Reminder American Antiquity 56 (1), 138-142.

Stevens, W., 2002. Underwater Archaeology and the Future of Submerged Cultural Resources on the Trent-Severn Waterway Ontario Archaeology 73, 76-78.

Westley, K., Quinn, R., Forsythe, W., Plets, R., Bell, T., Benetti, S., McGrath, F. and Robinson, R., 2010. Mapping submerged landscapes using multibeam bathymetric data: a case study from the north coast of Ireland International Journal of Nautical Archaeology.

Yu, Z. and McAndrews, J.H., 1994. Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen and plant macrofossil evidence Holocene 4 (2), 141-152.

Yu, Z., McAndrews, J.H. and Eicher, U., 1997. Middle Holocene dry climate caused by change in atmospheric circulation patterns: Evidence from lake levels and stable isotopes Geology 25 (3), 251-254.

Chapter 5: Conclusions

5.1 Summary and Significance of Results

5.1.1 Quartz flakes in lakes: microdebitage evidence for submerged Great Lakes prehistoric (Late Paleoindian-Early Archaic tool-making sites

This paper documents the discovery of new submerged Paleoindian finds at Rice Lake, Ontario. The study is highly innovative, as it is the first time underwater Prehistoric anthropogenic material has been identified through microdebitage analysis of lake sediments in North America or elsewhere. It also represents the first documented evidence for an underwater tool knapping site in the Great Lakes basins. Quartz fragments were extracted from cores in the McIntyre basin in Rice Lake and analyzed under SEM. Fragments with high angularity, flake scars and lack of weathering were identified as microdebitage, providing clear evidence that they are anthropogenic lithic fragments. Microdebitage was restricted to a distinctive detritus-mud/peat unit (Unit C), which was identified as a wetland facies through microfossil (testate amoebae) analysis. The layer that contained the microdebitage was ^{14}C dated to the Paleoindian period (ca. 10 ka BP) and demonstrates how these fragments can identify submerged archaeological sites.

5.1.2 Significance of Results

When Fladmark's landmark 1982 paper was published on the use and identification of microdebitage, one of his suggestions for potential uses was for identifying submerged archaeological sites (Fladmark 1982). Despite much work using microdebitage in the mid-1980s for identifying activity areas in terrestrial archaeological sites (Vance 1986; Hull 1987), until this study, no one had tried to use microdebitage for finding submerged archaeological sites. This research demonstrates that microdebitage can be extracted from lake sediment cores providing evidence (along with appropriate water-level and paleoenvironmental reconstructions) for submerged Paleoindian archaeological sites. This approach is easily implemented and applied broadly to locating submerged sites in the Great Lakes and other submerged landscapes, such as continental shelf environments. Submerged continental shelves may provide evidence of early human migration routes (e.g. first anatomically modern humans out of Africa and the first North Americans)(Bailey and Flemming 2008), however, their underwater context and the vast tracts of potential survey area make it exceedingly difficult to discover archaeological evidence. Microdebitage analysis of existing core data could provide an efficient and cost-effective way of locating evidence of human occupation of continental shelves world-wide.

5.1.3 Multi-proxy lake sediment record of prehistoric (Paleoindian-Archaic) archaeological paleoenvironments at Rice Lake, Ontario, Canada

This paper presents an innovative, multi-proxy approach combining sediment coring, particle size, micropaleontological (testate amoebae) and previously published palynological analysis (Yu and McAndrews 1994) to reconstruct the archaeological paleoenvironments of Rice Lake. Testate amoebae and high-resolution particle size analysis show environmental differences between the main lake basin and the isolated McIntyre basin. The main lake is dominated by *Arcella vulgaris* throughout the Holocene and despite changes in water-levels and environment, the trophic status remains relatively stable. In the McIntyre basin, the appearance of wetland species *Bullinaria* and *Phyraginella* at ca. 10 ka BP within the microdebitage layer provides compelling evidence that this area provided abundant resources for Paleoindian resource procurement. These species were not found in the main lake basin core, which indicates this area of the main basin did not provide the same wetland habitat. The McIntyre basin, in contrast to the open lake, has species indicative of eutrophic environments and a higher overall diversity of species. The post-4 ka BP sediment record, however, is characterized by assemblages and particle size data that are more consistent with the main lake basin. This shift reflects the recovery of water-levels after 4 ka BP, which resulted in the basin becoming hydrologically connected to the main lake.

Comparison of testate amoebae with pollen data from Rice Lake shows that the two data sets are synchronous and responding to the same shifts in environmental conditions. The combination of the two datasets provides a more robust and site-specific paleoenvironmental reconstruction. While pollen was able to determine vegetation changes related to climate changes, the thecamoebians detected small scale water-level fluctuations, identifying the Early Holocene lowstand event (EH-1) ca. 10 ka BP, which was not discernable in the pollen record.

5.1.4 Significance of Results

Testate amoebae have a proven record in reconstructing past lake environments, however their use in archaeology has been limited to wetlands in the UK (Gearey and Caseldine 2006; Plunkett et al. 2009). This is the first time that testate amoebae have been used to reconstruct submerged archaeological landscapes and identify areas of archaeological potential in North America. This study demonstrates the usefulness of multi-proxy analysis, in particular testate amoebae assemblages to gain a better understanding of paleoenvironmental changes applied to archaeological contexts.

Previous paleoenvironmental reconstructions of sediment samples from archaeological sites in the Great Lakes have relied primarily on more coarse resolution (>10 cm intervals) pollen analysis of regional, long-term vegetation changes related to climate. Pollen does not provide information on short-term, site-specific environmental or hydrological changes. High-resolution testate amoebae (5 cm intervals) particle size (1 cm intervals) provide detailed information on differences in the main lake and McIntyre basin trophic status and water-level fluctuations that were not discernable through previous palynological study. In this study, testate amoebae were able to determine differences in water-levels and extent of wetland environments to identify a previously unknown submerged wetland area that was used for resource procurement ca. 10 ka BP (Chapter 2). Previous palynological data was unable to determine the extent of lowered water-levels, and widely dispersed pollen from trees and grasses would not have identified a small (< $1km^2$) isolated basin and fringing wetland. The geophysical data collected for this study would not have been able to identify this environment in this context either, as it was underneath 2.5 m of sediment.

This research also highlights the importance of wetland environments as a location for archaeological materials. While the utilization of wetland resources by prehistoric peoples have been extensively investigated in Europe, they are often neglected in North America as areas of archaeological interest. The discovery of microdebitage in a lithologic unit that was identified as a wetland through testate amoebae analysis, demonstrates that wetland environments played a more important role in the resource strategy of Paleoindian peoples than previously thought (Mason 1981; Jackson 1998). Previous studies have focused on the importance of large game as the primary resource of

Paleoindian peoples, with later Archaic peoples exploiting a wider variety of resources (such as fish and wild rice) (Ellis and Deller 1990; Ellis et al. 1990). The identification of wetland habitats through testate amoebae analysis with archaeological material from the Paleoindian time period provides compelling evidence that these peoples were exploiting a wide variety of resources. The identification of Early Holocene wetlands in the paleoenvironmental record may be an important key to discovering additional Paleoindian sites in the Great Lakes.

5.1.5 Holocene paleoshorelines, water levels and submerged prehistoric site archaeological potential of Rice Lake, Ontario, Canada

The accurate reconstruction of water-level fluctuations in the Great Lakes basins is critical to understanding archaeological potential in submerged contexts. In this paper, changes in the Holocene water levels and shoreline positions at Rice Lake were reconstructed using a digital elevation model (DEM) and core data. The paleo water depths were estimated from ^{14}C-constrained water level indicators in core and the paleoshorelines reconstructed on the DEM following corrections for isostatic tilt of the basin and sediment back-stripping.

Reconstruction of Rice Lake water-levels post-Iroquois drainage shows water-levels at their maximum lowstand (~12 m bpl) at ca. 12 ka BP (EH-1). By 10 ka BP, lake levels had begun to rise but were still at a relative lowstand (~9 m bpl) relative to present lake levels. The Early Holocene shoreline reconstructions of this period coinciding with Paleoindian occupation of Rice Lake show a large area (> 40 km^2) of exposed lake plain in the western basin and more than 40 km^2 of open water in the eastern basin. Water-levels rose to an undetermined highstand level (TS) by about 8 ka BP, and dropped rapidly after 6.5 ka BP to a second lowstand (EH-2). During this lowstand phase the upper portion of the marl sediments were eroded and most evidence of archaeological sites on the exposed lake plain may have been removed. Water-levels recovered after 4 ka BP and shoreline reconstruction indicate the lake was starting to resemble its modern extents.

The shoreline reconstructions and known site locations for 10 (Paleoindian) 6.5 (Archaic) and 4 ka (Late Archaic/Woodland) BP identified 4 areas of archaeological potential in Rice Lake. During the Paleoindian period, the eastern portion of the basin during 10 ka BP was flooded, and terrestrial sites may appear in stranded wetland deposits above the modern shoreline. The discovery of Paleoindian-age archaeological materials in the McIntyre basin has also identified the surrounding area as having high-archaeological potential, due to its collection of small isolated ponds and wetlands. There are few known sites on the southern shore of Rice Lake, possibly due to survey bias, however a few existing Archaic sites and adjacent areas of exposed lake plain and wetlands highlight this area for potential submerged archaeological sites. While it is likely that some Archaic-era archaeological materials have been eroded by the post- 6.5 ka lowstand, it is possible that sediment from the mouth of the Otonobee River may have preserved some deposits. This area has been identified as having good potential due to its large number of known sites, and that the area has been exposed lake plain until after 4 ka BP.

5.1.6 Significance of results

While there has been much discussion in the Great Lakes region regarding the potential of submerged landscapes to yield prehistoric archaeological sites (Lovis et al. 1994; Jackson et al. 2000), very few detailed surveys have been conducted to locate these sites (Sonnenburg and Boyce 2008; O'Shea and Meadows 2009). Previous attempts to outline prehistoric shorelines have been hindered by the lack of high-resolution data, as shoreline reconstructions are based on existing low-resolution navigation charts (Jackson et al. 2000). The other problems that have not been addressed widely are the effect of isostatic movements and basin sedimentation on the location of paleoshorelines. While it has long been acknowledged that isostatic effects greatly affect the water-level plane of the Great Lakes (Coakley and Karrow 1994) and also continental shelf areas (Fedje and Josenhans 2000; Westley et al. 2010), isostatic and local tectonic effects (i.e. sediment compaction, subsidence) have been largely ignored in paleoshoreline reconstructions. The method of shoreline reconstructions of Rice Lake outlined in this thesis is the first attempt to combine high-resolution bathymetry data with corrections for isostatic rebound and sediment infill to identify areas of archaeological potential in the Great Lakes.

5.2 Contributions

5.2.1 Holocene Paleoenvironments of the Great Lakes

Holocene paleoenvironmental reconstruction in the Great Lakes has relied almost exclusively on palynological data (McAndrews 1994). While pollen data has played an important role in understanding vegetation and climate changes throughout this time period, pollen cannot provide a complete picture of paleoenvironmental changes. Pollen cannot identify changes in hydrology, trophic status or more subtle and localized environmental changes such as minor water-level fluctuations, which may have created temporary wetlands. Pollen grains are subject to wide dispersal by winds and can be carried large distance in rivers and lakes, and are therefore a much more 'regional' indicator of changes in vegetation and ecotopes. Thecamoebians in contrast, respond quickly to changes in water depth and lake trophic status and have fragile tests that are rapidly destroyed by fluvial transport. When combined with previously published paleoenvironmental reconstructions of regional vegetation changes, testate amoebae provide site-specific information regarding changes in hydrology and trophic status. In the case of Rice Lake, testate amoebae were able to identify previously unknown local wetland habitats and illustrate environmental differences within a larger lake environment. Testate amoebae were also able to more clearly identify the Early Holocene lowstand in Rice Lake, where previous pollen analysis did not.

5.2.2 Great Lakes Archaeology

Much work on locating Paleoindian sites has focused on the search along glacial strandlines. The discovery of Paleoindian sites along the former shoreline of glacial Lake Algonquin helped promote these assumptions. However, sites were not to be found along the former shoreline of glacial Lake Iroquois. By analyzing existing geological data, Lawrence Jackson soon realized that the maximum extent of Lake Iroquois was too early to have been inhabited by prehistoric peoples, as they would have first settled about five centuries later the area during the lowstand Admiralty phase of Lake Ontario (Jackson et al. 2000). This implied that many Paleoindian sites were actually submerged; evidence collected from this research supports Jackson's hypothesis and shows that large areas of the lakebed at Rice Lake were sub-aerially exposed wetlands with high archaeological potential.

For many years, the assumption was that Paleoindians were large game hunters who would have settled along shorelines (Mason 1981). However, more recent work has demonstrated that Paleoindian settlement patterns are far more complex (Ellis et al. 1998; Jackson 1998). In the case of Rice Lake, all the well-studied Paleoindian sites are all clustered around the western edge of the basin and along a river valley south of the lake (see Chapter 4, Fig 4.9). In addition to survey bias (most of the archaeological survey work has focused on that area and exclusively on terrestrial sites), the reconstructions in this study indicate that the eastern portion of the basin was indundated and it is unlikely that submerged sites would be found in this location. However, this also means that some sites may be located on uplifted terraces away from the modern shoreline. Evidence from the McIntyre site indicates that Paleoindian peoples were exploiting wetland resources and possibly using local, readily available materials to do so. This implies that Paleoindian peoples were exploiting a broader range of resources and utilizing local as well as more distant sources of lithic materials.

5.3 Limitations of Current Research

This research has provided some unique approaches to solving problems related to locating submerged archaeological sites. However, while these approaches have multiple advantages, there are limitations to each method.

Initial use of microdebitage focused on its potential ability to interpret archaeological site structure and site formation processes (Fladmark 1982). This approach became problematic as subsequent studies focused on the analysis of microdebitage to the exclusion of other artifacts with preconceived ideas of spatial variability (e.g. all lithic activity occurs in discrete location and does not travel outside of the site boundaries). In addition, they also had limited understanding of natural and cultural processes that could moved microdebitage from its initial discard location (Fladmark 1982; Vance 1986; Hull 1987). The use of microdebitage for any purpose seemed to diminish until the early part of the century, when Dragovich and Susino (2001) created a quantitative approach based on sediment roundness and SEM to determine differences between naturally occurring quartz fragments and microdebitage in aeolian sediments. The research presented in this thesis builds on Dragovich and Susino's work by utilizing their sediment roundness index along with SEM to identify quartz microdebitage in glacially derived sediments. Additional work has focused on the geochemical characterization of microdebitage compared to larger flakes; microdebitage seems to have greater source diversity and are located farther from their original source (Eerkens et al. 2007).

In the research outlined here, microdebitage was able to detect the presence of humans in a submerged environment. Since it is the only attempt to use microdebitage in this context, the research suffers from a lack of other similar studies for comparison. It is unclear where the microdebitage source is, or what type of tools (e.g. scrapers, retouch flakes) were being utilized based on the fragments found. While there is considerable study on the reconstruction of larger (> 1mm) fragments to their parent tool types, this type of research has not been applied to microdebitage fragments (Shott 1994). The use of microdebitage in submerged contexts and elsewhere would have greater potential to answer questions regarding source material, tool types and resource extraction if this information were available.

Testate amoebae have a well-established track record for identifying environmental and trophic changes in lake basins. Much of the research has focused on the type of species that occur in specific environments (e.g. peatlands, arctic lakes) (Dallimore et al. 2000; Asada and Warner 2009). Some studies have focused on the morphological variabilities that occur due to specific environmental influences (Reinhardt et al. 1998; Van Hengstum et al. 2008); it is still unclear whether these morphological characteristics are the result of natural species variability or represent adaptations to environmental stresses (Bobrov and Mazei 2004). In the case of the research in Rice Lake, the large abundances of *A. vulgaris* had a wide range of morphological variability; a closer investigation of the differences within this species may detect more subtle changes in environment than the study was able to discern.

A major debate that rages in archaeology surrounds the use of paleoenvironmental reconstruction and predictive modelling applied to archaeological contexts. One of the major criticisms of paleoenvironmental reconstruction and predictive modelling is that it relies too heavily on environmental factors and does not consider cultural or spiritual issues when determining and interpreting settlement patterns (Conolly and Lake 2006). Cultural and spiritual parameters are difficult to quantify and are often unknown, especially in the case of Paleoindian archaeology, where sites are sparse and often the only evidence of occupation are stone tools. In the case of this research, the continued utilization of sites over long periods of time, despite the major changes in environments and water-levels, raises questions as to the decision making process involved in determining settlement. While resource and water availability is obviously important it should be noted that there are also other, less tangible reasons why people would return to the same area generation after generation. Unfortunately, this is not something that can be measured with scientific principles or paleoenvironmental data and will likely remain a mystery without more detailed understanding of the culture and belief systems of these ancient peoples. However, it should be noted that despite changing environments in Rice Lake, abundant lithic and biological resources and a source of freshwater would have remained relatively constant. While it is unclear as to the exact reasons why people initially settled near Rice Lake and continued to occupy the area to the present day, this current research clearly indicates that availability of a wide variety of resources played an important role in the initial and continued occupation of the area.

5.4 Future Work

5.4.1 Great Lakes Shoreline Reconstructions

The results of this study demonstrate the effectiveness of combining coring, remote sensing and paleoenvironmental proxies (i.e. grain size, thecamoebians, microdebitage) for reconstructing paleoshorelines in Rice Lake. This approach could easily be applied to larger lake basins, especially in the lower Great Lakes. While there has been much speculation as to the potential for submerged prehistoric sites along paleoshorelines throughout the Great Lakes, there have been no large-scale attempts to model and potentially locate them. For Lake Ontario, there is an abundance of bathymetric, sub-bottom seismic and core data that could be utilized to reconstruct the paleoshorelines and create paleogeographic maps with areas of archaeological potential.

The regional model for the post-Iroquois water plane (Coakley and Karrow 1994) used in this thesis could be applied to untilt existing bathymetric data and create a DBM of the Lake Ontario basin throughout the Holocene. Existing seismic data could be used to identify the base of the Holocene shoreline and generate a sediment isopach map. The isopach maps could be subtracted from the tilted bathymetry data to backstrip sediment. Shorelines from the Paleoindian period in Lake Ontario could then be determined by referencing the available water-level curves (Anderson and Lewis 1985; Coakley and Karrow 1994).

5.4.2 Testing and Predictive Modelling

In this study archaeological potential mapping has identified several areas in Rice Lake with the potential for both submerged and terrestrial (raised shoreline) prehistoric sites. A more detailed archaeological predictive model could be developed for Rice Lake based on the approach developed for Boreal forest sites (Dalla Bona 1994). This approach employs both inductive and deductive modelling methods to allow for integration of environment factors, with cultural variables that may have influenced settlement patterns (i.e. access to resources and cultural/spiritual reasoning). It also uses statistical methods as a means of both discovering and evaluating the association between environmental and cultural variables and potential site locations (Kvamme 1990; Dalla Bona 1994). This model is suitable for Rice Lake because of the similarities in the ephemeral nature of the sites being modeled.

Available baseline environmental data and the paleogeographic maps created for this research provide an important fist step for creating a predictive model. The next step would involve creating both inductive and deductive models by identifying variables using statistical methods and existing archaeological knowledge, assigning weighted values and combining them into one predictive model. The inductive model uses the weighted value method that assumes that landscape variables are related to settlement of prehistoric peoples. Categories are created which are assigned values based on perceived importance (i.e., distance to water, slope, soil drainage), and variables are derived from these categories (i.e., well drained soils, poorly drained soils, etc.). The value of the variable is multiplied by the weight of the category, which gives an overall weighted value that is applied to the model (Dalla Bona 1994).

The deductive model uses existing archaeological knowledge and theories, such as landscape archaeology and local ethnographic/cultural information. These variables are measured using the intersection method, where variables are not weighted, but are considered as equally important. This method allows for the integration of variables that are not quantifiable, and therefore, cannot be statistically evaluated. This method allows for the application of cultural and ethnographic information, creating a more comprehensive model and addressing the issue of environmental determinism (Dalla Bona 1994; Church et al. 2000).

The fourth and final step involves identifying areas of low, medium and high potential, evaluation and testing of the model. Areas of high potential will have the highest values, and areas of lowest potential will have the lowest values. The determination of the cut off for these values can only be ascertained after the values are calculated. Despite the subjectiveness of the determination of high and low values, the strength of the model can be statistically evaluated prior to ground-truthing, allowing for a quantitative analysis of a qualitative judgement (Dalla Bona 1994).

In order to prove the effectiveness of this approach, further ground-truthing needs to be undertaken within Rice Lake to verify the presence of archaeological sites. A series of cores could be collected using a Livingstone piston corer in a closely spaced grid pattern, as is done in preliminary test surveys in terrestrial archaeology (Stein 1991). The short cores would sub-sampled at 5-10 cm intervals and screened for lithic fragments (microdebitage) and other archaeological materials (e.g. charcoal, bone). The relative concentration of microdebitage and other materials will then be gridded using a Kriging algorithm (Fladmark 1982; Davis 2002) to produce a map showing density of cultural finds which will then be compared by overlay with the predicted site locations.

Areas of high, low and medium potential will be surveyed with this approach using the 6:3:1 criteria as described in Dalla Bona (1994). This ratio means that 60 % of the survey time is dedicated to high potential areas, 30% to medium and 10% to low potential areas. The 6:3:1 criteria can also be used to test the model's accuracy, as the high potential areas should have twice as many find spots as the medium, which should have three times as many as the low potential areas. If the model proves unsuccessful, it does not necessarily mean there is not submerged archaeology in Rice Lake. The predictive model can be reanalyzed, adjusted, and retested at a later date.

For Rice Lake and elsewhere through the Great Lakes, this thesis provides a baseline from which to build more detailed predictive models. Predictive models for submerged landscapes in Southern Ontario combining detailed geophysical and paleoenvironmental data have not been attempted. Most work in Southern Ontario has focused on urban master plans and terrestrial sites (MacDonald 1994). As waterfronts become more threatened due to increased development, knowledge of potential submerged cultural resources will become of utmost importance in planning for development.

5.4.3 Microdebitage

This thesis demonstrates that microdebitage analysis is a rapid and effective tool for identifying submerged archaeological sites. For the purposes of this study, simply determining presence/absence, characteristics and degree of angularity was enough to provide evidence of archaeological activity. However, a more robust approach will be needed in the future in order for microdebitage to answer more questions than simple presence of activity. Further work needs to be done in the characterization of microdebitage features (e.g. flake scars, morphology, size) related to tool types and source material For example, the microdebitage assemblage consisted almost entirely of quartz fragments, despite the fact that the majority of stone tools recovered from terrestrial Paleoindian sites consist of chert (although quartz in found at these sites as well) (Jackson 1998). Future work to ameliorate these issues would involve taking modern samples of different source materials (chert and quartz), comparing naturally crushed material (using a mechanical rock crusher for example) and knapping the material in a controlled setting. This would allow for analysis of differences in features between different source materials and naturally altered versus and human modified fragments. Utilizing different knapping techniques (such as percussion and pressure flaking) and creating specific tool types (e.g., projectile points, scrapers, retouched flakes) would help determine if different methods and tool types create unique characteristics in microdebitage.

Determining transportation processes of microdebitage in both terrestrial and underwater sites is more difficult. There is a lack of information on exactly how far microdebitage gets transported from its original discard area, and whether long distance travel would erase the distinguishing features that separate microdebitage from naturally occurring sediments. The main features of quartz microdebitage in Rice Lake are flake scars, high-angularity and lack of weathering; the sedimentological evidence indicates that the material was not transported very far. Since there is a lack of archaeological sources on microdebitage transport, studies on the transport of naturally occurring sediment may be used as an analogy. Glacial sediments can be geochemically characterized to see how far they have been transported from their source rock (Hardy et al. 2010). This method could be applied to both the naturally occurring sediment and the microdebitage recovered at Rice Lake. The effects of different transport mechanisms on the angularity and weathering of naturally occurring grains of similar size (Mahaney 2002; Sweet and Soreghan 2010) could also be applied to microdebitage to determine when and if distinguishing features are erased.

5.5 Conclusion

The papers presented in this thesis provide new approaches to determining submerged archaeological site potential. This is the first time that microdebitage has been used to locate submerged archaeological sites in the world, and the first time that isostatic rebound and sediment infill have been utilized to reconstruct shorelines in the Great Lakes. This is also one of the few studies to use of testate amoebae to characterize archaeological paleoenvironments. The use of these multiple techniques for reconstructing paleoenvironments and areas of archaeological potential in the Great Lakes provides key information such as the location of submerged sites, localized wetlands and more accurate shoreline reconstructions. The Great Lakes region has a vast untapped archaeological record that is now underwater. The methods proposed in this study provide new means of investigating these largely unexplored areas. The lack of Early Holocene archaeological sites has greatly hindered understanding of prehistoric resource procurement and settlement strategies. The results of this thesis provide a much more comprehensive view of the environmental changes and new ways of exploring the submerged archaeological potential of the Great Lakes.

References

Anderson, T. W. and C. F. M. Lewis (ed) (1985). Postglacial water-level history of the Lake Ontario basin. GAC Special Paper. St. John's, Geological Association of Canada.

Asada, T. and B. G. Warner (2009). Plants and testate amoebae as environmental indicators in cupriferous peatlands, New Brunswick, Canada. Ecological Indicators 9: 129-137.

Bailey, G. N. and N. C. Flemming (2008). Archaeology of the continental shelf: marine resources, submerged landscapes and underwater archaeology. Quaternary Science Reviews 27: 2153-2165.

Bobrov, A. A. and Y. Mazei (2004). Morphological variability of testate amoebae (Rhizopoda: Testacealobosea: Testaceafilosea) in natural populations. Acta Protozool 43: 133-146.

Church, T., R. J. Brandon and G. R. Burgett (2000). GIS Applications in Archaeology: Method in Search of Theory. Practical Applications of GIS for Archaeologists. K. L. Wescott and R. J. Brandon (eds.), London, Taylor and Francis. Vol.: 135-155.

Coakley, J. P. and P. F. Karrow (1994). Reconstruction of post-Iroquois shoreline evolution in western Lake Ontario. Canadian Journal of Earth Science 31: 1618-1629.

Conolly, J. and M. Lake (2006). Geographical Information Systems in Archaeology. Cambridge, United Kingdom, Cambridge University Press.

Dalla Bona, L. (1994). Volume 4: A predictive model of prehistoric activity location for Thunder Bay District, Ontario. Cultural Heritage Resource Predictive Modeling Report. Thunder Bay, Ontario, Centre for Archaeological Resource Prediction, Lakehead University: 98.

Dallimore, A., C. J. Schroder-Adams and S. J. Dallimore (2000). Holocene environmental history of thermokarst lakes on Richard Island, Northwest Territories, Canada: thecamoebians as paleolimnological indicators. Journal of Paleolimnology 23: 261-283.

Davis, J. C. (2002). Statistics and Data Analysis in Geology. New York, John Wiley and Sons.

Dragovich, D. and G. J. Susino (2001). Identification of experimental quartz microdebitage from rock engravings. Earth Surface Processes and Landforms 26: 859-868.

Eerkens, J. W., J. R. Ferguson, M. D. Glascock, C. E. Skinner and S. A. Waechter (2007). Reduction strategies and geochemical characterization of lithic assemblages: a comparison of three case studies from Western North America. American Antiquity 72(3): 585-597.

Ellis, C. and D. B. Deller (1990). Paleo-Indians. Archaeology of Southern Ontario to A.D. 1650. C. Ellis and N. Ferris (eds.), London, Ontario Archaeological Society. Vol.: 37-63.

Ellis, C., A. C. Goodyear, D. F. Morse and K. B. Tankersley (1998). Archaeology of the Pleistocene-Holocene transition in eastern North America. Quaternary International 49/50(151-166).

Ellis, C., I. T. Kenyon and M. W. Spence (1990). The Archaic. Archaeology of Southern Ontario to A.D. 1650. C. Ellis and N. Ferris (eds.), London, Ontario Archaeological Society. Vol.: 65-124.

Fedje, D. W. and H. Josenhans (2000). Drowned forests and archaeology on the continental shelf of British Columbia, Canada. Geology 28: 99-102.

Ferguson, M. L. and C. D. Metcalfe (1989). Distribution of PCB congeners in sediments of the Otonabee River-Rice Lake system, Peterborough, Canada. Chemosphere CMSHAF 19(8/9): 1321-1328.

Fladmark, K. (1982). Microdebitage analysis: Initial considerations. Journal of Archaeological Science 9(2): 205-220.

Gearey, B. R. and C. J. Caseldine (2006). Archaeological applications of testate amoebae analyses: a case study from Derryville, Co. Tipperary, Ireland. Journal of Archaeological Science 33: 49-55.

Hardy, F., L. Bariteau, S. Lorrain, I. Theriault, G. Gagnon, D. Messier and J.-F. Rougerie (2010). Geochemical tracing and spatial evolution of the sediment bed load of the Romaine River, Quebec, Canada. CATENA 81(1): 66-76.

Hull, K. (1987). Identification of cultural site formation processes through microdebitage. American Antiquity 52(4): 772-783.

Jackson, L. J. (1998). The Sandy Ridge and Halstead Paleo-Indian sites. Ann Arbor, Michigan, Museum of Anthropology, University of Michigan.

Jackson, L. J., C. Ellis, A. V. Morgan and J. H. McAndrews (2000). Glacial lake levels and eastern Great Lakes Palaeo-Indians. Geoarchaeology 15(5): 415-440.

Kvamme, K. (1990). One-sample test in regional archaeological analysis: new possibilities through computer technique. American Antiquity 55(2): 367-381.

Lovis, W. A., M. B. Holman, G. W. Monaghan and R. K. Skowronek (1994). Archaeological, geological and paleoecological perspectives on regional research design in the Saginaw Bay Region of Michigan. Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties. R. I. MacDonald (eds.), Waterloo, Quaternary Sciences Institute. Vol.: 81-94.

MacDonald, R. I. (ed) (1994). Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties. Waterloo, ON, Quaternary Sciences Institute.

Mahaney, W. C. (2002). Atlas of Sand Grain Surface Textures and Applications. New York, NY, Oxford University Press.

Mason, R. J. (1981). Great Lakes Archaeology. New York, New York, Academic Press.

McAndrews, J. H. (1994). Pollen diagrams for southern Ontario applied to archaeology. Great Lakes Archaeology and Paleoecology: Exploring Interdisciplinary Initiatives for the Nineties. R. I. MacDonald and B. G. Warner (eds.), Waterloo, Quaternary Sciences Institute. Vol.: 179-195.

O'Shea, J. M. and G. A. Meadows (2009). Evidence for early hunters beneath the Great Lakes. PNAS 106: 10120-10123.

Plunkett, G., N. J. Whitehouse, V. A. Hall, D. J. Charman, M. Blaauw, E. Kelly and I. Mulhall (2009). A multi-proxy investigation of the findspot of an Iron Age bog body from Oldcroghan, Co. Offaly, Ireland. Journal of Archaeological Science 36: 265-277.

Reinhardt, E. G., A. Dalby, A. Kumar and R. T. Patterson (1998). Arcellaceans as pollution indicators in mine tailing contaminated lakes near Cobalt, Ontario, Canada. Micropaleontology 44: 131-148.

Shott, M. J. (1994). Size and form in the analysis of flake debris: review and recent approaches. Journal of Archaeological Method and Theory 1(1): 69-110.

Sonnenburg, E. P. and J. I. Boyce (2008). Digital bathymetric model and integrated side-scan as a base for archaeological inventory of submerged landscapes in the Rideau Canal (Ontario, Canada). Geoarchaeology 23(5): 654-674.

Stein, J. K. (1991). Coring in CRM and Archaeology: A Reminder. American Antiquity 56(1): 138-142.

Sweet, D. E. and G. S. Soreghan (2010). Application of quartz sand microtextural analysis to infer cold-climate weathering for the Equatorial Fountain Formation (Pennsylvania-Permian, Colorado, USA). Journal of Sedimentary Research 80(7): 666-677.

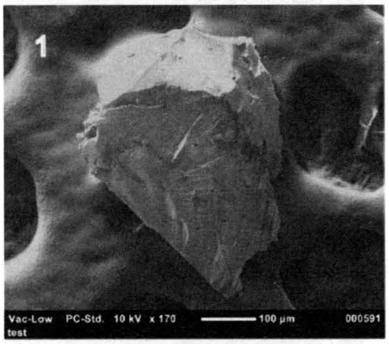
Van Hengstum, P. J., E. G. Reinhardt, P. A. Beddows, R. J. Huang and J. J. Gabriel (2008). Thecamoebians (testate amoebae) and foraminifera from three anchialine cenotes in Mexico: low salinity (1.5-4.5 psu) faunal transitions. Journal of Foraminiferal Research 38(4): 305-317.

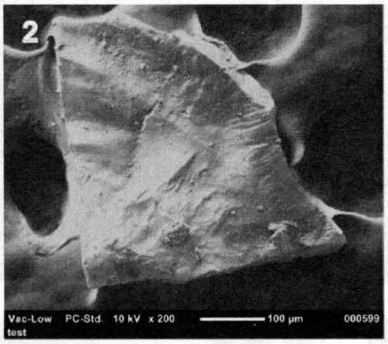
Vance, E. D. (1986). Microdebitage analysis in activity analysis: an application. Northwest anthropological research notes 20: 179-189.

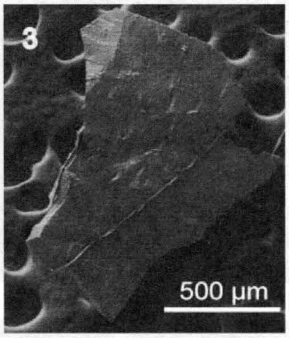
Westley, K., R. Quinn, W. Forsythe, R. Plets, T. Bell, S. Benetti, F. McGrath and R. Robinson (2010). Mapping submerged landscapes using multibeam bathymetric data: a case study from the north coast of Ireland. International Journal of Nautical Archaeology.

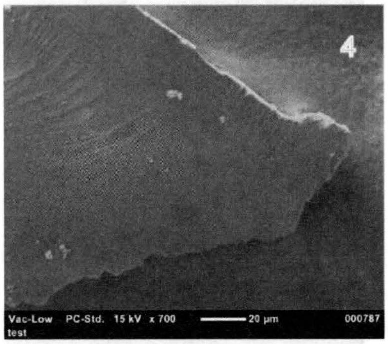
Yu, Z. and J. H. McAndrews (1994). Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen and plant macrofossil evidence. Holocene 4(2): 141-152.

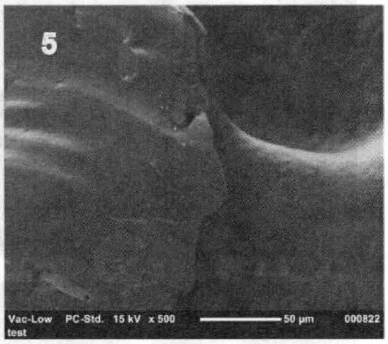
Appendix 1: Microdebitage SEM Images

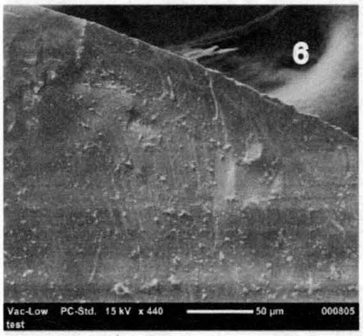


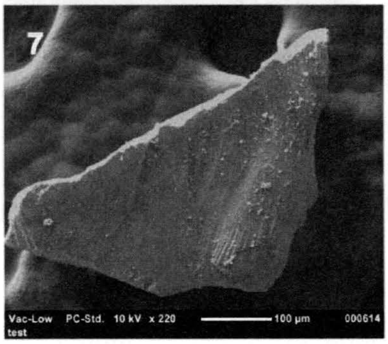


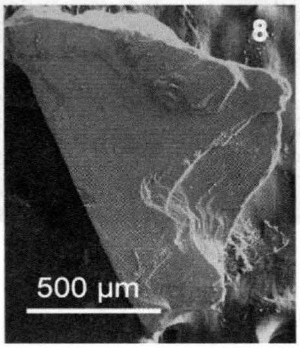


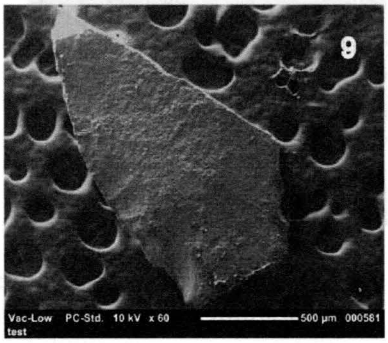






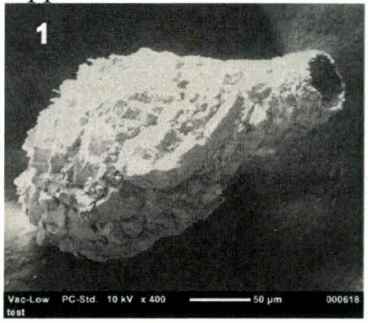


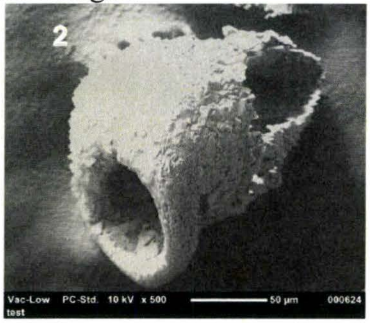


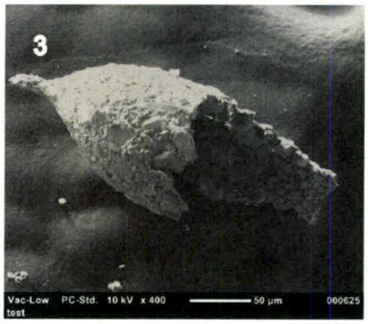


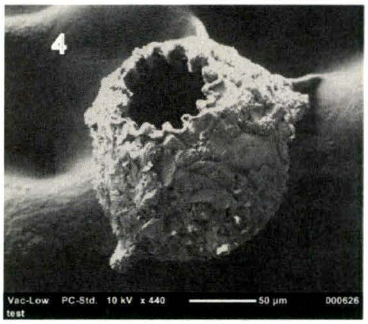
1. Microdebitage from McIntyre Site.
2. Microdebitage from RIL 10
3. Experimental obsidian microdebitage
4. Close-up of microdebitage showing feathered edges and unidirectional striations
5. Close-up of microdebitage showing thinned edge and unidirectional conchoidal fractures
6. Close-up of microdebitage showing thinned edge, and unidirectional striations
7. Naturally occurring angular quartz grain from RIL 10
8. Naturally occurring angular quartz grain from RIL 10
9. Naturally occurring angular quartz grain from RIL 10

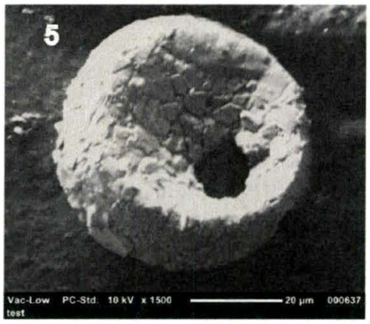
Appendix 2: Thecamoebian SEM Images

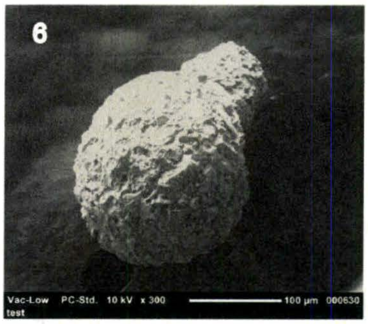


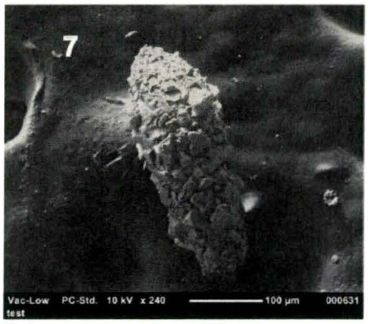


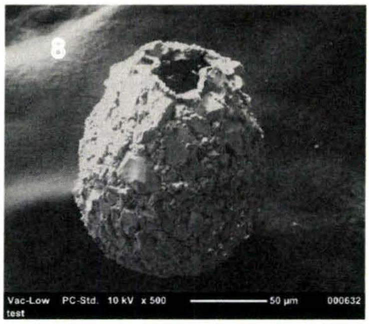


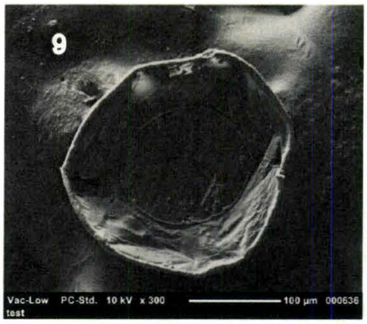












1. *Difflugia oblonga* 'oblonga'
2. *Centropyxis constricta* 'aerophila'
3. *Difflugia proteiformis* 'proteiformis'
4. *Difflugia corona*
5. *Centropyxis aculeata* 'discoides'
6. *Lagenodifflugia vas*
7. *Difflugia oblonga* 'linearis'
8. *Cucurbitella tricuspis*
9. *Arcella vulgaris*

Appendix 3: Thecamoebian data

RIL 10								
Interval	**1.5**	**25.5**	**50.5**	**75.5**	**90.5**	**95.5**	**100.5**	**105.5**
Total counted	378	528	654	279	204	726	691	532
Counts per cc	189	264	327	139.5	102	363	345.5	266
Number of species	13	15	13	10	11	15	7	10
Diversity	1.317	1.346	1.618	1.63	1.858	1.996	1.232	1.225
Biofacies	DO	DO	DO	SO	E	E	SO	SO
A. vulgaris	65.87301587	60.79545455	48.31804281	36.55913978	33.33333333	23.00275482	35.45586107	19.17293233
per cc	124.5	160.5	158	51	34	83.5	122.5	51
Fractional Abundance	0.658730159	0.607954545	0.483180428	0.365591398	0.333333333	0.230027548	0.354558611	0.191729323
Standard Error ±	*0.067597074*	*0.058892213*	*0.054163452*	*0.079919265*	*0.091484965*	*0.043294256*	*0.050443414*	*0.047308365*
D. proteiformis amphoralis	2.645502646	10.60606061	9.021406728	5.376344086	11.76470588	13.91184573	0.1447178	0.751879699
per cc	5	28	29.5	7.5	12	50.5	0.5	2
Fractional Abundance	0.026455026	0.106060606	0.090214067	0.053763441	0.117647059	0.139118457	0.001447178	0.007518797
Standard Error ±	*0.022880066*	*0.037143703*	*0.031051954*	*0.037429356*	*0.062527014*	*0.03560138*	*0.004008469*	*0.010381272*
D. globulus	7.407407407	1.893939394	2.140672783	5.376344086	13.23529412	20.52341598	29.95658466	21.80451128
per cc	14	5	7	7.5	13.5	74.5	103.5	58
Fractional Abundance	0.074074074	0.018939394	0.021406728	0.053763441	0.132352941	0.20523416	0.299565847	0.218045113
Standard Error ±	*0.037337601*	*0.016443152*	*0.01568767*	*0.037429356*	*0.065764926*	*0.041547718*	*0.048301637*	*0.049622573*
L. vas	1.322751323	1.136363636	0.458715596	0	0	2.066115702	2.026049204	0.939849624
per cc	2.5	3	1.5	0	0	7.5	7	2.5
Fractional Abundance	0.013227513	0.011363636	0.004587156	0	0	0.020661157	0.020260492	0.009398496
Standard Error ±	*0.016288189*	*0.012785893*	*0.007324122*	*0*	*0*	*0.014633445*	*0.014856358*	*0.011595619*
C. constricta constricta	6.878306878	5.871212121	11.16207951	13.62007168	6.862745098	10.05509642	0	2.443609023
per cc	13	15.5	36.5	19	7	36.5	0	6.5
Fractional Abundance	0.068783069	0.058712121	0.111620795	0.136200717	0.068627451	0.100550964	0	0.02443609
Standard Error ±	*0.036082064*	*0.028358237*	*0.034131387*	*0.056920025*	*0.049064416*	*0.030937425*	*0*	*0.018554915*
D. oblonga glans	1.058201058	0.378787879	3.669724771	1.792114695	0	1.928374656	0	0
per cc	2	1	12	2.5	0	7	0	0
Fractional Abundance	0.010582011	0.003787879	0.036697248	0.017921147	0	0.019283747	0	0
Standard Error ±	*0.014588115*	*0.007410168*	*0.020378881*	*0.022015322*	*0*	*0.014147189*	*0*	*0*
D. oblonga byrophila	1.058201058	0.378787879	0	0	0	0	0	0
per cc	2	1	0	0	0	0	0	0
Fractional Abundance	0.010582011	0.003787879	0	0	0	0	0	0
Standard Error ±	*0.014588115*	*0.007410168*	*0*	*0*	*0*	*0*	*0*	*0*
C. constricta aerophila	7.407407407	14.39393939	17.58409786	27.59856631	15.19607843	15.15151515	31.40376266	53.57142857
per cc	14	38	57.5	38.5	15.5	55	108.5	142.5
Fractional Abundance	0.074074074	0.143939394	0.175840979	0.275985663	0.151960784	0.151515152	0.314037627	0.535714286
Standard Error ±	*0.037337601*	*0.042344421*	*0.04126176*	*0.074179826*	*0.069667418*	*0.036885259*	*0.048941022*	*0.059934174*
D. urceolata urceolata	1.058201058	0.189393939	2.293577982	2.508960573	0	0.550964187	0	0
per cc	2	0.5	7.5	3.5	0	2	0	0
Fractional Abundance	0.010582011	0.001893939	0.02293578	0.025089606	0	0.005509642	0	0
Standard Error ±	*0.014588115*	*0.005244758*	*0.01622559*	*0.025953638*	*0*	*0.007614909*	*0*	*0*
C. tricuspis	3.439153439	1.325757576	0.611620795	0	0.490196078	1.239669421	0	0.187969925
per cc	6.5	3.5	2	0	0.5	4.5	0	0.5
Fractional Abundance	0.034391534	0.013257576	0.006116208	0	0.004901961	0.012396694	0	0.001879699
Standard Error ±	*0.025980738*	*0.013797108*	*0.00845067*	*0*	*0.013554198*	*0.011382744*	*0*	*0.005205361*
C. aculeata aculeata	0.793650794	0.378787879	0.458715596	0	7.843137255	4.269972452	0	0
per cc	1.5	1	1.5	0	8	15.5	0	0
Fractional Abundance	0.007936508	0.003787879	0.004587156	0	0.078431373	0.042699725	0	0
Standard Error ±	*0.012650557*	*0.007410168*	*0.007324122*	*0*	*0.052175273*	*0.020798853*	*0*	*0*
C. aculeata discoides	0.793650794	0.757575758	0.764525994	0	1.960784314	1.101928375	0.868306802	0.563909774
per cc	1.5	2	2.5	0	2	4	3	1.5
Fractional Abundance	0.007936508	0.007575758	0.00764526	0	0.019607843	0.011019284	0.008683068	0.005639098
Standard Error ±	*0.012650557*	*0.010459618*	*0.009440865*	*0*	*0.026907343*	*0.010739235*	*0.009783064*	*0.008998955*
D. oblonga oblonga	0.264550265	1.325757576	2.293577982	4.659498208	4.411764706	2.479338843	0	0
per cc	0.5	3.5	7.5	6.5	4.5	9	0	0
Fractional Abundance	0.002645503	0.013257576	0.02293578	0.046594982	0.044117647	0.024793388	0	0
Standard Error ±	*0.007323253*	*0.013797108*	*0.01622559*	*0.034976573*	*0.039853308*	*0.015996281*	*0*	*0*
D. proteiformis proteiformis	0	0.378787879	0	0.358422939	0	0	0	0
per cc	0	1	0	0.5	0	0	0	0
Fractional Abundance	0	0.003787879	0	0.003584229	0	0	0	0
Standard Error ±	*0*	*0.007410168*	*0*	*0.009917156*	*0*	*0*	*0*	*0*

RIL 10								
Interval	**1.5**	**25.5**	**50.5**	**75.5**	**90.5**	**95.5**	**100.5**	**105.5**
Total counted	378	528	654	279	204	726	691	532
Counts per cc	189	264	327	139.5	102	363	345.5	266
Number of species	13	15	13	10	11	15	7	10
Diversity	1.317	1.346	1.618	1.63	1.858	1.996	1.232	1.225
Biofacies	DO	DO	DO	SO	E	E	SO	SO
H. sphagni	0	0.189393939	1.22324159	0	0	0.550964187	0	0
per cc	0	0.5	4	0	0	2	0	0
Fractional Abundance	0	0.001893939	0.012232416	0	0	0.005509642	0	0
Standard Error ±	*0*	*0.005244758*	*0.011914222*	*0*	*0*	*0.007614909*	*0*	*0*
D. oblonga spinosa	0	0	0	2.150537634	4.411764706	2.61707989	0.1447178	0.37593985
per cc	0	0	0	3	4.5	9.5	0.5	1
Fractional Abundance	0	0	0	0.021505376	0.044117647	0.026170799	0.001447178	0.003759398
Standard Error ±	*0*	*0*	*0*	*0.024072529*	*0.039853308*	*0.016423006*	*0.004008469*	*0.007354558*
N. colaris	0	0	0	0	0.490196078	0	0	0
per cc	0	0	0	0	0.5	0	0	0
Fractional Abundance	0	0	0	0	0.004901961	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0.013554198*	*0*	*0*	*0*
D.oblonga triangularis	0	0	0	0	0	0.550964187	0	0.187969925
per cc	0	0	0	0	0	2	0	0.5
Fractional Abundance	0	0	0	0	0	0.005509642	0	0.001879699
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0.007614909*	*0*	*0.005205361*
D.oblonga lanceolata	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.fragosa	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis acuminata	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L. spirialis	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Trinema	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Bullinularia	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Corythion	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0
Euglypha	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0
Cyclopyxis	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0
D.urens	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0
Plagiopyxis	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0

RIL 10										
Interval	**110.5**	**115.5**	**120.5**	**125.5**	**130.5**	**135.5**	**140.5**	**145.5**	**150.5**	**155.5**
Total counted	553	419	232	255	318	256	190	220	246	193
Counts per cc	276.75	209.5	928	1020	1272	1024	760	880	984	772
Number of species	9	7	3	7	5	3	5	7	12	11
Diversity	1.44	1.101	0.9221	1.042	1.012	0.9679	1.008	1.231	1.646	1.697
Biofacies	SO	SO	SO	SO	SO	SO	SO	SO	SO	SO
A. vulgaris	29.4755877	52.2673031	27.5862069	55.29411765	53.77358491	44.140625	37.36842105	45	28.04878049	29.53367876
per cc	12.75	109.5	256	564	684	452	284	396	276	228
Fractional Abundance	0.046070461	0.522673031	0.275862069	0.552941176	0.537735849	0.44140625	0.373684211	0.45	0.280487805	0.295336788
Standard Error ±	*0.024699132*	*0.067637429*	*0.028756679*	*0.0305125*	*0.027399467*	*0.030413988*	*0.034395239*	*0.032870199*	*0.028069495*	*0.032180812*
D. proteiformis amphoralis	0.180831826	0.238663484	0	0.784313725	0	0	0	0	1.62601626	6.21761658
per cc	160.5	0.5	0	8	0	0	0	0	16	48
Fractional Abundance	0.579945799	0.002386635	0	0.007843137	0	0	0	0	0.016260163	0.062176166
Standard Error ±	*0.058151193*	*0.006607515*	*0*	*0.005413661*	*0*	*0*	*0*	*0*	*0.007902438*	*0.017034133*
D. globulus	17.90235081	14.55847255	12.5	10.58823529	10.37735849	11.328125	9.473684211	9.090909091	13.82113821	18.65284974
per cc	28	30.5	116	108	132	116	72	80	136	144
Fractional Abundance	0.101174345	0.145584726	0.125	0.105882353	0.103773585	0.11328125	0.094736842	0.090909091	0.138211382	0.186528497
Standard Error ±	*0.03552918*	*0.047759136*	*0.021278505*	*0.018882744*	*0.016759644*	*0.019412347*	*0.020820739*	*0.018994246*	*0.021564074*	*0.027478384*
L. vas	0	0	0	0	0	0	0	6.363636364	6.097560976	6.735751295
per cc	5	0	0	0	0	0	0	56	60	52
Fractional Abundance	0.018066847	0	0	0	0	0	0	0.063636364	0.06097561	0.067357513
Standard Error ±	*0.015692582*	*0*	*0*	*0*	*0*	*0*	*0*	*0.01612834*	*0.014951165*	*0.017680642*
C. constricta constricta	1.98915009	0.954653938	0	0.392156863	0.628930818	0	0.526315789	0	0.406504065	0
per cc	3	2	0	4	8	0	4	0	4	0
Fractional Abundance	0.010840108	0.009546539	0	0.003921569	0.006289308	0	0.005263158	0	0.004065041	0
Standard Error ±	*0.01220007*	*0.013167523*	*0*	*0.003835594*	*0.004344541*	*0*	*0.005144303*	*0*	*0.003975635*	*0*
D. oblonga glans	0	0	0	0	0	0	0	0	0	0
per cc	15.5	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.056007227	0	0	0	0	0	0	0	0	0
Standard Error ±	*0.0270906*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga byrophila	0	0	0	0	0	0	0	1.363636364	0.81300813	1.554404145
per cc	1	0	0	0	0	0	0	12	8	12
Fractional Abundance	0.003613369	0	0	0	0	0	0	0.013636364	0.008130081	0.015544041
Standard Error ±	*0.007069397*	*0*	*0*	*0*	*0*	*0*	*0*	*0.007662713*	*0.00561091*	*0.008726248*
C. constricta aerophila	47.73960217	30.7875895	59.9137931	31.76470588	34.27672956	44.53125	51.57894737	36.81818182	38.61788618	30.56994819
per cc	1	64.5	556	324	436	456	392	324	380	236
Fractional Abundance	0.003613369	0.307875895	0.599137931	0.317647059	0.342767296	0.4453125	0.515789474	0.368181818	0.386178862	0.305699482
Standard Error ±	*0.007069397*	*0.062509193*	*0.03153138*	*0.028571493*	*0.026083856*	*0.030441267*	*0.035530607*	*0.031867058*	*0.030421014*	*0.032498889*
D. urceolata urceolata	0	0	0	0	0	0	0	0	0	0
per cc	38	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.13730804	0	0	0	0	0	0	0	0	0
Standard Error ±	*0.040549744*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. tricuspis	0.180831826	0.238663484	0	0	0	0	0	0	0	0.518134715
per cc	0.5	0.5	0	0	0	0	0	0	0	4
Fractional Abundance	0.001806685	0.002386635	0	0	0	0	0	0	0	0.005181347
Standard Error ±	*0.005003349*	*0.006607515*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.005064548*
C. aculeata aculeata	0	0	0	0.784313725	0	0	0	0	0	1.554404145
per cc	3.5	0	0	8	0	0	0	0	0	12
Fractional Abundance	0.012646793	0	0	0.007843137	0	0	0	0	0	0.015544041
Standard Error ±	*0.013165542*	*0*	*0*	*0.005413661*	*0*	*0*	*0*	*0*	*0*	*0.008726248*
C. aculeata discoides	1.98915009	0.954653938	0	0.392156863	0.943396226	0	1.052631579	0.454545455	0.81300813	1.03626943
per cc	1	2	0	4	12	0	8	4	8	8
Fractional Abundance	0.003613369	0.009546539	0	0.003921569	0.009433962	0	0.010526316	0.004545455	0.008130081	0.010362694
Standard Error ±	*0.007069397*	*0.013167523*	*0*	*0.003835594*	*0.005312529*	*0*	*0.007255872*	*0.00444441*	*0.00561091*	*0.007143677*
D. oblonga oblonga	0.361663653	0	0	0	0	0	0	0	2.845528455	0
per cc	2	0	0	0	0	0	0	0	28	0
Fractional Abundance	0.007226739	0	0	0	0	0	0	0	0.028455285	0
Standard Error ±	*0.009979493*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.010388944*	*0*
D. proteiformis proteiformis	0	0	0	0	0	0	0	0	3.25203252	0
per cc	3.5	0	0	0	0	0	0	0	32	0
Fractional Abundance	0.012646793	0	0	0	0	0	0	0	0.032520325	0
Standard Error ±	*0.013165542*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.011082989*	*0*

RIL 10										
Interval	**110.5**	**115.5**	**120.5**	**125.5**	**130.5**	**135.5**	**140.5**	**145.5**	**150.5**	**155.5**
Total counted	553	419	232	255	318	256	190	220	246	193
Counts per cc	276.75	209.5	928	1020	1272	1024	760	880	984	772
Number of species	9	7	3	7	5	3	5	7	12	11
Diversity	1.44	1.101	0.9221	1.042	1.012	0.9679	1.008	1.231	1.646	1.697
Biofacies	SO	SO	SO	SO	SO	SO	SO	SO	SO	SO
H. sphagni	0	0	0	0	0	0	0	0	0	0
per cc	1	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.003613369	0	0	0	0	0	0	0	0	0
Standard Error ±	*0.007069397*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga spinosa	0.180831826	0	0	0	0	0	0	0.909090909	1.219512195	0
per cc	0.5	0	0	0	0	0	0	8	12	0
Fractional Abundance	0.001806685	0	0	0	0	0	0	0.009090909	0.012195122	0
Standard Error ±	*0.005003349*	*0*	*0*	*0*	*0*	*0*	*0*	*0.006270978*	*0.006857837*	*0*
N. colaris	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga triangularis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga lanceolata	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.fragosa	0	0	0	0	0	0	0	0	2.43902439	0
per cc	0	0	0	0	0	0	0	0	24	0
Fractional Abundance	0	0	0	0	0	0	0	0	0.024390244	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.009638394*	*0*
D.proteiformis acuminata	0	0	0	0	0	0	0	0	0	1.554404145
per cc	0	0	0	0	0	0	0	0	0	12
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.015544041
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.008726248*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	2.07253886
per cc	0	0	0	0	0	0	0	0	0	16
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.020725389
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.010049652*
L. spirialis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Trinema	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Bullinularia	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Corythion	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Euglypha	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Cyclopyxis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
D.urens	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Plagiopyxis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0

RIL 10										
Interval	**160.5**	**165.5**	**170.5**	**175.5**	**180.5**	**185.5**	**190.5**	**195.5**	**200.5**	**205.5**
Total counted	181	213	265	281	257	219	194	240	225	268
Counts per cc	724	852	530	70.25	514	876	776	478	450	536
Number of species	8	12	10	11	11	13	11	12	12	13
Diversity	1.428	1.699	1.713	1.645	1.605	1.623	1.524	1.662	1.837	1.906
Biofacies	SO	SO	SO	SO	SO	SO	SO	SO	E	E
A. vulgaris	29.83425414	5.633802817	17.35849057	11.38790036	15.95330739	8.675799087	6.18556701	5.833333333	11.55555556	8.208955224
per cc	216	48	92	8	82	76	48	28	52	44
Fractional Abundance	0.298342541	0.056338028	0.173584906	0.113879004	0.159533074	0.086757991	0.06185567	0.058577406	0.115555556	0.082089552
Standard Error ±	*0.033327824*	*0.015482651*	*0.032245806*	*0.074285021*	*0.031656303*	*0.018640249*	*0.016949223*	*0.021052298*	*0.029537961*	*0.023239018*
D. proteiformis amphoralis	3.314917127	13.14553991	12.83018868	6.761565836	6.614785992	6.849315068	5.154639175	5.416666667	16.88888889	15.67164179
per cc	24	112	68	4.75	34	60	40	26	76	84
Fractional Abundance	0.033149171	0.131455399	0.128301887	0.067615658	0.06614786	0.068493151	0.051546392	0.054393305	0.168888889	0.156716418
Standard Error ±	*0.013040759*	*0.022689324*	*0.028471983*	*0.058715672*	*0.021486787*	*0.016727099*	*0.015557234*	*0.020331533*	*0.03461624*	*0.030776395*
D. globulus	13.25966851	17.37089202	19.24528302	16.01423488	11.67315175	14.15525114	13.40206186	19.58333333	8.888888889	12.31343284
per cc	96	148	102	11.25	60	124	104	94	40	66
Fractional Abundance	0.132596685	0.17370892	0.19245283	0.160142349	0.116731518	0.141552511	0.134020619	0.19665272	0.088888889	0.123134328
Standard Error ±	*0.024703794*	*0.02543981*	*0.033563268*	*0.085760804*	*0.027759711*	*0.023084458*	*0.023969821*	*0.035632293*	*0.026294155*	*0.027818249*
L. vas	7.73480663	9.85915493	7.169811321	6.40569395	5.058365759	6.849315068	3.608247423	6.25	8.444444444	9.328358209
per cc	56	84	38	4.5	26	60	28	30	38	50
Fractional Abundance	0.077348066	0.098591549	0.071698113	0.06405694	0.050583658	0.068493151	0.036082474	0.062761506	0.084444444	0.093283582
Standard Error ±	*0.019459446*	*0.020017827*	*0.021964262*	*0.057258599*	*0.018945583*	*0.016727099*	*0.013121797*	*0.021742719*	*0.025690805*	*0.024621359*
C. constricta constricta	0	0.938967136	0.377358491	0	0.389105058	0	0.515463918	0	0	0
per cc	0	8	2	0	2	0	4	0	0	0
Fractional Abundance	0	0.009389671	0.003773585	0	0.003891051	0	0.005154639	0	0	0
Standard Error ±	*0*	*0.00647609*	*0.005220045*	*0*	*0.005382219*	*0*	*0.00503851*	*0*	*0*	*0*
D. oblonga glans	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga byrophila	0.552486188	0	0	0	0	0	0	0	0	0
per cc	4	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.005524862	0	0	0	0	0	0	0	0	0
Standard Error ±	*0.005399387*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. constricta aerophila	43.09392265	43.19248826	35.8490566	48.39857651	48.24902724	49.7716895	53.09278351	47.08333333	30.22222222	24.25373134
per cc	312	368	190	34	248	436	412	226	136	130
Fractional Abundance	0.430939227	0.431924883	0.358490566	0.483985765	0.482490272	0.497716895	0.530927835	0.472803347	0.302222222	0.242537313
Standard Error ±	*0.036072324*	*0.03326161*	*0.040828039*	*0.11686381*	*0.043199433*	*0.033110786*	*0.035112584*	*0.044757798*	*0.042429858*	*0.036286375*
D. urceolata urceolata	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. tricuspis	0.552486188	0	0	0	1.167315175	1.369863014	2.06185567	2.083333333	0.888888889	3.358208955
per cc	4	0	0	0	6	12	16	10	4	18
Fractional Abundance	0.005524862	0	0	0	0.011673152	0.01369863	0.020618557	0.020920502	0.008888889	0.03358209
Standard Error ±	*0.005399387*	*0*	*0*	*0*	*0.00928579*	*0.007697459*	*0.009998395*	*0.01283031*	*0.008672309*	*0.015251411*
C. aculeata aculeata	1.657458564	0.469483568	0	0	0	0	0	0	0	0
per cc	12	4	0	0	0	0	0	0	0	0
Fractional Abundance	0.016574586	0.004694836	0	0	0	0	0	0	0	0
Standard Error ±	*0.009299912*	*0.004590126*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata discoides	0	1.408450704	0.377358491	0.711743772	0.778210117	1.369863014	0.515463918	2.5	1.777777778	1.865671642
per cc	0	12	2	0.5	4	12	4	12	8	10
Fractional Abundance	0	0.014084507	0.003773585	0.007117438	0.007782101	0.01369863	0.005154639	0.025104603	0.017777778	0.018656716
Standard Error ±	*0*	*0.007912741*	*0.005220045*	*0.019658197*	*0.007596726*	*0.007697459*	*0.00503851*	*0.014024837*	*0.012209375*	*0.011455176*
D. oblonga oblonga	0	1.408450704	2.641509434	2.846975089	8.171206226	8.219178082	11.8556701	7.916666667	16.88888889	17.1641791
per cc	0	12	14	2	42	72	92	38	76	92
Fractional Abundance	0	0.014084507	0.026415094	0.028469751	0.081712062	0.082191781	0.118556701	0.079497908	0.168888889	0.171641791
Standard Error ±	*0*	*0.007912741*	*0.013653096*	*0.03889134*	*0.023681382*	*0.018188387*	*0.022744974*	*0.024251151*	*0.03461624*	*0.031922308*
D. proteiformis proteiformis	0	2.34741784	3.018867925	3.558718861	1.167315175	1.369863014	1.546391753	1.666666667	0.888888889	0.746268657
per cc	0	20	16	2.5	6	12	12	8	4	4
Fractional Abundance	0	0.023474178	0.030188679	0.035587189	0.011673152	0.01369863	0.015463918	0.016736402	0.008888889	0.007462687
Standard Error ±	*0*	*0.010166544*	*0.014567459*	*0.043322273*	*0.00928579*	*0.007697459*	*0.00868162*	*0.011500273*	*0.008672309*	*0.007286093*

RIL 10										
Interval	**160.5**	**165.5**	**170.5**	**175.5**	**180.5**	**185.5**	**190.5**	**195.5**	**200.5**	**205.5**
Total counted	181	213	265	281	257	219	194	240	225	268
Counts per cc	724	852	530	70.25	514	876	776	478	450	536
Number of species	8	12	10	11	11	13	11	12	12	13
Diversity	1.428	1.699	1.713	1.645	1.605	1.623	1.524	1.662	1.837	1.906
Biofacies	SO	SO	SO	SO	SO	SO	SO	SO	E	E
H. sphagni	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga spinosa	0	2.816901408	1.132075472	1.423487544	0.778210117	0.456621005	2.06185567	0.416666667	1.777777778	2.985074627
per cc	0	24	6	1	4	4	16	2	8	16
Fractional Abundance	0	0.028169014	0.011320755	0.014234875	0.007782101	0.00456621	0.020618557	0.0041841	0.017777778	0.029850746
Standard Error ±	*0*	*0.011110087*	*0.00900707*	*0.027701065*	*0.007596726*	*0.004464658*	*0.009998395*	*0.005786723*	*0.012209375*	*0.0144069*
N. colaris	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga triangularis	0	0	0	0.711743772	0	0.456621005	0	0	1.333333333	1.492537313
per cc	0	0	0	0.5	0	4	0	0	6	8
Fractional Abundance	0	0	0	0.007117438	0	0.00456621	0	0	0.013333333	0.014925373
Standard Error ±	*0*	*0*	*0*	*0.019658197*	*0*	*0.004464658*	*0*	*0*	*0.010597524*	*0.010265281*
D.oblonga lanceolata	0	0	0	0	0	0	0	0	0	2.23880597
per cc	0	0	0	0	0	0	0	0	0	12
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.02238806
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.012524637*
D.fragosa	0	0	0	1.779359431	0	0.456621005	0	0.833333333	0.444444444	0.373134328
per cc	0	0	0	1.25	0	4	0	4	2	2
Fractional Abundance	0	0	0	0.017793594	0	0.00456621	0	0.008368201	0.004444444	0.003731343
Standard Error ±	*0*	*0*	*0*	*0.030914778*	*0*	*0.004464658*	*0*	*0.008166452*	*0.006145982*	*0.005161721*
D.proteiformis acuminata	0	1.408450704	0	0	0	0	0	0	0	0
per cc	0	12	0	0	0	0	0	0	0	0
Fractional Abundance	0	0.014084507	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0.007912741*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L. spirialis	0	0	0	0	0	0.456621005	0	0.416666667	0	0
per cc	0	0	0	0	0	4	0	2	0	0
Fractional Abundance	0	0	0	0	0	0.00456621	0	0.0041841	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0.004464658*	*0*	*0.005786723*	*0*	*0*
Trinema	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Bullinularia	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Corythion	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Phyraginella	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Euglypha	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Cyclopyxis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
D.urens	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0
Plagiopyxis	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0

RIL 10											
Interval	**210.5**	**215.5**	**220.5**	**225.5**	**230.5**	**235.5**	**240.5**	**245.5**	**250.5**	**255.5**	**256.5**
Total counted	266	245	241	267	229	247	250	229	167	241	209
Counts per cc	532	980	964	534	916	494	62.5	57.25	41.75	60.25	52.25
Number of species	13	15	12	11	11	13	11	9	10	12	11
Diversity	1.885	1.938	1.964	1.918	1.757	1.848	1.881	1.662	1.28	1.554	1.618
Biofacies	E	E	E	E	E	E	E	E	B/W	B/W	B/W
A. vulgaris	9.77443609	11.42857143	9.958506224	16.10486891	10.48034934	14.57489879	35.6	19.65065502	8.383233533	0.829875519	0.956937799
per cc	52	112	96	86	96	72	22.25	11.25	3.5	0.5	0.5
Fractional Abundance	0.097744361	0.114285714	0.099585062	0.161048689	0.104803493	0.145748988	0.356	0.19650655	0.083832335	0.008298755	0.009569378
Standard Error ±	*0.025235442*	*0.019919839*	*0.018903229*	*0.031176863*	*0.01983606*	*0.031116312*	*0.118709095*	*0.102931431*	*0.084066137*	*0.022907329*	*0.026397744*
D. proteiformis amphoralis	21.80451128	7.755102041	14.52282158	8.61423221	5.240174672	6.072874494	4	0	0	0	0
per cc	116	76	140	46	48	30	2.5	0	0	0	0
Fractional Abundance	0.218045113	0.07755102	0.145228216	0.086142322	0.052401747	0.060728745	0.04	0	0	0	0
Standard Error ±	*0.035088458*	*0.01674588*	*0.022241708*	*0.023797592*	*0.014430898*	*0.021061304*	*0.048582703*	*0*	*0*	*0*	*0*
D. globulus	14.28571429	7.346938776	11.2033195	16.47940075	17.46724891	12.95546559	6	18.77729258	0	0	0
per cc	76	72	108	88	160	64	3.75	10.75	0	0	0
Fractional Abundance	0.142857143	0.073469388	0.112033195	0.164794007	0.174672489	0.129554656	0.06	0.187772926	0	0	0
Standard Error ±	*0.029735678*	*0.016335263*	*0.019910826*	*0.031466827*	*0.024588597*	*0.029613508*	*0.058878348*	*0.101163429*	*0*	*0*	*0*
L. vas	4.887218045	4.897959184	5.809128631	2.247191011	2.183406114	3.238866397	0	0	0	0	0
per cc	26	48	56	12	20	16	0	0	0	0	0
Fractional Abundance	0.04887218	0.048979592	0.058091286	0.02247191	0.021834061	0.032388664	0	0	0	0	0
Standard Error ±	*0.018321058*	*0.013512806*	*0.014766496*	*0.012571007*	*0.009464155*	*0.015611319*	*0*	*0*	*0*	*0*	*0*
C. constricta constricta	0	0.408163265	0	0	0	1.619433198	1.6	1.746724891	0.598802395	0	0
per cc	0	4	0	0	0	8	1	1	0.25	0	0
Fractional Abundance	0	0.004081633	0	0	0	0.016194332	0.016	0.017467249	0.005988024	0	0
Standard Error ±	*0*	*0.003991828*	*0*	*0*	*0*	*0.011130861*	*0.031108108*	*0.033935488*	*0.02340267*	*0*	*0*
D. oblonga glans	0	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga byrophila	0	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. constricta aerophila	13.53383459	34.28571429	22.82157676	11.61048689	13.97379913	11.33603239	12	17.90393013	15.56886228	14.10788382	8.612440191
per cc	72	336	220	62	128	56	7.5	10.25	6.5	8.5	4.5
Fractional Abundance	0.135338346	0.342857143	0.228215768	0.116104869	0.139737991	0.113360324	0.12	0.179039301	0.155688623	0.141078838	0.086124402
Standard Error ±	*0.029069247*	*0.029718681*	*0.026493439*	*0.027171338*	*0.02245334*	*0.027957396*	*0.080565299*	*0.09931245*	*0.109978449*	*0.087899243*	*0.076071079*
D. urceolata urceolata	0	0.816326531	0	0	0	0	0	0	0	0	0
per cc	0	8	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0.008163265	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0.005633718*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. tricuspis	6.390977444	6.93877551	9.543568465	22.09737828	37.11790393	35.62753036	15.2	8.733624454	1.19760479	0	0
per cc	34	68	92	118	340	176	9.5	5	0.5	0	0
Fractional Abundance	0.063909774	0.069387755	0.095435685	0.220973783	0.371179039	0.356275304	0.152	0.087336245	0.011976048	0	0
Standard Error ±	*0.020784652*	*0.015909951*	*0.018547812*	*0.03519102*	*0.031286974*	*0.042231406*	*0.089009381*	*0.073134279*	*0.032996535*	*0*	*0*
C. aculeata aculeata	0.37593985	0	0	0	0	0	2	13.97379913	34.13173653	19.08713693	6.220095694
per cc	2	0	0	0	0	0	1.25	8	14.25	11.5	3.25
Fractional Abundance	0.003759398	0	0	0	0	0	0.02	0.139737991	0.341317365	0.190871369	0.062200957
Standard Error ±	*0.005200458*	*0*	*0*	*0*	*0*	*0*	*0.03470916*	*0.08981336*	*0.143828559*	*0.099233138*	*0.065488697*
C. aculeata discoides	1.127819549	2.040816327	1.244813278	1.498127341	0.873362445	0.4048583	3.2	17.03056769	26.34730539	24.06639004	27.75119617
per cc	6	20	12	8	8	2	2	9.75	11	14.5	14.5
Fractional Abundance	0.011278195	0.020408163	0.012448133	0.014981273	0.008733624	0.004048583	0.032	0.170305677	0.263473054	0.2406639	0.277511962
Standard Error ±	*0.008973402*	*0.008852533*	*0.00699922*	*0.010303435*	*0.006025607*	*0.00559968*	*0.043634372*	*0.097373762*	*0.13362578*	*0.107944382*	*0.121414095*
D. oblonga oblonga	14.28571429	11.02040816	10.37344398	10.86142322	6.113537118	7.692307692	8.8	1.746724891	1.19760479	0	0
per cc	76	108	100	58	56	38	5.5	1	0.5	0	0
Fractional Abundance	0.142857143	0.110204082	0.1037344	0.108614232	0.061135371	0.076923077	0.088	0.017467249	0.011976048	0	0
Standard Error ±	*0.029735678*	*0.019605913*	*0.019248522*	*0.026391353*	*0.015515154*	*0.023498485*	*0.070235199*	*0.033935488*	*0.032996535*	*0*	*0*
D. proteiformis proteiformis	0.751879699	3.265306122	1.659751037	1.498127341	0.873362445	1.214574899	6	0	0	0	0
per cc	4	32	16	8	8	6	3.75	0	0	0	0
Fractional Abundance	0.007518797	0.032653061	0.01659751	0.014981273	0.008733624	0.012145749	0.06	0	0	0	0
Standard Error ±	*0.007340668*	*0.011127462*	*0.008065006*	*0.010303435*	*0.006025607*	*0.009659423*	*0.058878348*	*0*	*0*	*0*	*0*

RIL 10											
Interval	**210.5**	**215.5**	**220.5**	**225.5**	**230.5**	**235.5**	**240.5**	**245.5**	**250.5**	**255.5**	**256.5**
Total counted	266	245	241	267	229	247	250	229	167	241	209
Counts per cc	532	980	964	534	916	494	62.5	57.25	41.75	60.25	52.25
Number of species	13	15	12	11	11	13	11	9	10	12	11
Diversity	1.885	1.938	1.964	1.918	1.757	1.848	1.881	1.662	1.28	1.554	1.618
Biofacies	E	E	E	E	E	E	E	E	B/W	B/W	B/W
H. sphagni	0	0	0	0	0	0	0	0	0	0.829875519	0.956937799
per cc	0	0	0	0	0	0	0	0	0	0.5	0.5
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.008298755	0.009569378
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.022907329*	*0.026397744*
D. oblonga spinosa	7.142857143	4.489795918	6.639004149	5.992509363	2.183406114	2.429149798	5.6	0	0	0	0
per cc	38	44	64	32	20	12	3.5	0	0	0	0
Fractional Abundance	0.071428571	0.044897959	0.066390041	0.059925094	0.021834061	0.024291498	0.056	0	0	0	0
Standard Error ±	*0.021884866*	*0.01296526*	*0.015716353*	*0.020131264*	*0.009464155*	*0.013576249*	*0.057002785*	*0*	*0*	*0*	*0*
N. colaris	0	0	0	0	0	0	0	0	0	0	0.4784689
per cc	0	0	0	0	0	0	0	0	0	0	0.25
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0.004784689
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.018711056*
D.oblonga triangularis	0.751879699	0.408163265	0	0	0	0	0	0	0	0	0
per cc	4	4	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.007518797	0.004081633	0	0	0	0	0	0	0	0	0
Standard Error ±	*0.007340668*	*0.003991828*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga lanceolata	4.887218045	4.489795918	5.809128631	2.996254682	3.493449782	2.429149798	0	0	0	0	0
per cc	26	44	56	16	32	12	0	0	0	0	0
Fractional Abundance	0.04887218	0.044897959	0.058091286	0.029962547	0.034934498	0.024291498	0	0	0	0	0
Standard Error ±	*0.018321058*	*0.01296526*	*0.014766496*	*0.014460025*	*0.01189088*	*0.013576249*	*0*	*0*	*0*	*0*	*0*
D.fragosa	0	0.408163265	0.414937759	0	0	0	0	0	0	0	0
per cc	0	4	4	0	0	0	0	0	0	0	0
Fractional Abundance	0	0.004081633	0.004149378	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0.003991828*	*0.004057945*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis acuminata	0	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	0	0
per cc	0	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L. spirialis	0	0	0	0	0	0.4048583	0	0	0	0	0
per cc	0	0	0	0	0	2	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0.004048583	0	0	0	0	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0.00559968*	*0*	*0*	*0*	*0*	*0*
Trinema	0	0	0	0	0	0	0	0	0	0.829875519	0
per cc	0	0	0	0	0	0	0	0	0	0.5	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.008298755	0
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.022907329*	*0*
Bullinularia	0	0	0	0	0	0	0	0	0	16.18257261	24.88038278
per cc	0	0	0	0	0	0	0	0	0	9.75	13
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.161825726	0.248803828
Standard Error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.092996904*	*0.117224432*
Corythion	0	0	0	0	0	0	0	0.436681223	0.598802395	1.659751037	0
per cc	0	0	0	0	0	0	0	0.25	0.25	1	0
Fractional Abundance	0	0	0	0	0	0	0	0.004366812	0.005988024	0.01659751	0
Standard Error ±	0	0	0	0	0	0	0	0.017080488	0.02340267	0.032260023	0
Phyraginella	0	0	0	0	0	0	0	0	5.389221557	14.10788382	19.61722488
per cc	0	0	0	0	0	0	0	0	2.25	8.5	10.25
Fractional Abundance	0	0	0	0	0	0	0	0	0.053892216	0.141078838	0.196172249
Standard Error ±	0	0	0	0	0	0	0	0	0.068495361	0.087899243	0.107674585
Euglypha	0	0	0	0	0	0	0	0	0	1.244813278	0.4784689
per cc	0	0	0	0	0	0	0	0	0	0.75	0.25
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.012448133	0.004784689
Standard Error ±	0	0	0	0	0	0	0	0	0	0.027996878	0.018711056
Cyclopyxis	0	0	0	0	0	0	0	0	0	0.414937759	0
per cc	0	0	0	0	0	0	0	0	0	0.25	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0.004149378	0
Standard Error ±	0	0	0	0	0	0	0	0	0	0.016231779	0
D.urens	0	0	0	0	0	0	0	0	6.586826347	6.639004149	7.655502392
per cc	0	0	0	0	0	0	0	0	2.75	4	4
Fractional Abundance	0	0	0	0	0	0	0	0	0.065868263	0.066390041	0.076555024
Standard Error ±	0	0	0	0	0	0	0	0	0.075243676	0.06286541	0.072095023
Plagiopyxis	0	0	0	0	0	0	0	0	0	0	2.392344498
per cc	0	0	0	0	0	0	0	0	0	0	1.25
Fractional Abundance	0	0	0	0	0	0	0	0	0	0	0.023923445
Standard Error ±	0	0	0	0	0	0	0	0	0	0	0.041434941

RIL2							
Interval (cm)	**3.5**	**25.5**	**50.5**	**75.5**	**100.5**	**125.5**	**155.5**
Total counted	220	569	305	397	238	303	268
Counts per cc	330	284.5	1220	794	476	1212	1072
Number of species	11	14	9	12	11	10	8
Diversity	1.185	1.776	1.357	1.377	1.45	1.427	1.09
Biofacies	DO	E	DO	DO	DO	DO	DO
A.vulgaris	67.27272727	38.31282953	58.03278689	61.96473552	55.88235294	51.48514851	72.3880597
# per cc	222	109	708	492	266	624	776
Fractional Abundance	0.672727273	0.383128295	0.580327869	0.619647355	0.558823529	0.514851485	0.723880597
Standard error ±	*0.05062599*	*0.056491678*	*0.027692868*	*0.033768467*	*0.04460629*	*0.028137344*	*0.026763358*
C.constricta constricta	2.727272727	1.933216169	3.278688525	5.289672544	10.08403361	6.270627063	2.23880597
# per cc	9	5.5	40	42	48	76	24
Fractional Abundance	0.008264463	0.006795136	0.00268745	0.006662056	0.021184945	0.005173785	0.002088438
Standard error ±	*0.009767971*	*0.009546264*	*0.002905106*	*0.005658463*	*0.012936494*	*0.004039081*	*0.002732848*
C. tricuspis	9.545454545	20.73813708	0.655737705	1.763224181	0.420168067	0.99009901	5.223880597
# per cc	31.5	59	8	14	2	12	56
Fractional Abundance	0.095454545	0.207381371	0.006557377	0.017632242	0.004201681	0.00990099	0.052238806
Standard error ±	*0.02351505*	*0.047112044*	*0.004529107*	*0.009154542*	*0.005810986*	*0.005574211*	*0.013320016*
C. aculeata discoides	5	1.405975395	0	0	0	0	0
# per cc	16.5	4	0	0	0	0	0
Fractional Abundance	0.05	0.014059754	0	0	0	0	0
Standard error ±	*0.02351505*	*0.013681354*	*0*	*0*	*0*	*0*	*0*
C.constricta aerophila	7.727272727	14.23550088	10.49180328	6.549118388	5.042016807	4.290429043	5.597014925
# per cc	25.5	40.5	128	52	24	52	60
Fractional Abundance	0.023415978	0.05003691	0.008599839	0.00824826	0.010592472	0.003539958	0.005221096
Standard error ±	*0.016315863*	*0.02533457*	*0.005181384*	*0.006291127*	*0.009196845*	*0.00334375*	*0.004314225*
D. proteiformis amphoralis	4.090909091	8.260105448	13.1147541	10.07556675	12.18487395	14.19141914	6.343283582
# per cc	13.5	23.5	160	80	58	172	68
Fractional Abundance	0.040909091	0.082601054	0.131147541	0.100755668	0.121848739	0.141914191	0.063432836
Standard error ±	*0.021371692*	*0.031987983*	*0.018942149*	*0.020937239*	*0.029386494*	*0.019646402*	*0.014591005*
D.globulus	1.363636364	2.108963093	1.967213115	1.763224181	0.840336134	1.320132013	4.47761194
# per cc	4.5	6	24	14	4	16	48
Fractional Abundance	0.013636364	0.021089631	0.019672131	0.017632242	0.008403361	0.01320132	0.044776119
Standard error ±	*0.012513158*	*0.016696325*	*0.007792692*	*0.009154542*	*0.008200619*	*0.006425808*	*0.012380395*
D. oblonga	0.454545455	0	0	0	0.420168067	0.660066007	0.746268657
# per cc	1.5	0	0	0	2	8	8
Fractional Abundance	0.004545455	0	0	0	0.004201681	0.00660066	0.007462687
Standard error ±	*0.007257691*	*0*	*0*	*0*	*0.005810986*	*0.004558903*	*0.005152046*
D. proteiformis proteiformis	0.454545455	1.58172232	0	0.251889169	0	0	0
# per cc	1.5	4.5	0	2	0	0	0
Fractional Abundance	0.004545455	0.015817223	0	0.002518892	0	0	0
Standard error ±	*0.007257691*	*0.014498329*	*0*	*0.003486606*	*0*	*0*	*0*
D.urens	0.909090909	0	0	0	0	0	0
# per cc	3	0	0	0	0	0	0
Fractional Abundance	0.009090909	0	0	0	0	0	0
Standard error ±	*0.010240465*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata aculeata	0.454545455	0.878734622	0.327868852	0	0	0	0
# per cc	1.5	2.5	4	0	0	0	0
Fractional Abundance	0.004545455	0.008787346	0.003278689	0	0	0	0
Standard error ±	*0.007257691*	*0.010844942*	*0.003207843*	*0*	*0*	*0*	*0*
D.oblonga glans	0	8.611599297	0	0.755667506	1.680672269	0	0
# per cc	0	24.5	0	6	8	0	0
Fractional Abundance	0	0.086115993	0	0.007556675	0.016806723	0	0
Standard error ±	*0*	*0.032598858*	*0*	*0.00602371*	*0.01154818*	*0*	*0*
D.oblonga linearis	0	0.175746924	0	0.755667506	0	0.660066007	0
# per cc	0	0.5	0	6	0	8	0
Fractional Abundance	0	0.001757469	0	0.007556675	0	0.00660066	0
Standard error ±	*0*	*0.004867174*	*0*	*0.00602371*	*0*	*0.004558903*	*0*
D.bidens	0	0.527240773	1.31147541	0.503778338	0	0	0
# per cc	0	1.5	16	4	0	0	0
Fractional Abundance	0	0.005272408	0.013114754	0.005037783	0	0	0
Standard error ±	*0*	*0.008415337*	*0.006383951*	*0.004924576*	*0*	*0*	*0*
N.colaris	0	0.878734622	0	1.007556675	0.840336134	0	0
# per cc	0	2.5	0	8	4	0	0
Fractional Abundance	0	0.008787346	0	0.010075567	0.008403361	0	0
Standard error ±	*0*	*0.010844942*	*0*	*0.006946749*	*0.008200619*	*0*	*0*
D.proteiformis claviformis	0	0.351493849	0	0	0	0	0
# per cc	0	1	0	0	0	0	0
Fractional Abundance	0	0.003514938	0	0	0	0	0
Standard error ±	*0*	*0.006877161*	*0*	*0*	*0*	*0*	*0*
D. urceloata	0	0	10.81967213	9.319899244	11.34453782	19.8019802	2.985074627
# per cc	0	0	132	74	54	240	32
Fractional Abundance	0	0	0.108196721	0.093198992	0.113445378	0.198019802	0.029850746
Standard error ±	*0*	*0*	*0.017430817*	*0.020221223*	*0.028490413*	*0.022435766*	*0.010187217*
H.sphagni	0	0	0	0	1.260504202	0.330033003	0
# per cc	0	0	0	0	6	4	0
Fractional Abundance	0	0	0	0	0.012605042	0.00330033	0
Standard error ±	*0*	*0*	*0*	*0*	*0.010022365*	*0.003228982*	*0*
L.vas	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga triangularis	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0

RIL2									
Interval (cm)	**160.5**	**165.5**	**170.5**	**175.5**	**180.5**	**185.5**	**190.5**	**195.5**	**200.5**
Total counted	236	235	217	202	199	320.5	228	191	223
Counts per cc	944	940	434	101	99.5	641	456	382	446
Number of species	9	7	12	10	7	4	5	4	5
Diversity	0.8728	1.089	1.812	1.071	0.83	0.43	0.65	0.6425	1.003
Biofacies	DO	DO	E	DO	DO	DO	DO	DO	DO
A.vulgaris	77.54237288	68.93617021	46.08294931	73.26732673	78.3919598	89.23556942	81.14035088	81.67539267	66.8161435
# per cc	732	648	200	74	78	286	370	312	298
Fractional Abundance	0.775423729	0.689361702	0.460829493	0.732673267	0.783919598	0.446177847	0.811403509	0.816753927	0.668161435
Standard error ±	*0.026620827*	*0.029583069*	*0.046896929*	*0.086312114*	*0.0808701*	*0.038482761*	*0.035905328*	*0.038796035*	*0.043701141*
C.constricta constricta	3.389830508	5.957446809	0.921658986	5.940594059	8.040201005	2.496099844	1.315789474	4.188481675	5.829596413
# per cc	32	56	4	6	8	8	6	16	26
Fractional Abundance	0.003590922	0.006337709	0.002123638	0.058817763	0.08080604	0.003894072	0.002885503	0.010964612	0.013070844
Standard error ±	*0.003815855*	*0.00507315*	*0.004331017*	*0.045886665*	*0.053551301*	*0.004821496*	*0.004923307*	*0.01044304*	*0.01054104*
C. tricuspis	0.423728814	7.234042553	7.834101382	0.99009901	1.005025126	0	0	0	0
# per cc	4	68	34	1	1	0	0	0	0
Fractional Abundance	0.004237288	0.072340426	0.078341014	0.00990099	0.010050251	0	0	0	0
Standard error ±	*0.004143735*	*0.016560635*	*0.025280807*	*0.019309633*	*0.019599255*	*0*	*0*	*0*	*0*
C. aculeata discoides	0.423728814	0	2.304147465	2.475247525	2.010050251	0	0	0	0
# per cc	4	0	10	2.5	2	0	0	0	0
Fractional Abundance	0.004237288	0	0.023041475	0.024752475	0.020100503	0	0	0	0
Standard error ±	*0.004143735*	*0*	*0.014115765*	*0.030301361*	*0.027576475*	*0*	*0*	*0*	*0*
C.constricta aerophila	8.050847458	11.91489362	7.834101382	5.940594059	5.025125628	7.176287051	13.59649123	11.51832461	18.83408072
# per cc	76	112	34	6	5	23	62	44	84
Fractional Abundance	0.00852644	0.012675419	0.018050925	0.058817763	0.050503775	0.011195456	0.029816867	0.030152682	0.042228881
Standard error ±	*0.00586604*	*0.007151601*	*0.012525798*	*0.045886665*	*0.04302819*	*0.008145227*	*0.015611028*	*0.01714901*	*0.018664841*
D. proteiformis amphoralis	7.627118644	2.978723404	2.304147465	5.445544554	2.512562814	0	1.754385965	0	1.793721973
# per cc	72	28	10	5.5	2.5	0	8	0	8
Fractional Abundance	0.076271186	0.029787234	0.023041475	0.054455446	0.025125628	0	0.01754386	0	0.01793722
Standard error ±	*0.016932558*	*0.010867777*	*0.014115765*	*0.04425446*	*0.03075228*	*0*	*0.01205016*	*0*	*0.012317876*
D.globulus	0.423728814	2.553191489	9.677419355	0.99009901	0	1.092043682	2.192982456	2.617801047	6.726457399
# per cc	4	24	42	1	0	3.5	10	10	30
Fractional Abundance	0.004237288	0.025531915	0.096774194	0.00990099	0	0.005460218	0.021929825	0.02617801	0.067264574
Standard error ±	*0.004143735*	*0.010083647*	*0.027815646*	*0.019309633*	*0*	*0.005704836*	*0.013442382*	*0.016011518*	*0.023246687*
D. oblonga	0	0	0	1.485148515	0	0	0	0	0
# per cc	0	0	0	1.5	0	0	0	0	0
Fractional Abundance	0	0	0	0.014851485	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0.023590176*	*0*	*0*	*0*	*0*	*0*
D. proteiformis proteiformis	0	0	0.921658986	0.99009901	0	0	0	0	0
# per cc	0	0	4	1	0	0	0	0	0
Fractional Abundance	0	0	0.00921659	0.00990099	0	0	0	0	0
Standard error ±	*0*	*0*	*0.008990538*	*0.019309633*	*0*	*0*	*0*	*0*	*0*
D.urens	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata aculeata	0	0	0.921658986	2.475247525	3.015075377	0	0	0	0
# per cc	0	0	4	2.5	3	0	0	0	0
Fractional Abundance	0	0	0.00921659	0.024752475	0.030150754	0	0	0	0
Standard error ±	*0*	*0*	*0.008990538*	*0.030301361*	*0.0336005*	*0*	*0*	*0*	*0*
D.oblonga glans	0	0	4.608294931	0	0	0	0	0	0
# per cc	0	0	20	0	0	0	0	0	0
Fractional Abundance	0	0	0.046082949	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0.019725892*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga linearis	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.bidens	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
N.colaris	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. urceloata	1.694915254	0.425531915	0	0	0	0	0	0	0
# per cc	16	4	0	0	0	0	0	0	0
Fractional Abundance	0.016949153	0.004255319	0	0	0	0	0	0	0
Standard error ±	*0.008234402*	*0.004161331*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
H.sphagni	0.423728814	0	11.05990783	0	0	0	0	0	0
# per cc	4	0	48	0	0	0	0	0	0
Fractional Abundance	0.004237288	0	0.110599078	0	0	0	0	0	0
Standard error ±	*0.004143735*	*0*	*0.029507726*	*0*	*0*	*0*	*0*	*0*	*0*
L.vas	0	0	5.529953917	0	0	0	0	0	0
# per cc	0	0	24	0	0	0	0	0	0
Fractional Abundance	0	0	0.055299539	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0.021503989*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga triangularis	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0

RIL2										
Interval (cm)	**205.5**	**210.5**	**215.5**	**220.5**	**225.5**	**230.5**	**235.5**	**240.5**	**245.5**	**250.5**
Total counted	200	239	239	229	253	190	212	487	224	212
Counts per cc	400	956	478	916	506	380	106	243.5	112	53
Number of species	5	5	7	7	5	8	5	7	10	9
Diversity	1.051	0.7191	0.8709	0.8984	0.9216	1.263	0.791	0.596	1.172	1.316
Biofacies	DO	DO	DO	DO	DO	DO	DO	DO	DO	DO
A.vulgaris	61.5	79.91631799	74.89539749	75.10917031	66.79841897	57.89473684	76.41509434	84.59958932	63.83928571	57.54716981
# per cc	246	764	358	688	338	220	81	206	71.5	30.5
Fractional Abundance	0.615	0.79916318	0.748953975	0.751091703	0.66798419	0.578947368	0.764150943	0.845995893	0.638392857	0.575471698
Standard error ±	*0.047686341*	*0.025396071*	*0.038872848*	*0.028001062*	*0.041033946*	*0.049642313*	*0.080818314*	*0.045337427*	*0.088983518*	*0.133071008*
C.constricta constricta	6	5.020920502	5.020920502	6.986899563	6.719367589	8.421052632	4.716981132	2.874743326	12.5	8.018867925
# per cc	24	48	24	64	34	32	5	7	14	4.25
Fractional Abundance	0.015	0.005252009	0.010504018	0.00762762	0.013279383	0.022160665	0.044499822	0.011805927	0.111607143	0.151299396
Standard error ±	*0.011912141*	*0.004581908*	*0.009139593*	*0.005634303*	*0.009973942*	*0.014800944*	*0.039255242*	*0.013566811*	*0.058317055*	*0.096474822*
C. tricuspis	0	0	0	0	0	0	0	0	0.446428571	0.471698113
# per cc	0	0	0	0	0	0	0	0	0.5	0.25
Fractional Abundance	0	0	0	0	0	0	0	0	0.004464286	0.004716981
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.012346716*	*0.018446905*
C. aculeata discoides	0	0	0.418410042	0	0	0	0	0	0.892857143	7.547169811
# per cc	0	0	2	0	0	0	0	0	1	4
Fractional Abundance	0	0	0.0041841	0	0	0	0	0	0.008928571	0.075471698
Standard error ±	*0*	*0*	*0.005786723*	*0*	*0*	*0*	*0*	*0*	*0.0174217*	*0.071116488*
C.constricta aerophila	25.5	11.29707113	14.22594142	11.35371179	23.3201581	22.10526316	13.67924528	9.856262834	14.28571429	16.98113208
# per cc	102	108	68	104	118	84	14.5	24	16	9
Fractional Abundance	0.06375	0.01181702	0.029761384	0.012394882	0.046087269	0.058171745	0.129049484	0.040477465	0.12755102	0.320398718
Standard error ±	*0.023942091*	*0.006850145*	*0.01523379*	*0.007165083*	*0.018269456*	*0.023534565*	*0.063823118*	*0.02475374*	*0.061781585*	*0.125629206*
D. proteiformis amphoralis	3.5	0.836820084	1.255230126	2.183406114	1.581027668	5.789473684	4.716981132	1.232032854	5.357142857	3.301886792
# per cc	14	8	6	20	8	22	5	3	6	1.75
Fractional Abundance	0.035	0.008368201	0.012552301	0.021834061	0.015810277	0.057894737	0.047169811	0.012320329	0.053571429	0.033018868
Standard error ±	*0.018010416*	*0.005774553*	*0.009980697*	*0.009464155*	*0.010869009*	*0.023481916*	*0.040359238*	*0.013855614*	*0.041702068*	*0.048106995*
D.globulus	3.5	2.928870293	2.928870293	2.183406114	1.581027668	2.105263158	0	1.026694045	0.892857143	1.41509434
# per cc	14	28	14	20	8	8	0	2.5	1	0.75
Fractional Abundance	0.035	0.029288703	0.029288703	0.021834061	0.015810277	0.021052632	0	0.01026694	0.008928571	0.014150943
Standard error ±	*0.018010416*	*0.010688635*	*0.015116012*	*0.009464155*	*0.010869009*	*0.014434347*	*0*	*0.012661529*	*0.0174217*	*0.031799189*
D. oblonga	0	0	0	0.873362445	0	0	0	0	0	0.943396226
# per cc	0	0	0	8	0	0	0	0	0	0.5
Fractional Abundance	0	0	0	0.008733624	0	0	0	0	0	0.009433962
Standard error ±	*0*	*0*	*0*	*0.006025607*	*0*	*0*	*0*	*0*	*0*	*0.02602597*
D. proteiformis proteiformis	0	0	0	0	0	1.578947368	0	0	0	0
# per cc	0	0	0	0	0	6	0	0	0	0
Fractional Abundance	0	0	0	0	0	0.015789474	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0.01253407*	*0*	*0*	*0*	*0*
D.urens	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata aculeata	0	0	1.255230126	0	0	0.526315789	0.471698113	0.205338809	0.446428571	3.773584906
# per cc	0	0	6	0	0	2	0.5	0.5	0.5	2
Fractional Abundance	0	0	0.012552301	0	0	0.005263158	0.004716981	0.002053388	0.004464286	0.037735849
Standard error ±	*0*	*0*	*0.009980697*	*0*	*0*	*0.007275144*	*0.013043931*	*0.005685855*	*0.012346716*	*0.051302952*
D.oblonga glans	0	0	0	1.310043668	0	1.052631579	0	0.205338809	0.892857143	0
# per cc	0	0	0	12	0	4	0	0.5	1	0
Fractional Abundance	0	0	0	0.013100437	0	0.010526316	0	0.002053388	0.008928571	0
Standard error ±	*0*	*0*	*0*	*0.007363558*	*0*	*0.010261352*	*0*	*0.005685855*	*0.0174217*	*0*
D.oblonga linearis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.bidens	0	0	0	0	0	0	0	0	0.446428571	0
# per cc	0	0	0	0	0	0	0	0	0.5	0
Fractional Abundance	0	0	0	0	0	0	0	0	0.004464286	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.012346716*	*0*
N.colaris	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. urceloata	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
H.sphagni	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L.vas	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga triangularis	0	0	0	0	0	0.526315789	0	0	0	0
# per cc	0	0	0	0	0	2	0	0	0	0
Fractional Abundance	0	0	0	0	0	0.005263158	0	0	0	0
Standard error ±	0	0	0	0	0	0.007275144	0	0	0	0

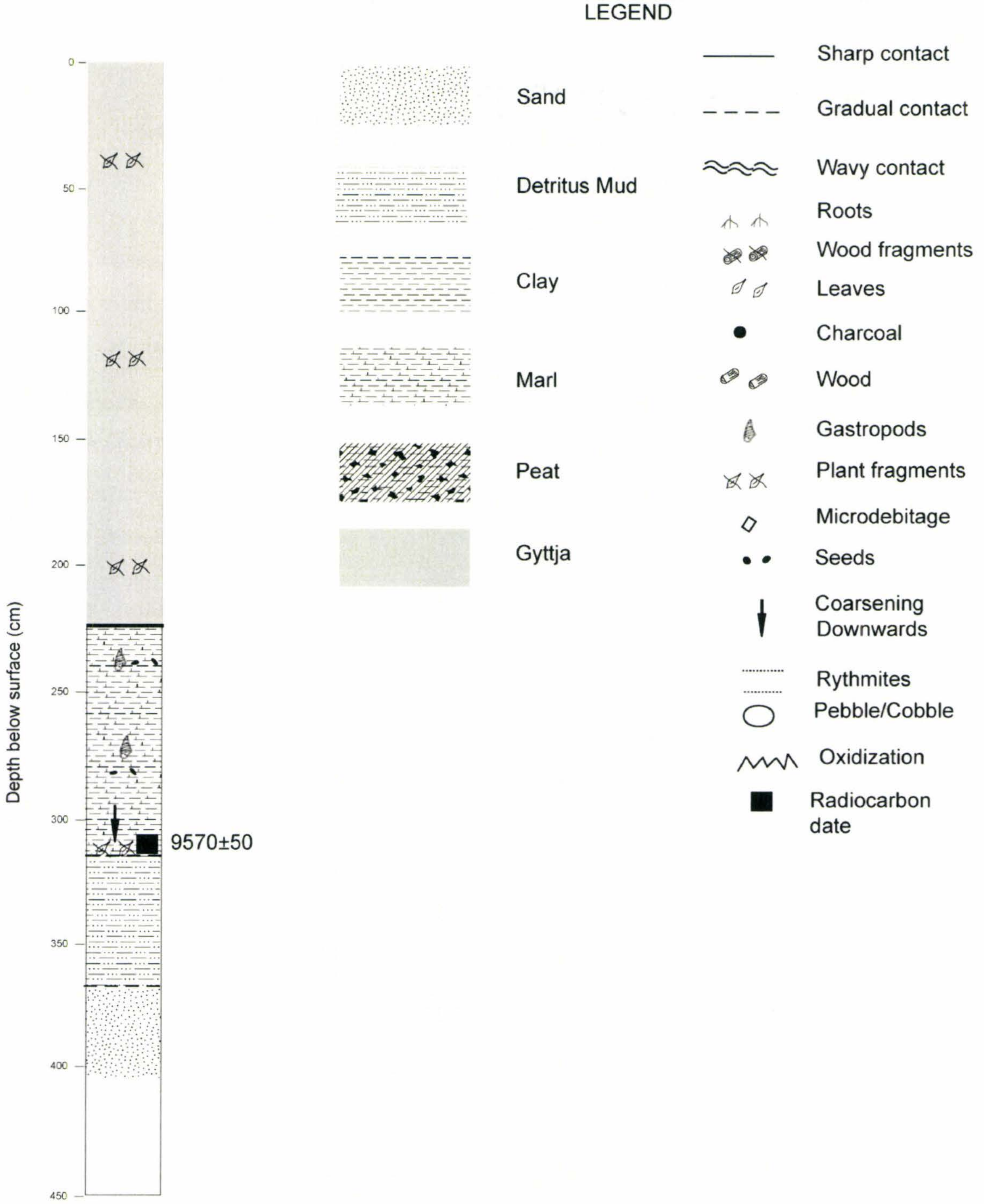
RIL2										
Interval (cm)	**255.5**	**260.5**	**265.5**	**270.5**	**275.5**	**280.5**	**285.5**	**290.5**	**295.5**	**300.5**
Total counted	262	478	589	355	326	242	218	215	292	226
Counts per cc	262	239	294.5	177.5	163	121	109	107.5	146	226
Number of species	8	9	5	7	8	7	8	5	5	6
Diversity	0.6955	0.6064	0.2955	0.6627	0.7138	0.8333	0.8855	0.8018	0.5462	0.5125
Biofacies	DO	DO	DO	DO	DO	DO	DO	DO	DO	DO
A.vulgaris	82.44274809	84.51882845	93.5483871	82.53521127	80.06134969	73.55371901	73.85321101	73.48837209	85.2739726	87.16814159
# per cc	216	202	275.5	146.5	130.5	89	80.5	79	124.5	197
Fractional Abundance	0.824427481	0.845188285	0.935483871	0.825352113	0.800613497	0.73553719	0.73853211	0.734883721	0.852739726	0.871681416
Standard error ±	0.046069121	0.045860181	0.028058582	0.055854503	0.061336869	0.078586511	0.082496722	0.083440971	0.057481844	0.043603919
C.constricta constricta	6.106870229	1.673640167	0.679117148	3.943661972	2.760736196	3.719008264	4.587155963	4.651162791	2.739726027	3.097345133
# per cc	16	4	2	7	4.5	4.5	5	5	4	7
Fractional Abundance	0.023308665	0.007002679	0.002306001	0.022217814	0.016937032	0.030735605	0.042084	0.043266631	0.018765247	0.013705067
Standard error ±	0.018270179	0.010572148	0.005478249	0.021683462	0.019809412	0.030754269	0.037693376	0.038461289	0.022011176	0.015158137
C. tricuspis	0	0.209205021	0	0	0	0	0.458715596	0	0	0
# per cc	0	0.5	0	0	0	0	0.5	0	0	
Fractional Abundance	0	0.00209205	0	0	0	0	0.004587156	0	0	0
Standard error ±	0	0.005792798	0	0	0	0	0.012685751	0	0	0
C. aculeata discoides	1.145038168	0.836820084	0.679117148	0.563380282	1.226993865	0.41322314	2.293577982	1.860465116	0	0.442477876
# per cc	3	2	2	1	2	0.5	2.5	2	0	1
Fractional Abundance	0.011450382	0.008368201	0.006791171	0.005633803	0.012269939	0.004132231	0.02293578	0.018604651	0	0.004424779
Standard error ±	0.01288293	0.011549107	0.009380069	0.011011105	0.016900619	0.011430271	0.028103547	0.025543747	0	0.008653358
C.constricta aerophila	7.633587786	10.66945607	4.753820034	10.70422535	13.19018405	18.18181818	16.05504587	19.06976744	10.2739726	7.96460177
# per cc	20	25.5	14	19	21.5	22	17.5	20.5	15	18
Fractional Abundance	0.029135831	0.044642076	0.016142004	0.060305495	0.080921375	0.15026296	0.147293999	0.177393186	0.070369675	0.035241601
Standard error ±	0.020365654	0.026182576	0.014393233	0.035021011	0.041866844	0.063669528	0.066532679	0.072213178	0.041488483	0.024040248
D. proteiformis amphoralis	1.908396947	0.836820084	0.339558574	1.126760563	1.533742331	3.305785124	1.376146789	0.930232558	1.02739726	0.884955752
# per cc	5	2	1	2	2.5	4	1.5	1	1.5	2
Fractional Abundance	0.019083969	0.008368201	0.003395586	0.011267606	0.015337423	0.033057851	0.013761468	0.009302326	0.010273973	0.008849558
Standard error ±	0.016567451	0.011549107	0.006644039	0.015527877	0.018866102	0.031856711	0.021870876	0.018147557	0.016357101	0.012210471
D.globulus	0.381679389	0.627615063	0	0.845070423	0.306748466	0	0.917431193	0	0.684931507	0
# per cc	1	1.5	0	1.5	0.5	0	1	0	1	0
Fractional Abundance	0.003816794	0.006276151	0	0.008450704	0.003067485	0	0.009174312	0	0.006849315	0
Standard error ±	0.007466626	0.010012365	0	0.013466679	0.008489583	0	0.017898977	0	0.013378604	0
D. oblonga	0	0	0	0	0	0.41322314	0	0	0	0
# per cc	0	0	0	0	0	0.5	0	0	0	0
Fractional Abundance	0	0	0	0	0	0.004132231	0	0	0	0
Standard error ±	0	0	0	0	0	0.011430271	0	0	0	0
D. proteiformis proteiformis	0	0	0	0.281690141	0	0	0	0	0	0
# per cc	0	0	0	0.5	0	0	0	0	0	0
Fractional Abundance	0	0	0	0.002816901	0	0	0	0	0	0
Standard error ±	0	0	0	0.007797047	0	0	0	0	0	0
D.urens	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
C. aculeata aculeata	0	0.209205021	0	0	0.613496933	0.41322314	0.458715596	0	0	0.442477876
# per cc	0	0.5	0	0	1	0.5	0.5	0	0	1
Fractional Abundance	0	0.00209205	0	0	0.006134969	0.004132231	0.004587156	0	0	0.004424779
Standard error ±	0	0.005792798	0	0	0.011987598	0.011430271	0.012685751	0	0	0.008653358
D.oblonga glans	0	0.418410042	0	0	0.306748466	0	0	0	0	0
# per cc	0	1	0	0	0.5	0	0	0	0	0
Fractional Abundance	0	0.0041841	0	0	0.003067485	0	0	0	0	0
Standard error ±	0	0.008183662	0	0	0.008489583	0	0	0	0	0
D.oblonga linearis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
D.bidens	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
N.colaris	0.381679389	0	0	0	0	0	0	0	0	0
# per cc	1	0	0	0	0	0	0	0	0	0
Fractional Abundance	0.003816794	0	0	0	0	0	0	0	0	0
Standard error ±	0.007466626	0	0	0	0	0	0	0	0	0
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
D. urceloata	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
H.sphagni	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
L.vas	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0
D. oblonga triangularis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0

RIL2										
Interval (cm)	**305.5**	**310.5**	**315.5**	**320.5**	**325.5**	**330.5**	**335.5**	**340.5**	**345.5**	**350.5**
Total counted	217	271	263	210	220	302	232	211	314	202
Counts per cc	108.5	135.5	131.5	105	110	151	116	105.5	157	101
Number of species	4	5	6	6	5	4	4	6	4	6
Diversity	0.457	0.3828	0.5444	0.4177	0.4194	0.2317	0.3046	0.2703	0.1226	0.6323
Biofacies	DO	DO	DO	DO	DO	DO	DO	DO	DO	DO
A.vulgaris	88.47926267	91.14391144	86.31178707	89.52380952	87.72727273	94.70198675	93.10344828	94.31279621	97.4522293	83.66336634
# per cc	96	123.5	113.5	94	96.5	143	108	99.5	153	84.5
Fractional Abundance	0.884792627	0.911439114	0.863117871	0.895238095	0.877272727	0.947019868	0.931034483	0.943127962	0.974522293	0.836633663
Standard error ±	*0.060076149*	*0.047837803*	*0.058749155*	*0.05857771*	*0.061319356*	*0.035727585*	*0.046113274*	*0.044194126*	*0.024648035*	*0.072101506*
C.constricta constricta	3.225806452	2.58302583	2.661596958	0.476190476	0.454545455	0.331125828	0	0	0	2.97029703
# per cc	3.5	3.5	3.5	0.5	0.5	0.5	0	0	0	3
Fractional Abundance	0.029730935	0.019062921	0.020240281	0.004535147	0.004132231	0.002192886	0	0	0	0.029408881
Standard error ±	*0.031958882*	*0.023025111*	*0.024069178*	*0.012851981*	*0.01198817*	*0.007461033*	*0*	*0*	*0*	*0.032949801*
C. tricuspis	0	0	0.380228137	0	0	0.331125828	1.724137931	0.473933649	0	0
# per cc	0	0	0.5	0	0	0.5	2	0.5	0	0
Fractional Abundance	0	0	0.003802281	0	0	0.003311258	0.017241379	0.004739336	0	0
Standard error ±	*0*	*0*	*0.01051933*	*0*	*0*	*0.009163131*	*0.023688443*	*0.013105604*	*0*	*0*
C. aculeata discoides	0	0.36900369	0	0	0.454545455	0	0.431034483	0.473933649	0	1.98019802
# per cc	0	0.5	0	0	0.5	0	0.5	0.5	0	2
Fractional Abundance	0	0.003690037	0	0	0.004545455	0	0.004310345	0.004739336	0	0.01980198
Standard error ±	*0*	*0.010209372*	*0*	*0*	*0.01257069*	*0*	*0.011921889*	*0.013105604*	*0*	*0.027171062*
C.constricta aerophila	7.373271889	5.535055351	8.745247148	8.095238095	10.90909091	4.635761589	4.74137931	3.791469194	2.229299363	9.900990099
# per cc	8	7.5	11.5	8.5	12	7	5.5	4	3.5	10
Fractional Abundance	0.067956423	0.040849117	0.066503781	0.077097506	0.099173554	0.030700408	0.04087396	0.035938097	0.014199359	0.098029605
Standard error ±	*0.047355951*	*0.033328919*	*0.042586568*	*0.051022237*	*0.05585708*	*0.027514947*	*0.036031992*	*0.035518927*	*0.018506963*	*0.057992276*
D. proteiformis amphoralis	0.921658986	0	1.520912548	0.476190476	0.454545455	0	0	0.473933649	0	0.495049505
# per cc	1	0	2	0.5	0.5	0	0	0.5	0	0.5
Fractional Abundance	0.00921659	0	0.015209125	0.004761905	0.004545455	0	0	0.004739336	0	0.004950495
Standard error ±	*0.017981077*	*0*	*0.020917863*	*0.013167862*	*0.01257069*	*0*	*0*	*0.013105604*	*0*	*0.013688065*
D.globulus	0	0	0	0.952380952	0	0	0	0	0.318471338	0.99009901
# per cc	0	0	0	1	0	0	0	0	0.5	1
Fractional Abundance	0	0	0	0.00952381	0	0	0	0	0.003184713	0.00990099
Standard error ±	*0*	*0*	*0*	*0.018577565*	*0*	*0*	*0*	*0*	*0.008813507*	*0.019309633*
D. oblonga	0	0.36900369	0	0	0	0	0	0.473933649	0	0
# per cc	0	0.5	0	0	0	0	0	0.5	0	0
Fractional Abundance	0	0.003690037	0	0	0	0	0	0.004739336	0	0
Standard error ±	*0*	*0.010209372*	*0*	*0*	*0*	*0*	*0*	*0.013105604*	*0*	*0*
D. proteiformis proteiformis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.urens	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata aculeata	0	0	0.380228137	0.476190476	0	0	0	0	0	0
# per cc	0	0	0.5	0.5	0	0	0	0	0	0
Fractional Abundance	0	0	0.003802281	0.004761905	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0.01051933*	*0.013167862*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga glans	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga linearis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.bidens	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
N.colaris	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. urceloata	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
H.sphagni	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L.vas	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga triangularis	0	0	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0	0	0

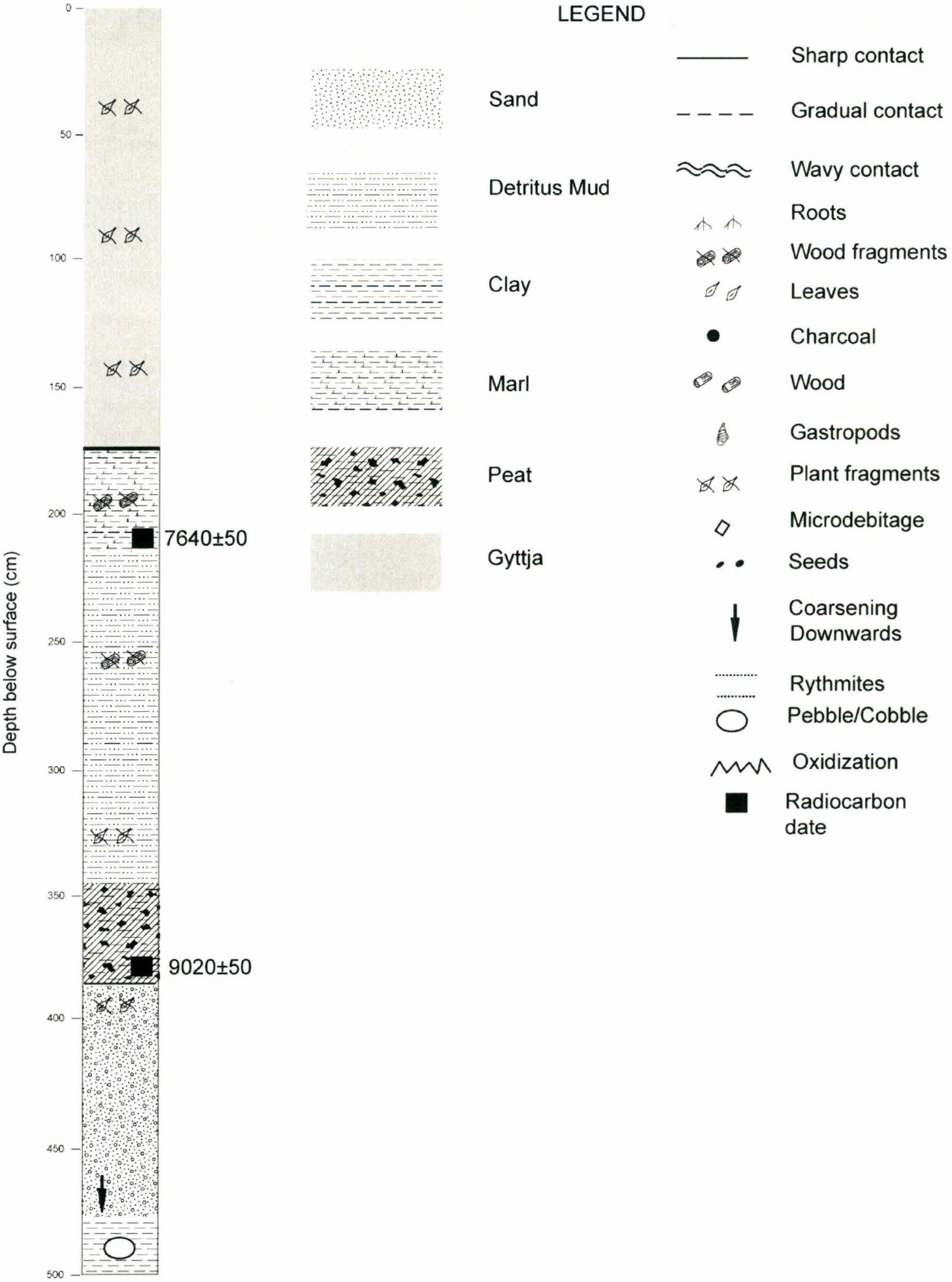
RIL2								
Interval (cm)	**355.5**	**360.5**	**365.5**	**370.5**	**375.5**	**380.5**	**385.5**	**390.5**
Total counted	221	353	229	457	466	382	206	206
Counts per cc	110.5	176.5	114.5	228.5	233	191	51.5	25.75
Number of species	5	5	4	7	6	5	9	9
Diversity	0.4681	0.4692	0.2371	0.2257	0.303	0.256	1.419	1.487
Biofacies	DO	DO	DO	DO	DO	DO	SO	E
A.vulgaris	88.23529412	89.23512748	95.19650655	95.84245077	93.56223176	94.76439791	37.37864078	39.80582524
# per cc	97.5	157.5	109	219	218	181	19.25	2.40625
Fractional Abundance	0.882352941	0.892351275	0.951965066	0.958424508	0.935622318	0.947643979	0.373786408	0.093446602
Standard error ±	*0.060074012*	*0.04572525*	*0.039168996*	*0.025882762*	*0.031513458*	*0.031589686*	*0.132137308*	*0.112420602*
C.constricta constricta	1.809954751	1.416430595	0	0.437636761	0.429184549	0.261780105	14.5631068	2.912621359
# per cc	2	2.5	0	1	1	0.5	7.5	0.9375
Fractional Abundance	0.016379681	0.008025103	0	0.001915259	0.001841994	0.001370576	0.282778773	0.113111509
Standard error ±	*0.023666901*	*0.013163136*	*0*	*0.005669052*	*0.005505818*	*0.005246784*	*0.12299924*	*0.122336306*
C. tricuspis	0	0	0	0.218818381	0	0	0.970873786	11.16504854
# per cc	0	0	0	0.5	0	0	0.5	0.0625
Fractional Abundance	0	0	0	0.002188184	0	0	0.009708738	0.002427184
Standard error ±	*0*	*0*	*0*	*0.006058696*	*0*	*0*	*0.026780293*	*0.019006019*
C. aculeata discoides	0.452488688	0	1.310043668	0.656455142	1.072961373	0	2.427184466	10.67961165
# per cc	0.5	0	1.5	1.5	2.5	0	1.25	0.15625
Fractional Abundance	0.004524887	0	0.013100437	0.006564551	0.010729614	0	0.024271845	0.006067961
Standard error ±	*0.012513938*	*0*	*0.020827287*	*0.010470932*	*0.01322902*	*0*	*0.042030859*	*0.029996266*
C.constricta aerophila	8.597285068	5.66572238	2.620087336	2.407002188	4.291845494	3.141361257	37.37864078	25.24271845
# per cc	9.5	10	3	5.5	10	6	19.25	2.40625
Fractional Abundance	0.077803485	0.03210041	0.022882859	0.010533926	0.018419938	0.016446918	0.72579885	0.980299745
Standard error ±	*0.04994433*	*0.026004838*	*0.027389354*	*0.013237579*	*0.017265734*	*0.018037675*	*0.121841498*	*0.05367633*
D. proteiformis amphoralis	0	2.266288952	0.873362445	0.218818381	0.429184549	0.261780105	1.45631068	1.45631068
# per cc	0	4	1	0.5	1	0.5	0.75	0.09375
Fractional Abundance	0	0.02266289	0.008733624	0.002188184	0.004291845	0.002617801	0.014563107	0.003640777
Standard error ±	*0*	*0.021956522*	*0.017042989*	*0.006058696*	*0.008393946*	*0.00724667*	*0.032718538*	*0.02326336*
D.globulus	0.904977376	1.416430595	0	0.218818381	0.214592275	1.570680628	4.368932039	5.339805825
# per cc	1	2.5	0	0.5	0.5	3	2.25	0.28125
Fractional Abundance	0.009049774	0.014164306	0	0.002188184	0.002145923	0.015706806	0.04368932	0.01092233
Standard error ±	*0.017657114*	*0.017433462*	*0*	*0.006058696*	*0.005941809*	*0.017633786*	*0.055826398*	*0.040145817*
D. oblonga	0	0	0	0	0	0	0.970873786	2.427184466
# per cc	0	0	0	0	0	0	0.5	0.0625
Fractional Abundance	0	0	0	0	0	0	0.009708738	0.002427184
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0.026780293*	*0.019006019*
D. proteiformis proteiformis	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.urens	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
C. aculeata aculeata	0	0	0	0	0	0	0.485436893	0.970873786
# per cc	0	0	0	0	0	0	0.25	0.03125
Fractional Abundance	0	0	0	0	0	0	0.004854369	0.001213592
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0.018982883*	*0.013447457*
D.oblonga glans	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.oblonga linearis	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.bidens	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
N.colaris	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D.proteiformis claviformis	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. urceloata	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
H.sphagni	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
L.vas	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
D. oblonga triangularis	0	0	0	0	0	0	0	0
# per cc	0	0	0	0	0	0	0	0
Fractional Abundance	0	0	0	0	0	0	0	0
Standard error ±	0	0	0	0	0	0	0	0

Appendix 4: Core Lithostratigraphic Logs

RIL-1 E 728399 N 4897077 WD: 4.38 m
Length: 4.07 m

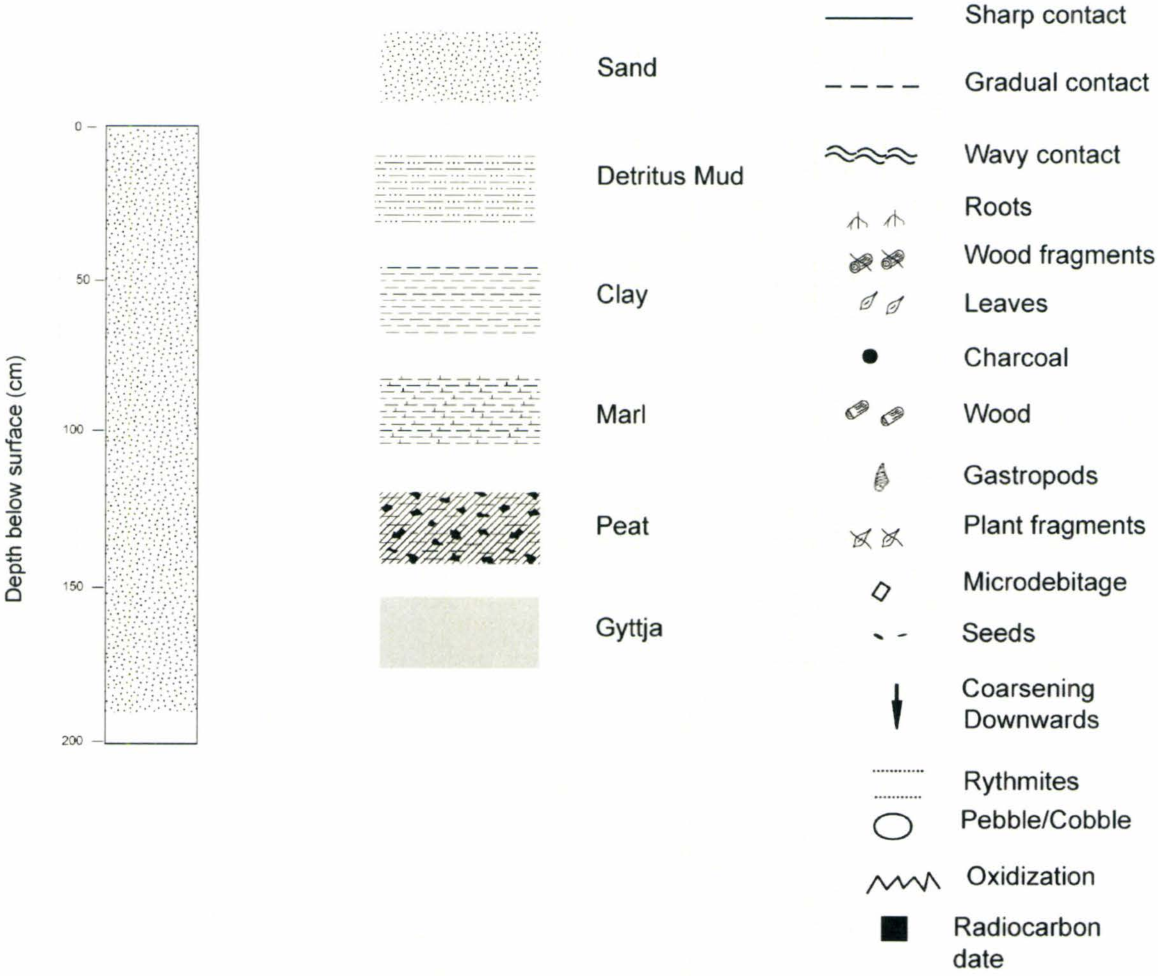


RIL-2 E 728794 N 4899432 WD: 2.2 m
Length: 4.945 m

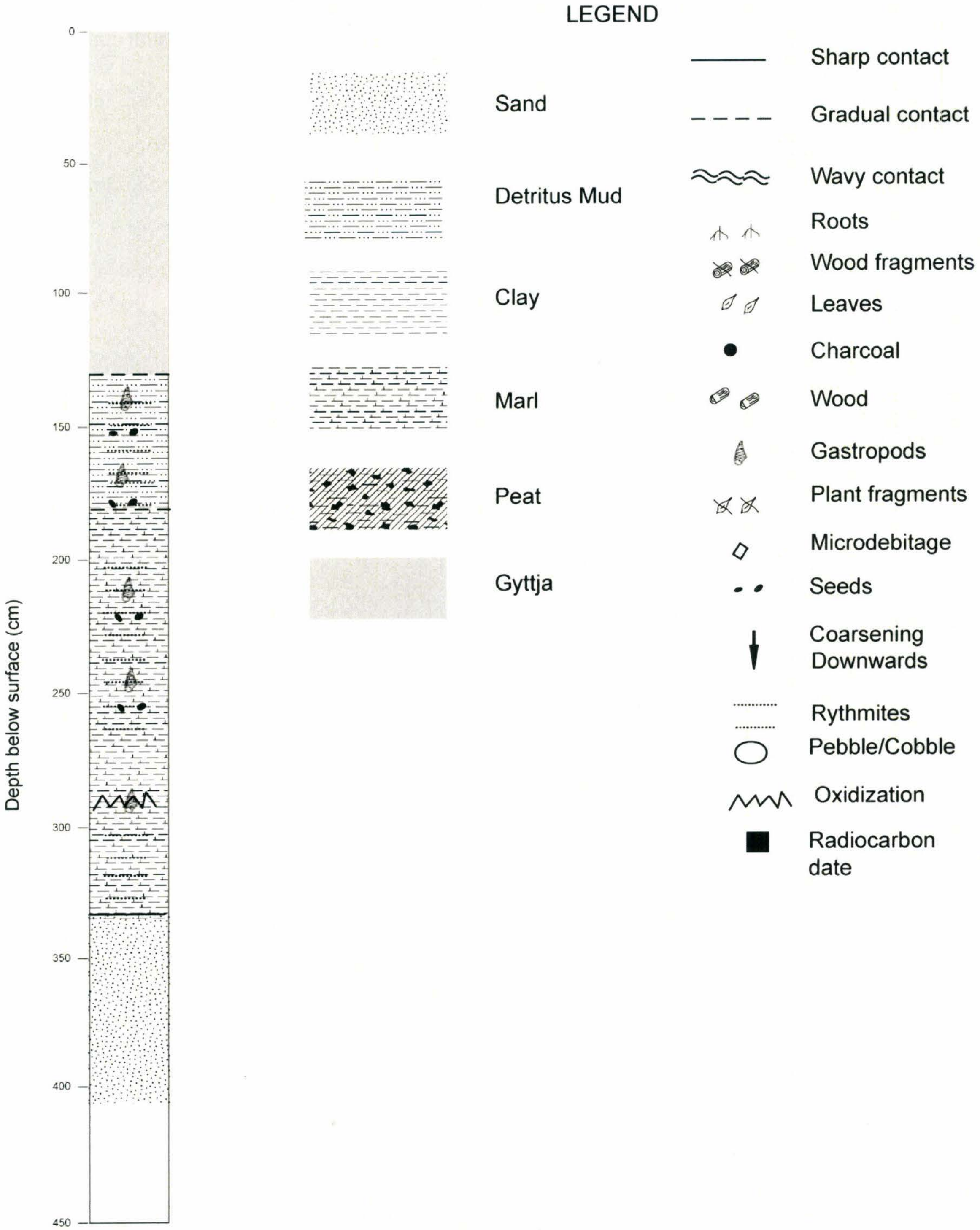


RIL-3 E 728298 N 4896971 WD: 3.24 m
Length: 1.89 m

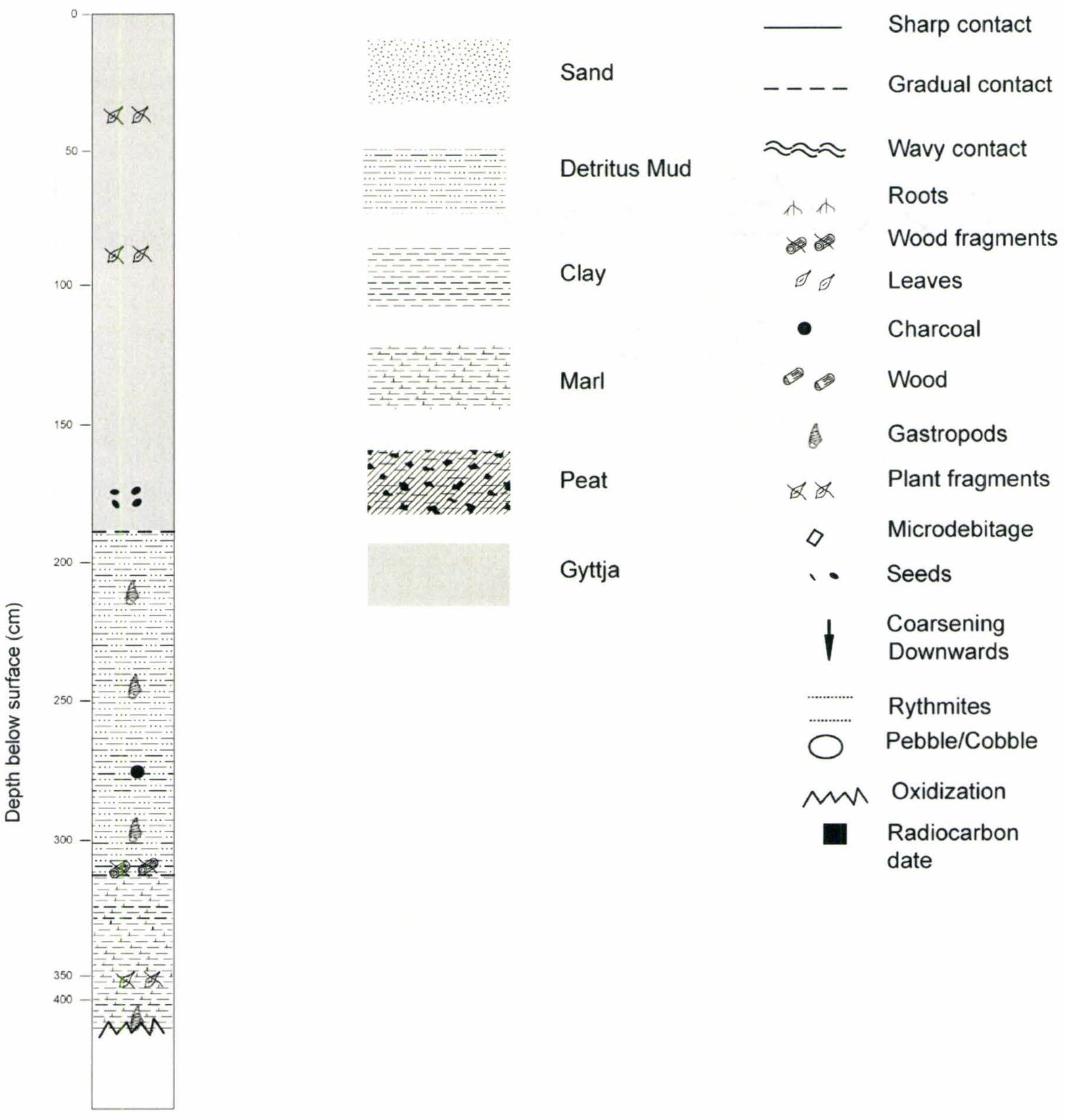
LEGEND



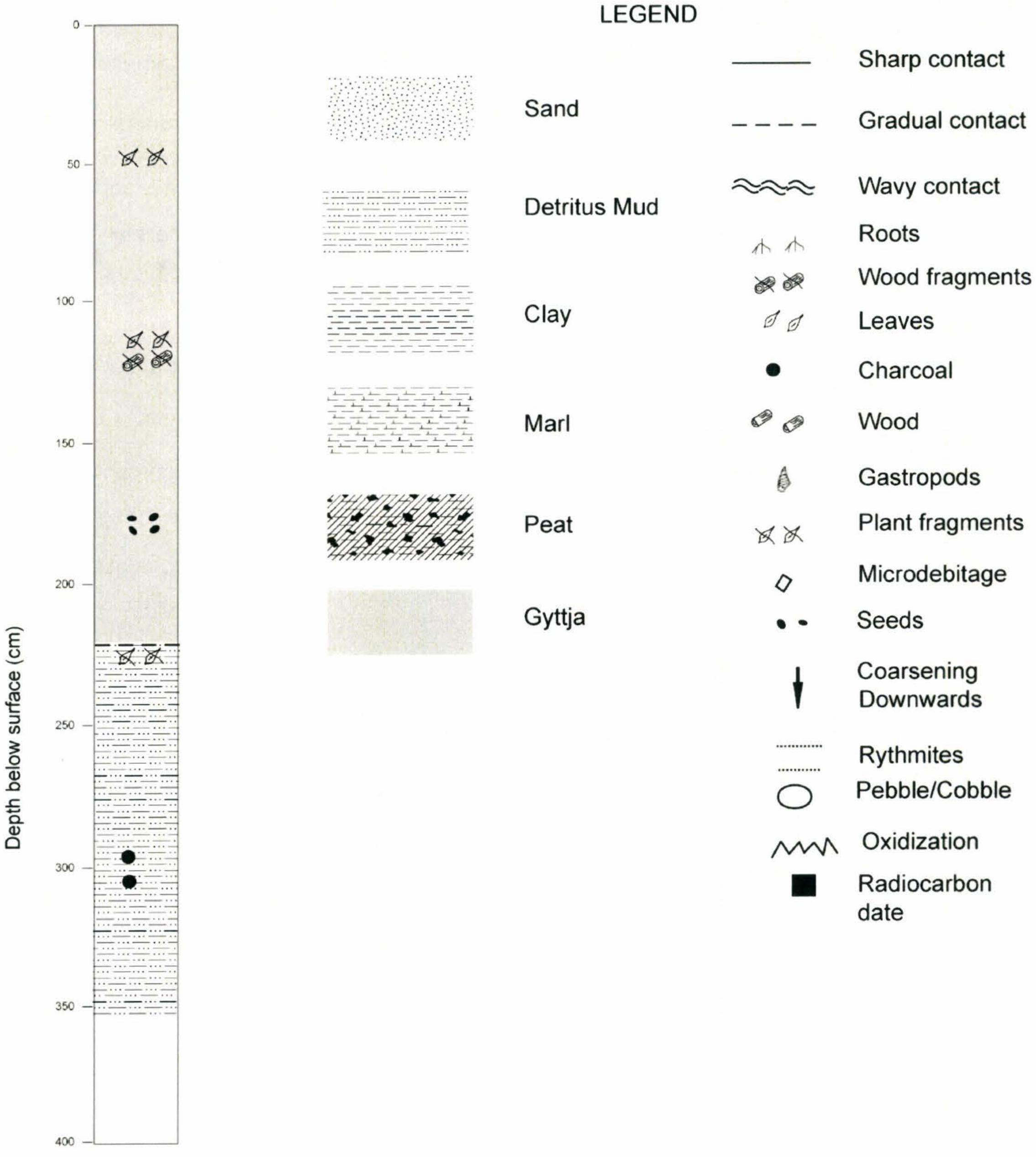
RIL-4 E 728185 N 4898390 WD: 2.33 m
Length: 4.11 m



RIL-5 E 728145 N 4899892 WD: 1.82 m
Length: 3.70 m

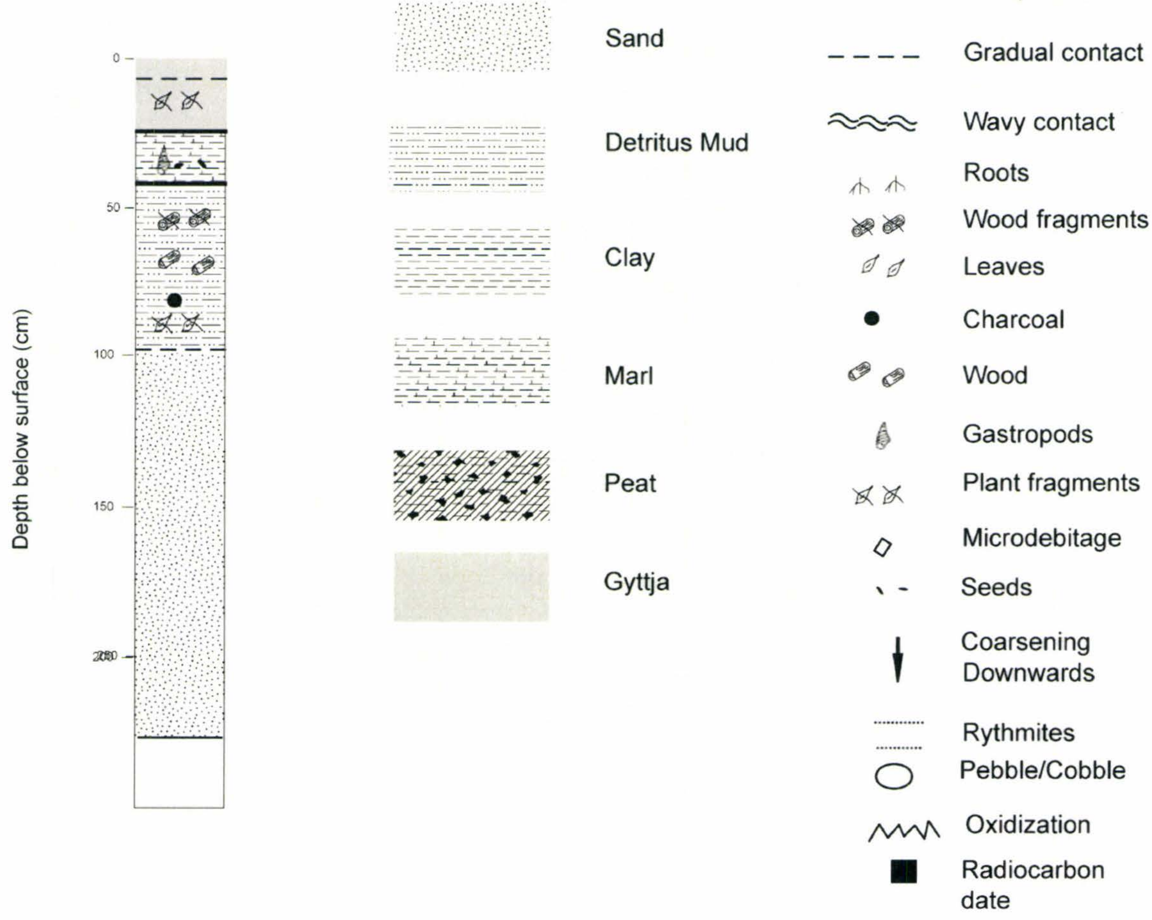


RIL-6 E 728826 N 4900736 WD: 1.52 m
Length: 3.57 m

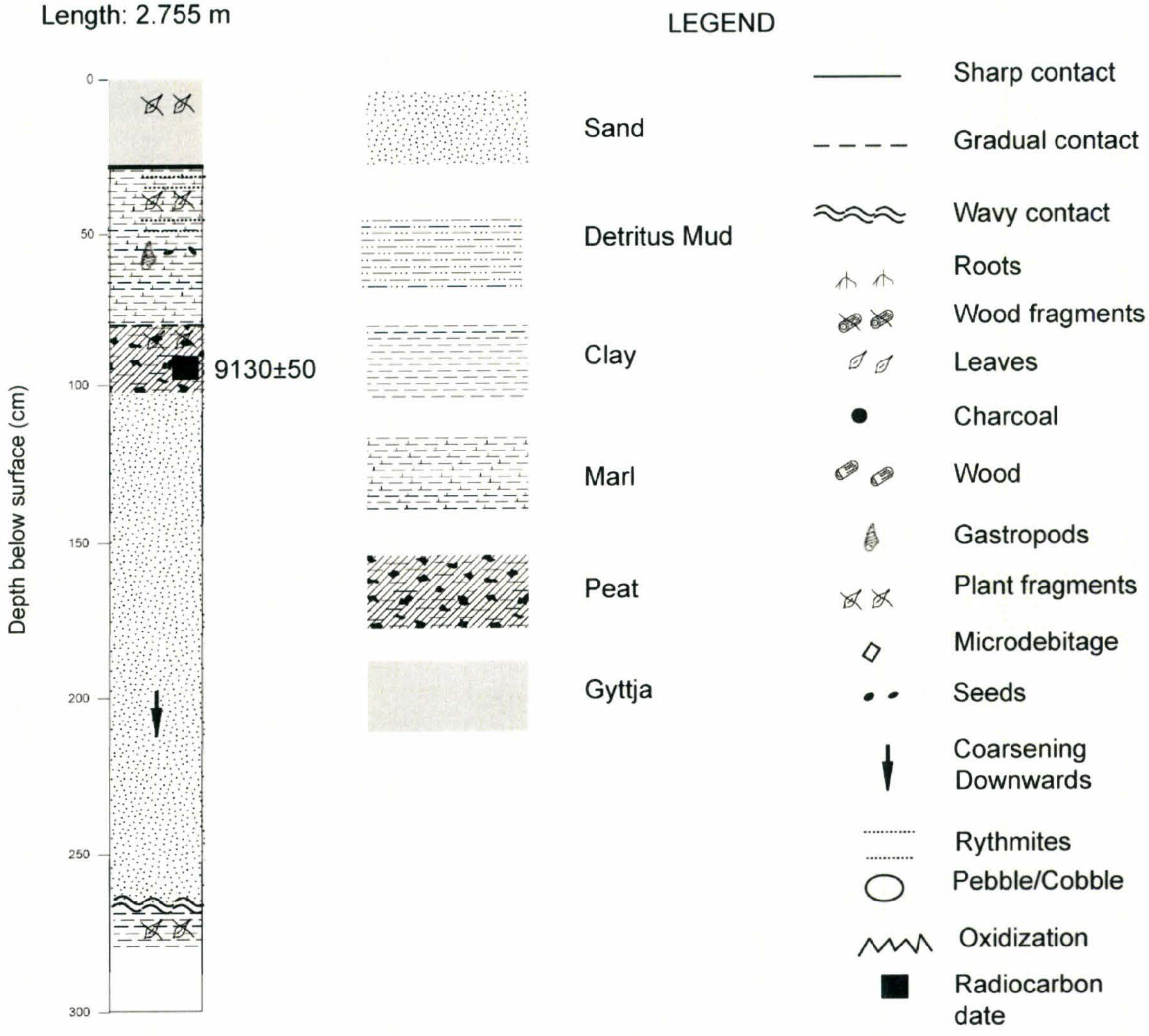


RIL-7 E 725830 N 4894703 WD: 3.88 m
Length: 2.275 m

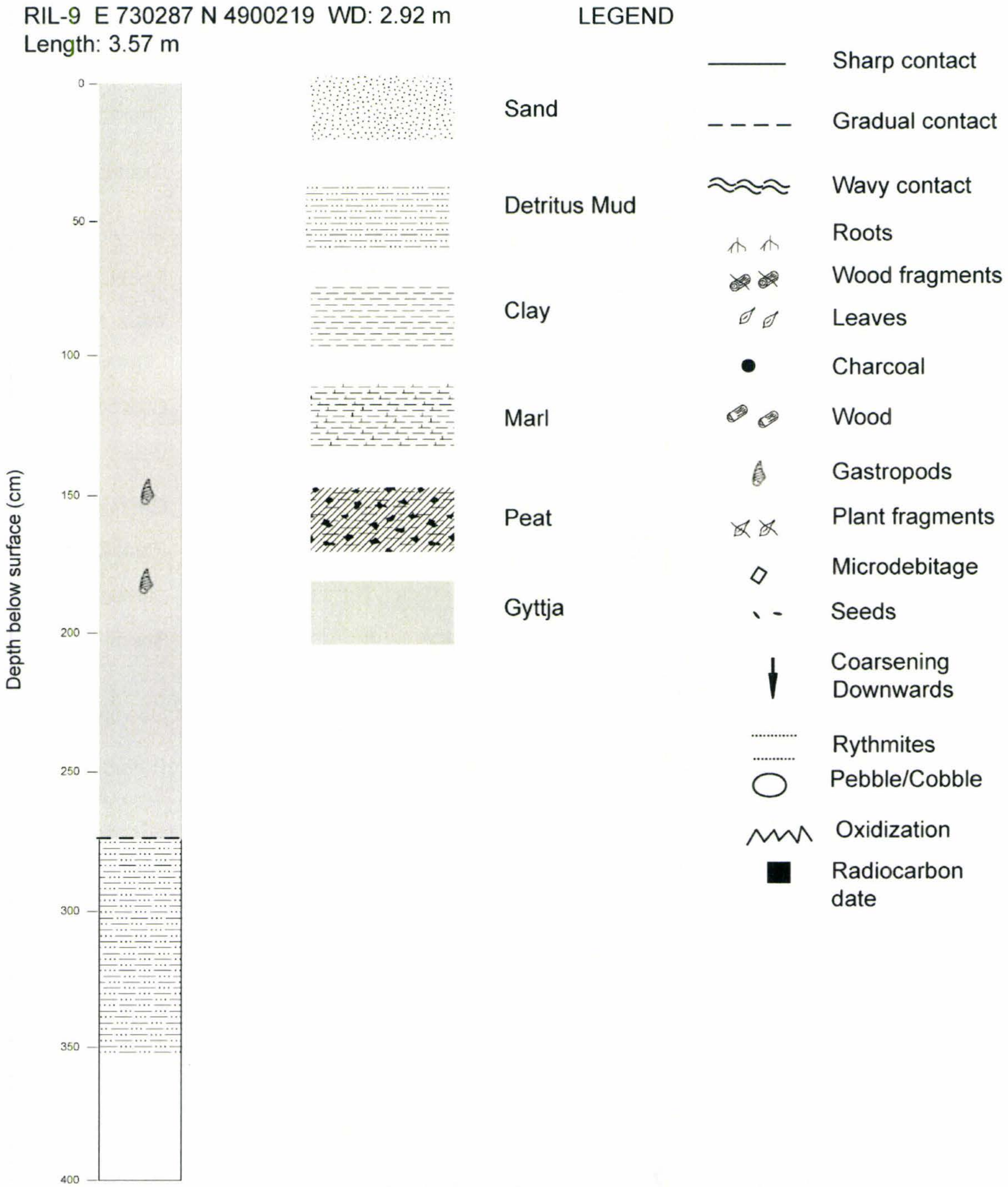
LEGEND



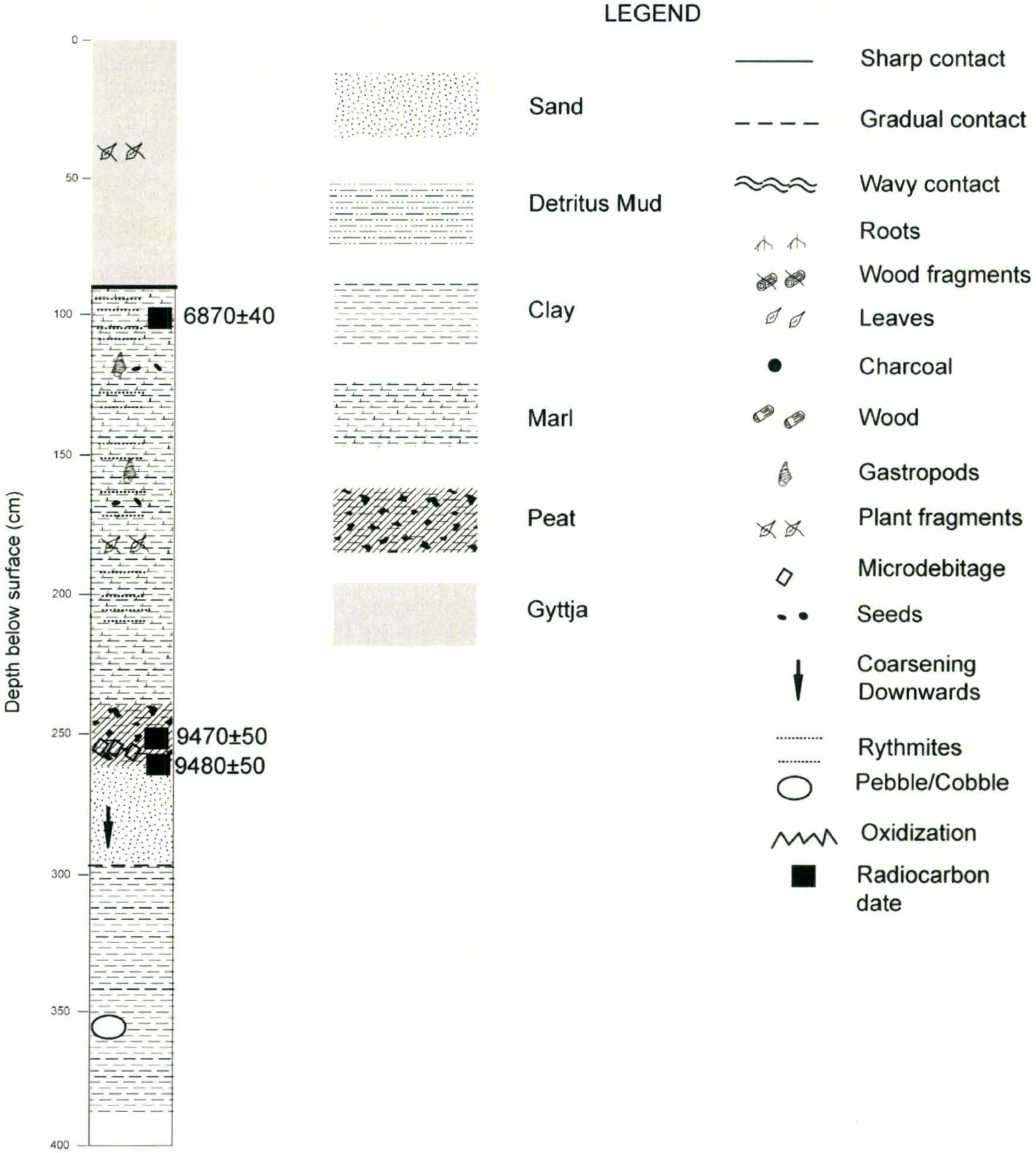
RIL-8 E 724513 N 4895106 WD: 3.79 m
Length: 2.755 m



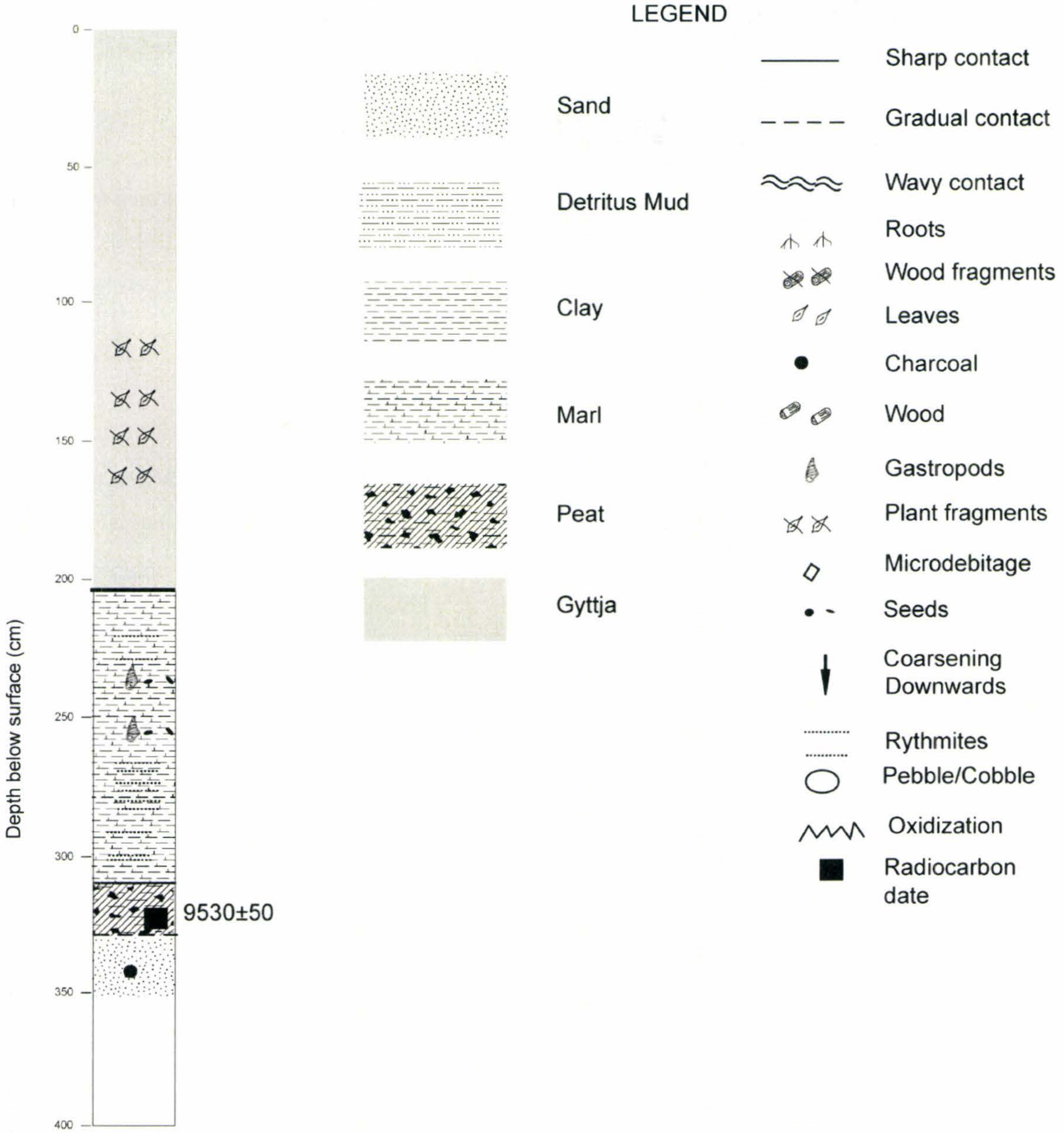
RIL-9 E 730287 N 4900219 WD: 2.92 m
Length: 3.57 m



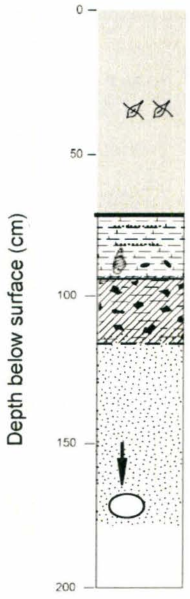
RIL-10 E 725329 N 4897831 WD: 1.31 m
Length: 3.74 m

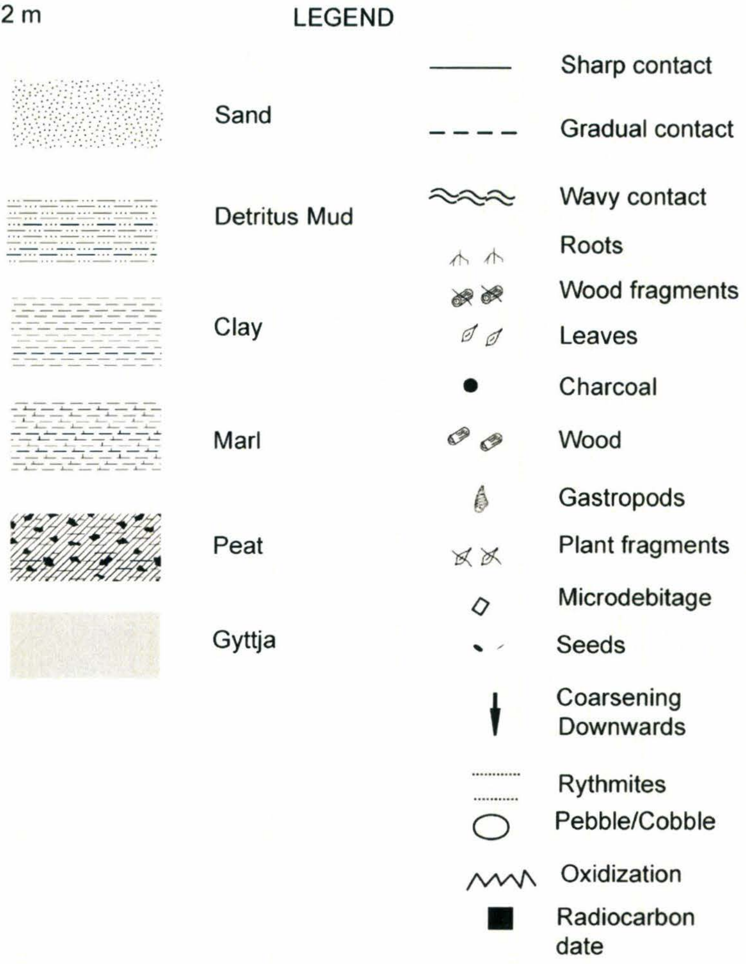


RIL-11 E 726361 N 4896695 WD: 2.34 m
Length: 3.515 m

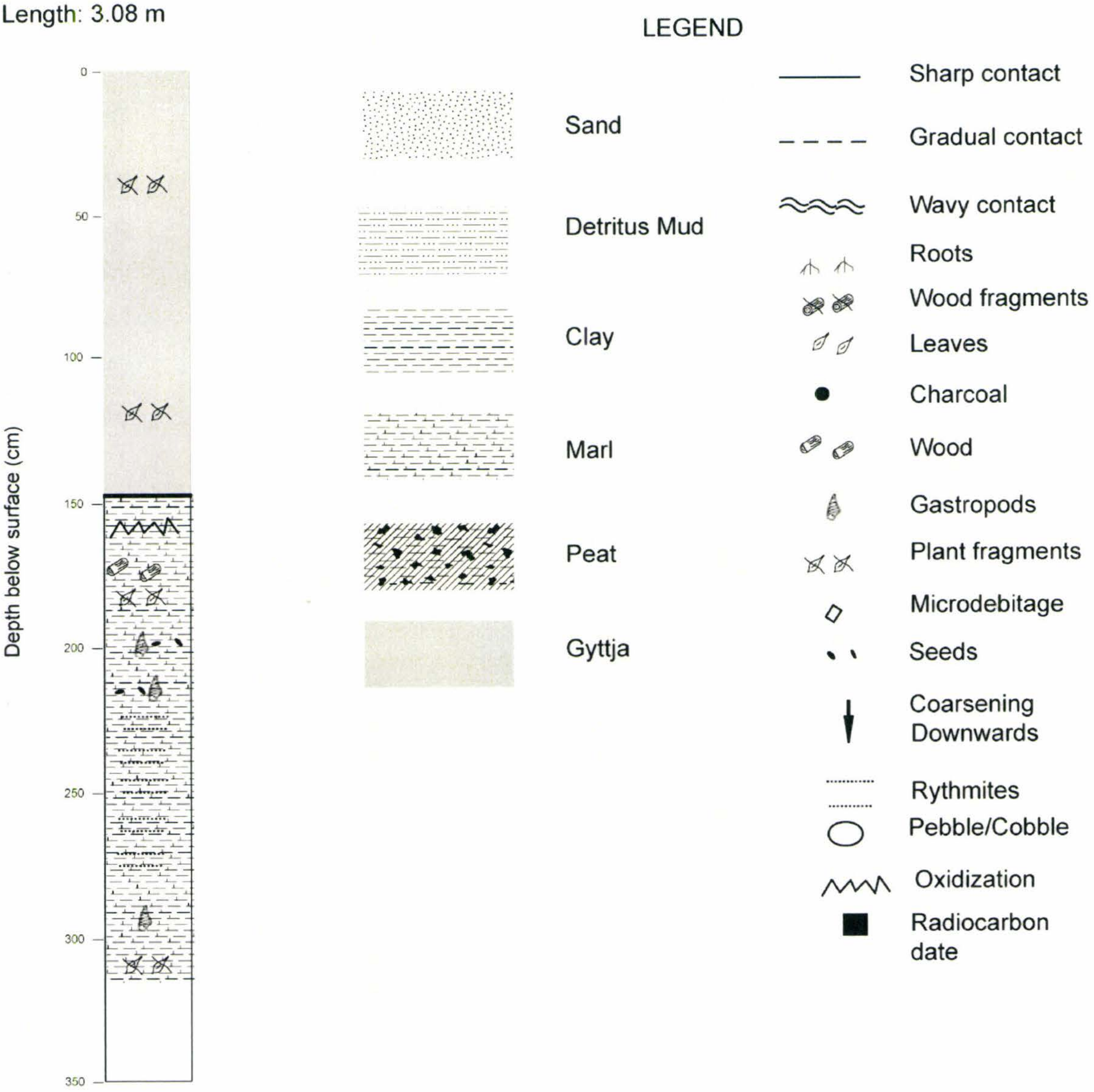


RIL-12 E 726217 N 4893393 WD: 3.72 m
Length: 1.78 m

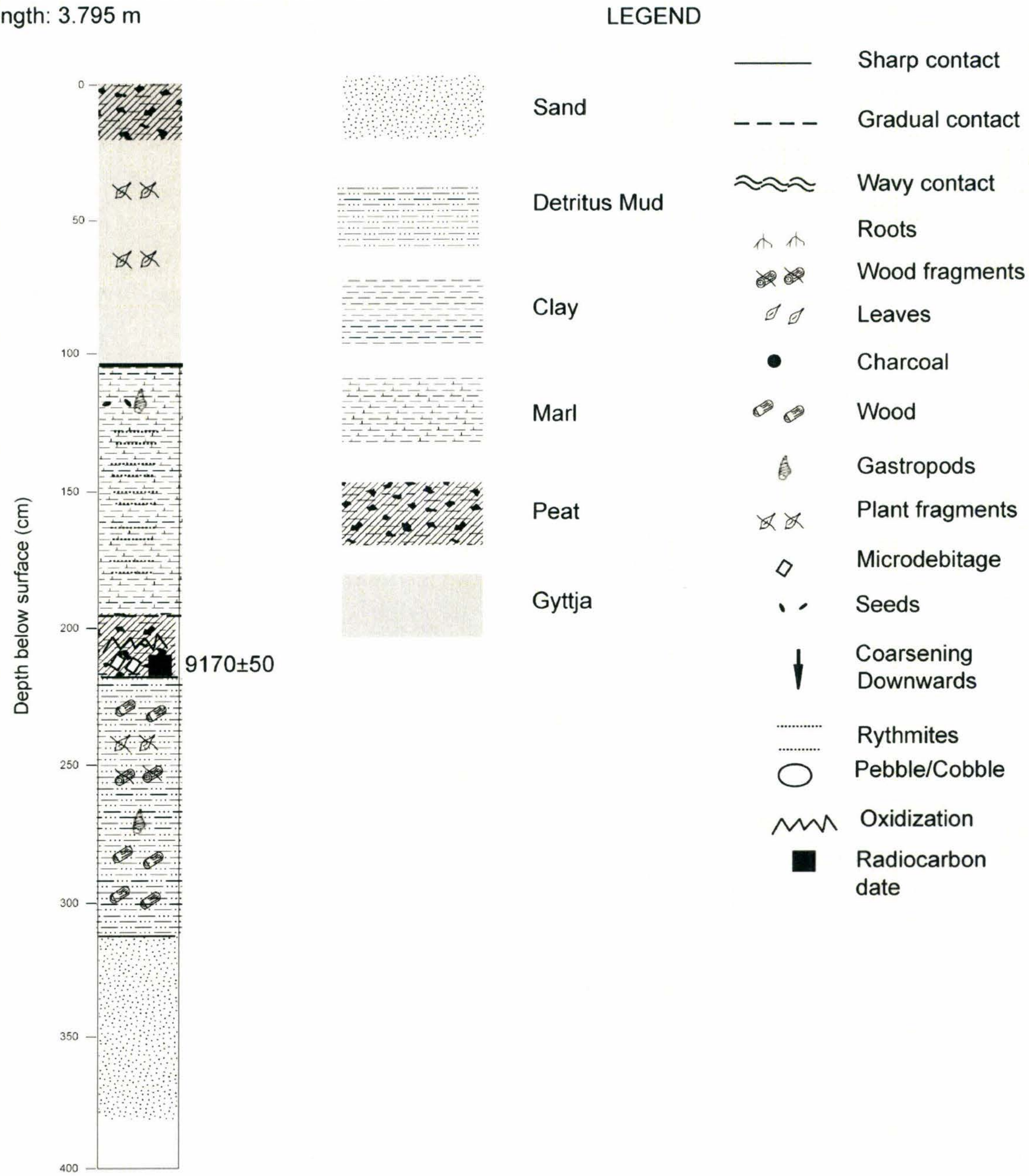




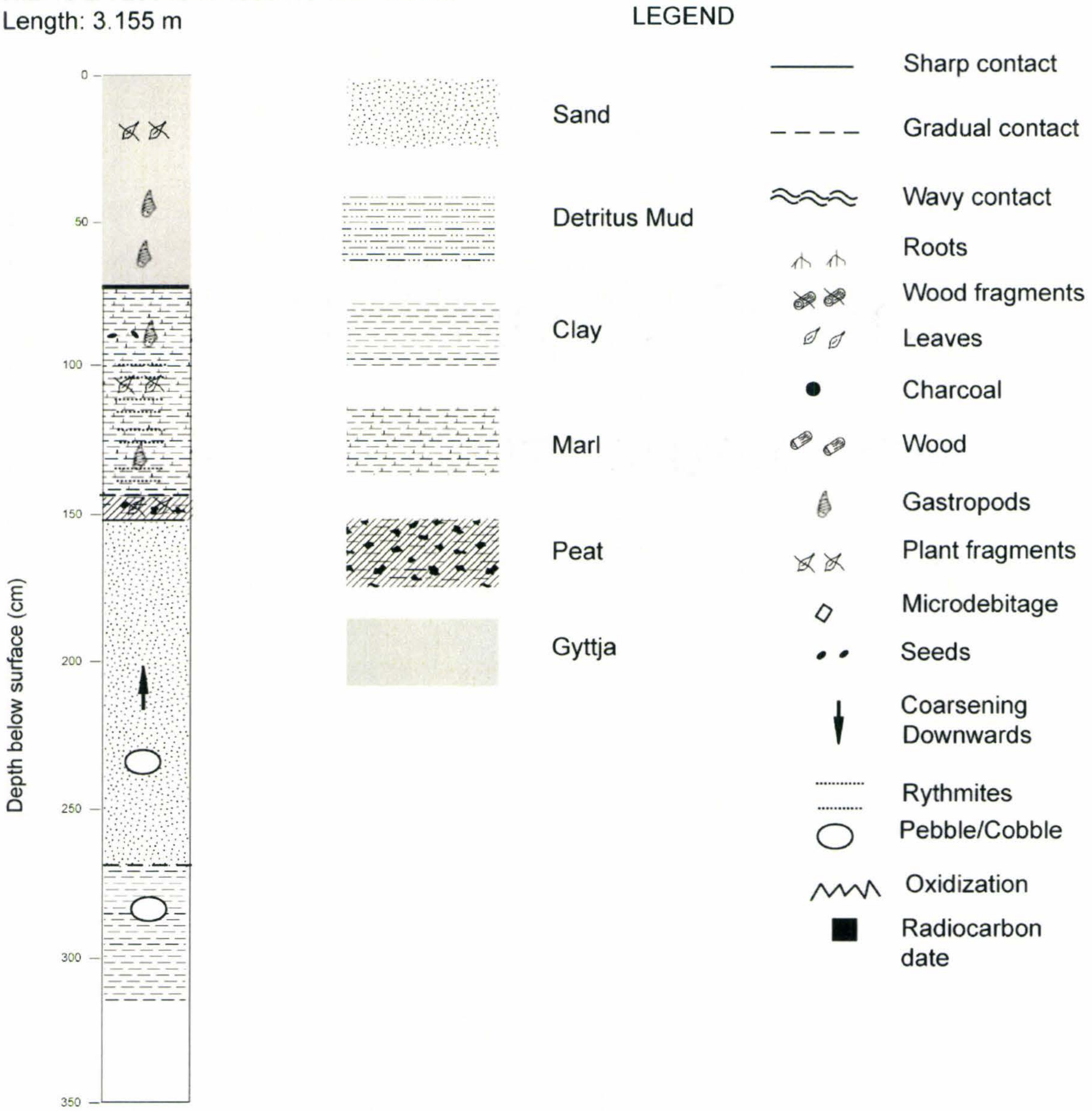
RIL-13 E 725568 N 4897854 WD: 1.43 m
Length: 3.08 m



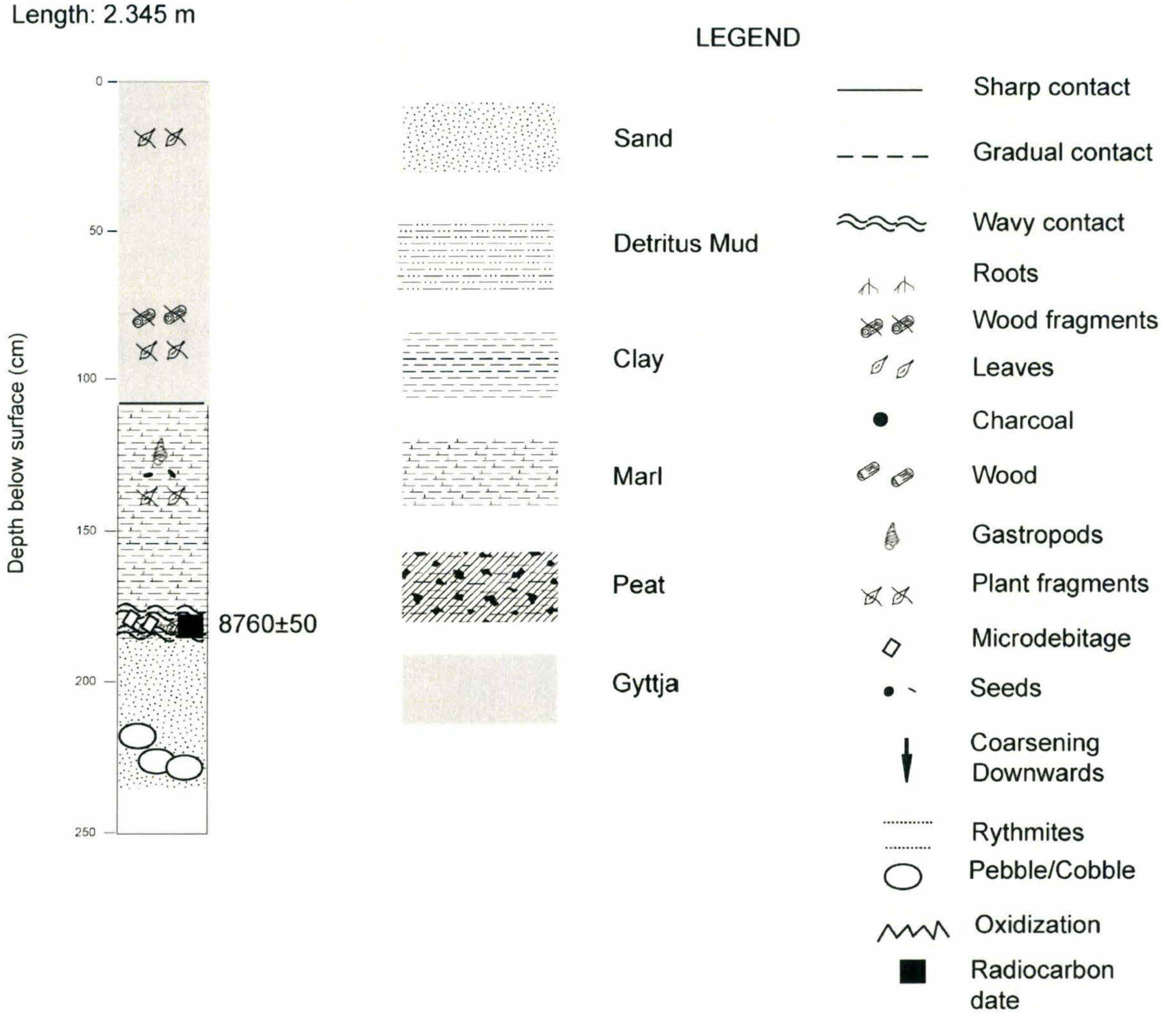
RIL-14 E 725287 N 4897691 WD: 1.59 m
Length: 3.795 m



RIL-15 E 725343 N 4898116 WD: 1.41 m
Length: 3.155 m



RIL-16 E 725879 N 4897863 WD: 1.18 m
Length: 2.345 m



Appendix 5: Tilt correction trigonometry (calculations and diagram by P. Suttak)

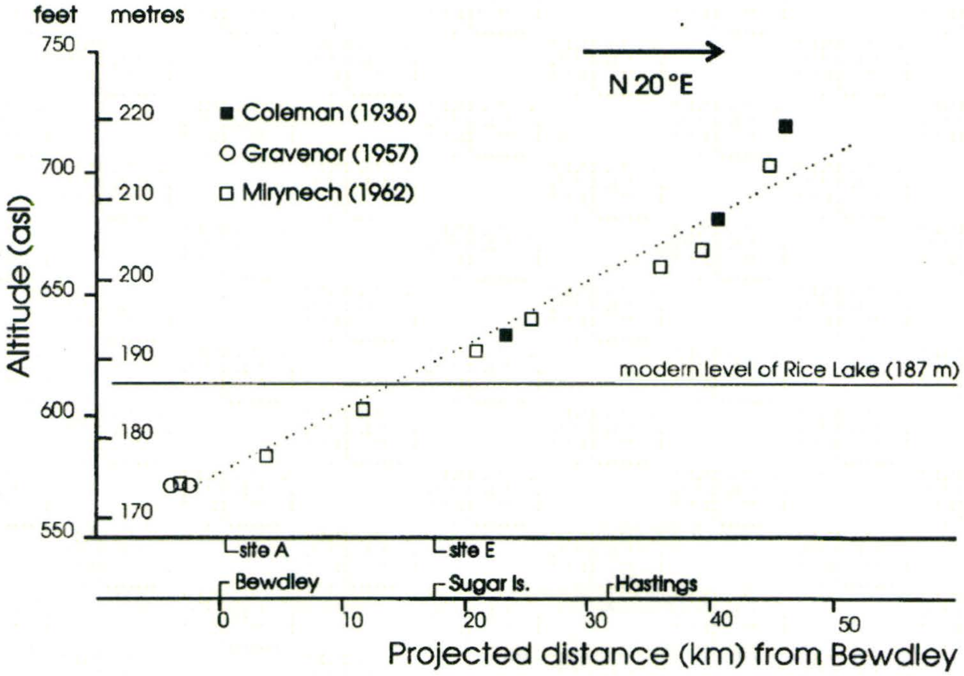
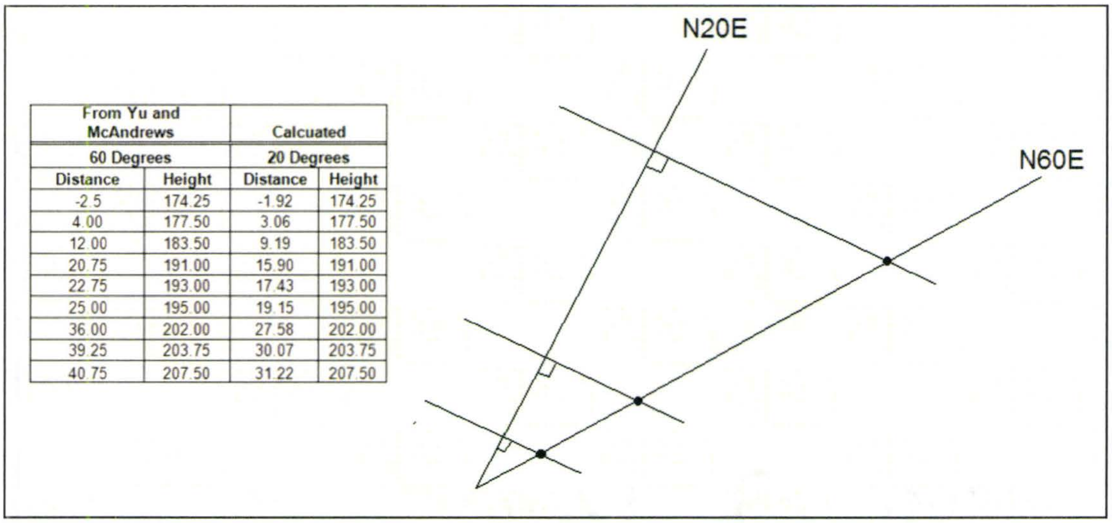


Figure 1. Isostatic tilt profile from 12000 BP of Rice Lake (Yu & McAndrews, 1994)



From Yu and McAndrews		Calcuated	
60 Degrees		20 Degrees	
Distance	Height	Distance	Height
-2.5	174.25	-1.92	174.25
4.00	177.50	3.06	177.50
12.00	183.50	9.19	183.50
20.75	191.00	15.90	191.00
22.75	193.00	17.43	193.00
25.00	195.00	19.15	195.00
36.00	202.00	27.58	202.00
39.25	203.75	30.07	203.75
40.75	207.50	31.22	207.50

Figure 2: Calculated points along N20E line