HOLOCENE FLOODPLAIN DEVELOPMENT AND PREHISTORIC HUMAN OCCUPATION: LOWER NOTTAWASAGA RIVER, SOUTHERN ONTARIO, CANADA

by

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ABSTRACT

A geomorphologic investigation of the lower Nottawasaga River, Simcoe County, southern Ontario, Canada was undertaken to address Holocene floodplain development processes to aid cultural interpretations of known prehistoric campsites. The thesis examines the mode of alluvial accretion in unconfined versus confined sections, respectively outside and inside the Edenvale Moraine, as well as the character of channel entrenchment. Reach-scale comparisons were made, including the specific study of Doran Lake which forms a neck cutoff within the study area. Results show a predominantly vertically accreted sandy floodplain, with some evidence of lateral accretion in unconfined sections. The present channel morphology was established in the early Holocene contingent on entrenchment at around the glacial Lake Hough phase. No strong evidence for catastrophic stripping was found in the higher energy confined reaches. Throughout, the erosion and re-deposition of cultural remains on the floodplain surface is unlikely for materials larger than sand.

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CHAPTER 1: INTRODUCTION

1.1 Scope

This as an interdisciplinary geomorphologic investigation of the lower Nottawasaga River valley, Simcoe County, southern Ontario, Canada assessing sedimentological, geomorphic, and hydrologic controls of archaeological sites information. A multifaceted approach as such lends to a holistic understanding of landscape development in conjunction with human settlement. It focuses on the preserved natural record throughout the Holocene and the shaping of available prehistoric evidence of floodplain occupation. In the realm of alluvial geoarchaeological research, it explores modern floodplain deposits to deduce formation and development, and applies a paleogeomorphologic framework in understanding cultural evidence.

This study poses three river-scale research questions pertaining to floodplain geomorphology in the study area, each with ramifications for the extant prehistoric cultural record. These are:

1) What is the dominant mode of Holocene floodplain accretion?

2) Is fluvial confinement sufficient for disequilibrium floodplain development?

3) When in the Holocene does fluvial entrenchment reduce lateral channel shifting?

The paleogeomorphologic research involves systematic interpretation of reach-scale morphology and sedimentology as well as the environmental reconstruction of an oxbow lake infill history. The purpose of the chosen questions is to demonstrate the utility of a fluvial geomorphologic methodology that is relevant archaeologically with regards to taphonomy, post-depositional disturbance, and locational analysis.

1.2 Fluvial geomorphologic research

1.2.1 Channel and floodplain characterizations

The main factors determining fluvial morphology and floodplain development in alluvial systems include discharge and sediment supply, sediment load (especially bed-material load), physiographic setting, and geologic history. Vegetation, land use, and climate have secondary effects (Kellerhals and Church 1989). For 18 meandering river channels in western Canada, for instance, Nanson and Hickin (1986) identify discharge, stream power, and sediment size as the main factors controlling bank erosion and lateral channel migration. The magnitude and frequency of bankfull discharge is critical for controlling river morphology (channel width, mean depth, and mean velocity), as well as slope, riverbed and bank resistance (both Manning's n and the Darcy-Weisbach ff), and suspended sediment load (Knighton 1998). Geologic control is an important underlying factor.

Alluvial river systems have been predominantly classified according to channel morphology. Leopold and Wolman (1957) originally adopted slope-discharge curves as a basis for typifying channel morphology for single- versus multi-channel varieties as the major channel patterns. Others have expanded on these to include wandering, anastomosed, and anabranched channel types by considering channel sinuosity and lateral stability (Schumm 1981; Church 1983; Morisawa 1985; Nanson and Knighton 1996). Rosgen (1994) provides a classification of major stream types starting with a consideration of streambank stability for single- versus multiple-thread channels, using as delineative criteria dominant bed material, entrenchment ratio, sinuosity, width-to-depth ratio, and slope. Kellerhals et al. (1976) furnish a classification of fluvial features used in conjunction with photo interpretation or field reconnaissance which included valley wall, valley flat and channel features, codifications of channel patterns addressing meander bend regularity, islands, and channel bars, and different classes of channel lateral activity. Schumm (1963) differentiates sand-bed channel types on the basis of dominant mode of sediment transport with a primary consideration of percent silt-clay in the channel banks as a means of distinguishing between bed-load, mixed-load, and suspended-load or wash-load channels. Church (1996) establishes a continuum of wandering, braided, meandering, and anastomosed channels, using two categories: bed material supply-dominated versus wash material supply-dominated channels both related to channel gradient as well as sediment calibre and supply influencing stability.

Floodplain typology and associated landscape features have been less rigorously characterized. The only substantial classification scheme for floodplains is that of Nanson and Croke (1992) which establishes a genetic floodplain classification primarily based on specific stream power (which is a function of discharge and slope) and sediment texture, as well as geomorphic characteristics including alluvium cohesiveness and channel boundary conditions. Butzer (1976) had earlier acknowledged two predominant types: laterally accreted flat floodplains and vertically accreted convex floodplains, the latter diagnostic of non-migrating channels with levees. Classifications of specific floodplain features are limited, except for Weihaupt's (1977) shape-based classifications of oxbow lakes on the Yukon River, Alaska where he applies geometric elements in the derivation of two classifications: complexity (including simple, compound, and complex oxbow types), and closure (differentiating between open, normal, and closed oxbows). Lewis and Lewin (1983) for Wales and the Borderlands, identified common channel cutoff typologies of simple cutoffs, including chute and neck types, by specifying multiloop forms and mobile bar cutoffs.

1.2.2 Meandering river floodplains

Classical observations on meandering river floodplain formation by Wolman and Leopold (1957), convey the dominance of lateral channel migration by way of cutbank erosion and point bar accretion, thereby also accrediting the importance of in-channel sedimentation over sedimentation by overbank flow (Visher 1965; Thornbury 1969). According to Miall (1985), lateral accretion deposits often are trough cross-bedded with height or thickness approximating channel bankfull depth, whereas overbank fines of vertically-accreted deposits build up sequentially during flood events, as outlined by Zwolinski (1992), and have a sheet-like geometry. Miall (1992) demonstrates that, though cobble gravel bars exist, most laterally accreted deposits in rivers are sand-dominated and exhibit upward-fining and cross-bedding structures indicative of decreasing flow velocities. Whereas lateral accretion accretion facies assemblages may include sedimentary structures with beds, lamination, and scours, vertically accreted facies of overbank fines are massive and finely laminated possibly with very small ripples and sandy bedforms.

More recent studies ascribe relatively more importance to vertical accretion, as for example, Walling et al. (1996) who discern lowland floodplains as suspended sediment sinks. Others indicate the dominance of vertical over lateral accretion in aggrading systems as in the Delaware River valley (Ritter et al. 1973), and the Galena River basin, Wisconsin (Magilligan 1992). Nanson and Young (1981) observe that in the Illawarra region of New South Wales, Australia small coastal rivers show a dominance of overbank deposition where there is a high frequency and magnitude of overbank flow or discharge per unit area catchment, sharp stream gradient declines, increased valley width, and reduced channel size. Lecce (1997) reports for the Blue River watershed, Wisconsin an increased storage of vertically accreted historical sediments with increased valley width and decreased cross-sectional stream power. Away from the active channel, floodplain sediments become increasingly older (Nakamura and Kikuchi 1996), finer (Marriott 1992; Lewin 1996; Kalicki 2000), and thinner (Pizzuto 1987), as coarser-grained natural levees develop near the channel in rivers with overbank deposition. Researchers are recognizing the concurrence of lateral and vertical accretion as independent floodplain-forming processes, as for the ingrown meandering Duck River, Tennessee (Brakenridge 1984, 1988).

More complex patterns of floodplain development are also being increasingly documented. Lewin (1983) recognizes counterpoint sedimentation at the Welsh Twymyn River where the channel recedes away from cutbanks. Similarly, concave benches have been identified forming on the upstream limb of concave banks of confined meandering rivers such as the Squamish River, British Columbia, as well as the Murrumbidgee and Barwon Rivers of southeastern Australia (Hickin 1979; Woodyer et al. 1979; Page and Nanson 1982). Nanson (1986) asserts that, for irregularly meandering, partially confined rivers in montane coastal areas of humid temperate southeastern Australia, floodplains are susceptible to episodes of vertical accretion and catastrophic stripping. Where high-energy channels are laterally stable, he proposes gradual overbank alluvial sedimentation, for a time scale between 10^2 and 10^3, followed by floodplain erosion and stripping in circumstance of an extreme flood event reinitiating the cycle with rebuilding to maturation (Fig. 1.1). His understanding is that floodplain formation is chiefly based on a balance between vertical and lateral accretion.

Channel cutoffs and oxbow lakes have been scrutinized for meandering river systems. According to Allen (1965), the occurrence of chute and neck cutoffs (and consequently oxbow lakes), increases in frequency with increased channel sinuosity and is respectively contingent on gradual meander loop migration (usually along a swale or depression) and sudden abandonment or loop capture. From an investigation of planform geometry, it has been contended that the formation of oxbow lakes is an intrinsic property of meandering dynamics (Stølum 1998). Gay et al. (1998) propose a mechanism of flood-induced gully-headcut development for chute-cutoff formation at the Powder River, Montana. At an unconfined section of the lower Hunter River in southeastern Australia, reduced channel length has increased slope and decreased

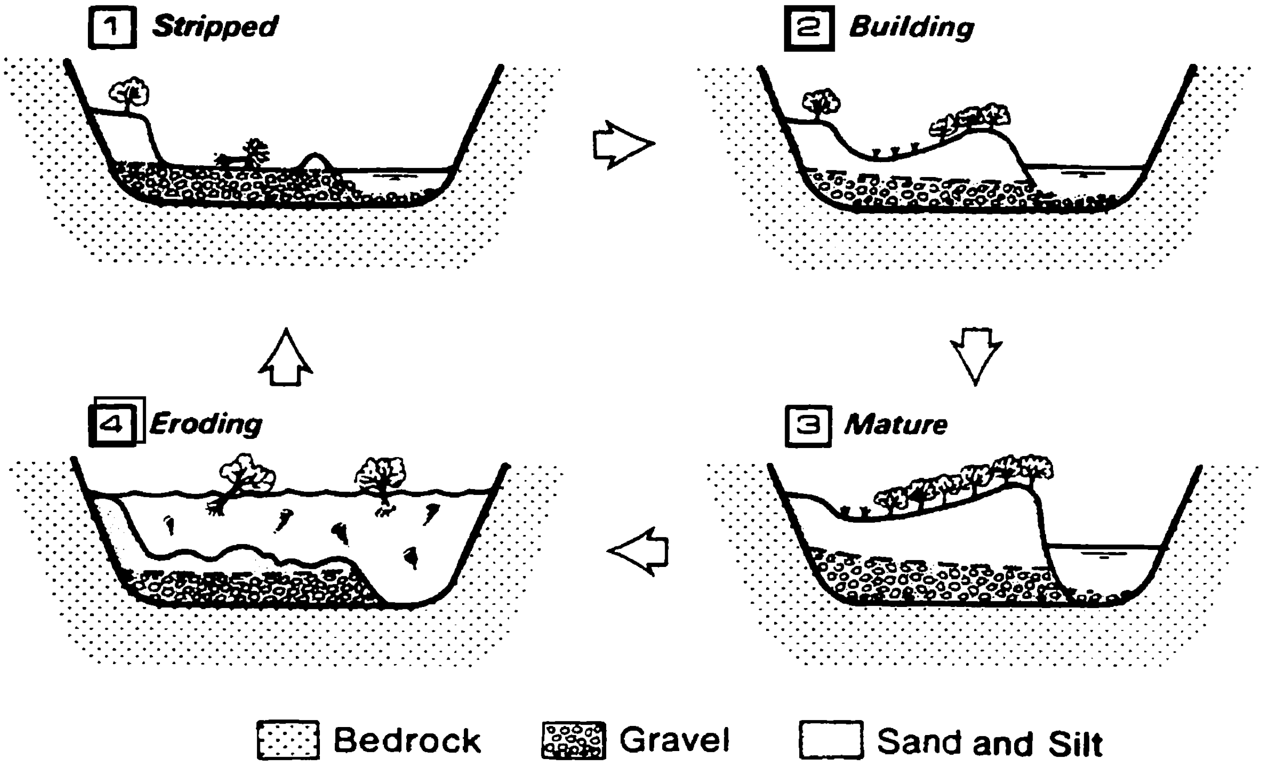


Fig. 1.1. Nanson's (1986, p. 1473) model of disequilibrium floodplain development through episodic catastrophic stripping and gradual vertical accretion, demonstrating floodplain stripping (1), building (2), maturing (3), and eroding (4) stages for the Clyde and Manning Rivers, New South Wales, Australia.

channel sinuosity with the historical formation of eight cutoffs (Erskine et al. 1992). Fig. 1.2 from Walker and Cant (1984), shows chute cutoffs as having major sand infills with minor vertical accretion whereas neck cutoffs have major vertical accretion infills, each representative of gradual versus sudden loop abandonment mostly controlled by distance to the sediment source after cutoff. A recent study of meander cutoffs at the Rivers Bollin and Dane in northwest England finds that vertical-accretion rates at the entrances to neck cutoffs are much higher than previously reported (Hooke 1995). In contrast to neck cutoffs, there is a greater preponderance of coarse units in chute-cutoff fills, though overall they are finer-grained than concave benches and point bars (Erskine et al. 1982). Research is lacking on floodplain features pertaining to vertical-accretion floodplain development such as natural levees.

1.2.3 Holocene channel entrenchment

Climatic change is a notable extrinsic factor affecting river stabilization during the Holocene. Knox (1983) has shown for rivers in the Driftless Area of Wisconsin that climatic fluctuations, from a cool and moist early and late Holocene with a relatively warm and dry middle Holocene, led to fluvial destabilization characterized by episodes of aggradation and degradation. Macklin and Lewin (1993) suggest a climatically controlled widespread synchrony of North American, central European, and British Holocene fluvial episodes spanning the last 5000 yr. In the early Holocene record, alluvial discontinuities represent channel incision, slow alluviation or stability for American rivers between 8 ka and 6 ka BP, valley floor incision in Europe, and floodplain stability or incision in Britain between 8 ka and 5.2 ka BP. The Rivers Ivalojoki and Oulankajoki in Northern Finland show increasing channel incision, particularly in the first 2000 yr after deglaciation, as a consequence of climatic rather than glacio-isostatic factors as ascertained by Koutaniemi (1991).

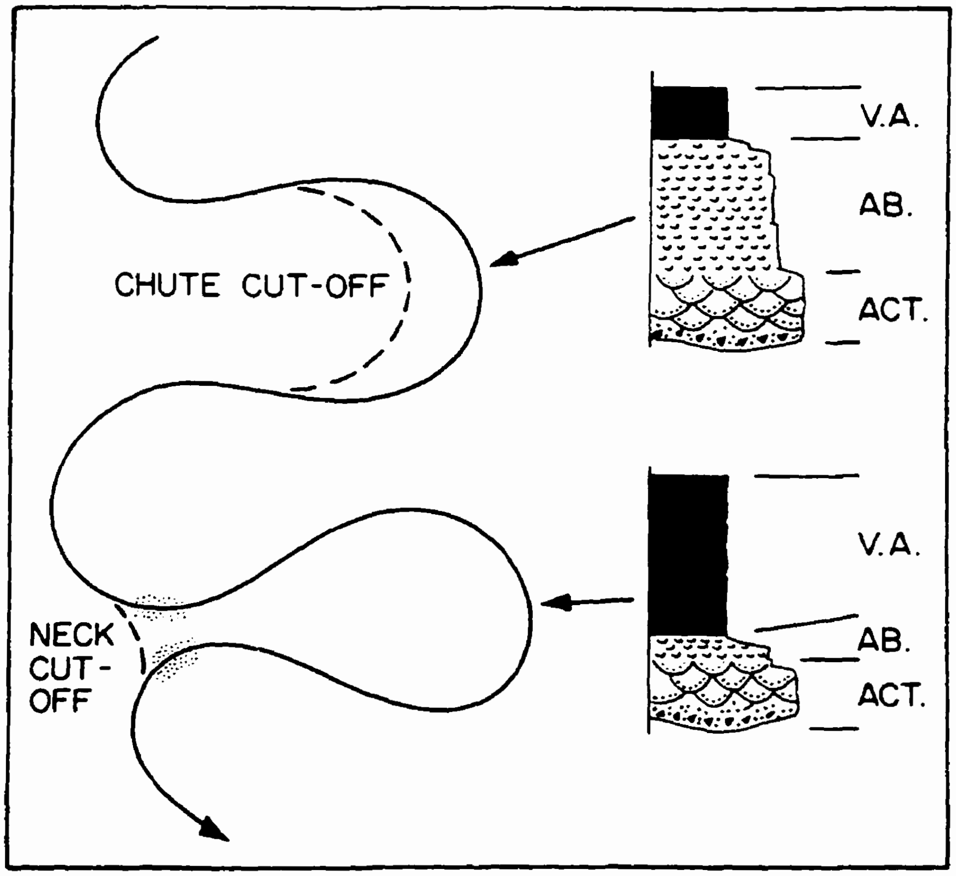


Fig. 1.2. Meander-loop chute (a, above) and neck (b, below) cutoffs for sandy meandering river systems. Respective stratigraphic sequences show chute cutoffs consisting of active (ACT) river trough cross-bedded deposits, a thick abandonment (AB) sequence of ripple cross-laminated deposits, topped by a vertical-accretion (VA) segment following the cutoff event. Neck cutoffs consist of bed-load sediment plugs in the ACT sequence, followed by a thin AB sequence, with a predominance of VA deposits (from Walker and Cant 1984, p. 75).

At the upper San Pedro River, Arizona climate and land use are the principal controls on channel entrenchment in part because of the role of high-frequency large floods (Hereford 1993). A reduction of peak-flow rates occurred as a consequence of increased channel sinuosity, floodplain development, and riparian vegetation. Miller and Nudds (1996) observe that neither climate change or channel confinement alone can account for increasing flood magnitudes, which are most probably attributable to vegetation reduction associated with agricultural land use and wetland drainage in upper reaches of the Mississippi River valley. Miller et al. (1993) observe for the Drury Creek watershed, southern Illinois, that entrenchment occurs with reduced sediment yields brought about by watershed revegetation and an intensification of storms augmenting discharge.

The retreat of the Laurentide continental ice sheet and isostatic uplift in northern North America, coupled with an eventual lowering base level, resulted in rapid degradation as rivers eroded their beds and became increasingly entrenched. Rivers can also become aggrading associated with base-level changes, as delineated by Weninger and McAndrews (1989) at the lower Humber River valley, Toronto in consequence of prehistoric base-level rising in Lake Ontario. Aggradation also may be attributable to an increased sediment load as with land clearing for agriculture, reduced discharge following climatic change, or changes of boundary conditions such as reduced riparian vegetation (Knighton 1998). During the Hypsithermal, between 8 ka and 4 ka BP, there is a shift from degradation and increasing channel incision apparent in the early Holocene to net aggradation and relative stabilization creating an enrichment of floodplain environments ascribable to post-glacial warming (Smith 1987).

The magnitude of base-level change also determines the rate at which a river will aggrade or degrade. For confined channels, only vertical adjustments are possible whereas lateral shifting is likely for unconfined channels (Schumm 1993). Increasing channel entrenchment has resulted in channel confinement especially in mid-latitude environments (Lewin and Brindle 1977). The Red River, Manitoba became entrenched in clay plains of Lake Agassiz by 7.5 ka BP, and since 5.2 ka BP it has been vertically accreting (Nielsen et al. 1993). Brown and Keough (1992a) ascribe a middle- to late-Holocene metamorphosis in lowland rivers of the United Kingdom consisting most notably of increased fine sediment supply and accelerated vertical accretion causing floodplain aggradation, as well as decreased width-to-depth ratios and relative incision as proposed by the stable-bed aggrading-banks model (SBAB). In addition to an increased rate of alluviation in the late Holocene, Brown (1996) observes an increase in flood frequency since the Bronze Age in the lowlands of northwest Europe as evidenced, amongst other things, by coarsening-up sequences.

On the basis of current investigations, there is a likelihood of post-glacial sediment yield changes and base-level effects on southern Ontario floodplains. A detailed investigation of the lower Grand River, delineates a primarily vertically-accreting floodplain whose initial formation and subsequent stability are affected by base-level changes in Lake Erie (Walker et al. 1997). At the lower Humber River valley, there is evidence for aggradation as the dominant mode of floodplain development between 6500 and 1800 yr ago reducing the potential for lateral channel migration (Weninger and McAndrews 1989). A recent study reveals a discrepancy in sediment yield for southern Ontario relative to the rest of Canada, eastern prairies excepted, of a uniform unit sediment yield at 0.15 Mg km^{-2} day^{-1} (Church et al. 1999). Work on the south Saugeen River, on the other hand, exposes a typical pattern of increasing specific sediment yields with drainage area as found elsewhere in Canada, stressing the significance of riverbank glacial sediment sources in such entrenched river valleys (Campo and Desloges 1994). These few findings pointed to the need for more research on Holocene floodplain development in southern Ontario.

1.3 Floodplain archaeology in southern Ontario

Though spatial analyses have been conducted for archaeological sites in southern Ontario (i.e., Roberts 1980, 1981; Young et al. 1995; Ellis and Deller 1997), fluvial systems remain mostly peripheral as sites of detailed investigations. Paleo-Indian floodplain occupation and the use of interior resources, for example, remain poorly understood as few sites have been located in proximity to rivers mainly because of site location strategies limited to glacial lake strandlines (Jackson 1986; Ellis 1994; i.e., Storck 1979). Storck (1982, 1984) acknowledges limitations to this approach and encourages site prospecting strategies allowing for a broader geological context, as for example his examination of the Bighead and Beaver valleys and in sourcing Fossil Hill chert (Storck 1993; 1995, 1996, 1997). One of the few published studies on Paleo-Indian riverine occupation in southern Ontario is the Alder Creek site in Waterloo, a Paleo-Indian component dating to 10.4 ka BP (Timmins 1994).

It has been suggested that with the introduction of corn to Ontario, there is a major shift in subsistence systems (Spence and Pihl 1984). Floodplains in particular become locales of intensive corn horticulture. This is evident for Princess Point sites which have a distinct association with riverine, as well as wetland and lacustrine environments (Crawford and Smith 1996; Smith 1996; Smith and Crawford 1997). Likewise, Riviere-au-Vase phase occupations in southwestern Ontario have been discovered in lakeshore areas and interior river valleys. The Sibelius site, for example, is a hunting camp on the Thames River floodplain, and other sites have been found on the lower Sydenham and Ausable Rivers (Murphy and Ferris 1990).

In addition to prehistoric evidence of plant crop gardening and horticulture in Ontario floodplains as elsewhere, archaeological sites located in river valley bottoms should characterize water-specific activities including transport, fishing, fowling, small-game hunting, digging for roots and tubers, and peat extraction (Evans 1992), as well as gathering of riparian resources. Laurentian Archaic people in southern Ontario hunted deer, elk, bear, and beaver, procured fish and shellfish, and collected wild plants. They picked berries in the spring and fall, gathered nuts in the fall, and engaged in bird trapping and fishing in the fall (Wright 1972). At the Donaldson site on the Saugeen River, Ontario, a Late Woodland Saugeen culture occupation, riverine fishing of spring-spawning species appears to be the main subsistence activity (Mason 1981). Fish remains have been recovered from the Barrie, Dunsmore, and Carson sites, Pre-Contact Iroquoian village sites near Barrie, Ontario (Needs-Howarth 1999), indicative of a continued reliance on fishing after the incipience of corn horticulture in southern Ontario. Research by Latta (1995) on Contact-period Huron village sites at Coldwater River, Simcoe County also denotes this, as at the Auger site where fishbone (particularly of suckers, catfish, and yellow perch) outnumbers all other artifact classes combined.

Though alluvial geoarchaeology has gained some acclaim in recent decades, particularly in the United Kingdom and in the United States, it is mostly unpracticed in southern Ontario and only now is it being considered (i.e., Walker et al. 1997; Crawford et al. 1998). Even though terraces have been studied as remnants of former floodplains in southwestern Alberta and at the Peace River valley, British Columbia (i.e., Stene 1980; Valentine et al. 1980), the modern floodplain is rarely considered in any great detail. It is necessary to establish research partnerships enabling fluvial geomorphologists to consider archaeological applications of their work and for archaeologists to understand artifacts as context-specific deposits susceptible to post-depositional taphonomic processes (i.e., Shackley 1978; Hanson 1980; Butzer 1982; Hiscock 1985; Stein 1987). Examples of floodplain geoarchaeological research already exist for Britain (i.e., Brown and Keough 1992b), for the United States (i.e., Ferring 1992; Waters 1992), and for Alaska, Africa, and China (i.e., Crozier 1984; Hassan 1997; Jing et al. 1997). Though the importance of considering river valley and terrace development in Canadian archaeology has been recognized as by Karrow (1994), in southern Ontario the published research is sparse.

The lack of alluvial archaeological research on floodplain development and dynamics in southern Ontario is a major shortcoming in the literature towards the differentiation of natural versus cultural signatures in the archaeological record. In his book on alluvial geoarchaeology, Brown (1997) posits the issue of negative evidence, entailing natural-site destruction and invisibility, as mostly controlled by rates and processes of floodplain development. Lateral channel migration associated with sideways erosion at cutbanks and the lateral accretion of sediments naturally destroys contextual evidence and reworks cultural deposits at rates of floodplain erosion-deposition cycles. At the lower Vyrnwy River in Wales, Lewin (1992) attributes lateral channel migration, associated with bars, cutoffs, and oxbow lakes in a meandering river as naturally destructive of cultural remains, whereas the overbank deposition of alluvial sediments preserves archaeological information though rendering it invisible by burial. For the Little Missouri River in the western North Dakota Badlands, the lack of Paleo-Indian and Early and Middle Archaic cultural remains in lowland alluvial deposits was ascribed to natural site destruction rather than human avoidance of floodplains (Waters and Kuehn 1996).

1.4 Research objective

This research intends to pick up on recommendations in the geoarchaeological literature for an interdisciplinary approach to archaeology based on an Earth-sciences foundation (i.e., Gladfelter 1985; Rapp and Hill 1998). Following Davidson (1985), this was accomplished through a detailed examination of the effects of fluvial geomorphic processes on archaeological sites. This research is essentially in archaeological geomorphology (after McDowell 1984), focusing on floodplain geomorphology. It represents a concerted effort to merge the extant natural and cultural records for a chosen portion of the Nottawasaga River. The field-based research is on floodplain development at two distinct reaches in the study area for unconfined versus confined sections where the channel pattern of confinement is ascertained topographically by the Edenvale Moraine, a natural barrier laterally restricting the Nottawasaga River.

1.4.1 Hypotheses

Preliminary field investigations provide the premises for generating archaeology-relevant fluvial hypotheses for confined sections (Fig. 1.3):

1) vertical accretion is the predominant mode of Holocene floodplain development, thereby rendering invisible via alluvial burial much archaeological evidence;
2) occasional but significant catastrophic stripping and translocation of natural and cultural particles occurs in the modern floodplain; and
3) entrenchment coupled with reduced channel shifting throughout the Holocene, places earlier archaeological remains away from the active channel.

Hypotheses will be examined at the river scale, and a reach-scale case study of Doran Lake will supplement the sedimentological record particularly with respect to base-level change and its impact on channel stability.

1.4.2 Assumptions

Associative research assumptions are as follows:

1) sedimentation style and rate have varied in the study area both spatially as well as temporally;
2) sediment stripping occurs mainly in confined sections following rare extreme flood events; and
3) the present spatial distribution of known archaeological sites may be reflective of environmental processes, assuming that most remains have been identified and preserved and that there is no confounding cultural influence.

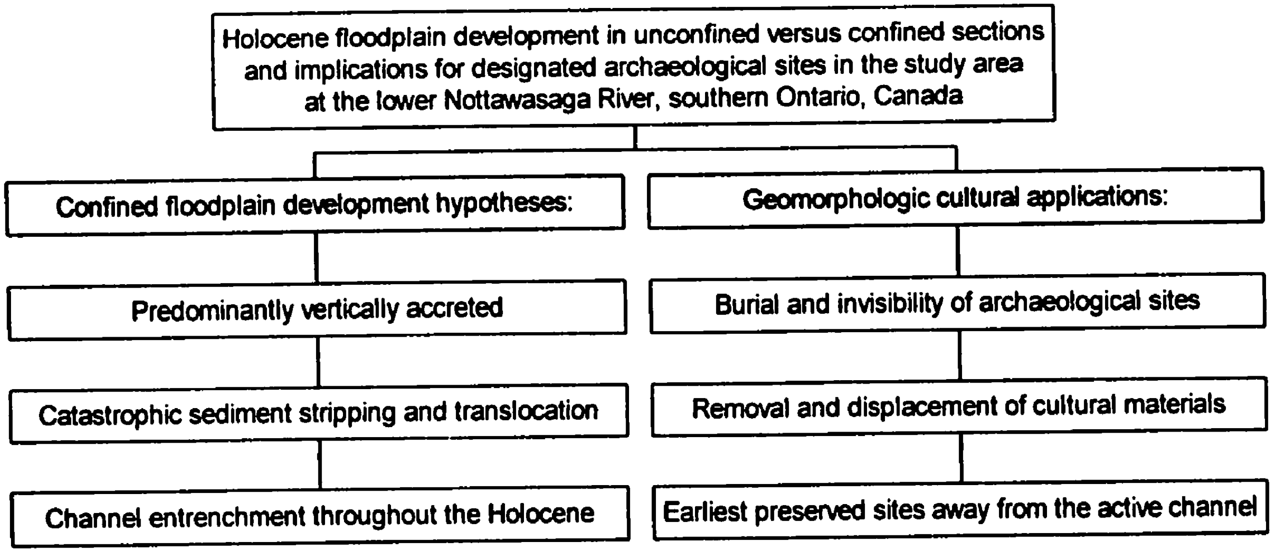


Fig. 1.3. Research topic and floodplain development hypotheses at the Edenvale Moraine: 1) vertical mode of accretion, 2) disequilibrium, and 3) Holocene channel entrenchment and reduced channel shifting. Geomorphologic cultural applications are made for each hypothesis as follows: 1) archaeological sites burial and invisibility, 2) water transport of cultural remains, and 3) earliest preserved sites are located farthest away from the active channel, as nearby abandoned courses.

1.4.3 Thesis layout

Chapter 2 introduces the study area, incorporating previous research and information on the current physical environment. Subsequently, Chapter 3 delineates and justifies the methodology utilized in this research, including field methods and equipment necessary to carry out this study. Results appear in Chapters 4 and 5, respectively for river- and reach-scale investigations, along with interpretations. Finally, Chapter 6 provides a study summary and conclusions, as well as recommendations for future research.

CHAPTER 2: SETTING

2.1 Nottawasaga River watershed

2.1.1 Location

The Nottawasaga River valley is situated northwest of Toronto between Lake Simcoe and Georgian Bay in south-central Ontario, Canada (Fig. 2.1). The river and drainage basin of the Nottawasaga were selected for the following reasons:

1) morainic confinement in the lower reaches allowing for investigation of a range of possible floodplain development styles;
2) part of this lower portion has formed in a sand plain where the alluvial record should be more easily interpretable, as compared to rivers that have formed on glaciolacustrine deposits;
3) the oxbow lake area, for which a long record of mostly vertically accreting sedimentation, might be reconstructed;
4) the archaeological record, while not well known, suggested an affinity towards riverine occupation; and
5) the size and accessibility of the reaches under investigation were both optimal.

The detailed study area extends some 16 km upstream from the Klondike Park Road bridge (4926200mN and 579600mE, UTM Zone 17) southeast to Edenvale at the Highway 26 bridge (4922500mN and 587400mE) (after Ontario Surveys and Mapping Branch 1986). The downstream boundary in this reach is approximately 14 km along the river channel from the outlet into Nottawasaga Bay, and its boundary at the farthest point upstream is about 30 km from the outlet. The entire study area is situated in the Minesing flats of Simcoe County commencing at the Flos-Vespra Townships boundary and terminating in Sunnidale Township immediately southwest of Jack's Lake (Fig. 2.2), approximately 7 km from Wasaga Beach.

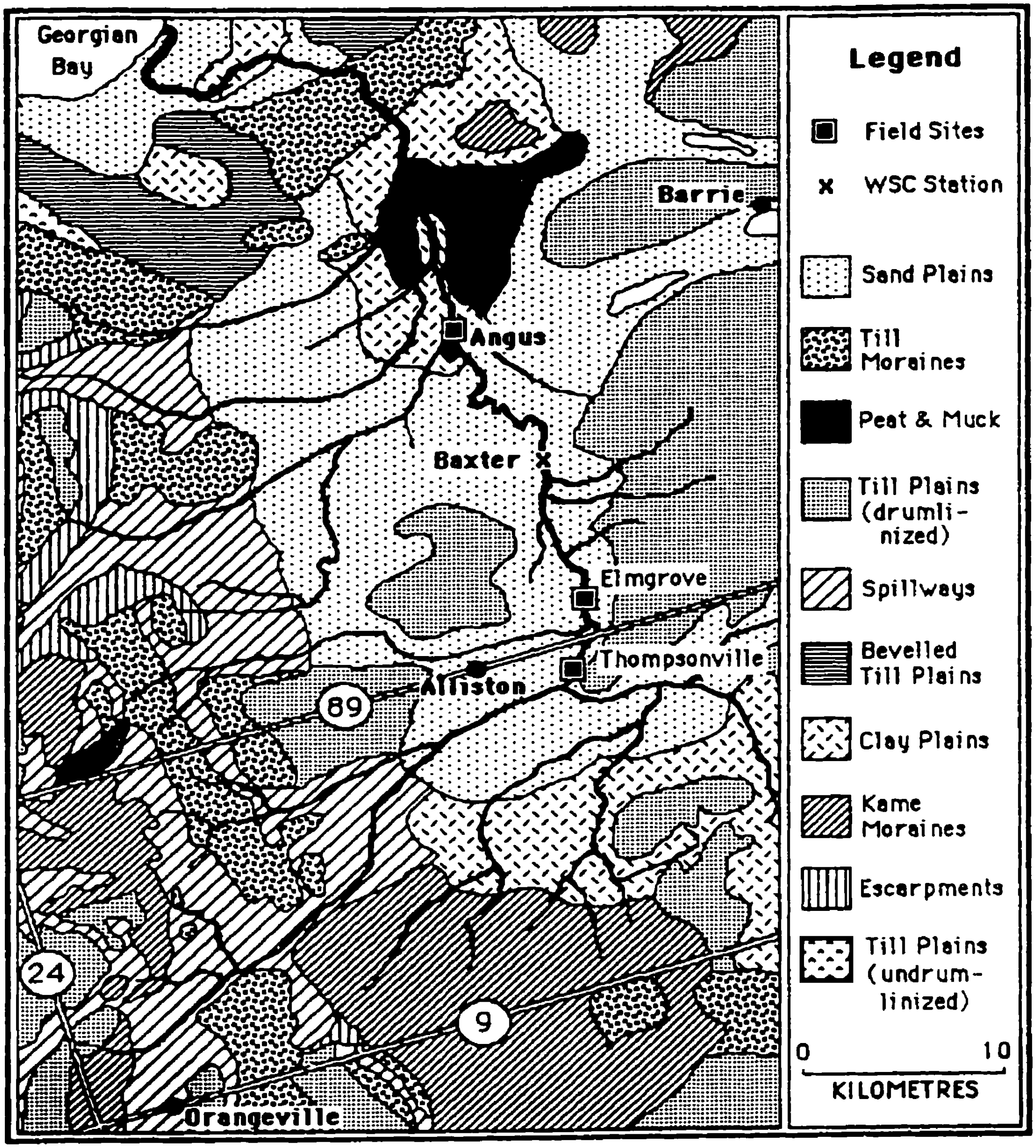


Fig. 2.1. The Nottawasaga River watershed and its surficial geology, showing the location of Alliston, Baxter, Angus, the Minesing Swamp, and the study area at the Edenvale Moraine (till moraine) in the lower portion before emptying into Georgian Bay (from Chandler and Kostaschuk 1994, p. 771).

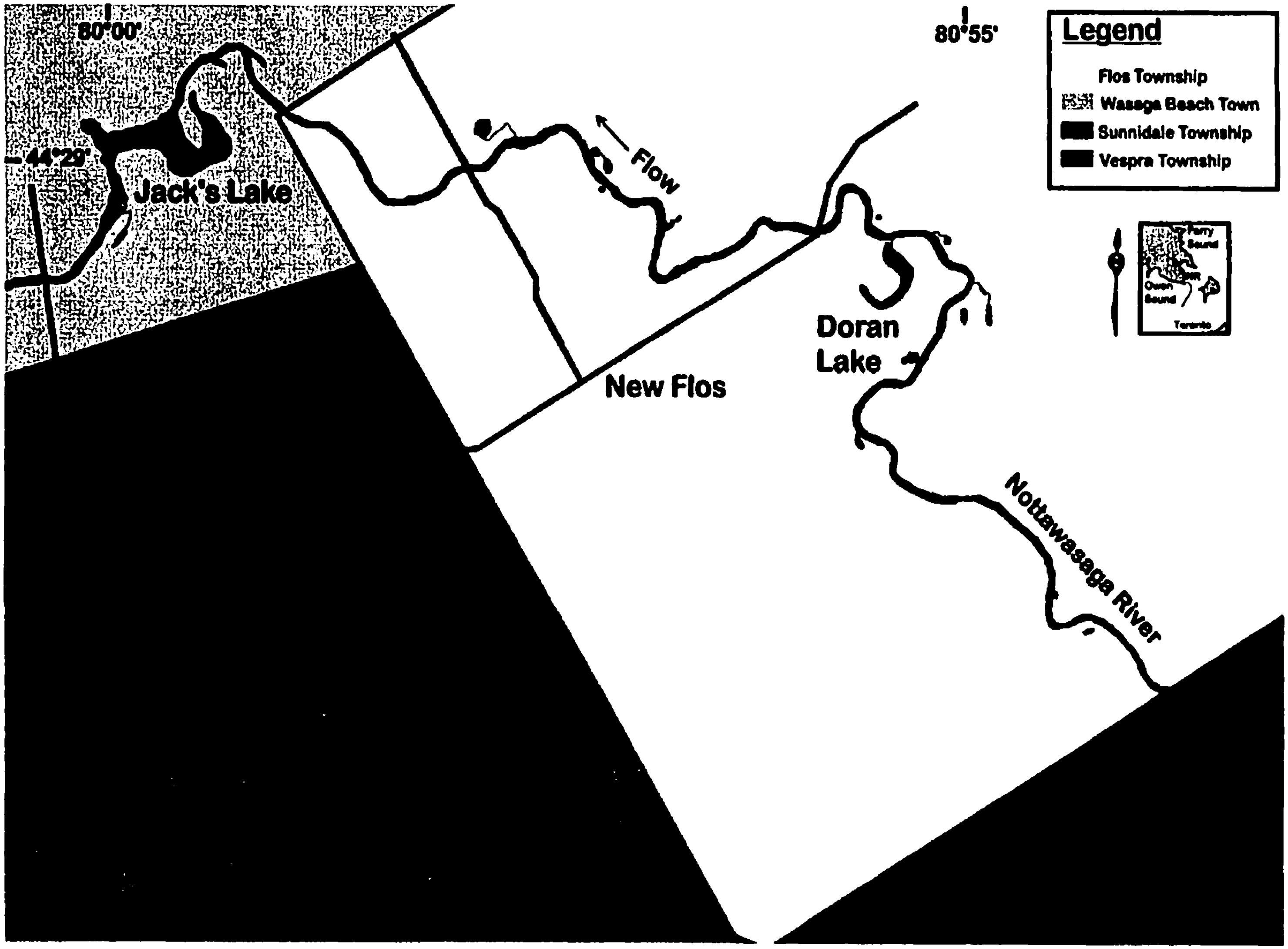


Fig. 2.2. Map of the study area at the lower Nottawasaga River, Simcoe County, southern Ontario with townships and major roadways (based on Ontario Surveys and Mapping Branch 1986, from aerial photographs taken in 1981). Elevation contours are in m ASL.

2.1.2 Bedrock and soils

Liberty (1969) describes the underlying Paleozoic bedrock in the watershed as grey fine- and medium-grained limestone with alternating calcareous shale and claystone of the Verulam Formation, a member of the Middle Ordovician Simcoe Group. It does not outcrop between Nottawasaga Bay and Lake Simcoe, generally having an overburden 61 to 91 m thick (in Ontario Geological Survey 1982). Beneath the Ordovician sedimentary rocks in the southwestern part of Flos Township, is the Bobcaygeon Formation consisting of thin-bedded homogeneous fine-grained limestone with some shale. Soils in the vicinity of the Nottawasaga River have been classified by Webber and Hoffman (1967) generally as undulating sandy soils in the Gray Brown Podzolic great group, with some organic Humic Gleysols where drainage is imperfect or poor.

The Nottawasaga River in the study area cuts into a clay plain at Edenvale, works into the till plain of the Edenvale Moraine, and emerges relatively unconfined into a sand plain near New Flos, before reentering into clay plain near Jack's Lake (after Chapman and Putnam 1984b; see Fig. 2.1). As in Fig. 2.3, local relief in the study area is approximately 30 m, much of this between the Edenvale Moraine (210 m ASL) and Jack's Lake (180 m ASL). Burwasser and Ford (1974) show that bedrock elevations range from 107 to 152 m ASL (see Fig. 2.3). The total drift thickness in this section varies between 103 m at the Edenvale Moraine to 28 m outside it. Hoffman et al. (1962) represent over 75% of the study area as comprising of light grey and sandy loam till of the Bondhead series. Soil types in the area include the well-drained Tioga series and the imperfectly drained Alliston series (Ontario Conservation Authorities Branch 1964).

2.1.3 Relief and gradient

The Nottawasaga River drains much of the west plains of the Simcoe lowlands, a flat to gently rolling lowland plain situated west of Lake Simcoe, between 177 and 229 m

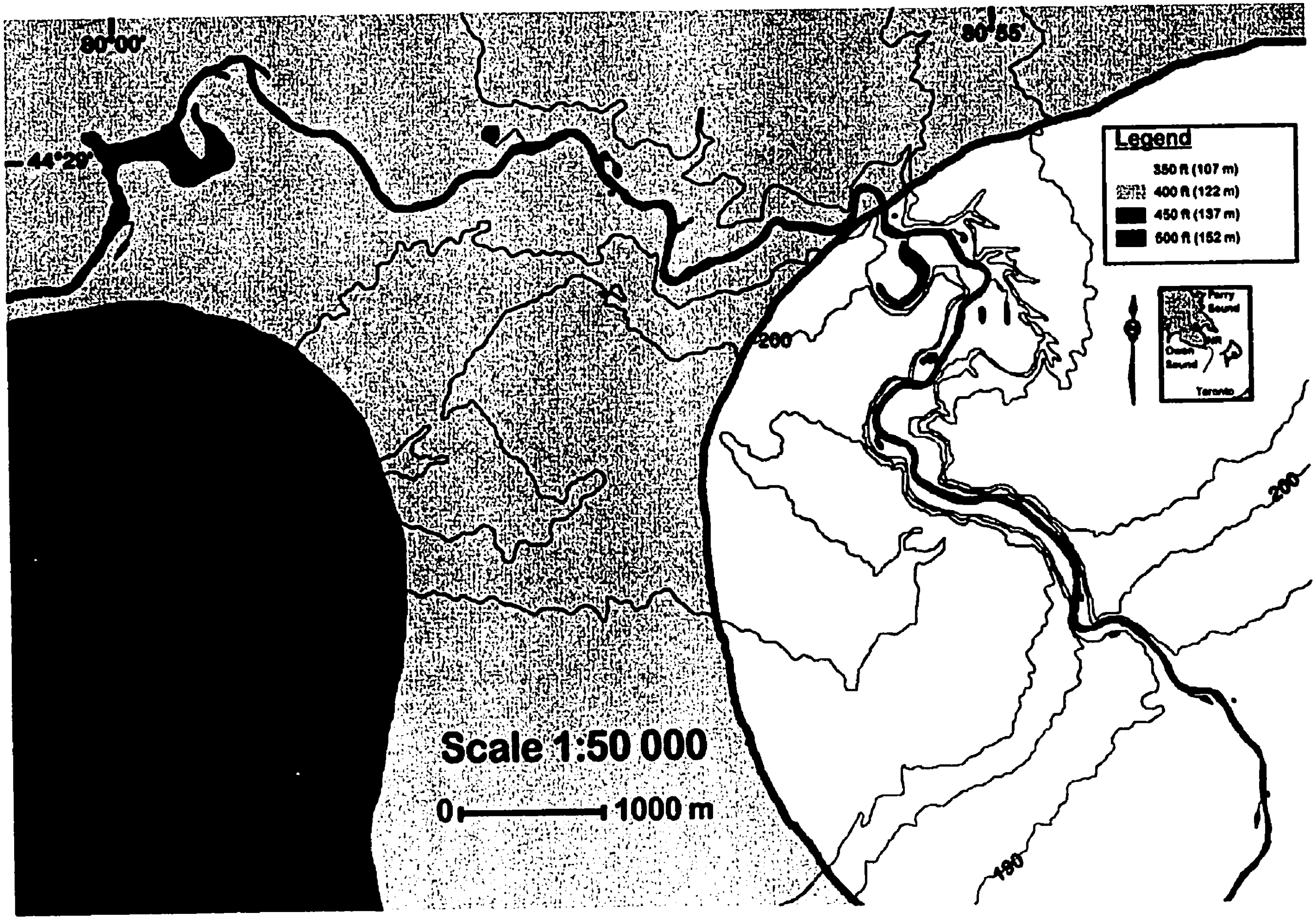


Fig. 2.3. Map of topography in the study area (surface topography based on Ontario Surveys and Mapping Branch 1986; bedrock topography modified from Burwasser and Ford 1974). Elevation contours are in m ASL.

ASL (Chapman and Putnam 1984a). The most prominent topographic features in the Nottawasaga Basin include the Niagara Escarpment towards the west, and the Edenvale Moraine in the east. Nottawasaga River headwaters have a southwestern source at an elevation of 488 m in Amaranth Township, draining into Nottawasaga Bay at a water elevation of 177 m in the southern portion of Georgian Bay at Wasaga Beach (Fig. 2.4). From its outlet to roughly 51 km upstream the Nottawasaga River's gradient is low at 0.0001. Farther upstream to about 79 km the channel slope is moderate at 0.0008, and then becomes steep at a high slope of 0.0065 from there to its headwaters (after Ontario Conservation Authorities Branch 1973). Though it ranks low among the steep-graded escarpment draining rivers, it still has a characteristically large average gradient in the area of 0.0025 (Sangal and Kallio 1977).

2.1.4 Climate

For the weather station at Angus (1941–1970), mean annual temperature ranges from 0°C to 12°C with an annual mean of 7°C. Precipitation averages 829 mm for the year, 588 mm of rainfall, and 241 cm of snowfall (Ontario Conservation Authorities Branch 1973). This 30-yr normals record shows 140 mean annual days with precipitation and 171 with frost. Mean daily temperature peaks around July and is lowest between December and February for that time period record. Mean monthly precipitation is shown to be highest in July and lowest in February/March, though the most average annual number of days with precipitation occur in January (16/140 days) and the least between June and August (9/140 days).

2.1.5 Vegetation and land use

The bottomland forests that make up the dominant vegetation along waterways in the Minesing Basin, contain silver maples, black ash, alders, willows, and buttonbush as well as vines and creepers, nettles, and ferns (Sparling 1985). The watershed consists of between 10% and 30% of aspen, sugar maple-basswood, white elm, and

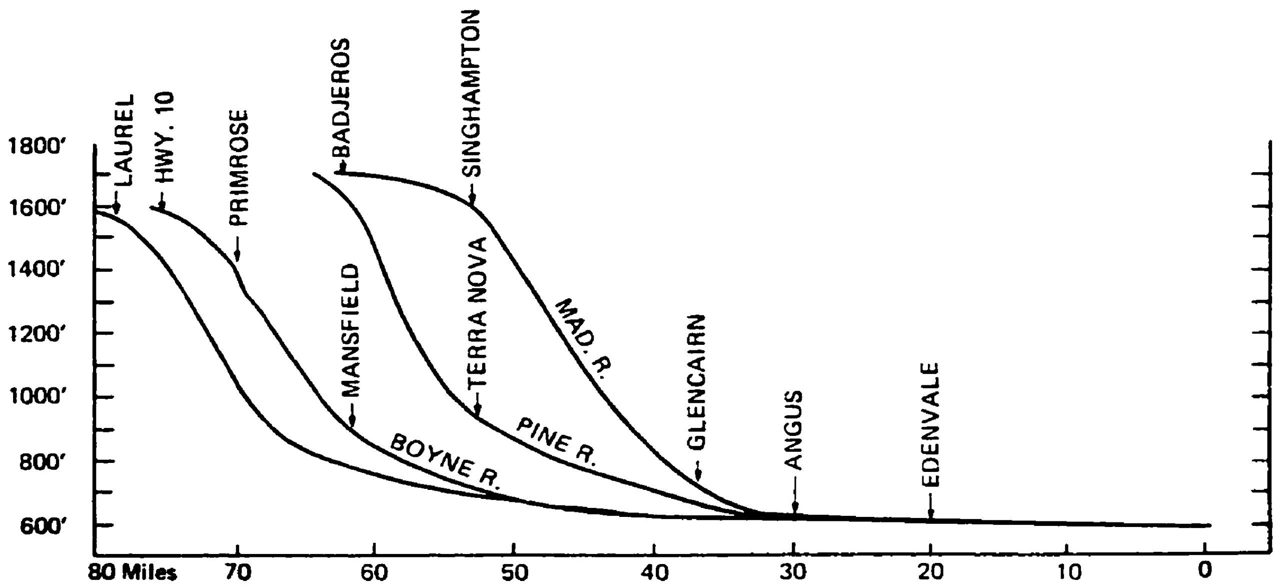


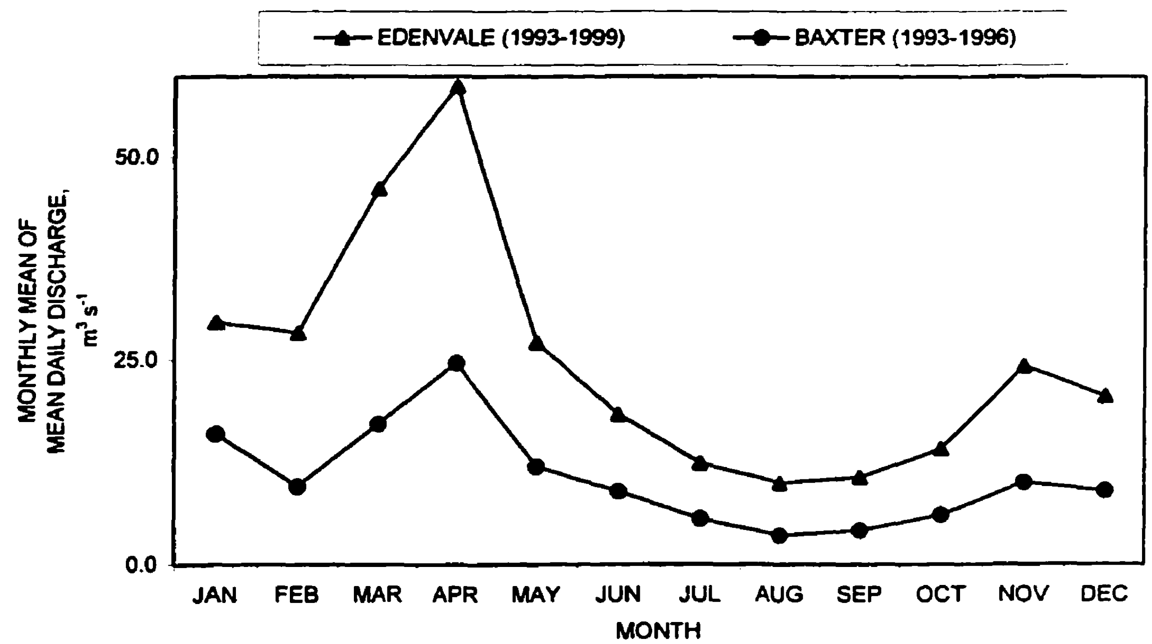
Fig. 2.4. Elevation profiles along the main channel and tributaries of the Nottawasaga River (from Chapman and Putnam 1984a, p. 87).

white cedar mostly of uneven age (Ontario Conservation Authorities Branch 1964). Land use in the valley flat of the upper watershed is woodland, consisting of trees and scrub growth (Sibul and Choo-Ying 1971). In 1961, about 72% of the Nottawasaga area was diversely cultivated, including specialized crops of winter wheat, potatoes, tobacco, apple and cherry orchards as well as crops of tomatoes and asparagus, nursery sod, and Christmas trees, the remainder was woodland or idle. It is recognized as an intensively cropped small agricultural watershed (Hill 1983).

2.1.6 Drainage and channel pattern

The Nottawasaga River and its tributaries is the largest drainage system into Georgian Bay (Ontario Conservation Authorities Branch 1973), with a dendritic drainage network encompassing a total area of 2966 km^2. About 40% is upstream of Baxter (Airphoto Analysis Consultants Ltd. 1977). The main channel flows in a northwesterly direction for a total distance of about 122 km. It is narrow and deep with variable sinuosity and degree of entrenchment. The river denotes an irregularly meandering channel pattern with some tortuous meanders (after Kellerhals et al. 1976), as for example near the Minesing Swamp and at the sand dunes in Wasaga Beach. It has three major western tributaries, the Boyne, Pine, and Mad Rivers, and two major eastern tributaries, Innisfil and Willow Creeks (Ontario Conservation Authorities Branch 1973). An areal peculiarity is the low count of natural lakes, there being only Edward, Little, and Marl Lakes.

Hydrometric gauges at the Nottawasaga River below Edenvale (02ED027) and near Baxter (02ED003) have monthly means of mean daily discharge peaking in April during the spring freshet (Fig. 2.5a). Flooding has been a major concern historically on the Nottawasaga River, and flood discharges can occur in all months except in August and September (MacLaren Plansearch Inc. 1988). Hurricane Hazel created the second largest daily flow of 254 $m^3 s^{-1}$ at Baxter on 16 October 1954 for a 36-yr record period,



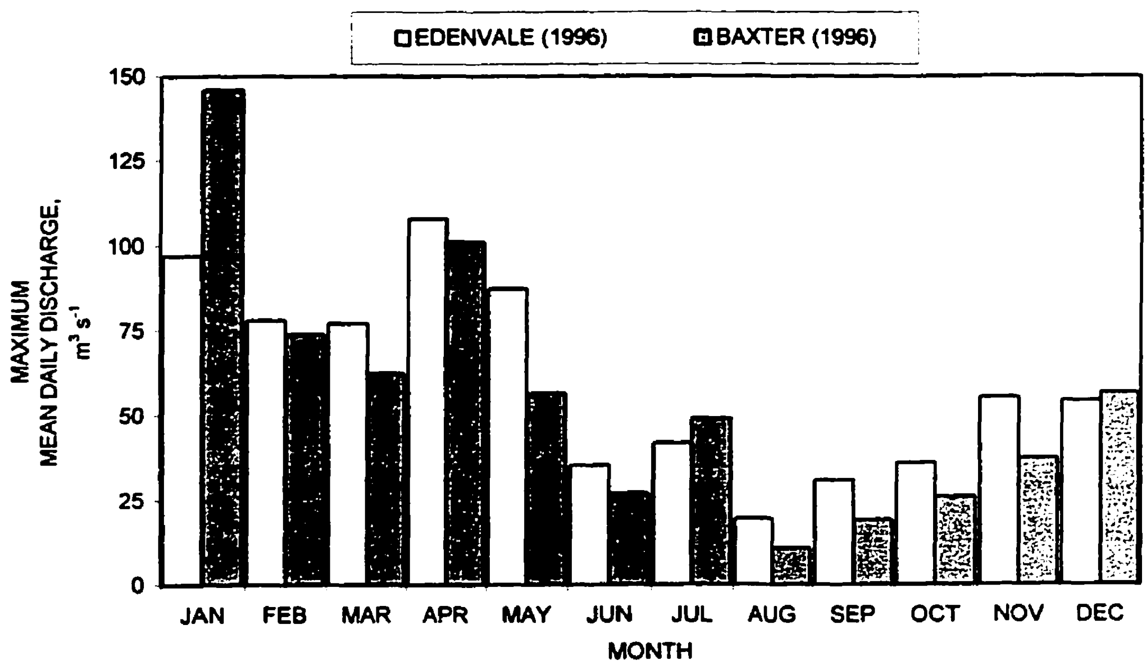


Fig. 2.5. Monthly mean of mean daily discharge for a 7-yr period of record at the Nottawasaga River below Edenvale (02ED027) and a 4-yr period of record at the Nottawasaga River near Baxter (02ED003) upstream of the study area (a, above). Below (b) is the monthly maximum mean daily discharge for 1996 at the Edenvale and Baxter gauges (compiled from HYDAT data from the Nottawasaga Valley Conservation Authority and Environment Canada).

and conferred the greatest damage from a single flood event. Here this was exceeded previously in 1951 by a maximum flow event of 267 $m^3 s^{-1}$ for a 29-yr period of record (Sangal and Kallio 1977). According to recent gauge records from the Nottawasaga Valley Conservation Authority, the maximum 7-yr flow event for the Edenvale gauge occurred on 2 April 1997 with a mean daily discharge of 138 $m^3 s^{-1}$. Recent discharge between 1993 and 1999 is greater below Edenvale than near Baxter (with about 94% of the discharge at Edenvale), though there is a similar seasonal pattern (i.e., for 1996 in Fig. 2.5b).

At Angus there appears to be a 5-yr major flood cyclicity (MacLaren Plansearch Inc. 1988). Some major causes of flooding, besides high flows, includes ice jamming (i.e., ice jam blasting occurred in the spring of 1981 as a relief measure) which has been linked to vertical accretion in some northern Canadian rivers (in Trenhaile 1998). Log jamming, possibly retarding downstream sediment transport and enhancing floodplain storage (Airphoto Analysis Consultants Ltd. 1977), is another likely flood implement. The Minesing Swamp is a sediment sink conceived as a considerable dead-water storage area with a significant attenuating effect on flood peaks upstream of the study area (MacLaren Plansearch Inc. 1988). The Nottawasaga River is regulated and has over five recreation, mill, and multipurpose dams and reservoirs in Essa, Mono, and Tosorontio Townships ranging in age from 7 to about 120 yr (Ontario Conservation Authorities Branch 1973). There is an artificial reservoir nearby New Flos. Doran Lake and Jack's Lake are small flood storage areas in the study area that are not expected to have any major impact on hydrologic routing (MacLaren Plansearch Inc. 1988).

The Nottawasaga River in the study area is a fifth-order stream (after Strahler 1969). It is a single-thread irregularly meandering narrow and deep river with significant natural levee development apparent as far upstream as Nicolson near Alliston. Its pattern of lateral activity is mainly cutoffs (after Kellerhals et al. 1976). A neck cutoff

(Doran Lake) can be seen in the study area, and there are some chute cutoffs. About two-thirds to one-half of the valley is taken up by the river channel. There is one terrace contiguous with the valley wall on both sides containing Pleistocene glaciolacustrine clays and aeolian sand deposits (after Burwasser and Cairns 1974). Though generally classified as a small sand-bed stream where it cuts through till and kame moraine in its upper reaches, the riverbed consists of coarse gravel and cobbles becoming sandy in reaches of glaciolacustrine deposits such as between Alliston and Angus upstream of the study area (Chandler and Kostaschuk 1994).

2.2 Post-glacial history

According to Fitzgerald (1985), deglaciation of the Minesing Basin was complete by 12 ka BP. Lake Algonquin inundated the basin between 11 ka and 10.6 ka BP. The upstream extent of the transgression is apparent near Angus in the west bank of the Nottawasaga River where there are sub-laminated varved silt and clay layers deposited by Lake Algonquin (Gravenor and Coyle 1985). The draining of Lake Algonquin established Lake Wyebridge and then Lake Penetang, followed by Lake Minesing, and Lake Edenvale (Fig. 2.6). Well-developed scarp or beaches are evident for Lake Wyebridge at an elevation of 212 m, for Lake Minesing between 206 and 207 m, and for Lake Edenvale at 191 m (Fig. 2.7). The Penetang phase is evident by poorly developed shoreline features on the Edenvale Moraine. Lake Minesing was drained as the Nottawasaga River downcut into the Edenvale Moraine. Lake Edenvale is the product of the rise of Nipissing waters and blockage by the Edenvale Moraine in the Minesing Basin between 6 ka and 4 ka BP. The Minesing Basin is emergent some 8000 yr ago, but parts again become submerged with the high-water effects of Lake Nipissing at about 5 ka BP, evident today some 184 m ASL (Lewis and Anderson 1985).

At Wasaga Beach, Martini (1975) has noted a lacustrine barrier system formed in the Holocene, its gravel spit formed approximately 7000 yr ago by the Early Nipissing

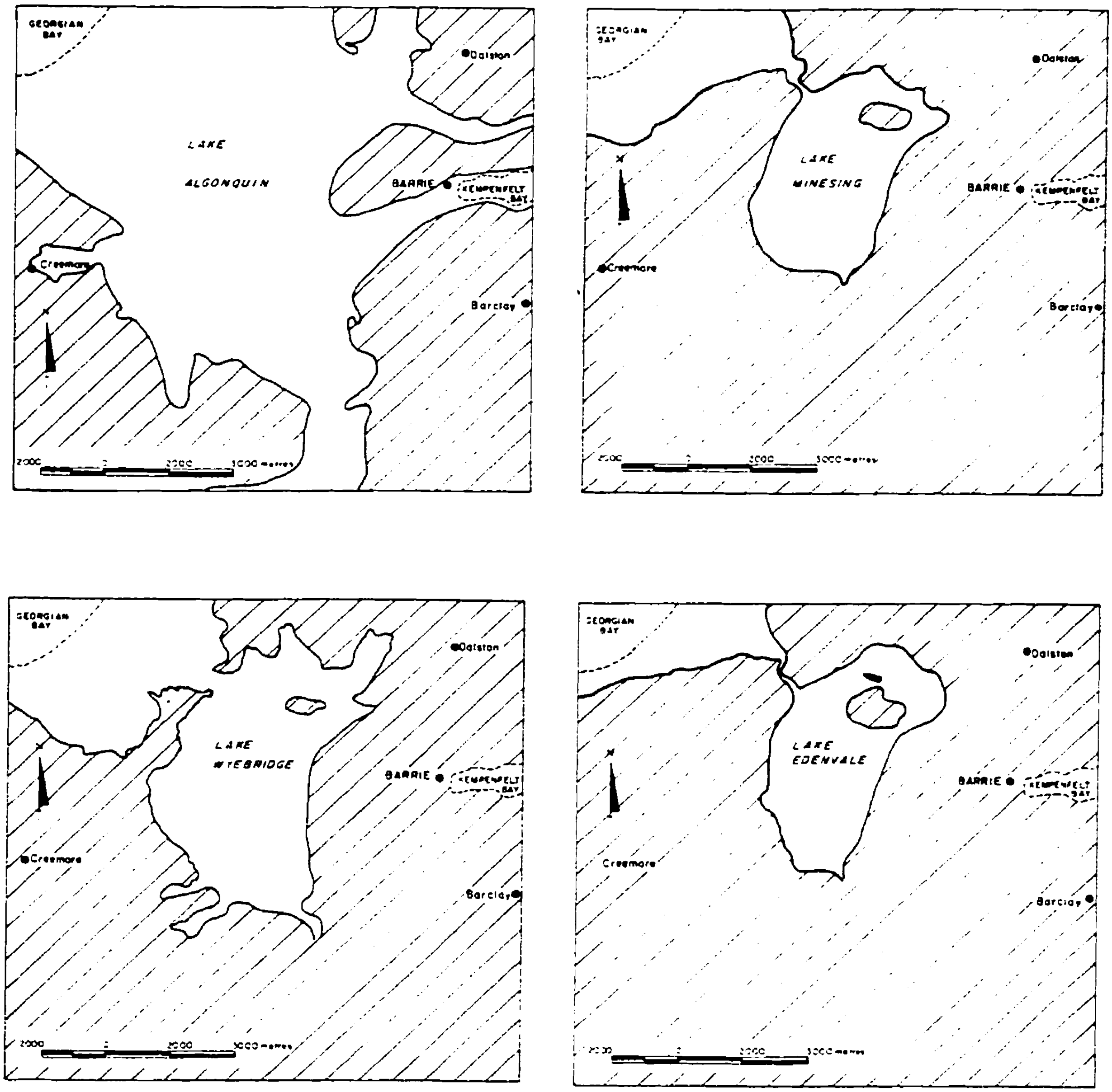


Fig. 2.6. Shoreline interpretation for glacial Lakes Algonquin (top left), Wyebridge (bottom left), Minesing (top right), and Edenvale (bottom right) in the Minesing Basin (from Fitzgerald 1985, p. 137).

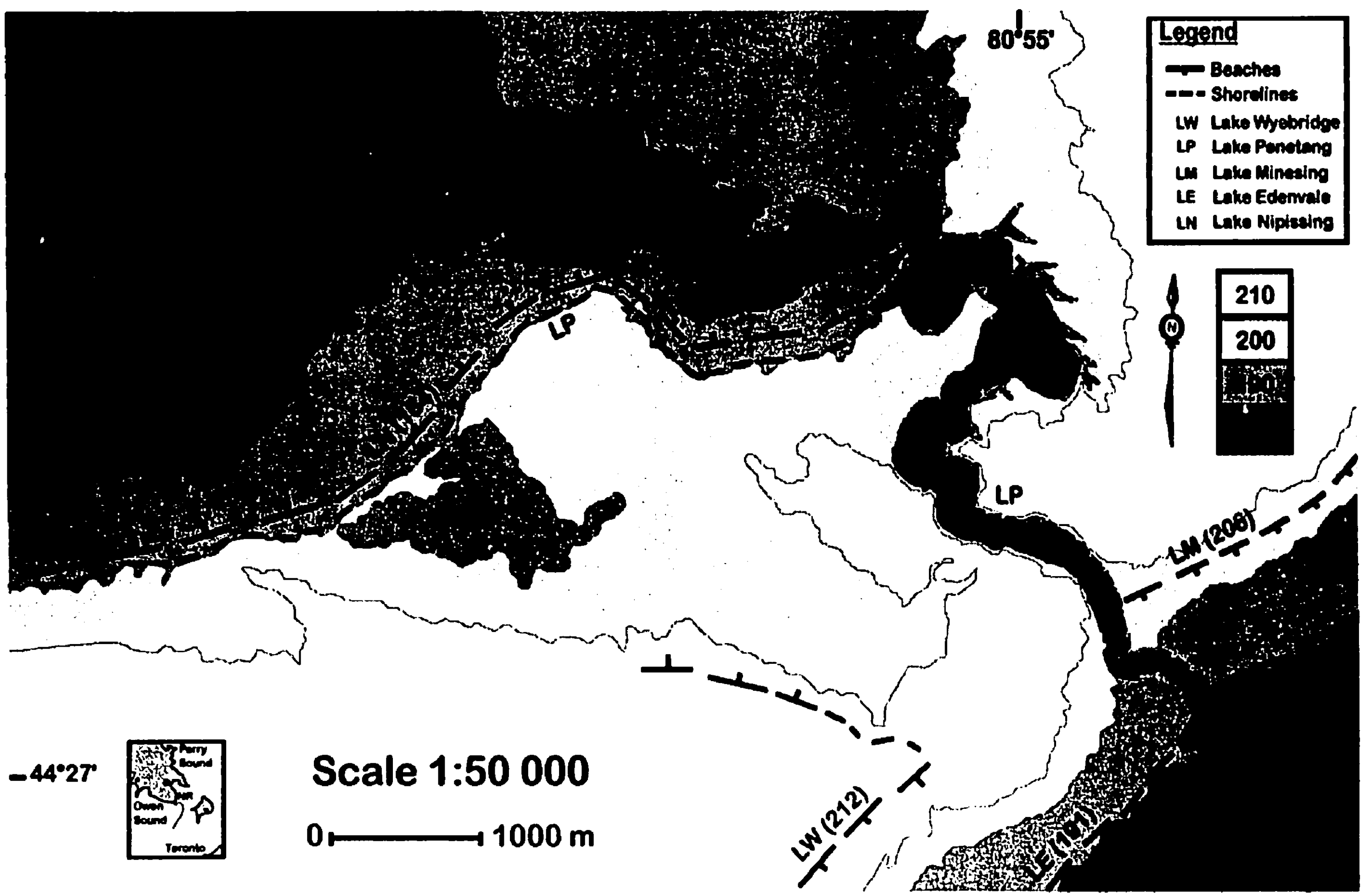


Fig. 2.7. Map of the study area displaying abandoned shoreline features (modified from Fitzgerald 1985, p. 135). The drainage of glacial Lake Algonquin in the Minesing Basin gave way to several phases including Lake Wyebridge, Lake Penetang (by which point the Edenvale Moraine was exposed), Lakes Minesing and Edenvale (whose drainage is contingent on downcutting of the Nottawasaga River through the Edenvale Moraine), and Lake Nipissing (after Lewis and Anderson 1985). Elevation contours are in m ASL

phase enclosing a lagoon. The draining of this lagoon is incomplete at Jack's Lake (Chapman and Putnam 1984a), which is a widening in the Nottawasaga River consisting of sand, marl, and peat situated on a clay plain cut off from post-glacial Lake Nipissing by the barrier system and sand dunes. The spit at Wasaga Beach continues to extend eastward essentially as a consequence of sediment supply from the Nottawasaga River (Davidson-Arnott and Pollard 1980). Much of the fluvial sediment out of the Nottawasaga River is deposited at Wasaga Beach, as at Nancy Island where alluvium has built up around the hull of the schooner Nancy sunk during the War of 1812 (Chapman and Putnam 1984a).

2.3 Edenvale Moraine

The Edenvale Moraine is a morainic ridge about 0.40 km wide and 6.4 km in length (Chapman and Putnam 1984a). It is bisected by the Nottawasaga River, which has entrenched into the Edenvale Moraine by approximately 30 m. Frequently exposed on its surface along the southern face is Allenwood Till, a sandy silt till with glacial flutings and fabric indicative of the northwest ice retreat out of Georgian Bay (Ontario Geological Survey 1982). It is the oldest till in the Simcoe Lowlands portion of Vespra Township and in Sunnidale Township, outcropping west of Edenvale nearby the Flos-Vespra Townships boundary and near Minesing, and is mostly covered by lacustrine silt and clayey silt in the Minesing-Edenvale area (Ontario Geological Survey 1984). At its northern slope is Kettleby Till, the youngest glacial material in Sunnidale Township, a gritty till consisting of laminated silty clay of glaciolacustrine origin containing clay pebbles (Ontario Mines and Minerals Division 1988).

Chapman and Putnam (1984a) identify the Edenvale Moraine as simply a ridge in alignment with the upland topography of north Simcoe County. Others as Deane (1949) identify it, for its ridge-like form, as a recessional moraine of marginal ice-front drift accumulation. The Edenvale Moraine became emergent between the Lake

Wyebridge and Penetang phases establishing Lake Minesing (Fitzgerald 1985). Delayed draining of Lake Penetang triggered downcutting of its outlet through the Edenvale Moraine. It subsequently was downcut by the Nottawasaga River as an outlet of glacial Lakes Minesing and Edenvale. Rising base level during the Nipissing phase created Lake Edenvale some 4.3 ka BP. Channel and floodplain confinement at the Edenvale Moraine is a consequence of progressive post-glacial channel incision accompanying base-level lowering and the draining of these glacial lakes.

2.4 Prehistoric and historic settlement

Prehistoric human occupation at the lower Nottawasaga River has been subject to some investigation particularly in the 1970s, though these studies focus on sections of the Nottawasaga River downstream of the study area (i.e., O'Brien 1975; Cooke 1990, 1993; Garrad 1993). O'Brien (1975) notes the common representation of Nottawasaga peoples of the Middle Woodland period (AD 0 to 800) in the lower Nottawasaga River, and claims that the earliest human presence is at about 5500 yr ago in the Archaic cultural period. The Ministry of Citizenship, Culture and Recreation (MCZCR) archaeological sites database shows a total of 13 sites with Borden provenance designations of BcGx and BcHa (Fig. 2.8). These sites have been derived from work by O'Brien (1974, 1975), and rely on her archaeological survey of Wasaga Beach. All sites except BcHa-38 have artifact-based estimations of cultural period affiliation (Table 2.1). All are surface collections of campsites with varying sizes spanning an elevation between 181 and 206 m ASL inside and outside the Edenvale Moraine in the study area.

According to Jury and Jury (1960), the French named the people they encountered "Huron" and their land "Huronia" rather than properly acknowledging them as Wendat or Wyandot of Wendake. These 17th century Iroquoian-speaking horticulturalists resided in longhouse village settlements between Georgian Bay and Lake Simcoe (Ramsden 1990). They planted corn, as well as beans, squash, sunflower,

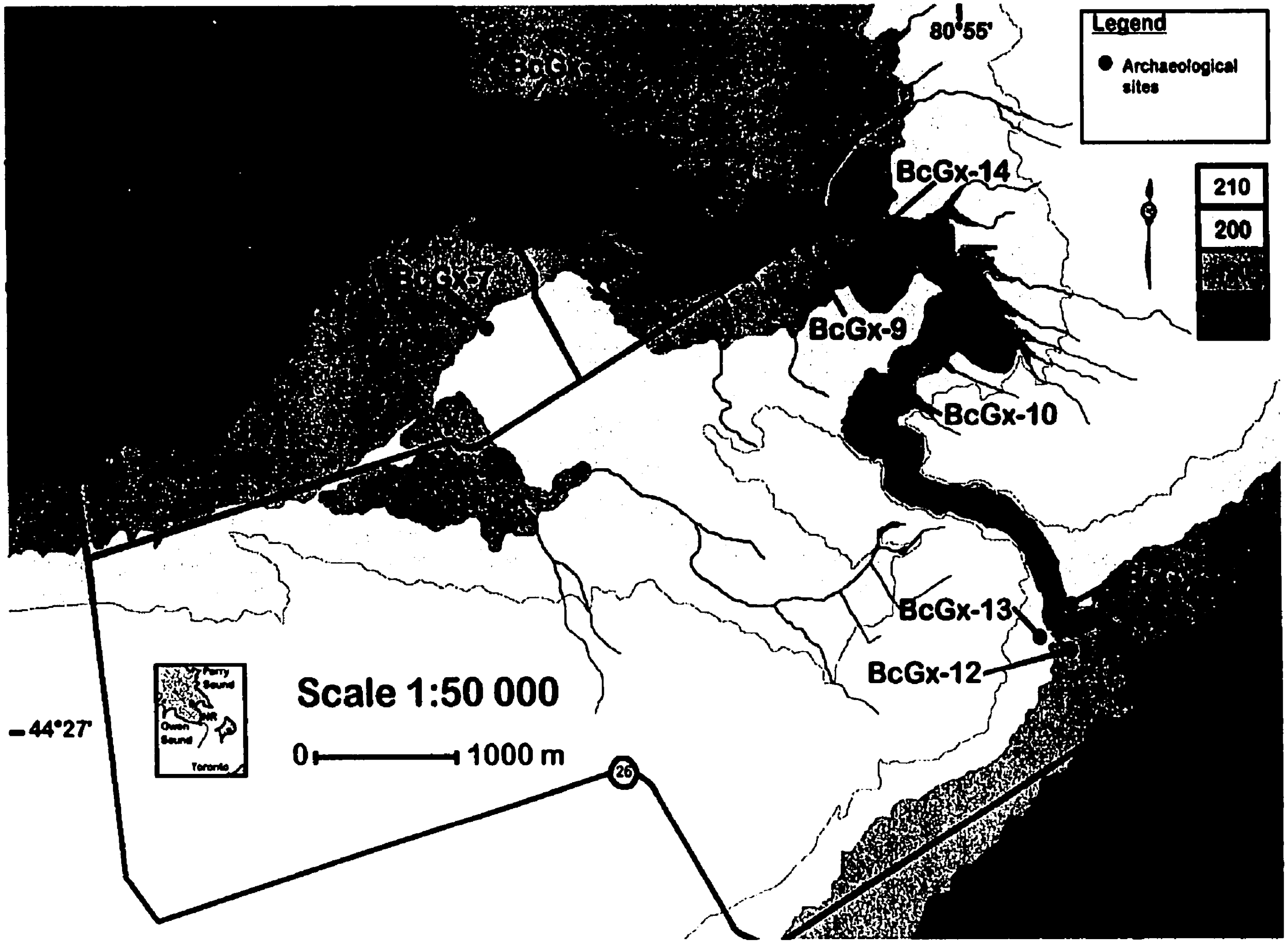


Fig. 2.8. Map of 13 designated archaeological sites in the study area, with Borden provenances of BcGx and BcHa (as in the MCZCR database, March 2000). Elevation contours are in m ASL.

Borden Number (Site Name)	Artifact Inventory	Cultural Period(s)
BcHa-38 (Jack Lake)	2 chert	?
BcHa-36 (Klondike Park)	34 ceramics, 2 lithics (scraper), 1 faunal	Middle Woodland (Nottawasaga)
BcGx-6 (Fisherman)	17 ceramics, 3 lithics, 7 faunal (calcined bone, clamshell)	Middle, Late Woodland? (Nottawasaga)
BcGx-7 (Pebble Bridge)	1 lithic (point)	Archaic/ Middle Woodland?
BcGx-5 (Dominici)	2 ceramics, 5 lithics (scraper), 1 faunal	Middle Woodland (Saugeen?)
BcGx-4 (Bridge)	14 ceramics, 1 lithic (projectile point)	Middle Woodland (Saugeen)
BcGx-8 (New Flos)	8 ceramics, 5 chert, 16 misc. lithics, 4 bones	Middle Woodland, early Late Woodland (?)
BcGx-9 (Edenvale One)	1 chert flake, 3 bones	Archaic (?)
BcGx14 (Edenvale Six)	1 adze, 3 misc. lithics	Archaic
BcGx-10 (Edenvale Two)	1 chert flake, 1 quartz flake, 2 misc. lithics	Archaic (?)
BcGx13 (Edenvale Five)	6 chert, 8 misc. lithics	Archaic (?)
BcGx-12 (Edenvale Four)	23 chert, 2 ground stones, 1 misc. lithic, 2 bones	Archaic
BcGx-11 (Edenvale Three)	35 chert, 3 misc. lithics, 3 bones	Archaic (?)

Table 2.1. Archaeological sites in unconfined versus confined (shaded) sections of the study area with Borden numbers and site names, artifacts, and associative cultural period (compiled from O'Brien 1974, 1975; MCZCR database, March 2000).

and tobacco. Corn contributed as much as 58% of their dietary calories (Monckton 1994). Its cultivation could have established an increased reliance on floodplain habitats and an increasingly sedentary lifestyle (Heckenberger et al. 1992). They also organized deer hunts sometimes driving them into rivers, and captured bears and beaver (Jury and Jury 1960). Fishing occurred at both rivers and lakes using bone-barbed fishhooks and harpoons, as well as nettle-woven nets. Ice fishing took place in the bay during winter using stone-weighted nets and wooden sticks. Granite was used for stone tool implements including axes, adzes, hammerstones, and celts. Flint was traded for cutting tools as scrapers, blades, drills, and arrowheads. Bone was shaped into awls, needles, hoes, pottery markers, beads, bracelets, pendants, and combs. Conch shells were popular items for beads and pendants, and clamshells as hoes, spoons, scrapers, and pottery implements. Woodworking for various items including canoes, toboggans, snowshoes, paddles, clubs, bowls, mortars, and more was a major industry utilizing birch, ash, hickory, ironwood, maple, tamarack, basswood, elm, cedar.

Since 1609, the extensive Wendat trading network originally attracted Samuel de Champlain and French Jesuit missionaries. It was as French allies that this trading nation met with their demise under the hands of the Iroquois siding with Dutch and English colonists. "Nottawasaga" translates to "the outburst of the Iroquois" (Nottawasaga Centennial Celebration 1934), as it was off Nottawasaga Bay that these enemies spurted on their raids. The sinking of the Nancy is remnant of an American attack on English colonizers during the War of 1812. Under Lieutenant-Governor John Graves Simcoe, the aboriginal Nine-Mile Portage was reinstated as a west route in Upper Canada linking Lake Ontario by Lake Simcoe at Kempenfeldt Bay to Lake Huron along Willow Creek and the Nottawasaga River thereby by-passing Lake Erie (Jury and Jury 1956). At Fort Nottawasaga (or Schooner Town) the Royal Navy had winter quarters between 1814 and 1817, and Glengarry Landing nearby the study area is where the Glengarry Light Infantry in 1813 to 1814 constructed bateaux for the transportation of supplies to British Forts (Braithwaite 1974).

Since 1831 an influx of immigrant pioneers to Simcoe County settled according to their nationality. The Scotch Settlement, for instance, was established north-west of Bradford, coming up the Nottawasaga River to Willow Creek, and down Lake Simcoe (Ontario Conservation Authorities 1964). Together with English colonialists, Lowland Scots were reputable early farmers in the Nottawasaga region becoming agricultural leaders with wheat as their staple crop. Jay Blair, whose ancestors immigrated from the Hebridean island of Islay in Scotland, became an authority on the local archaeology and prehistory of 1600s village-dwellers alternately called the Petun, Tobacco Nation, Tionnontate, Huron, and Wyandot (Garrad 1982). The Nottawasaga valley is presently an area with high potential for growth, particularly as baby boomers establish retirement communities in the vicinity of Georgian Bay (Palmer et al. 1998).

CHAPTER 3: METHODS

3.1 Research design

The design of this study is fashioned to consider multifaceted interdisciplinary objectives. On one level there is the issue of scale, selecting one that is relevant both for geomorphologic and archaeological investigations. As Stein (1993) posits, it is necessary for geoarchaeological research to operate at a human scale in avoidance of traditional large-resolution geomorphologic studies not addressing social processes. A compromise can be reached, as in the present study, using a regional scale considering the human element in an evolving landscape on the order of thousands of years. This approach has gained popularity since the 1970s linked to ecological and environmental archaeology as well as cultural resource management projects from surface surveys (Linse 1993). Selecting a landscape scale to examine floodplain evolution and paleoenvironment alongside regional archaeological evidence of human occupation, this study contributes to Wandsnider's (1992) "archaeogeomorphology". The timeframe chosen for this study is the Holocene, with an emphasis on the last few thousand years, allowing for tracking channel form adjustment as well as human floodplain occupation.

The methodology at the river scale has been adopted to test the first two research hypotheses of floodplain accretion style and the effect of confinement (see Fig. 1.3). Reach-scale research allows for an examination of channel shifting chiefly addressing timing and rate of lateral channel migration and entrenchment in the Holocene, the subject of the third hypothesis (in Fig. 1.3). Throughout, applications are made to the prehistoric cultural record particularly to address issues of site exposure and preservation. Field collections and laboratory analyses focus on physical, chemical, and sedimentological information from cores. This includes sediment stratigraphy, moist Munsell colouration, particle size, organic matter and carbonate content, with some biological consideration of pollen and macrofossils (shells). Terrace samples have been excluded for the most part since they are contingent with Pleistocene deposits on the valley wall. As the emphasis is on the more recent floodplain, coring in the valley flat was relatively shallow. Radar profiling provides deeper but unconfirmed information. Measurements of channel width were estimated from 1989 aerial photographs merged with Ontario Base Maps. Aerial photography interpretation after Mollard (1973), Kellerhals et al. (1976), and Mollard and Janes (1984) was indispensable for planform exploration off sets from 1953, 1989, and 1999.

3.2 River-scale methods

3.2.1 Methodology

The focus here was to investigate possible modes of floodplain accretion in the context of morainic confinement. Is alluvial build-up on the modern floodplain primarily through lateral channel erosion and deposition or overbank sedimentation, and how is confinement affecting accretion style? This component of the investigation required extraction of cores to determine spatial variation in particle size. In order to assess lateral versus vertical accretion modes it was necessary to sample broadly within the study area, as well as undertake detailed measurements at each site. The methodology was similar for both, establishing a series of transects in which hand-auger cores, cutbank profiles, topographic profiles, and radar surveys were used to reconstruct the geometry and composition of floodplain materials.

For the large-scale portion of the research, 11 transects were established through survey perpendicular to flow on the modern floodplain in the study area spaced at intervals between 0.5 to 3.4 km (Fig. 3.1 and Appendix A). To enable a geomorphic comparison of the Nottawasaga River floodplain in the two distinct sections, an almost equal number of cross-sections (five and six) were respectively situated in unconfined and confined sections. Transects have been labelled numerically (T1 to T11) increasing

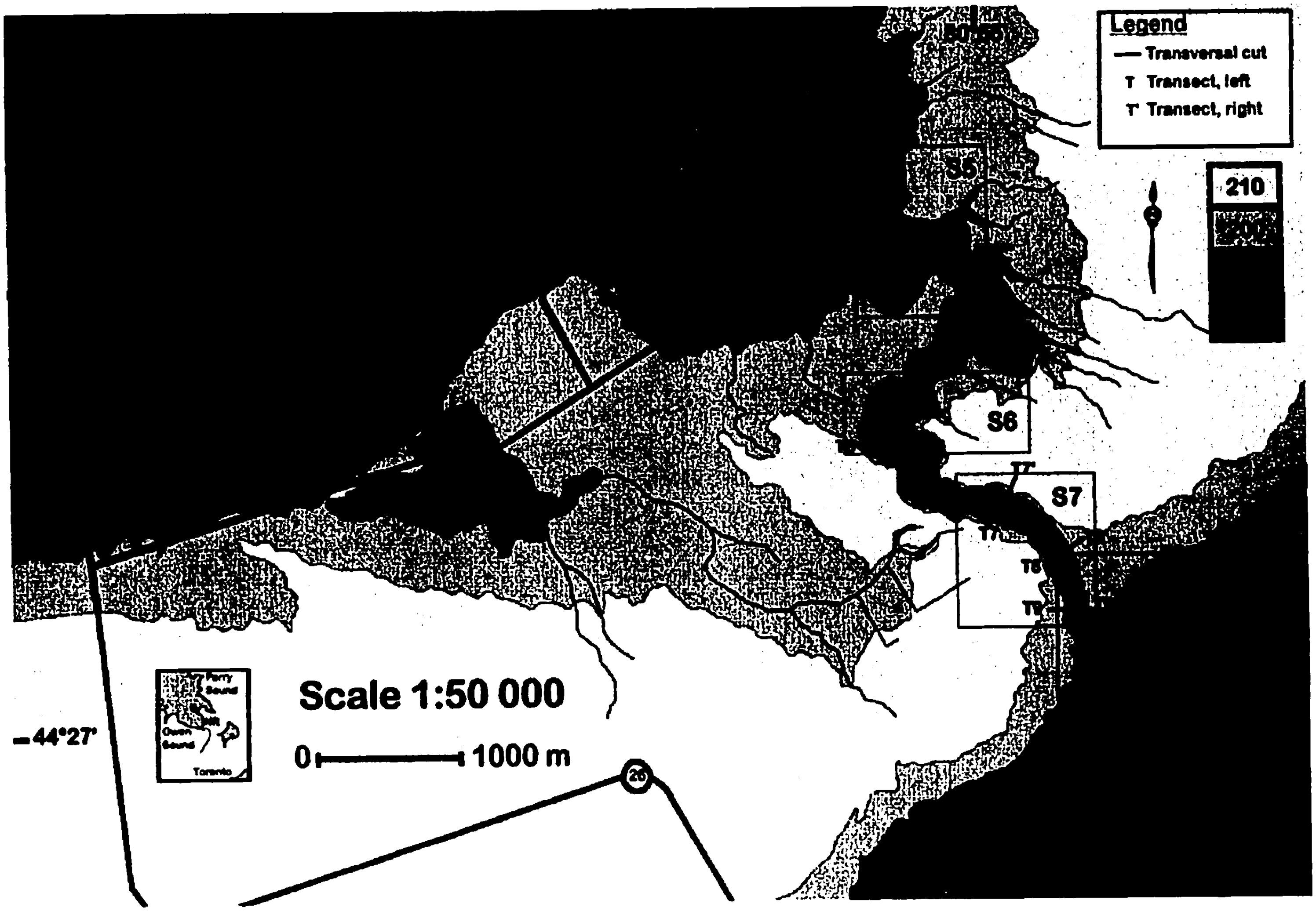


Fig. 3.1. Key of the 11 transects (laterally extended) used for geomorphic cross-sectional profiling upstream in the study area. See Appendix A for smaller-scale (1:7500) 1989 aerial photographs (acquired from Airborne Sensing Corp.) with Ontario Base Map overlays (from the Ontario Ministry of Natural Resources, printed in 2000 based on 1983 air photography) for eight sections (S1 to S8) of transects (also laterally not to scale). Elevation contours are in m ASL.

in an upstream direction extending from both sides of the channel on the left (L) and right (R) banks. T1 through T4 and T11 are in unconfined sections and T5 through T10 are in confined sections. The location of transects within the study area were subject to access constraints governed by underbrush and flooding considerations as well as landowner permission. With these constraints, transects were placed in an as even as possible spacing inside and outside the moraine.

3.2.2 Field investigations

Field work was conducted in June 2000, though some radar profiles were acquired earlier in February that year. Surveying was executed on the floodplain using Sokkia's SET4B total station. Transversal cuts perpendicular to river flow were established, and a portable GPS device was used to keep track of UTM coordinates. Detailed topographic surveying of the floodplain occurred away from the active channel on both sides. Water surface slope estimations were taken with the total station steadily held on the water's surface where underbrush was minimal, near unconfined T1(R), at T4(L), and T11(R) as well as at confined T8(L) and T9(R), for the derivation of an average regional channel slope in each section.

Alluvial samples from 53 cores were acquired with an Oakfield auger at 10 to 20 m intervals along each transect on both sides of the channel. Samples were bagged at regular increments of 10 cm, retaining field notes on boundary types, wet Munsell colouration and hand texturing. Coring refusal was specified for each auger hole (i.e., sediment saturation where samples were sliding out of the auger into the hole, hard-layer barrier usually for hard clay layers preventing further penetration with a hand auger). Depth to refusal here refers to sample-acquirement restrictions rather than bedrock contact. Two prominent cutbanks in the study area were excavated at unconfined T3(L) and at confined T7(L).

Ground-penetrating radar (GPR) is a geophysical application for scanning shallow sediments using a short pulse of high-frequency electromagnetic energy in the range of 10 to 1000 MHz (Davis and Annan 1989). The technique has been most successfully applied to sandy, gravelly, and organic rich fluvial, deltaic, and beach deposits, and operates relatively poorly on muddy sediments with a high clay or saline water content because of signal attenuation where conductivity is high (Jol and Smith 1991). It provides high quality data of quartz-rich non-clayey sand and gravel deposits even in water-saturated conditions. According to these researchers, the most versatile antennae frequency is 100 MHz since there is a tradeoff between penetration depth and resolution. Whereas 50 MHz antennae allow for deeper penetration, for instance, 200 MHz antennae permit higher resolution for shallow penetration. For this reason, 50 and 100 MHz antennae were utilized in this study, and some of the results for the former are reported here. PulseEKKO IV software was used to process all GPR profiles. Radar profiles are available for unconfined T1(R) and T2(L), plus confined T5(L) at Doran Lake (over snow) and T6(cross-channel and L over snow).

An Apelco echosounder (XCD 600, LCD Fish Finder) with a transducer frequency of 200 kHz was mounted at the rear of a Zodiac watercraft for detection of streambed shape, thalweg depth, and channel cross-sectional area. This technique was applied at all transect locations within about 2 m of each riverbank and as close as possible (±5 m) to the ground survey.

3.2.3 Laboratory analyses

Particle size analysis was performed in the laboratory after Folk (1968) for auger (N=179; n_{UC}=83, n_{CF}=96) and cutbank (N=15) samples. As there were no clasts ≥2000 μm (≥granules/gravel), coarse-fraction samples 2000–63 μm (-1.00 to 4.00 ϕ) in size were oven dried for at least 4 hr at 100°C (after Gardner 1965). They were granulated using a mortar and pestle and then dry sieved for 15 min with pan increments of 0.50 ϕ. The Wentworth scale was utilized in μm for ascribing size categories (Table 3.1), as well as the percentile-intercept method to acquire median grain size (after Folk 1966). For the fine fraction (<63 μm), the Micromeritics SediGraph 5100 Particle Size Analysis System (V3.07) was used. This method requires a silt-clay dry weight of about 2.5 g dispersed in a solution of 0.05% $Na(PO_3)_6$ in distilled water. All samples were heated to ~35°C in ultrasonic bath for 1 min immediately preceding the analysis.

A differential thermal analysis technique loss on ignition (LOI) was used after Dean (1974), on 3–5 g of sample in batches of 25 lidded crucibles, to quantitatively measure organic and carbonate carbon content in each sample. Notably, for both particle size and LOI analyses, samples were selected from the top, middle, and bottom of auger cores, though an attempt was made to represent all distinct strata particularly in cutbank samples.

3.3 Reach-scale methods

3.3.1 Methodology

The intention of the detailed study reach at Doran Lake was to address channel shifting, and the third hypothesis of entrenchment. As a neck cutoff with a preserved and possibly vertically accreted sediment record since the cut-off event, the purpose was to determine the age of Doran Lake and what can it reveal about alluvial environmental change? Since Doran Lake is situated at T5(L), the reach-scale examination keyed in on the left bank. River-scale sampling, techniques, and equipment similarly were applied here and T5 data are included in the river-scale investigation. The chief objective of this portion of the research is age determination of the present waterway and an environmental reconstruction since the cut-off event.

Types	ϕ units	Wentworth (mm)
Boulder	more than −8·0	more than 256
Cobble	−8·0 to −6·0	256 −64
Pebble	−6·0 to −2·0	64 − 4
Granule	−2·0 to −1·0	4 − 2
Very coarse sand	−1·0 to 0	2 − 1
Coarse sand	0·0 to 1·0	1 − 0·5
Medium sand	1·0 to 2·0	0·5 − 0·25
Fine sand	2·0 to 3·0	0·25 − 0·125
Very fine sand	3·0 to 4·0	0·125 − 0·0625
Coarse silt	4·0 to 5·0	0·0625 − 0·0312
Medium silt	5·0 to 6·0	0·0312 − 0·0156
Fine silt	6·0 to 7·0	0·0156 − 0·0078
Very fine silt	7·0 to 8·0	0·0078 − 0·0039
Coarse clay	8·0 to 9·0	0·0039 − 0·00195
Medium clay	9·0 to 10·0	0·00195 − 0·00098

Table 3.1. Wentworth and ϕ unit sediment classification (Krumbein 1934 in King 1972, p. 216).

3.3.2 Field investigations

Three long cores were collected from the oxbow lake off the back of an anchored Zodiac watercraft using a Livingstone piston sampler (after Wright et al. 1965). Core locations at Doran Lake were marked using a hand-held GPS device around 140, 280, and 420 m away from the active channel. Pole extensions permitted long cores between 2.5 and 5.4 m in (uncompressed) length. The acquirement of long cores from a peat-bog environment necessitated using this technique.

3.3.3 Laboratory analyses

Samples roughly 5 cm thick were examined at depth increments of 20 cm (beginning at 0 cm) along each of the three cores. The cores were logged for stratigraphy, moist Munsell colouration, grain size and structure, sediment inclusions (gley, marl, peat), and macrofossils. Particle size analysis and LOI were executed on a total of 64 samples. Pollen analysis was performed for C2 at depths of 85, 280, and 485 cm. Extracted mollusc shells were classified after Strayer (1990). An AMS radiocarbon date was derived for a wood sample located at a depth of 486 cm in C2.

3.4 Archaeology

As small-scale archaeological work was omitted from this regional-scale analysis, archaeological excavation and the like regrettably have been excluded from this research. The sample size of the known 13 archaeological sites was too small for statistical analysis so that a qualitative examination was undertaken instead employing a planform view of known site locations and cultural age estimations as in the MCZCR archaeological sites database. Using known archaeological sites with associative cultural age estimations in unconfined versus confined sections, it was possible to establish connections to floodplain formation. The case study of Doran Lake is applied archaeologically mostly for Holocene environmental reconstruction and for conceptualizing site prospecting.

CHAPTER 4: RIVER-SCALE RESULTS

4.1 Alluvial grain size and organics

4.1.1 Downstream

For all auger samples taken throughout the study area, the smallest median particle diameter (D_{50}) is 3 μm (coarse clay) at confined T5 and T7, and the largest D_{50} is 340 μm (medium sand) at unconfined T3. The $\bar{D}_{50}$ (mean median particle diameter) for all auger samples across all transects in unconfined and confined sections is 68 μm (very fine sand). Fig. 4.1a shows the spatial variation in $\bar{D}_{50}$ and variance across all transects. Particle size is greatest at T3 with a $\bar{D}_{50}$ of 148 μm (fine sand), and finest downstream of Jack's Lake at unconfined T1 as indicated by a $\bar{D}_{50}$ of 24 μm (coarse clay). There is no obvious downstream trend in $\bar{D}_{50}$. However, there is a weak pattern towards increasing grain size through the Edenvale Moraine to T6. Doran Lake at T5 is unusually fine. T3 and T4 downstream of the moraine suggest local coarsening. A two-sample t-test on $\bar{D}_{50}$ reveals a statistically non-significant difference ($P(T\leq t)=0.814$, two-tailed) across unconfined versus confined transects, as indicated by respective means of 66 μm versus 68 μm (both very fine sand) (Table 4.1a).

A downstream examination of sand content reveals a pattern very similar to the D_{50} results (Fig. 4.1b). Sand content in confined reaches varies from 38% at T5 to 72% at T6. Downstream of the confined section, sand content increases to a high of 73% at T3 combined again with a much higher variance. The highest proportion of fine particles (<63 μm or silt and clay) is apparent in unconfined reaches at T1 (65%) and T11 (66%), and at T5 (62%) in the moraine area (Fig. 4.2a). Clay mimics the above pattern, being highest at T1 (32%) and T11 (35%) in unconfined reaches and at T5 (24%) for confined sections (Fig. 4.2b).

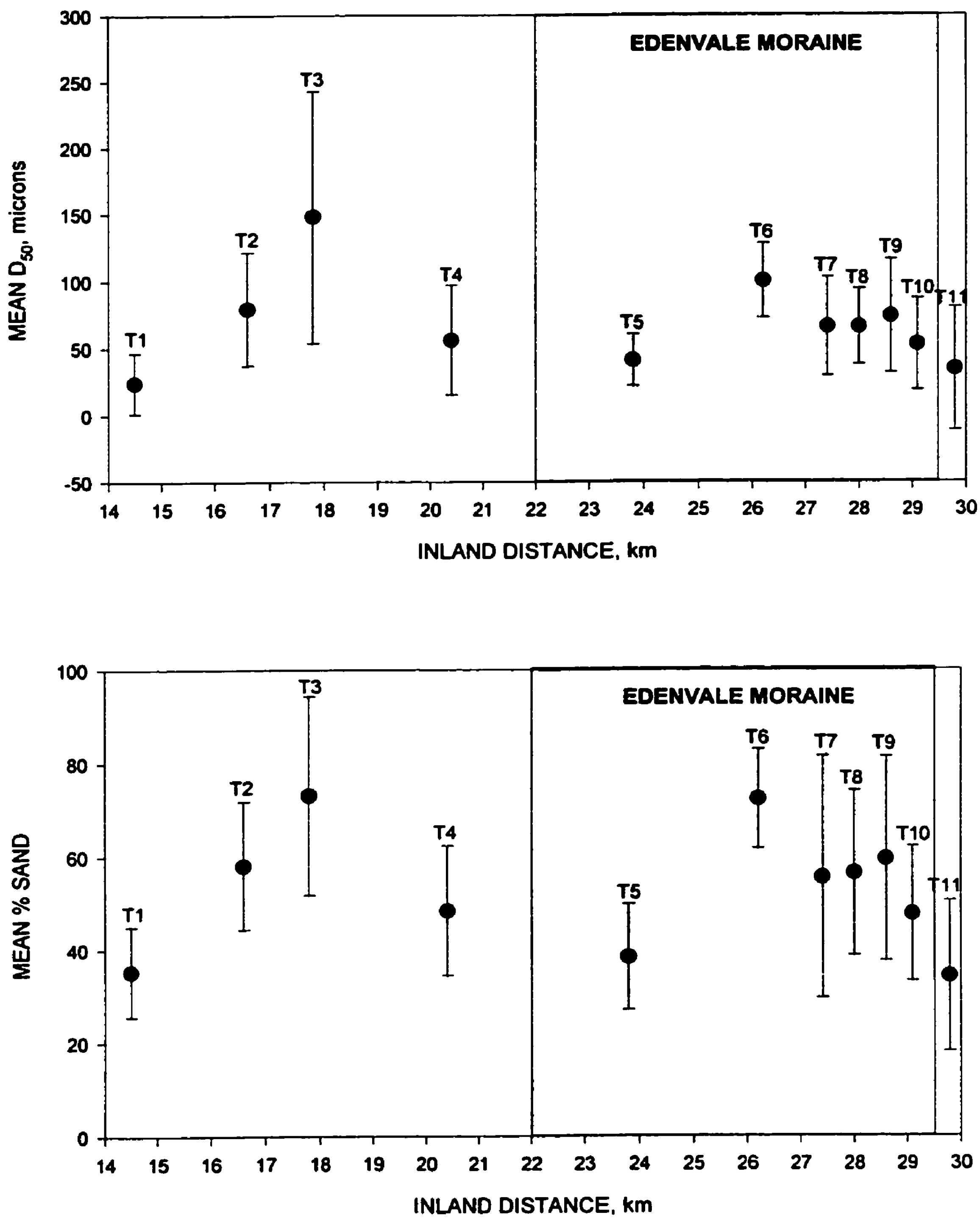


Fig. 4.1. Mean median grain size (a, above) and mean proportion of sand (b, below) upstream at each transect, with respective standard deviation bars. Confined sections are represented by the shaded area.

a) D_{50}

	Unconfined	Confined
Mean	66.355	68.328
Variance	4581.625	1340.492
Observations	82	95
Hypothesised Mean Difference	0	
Df	120	
t Stat	-0.236	
P(T<=t) one-tail	0.407	
t Critical one-tail	1.658	
P(T<=t) two-tail	0.814	
t Critical two-tail	1.980	

b) Organic Matter

	Unconfined	Confined
Mean	3.790	3.208
Variance	5.202	3.981
Observations	82	95
Hypothesised Mean Difference	0	
Df	162	
t Stat	1.793	
P(T<=t) one-tail	0.037	
t Critical one-tail	1.654	
P(T<=t) two-tail	0.075	
t Critical two-tail	1.975	

c) $CaCO_3$

	Unconfined	Confined
Mean	34.407	20.125
Variance	449.153	160.845
Observations	82	95
Hypothesised Mean Difference	0	
Df	128	
t Stat	5.333	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.657	
P(T<=t) two-tail	0.000	
t Critical two-tail	1.979	

Table 4.1. Two-sample t-tests assuming unequal variances for unconfined versus confined $\bar{D}_{50}$ (a), proportions of organic matter (b) and $CaCO_3$ (c).

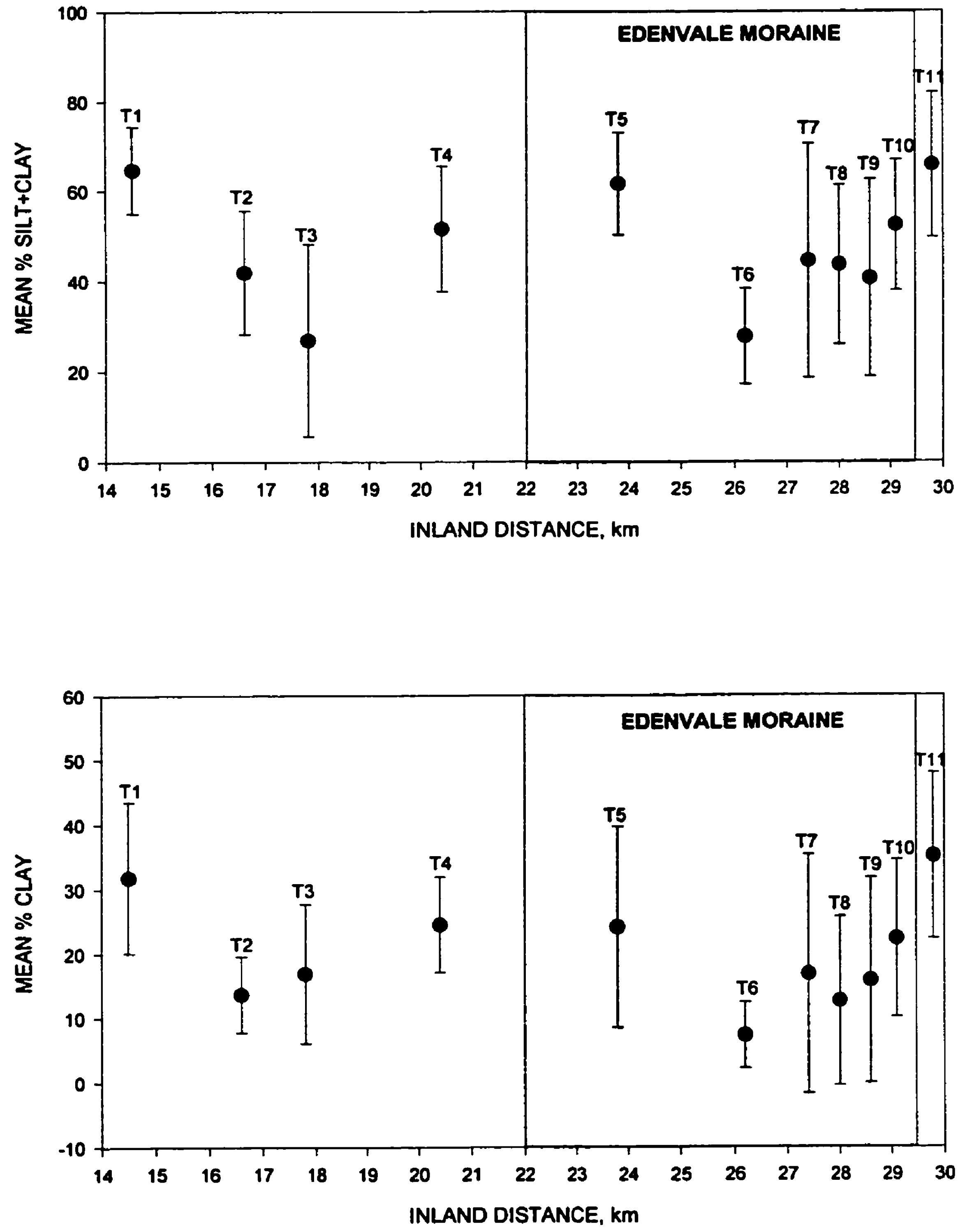


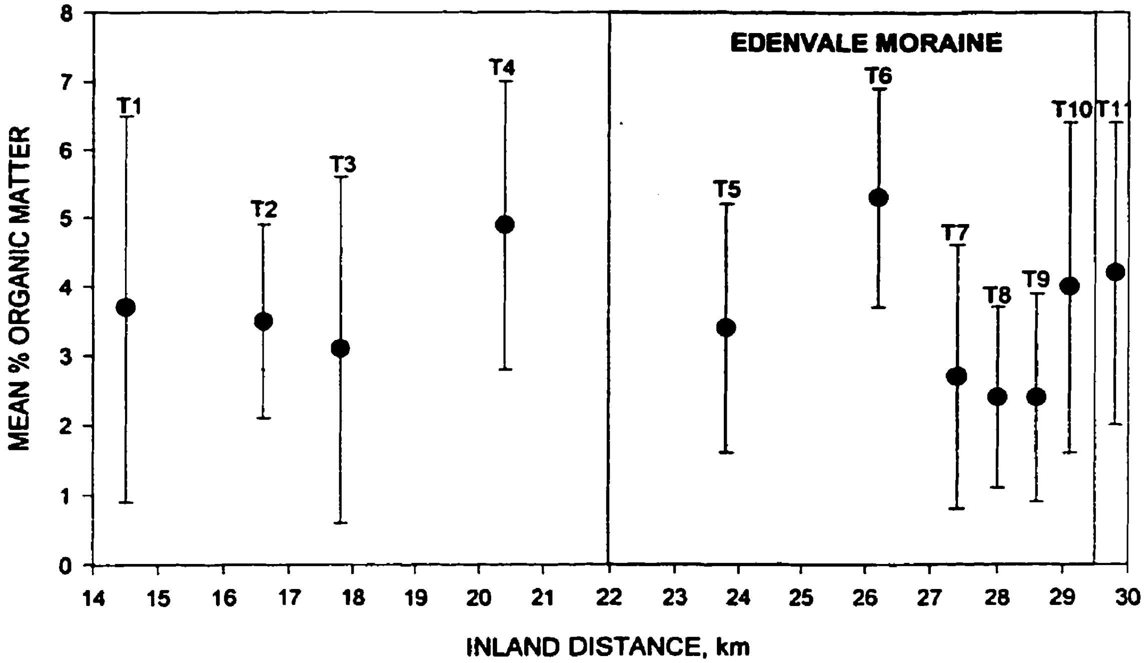
Fig. 4.2. Mean proportions of silt and clay (a, above) and mean proportion of clay (b, below) upstream at each transect, with respective standard deviation bars. Confined sections are represented by the shaded area.

Mean organic matter varies between 2% and 5% being greatest at T4 and T6 and lowest at confined T8 and T9 (Fig. 4.3a). Mean $CaCO_3$ is greatest at T1 (56%), T4 (28%), T11 (43%) and lowest at T3 (18%) and T8 (17%) (Fig. 4.3b). The t-test result for proportion of organic matter is statistically non-significant ($P(T \leq t)=0.075$, two-tailed), though unconfined sections show a slightly greater abundance (4% versus 3% in confined sections, Table 4.1b). Carbonate content is significantly ($P(T \leq t)=0.000$, two-tailed) greater in unconfined sections (particularly for T1) at 34%, versus 20% $CaCO_3$ in confined sections (Table 4.1c).

4.1.2 Cross-valley

Cross-sectional profiles of valley bottom topography with sand, organic matter, and $CaCO_3$ content provide an overview of spatial variability at each transect (see Appendix B for details of each sampling site). Fig. 4.4 showing T4 is most diagnostic of the pattern observed in unconfined sections. Overbank deposits are mostly sandy with some silt and clay. The floodplain becomes coarser (sandier) away from the channel, and levee development is apparent along the margin where finer sediments prevail. Organic matter and carbonate content convey no clear cross-valley trends in unconfined transects, though both may somewhat decrease away from the channel. Fig. 4.5 is representative of confined transect results at T8 displaying a well-developed levee which is also apparent nearby at T7 (Fig. 4.6). The left bank for T8 (see Fig. 4.5) shows finer, more organic rich, and higher $CaCO_3$ content away from the levee. T7 is similar but $CaCO_3$ is low everywhere on the left bank.

Ternary plots of cross-sectional particle size by proximity to the active channel, where proximal samples are closest to the channel on both sides (from half the topographic survey extent at each transect) and distal samples are from the remainder farthest from the channel on both sides, reveal less variance and more mixing in



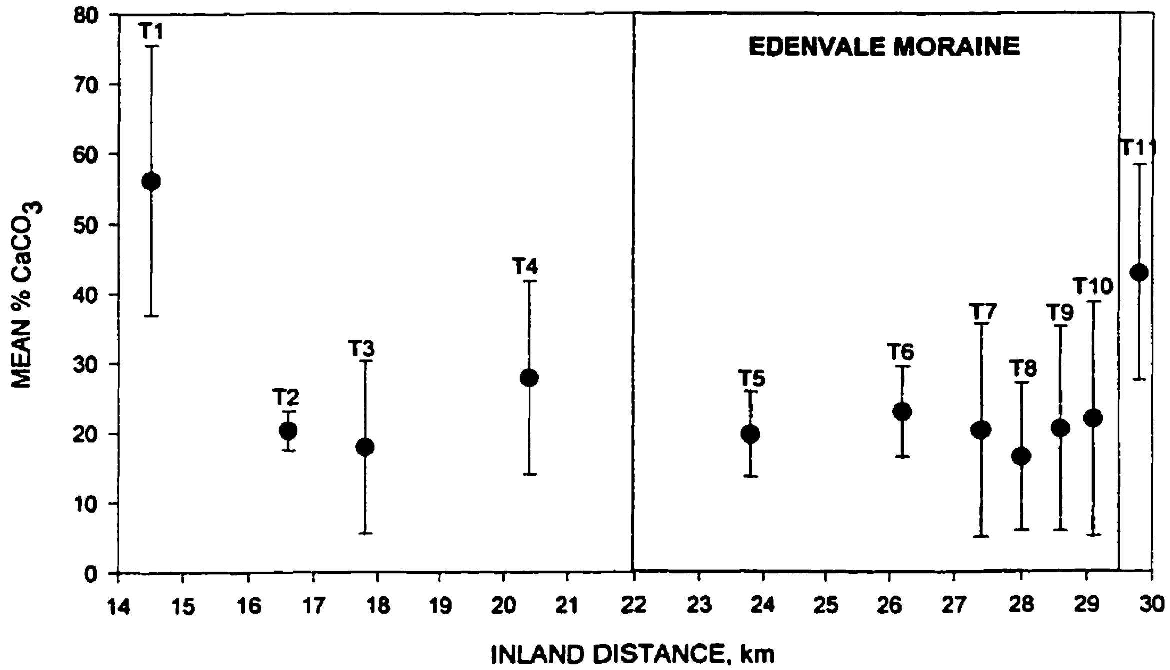
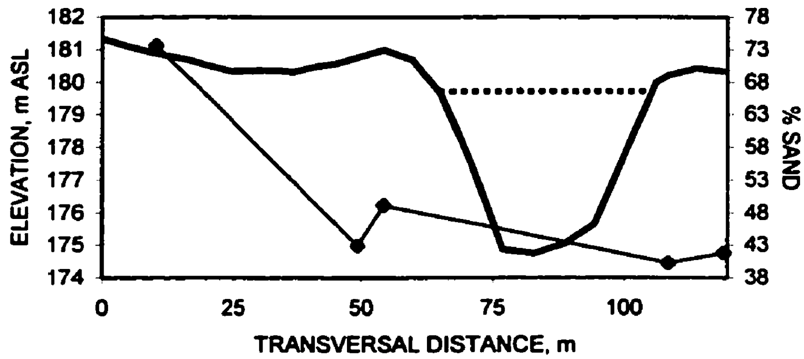
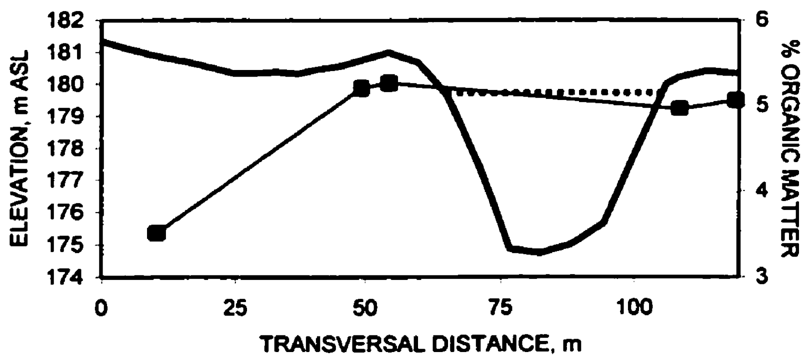


Fig. 4.3. Mean percentage of organic matter (a, above) and mean proportion of calcium carbonate (b, below) upstream at each transect, with respective standard deviation bars. Confined sections appear in shaded area.





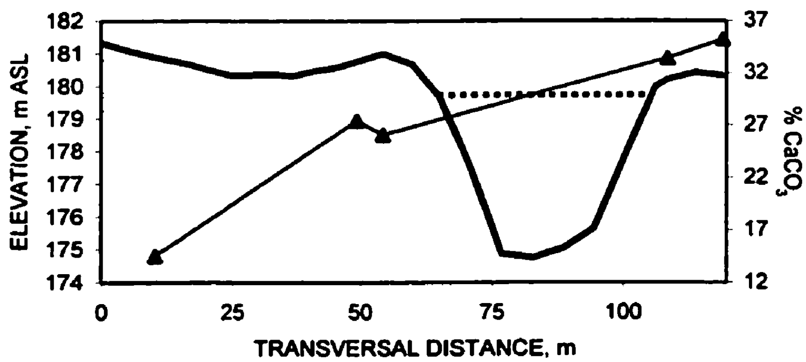
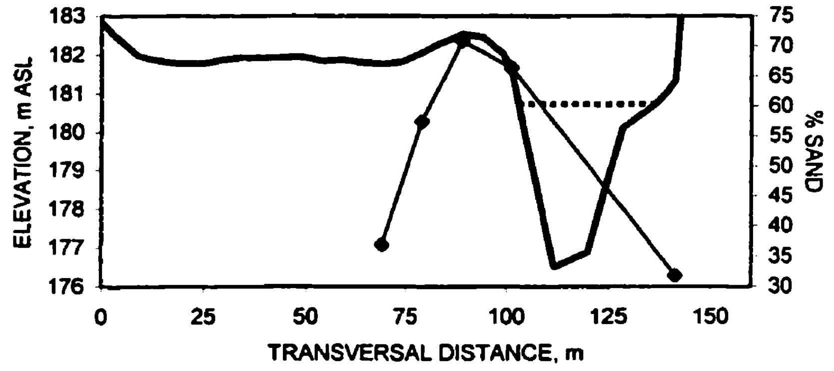
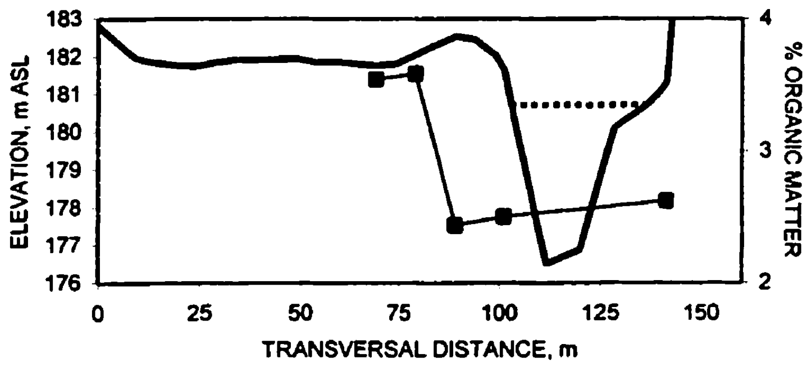


Fig. 4.4. Cross-sectional profiles at unconfined T4 of topography (solid thick line, looking downstream) and sand (a, above) organic matter (b, centre), and carbonate content (c, below) in auger samples at each coring location.





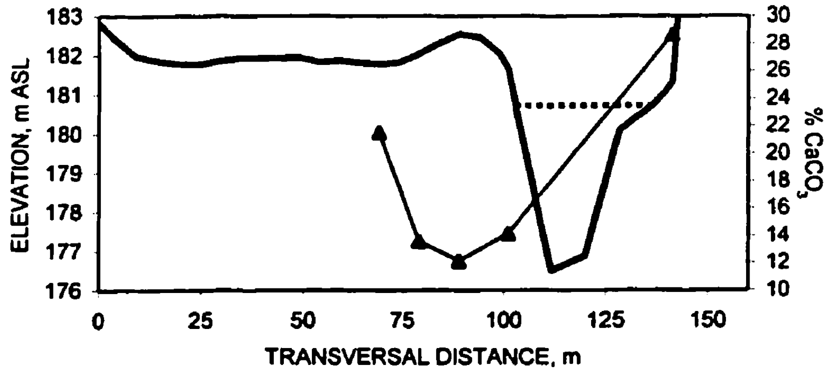


Fig. 4.5. Cross-sectional profiles at confined T8 of topography (solid thick line, looking downstream) and sand (a, above) organic matter (b, centre), and carbonate content (c, below) in auger samples at each coring location.

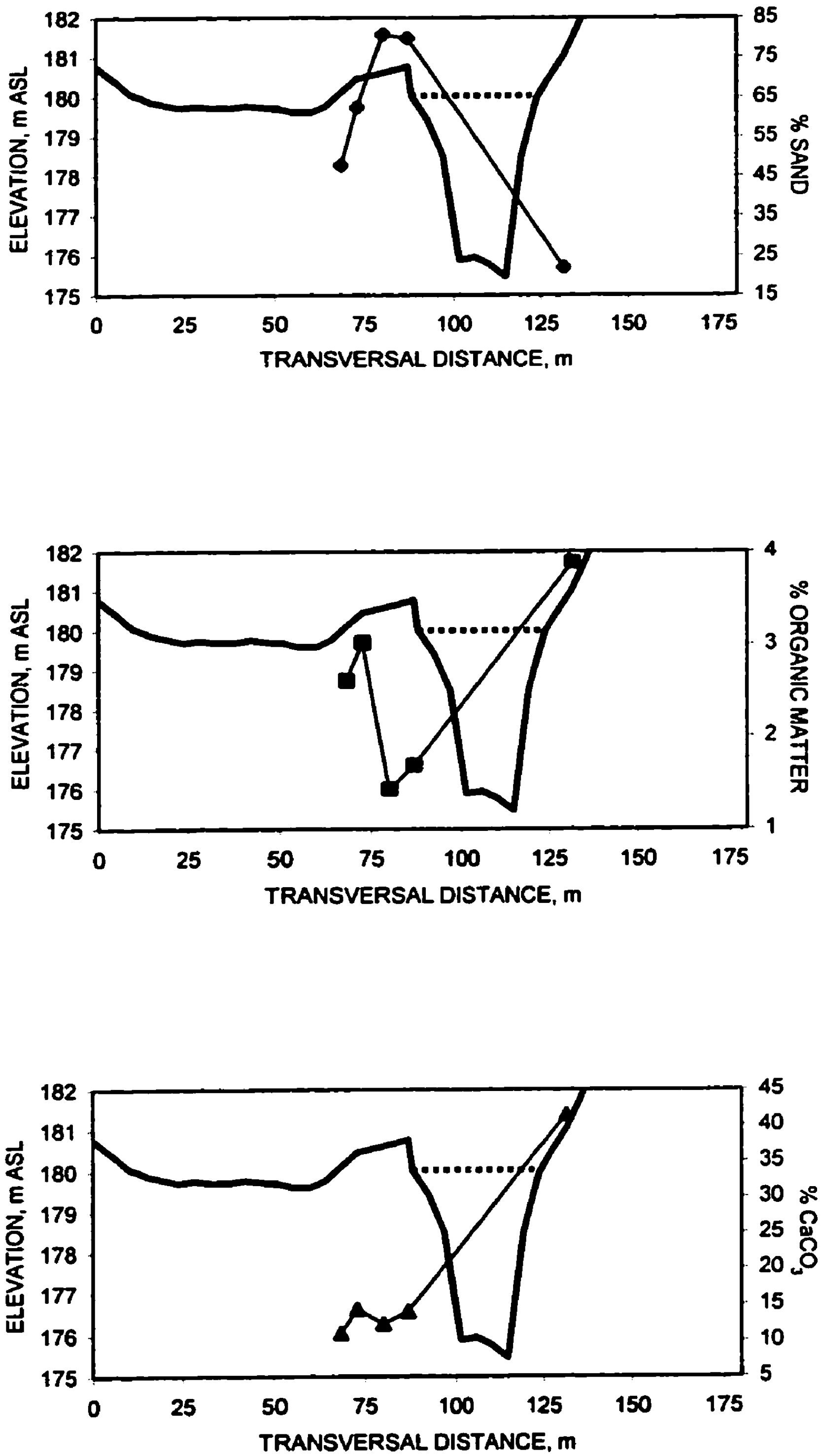


Fig. 4.6. Cross-sectional profiles at confined T7 of topography (solid thick line, looking downstream) and sand (a, above) organic matter (b, centre), and carbonate content (c, below) in auger samples at each coring location.

unconfined sections and the opposite trend (of more variance and less mixing) in confined sections (Fig. 4.7). Proximal auger samples in unconfined sections have a mean sand content of 51% versus 57% for confined sections, 30% versus 29% mean silt content and 23% versus 14% mean clay content. Distal auger samples in unconfined sections consist of 47% mean sand content versus 53% in confined sections, 30% versus 28% mean silt content and 29% versus 22% mean clay content. Confined sections have more sand content on average, especially if sampling sites are closer to the active channel. Mean silt content is comparable throughout, average clay content is greater away from the channel particularly in unconfined sections of the floodplain.

χ^2-test results for cross-sectional differences in grain size away from the active channel at each transect are statistically significant (α=0.05). Counts show that 127 of the total 179 auger samples (or 71%) consist of mostly sand. Of these, 56 are located in unconfined sections and 71 in confined reaches, 97 are classifiable as proximal and 30 as distal (Table 4.2). The observed values differ significantly from expected values in that there are more sandy samples (with a majority $\geq$63 μm) for unconfined-distal (16 versus 13) and confined-proximal (57 versus 54) samples. Conversely, the observed values are smaller than expected values for unconfined-proximal (40 versus 43) and confined-distal (14 versus 17) samples.

4.1.3 Sedimentary structures

Samples extracted from a 175-cm tall cutbank on the left bank at T3 (Fig. 4.8), denote a generally fining-upwards stratigraphic sequence with a wide range of D_{50} particle sizes between 270 and 5 μm (medium sand to very fine silt). The unconfined cutbank consists mostly of sand, except for a clay-rich layer at a depth of 115 cm and some evidence of greater fining within the top 27 cm. Organic matter ranges between 0% and 4%, and is greatest towards the top in the occupational surface and at a depth

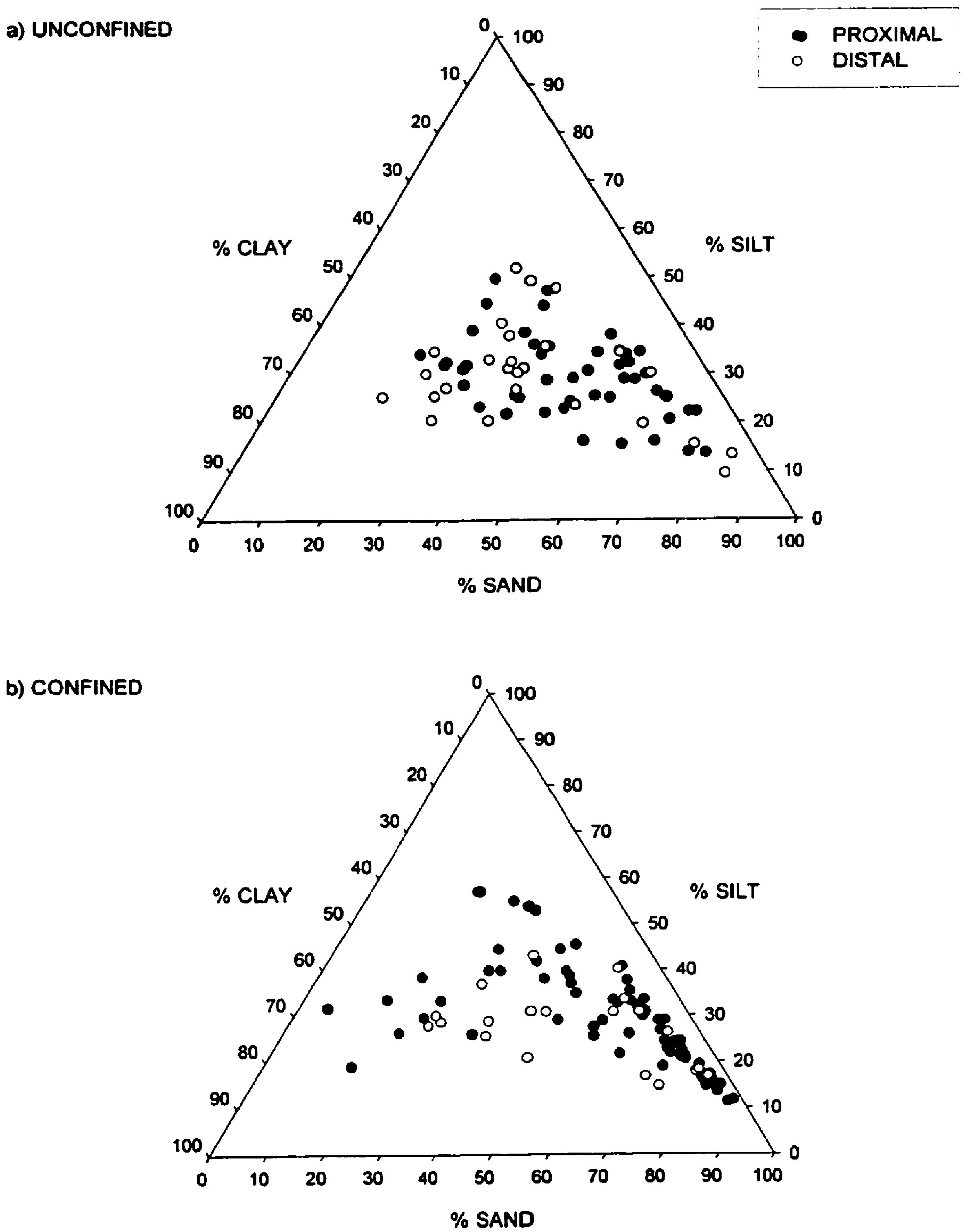


Fig. 4.7. Ternary plots of sand, silt, and clay fractions for proximal versus distal auger samples at unconfined (a, above) and confined (b, below) sections.

	Unconfined	Confined	Total
Proximal	40 (43)	57 (54)	97
Distal	16 (13)	14 (17)	30
Total	56	71	127

Table 4.2. χ^2-test grid of actual values (and expected values) for 127 auger samples with a modal sand fraction located in proximal versus distal distances from the active channel in unconfined and confined sections.

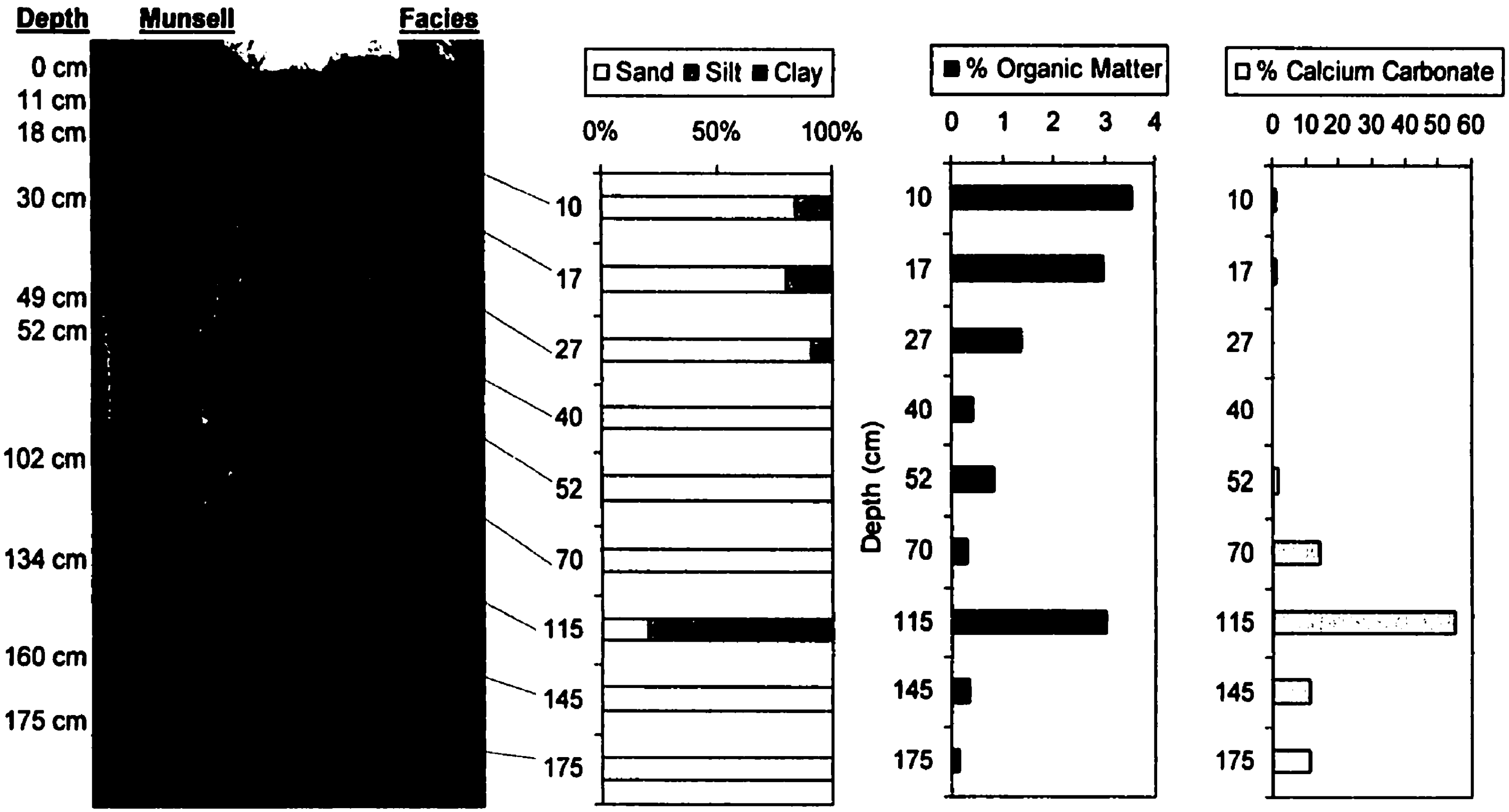


Fig. 4.8. Unconfined cutbank at T3 showing moist Munsell colours, and facies stratigraphy (after Miall 1977), particle size, organic matter and carbonates content are plotted with increasing depth. Clay-rich alluvium evident at a depth of 115 cm. Darker colouration between 134 and 160 cm of a water-saturated sand layer. (Facies abbreviations: Ah=A-horizon soil; OS=occupational surface; Cox=oxidized C-horizon soil; Sm=massive sand; Fsc=massive silt, mud, organics; Sr=rippled sand; Sh=horizontally laminated sand)

of 115 cm at the clay-rich layer, where $CaCO_3$ is also the largest (55%). Strata within this cutbank are mostly unlaminated massive sands. However, the basal unit exposed during excavation below ~160 cm is probably rippled sand (Sr).

Farther upstream near confined T7, a 120-cm tall cutbank also on the left bank exposes massive sands with lamination present to a depth of ~74 cm (Fig. 4.9), above a buried A-horizon soil from ~90 to ~104 cm. At a 94-cm depth, the buried Ah is a very dark greyish brown (10YR 3/2, moist) granular sandy loam with 4% organic matter and 7% $CaCO_3$. Whole sediments coarsen upwards slightly with a narrow range of D_{50} between 125 and 83 μm (very fine sand). Sand predominates and clay is minimal throughout. Organic matter is greatest in the buried soil layer, and $CaCO_3$ is more abundant between 11% and 13% in the sediments just above and to the surface. This contrasts significantly with the very lower almost absent $CaCO_3$ content in the upper profile at T3.

4.2 Buried and active channels

The GPR profile for the left side of unconfined T2 shows what may be a buried channel about 4 m in depth some 21 m away from the active channel (Fig. 4.10). This depth roughly corresponds with the echosounder results of the active channel thalweg depth sampled along the same transect (see Appendix B: Transect 2). Similarly at confined T6, a cross-channel GPR profile shows the active channel thalweg at approximately 27 m from the river-right bank with a depth of over 4 m (Fig. 4.11a). When compared to the cross-sectional profile (see Appendix B: Transect 6) of the modern active channel from the echosounder, thalweg depths are also similar (within the range of vertical positioning error). Likewise, radar results across the left bank of the floodplain at T6 show a backwater channel at a distance of some 70 m from the active channel with a depth about 5 m (Fig. 4.11b).

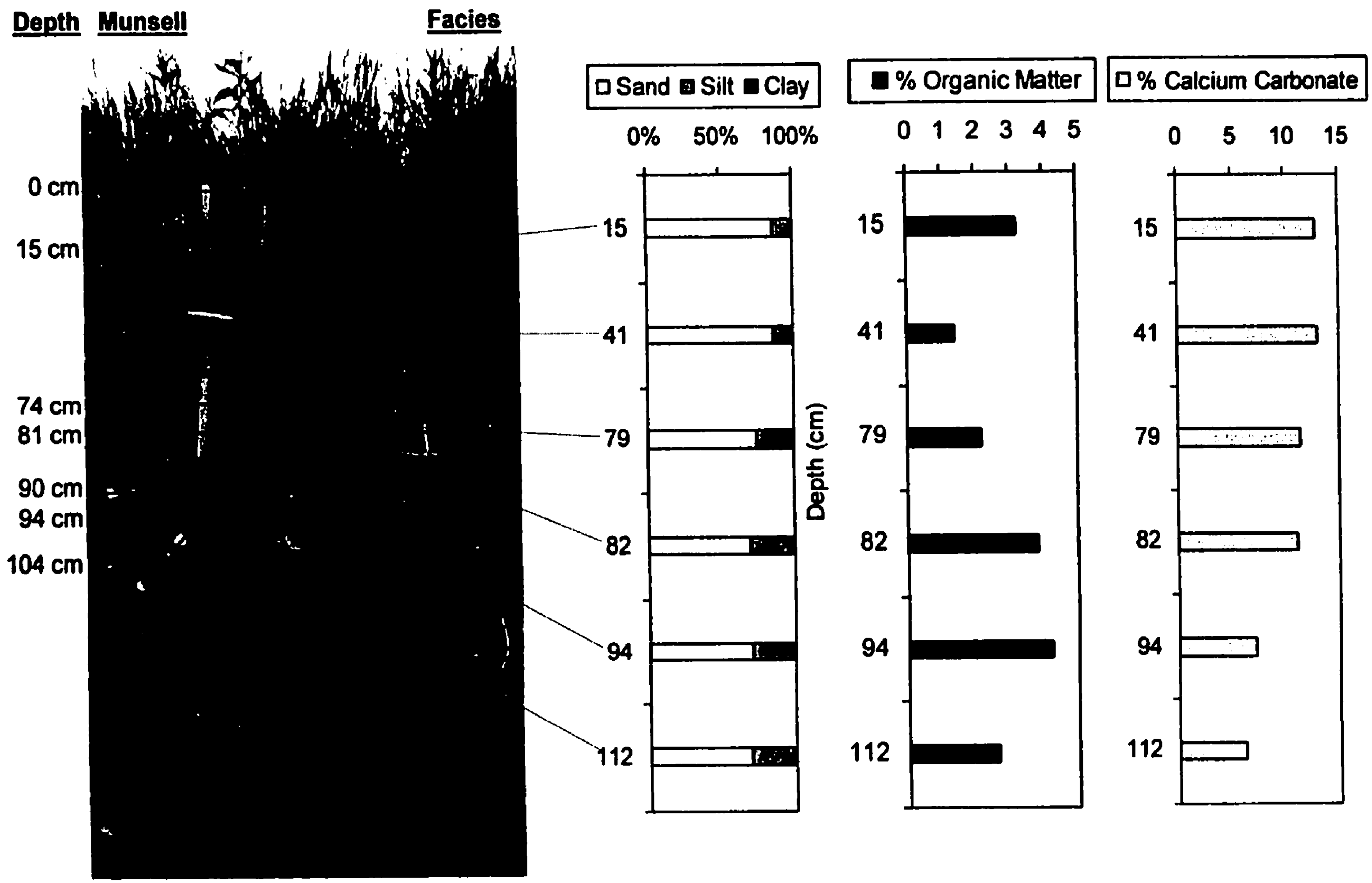


Fig. 4.9. Confined cutbank at T7 denoting moist Munsell colours, and facies stratigraphy (after Miall 1977), particle size, organic matter and carbonates content are plotted with increasing depth. There is a possible erosional contact between a depth of 90 and 94 cm (represented by the dashed line). Below it to a depth of 104 cm is a buried A-horizon soil. (Facies abbreviations as in Fig. 4.8.)

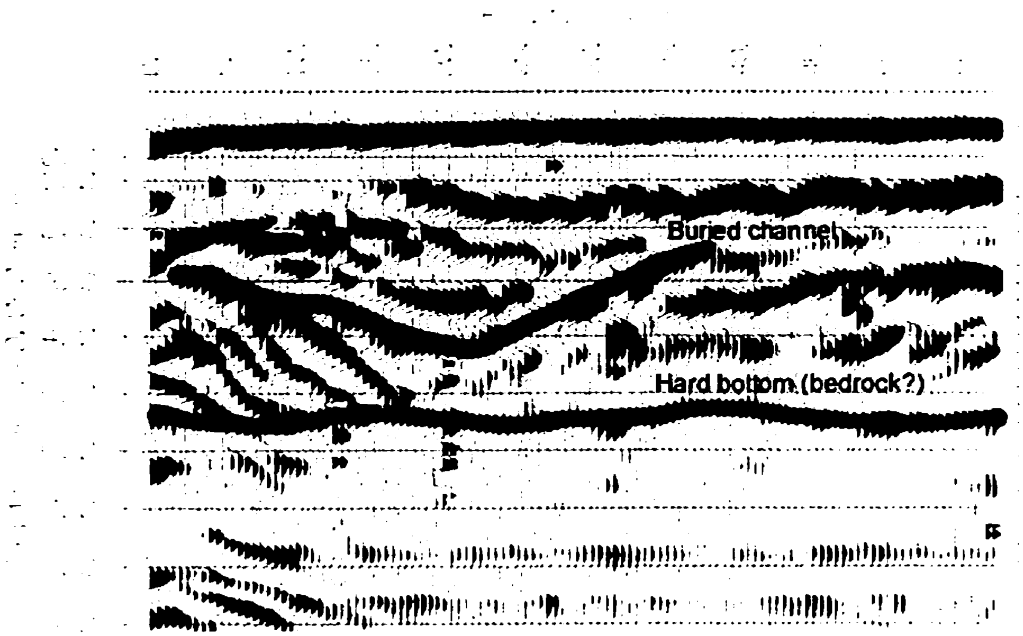
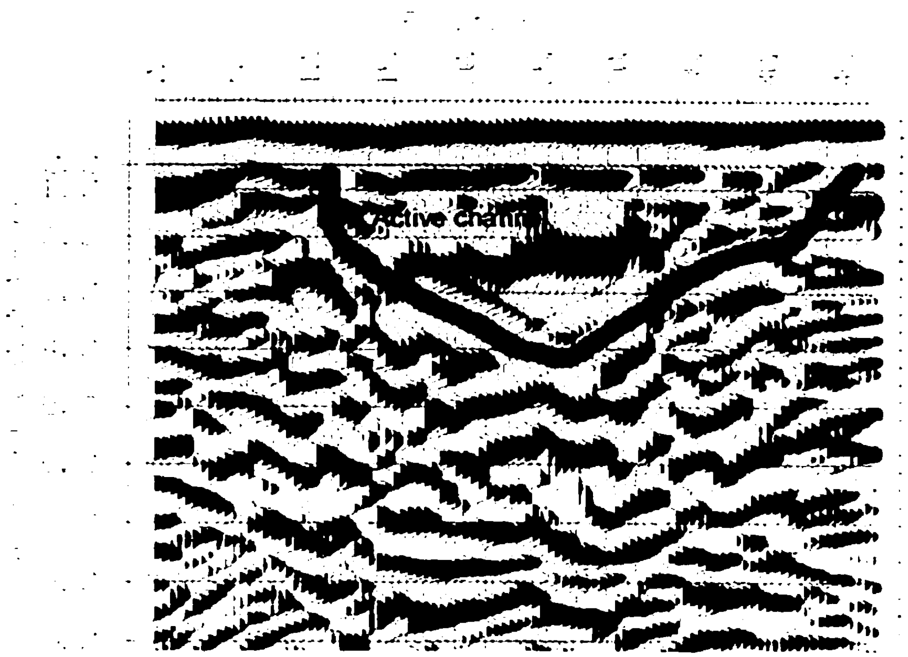


Fig. 4.10. GPR profile from the left bank away from the active channel at unconfined T2 using 50 MHz antennae. The inverted-cone shaped outline may be a buried channel with a thalweg depth over 4 m approximately 21 m from the active channel and about 1.5 m above a hard bottom layer of potentially bedrock.



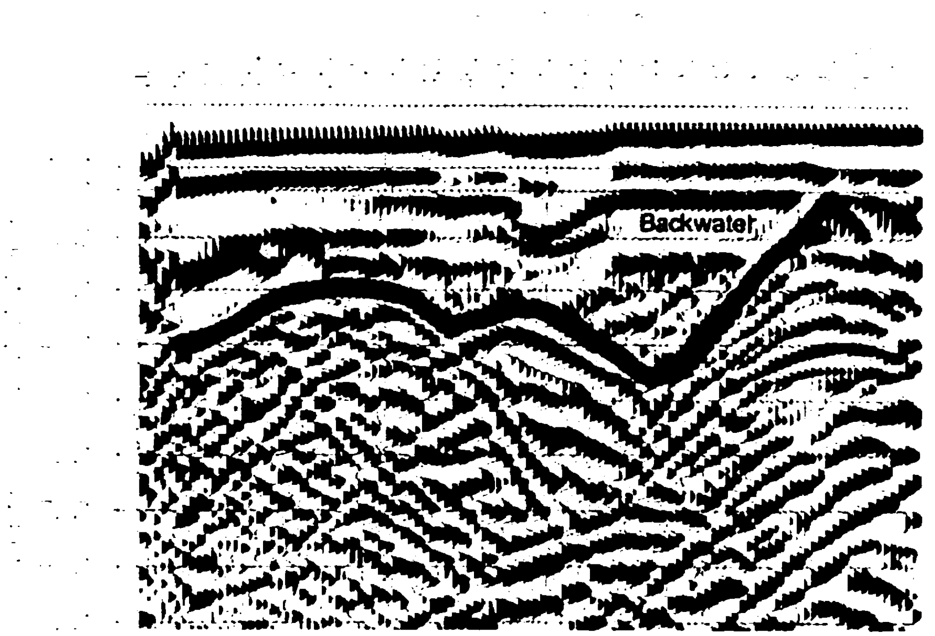


Fig. 4.11. GPR profiles at confined T6 of the active channel looking upstream (a, above) and away from it on the left bank of the floodplain (b, below), using 50 MHz antennae. Above is the inverted-cone shaped outline of the riverbed with an approximate thalweg depth over 4 m apparent at about 27 m away from the right riverbank. Below can be seen a backwater channel with a maximum depth of about 5 m some 70 m away from the left riverbank.

Widths of the active channel are greatest in the reaches at unconfined T1, T2, and confined T5 (~45 m) and smallest at confined T9 (~30 m) (Table 4.3). Estimates of the average width (from 1989 aerial photography) in unconfined sections is 40 ±5.4 m (ranging between 32 and 45 m) and 36 ±5.1 m in confined reaches (ranging between 30 and 45 m), compared to 38 ±5.4 m average channel width across all transects. Echosounder profiles show that the channel is shallowest in the study area at unconfined T3 (thalweg depth less than 4 m) and deepest at confined T10 (thalweg depth ~7 m). Average depth across all transects is 3.8 ±0.5 m, ranging from 2.9 to 4.3 m in unconfined sections and 3.8 to 4.5 m in confined reaches. Respective sectional means of average depth are 3.5 ±0.5 m and 4.1 ±0.3 m. The resultant width-to-depth ratio for all transects is 10.1 ±2.5 varying between 8.6 and 14.3 in unconfined sections versus 7.4 and 11.2 in confined sections, with respective sectional means of 11.8 ±2.5 versus 8.8 ±1.5. The mean cross-sectional areas are not significantly different at ~154 m^2 in unconfined reaches and ~158 m^2 in confined sections.

For the hydrometric gauge below Edenvale, bankfull flow (Q_b approximated by Q_2) is 92.4 $m^3 s^{-1}$ (based on a 7-yr record (1993–1999) of HYDAT data from the Nottawasaga Valley Conservation Authority and Environment Canada). Using this index Q_b and cross-sectional areas, it is possible to make estimations of flow velocity. In unconfined reaches velocity varies between 0.50 and 0.78 m s^{-1}, and between 0.48 and 0.69 m s^{-1} in confined reaches. Respective sectional averages are 0.62 and 0.60 m s^{-1}. The derivative specific stream power (ω), using respective measured average regional channel slopes of 0.00072 and 0.02615, averages approximately 16 ±2 W m^{-2} in unconfined sections and 665 ±89 W m^{-2} in confined sections. It ranges between 14 and 20 W m^{-2} in the former section and between 526 and 789 W m^{-2} in the latter.

Transect	w (m)	$\bar{d}$ (m)	w/d (m m^{-1})	A (m^2)	v (m s^{-1})	s (m m^{-1})	ω (W m^{-2})
T1	45	3.1	14.3	162	0.57	0.00072	14
T2	45	3.3	13.6	173	0.53	0.00072	14
T3	38	2.9	12.9	119	0.78	0.00072	17
T4	41	4.3	9.6	184	0.50	0.00072	16
T5	45	4.0	11.2	192	0.48	0.02615	526
T6	35	4.4	7.9	169	0.55	0.02615	676
T7	36	3.8	9.4	143	0.65	0.02615	658
T8	33	4.5	7.4	134	0.69	0.02615	717
T9	30	4.0	7.5	136	0.68	0.02615	789
T10	38	4.1	9.2	172	0.54	0.02615	623
T11	32	3.7	8.6	133	0.69	0.00072	20

Table 4.3. Summary table of channel morphometry results (with commutations of estimated velocity, using Q_2=92.4 m^3 s^{-1} throughout). Shaded cells represent confined sections. (Abbreviations: w=width; $\bar{d}$=average depth; w/d=width-to-depth ratio; A=cross-sectional area; v=velocity (based on Q_2/A); s=average regional channel slope; ω=specific stream power.)

4.3 Interpretations

Light-dark banding in the Sh layer in the cutbank near confined T7 suggests seasonal flooding during the timespan above ~74 cm. Generally, the decreasing silt content and marginally increasing sand content in this uppermost recent deposit, may be indicative of more energetic floods or processes linked to natural levee development in the confined section. Horizontally laminated layers are also evident elsewhere in confined sections, as near the left bank at T6 where there is a levee with a maximum height of ~1 m and on the right bank at T9 where there is levee and backwater sedimentation. Laminated fine sand layers, diagnostic of episodic overbank deposition on levees, appear more frequently in confined-section auger samples. The absence of thicker sandy units with strong cross-bedding, coupled with a high frequency of thinner and finer laminations, indicate deposition from overbank flows is a dominant process. Coarse sediment tends to settle along channel margins in levees and finer sediments are diffused outwards to distal floodplain sites (cf. Pizzuto 1987).

Unconfined $\bar{D}_{50}$ at each transect is more variable than in confined sections where points seem to cluster more readily around very fine sand. This is quantitatively supported by the t-test on D_{50} showing a noteworthy inflation in variance of over three times in magnitude for unconfined $\bar{D}_{50}$ relative to the confined reach (see Table 4.1a). There is a notable greater range in unconfined samples evident especially for $\bar{D}_{50}$ (extreme range difference of 64 μm in unconfined versus confined sections) and also for the sand fraction (5% difference between sectional extreme ranges). The statistically significant higher $CaCO_3$ in unconfined sections (34% versus 20% for confined), may be indicative of the more significant storage of upstream derived carbonate-rich sediments in these downstream locations. Exact interpretations are difficult to make, though this coincides with findings by Lecce (1997) for the Blue River, Wisconsin where there is greater storage of alluvium from adjacent upstream sources in a vertically accreted floodplain associated with increased (valley) width and reduced stream power. Auger samples proximal to the active channel in unconfined sections are less sandy than expected and their distal counterparts are sandier than expected. The additional possibility of an Sr layer in the unconfined cutbank at T3, all in a generally fining-upwards sequence, conveys the notion of more lateral accretion in this reach compared to confined sections. The GPR profile at T2 in an unconfined reach further suggests previous lateral migration of the channel, though it is difficult to determine if this is due to slow progressive channel migration or avulsion.

In confined sections, a ω of 300–1000 W m^{-2} is in the high-energy class of rivers as outlined by Nanson and Croke (1992) for non-cohesive floodplains with confined vertical accretion. Though these typify a disequilibrium floodplain in the classification, it is difficult to positively distinguish whether confined sections are responding to recent environmental change (i.e., greater flood magnitude in response to climatic change, cf. Knox 1993) and generally tending towards dynamic equilibrium (cf. Renwick 1992). However, the appearance of an erosional surface on the buried soil in the cutbank near T7 (see Fig. 4.9), suggests that some sediment stripping has occurred in confined sections.

4.4 Archaeological evidence

4.4.1 Designated sites

According to O'Brien (1974), known floodplain sites include BcGx-4, -5, -6, -8, -10, -11, and -13 (Table 4.4). Approximate elevations for designated archaeological sites in unconfined sections range between 181 and 183 m ASL, versus 185 and 206 m ASL for those in confined sections (the river in the study area is around 180 m ASL). Sites in unconfined sections are mostly floodplain sites (57%), with Woodland cultural age estimates in five out of seven (71%) of cases. Three sites in confined sections are

Archaeological Site (Borden Number)	Geomorphic Location	Elevation (m ASL)	Condition
BcHa-38	?	182	Destroyed
BcHa-36	?	?	Destroyed
BcGx-6	Floodplain (left side)	183	Intact, some erosion
BcGx-7	?	183	Destroyed (in garden)
BcGx-5	Floodplain (right bank)	181	Partially gardened
BcGx-4	Floodplain (left bank)	181	Eroding into river, very little left
BcGx-8	Floodplain (left bank)	183	Fair (ploughed)
BcGx-9	? (left side)	185	Disturbed (ploughing, blowouts, trails)
BcGx14	? (left side)	189	Poor/Fair (some undisturbed areas)
BcGx-10	Floodplain (left bank)	206	Ploughed
BcGx13	Floodplain (left bank)	198	Ploughed
BcGx-12	? (left bank)	191	Ploughed
BcGx-11	Floodplain (right bank)	198	Ploughed

Table 4.4. Designated archaeological sites in unconfined versus confined (shaded) sections of the study area with geomorphic location, elevation, and condition (compiled from O'Brien 1974).

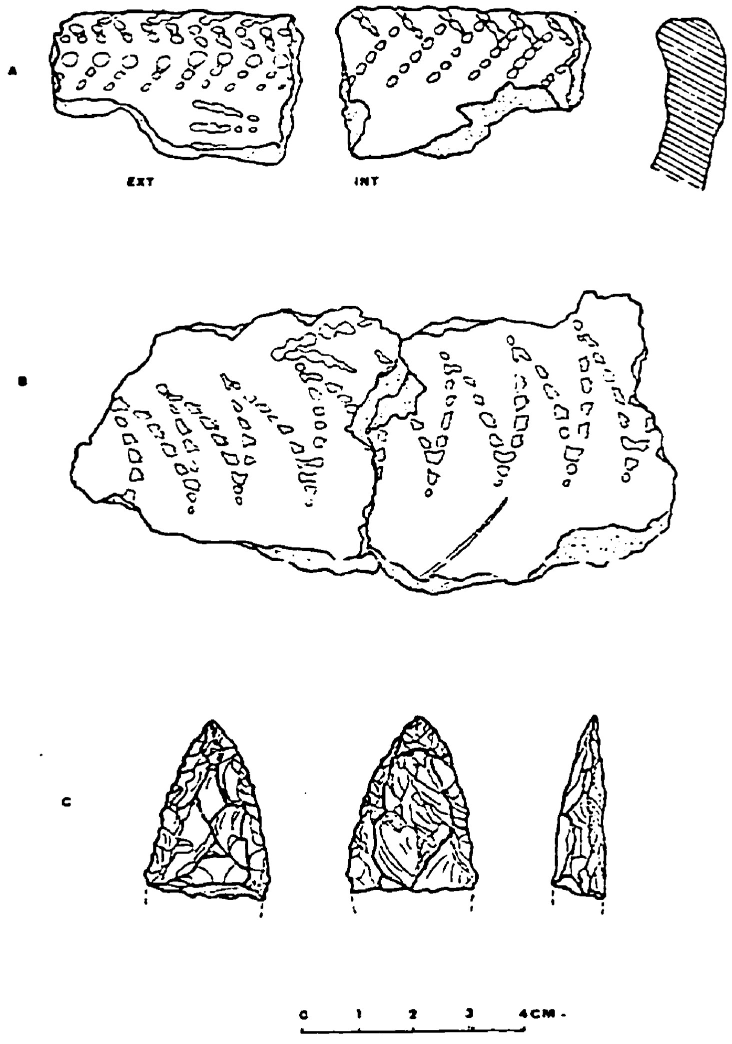
floodplain sites. All six confined sites are Archaic, most certainly for two cases (33%). Overall, Archaic sites (with the possible exception of BcGx-7) in the study area are located in confined sections, and (Middle) Woodland sites (with two exclusions) are found in unconfined sections. Small sample size prevented any statistical spatial analysis of sites.

4.4.2 Interpretations

All of the archaeological sites in the study area have been naturally exposed by river erosion such that Archaic sites, which O'Brien (1975) dates between 7 ka and 3 ka BP, appear in confined reaches as surface deposits. Downstream in unconfined sections Woodland sites, including Middle Woodland sites (3 ka to 1.2 ka BP) which she discerns as the majority of all known sites along the lower Nottawasaga River and possibly Late Woodland sites (1.2 ka to 0.3 ka BP), predominantly appear on the floodplain surface. The preservation of only older sites in confined reaches might suggest that:

1) this was not a suitable environment for Woodland cultures;
2) Woodland sites have been preferentially eroded; or
3) not all sites have been discovered.

It is difficult to understand why Woodland cultures would avoid the alluvial areas through the Edenvale Moraine especially since tall sandy levees would have provided elevated and well-drained sites for horticulture, with evidence of stability and pedogenesis (i.e., buried Ah near T7). Although archaeological sites may have been disturbed by fluvial erosion and might be missing small and light artifacts such as beads, bone fragments (i.e., some fishbones), and stone-knapping microdebitage, most artifacts in the high overbank environment would not have been easily transported by the Nottawasaga River. Moreover, artifacts that O'Brien (1975) reports at these sites (i.e., Fig. 4.12), are too large for river entrainment and hence water transport. At the



BcGx - 4

A. - Rim - Dentate stamp
B. - Body sherd - Dentate rocker stamp
C. - Chert projectile point

Fig. 4.12. Artifacts from the Middle Woodland period (Saugeen) in an unconfined section at BcGw-4, including dentate-stamp rim (a) and dentate rocker stamp body (b) potsherds mostly from a coiled vessel found in the riverbank approximately 3 m from the active channel, and a chert projectile point (c) from O'Brien (1975, p. 89).

unconfined Bridge site (BcGw-4), she reports a mostly intact vessel found in the right riverbank (Fig. 4.12b), implying that Woodland artifacts are in situ and are likely not to have been washed downstream from confined sections. Though transport disturbance may vary with increased stream competence (i.e., with increasing flood-flow magnitude, Olsen et al. 1997), ω in unconfined sections is at the lower end of 10 and 60 W m^{-2} typifying medium-energy non-cohesive floodplains (after Nanson and Croke 1992). However rare peak floods approximating Q_p can do much entrainment transport. The problem of negative evidence remains, and the spatial patterning of archaeological sites in the study area may well be explained by sediment accumulation in a predominantly vertically accreted floodplain.

O'Brien (1974, personal communication 2000) suggests that the distribution of the campsites can be tied to post-glacial lake levels. She posits that Archaic sites are clustered on the Edenvale Moraine as it was a prominent feature in the post-glacial landscape with the draining of glacial lakes (Fig. 4.13a). Following the low-water Lake Hough phase in the Huron basin (S-H in Fig. 4.14), the water level at 7000 to 4000 yr ago was high enough into the Nipissing Great Lakes (N in Fig. 4.14) for prehistoric peoples to camp on the island which was the Edenvale Moraine. As water levels continued to drop into the Modern phase in the Lake Huron basin (Mo in Fig. 4.14), Middle Woodland peoples in the study area at about 1800 yr ago camped or settled in areas nearby the post-Nipissing lagoon which is now Jack's Lake (Fig. 4.13b).

It would be convenient for prehistoric campers to be in close proximity to aquatic life in rivers given that they can have three times the fish production of lakes (Randall et al. 1995). The Nottawasaga River contains salmon and rainbow trout in the fall, a warm-water fishery of bass, pike, pickerel, and sturgeon in the spring, as well as minnows, carp, suckers, catfish, perch, and rock bass (C. Jones, personal communication 2000). O'Brien (1975) reports that late Iroquoian people (Huron, Petun, or both) used the lower

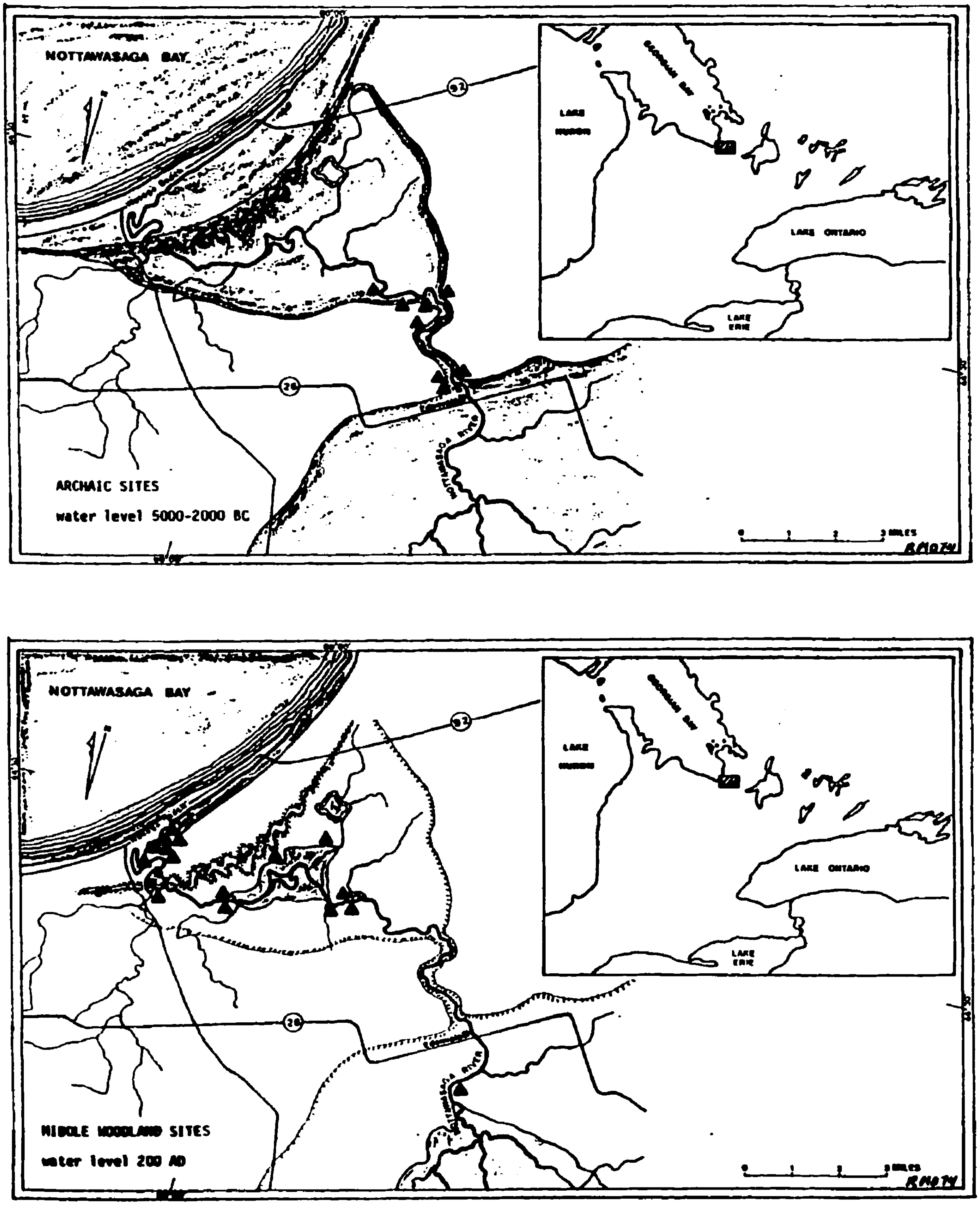


Fig. 4.13. Water level reconstruction from O'Brien (1974, personal communication 2000), showing the location of Archaic (a, above) and Middle Woodland (b, below) sites in the vicinity of the study area.

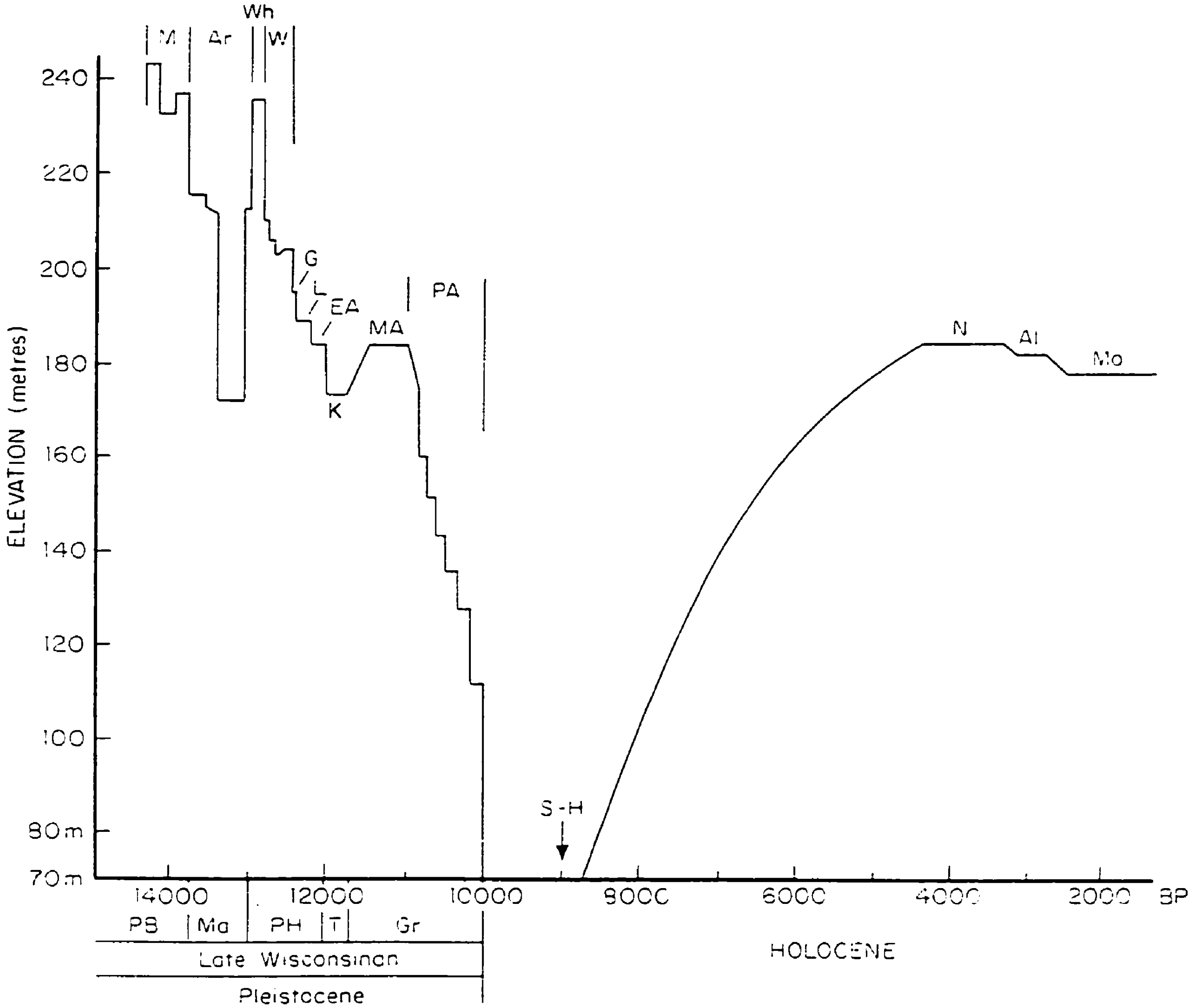


Figure 3. Lake phases in Lake Huron basin. Letter symbols: M – Maumee, Ar – Arkona, Wh – Whittlesey, W – Warren and Wayne, G – Grassmere, L – Lundy, EA – Early Algonquin, K – Kirkfield, MA – Main Algonquin, PA – Post-Algonquin, S-H – Stanley and Hough, N – Nipissing Great Lakes, Al – Algoma, Mo – Modern. Other letter symbols: Gr – Greatlakean Stade, Ma – Mackinaw Interstade, PB – Port Bruce Stade, PH – Port Huron Stade, T – Twocreekan Interstade.

Fig. 4.14. Phases of deglacial meltwater drainage in the Lake Huron basin (from Eschman and Karrow 1985, p. 81).

Nottawasaga River as fishing grounds. The Nottawasaga River also contains beavers and is home to snapping turtles as well as herons. It is on the flight path of migratory waterfowl, and mallards and geese can be seen year-round (C. Jones, part of personal communication 2000). As a forested river corridor, it houses plenty of deer, and the Minesing Swamp is one of the largest existing deer wintering yards.

Most Huronian villages in the Sturgeon, Coldwater, and North Rivers are situated on higher ground (M.A. Latta, personal communication 2000). Late Woodland horticulturalists would have preferred well-drained terrace soils for fields. Though gley appears less frequently in unconfined sections, it indicates anaerobic waterlogged conditions for at least a major part of the growing season (Brady and Weil 1999). Iron reduction associated with prolonged flooding (Wright 1999) is apparent in the study area, though more frequently in unconfined sections. It is very likely that prehistoric villagers purposely avoided the Nottawasaga River floodplain in their search for well-drained and stable surfaces.

4.4.3 Conceptual model

It is both relevant and necessary to understand nature-culture interactions in a landscape as dynamic as a floodplain environment. A conceptual model of exposure and preservation of natural and cultural particles and deposits in the modern floodplain is provided in Fig. 4.15. The generalized model of the evidence shows three distinct possible environmental sequences in decreasing order of stability (from vertical accretion to lateral accretion to vertical stripping). Vertically accreted floodplains have the least exposure, though preservation is greatest here. Laterally accreted floodplains have good selective exposure, but may have sites destroyed by lateral channel migration. Exposure is generally greatest, and in situ preservation poorest, where floodplains are stripped.

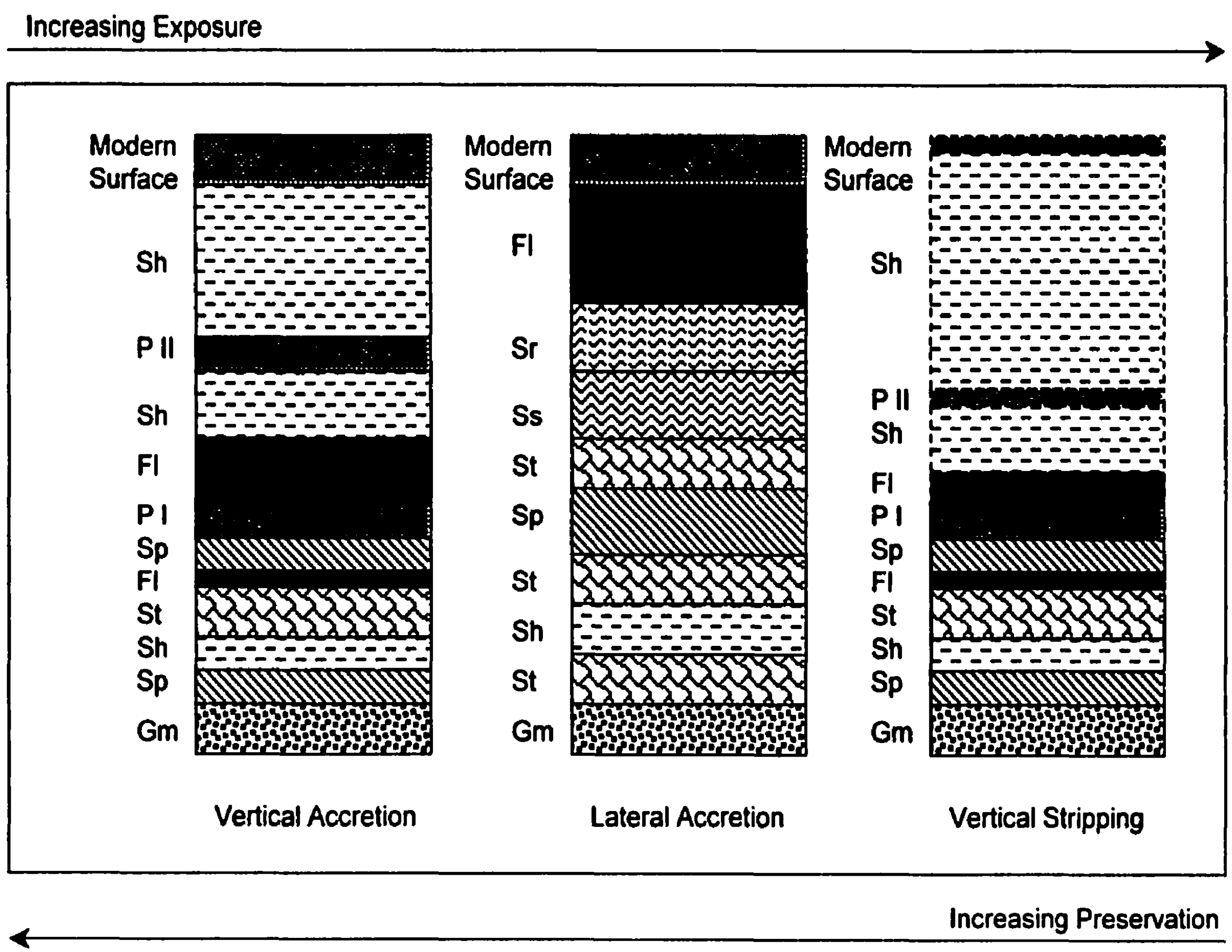


Fig. 4.15. Conceptual model of exposure and preservation of natural and cultural particles and deposits on the modern floodplain (exposure-preservation model). Based on floodplain accretion style (vertical, lateral, or vertical stripping) for which are shown probable facies sequences (after Miall 1977).

Applied to the study area at the Nottawasaga River, the exposure-preservation model suggests overall decreased exposure particularly in confined sections where alluvium is vertically accreted. The buried Ah in the confined cutbank near T7 best exemplifies the general preservation of vertically accreted deposits, though it contains evidence of a likely unconformity. In unconfined reaches, there is more evidence for lateral accretion and therefore increased selective exposure possibly of Woodland sites. Here there would be reduced point preservation as archaeological assemblages are laterally eroded. O'Brien (1975) inadvertently recognizes this in her field survey for the Bridge site (BcGx-4) in an unconfined reach (Fig. 4.16), where a Middle Woodland pot can be seen eroding from a bank located some 3 m above the channel (see Fig. 4.12b). She infers that by altering its course here as much as 30 m, the Nottawasaga River has washed away most of the site. Available information on sites condition suggests some natural destruction in unconfined sections due to sideways channel erosion (see Table 4.4). There may be increased point exposure of older sites at the Edenvale Moraine with the downstream stripping or translocation of particles sand-sized and smaller. The downward destruction of primary context in vertically eroded confined reaches suggests poor preservation of younger deposits as Woodland sites closer to the surface.

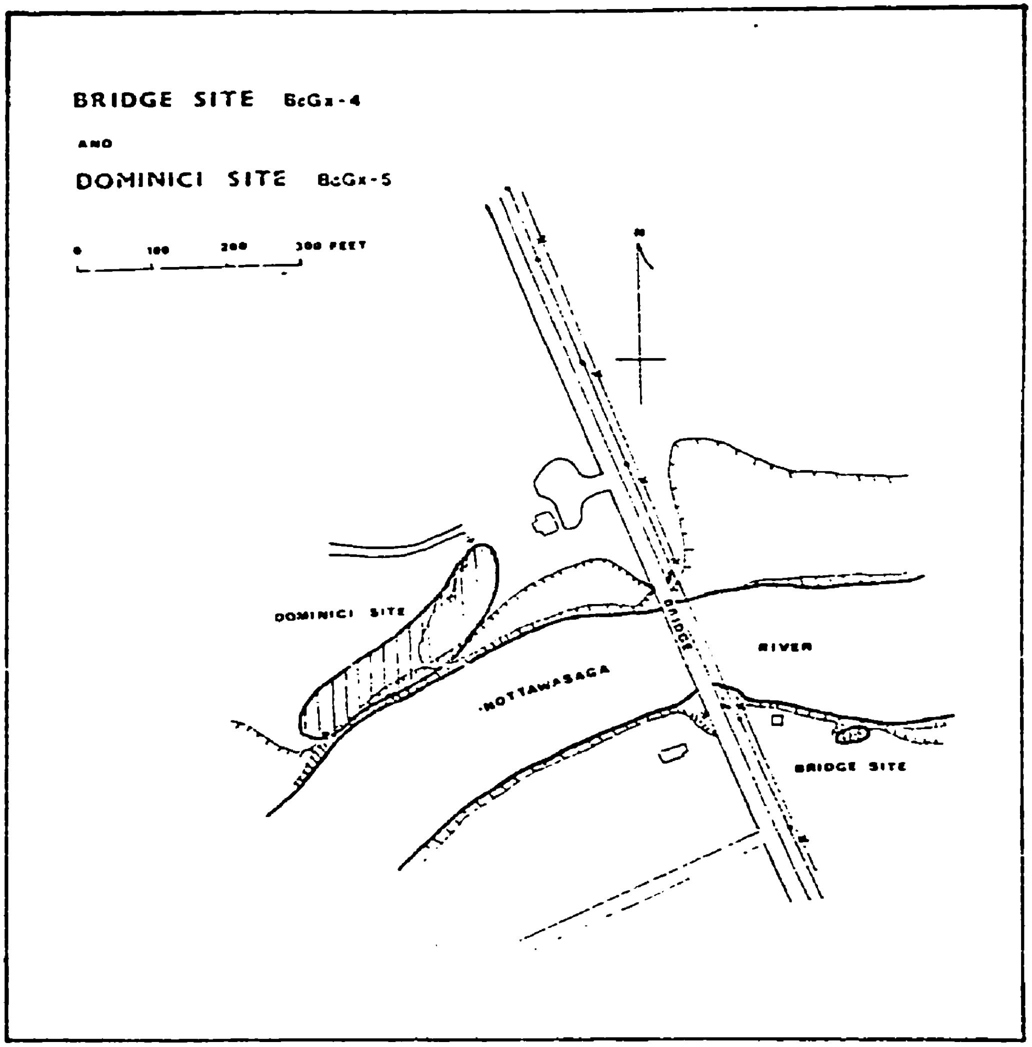


Fig. 4.16. The Bridge site (BcGx-4) in an unconfined section of the study area (from O'Brien 1975, p. 88).

CHAPTER 5: THE DORAN LAKE REACH

5.1 Overview

A detailed examination of the only neck cutoff in the study area was necessary to determine how and when in the Holocene the Nottawasaga River became entrenched in the Edenvale Moraine. The sedimentological record in Doran Lake can potentially provide a substantial record of the post-glacial flood histories and sediment yield record from the contributing watershed. Its formation may be associated with a shortening of the main channel from changes in streamflow possibly controlled by the water level in the Lake Huron basin. Sedimentation on the left side of the floodplain in this confined reach has topographically elevated this oxbow making it up to 0.50 m higher than the current water level in the study area around 180 m ASL (Fig. 5.1), making this a most promising natural record of Holocene environmental change.

Doran Lake is a recently regulated simple and possibly closed oxbow (after Weihaupt 1977). There is a two-way flow control structure on the Doran Lake side of the Nottawasaga River set up in 1982 to maintain water levels in the oxbow (D. West, personal communication 2000). In the past, beaver dams may have performed the same function. The area is now an established ducks wetland (commonly referred to as the duck pond), and a former fish-stock reservoir that presently contains carp. Apart from the mostly deciduous riparian vegetation in the study area, including silver maple, hemlock, elm, ironwood, and manitoba maple, this reach contains red-silver maple hybrids (A.M. Davis, personal field communication 2000), black ash, willow, and cedar.

The oxbow lake is quite extensive covering an estimated area of 0.25 km^2, and at it farthest point is some 0.51 km from the active channel. Coring and surveys here were mainly for the purpose of acquiring sedimentological and paleoecological evidence for Holocene infilling. Fig. 5.1 shows the locations of the near-channel topographic and

Fig. 5.1. 1989 aerial photograph (acquired from Airborne Sensing Corp.) of Doran Lake overlain by Ontario Base Map (based on 1983 air photography, printed in 2000 by the Ministry of Natural Resources). Shows the location of the auger survey line (T5 to T5', transect not to scale), the three points (C1, C2, and C3) from where were extracted Livingstone cores, and the GPR profile line (R to R'). Scale 1:7500 aligned with aerial photograph, elevation contours in m ASL.

auger survey (T5 to T5') also included in the river-scale results, three points of Livings7tone cores extraction (C1, C2, and C3), and radar survey (R to R'). The respective (compressed) lengths for the Livingstone cores are 250, 490, and 480 cm, with refusal due to hard clay layers at C1 and C3, and sand at C2. The longest floodplain GPR profile was acquired over snow at Doran Lake on river-left up to an approximate distance of 508 m away from the active channel (Fig. 5.2). The Livingstone cores are situated slightly upstream of the GPR profile, approximately 135 m (C1), 245 m (C2), and 405 m (C3) along it.

5.2 Results

Auger samples near the active channel on the modern floodplain show greater proportions of sand, organic matter, and $CaCO_3$ on the Doran Lake side (Fig. 5.3). $\bar{D}_{50}$ ranges from 69 μm (very fine sand) to 27 μm (medium silt) on the floodplain nearby Doran Lake, with an average of 50 ±14 μm (coarse silt). On the side opposite the oxbow $\bar{D}_{50}$ ranges between 47 μm (coarse silt) and 3 μm (coarse clay), with an average of 28 ±20 μm (medium silt). The average proportion of sand on the floodplain near Doran Lake is 44%, silt content is 36%, and clay content is 20%. On the opposite side of the floodplain sand content is 30%, with 39% silt and 31% clay content. Organic matter ranges from 3% to 8% on the Doran Lake side, and from 1% to 3% on the right-bank floodplain. $CaCO_3$ content ranges between 18% and 24% on the left bank, and from 10% to 32% on the opposite bank. Generally in both auger holes, organic matter decreases with increasing depth and $CaCO_3$ increases with increasing depth.

Across all Doran Lake cores (see Fig. 5.3), sand content decreases away from the active channel. The mean proportion of sand is 41% in C1, 34% in C2, and 22% in C3. Average silt content is 36% in C1, 29% in C2, and 38% in C3. Mean clay content

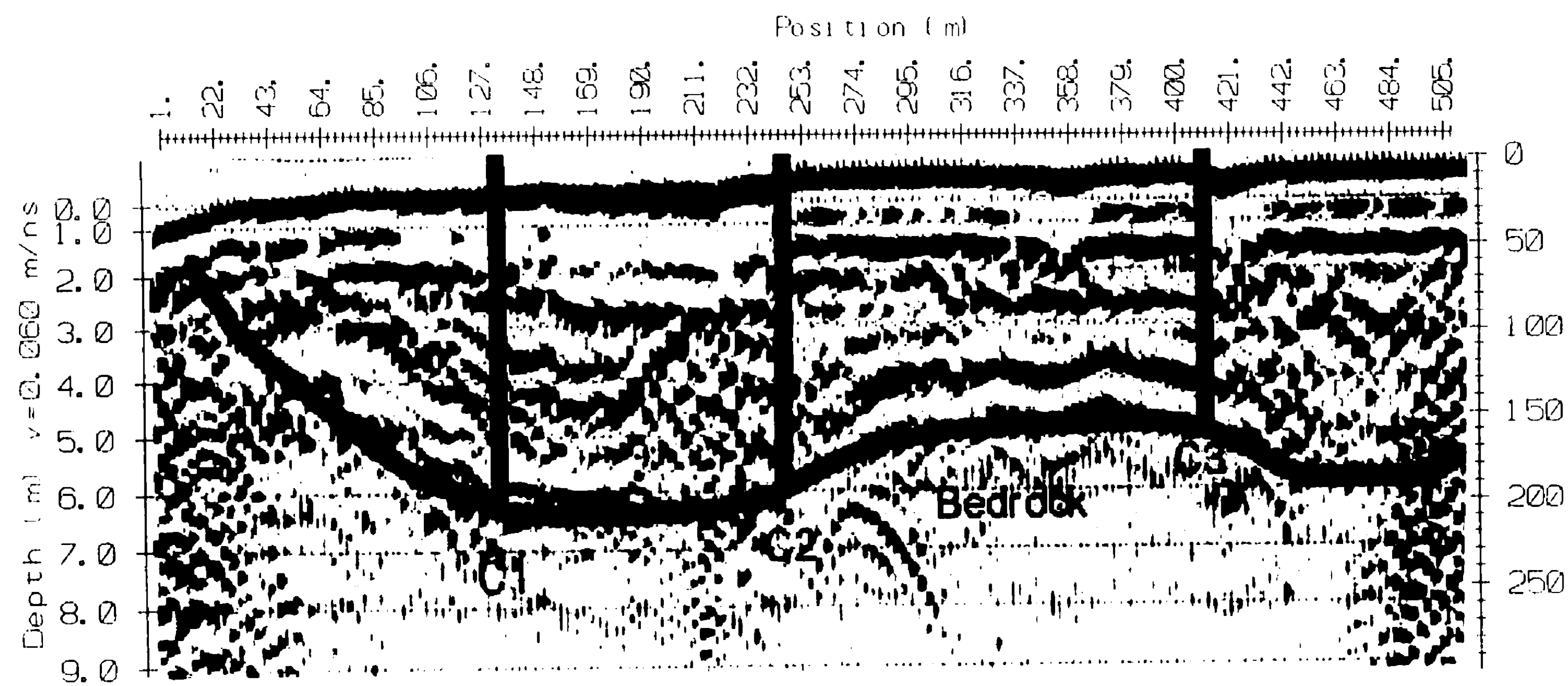


Fig. 5.2. GPR profile of Doran Lake on the left bank at confined T5 showing bedrock interpretation and location of the three Livingstone cores, C1 (~135 m), C2 (~245 m), and C3 (~405 m), extracted from the oxbow (vertically not to scale).

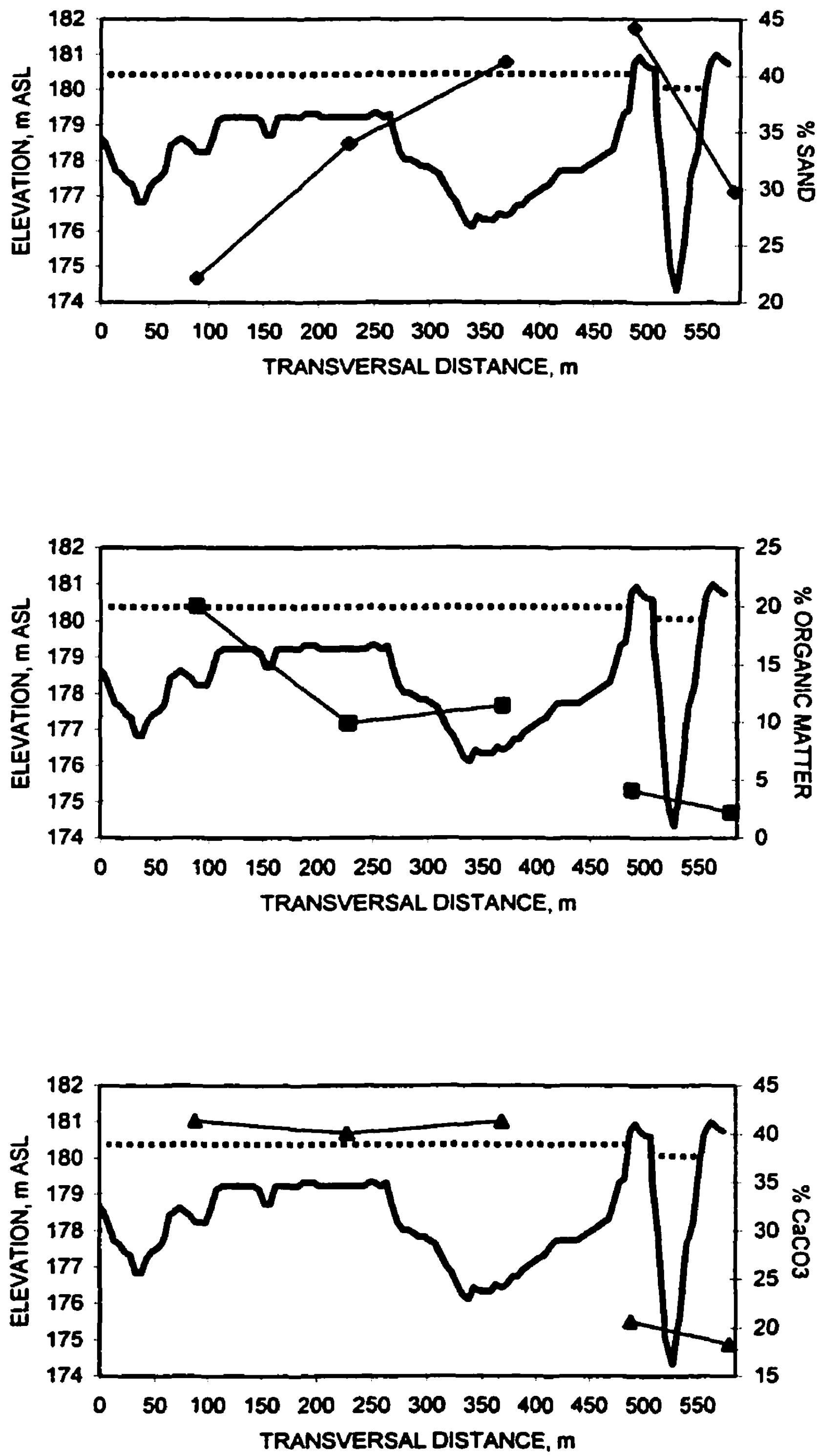


Fig. 5.3. Cross-sectional profiles, at confined T5 and Doran Lake on the left bank, of topography (solid thick line, looking downstream) and sand (a, above) organic matter (b, centre), and carbonate content (c, below) in auger samples at each coring location and Livingstone cores.

increases away from the active channel in Doran Lake from 22% in C1, to 37% in C2, and 40% in C3. Organic matter and carbonate content are greatest towards the edges of the oxbow and lowest in the middle. Mean organic matter content ranges from 12% in C1, to 10% in C2, and 20% in C3. Carbonate content is 41% in both C1 and C3, and 40% in C2.

Throughout C1, sediment colouration varies between very dark greyish brown (10YR 3/2, moist) at the surface, to dark brown (10YR 3/3, moist) and very dark grey (10YR 3/1, moist) downwards in the core (Fig. 5.4). All colour-based contacts in C1 are even and abrupt. From 60 to 114 cm there is a calcareous sandy laminated layer set in massive gyttja. The proportion of total sand in core samples generally decreases with increasing depth from 57% at 38 cm to 14% at 238 cm. Silt content increases down the core from 21% at 3 cm to 54% at 238 cm, and clay is variable within the core. Organic matter is greatest towards the top of the core and generally decreasing downwards, ranging between 17% at 18 cm and 8% at 218 cm. $CaCO_3$ content also generally decreases downwards, ranging between 27% at 3 cm and a high of 66% at 58 cm. Between 34 and 131 cm in C1 there is an abundance of shells, and one bivalve sample of the genus *Pisidium* from the family Sphaeriidae was extracted (Table 5.1).

C2 contains gyttja, and a thick marl layer between 163 and 400 cm with varying grey (10YR 5/1, moist) colouration (Fig. 5.5), and sediment that is very dark brown (10YR 2/2, moist), very dark greyish brown (10YR 3/2, moist), dark grey (10YR 4/1, moist), and very dark grey (10YR 3/1, moist). The proportion of sand in the core tends to decrease downwards except at 458 cm (90% sand) and 488 cm (82% sand) where it predominates. Silt roughly increases down in the core and is greatest at 478 cm (61%). Clay content increases with increasing depth and is greatest at 318 cm (69%). Boundaries are frequently gradual and there is an irregular contact at ~154 cm. Sediment structure between 200 and 371 cm is angular blocky, followed by granular

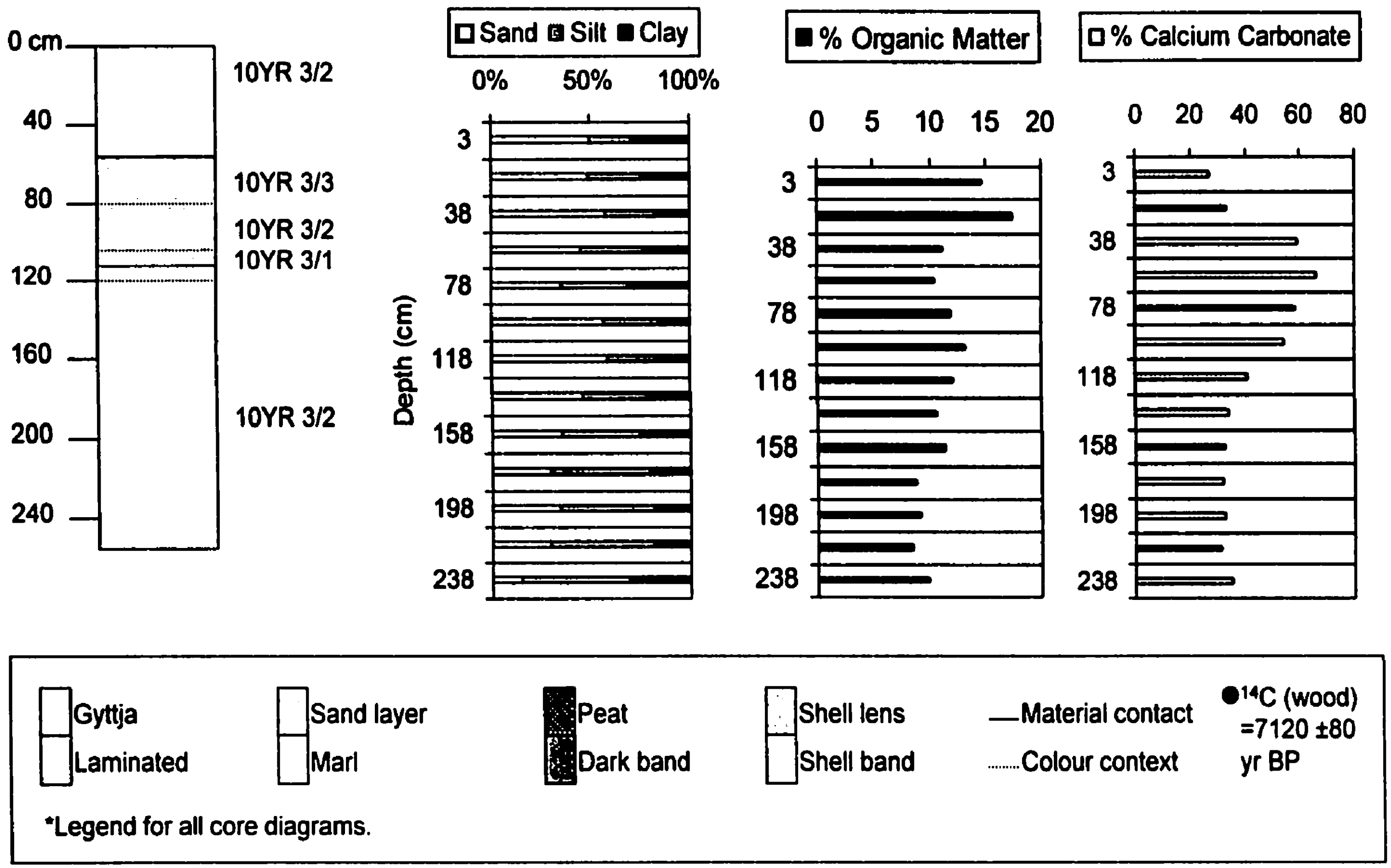


Fig 5.4. Stratigraphy, moist Munsell colours, particle size, organic and carbonate content for C1 at Doran Lake.

Core Sample (Depth in cm)	Physidae	Planorbidae	Sphaeriidae			Unionidae
		Gyraulus	*Musculium*	*Pisidium*	*Sphaerium*	
C1 (131)				1		
C2 (74)				5		
C2 (79)				1		
C2 (300)				1+		
C2 (373)						1?
C2 (413)						1?
C3 (120)				1	1	
C3 (140)					2	
C3 (210)	1				3	
C3 (320)		1, 2 *deflectus*			1	
C3 (373)					1	
C3 (458)			1			

Table 5.1. Frequency counts of shells, including gastropod and bivalve (shaded) families and genera (N≅24), extracted from various depths in Livingstone core samples from Doran Lake.

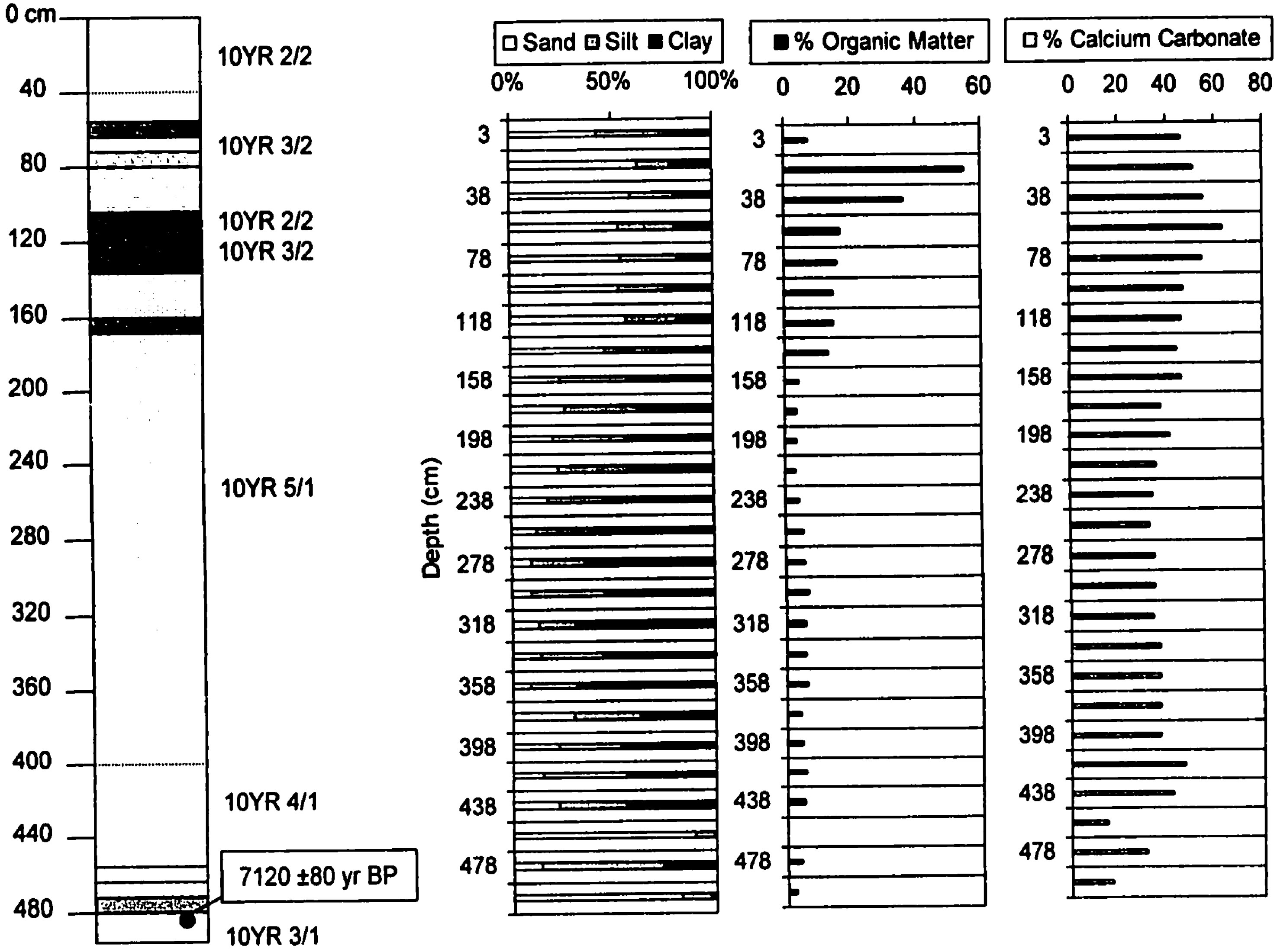


Fig. 5.5. Stratigraphy, moist Munsell colours, particle size, organic and carbonate content for C2 at Doran Lake. (See Fig. 5.4 for legend.)

sediment containing shells. Cattail peat appears between 100 and 142 cm, and sediment topping this sandy layer is laminated and contains shells. At 457 to 463 cm there is a sand band, and between 478 and 486 cm there appears a dark woody peat band. Wood deposits, possibly of twigs (tree parts or bark), are notable at 375, 470, 475, and 486 cm. All large organics were extracted and the wood immediately below the dark band in the laminated refusal sand layer at a depth of 486 cm, was AMS radiocarbon dated to 7120 ±80 yr BP (TO-8835). Organic matter content is significantly greater towards the top of the core, reaching a maximum of 55% at 18 cm and declining to 7% below 138 cm. $CaCO_3$ content is generally high but declines downwards in the core, being lowest in the sandy bands (15%) and highest at 58 cm (63%). There is a well-developed shell lens between 73 and 74 cm. Shell samples from C2 total five bivalves, including five of the genus *Pisidium* at 74 cm, one at 79 cm, more than one at 300 cm, and possibly two of the superfamily Unionacea at 373 and 413 cm (see Table 5.1).

C3 colouration consists of very dark brown (10YR 2/2, moist), very dark greyish brown (10YR 3/2, moist), and dark grey (5YR 4/1, moist) sediment (Fig. 5.6). Sediment structure is angular blocky between 110 and 150 cm, between 197 and 247 cm, and again from 255 cm to refusal. As in C1, the contacts in C3 are even and abrupt. The sand content of the core sharply decreases downwards, with a corresponding change in silt and clay which increase with increasing depth. Silt notably predominates at 158 cm (73%), and clay at 458 cm (84%) and 478 cm (79%). Organic matter is also high in this core ranging between 10% and 48%, tending to decrease downwards. $CaCO_3$ is variable throughout the core, peaking at 58 cm (67%). The core has a shell-rich layer between 64 and 71 cm and another between 174 and 196 cm. Shells include eight bivalves of the genus *Sphaerium* between 120 and 373 cm, one bivalve of *Pisidium* at

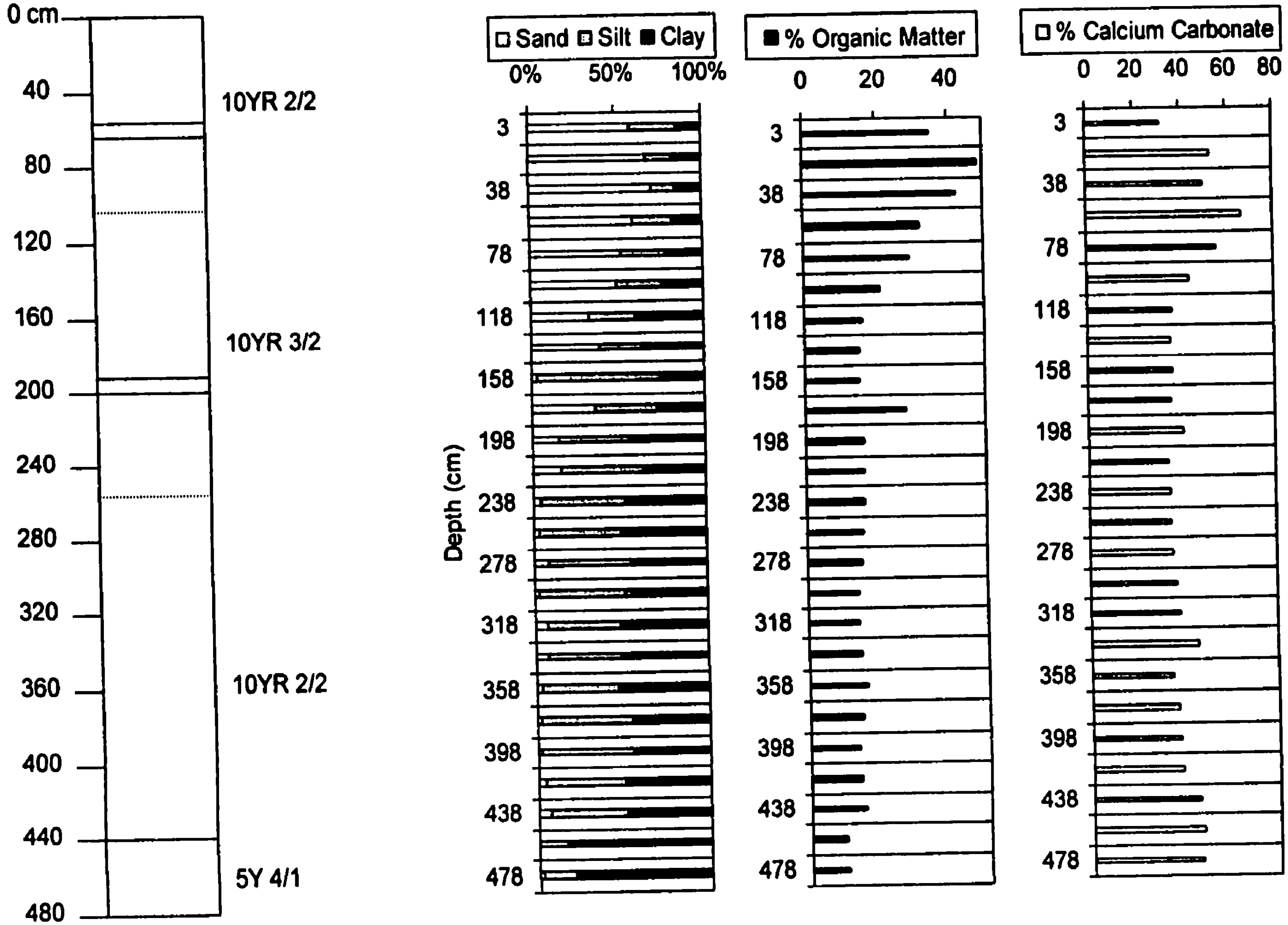


Fig. 5.6. Stratigraphy, moist Munsell colours, particle size, organic and carbonate content for C3 at Doran Lake. (See Fig. 5.4 for legend.)

120 cm, one gastropod of *Physidae* at 210 cm, gastropods one of *Gyraulus* and two of *Gyraulus deflectus* at 320 cm, and one bivalve of *Musculium* at 458 cm (see Table 5.1).

Pollen analysis was conducted on just a few samples towards the bottom, middle, and top of C2. Pollen concentrations in the basal 485-cm sample were insufficient for analysis (probably connected to minerogenic coarse-sized particles of the sand layer, cf. Dinnin and Brayshay 1999). At 280 cm the pollen is predominantly (white) pine, hemlock is secondarily most prevalent, followed by oak, beech, and maple (A.M. Davis, personal communication 2001). Preservation is generally good with modest concentrations of tree pollen (33 070 grains ml^{-1}). At 85-cm depth in C2, there is less pine, more beech, ash, and elm. Hemlock remains prominent and birch is well represented with a larger local input. Also at this depth there are more sedges and grass pollen than in the earlier sample. Similar tree pollen concentrations are found here (30 000 grains ml^{-1}).

5.3 Interpretations

The dated wood sample at 486 cm in C2 indicates an estimated net sediment accumulation rate of approximately 0.68 mm yr^{-1}. Assuming an accumulation rate similar to this during the preceding interval, the maximum sediment depth of around 6.5 m in the vicinity of C1 (see Fig. 5.2), suggests the formation of this neck cutoff by 9500 yr ago. This temporally places the formation of this oxbow sometime around the Lake Hough phase in Georgian Bay (see S-H in Fig. 4.14), when isostatic rebound brought about a rapidly falling base level. During this low-water phase in the Huron basin, nearby rivers became entrenched in their lower valley reaches (Eschman and Karrow 1985) as water levels plummeted to an elevation around 70 m ASL (see Fig. 4.14). This is closely comparable with the entrenchment of the Nottawasaga River in this reach of its lower portion. Base-level lowering, lateral channel shifting and meander cutoff development, and sediment storage with increasing gradient are probable causes for incision during this time (cf. Darby and Simon 1999), as the Nottawasaga River downcut its valley becoming entrenched and increasingly confined within the Edenvale Moraine.

As all three Doran Lake cores show increasing sand deposition particularly within the top 100 cm of sediment, with upward reductions in silt and generally reduced clay content, the area is probably susceptible more recently to energetic floods capable of transporting greater portions of sand into the oxbow area. Using the estimated sedimentation rate and assuming steady sediment inputs into Doran Lake without any major erosional hiatuses, the pond may be becoming sandier since about 1500 yr ago. The modern environment in Doran Lake is established by about 500 yr BP.

Fitzgerald (1985) presents pollen diagrams for the Minesing Swamp (UWBH 128-78 or P3, and UWBH 129-78 or P4) which are in strong agreement with the very limited general findings in this study. As P4 is closest to the study area, it will be considered here for a perspective of the preliminary pollen analysis at Doran Lake. Based on his published radiocarbon date of 6170 ±70 yr BP (WAT-507) some 3.5 m in this core (Fig. 5.7), the sedimentation rate at this site is roughly 0.60 mm yr^{-1} (versus 0.68 mm yr^{-1} for C2 in Doran Lake). A maximum depth to bedrock in Doran Lake of about 6.5 m would roughly correspond to 5.3 m down P4, near an unconformity evident in both cores at the top of the Pine Zone, which he interprets as marking an environmental change from a large lake (possibly Lake Algonquin) to that of an occasionally dry, shallow lake (possibly the Lake Hough phase). The dated wood sample at 486 cm in C2 corresponds to 4.0 m in P4, placing it nearing the Pine-Hemlock boundary. He states that core truncations above this point in the Hemlock Zone represent water-level fluctuations in Lake Edenvale.

The hemlock minimum, which is possibly diagnostic of the Hypsithermal as early as 5500 yr BP, is at a depth of 375 m in C2 where massive marl appears (also evident at 440 cm towards the bottom of C3). Marl is unconsolidated $CaCO_3$ developed in poorly

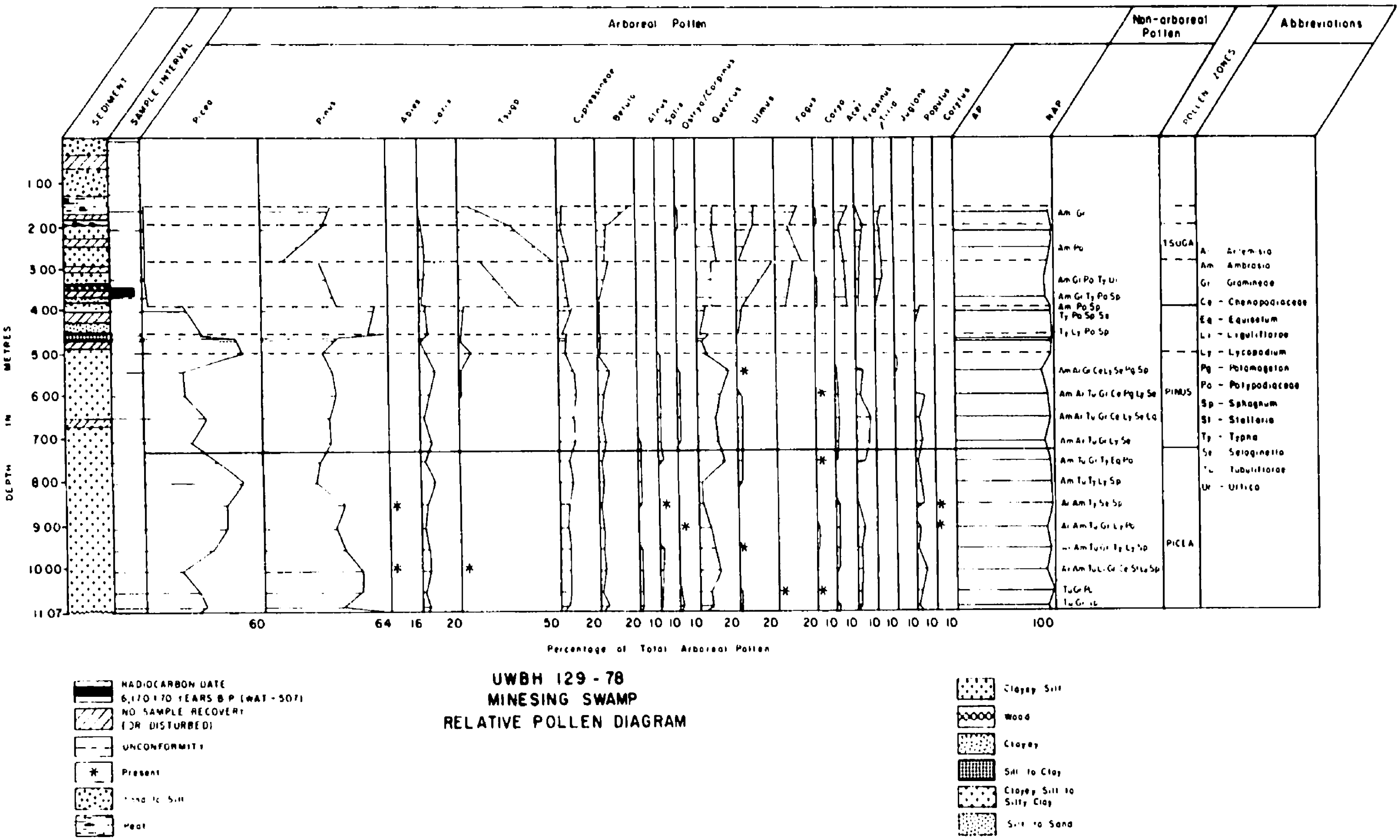


Fig. 5.7. Relative pollen diagram for the Minesing Swamp core P4 (UWBH 129-78) (from Fitzgerald 1985, p. 141).

drained possibly clayey sediments (Brady and Weil 1999), and is normally indicative of lacustrine environments (Ontario Ministry of Natural Resources 1990). Yu (1997) correlates the deposition of homogeneous marl, as well as lamina sedimentation and peat accumulation, with a rising lake level. Though it has been found in shallow depressions on alluvial bottoms rich in freshwater invertebrates (Gladfelter 1992), marl forms biogeochemically in lake-bottoms and ponds (Rapp and Hill 1998). As such, it could represent deeper water in Doran Lake, possibly as isostatic uplift of the North Bay outlet brought about eustatic rise heading into the Nipissing Great Lakes. Interestingly, according to O'Brien (1975), it was about this time in the Archaic period that the earliest settlers appear in the extant areal cultural record. As an enriched aggrading wetland environment in the Hypsithermal (cf. Smith 1987) with much wildlife (including waterfowl, fish, deer, beaver, and clams) during a warm and dry period in the middle Holocene (cf. Knox 1983; Yu 1997), it must have attracted humans for the procurement of freshwater resources.

Pollen analysis for C2 at 280 cm most likely correlates with 2.3 m in P4 in the Hemlock Zone. Both the P4 and the Doran Lake results capture a dominance of pine (*Pinus*), followed by hemlock (*Tsuga*), then oak (*Quercus*), and beech (*Fagus*). At this depth, maple (*Acer*) may be better represented in the Doran Lake sample than in P4, whereas elm (*Ulmus*) is probably more abundant in the Minesing Swamp core (see Fig. 5.7). Birch (*Betula*) is well represented in the topmost sample at 85 cm, corresponding to 0.70 m in P4 which is not covered in the Minesing Swamp core, having a larger local input here in the Hemlock Zone. Birch (particularly white birch) can be considered an early successional taxon, especially as it is found with greater sedges and grass pollen influx (cf. Whittington 1993), possibly portraying open water conditions. High organic matter (i.e., peat in C2) and carbonates (i.e., a shell lens in C2 and shell band in C3) around this time in all cores, denote a quiet environment with steady sediment input and the amassment of *Pisidium* bivalves pertaining to a shallow lacustrine environment (Fitzgerald 1985).

All shells recovered from Doran Lake are aquatic, consisting of sphaeriid clams (*Musculium*, *Pisidium*, *Sphaerium*), unionid clams, and aquatic gastropods including a physid and planorbids (*Gyraulus deflectus*) (refer to Table 5.1). Although unionid clams are difficult to recover because of high decomposition, possibly two have been recovered from 373 and 413 cm in C2 nearby the potential Hypsithermal depth roughly in agreement with their link to the Nipissing phase (Miller et al. 1985). These findings (i.e., marl, peat, and aquatic molluscs) suggest that Doran Lake remained a wetland throughout much of the Holocene with varying amounts of moisture (as evidenced by angular blocky structures in C2 and throughout much of C3, cf. Birkeland 1999). Cut off activity was early in the Holocene during a phase of fluvial degradation and channel incision (cf. Smith 1987), leading to entrenchment of the Nottawasaga River in this confined reach where only vertical adjustments were possible (cf. Schumm 1993). This was followed by net sediment aggradation in the Hypsithermal into the Nipissing Great Lakes system, and the accumulation of the sediment record in Doran Lake with evidence of a generally declining water level and increasing organics.

CHAPTER 6: CONCLUSIONS

6.1 Summary

This research has made the following major findings for the study area at the lower Nottawasaga River, southern Ontario. In unconfined sections:

1) poor particle sorting, with a notable larger variance in D_{50};
2) coarsening of sediments away from the active channel, with reduced organic matter and carbonate content;
3) the cutbank at T3 denotes a generally fining-upwards sequence (particularly towards the top), with organic matter content increasing upwards and downward-increasing carbonate content, and the possibility of a rippled basal sand layer;
4) a GPR profile with the appearance of a buried channel in the modern floodplain on the left bank at T2;
5) specific stream power typifies this as a medium-energy floodplain; and
6) five known archaeological sites are (Middle) Woodland in age, and there are two undeterminable sites.

Confined sections show:

1) alluvial fining occurs away from the active channel, with increasing organic matter and carbonate content;
2) non-parametric statistical results show a significant trend for the greater abundance of sand in sites more proximal to the active channel;
3) the cutbank near T7 is upward-coarsening, with a generally downward-increasing organic matter content and the upward depletion of carbonates, and a buried Ah below the appearance of an erosional surface;
4) alluvial laminations can be seen where natural levees are well developed;

5) specific stream power typifies this as a high-energy floodplain through confined reaches; and

6) all six designated archaeological sites in confined sections are Archaic.

For the confined reach at Doran Lake:

1) an AMS radiocarbon date on wood of 7120 ±80 yr BP at a depth of 486 cm in the Doran Lake core C2;

2) the extensive GPR profile over Doran Lake shows its foundation some 6.5 m below the modern surface; and

3) preliminary pollen results from C2 in Doran Lake correlate well with published results for the Minesing Swamp core P4.

6.2 Conclusions

Unconfined sections in the lower Nottawasaga River show more evidence of lateral accretion than confined sections. Few studies in southern Ontario have been conducted on unconfined river reaches so the extent to which lateral accretion is important is not well known. However, on these low gradient former lake bottom settings, extensive lateral migration is possible. The strongest indicators of lateral accretion in unconfined sections at the lower Nottawasaga River include a fining-upwards stratigraphic sequence in the cutbank at T3, with a possible rippled basal sand layer, and a GPR profile on the left bank at T2 denoting what appears to be a buried channel in the modern floodplain. This research demonstrates the importance of vertical accretion in confined sections. This is especially supported by alluvial fining away from the active channel, laminated sediments where there is strong levee development, and a buried Ah in the confined cutbank near T7. These findings are in agreement with other floodplain research for vertically accreted systems, showing coarser near-channel sedimentation with levee development (i.e., Marriott 1992; Lewin 1996; Kalicki 2000). Walker et al. (1997) have shown that buried soils at the Grand Banks site in the lower

Grand River, southern Ontario were also indicative of dominant vertical accretion processes, and very stable channel positions during the Holocene.

Catastrophic stripping is plausible on the modern floodplain surface in confined reaches. Though Q_b below Edenvale is approximates 92 m^3 s^{-1}, the specific stream power of the Nottawasaga River through the Edenvale Moraine denotes a high-energy environment which Nanson and Croke (1992) suggest could be subject to catastrophic erosion followed by episodes of vertical accretion. This classification is a product of a notable increased average local gradient through the moraine coupled with a narrower channel for the given streamflow. Grains smaller than coarse sand, which are deposited on the modern floodplain, have the potential for floodwater erosion. The coarsening-upwards sequence in the confined cutbank near T7 and sandy laminations apparent where there is levee formation, as well as towards the top of C1 and C2 from Doran Lake, are indicative of more energetic high-magnitude floods through the moraine. Though the evidence for catastrophic stripping through the confined section is not unequivocal, an erosional surface on the buried Ah in the cutbank sequence near T7 suggests this is possible.

The evidence converges on early Holocene cutoff activity at Doran Lake. This may be representative of channel shortening and entrenchment of the Nottawasaga River where it is confined by the Edenvale Moraine, probably in response to falling lake levels in Georgian Bay around the Lake Hough phase. Walker et al. (1997) showed that in low gradient reaches of the lower Grand River, Lake Erie influenced floodplain stability (cf. Garaci 1998 for the lower Saugeen River controlled by Lake Huron, and the lower Humber River controlled by Lake Ontario cf. Weninger and McAndrews 1989). During episodes of high lake level, surfaces were subject to renewed sediment input and burial of soils which developed on the floodplain alluvium during stable low lake-level phases.

The unconfined low gradient sections of the Nottawasaga River appear to operate differently through processes of lateral channel migration.

At the Red River in Manitoba where with entrenchment follows alluvial vertical accretion (Nielsen et al. 1993), so at the lower Nottawasaga River major sediment accumulation probably occurred into the Nipissing Great Lakes. The current channel configuration and some of the overbank floodplain sediments were probably in place by the time the Nottawasaga River became entrenched. However, this interpretation is limited by poor dating control, an assumption of steady sediment inputs into the oxbow, and an accurate identification of the depth to bedrock in Doran Lake. Moreover, the environmental reconstruction in the previous chapter may be susceptible to misinterpretations from assuming a complete, continuous sediment record devoid of any hiatuses in the Doran Lake cores, which may not be the case especially considering the irregular contact in C2.

For designated archaeological sites, error is mostly linked with invisibility, discovery, and sampling (cf. Wilson 1983). It is probable that most sites in the study area have yet to be discovered (D.G. Smith, personal communication 2000). Any spatial analysis of sites is subject to non-random sampling error as surveys may over-represent more accessible sites, as near-bridge areas (i.e., BcGx-4, BcGx-5, and BcGx-9; as in Fig. 2.8), and also may reflect urban development (i.e., BcHa-36 and BcHa-38). Cultural age estimations based on present-absent criteria may be faulty, as for instance identifying an Archaic site based on the absence of pottery found at the site. Also, it is quite conceivable that sites which O'Brien (1974) identifies as floodplain sites may be terrace sites, particularly for unconfined sections where it is difficult to make out the modern floodplain. It is arguable that for a vertical span of no more than 3 m for the modern floodplain in all sections, Archaic sites located in confined sections all above 183 m ASL may be terrace sites. As noted for research at the Grand River (Smith and

Crawford 1995), the MCZCR archaeological sites database may be incomplete for the Nottawasaga River. This is very likely as evidenced by the omission of village sites noted by Hunter (i.e., Site No. 5, 1907).

Working within these constraints, though, the exposure-preservation model presented here may be applied to the study area in the lower Nottawasaga River. As it is unlikely that entire campsites have been washed downstream, selective exposure in a predominantly vertically accreting area may be failing to surface a majority of the archaeological evidence in confined sections. Rather than being a problem of destruction by erosion (cf. Waters and Kuehn 1996), this may be an issue of negative evidence (cf. Brown 1997) even across the moraine. For this reason, it remains impossible to take a definitive stance on O'Brien's explanation of the Archaic occupation of the moraine linked to base-level changes. It is obvious, however, that known archaeological sites throughout the study area do not noticeably age with increasing distance from the active channel, possibly denoting its early entrenchment and reduced lateral channel shifting particularly in confined sections and recent levee development.

6.3 Recommendations

Understanding fluvial dynamics, floodplain development, and site formation are key to archaeological endeavours in riverine environments. For archaeological sites prospecting, this study pinpoints the possibility of a buried Ah that may prove to contain evidence of prehistoric human occupation, probably from the Archaic period. It would be an interesting project to execute an archaeological survey of this landform. As age has not been ascertained, the artifacts may assist in temporally placing this pedogenic layer. From an archaeological perspective, the levee has much potential as a stable surface where human occupation is highly probable. After Binford (1996), it may benefit an anthropological understanding to examine site types ascertaining their organizational roles within systems of human behaviour (i.e., are all campsites temporary fishing sites (locations or field camps) or is there an increased redundancy in campsites so that they might be residential bases?).

There are several other cutoffs throughout the study area besides Doran Lake, including a large marshy chute cutoff just upstream of it. Tracing neck cutoffs, in particular, may be an effective strategy perhaps for uncovering early post-glacial sites cut off following low-water channel entrenchment. The confined section has proven to be particularly instrumental for tracking Archaic sites. Though it is necessary to discover more sites to develop the existing database, it would be prudent to focus on systematic excavations of known sites especially in unconfined sections where they are subject to natural destruction of sideways channel shifting. O'Brien (1975) advocates the excavation of the extensive Fisherman site (BcGx-6) situated nearby a creek in this section, as possibly "one of the most important of its kind in the Nottawasaga area" (Fig. 6.1). Previously noted by Hunter (Site No. 3, 1907), it is a Middle (possibly Late) Woodland manifestation spanning about 150 by 50 m in size (O'Brien 1974) perhaps comparable to the Donaldson site (BdHi-1) on the lower Saugeen River (Finlayson 1977).

From a paleoecological perspective, detailed pollen analysis is yet to be performed on the Doran Lake cores. Though C2 has been examined, only two samples were scrutinized and there are two remaining cores that have not been investigated for pollen. Doing this is crucial to verify interpretations made in this study based on depth estimations down the Minesing Swamp core. This site is also an ideal locale for a detailed molluscs study as a tool in paleoenvironmental reconstruction. There is also potential here for GIS analyses (i.e., as by Santos et al. 2000), with the availability of five sets of aerial photographs since 1953 and LANDSAT imagery. Existent wood fragments extracted from the floodplain at T2 may be radiocarbon dated for estimations of lateral accretion and erosion on the modern floodplain. It may also aid interpretations to

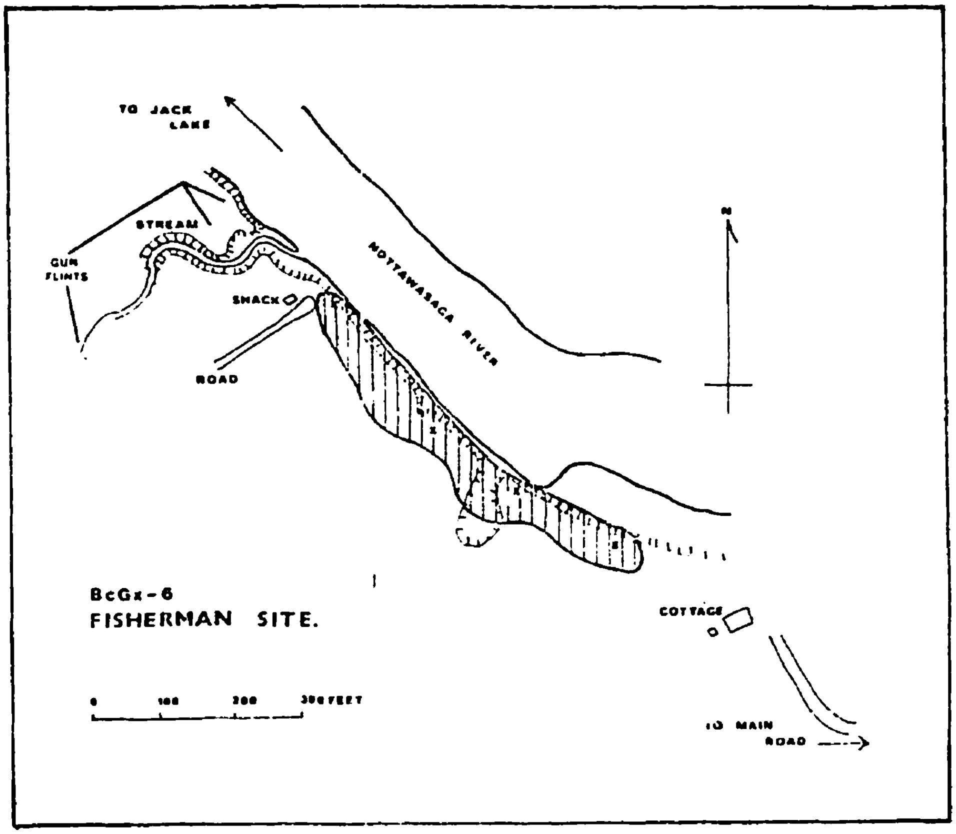


Fig. 6.1. The Fisherman site (BcGx-6) is an extensive site spanning an estimated area of ~183 m longitudinally by ~30 m laterally in an unconfined section nearby a creek on river-left some 3 m above the active channel (from O'Brien 1975, p. 95).

estimate the rate of vertical accretion in the confined floodplain as by deciphering the age of the buried Ah.

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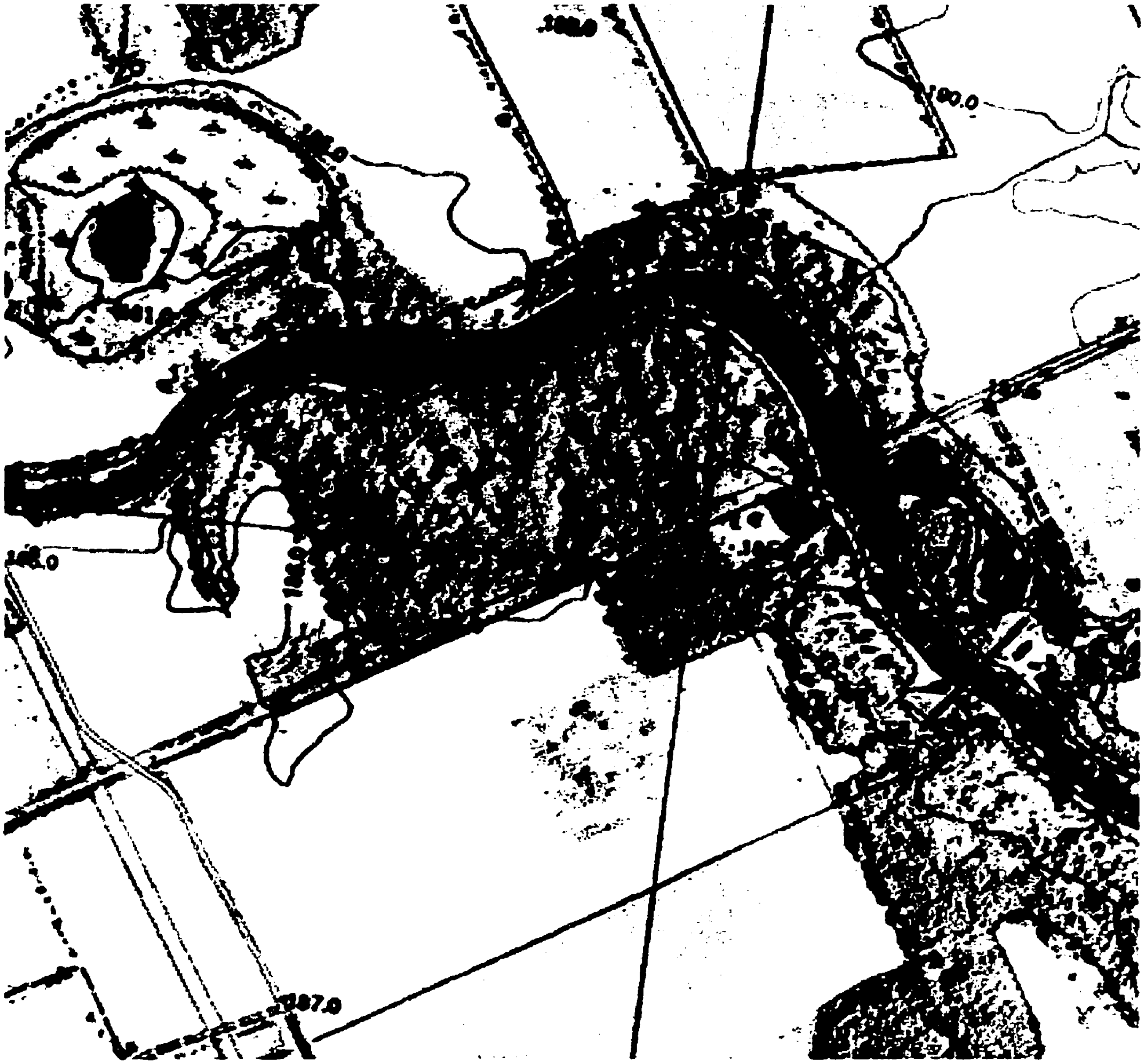
APPENDIX A: SECTION 1

APPENDIX A: SECTION 2

APPENDIX A: SECTION 3

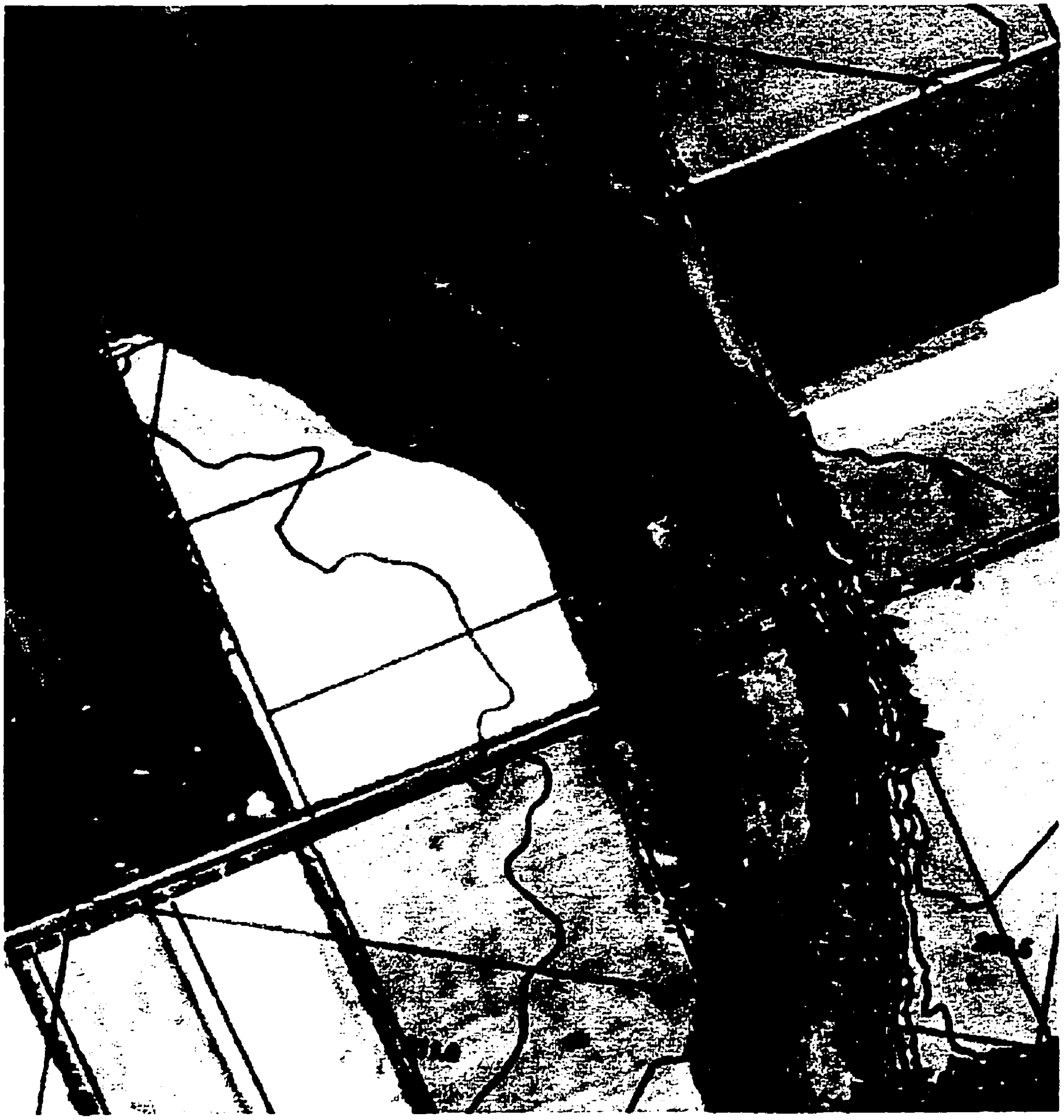
APPENDIX A: SECTION 4



APPENDIX A: SECTION 5

APPENDIX A: SECTION 6

APPENDIX A: SECTION 7



APPENDIX A: SECTION 8

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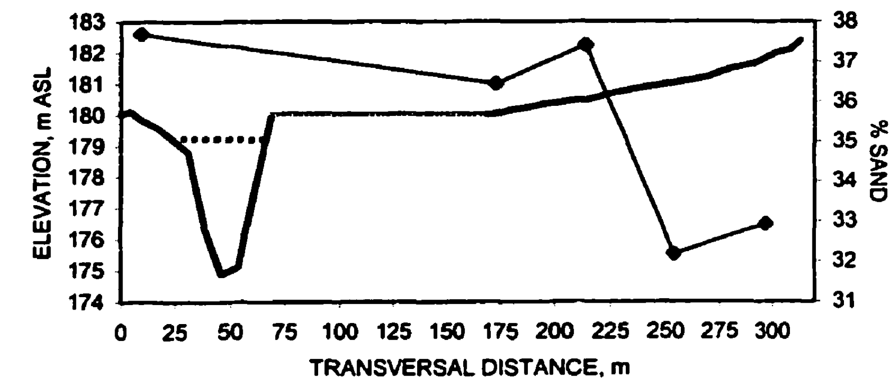

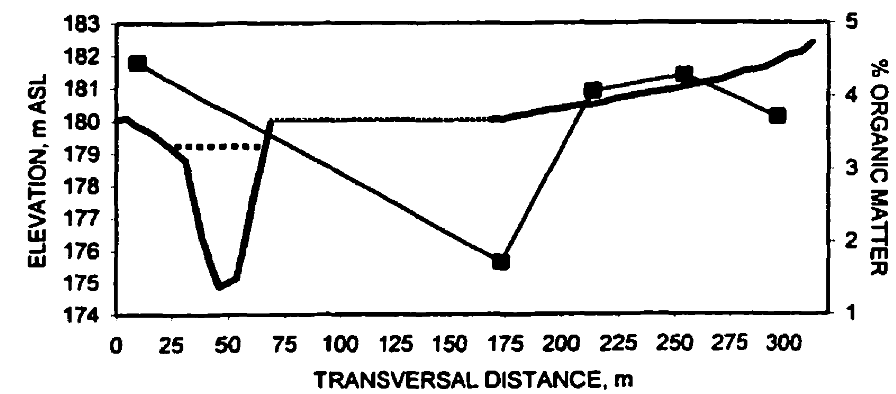

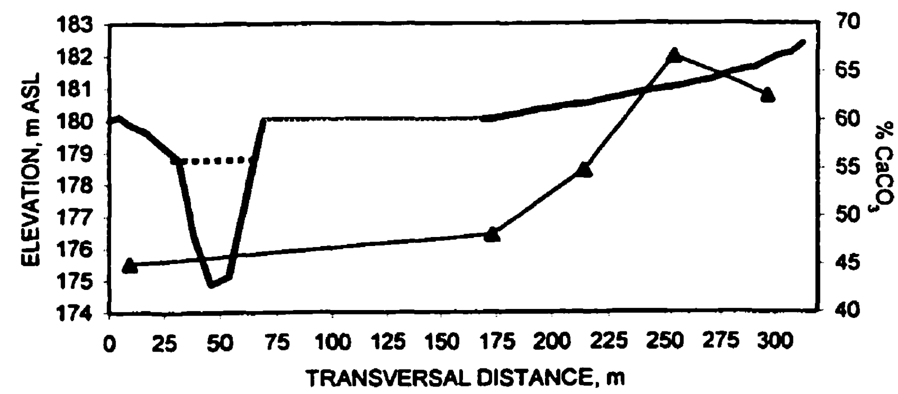

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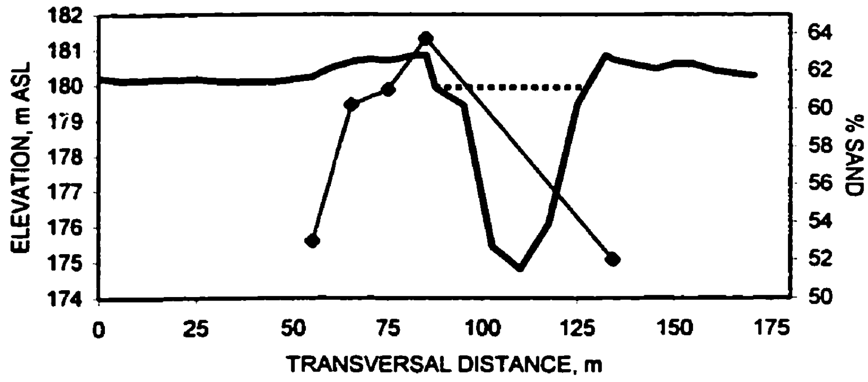

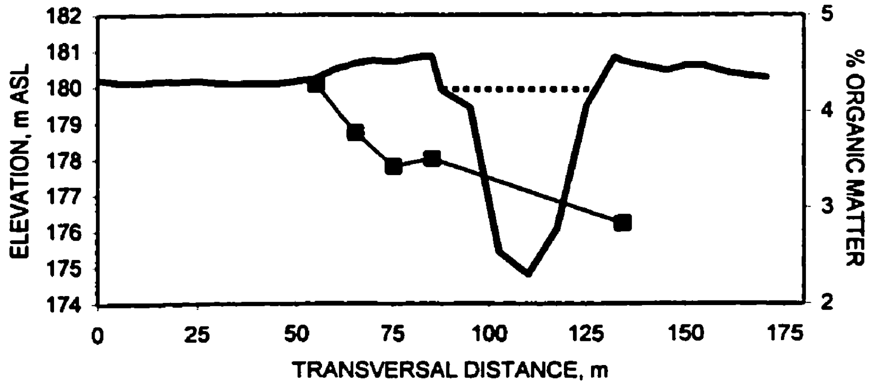

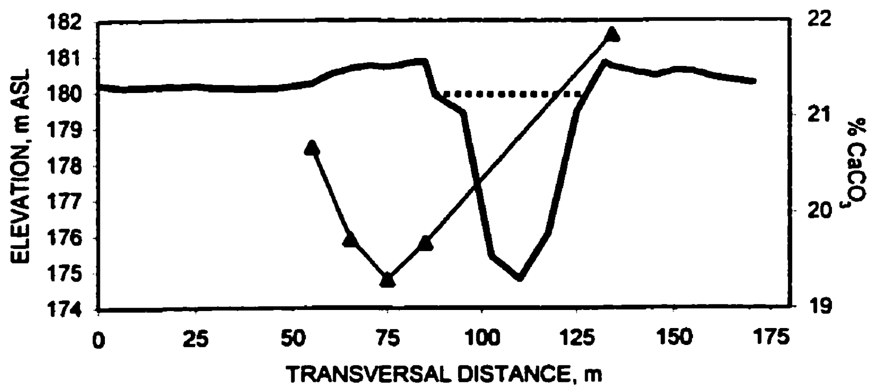

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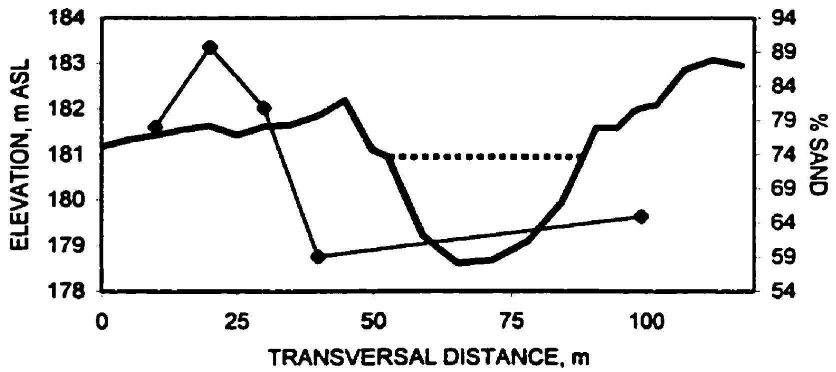

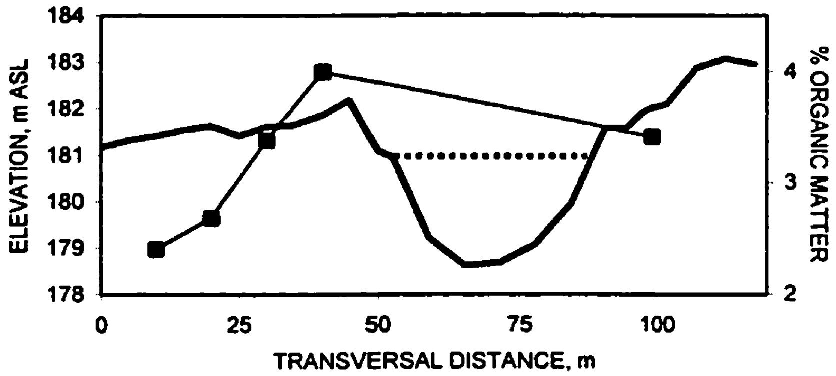

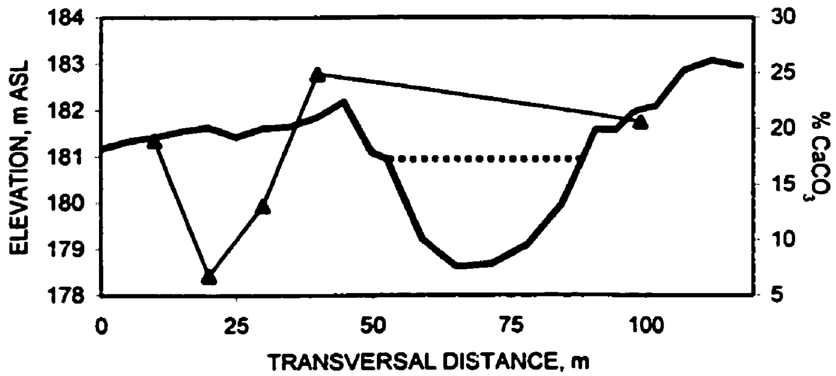

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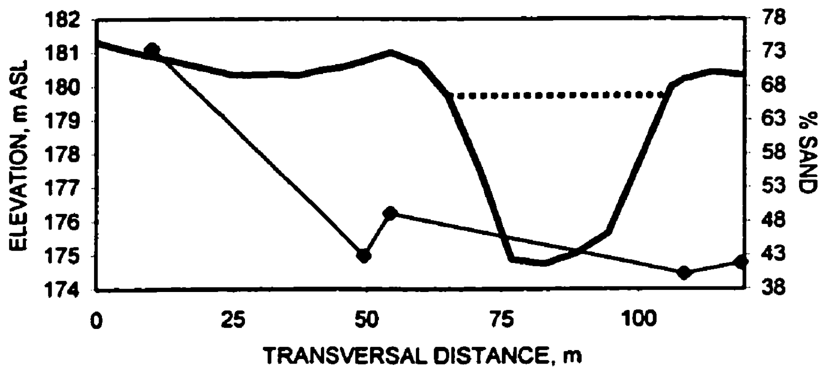

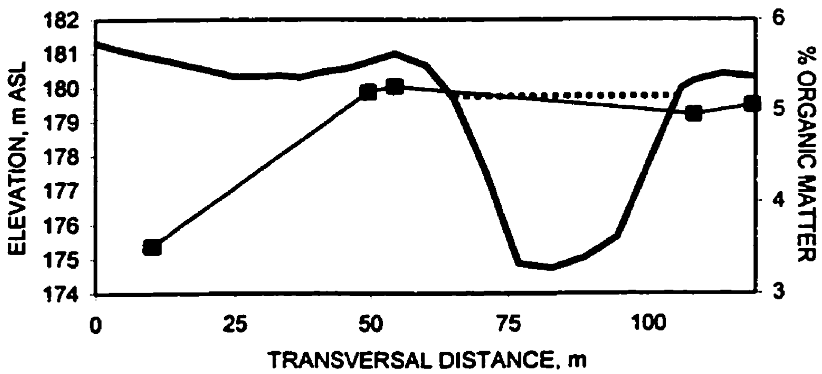

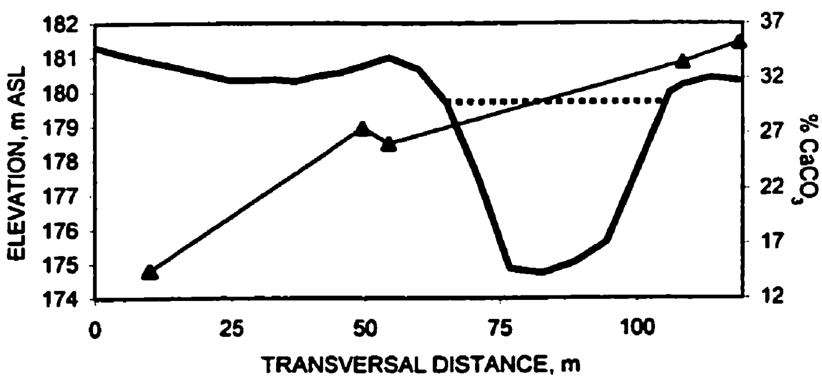

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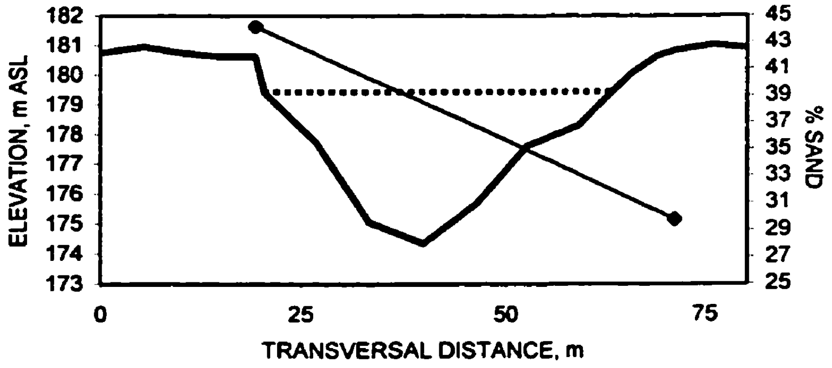

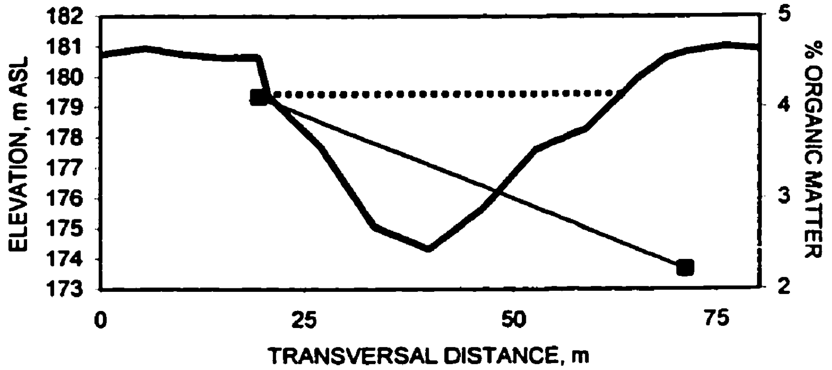

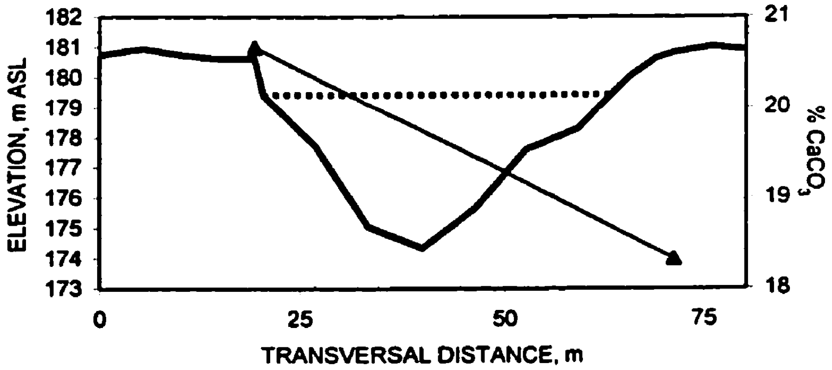

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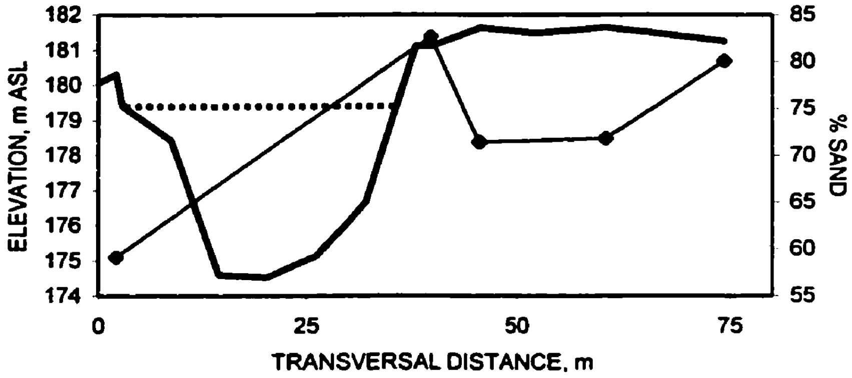

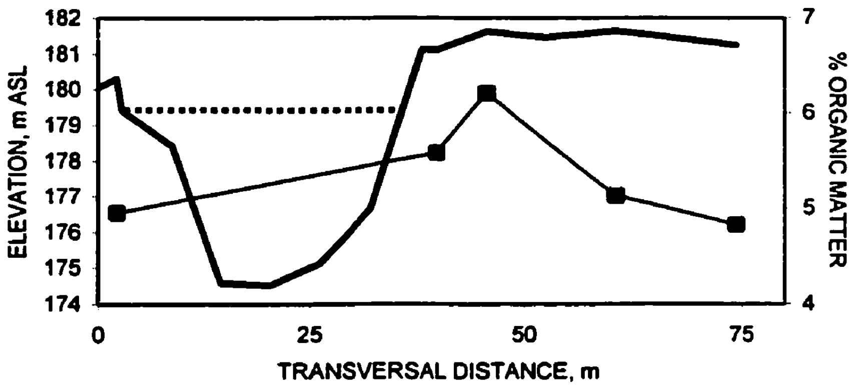

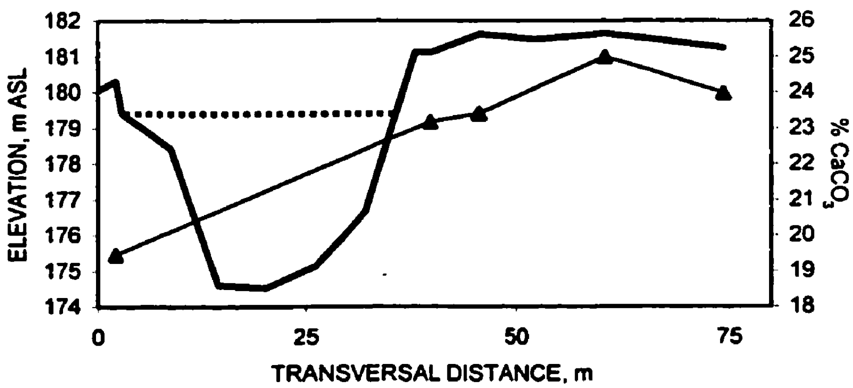

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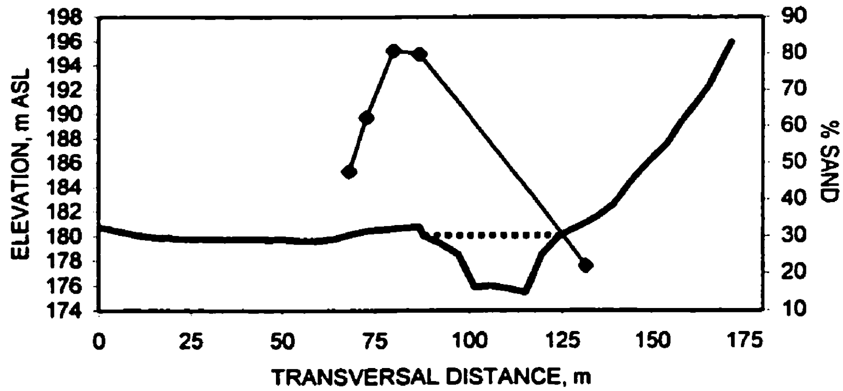

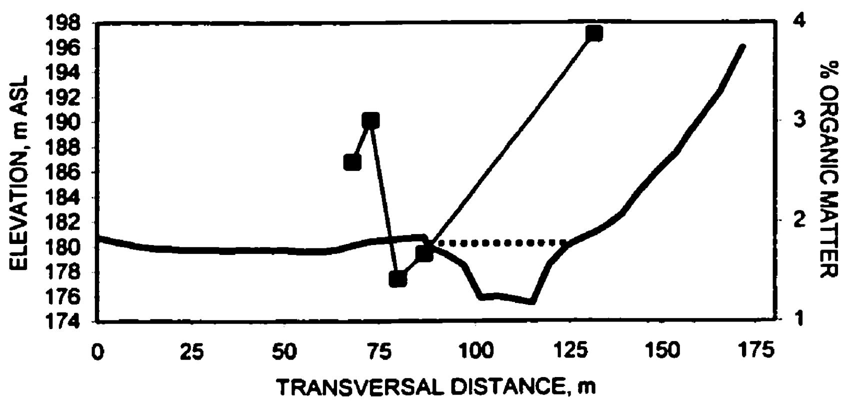

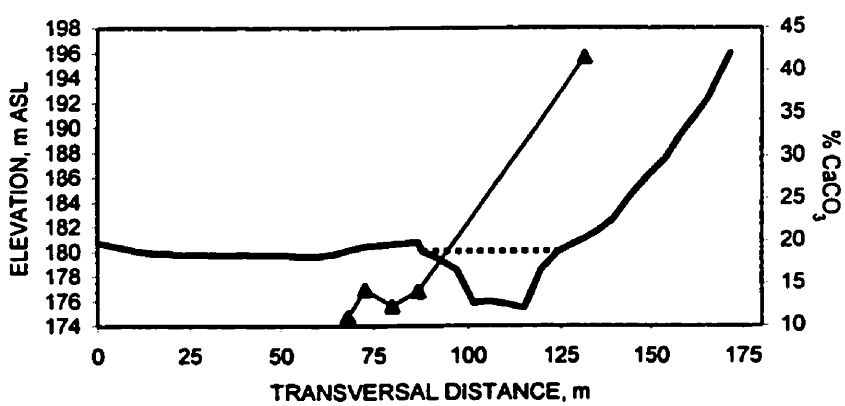

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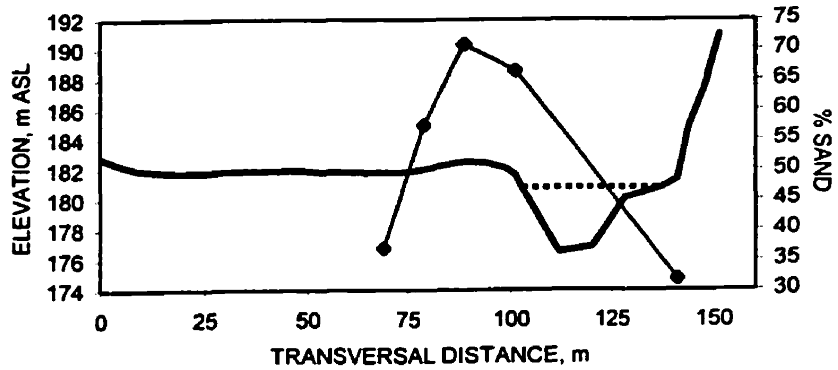

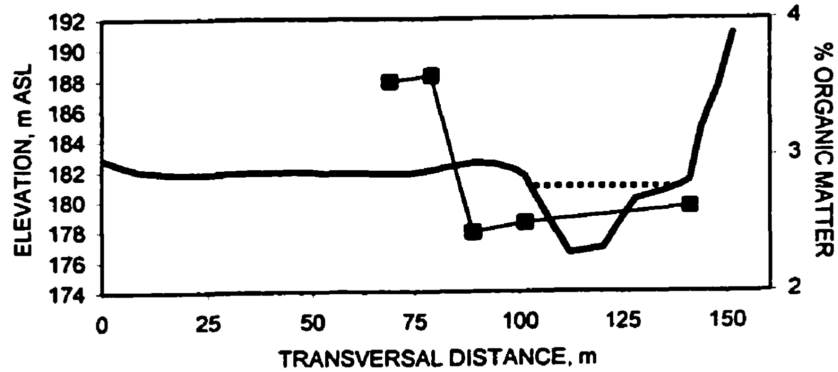

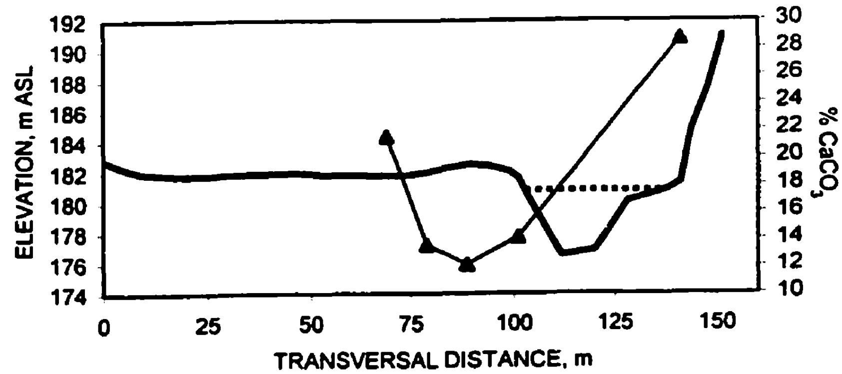

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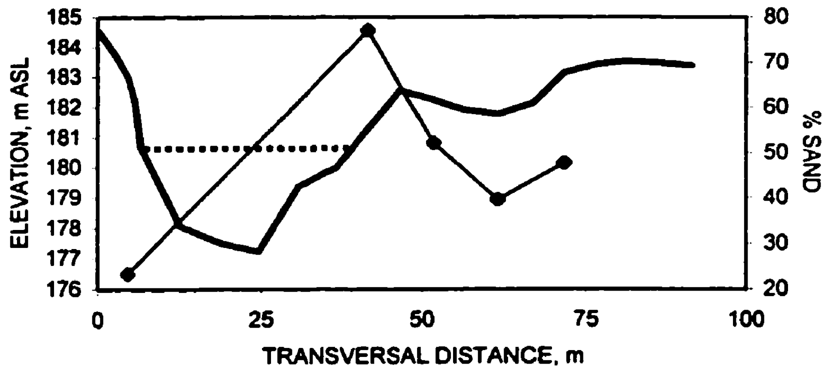

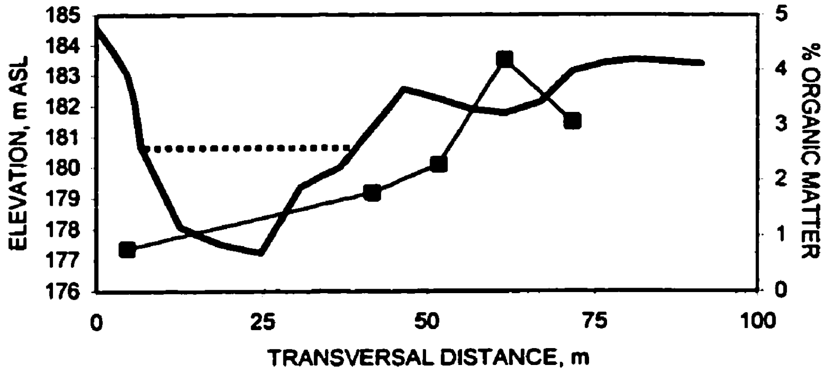

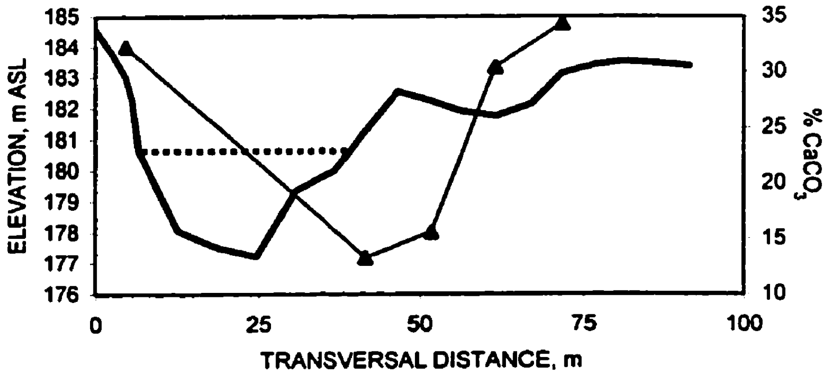

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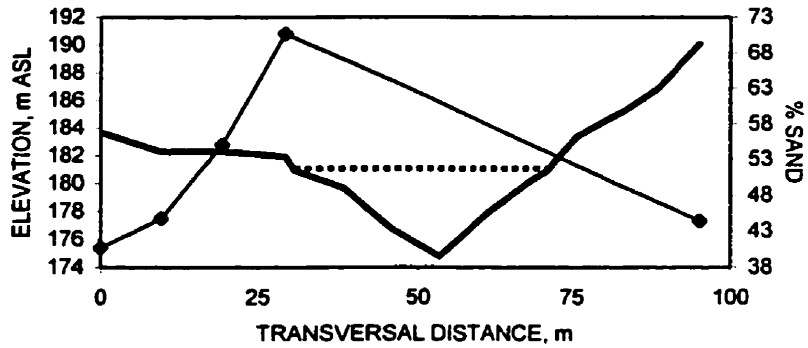

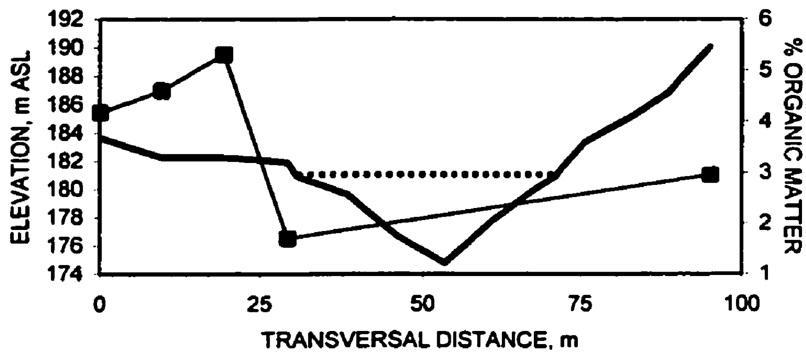

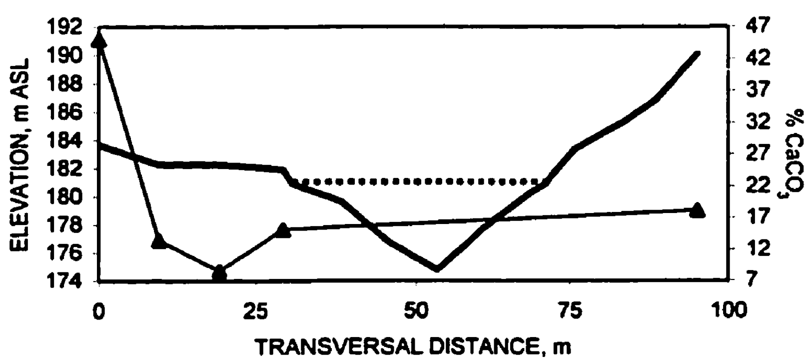

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