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# Shoreline Inheritance in Coastal Histories

## The significance of "inheritance" on Lake Superior shorelines in Cook County, Minnesota, is discussed.

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The reoccupation of a former water-level position by a later water level is not uncommon in the history of shoreline development, and many portions of the world's coastline are now recognized as polygenetic in their form. Early references to instances in which the modern tidal foreshore was observed to continue beneath till (*1*) led to later general recognition of the exhumed and "inherited" nature of the present tidal platform in western Britain, and similar observations have since been made in many other areas. Thus the freshness of presently wave-washed forms can provide a deceptive measure of effective wave activity (*2*) from which erroneous conclusions may be drawn concerning the environments in which remnant raised shoreline forms were developed. The significance of inheritance is that former erosional and depositional forms are modified and freshened such that their present character bears no direct relationship to any one of the earlier periods of wave margin occupation; the present form does indicate the composite effects of earlier shoreline forms, masked perhaps by the most recent and transitory modifications. The recognition of inheritance in coastal histories has a considerable bearing on the interpretation of paleoenvironments based on the observation of relict forms, and, where it has been shown that elements of the shore are not the product of a single, sea-level phase, Quaternary chronologies have had to be revised (*2*).

Few freshwater, nontidal lakes are of sufficient size and antiquity to have experienced prolonged periods of active shore-forming processes. However, lakes occupying the Superior Basin have oscillated over a 200-meter vertical range during the last 11,000 years (*3*); although evidence of wave cutting of rock features is relatively minor, wave action has been sufficient to mark the coastal slopes with a staircase of bluffs and accumulation forms in superficial tills and fluvioglacial materials. Even though the coastal history of this area is known in outline, the significance of inheritance has not been appreciated (*4*). The coast of Cook County, Minnesota, exemplifies a case in which a recognition of inheritance is important to paleoenvironmental interpretation of both that area and the Superior Basin as a whole.

### The Study Area

Sharp's work on the glacial deposits (*5*) and the former shorelines (*6*) of Cook County remains the most detailed statement available on the area. His diagram of isostatically tilted shorelines was revised considerably in the more extensive work on shoreline deformation of Farrand (*7*), but very little further attention has been given to Sharp's observations of specific coastal features and the conditions under which they formed. Much more is now known of the postglacial history of the basin margins.

The axis of isostatic deformation during the post-Wisconsin period lay parallel to the Minnesota coast of Lake Superior (Fig. 1, inset), and deglaciation proceeded from the southwestern end of the basin toward the northeastern shore. Since about 11,500 years before the present (B.P.), the retreat of the Wisconsin ice front successively revealed the Minnesota coast from under ice and submerged it by a succession of ever larger but lower proglacial lakes; the first lake to occupy the area of the present lake was Lake Minong (9500 years B.P.) (*3, 7–9*). Continued rapid uplift on the northeastern shore resulted in a succession of post-Minong lakes, marked by a staircase of abandoned shoreline features between 300 m and the present lake level (183.6 m), despite oscillations of the water level. However, on the Minnesota shore where the Minong shore now lies at an elevation of only 207 m, the rate of uplift was at times less rapid than the oscillations of the lake level, and in place of a history of continuous relative water-level decline an alternation of relative regression and transgression occurred.

Of particular significance is a low stage of the water level, that is, Lake Houghton, an event unrecognized by Sharp (*7*). After the rapid decline of the lake level from Lake Duluth (11,000 years B.P.; initial level, 315 m) to Lake Minong (9500 years B.P.; initial level, 128 m), the water level continued to decline with the erosion of the Sault Ste. Marie threshold until by 8000 years B.P. Lake Houghton was formed (initial level, 114 m). By about 7000 years B.P. water levels in the Huron and Michigan basins reached the level of the Sault threshold and initiated a transgressive phase of water-level rise which culminated about 5500 years B.P. with the formation of Lake Nipissing (initial level, 185 m) (*9*).

Because of a decreased rate of uplift on the Minnesota coast, the Nipissing transgression submerged the Houghton and Minong shorelines southwest of Grand Marais, and in Cook County it submerged the Houghton but reoccupied the Minong shore. The rate of uplift to the northeast of Thunder Bay was such

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that relative regression continued, and the Nipissing shoreline occurs below the altitude of both Lake Houghton and Lake Minong on the north shore (*7*). Subsequent deformation has raised the Nipissing shoreline 40 m above the present water level on the north shore, although it is only a meter or so above the present water level on the south shore. The water level declined slightly after the Nipissing, the Algoma phase (3200 years B.P.; initial level, 181 m) being preserved by uplift in the northeast, although very close to present storm levels in Cook County. A subsequent slow rise to the present water level (183.6 m) has been transgressive on most of the Superior shore, with consequent erosion of the margins of earlier shoreline forms.

Along much of the coast of Cook County the land rises to over 480 m within a few kilometers of the shore. Steep coastal slopes and resistant Precambrian rock types have caused the higher shorelines to be indistinct, but, because the ground near the present shore is less steep, there has been much better development of the Minong and Nipissing shorelines. It is in these locations that abandoned wave-cut cliffs and beach ridges are commonly found (Fig. 1). In this article I deal with the relationship between the Minong and Nipissing shorelines, the character and origin of the beach ridges, and the nature and age of the presently washed rock platform.

**The Minong-Nipissing Inheritance**

Nipissing features are frequently referred to as being more distinct than those of other former shorelines. Sharp (*6*) reported that the Nipissing shore was marked by a prominent wave-cut rock cliff 10 m high between Grand Marais and the Brule River, but he noted that, since some present rock cliffs reach a similar magnitude, the well-developed cliff might reflect rock hardness, structure, or exposure to wave attack rather than a particularly lengthy period of wave action during the Nipissing.

Reconstruction of Highway 61 in the late 1960's damaged many Nipissing features but revealed stratigraphic evidence of shoreline inheritance. In many locations the base of the Nipissing cliff is obscured by angular talus materials on which the uppermost beach ridges are formed, and at Kodonce Creek the Nipissing cliff is wholly cut in this material which locally masks the bedrock. A gully located 1 kilometer south of the creek reveals a stratum of beach cobbles in a fine sand matrix underlying the angular debris. Wave action took place against the bedrock cliff before the accumulation of the overlying debris and before reoccupation by the Nipissing lake margin. A nearby bay-headland site reveals a talus-covered cliff and rock platform on which a thin, well-sorted sand stratum is preserved, the upper limit of the Nipissing again being formed on talus material in the embayment. At Kimball Creek a road cut reveals a beach boulder stratum at the base of the rock cliff. One may thus conclude that along this length of coast the prominent Nipissing cliff is more the result of the inheritance of preexisting rock forms than of particularly effective wave activity during the Nipissing phase. Farrand (*7*) made no mention of the lower shorelines of this area although his shoreline diagrams show the close convergence of the Minong and Nipissing shorelines near Grand Marais. Since the Deronda (Minong) shore was identified by Sharp as lying a few meters above the Nipissing rock cliff at Kodonce Creek, one can conclude that the initial freshening of the rock step and the deposition of beach cobbles took place during the post-Minong regression, and the overlying rock debris accumulated

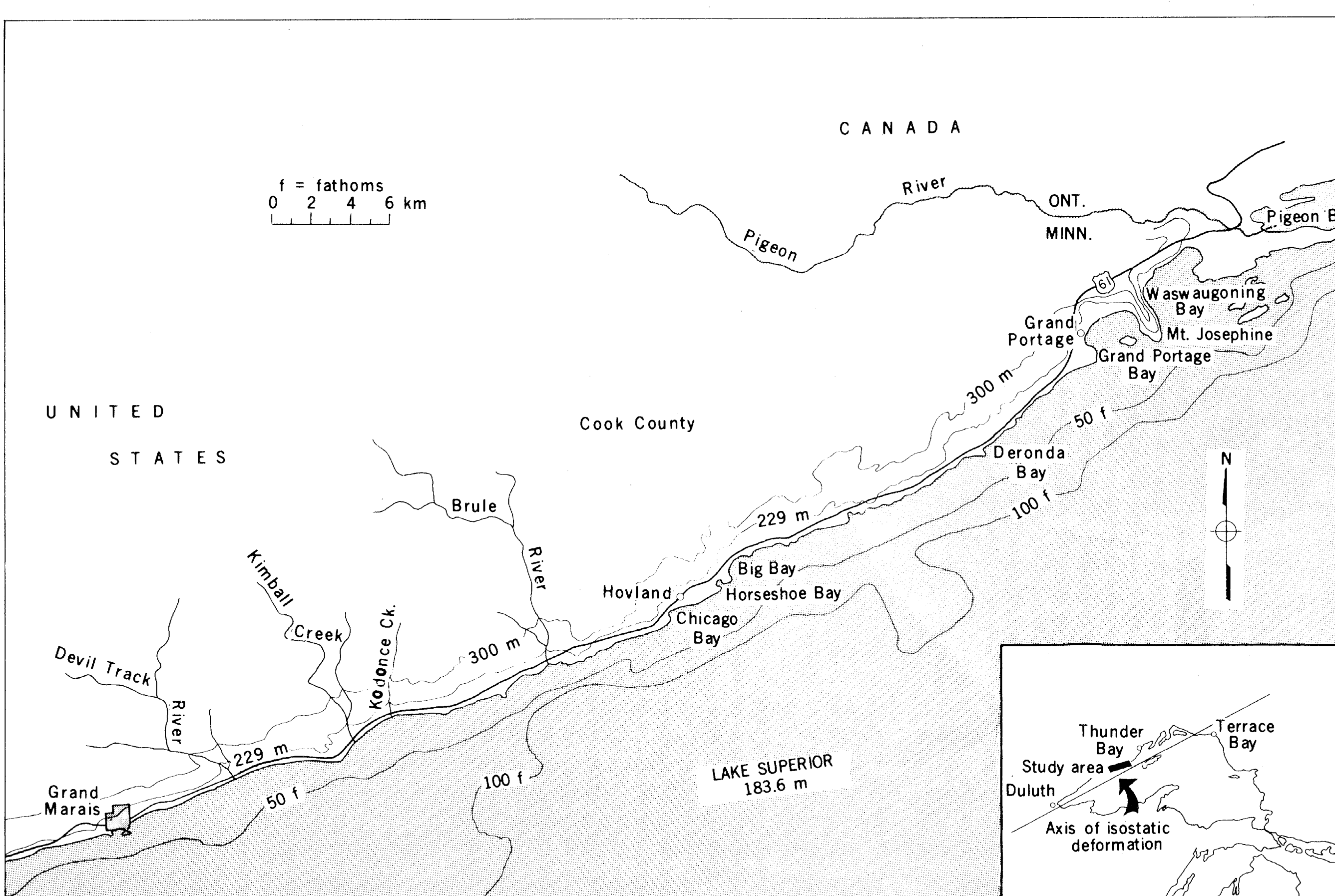


Fig. 1. Location map of northern Minnesota.

by weathering and mass wasting in the lengthy period before transgression from the Houghton low level. That this sequence of events was characteristic in fashioning the lower abandoned shorelines of Cook County is supported by observations at Horseshoe Bay and Deronda Bay (Fig. 1).

At Horseshoe Bay, Sharp (*6*) recorded a Deronda (Minong) gravel deposit at 205 m and a Nipissing beach ridge at 195.2 m. Farrand (*7*) included no description of Minong or lower shores between Hovland and the Canadian border, but interpolation of his shoreline diagram implies that at Horseshoe Bay the Minong should lie at 201.3 m and the Nipissing at 192 m. Both workers relied on hand leveling and altimetric survey but claimed a reasonable accuracy for the determination of deformation curves. Sharp noted that local conditions alone could cause the features of one water plane to vary by as much as 3 m. Figures 2 and 3 are the result of careful mapping and the use of a spirit level and topographic staff. Datum was the present calm water level, corrected by reference to the *Monthly Water Level Bulletin* (*10*).

The major features of Horseshoe Bay are a broad sand and gravel ridge, which crests at a maximum of 197.2 m, and a succession of boulder ridges formed between it and the present shore. The sand and gravel ridge, a Minong feature, emerges from the eastern coastal slopes and becomes a well-defined ridge before it terminates in a landward-facing embayment in the southwestern rock wall (Fig. 2). The ridge appears to be a wave accumulation form composed of materials winnowed from the veneer of ill-sorted, wave-modified till which blankets the slopes above. The material is stratified, and longshore transport to the southwest is suggested by the nature of the termination near the rock wall. The Nipissing ridges are composed entirely of subrounded boulders derived from the rock wall and transported northeast partly around the bay. The size mode of the boulders is 15 centimeters, the disintegration characteristics of the diabase being remarkably consistent. The uppermost boulder ridges are deposited on top of the lakeward face of the sand and gravel ridge (Figs. 2 and 3, profile 2), a relationship shown well in the pit wall. The juxtaposition of the two facies is unlikely to represent the depositional environment of a single water level phase, and although the shoreline sequence appears to be continuous, a situation of inheritance is being observed. At the time Lake Minong washed the bay, material the size of sand and gravel was readily available, and the present ridge may be the lone survivor of a number of similar features formed as the lake level declined toward the Houghton low. Before the Nipissing transgression, in freeze-thaw seasons of a warming climate, large quantities of talus materials must have been loosened from the rock walls. Then, by wave action both during transgression and the subsequent relative regression, the materials were transported and fashioned into ridge and swale forms. The abandoned beach face of the Minong ridge was temporarily inherited by the Nipissing, and material of the type then available was added to it.

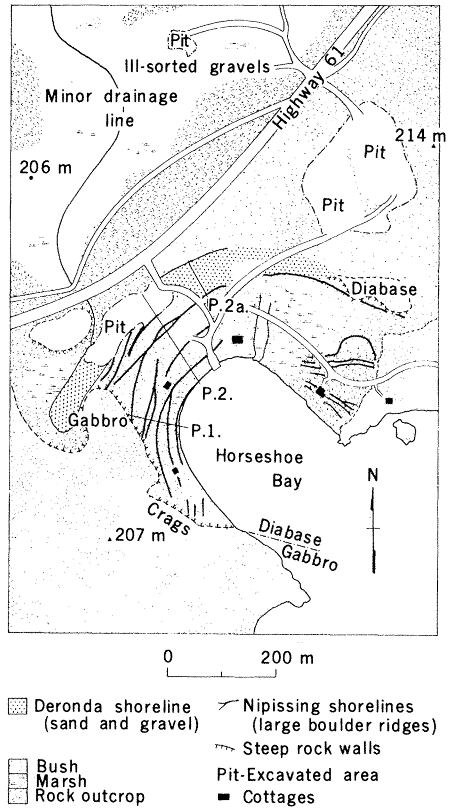


Fig. 2. Geomorphological map of Horseshoe Bay; for an explanation of *P.1.*, *P.2.*, and *P.2a.*, see Fig. 3.

Deronda Bay (Fig. 1) was examined by Sharp but was not referred to by Farrand. Sharp (*6*) included a sketch map of this area and named his Deronda (Minong) shoreline from this location. Figure 4 is the result of tape and compass mapping and a series of leveled traverses.

The major feature of Deronda Bay is what Sharp referred to as a "large beach ridge." From the base of bedrock slopes near Hollow Rock, 2 km northeast, a sand and gravel ridge runs southwest, crossing the flat, marshy Deronda embayment. Varying in width from 50 to over 150 m, the ridge maintains an elevation just below 200 m and rises 6 to 8 m above the marshland. Even though much modified by sand and gravel extraction, remaining parts of the ridge are asymmetrical, a steeper landward face of up to 26° being typical. The feature is of a magnitude such that the term "beach ridge" is inappropriate, although its bedded structure points to an origin by wave accumulation. Near Hollow Rock the feature suggests an initial fluvioglacial or ice marginal origin, and it seems likely that during late Minong times longshore transport of these materials built a spit-platform structure across the bay in shallow waters. The declining water level abandoned the feature after the former lakeward subaqueous slope had been modified by wave action.

The Nipissing transgression temporarily inherited the lower part of the lakeward face of the Minong feature, certainly to an elevation of 197 m. At this elevation the summit of a group of rock

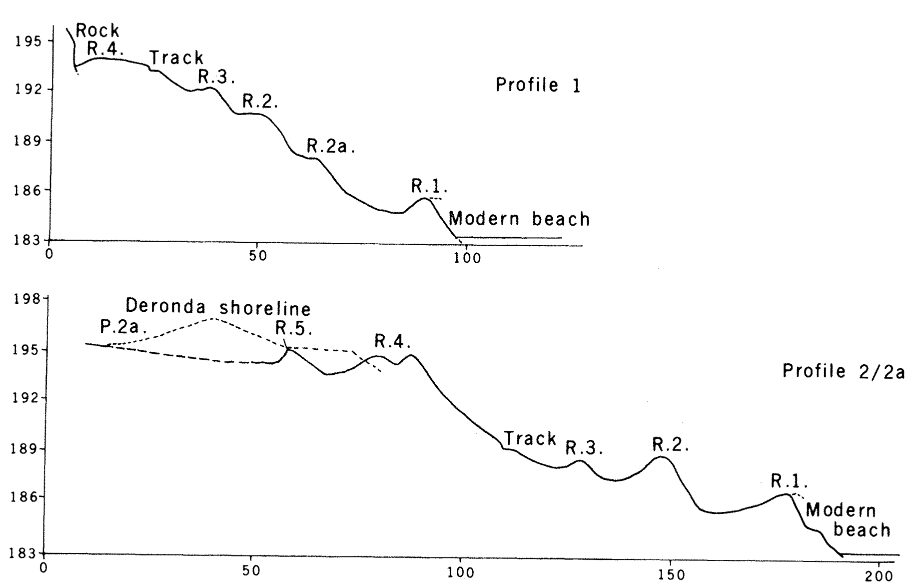


Fig. 3. Profiles across beach ridges (*R.*) at Horseshoe Bay (dimensions are in meters).

outcrops would have formed a small island about 650 m offshore. As the post-Nipissing water level fell, wave refraction around the emerging island induced longshore transport in opposing directions along the face of the Minong ridge, and two large tombolo structures were formed, both cresting at 194.6 m. Only the Nipissing tombolos are composed of sand and gravel; all other Nipissing and later features were constructed from coarse materials derived from the island complex. The contrast in the form and materials of the early Nipissing features is thus the result of inheritance.

### The Post-Nipissing Beach Ridges

These rock islands are composed of deeply weathered diabase which readily disintegrates into angular fragments 3 to 10 cm in diameter, and the outcrops are surrounded by a large volume of rock debris which infills the spaces between them to depths of 1 to 4 m. The surface of this locally derived material is fashioned into beach ridges. Figure 4 shows the positions of the ridges in the area. A comparison of profiles across the ridges illustrates that lateral and vertical correlation of the ridges is not realistic, even within small areas, the pattern involving branching, truncation, fading out, and some areas where there is no ridge development at all. Sharp (*5*) noted that ridges may be built in a relatively short time during storms and do not necessarily indicate a stability of a water plane. He also noted that ridges are built to heights a few feet above the mean water level. The pattern of ridges leaves no doubt that the beach ridges are the product of wave activity, for there is a detailed response to changing wave refraction as successive outcrops emerged. In almost every case the first ridge to form between islands and new shoals was one worked on by waves from both sides. Such tombolo structures are initiated by subaqueous accumulation, a platform being constructed ahead of a prograding subaerial spit form (*11*). It follows that the "beach ridge" pattern involves the formation of both offshore bars and beach forms, the former being modified by direct wave action as the water level declined. No equivalency in the number of ridges or correlation of individual ridge elevations between bays should be expected. However, the beach ridges represent the final action of waves during and since the Nipissing and are only superficial forms on the surface of large volumes of accumulated rock debris.

Since beach ridges are frequently interpreted as "storm beach ridges" (*12*) and much rock debris has obviously been transported from the rock outcrops, some investigators have concluded that the Nipissing and post-Nipissing periods were times of very effective storm-wave activity. Figure 4 confirms that those areas facing inland have beach ridges despite their very sheltered situation, and the volume of rock debris is distributed well away from the rock outcrops.

However, in some places beneath the beach ridges several meters of beach material rest on a glaciated rock surface on which remain large erratic boulders (Fig. 5). These represent the lag deposit derived from the red tills of the coastal area. That a declining wave margin would have almost simultaneously washed out a till cover, transported and distributed a large volume of local rock debris, and fashioned the surface of the materials into ridge and swale forms is improbable.

The composite nature of the areas of beach ridges is clearly demonstrated. Although the ridges themselves are an in-

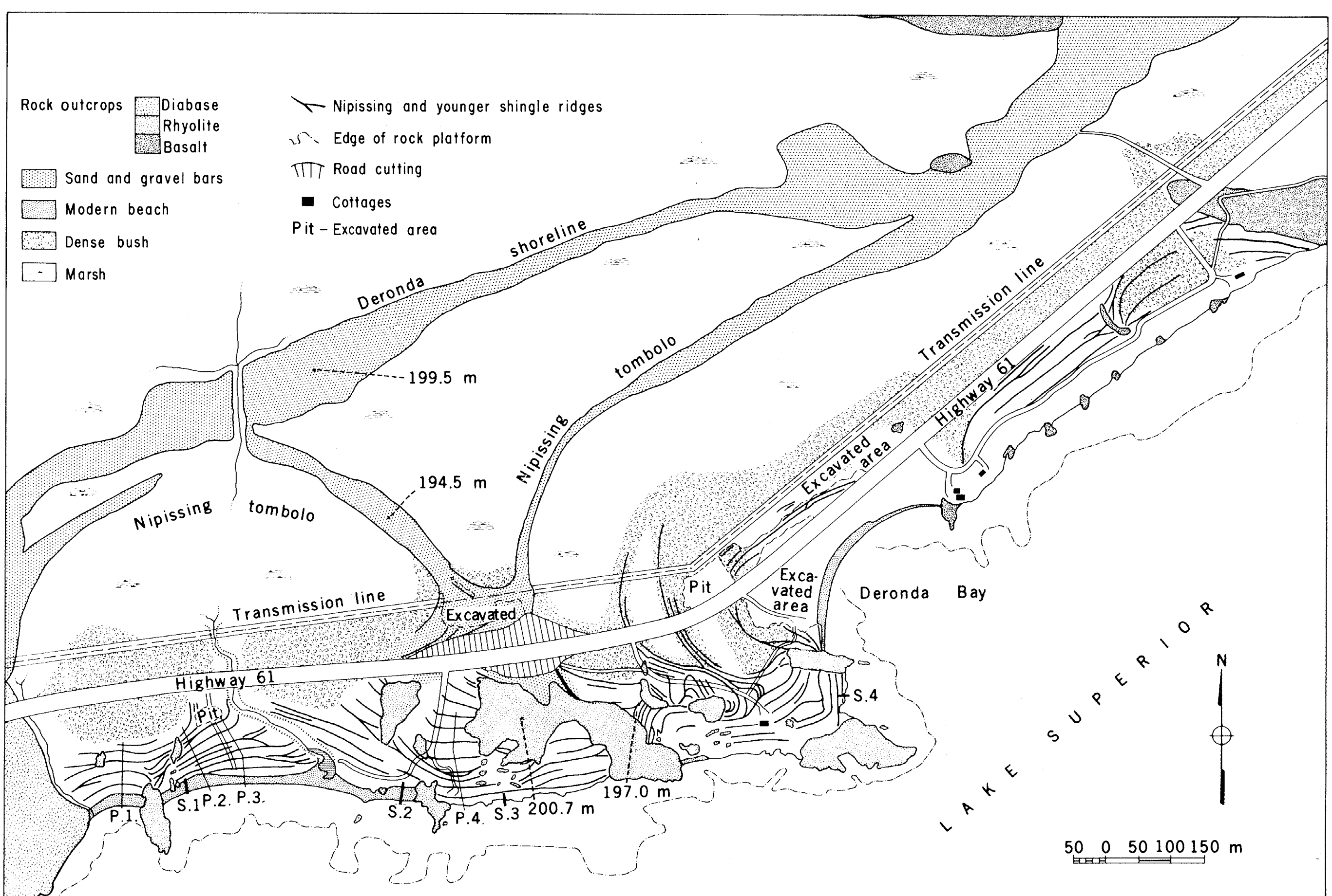


Fig. 4. Geomorphological map of Deronda Bay; for an explanation of *S.1.*, *S.2.*, etc., see Fig. 6.

dication of Nipissing and post-Nipissing wave activity, the mode of transport and the volume of material accumulated are not. It is probable that the till cover was largely removed during the decline of the water level to the Houghton low. The exposed weathered bedrock then became much broken during the period before the Nipissing transgression, and the waves of that water margin found abundant material available for distribution. The advancing water margin piled rock debris into embayments, burying part of the rock topography, somewhat like the sweepings before a broom (*13*). During the Nipissing and post-Nipissing period, the wave margin declined across existing accumulations of rock debris. With only minor transport involved in the construction of a ridge and swale topography, offshore bars and beach ridges were formed even in areas of relatively low energy. The fact of shoreline inheritance has endowed the Nipissing and post-Nipissing features with a character easily misinterpreted if conceived of as the product of those periods alone.

### The Present Shore and Platform

The emerged series of beach ridges does not extend to the present water level, a break of some form occurring on all profiles. Section 1 (Fig. 6) is typical. The modern beach is composed of well-rounded and sorted shingle and coarse sand derived directly from the raised beach materials by storm-wave erosion. The beach protects the raised features, although subject to rapid redistribution back and forth alongshore with changing wave conditions. Immediately offshore is a gently inclined rock platform on which there is little beach material. This platform appears to continue inland under the present beach and raised beach materials (section 2), and, when occasionally exposed on the foreshore, is seen to bear large well-rounded erratic boulders, some clustered in hollows and channels in the platform surface. The nature of the inland extension of this platform is shown in section 3 in which a sharp rock step divides the shore platform from the rock surface beneath the raised beach materials. Large erratic boulders can be seen partly exhumed from beneath beach material, resting on a fluted and striated surface (Fig. 5). The shore platform and small cliff appear very fresh in this section, although the platform was observed to pass laterally beneath raised beach materials in section 2 (Fig. 6). In several locations the shore

Fig. 5. Raised beach materials resting on a glaciated surface strewn with erratic boulders at Deronda Bay.

platform is overlain by a series of deposits lying under the raised beach materials (section 4). Excavation exposed minor differences between locations, but these deposits consist of a basal bed of rounded erratic boulders in a matrix of red clay and sand, overlain by thin, well-stratified coarse sand and gravel beds. The junction with the overlying local beach materials appears sharp in all cases, and certainly unconformable in one location (Fig. 7). I interpret the deposits, up to 2 m thick, as the residue of the wave-washed initial cover of red till. Section 5 (Fig. 6) summarizes the situation.

Underwater examination of the shore platform reveals a scatter of large erratic boulders resting on an otherwise bare rock surface which shows some signs of glacial fluting (Fig. 8). The junction of the platform with the base of rock stacks and promontories is often concealed by a jumble of boulders. Toward the lake, the platform terminates in an indented margin in 10 to 12 m of water about 100 m from the shoreline. In places it is cut by channels that are filled with boulders.

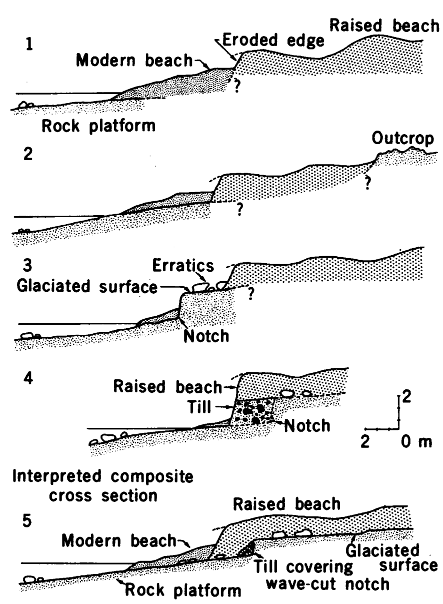


Fig. 6 (left). Sections across the modern shore at Deronda Bay. Fig. 7 (right). Drift remaining on the shore platform beneath raised beach materials at Deronda Bay.

Beyond the sharp margin the bottom slopes steeply, and echo traces and sampling reveal a red-brown silt floor beyond a belt of rock debris lying against the slope.

Although inherited and freshened by the present wave margin, the platform is not a modern element of the shore. Some recent ice rafting is possible, but the size and distribution of erratic boulders on the offshore portion suggest that they represent largely the residue of the washed till which still overlies parts of the upper portion of the platform. The platform predates the red till and could be dismissed as a glacially eroded surface. However, the lateral continuity of the surface across at least three rock types lacking horizontal structures, its sharp contact with the rock relief above water, and its absence in Deronda Bay itself make it most unlikely that ice erosion alone would have fashioned a gently sloping surface now coincident with water level after isostatic recovery. I conclude that the feature, although ice-modified, is a wave-cut platform.

Because the platform is overlain by till, the period of wave cutting must predate its deposition. I propose that the platform is of Sangamon age. The logic for this conclusion lies in the length of time required to cut a platform of these dimensions in resistant rock types and the present near coincidence with the water level after the completion of isostatic recovery. Even though no sediments of pre-Wisconsin age have yet been found on the Superior Basin floor (*14*), this finding does not negate the possibility that the basin existed during the earlier glacial phases. It is now recognized that the Lake Ontario Basin was occupied by a lake similar in size and shape to that of the present one in late Sangamon times (Lake Coleman), and it is suspected that a similar lake occupied the Erie Basin also (*15*). There is no reason why a lake in the Superior Basin in Sangamon times should not have been of similar elevation and size as that of present Lake Superior. It has been suggested that relatively little ice erosion took place on the shield and neighboring

Fig. 8. Erratic boulders resting on the offshore platform at Deronda Bay.

uplands (*16*), erosion being initially concentrated in drainage lines of the Tertiary surface and later in the developing series of basins lying peripheral to the ice centers, in which ice was thicker and lasted longer. It is unlikely that pre-Wisconsin sediments were entirely removed from the basin floor, although it is likely that the floor underwent much modification during the Wisconsin period. The survival of coastal rock features on the basin margins is not improbable, since relatively fragile forms, such as stacks, are known to have survived successive glaciations on the marine shores of northern Europe (*1, 2, 4*). I consider the suggestion that the Superior shore may contain elements inherited from an interglacial period realistic, and further examination of shore platform segments known to exist on the Minnesota and Ontario shore may provide further substantiation for this hypothesis.

## Conclusions

The reoccupation of a former water level position and the inheritance of its coastal features is an event recognized on world shores both where isostatic and eustatic controls have dominated relative sea level change. The postglacial history of water level change in the Superior Basin is more simple than on most marine coasts but includes the Nipissing transgression which had a differential effect alongshore as a result of relative isostatic uplift. In Cook County, the reoccupation of features of Lake Minong provided the Nipissing wave margin with a large volume of already wave-washed materials and existing bluffs and constructional forms. The ready modification of these features and the well-marked bluffs and beach ridges left by the subsequently declining waters have given the Nipissing and post-Nipissing periods an unearned reputation for being times of prolonged and effective wave activity. In addition, there is evidence to suggest that a longer-term inheritance of a former rock shore has taken place. The present lake margin occupies a well-developed, although glacially modified rock shoreline which predates local till and is possibly of Sangamon age. The fact that the ability of waves to cut extensive features in resistant rock and the ability of ice to easily erode rock surfaces have both often been overestimated in the past is testimony to the increased recognition of the significance of inheritance in the interpretation of marine and lacustrine coastal histories.

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