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Morphology and Formation of an Holocene Coastal Dune Field, Bruce Peninsula, Ontario

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Morphologie und Bildung eines Küstendunenfeldes im Holozän, Bruce-Halbinsel, Ontario

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Résumé de l'article

On fait ici la description d'un champ de dunes situé sur le rivage faiblement incliné de la péninsule de Bruce, au lac Huron. La limite intérieure est caractérisée par une chaîne de dunes de 60 m de large et jusqu'à 30 m de haut qui s'étend parallèlement au rivage sur une longueur de 19 km; elle a été formée il y a 5000 ans BP, presque la fin de la transgression de Nipissing. Les îles et les écueils rocheux qui protègent le rivage actuel étaient alors immergés sous des niveaux lacustres supérieurs, permettant ainsi la formation d'une plage découverte relativement rectiligne qui a fourni le sable nécessaire à l'édification de la chaîne de dunes. La formation, au cours de la régression post-Nipissing, de dunes moins hautes et plus dispersées, entre la chaîne de dunes et le rivage actuel, témoigne d'une faible alimentation en sédiments associée à la régression et d'une moindre exposition aux vagues en raison de l'émersion des îles. La séquence décrite ici corroborent les conclusions antérieures selon lesquelles les transgressions correspondent à des périodes de formation et d'instabilité des dunes littorales.

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MORPHOLOGY AND FORMATION OF AN HOLOCENE COASTAL DUNE FIELD, BRUCE PENINSULA, ONTARIO

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ABSTRACT This paper describes a dune field on the gently-sloping Lake Huron shoreline of the Bruce Peninsula, Ontario. The inland boundary is marked by a prominent dune ridge 60 m wide and up to 30 m high, which extends parallel to the shoreline for about 19 km, and was formed about 5000 years BP near the end of the Nipissing transgression. The islands and rock reefs which protect the modern shoreline were submerged under the higher lake levels, giving rise to a relatively straight, exposed beach from which sediment was supplied for building the dune ridge. Dunes formed between this ridge and the modern shoreline during the post-Nipissing regression decrease in height and continuity, reflecting decreased sediment supply associated with regression and reduced wave exposure as the offshore islands emerged. The sequence described here supports previous conclusions that transgressions are associated with periods of coastal dune formation and instability.

RÉSUMÉ *Morphologie et formation d'un champ de dunes littoral holocène, péninsule de Bruce, Ontario.* On fait ici la description d'un champ de dunes situé sur le rivage faiblement incliné de la péninsule de Bruce, au lac Huron. La limite intérieure est caractérisée par une chaîne de dunes de 60 m de large et jusqu'à 30 m de haut qui s'étend parallèlement au rivage sur une longueur de 19 km; elle a été formée il y a 5000 ans BP, presqu'à la fin de la transgression de Nipissing. Les îles et les écueils rocheux qui protègent le rivage actuel étaient alors immergés sous des niveaux lacustres supérieurs, permettant ainsi la formation d'une plage découverte relativement rectiligne qui a fourni le sable nécessaire à l'édification de la chaîne de dunes. La formation, au cours de la régression post-Nipissing, de dunes moins hautes et plus dispersées, entre la chaîne de dunes et le rivage actuel, témoigne d'une faible alimentation en sédiments associée à la régression et d'une moindre exposition aux vagues en raison de l'émersion des îles. La séquence décrite ici corroborent les conclusions antérieures selon lesquelles les transgressions correspondent à des périodes de formation et d'instabilité des dunes littorales.

ZUSAMMENFASSUNG *Morphologie und Bildung eines Küstendünenfeldes im Holozän, Bruce-Halbinsel, Ontario.* Dieser Aufsatz beschreibt ein Dünenfeld, das am schwach abfallenden Ufer des Huron-Sees, Bruce-Halbinsel liegt. Die Grenze zum Landinnern ist hervorgehoben durch eine Kette von Dünen, die 60 m breit und bis zu 30 m hoch sind, und die sich parallel zum Ufer über eine Länge von 19 km ausdehnt; sie wurde vor 5000 Jahren v.u.Z. gebildet, fast am Ende der Transgression von Nipissing. Die Inseln und die Felsklippen, die das heutige Ufer schützen, waren damals unter den höheren Seen-Niveaus untergetaucht, so dass ein offener, relativ gerader Strand entstehen konnte, der den für den Aufbau der Dünenkette notwendigen Sand lieferte. Während der Regression post-Nipissing haben sich zwischen der Dünenkette und dem heutigen Ufer weniger hohe und mehr verstreute Dünen gebildet, welche Zeugnis von einer schwachen Sediment-Zufuhr abgeben, in Verbindung mit der Regression und einem geringeren Einfluss der Wellen wegen des Auftauchens der Inseln. Die hier beschriebene Sequenz bestätigt frühere Schlussfolgerungen, denen zufolge die Transgressionen mit Perioden der Bildung und Instabilität von Küstendünen in Verbindung gebracht werden.

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INTRODUCTION

The effects of fluctuating ice margins, changing locations and elevations of lake outlets, and isostatic tilting have resulted in a complex history of lakes and lake levels in the Great Lakes basins over the past 14,000 years (Hough, 1958; Lewis, 1969; Karrow *et al.*, 1975; Terasmae, 1980; Karrow and Calkin, 1985). The resulting shoreline transgressions and regressions have greatly influenced the morphological and sedimentological characteristics of the modern coasts and coastal plains. As a result of postglacial isostatic uplift, shoreline features and sediments associated with ancient lakes in the Great Lakes Basin, and with large glacial lakes elsewhere on the continent, are frequently preserved inland from the modern shoreline. Among the most prominent of these features are dunes associated with ancient mainland and barrier beaches (Olson, 1958a, 1958b; Morrison, 1973; Martini, 1975; 1981; Coakley, 1976; Trenhaile and Dumala, 1978; David, 1981; Carson and Maclean, 1986). In addition to their local significance, these ancient lacustrine dune systems can provide more general evidence of the response of dunes to transgressions and regressions, particularly since the lake level chronology is well documented.

The purpose of this paper is to provide a brief description of a prominent dune field on the west coast of the Bruce Peninsula, Ontario, and to discuss the influence of changes in lake levels and sediment supply on the morphology and formation of the dune field.

STUDY AREA

The study area is located at the southern end of the Bruce Peninsula on the Lake Huron coast (Fig. 1). The bedrock of the peninsula consists of Paleozoic limestones, dolostones, shales and evaporites (Liberty and Bolton, 1971). The centre and west side of the peninsula is underlain by the dolomitic Guelph Formation which dips gently southwestward into the Michigan structural basin. Over much of the peninsula there is only a thin mantle of glacial and glacio-fluvial sediments, and the thickness of the overburden tends to increase southwards (Sharpe, 1982). In the study area the bedrock is mostly covered by eolian and beach sediments, except along the modern shoreline where numerous rocky bays are protected by offshore islands (Fig. 1). Due to restricted wave action in the bays, the bay heads are fringed by marshes and narrow, sand and gravel beaches.

The main dune field begins just south of Pike Bay, although some areas of eolian sediments occur further north, and extends southward to the Sauble River where it broadens into an extensive sand plain (Fig. 1). The eastern boundary is marked by a dune ridge 20-30 m high which is nearly continuous over the length of the study area, and smaller, lower dunes occur between this and the modern coast. In general, the thickness of the eolian sediment cover and the height of the dune ridges decreases westward towards the modern shoreline.

The general chronology of post-glacial lake levels in the Huron basin is well documented (Hough, 1958; Lewis, 1969; — see Fig. 2). The peninsula remained under active ice until well after the initiation of glacial Lake Algonquin, which eventually inundated all but a few isolated areas of higher ground (Stadelmann, 1973). With the opening up of drainage eastward through the Mattawa Valley to the Champlain Sea around 10,000 BP, water levels fell rapidly from about 184 m to a low of about 60 m (Hough, 1958; Lewis, 1969; Prest, 1970; Karrow *et al.*, 1975), forming lakes Stanley in the Huron Basin and Hough in Georgian Bay. Subsequent isostatic uplift of the eastern outlets then raised the water levels until drainage was re-established through the southern outlets at Chicago and Port Huron around 6000 to 5500 BP, forming early Lake Nipissing at an elevation of about 181 m. Lake levels continued to rise slowly to about 184 m, when all drainage to the east ceased. Lake level has since fallen slowly to the present level of about 176 m with downcutting of the Port Huron outlet.

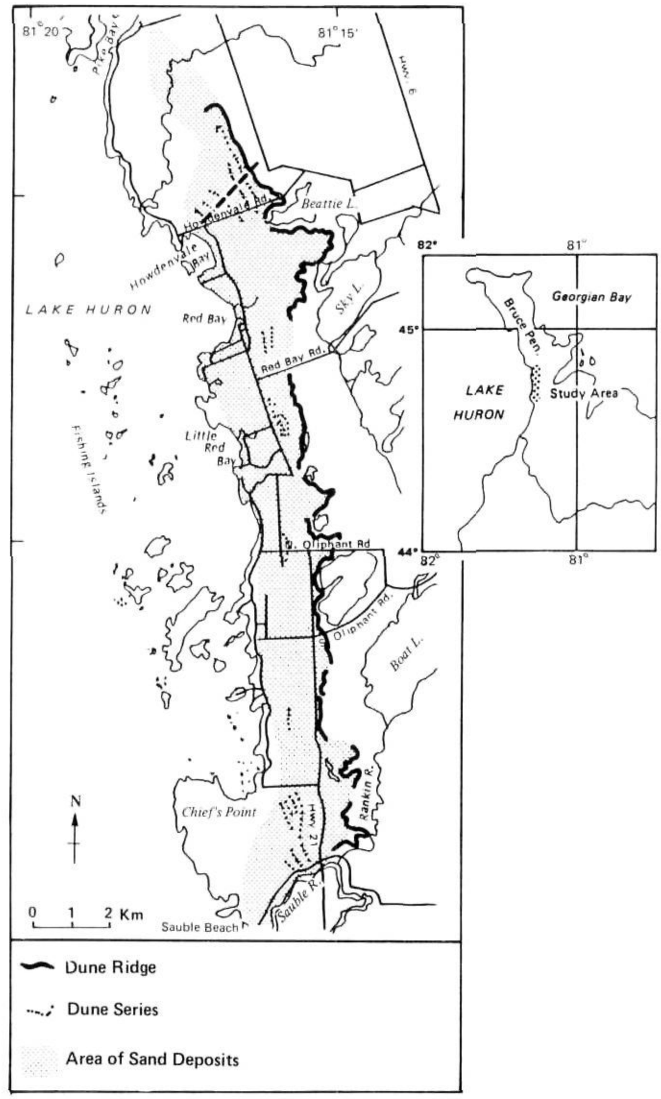

FIGURE 1. Location of study area and position of eastern dune ridge.

Localisation de la région à l'étude et emplacement de la chaîne de dunes orientales.

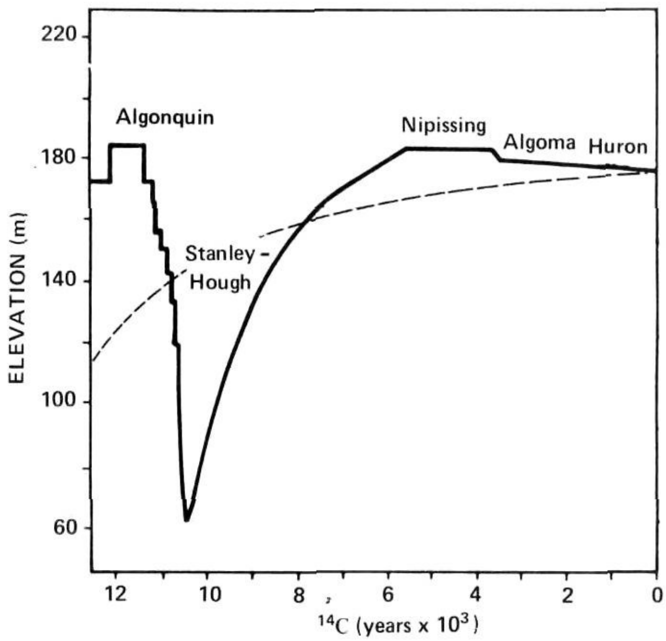

FIGURE 2. Postglacial lake levels in the Huron basin (after Lewis, 1969). The dashed line shows the elevation of the modern shoreline based on isostatic uplift rates.

Niveaux lacustres postglaciaires du bassin du lac Huron (selon Lewis, 1969). Les tirets donnent l'altitude du rivage actuel fondée sur les taux de relèvement isostatique.

The study area lies to the north of the hinge lines for both Lake Algonquin and Lake Nipissing shorelines, so that the elevations of these shorelines increase northward. The Lake Algonquin water plane in the study area ranges in elevation from about 230 m to 237 m, and that of Lake Nippissing from about 190 m to 192 m. The combination of isostatic recovery and the rapid fall in water levels from Lake Algonquin to Lake Stanley resulted in a very rapid rate of horizontal shoreline displacement, here averaging about 58 m yr^{-1} (Pyskir, 1984), and this would have restricted severely the amount of reworking of sediments by wave action. In contrast, the average rate of horizontal shoreline displacement during the succeeding Nipissing transgression was about 4.5 m yr^{-1}, in part because of the compensating effects of isostatic uplift. As a result, a stable shoreline position would have been established here somewhat earlier than in areas south of the hinge line where uplift had already ceased.

METHODOLOGY

The morphology of the dune field was examined on vertical aerial photographs, and on oblique ones taken in May, 1982. The continuity and features of the eastern dune ridge were examined in the field, the path of the ridge crest mapped for most of its length by compass traverse, and profiles surveyed across it at intervals. A 1700 m long transect across the whole dune field was surveyed by theodolite in the vicinity of Howdenvale Bay (Fig. 1), and the morphology of the other dune ridges determined by shorter transects. Sedimentary structures were examined in blowouts, road cuts and sand pits, as well as in short (1 m long) cores taken in the interdune areas. Size analysis of samples was carried out in a settling tube similar to that described by Rigler *et al.*, (1981). Further details are given in Pyskir (1984).

DUNE MORPHOLOGY AND SEDIMENTOLOGY

The general features of the study area and modern coast are shown in Figure 1, including the location of the dune ridge which defines the eastern margin of the dune field. The elevation and relative relief of the dunes can be seen in a transect across the system near Howdenvale (Fig. 3). The characteristics of the eastern dune ridge will be described first, followed by those of the dunes to the west of it.

EASTERN DUNE RIDGE

The eastern dune ridge extends from about 1.5 km south of Pike Bay to just north of Sauble Falls where it merges with the extensive sand plain to the south. The dune ridge was associated with the Lake Nipissing stage by Chapman and Putnam (1966, p. 264), and by Stadelmann (1973) who dated a charcoal sample found in the dune at 5109 ± 131 years BP. No dateable material was found in the sections examined in this study, probably because of the poor potential for preservation of organic material in the freely draining sands above the water table. Because of the presence of blowouts and smaller ridges, it was generally not possible to define clearly the base of the windward slope of the dune ridge. However, the elevation of the base of the leeward slope was determined at four locations where there was a distinct contact with the underlying, horizontal bedrock surface. These elevations ranged from 191 m to 197 m, thus supporting the association with Lake Nipissing.

The dune ridge is nearly continuous over the study area, with only a few short breaks resulting from blowouts, road cuts and sand pits (Fig. 1). The base of the leeward slope often rests directly on bedrock, and in places borders directly on several lakes which lie to the east of it. There is little or no eolian sand east of the dunes. The crest of the ridge averages 10-25 m in height and in places exceeds 30 m. Characteristically it has a steep, planar leeward slope, a narrow crest, and an irregular windward slope of varying angle and form. Measured leeward slope angles range from 20°-32°, with a mean of 27° and a mode of 30°. Those of the windward slope ranged from 15° to 34°, with a mean of 26° and a mode of 25°. In several profiles the windward slope is actually steeper than the leeward slope, with the steeper slopes usually associated with greater overall dune height, as recorded for dunes in Saskatchewan by David (1981). Because both sides are steep, the dune ridge is quite narrow, ranging from 40-70 m at measured sections.

The leeward slope is simple morphologically, with the base of the slope roughly parallel to the dune crest. The morphology of the windward slope can be more complex, with a second, lower ridge often producing a compound form, and saucer-shaped depressions with trailing arms extending westward produced by blowouts and incipient parabolic dune formation. The trend of the ridge crest over the whole area is generally parallel to the present coast, but there is some variation in its sinuosity. At the north end of the study area it is nearly straight, but towards the south it becomes quite sinuous, with an amplitude of 100-200 m. This appears to reflect local variations in the migration of the dune crest and blowout development on the windward slope.

Sediments in the dune are fine to medium sand, well-sorted and negatively skewed with mean size ranging from 0.20 mm to 0.27 mm (Table I). Most sedimentary structures exposed in road cuts and sand pits showed planar bedding dipping parallel to the lee slope at angles ranging from 23° to 32° (Fig. 4). Individual laminae could be traced for 5 m or more and there appeared to be little disturbance of the bedding. Some cross-stratified units dipping westward were also observed in a few places near the ridge crest, and these also had steep dip angles, ranging from 20°-30°. Because of the limited grain size variation and absence of distinct heavy mineral layers, sedimentary structures were often extremely difficult to distinguish.

WESTERN DUNE SERIES

The dunes found on the sand plain to the west of the large ridge described above, span elevations from about 190 m to 183 m and are associated with the post-Nipissing shoreline regression. They have a transverse ridge form with steep lee slope and more gentle windward slope. In contrast to the eastern dune ridge, they are generally less than 5 m high. The largest ridges are located close to the eastern boundary of the study area, and these are relatively straight and aligned parallel to the general trend of the coastline. Dune height decreases towards the modern shoreline, and the ridge pattern on aerial photographs shows an increasing tendency to curve around the major modern embayments such as Howdenvale Bay and Red Bay (Fig. 1). While the continuity and pattern of the ridges is evident on the vertical aerial photographs, individual ridges can seldom be traced for more than a few hundred metres on the ground.

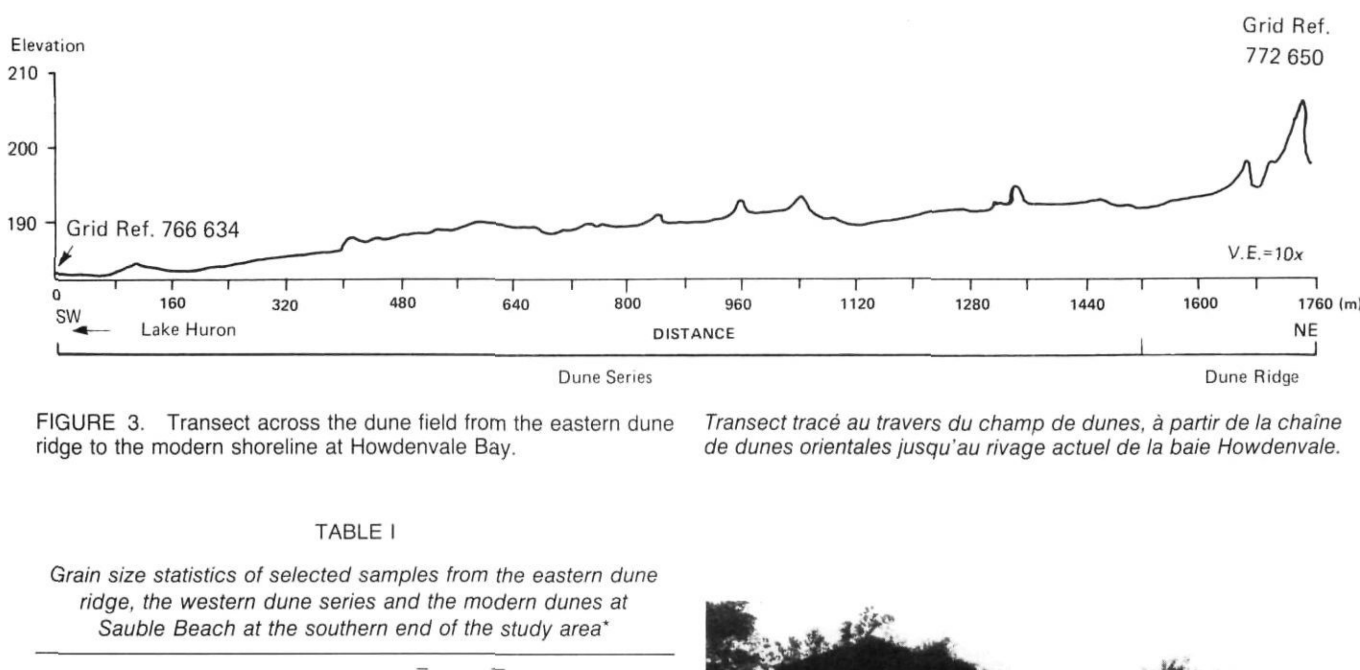

FIGURE 3. Transect across the dune field from the eastern dune ridge to the modern shoreline at Howdenvale Bay.

Transect tracé au travers du champ de dunes, à partir de la chaîne de dunes orientales jusqu'au rivage actuel de la baie Howdenvale.

TABLE I

*Grain size statistics of selected samples from the eastern dune ridge, the western dune series and the modern dunes at Sauble Beach at the southern end of the study area**

Location	$\bar{\chi}$ (CHI)	$\bar{X}$ (MM)	σ	Sk
S3, Dune crest, E. dune ridge	5.72	0.21	0.39	−4.88
S8b, Leeward slope, E. dune ridge	5.57	0.22	0.58	−1.62
S10, Dune crest, E. dune ridge	5.25	0.27	0.43	−1.12
S12, Dune crest, W. dune series	6.00	0.18	0.44	−4.92
C1a, Dune slack, W. dune series (depth 0.20 m)	5.87	0.19	0.56	−3.34
C1b, Dune slack, W. dune series (depth 0.6 m)	4.50	0.41	0.63	+0.91
S15, Dune crest, modern dunes, Sauble Beach	5.89	0.19	0.36	−0.70

* The statistics were calculated using the method of moments on the Chi log transform of settling velocity (May, 1984). The millimetre equivalent of the mean grain size was determined using the equation of Gibbs *et al.* (1971). Note the similarity of all the samples except C1b, which is interpreted to be a beach deposit.

FIGURE 4. Photograph of planar bedding in a pit located on the leeward slope near North Oliphant Road.

Photographie d'une stratification plane dans une sablière située sur la pente sous le vent près de North Oliphant Road.

Sediments exposed in road cuts generally appeared structureless, though in some areas indistinct, sub-horizontal parallel lamination was present. The size characteristics of samples taken from the dune crests and the surface of the interdune swales were similar to those of the eastern dune ridge and also to samples taken from the modern foredunes at Sauble Beach (Table I). Sediments exposed at the base of one core and in several pits in the interdune areas were much coarser (Table I), with interbedded units of lakeward-dipping coarse and medium sand, and some units of ripple cross-stratification. These were interpreted as beach sediments, deposited on the swash slope and near the step.

FORMATION OF THE DUNE FIELD

Coastal sand dunes form adjacent to a beach where there is an adequate sand supply and where wind velocities exceed the threshold for sediment transport on at least some occasions during the year. Sediment supply depends on: (1) the volume of sediment supplied to the beach from offshore, alongshore, and from rivers; and (2) the existence of a wide, vegetation-free backshore from which sand can be transported inland. In the study area the numerous offshore reefs and islands presently restrict wave energy reaching the shoreline, and as a result beaches are narrow, with poorly sorted sediments and little or no dune development. However, at the height of the Nipissing transgression the bedrock ridge which forms the present offshore islands was completely submerged and the shoreline exposed to high waves generated over fetches of 200 km or more (Fig. 5). This would have led to removal of fines offshore, and the development of a wide sandy beach and backshore similar to that found on the modern Sauble Beach just to the south of the study area. The Nipissing shoreline must have been relatively straight and uncompartmentalized. Indeed, the continuity of the eastern dune ridge itself can only be a reflection of the presence of a continuous sand beach, and the effects of increased compartmentalization of the coast as water levels fell from those of Lake Nipissing can be seen in the decrease in height and continuity of dunes towards the modern coast.

The lobate protuberances and sinuous form of the eastern dune ridge as well as the internal structure of the lee slope (Fig. 4), all indicate considerable lee slope accumulation and thus some landward migration of the ridge. However, because the ridge is so narrow and since it's elevation nearly coincides with the maximum extent of the Nipissing transgression, it is unlikely that migration took place for very long or over any great distance after the end of the transgression. Indeed, the ridge form and sedimentary structures are consistent with

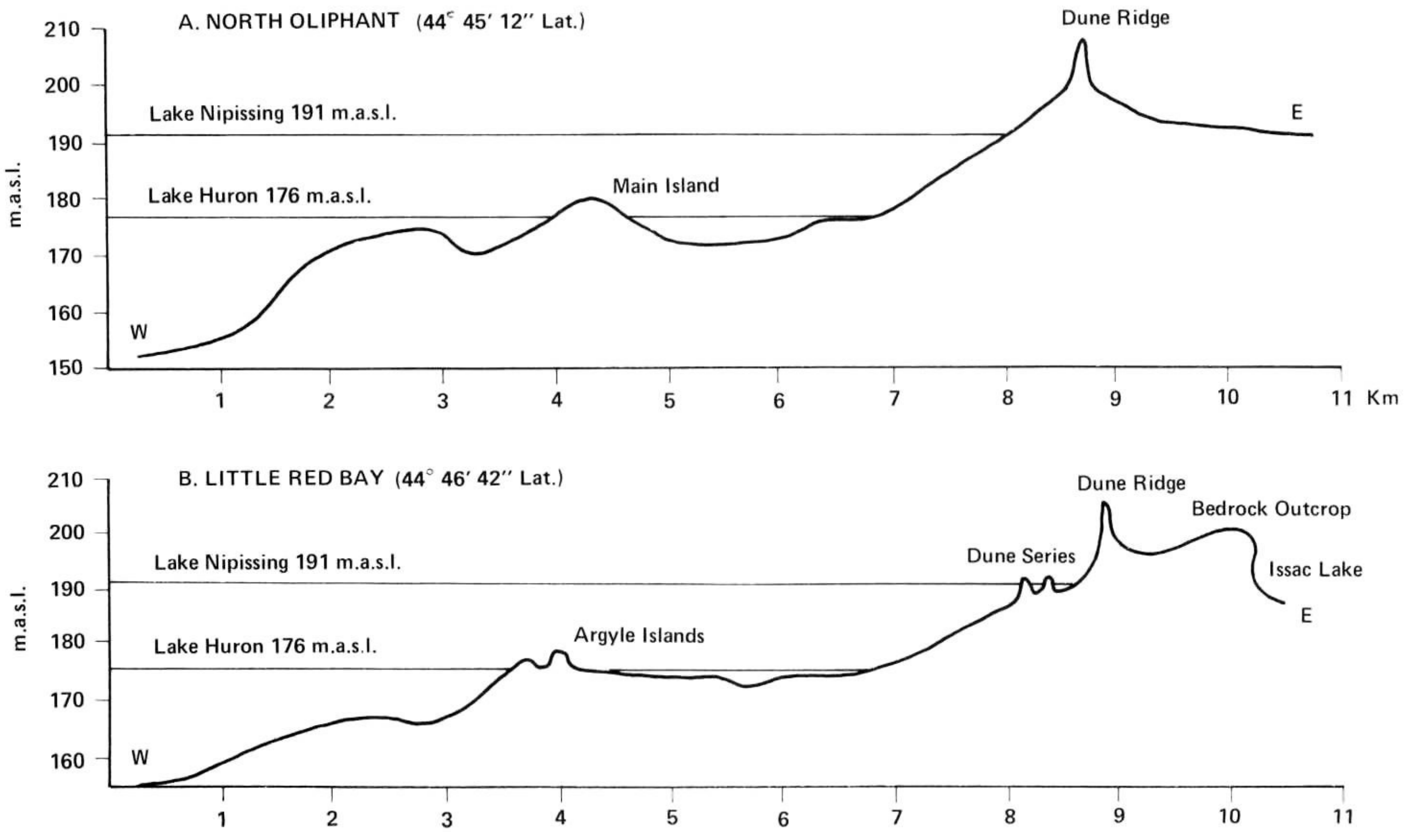

FIGURE 5. Profiles across the dune field and nearshore at two locations, illustrating the effects of lake level changes on shoreline exposure. The profiles are based on the 1:50,000 topographic map and 1:75,000 hydrographic chart of the area.

Profils tracés au travers de la chaîne de dunes et de la basse plage à deux endroits, qui démontrent les effets des changements du niveau lacustre sur le dégagement de la ligne de rivage. Les profils ont été dessinés à partir de la carte topographique à 1/50 000 et de la carte hydrographique à 1/75 000.

migration induced by the slow landward movement of the shoreline at the end of the transgression, with the windward slope in continuous contact with the beach. This, together with the height of the ridge (particularly in comparison to the dunes west of it) and the absence of eolian sediments to the east of it, all suggest that the ridge was not able to migrate freely, and that it may have formed as a precipitation ridge.

Precipitation ridges occur when transgressive dunes advance into a forested hind dune area (Buffault, 1942; Cooper, 1958; Goldsmith, 1978; Hunter *et al.*, 1983; Pye, 1983). The presence of trees ahead of the advancing dune enhances the deposition ("precipitation") of sand at the top of the lee slope, promoting vertical accretion and preventing rapid deflation of sand beyond the base of the dune. The ridge thus advances slowly, burying the trees and vegetation in its path. While no evidence of buried trees was found in the sections examined, little organic material is preserved above the water table in the freely draining dune sands. On the other hand, at the time of the Nipissing transgression forest vegetation was well-established in southern Ontario and there seems little reason to suppose that trees were not present landward of the transgressing shoreline. It is also worth noting that, in this freshwater environment, salt tolerance is not a major control on tree growth close to the beach.

There is no present source of river sediments in the study area or on the Bruce Peninsula to the north. Sediments from the Sauble River are transported southward (Ayers *et al.*, 1956) and the much more extensive dune development in that area suggests that this was also the case during the Lake Nipissing interval. However, some sediment transport northward may have occurred, since fetch lengths to the southwest are nearly equal to those to the northwest. Within the study area beach sediments were probably derived largely from sediments brought onshore during the Nipissing transgression, from reworking of older glacial and glacio-fluvial sediments, and from some longshore transport from the area to the north.

The volume of sediment available for dune building at the end of the transgression would have been quite large initially. However, the supply of sediment from offshore would have decreased as sediment stored in shallow water was exhausted and an equilibrium profile established. The scarcity of sandy sediments to the north of the study area suggests that sediment supply through longshore sediment transport also decreased through time. This probably accounts for the much more restricted dune development in the study area compared to other Nipissing dune systems such as those at Wasaga Beach (Martini, 1975) and Grand Bend (Cooper, 1979) where there was continuing input of sediment from rivers and longshore drift. During the regression phase, supply of sand to the dunes would have been further reduced by the increased compartmentalization of the coast and the sheltering effects of the emerging offshore islands, as reflected in the low height of the western dunes.

Based on the evidence presented above, it is possible to identify stages in the formation of the dune field in the study area, and these are illustrated schematically in Figure 6. The four stages can be summarised as follows:

Stage A — Near the end of the Nipissing transgression rising lake levels overtop the bedrock ridge, and sediment is swept onshore through channels between the islands. Wave energy at the shoreline increases, leading to the formation of a continuous sandy beach.

Stage B — A transverse dune ridge is established landward of the beach and grows rapidly because of the abundant sediment supply. Instability, promoted by the continuing slow rise in lake level, prevents progradational foredune development and results in a continuing supply of sediment to the dune crest. The presence of trees ahead of the dune promotes precipitation of sand at the top of the lee slope, encouraging vertical growth and restricting landward migration.

Stage C — At the beginning of the Nipissing to Algoma regression, stable dunes develop lakeward of the main dune ridge, protecting it from further instability and cutting off sediment supply.

Stage D — As water levels recede, a series of transverse dunes is formed on the emerging plain. The alongshore continuity of the transverse dune ridges decreases as the shoreline becomes compartmentalised, and dune height is restricted by the overall decrease in sediment supply from offshore and alongshore, and the reduced beach width resulting from the sheltering effect of the emerging offshore islands.

DISCUSSION

The sequence of events oulined in the model above reflects the interaction of several major controls on the development of coastal dunes, including: the volume of sediment supply to the beach; the role of foredune growth and stabilization by plants; and the effects of transgression or regression on dune development and stability. These are discussed briefly here in the context of the proposed model and their implications for dune development elsewhere.

Sediment supply for dune formation represents a loss to the littoral sediment budget (Bowen and Inman, 1966), so development of an extensive dune field necessitates the continuing replenishment of beach sediments. In the study area it is evident that overall sediment supply to the beach decreased through time, accounting in part for the restricted dune growth during the post-Nippissing regression. The indirect role of wave exposure, through it's control of beach width and sediment sorting, has also been recognised (*e.g.* Short and Hesp, 1982), although it has not been studied quantitatively. However, the role played by changing exposure is readily apparent in the contrast between the absence of modern dune development along the present shoreline in the study area and the active dune development behind the exposed beach at Sauble Beach just to the south.

The significance of transgressions and regressions for dune formation has been the subject of some debate. Cooper (1958) suggested that transgressive dune instability phases were associated with sea-level rise and shoreline erosion, and recent work by Pye and Bowman (1984) supported this view. However,

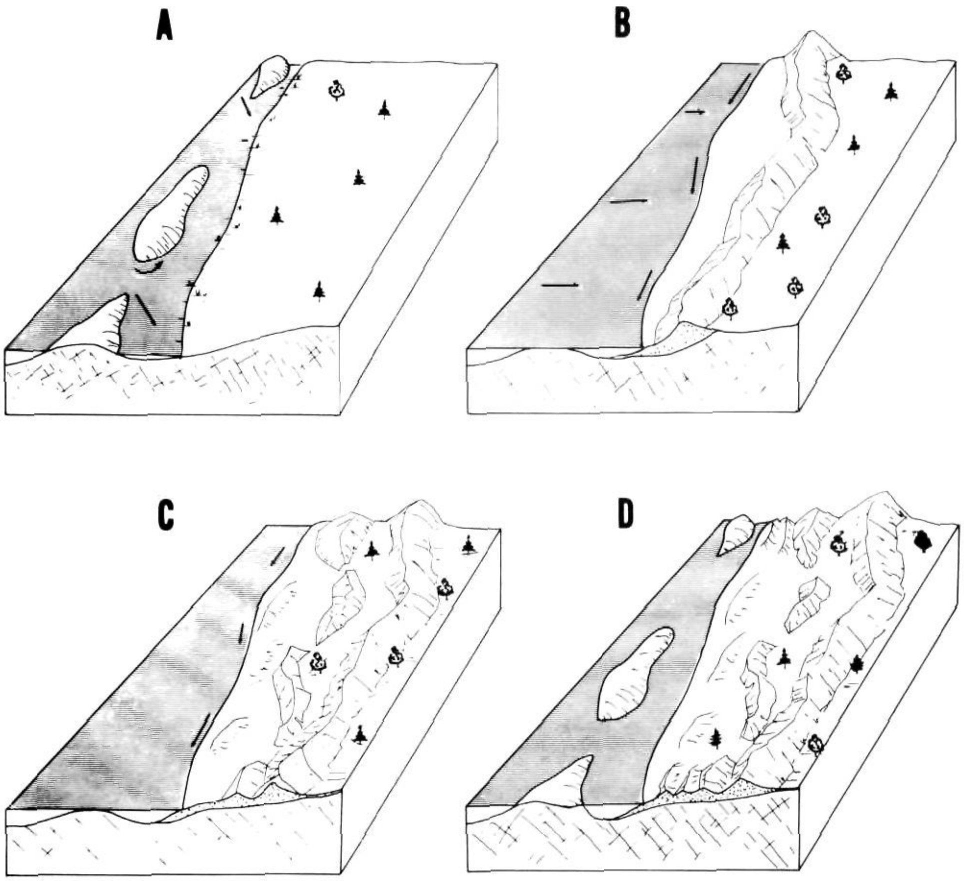

FIGURE 6. Stages in the formation of the dune field: A) Submergence of bedrock ridge near the end of the Nipissing transgression and onshore movement of sediment; B) At the end of the transgression a continuous, exposed beach is developed, with sediment supplied from onshore and alongshore transport. A transverse dune forms and migrates landward as water levels rise slowly; C) During the regression towards the modern lake level, the eastern dune ridge is stabilised and small transverse dunes are formed lakeward of it as sediment supply diminishes; D) Emergence of an offshore bedrock ridge protects the modern shoreline from high wave action, further reducing sediment supply for new foredune growth.

Les stades de formation du champ de dunes: A) Submersion de la crête rocheuse vers la fin de la transgression de Nipissing et transport de sédiments vers la rive; B) À la fin de la transgression, une plage continue et découverte se développe, l'alimentation en sédiments se faisant par un transport littoral et du large. Une dune transversale se forme et migre vers l'intérieur au fur et à mesure du relèvement du niveau lacustre; C) Au cours de la régression vers le niveau lacustre actuel, la crête de dunes orientales se stabilise et de petites dunes transversales se forment du côté du lac à mesure que diminue l'alimentation en sédiments; D) L'émersion d'une crête rocheuse protège le rivage actuel de l'action des vagues, contribuant ainsi à réduire davantage l'alimentation en sédiments nécessaires à la formation d'avant-dunes.

others (*e.g.* Roy and Thom, 1981) have associated periods of instability with low sea level and large areas of exposed sediment. In a more limited time frame, Richie (1972) and Schofield (1975) have associated periods of dune development with minor regressions and shoreline progradation. In this study, the high level of Lake Nipissing was obviously important in the development of a continuous, exposed sandy beach. We further suggest that the transgression was important for two other reasons: 1) reworking of glacial sediments during the transgression provided an abundant supply of sand to the beach, and thus for dune growth; and 2) the instability associated with periodic foredune cliffing enhanced sediment supply to the eastern dune ridge, promoting vertical growth and some landward movement. This effect is similar to that, on a much shorter time scale, associated with the rising phase of 10-20 year lake level cycles (Olson, 1958c). Once the transgression ceased and regression ensued, new foredune growth and stabilisation cut off the supply of sediment to this dune. Similar large dune ridges associated with the Nipissing transgression are found along the eastern and southern shore of Nottawasaga Bay (Davidson-Arnott *et al.*, 1982), at Wasaga Beach (Martini, 1975), and at Grand Bend on Lake Huron (Morrison, 1973; Cooper, 1979). Thus, the Nipissing transgression in the Huron, Michigan and Georgian Bay basins resembles closely the post-Pleistocene marine transgression and led to the initiation of a number of dune fields and barrier systems. In addition, the instability associated with the rising water levels appears to have been responsible for the generation of transgressive dunes, and thus lends support to the ideas of Cooper (1958) and Pye and Bowman (1984).

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