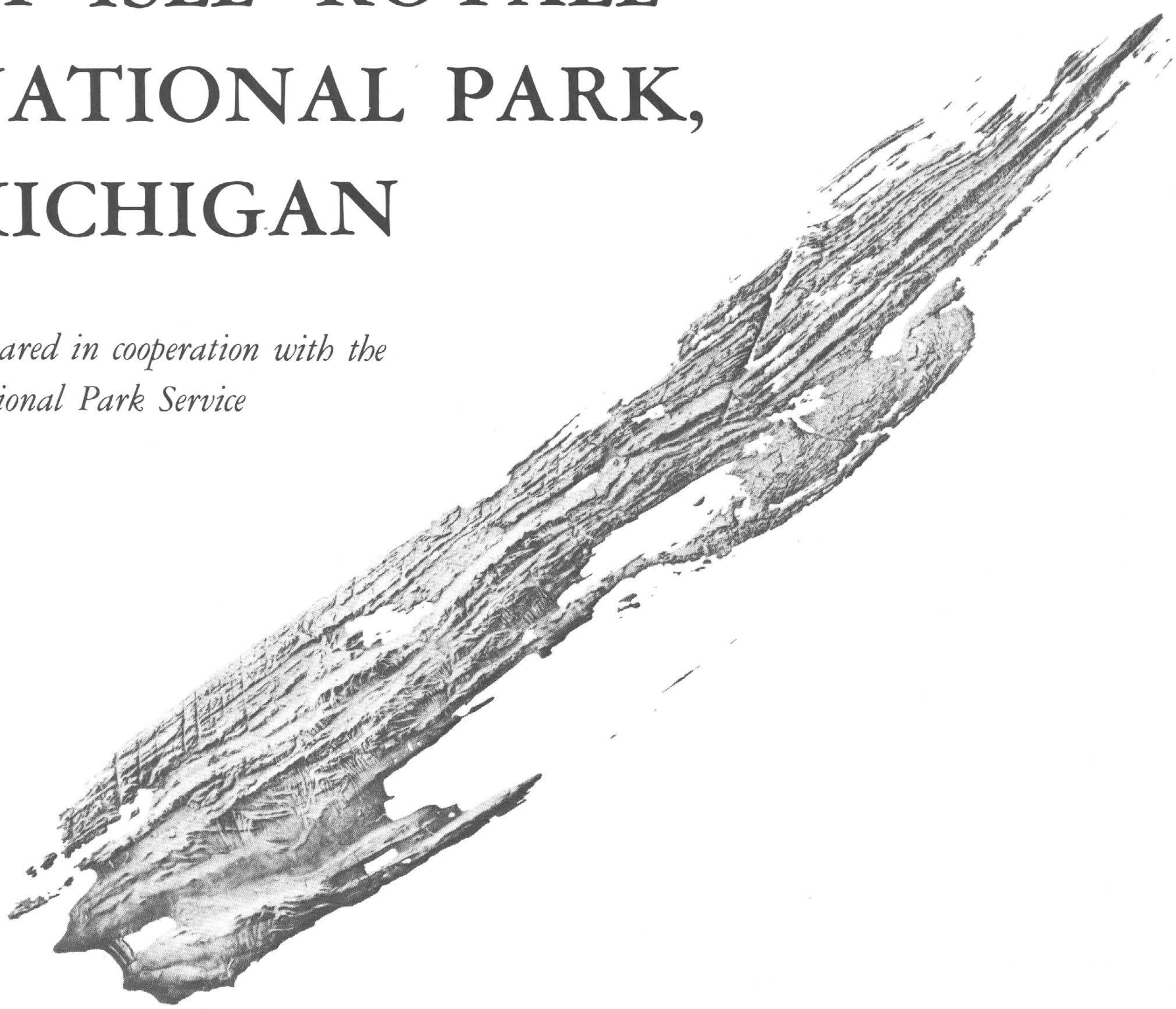
GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY OF ISLE ROYALE NATIONAL PARK, MICHIGAN

Prepared in cooperation with the National Park Service



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Glacial and Postglacial Geologic History of Isle Royale National Park, Michigan

By N. KING HUBER

THE GEOLOGY OF ISLE ROYALE NATIONAL PARK, MICHIGAN

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CONTENTS

ILLUSTRATIONS

GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY OF ISLE ROYALE NATIONAL PARK, MICHIGAN

By N. King Huber

ABSTRACT

Isle Royale was overridden by glacial ice during each of the four major glaciations of the Pleistocene Epoch, and each successive glaciation essentially obliterated all direct evidence of preceding glaciations on the island. In the waning phase of the last major glaciation, the Wisconsin Glaciation, the frontal ice margin retreated northward from at least the greater part of the Lake Superior basin, then readvanced into the basin during Valders time, about 11,000 years ago. We can attribute to the Valders ice the final aspect of glaciation on Isle Royale, including both erosional and depositional features.

It is impossible to estimate the quantity of glacial debris or other surficial materials that might have been present on Isle Royale prior to the Valders readvance, but the readvancing ice appears to have removed most of what might have been present, as judged by the thin surficial cover on the eastern two-thirds of the island today. During the Valders retreat, a series of lakes formed in the Lake Superior basin in front of the retreating ice margin.

The retreating ice opened successively lower outlets, and thus the general trend of lake elevations is downward. Distinct lake stages reflect periods of relative stability during which well-defined shoreline features developed. The ice front forming the north margin of the earlier lakes probably remained south of Isle Royale until about the time of glacial Lake Beaver Bay, when it retreated to a position straddling Isle Royale west of Lake Desor. Abundant deposits of glacial debris were left upon the newly deglaciated west end of the island, and the ice front remained stable long enough to build a complex of ice-margin deposits across the island. Shorelines formed by the glacial lake associated with this ice front are found on the western part of the island about 200 feet above present Lake Superior.

Subsequent renewed and complete retreat of the ice margin from Isle Royale was rapid enough that only a minor amount of glacial debris was deposited on the central and eastern parts of the island. When the ice margin reached the north edge of the Lake Superior basin, Lake Minong was formed, and the entire basin was filled for the first time since the Valders advance. Lake Minong marked a relatively stable episode in the history of the basin, and its beaches are among the best developed of the abandoned shoreline features on Isle Royale. Lake Minong beaches and later lower beaches are best developed on the southwest end of Isle Royale, where abundant glacial debris provided easily worked materials for beach construction.

INTRODUCTION

Isle Royale (fig. 1) lies within an area that was glaciated repeatedly during the Pleistocene Epoch; however, direct evidence remains for only the latest glaciation, the Valders Stade of the Wisconsin Glaciation. This stade represents a partial readvance, during the general retreat of the Wisconsin ice sheet, which returned ice to the greater part, if not all, of the Lake Superior basin about 11,000 years ago (fig. 2). Because this readvance obliterated nearly all evidence of previous glaciations, the striations, deposits, and most other features of glacial origin on the island can be attributed to Valders ice. Ice-margin deposits developed locally during pauses in the retreat of the Valders ice. In addition, glacial and postglacial lakes, many of which filled the Superior basin to higher elevations than the present Lake Superior, left their marks on the island, chiefly in the reworking of glacial materials to form wave-cut benches, cliffs, and beach deposits.

HISTORICAL BACKGROUND AND ACKNOWLEDGMENTS

Charles T. Jackson, noted physician, chemist, and geologist, was in charge of the first significant geological exploration of the Lake Superior region; his chief assistants were John W. Foster and Josiah D. Whitney. Mount Whitney in California was named for the latter. The survey, sponsored by the Federal Government, was completed in 1850 under the supervision of Foster and Whitney, after the resignation of Jackson.

Jackson and Foster first visited Isle Royale together in 1847. Jackson (1849, p. 609) later "characterized [the island] as a succession of ridges and swamps, densely covered with trees and shrubs." He (1849, p. 421) also commented upon the presence of "drift boulders" on the island and noted that as many were of a kind of rock not native to the island, they "must have

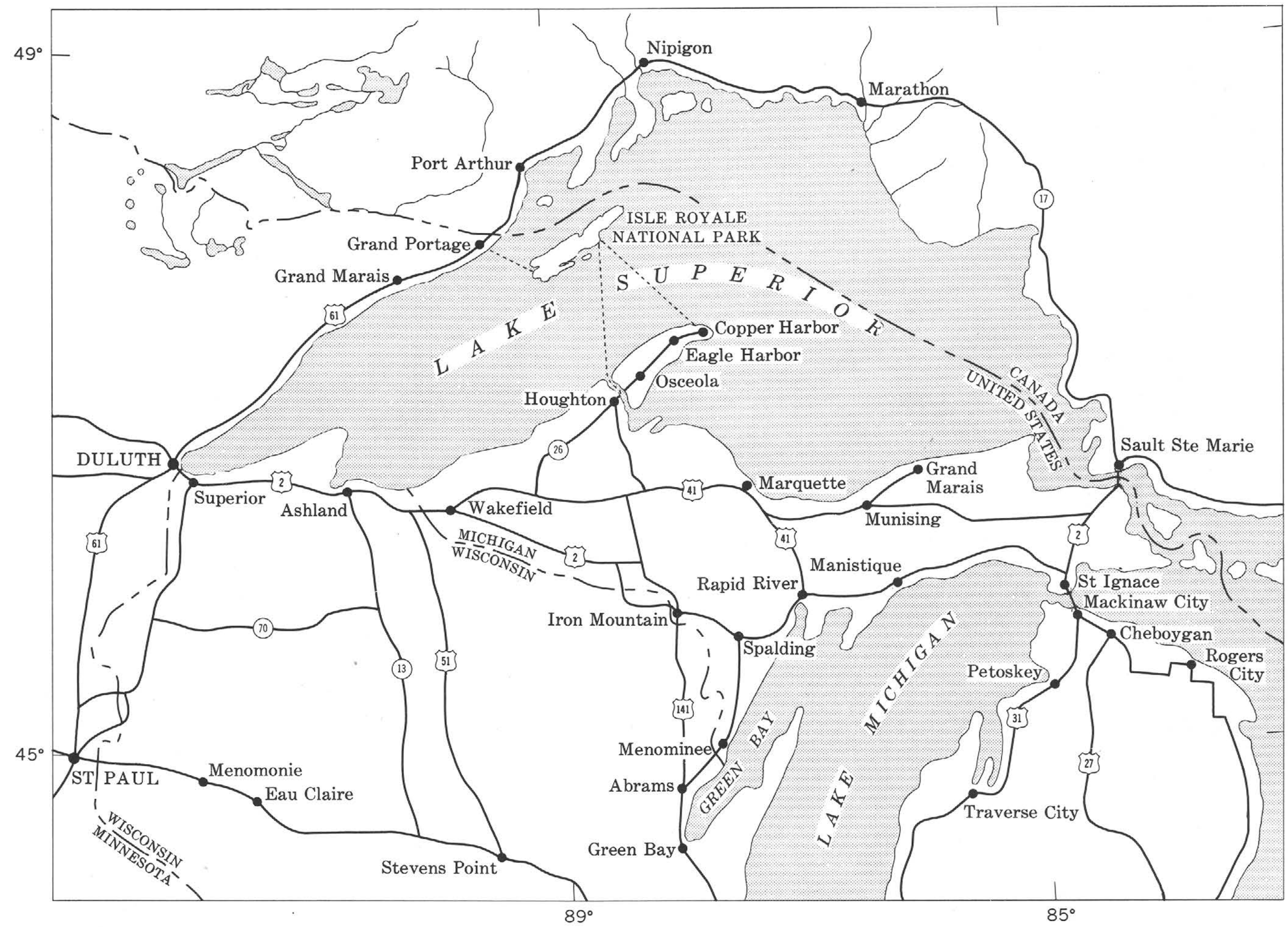

FIGURE 1.—Lake Superior region. Dotted lines from Isle Royale National Park to mainland indicate passenger ferry service.

been transported from a distance and deposited here." Jackson (1849, p. 388–389) believed these "erratic stones" to have been transported at least in part by ice and did discuss seasonal freezing of lakes and rivers, but he did not elaborate upon "the glacial theory" then recently expounded by Louis Agassiz.

Agassiz himself visited the Lake Superior region in 1848 and later published descriptions of glacial phenomena observed during that excursion (Agassiz, 1850). He traversed the north shore of Lake Superior as far west as the Hudson Bay Co. post at Fort William, opposite Isle Royale on the Canadian shore, but was unable to visit the island because of stormy weather.

During the final field season of the survey, in 1849, Foster and Whitney were fortunate in securing as an assistant geologist, Edouard Desor, who for the previous 10 years had served as secretary to Louis Agassiz, both in Switzerland and in America, until disagreements forced their separation (Marcou, 1896). Desor was not only intimately familiar with Agassiz's theory of continental glaciation, at that time new to the world, but had observed in Europe much of the evidence upon which the theory was based. Although Desor owes a great debt to Agassiz in his interpretations, he was nevertheless the first to provide detailed descriptions of the glacial geology of Isle Royale—striations, furrows, erratics, direction of transport, nature of the drift, and other features. Moreover, his summary of the glacial geology of the Lake Superior region was a significant contribution to the knowledge of that remote wilderness (*in* Foster and Whitney, 1850, p. 186–218; *in* Foster and Whitney, 1851 p. 232–273). Without specific reference to Isle Royale, Desor also described beaches and terraces related to higher lake levels, noting that they postdated the drift. The highest point on Isle Royale and the second largest lake on the island bear his name, Mount Desor and Lake Desor.

Since the days of Desor, numerous studies have increased the understanding of the glacial and postglacial record and geologic history of the Lake Superior region. Suprisingly few studies have been carried out on Isle Royale itself, however. Perhaps the following

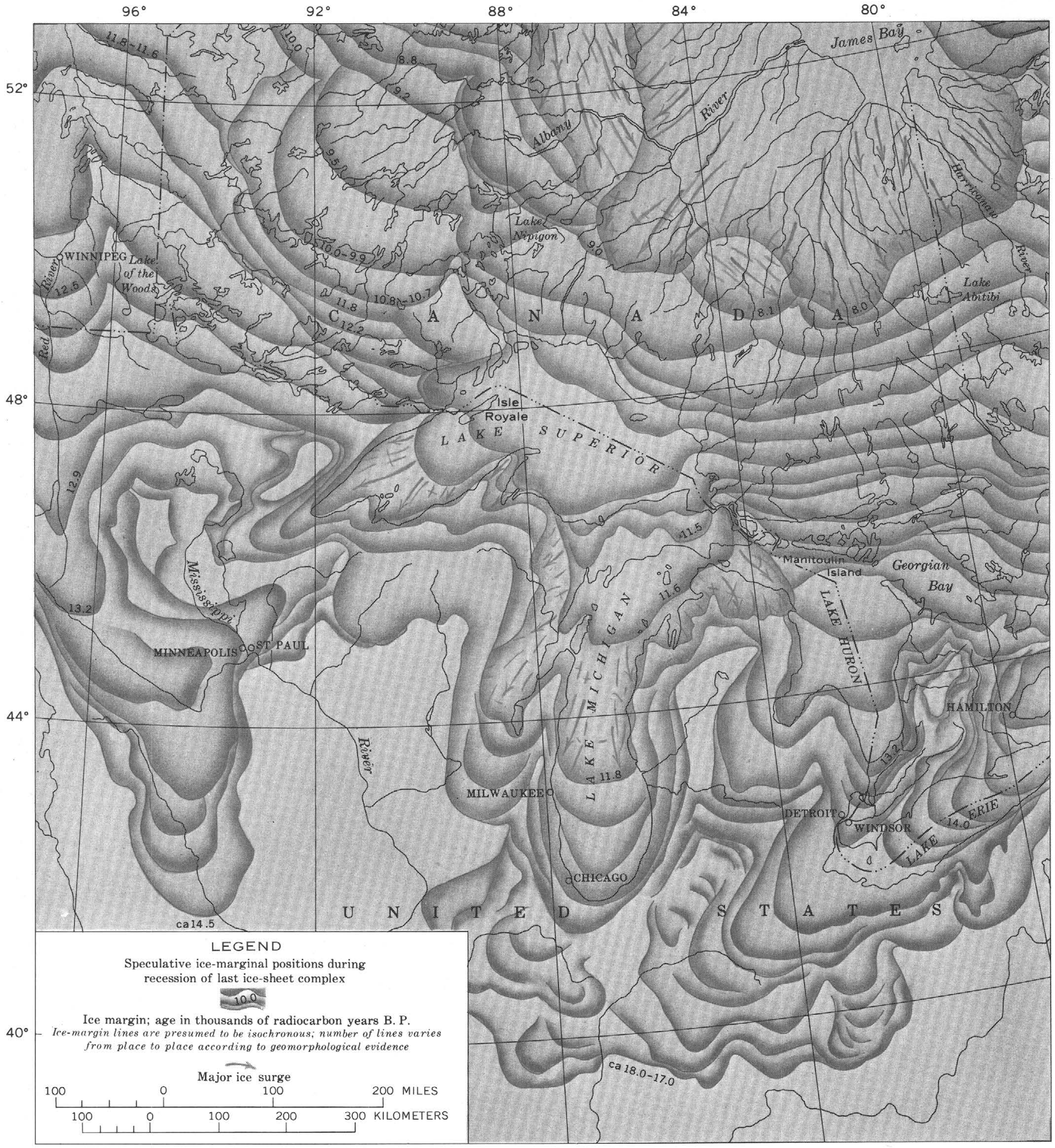

FIGURE 2.—Retreat of Wisconsin ice from central North America. Note major ice surge, or readvance (Valders Stade), in the Lake Superior basin (slightly modified from Prest, 1969, in region of Isle Royale).

quotation from Foster and Whitney (1850, p. 81) helps explain why.

The physical obstructions to a successful exploration of the island are greater than we encountered in any other portion of the mineral district. The shores are lined with dense but dwarfed forests of cedar and spruce, with their branches interlocking and wreathed with long and drooping festoons of moss. While the tops of the trees flourish luxuriantly, the lower branches die off and stand out as so many spikes, to oppose the progress of the explorer. So dense is the interwoven mass of foliage that the noonday sunlight hardly penetrates it. The air is stiffled; and at every step the explorer starts up swarms of musquitoes, which, the very instant he pauses, assail him.

Alfred C. Lane's (1898) classic report on the geology of Isle Royale placed greatest emphasis upon the bedrock formations, because of native copper mineralization within them on the island, and the glacial geology received only very brief treatment. George M. Stanley (1932; 1941) investigated shorelines of various lakes ancestral to Lake Superior and from evidence on Isle Royale was able to recognize a major postglacial lake stage, which he named Lake Minong. Minong is an old Indian name for Isle Royale, and the name is perpetuated as Minong Ridge on the Island. James H. Zumberge (1955) briefly discussed the nature of glacial erosion on Isle Royale in comparison with an area in northern Minnesota.

The present report is an outgrowth of a general study of the geology of Isle Royale National Park that is being carried out in cooperation with the National Park Service, in part to help provide geologic information for interpretive programs. The generous support by the Park Service staff that made this study possible is greatly appreciated. Discussions and a visit in the field with George Stanley have greatly furthered my understanding of the evidence for various glacial and postglacial lakes in the Superior basin.

During summers on the island, I was ably assisted, successively, by Robert J. Larson, Harrison T. Southworth, Charles E. Bartberger, and David R. Chivington.

DIRECTION OF ICE MOVEMENT

A brief summary of the direction of ice movement will be helpful to an understanding of discussions that follow; supporting details are presented in appropriate sections.

Glacial striations indicate that the last ice movement on the east half of the island was toward the southwest, parallel to the bedrock ridge and valley topography (pl. 1). On the west half, striations and drumlins indicate that the direction of movement was westward, crossing the linear landforms at an angle. The westerly direction is roughly perpendicular to a series of ice-margin deposits that crosses the island near its west end. This westerly swing appears to be associated with the ice margin that built these deposits. Southwesterly striations in the Huginnin Cove area presumably reflect the direction of the main Valders advance down the Lake Superior basin prior to retreat to the position of the ice-margin deposits. A few westerly striations in the Tobin Harbor area (at the east end of the Island) may have been caused by local aberrations in ice movement related to topography or even possibly by boulders pushed shoreward by lake ice (McLellan, 1971); no age relation between these striations and abundant ones in the same area with "normal" (southwest) direction was established.

BEDROCK GEOLOGY AND ITS CONTROL OF PREGLACIAL TOPOGRAPHY

The bedrock formations of Isle Royale consist of a series of lava flows with minor interbedded standstone, conglomerate, and pyroclastic rock (Portage Lake Volcanics) overlain by a thick sequence of conglomerate and sandstone (Copper Harbor Conglomerate). This succession of Precambrian rocks has been tilted southeastward and forms part of the north limb of the Lake Superior syncline or structural trough. Dips of the strata range from less than 10° to more than 50°; they are generally steeper on the north side of the island than on the south and average less than 20° for the island.

The present topography consists of a series of ridges and valleys alined in a northeast-southwest direction parallel to the regional strike of the bedrock formations (fig. 3). The southeast-facing slopes are controlled by the structural dip and are gentle compared with the northwest-facing antidip slopes; together the slopes provide a marked asymmetry to the ridge-and-valley cross section (fig. 4). Large variations in resistance to erosion are evident within the bedrock sequence. The sedimentary rocks and amygdaloidal zones at the base and top of flows are less resistant than the massive flow interiors and were selectively removed by stream erosion prior to glaciation. Moreover, the interflow sedimentary rocks and thinner flows have better developed and closer spaced jointing than the massive interiors of the thicker flows and are therefore more susceptible to erosion.

Although the primary ridge-and-valley topography is controlled by the strike direction of the tilted bedrock formations, crosscutting ravines and drainages (fig. 3) are controlled chiefly by the regional joint system, a system of fractures developed in the rock formations in response to stresses imposed during the development of the Lake Superior syncline. One prominent joint set of this system trends northward at the west end of the island and changes progressively eastward to trend about 30° E. of N. at McCargoe Cove. Minor faulting has occurred along some of these regional joints, resulting in zones of closely jointed and fractured rock more susceptible to erosion than the surrounding rock with wider spaced jointing. These zones are now marked by a series of prominent crosscutting ravines, especially well displayed along the north coast of the island between its west tip and Lake Desor. McCargoe Cove is an outstanding example of a joint-controlled, linear topographic feature.

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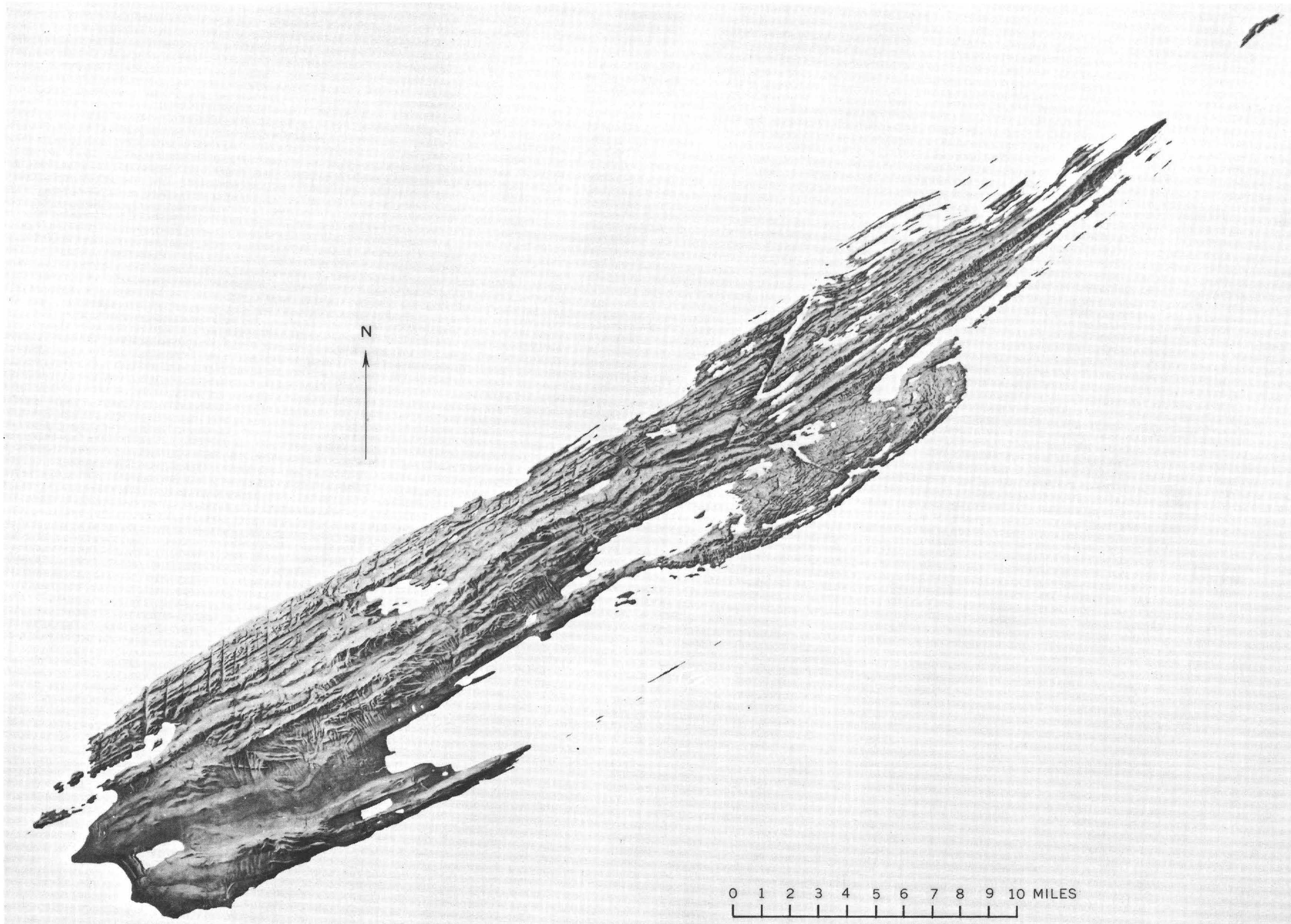

FIGURE 3.—Shaded-relief map of Isle Royale National Park (prepared by Alexius J. Burgess).

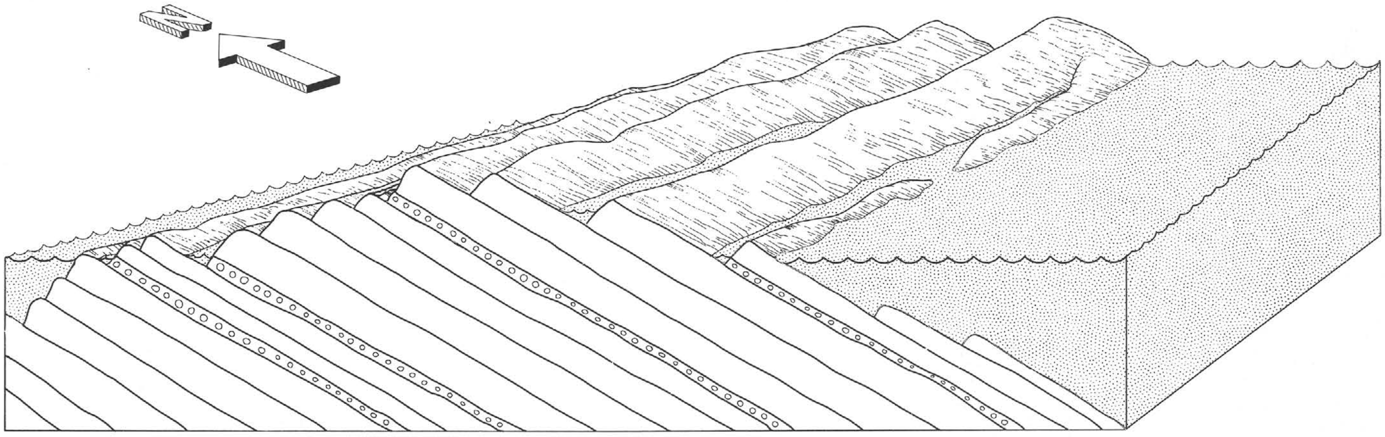

FIGURE 4.—Relation between ridge-and-valley topography and tilted lava flows and sedimentary rocks. Stippled areas indicate water; open circles, sedimentary deposits.

MODIFICATION OF TOPOGRAPHY BY GLACIAL EROSION

Glacial quarrying was probably the most important process of glacial erosion on Isle Royale (Zumberge, 1955); it was controlled chiefly by bedrock structures. The alternation of massive, poorly jointed rock and highly jointed rock furthered the development of the preglacial topography by stream erosion and was also the major control for glacial quarrying. The main role of glacial erosion was to accentuate the asymmetry of the existing ridge-and-valley topography and to interrupt the preglacial subsequent streams with alined bedrock lake basins.

It is unlikely that short tributary creeks of low gradient could be responsible for the development of the deep, narrow ravines along some of the regional joints on the northwest end of the island. These ravines probably were excavated by glacial quarrying along a weakened zone of fractured rock, but it is difficult to imagine how they could have been excavated to this degree by ice moving roughly perpendicular to the ravines, that is, in the direction indicated for the Valders advance. There is abundant evidence in the northwestern Lake Superior region to indicate that during one or more pre-Valders advances, ice moved in a southerly direction nearly parallel to the ravines (compare Sharp, 1953; Zoltai, 1965). It is therefore suggested that the bedrock of these ravines was excavated by pre-Valders ice.

Whereas glacial quarrying was the major modifying factor in the development of the gross topography of Isle Royale, glacial abrasion was responsible for rounding, polishing, and striating the many rock outcrops that characteristically indicate the former passage of glacial ice (figs. 5, 6). The quarrying and scouring was so effective, in fact, that deeply weathered rock is found only in a few places on the lee sides of outcrops where it was protected from the action of moving ice. In one such protected place on the northwesternmost promontory of the main island, a basalt lava flow is spheroidally weathered to a depth of about 6 feet (fig. 7). In cross section, the weathered zone, exposed by storm

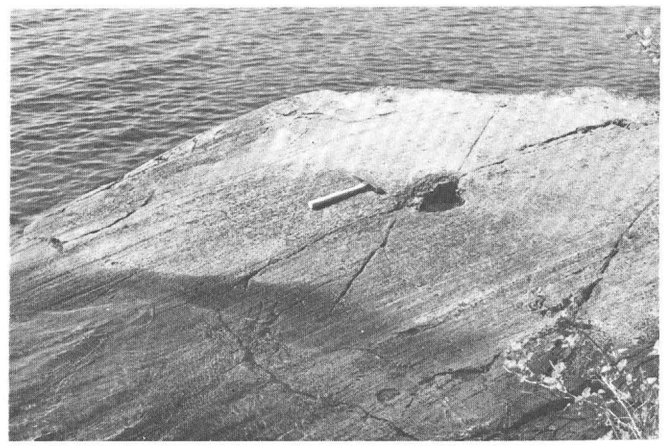

FIGURE 5.—Glacial striations. Near Moskey Basin campground.

FIGURE 6.—Glacially rounded and striated outcrop. Pickerel Cove near portage trail.

FIGURE 7.—Zone of spheroidal weathering in a basalt lava flow. This zone of partly decomposed rock escaped removal by glacial erosion because of its protected location. Northwesternmost promontory of Isle Royale.

waves along the shore, grades downward into less weathered rock that is more resistant to wave action. Here, chemical weathering along a rectilinear fracture system has resulted in the formation of remnant "corestones" embedded in decomposed material; the tendency of the corestones to become spheres is the result of more effective penetration by the decomposing solutions at edges and corners of the rectilinear blocks than in the middle of their planar faces. Because weathering to such depth could hardly have taken place since the retreat of the last ice sheet 10,000–11,000 years ago, the outcrop is interpreted as representing an earlier weathering cycle, either interglacial or possibly preglacial altogether.

There is no residual soil profile developed upon the present upper surface of the weathered rocks at the described locality, indicating that some weathered rock was removed during glaciation. Because depth of weathering depends upon many local variables, this spheroidally weathered zone may not be representative of large areas of the island. Nevertheless, it gives a qualitative measure of the possible depth of preglacial weathering under local conditions and an estimate of the amount of material that might have been removed in areas having similar weathering conditions but lacking adequate protection from glacial erosion during Valders and earlier glacial advances.

MODIFICATION OF TOPOGRAPHY BY GLACIAL DEPOSITION

GENERAL DISTRIBUTION OF GLACIAL DEPOSITS

Many workers have commented upon the scarcity of glacial drift on the east end of the island as compared with that on the west end (Desor *in* Foster and Whitney, 1850, p. 200; Lane, 1898, p. 182; Stanley, 1932, p. 20; Zumberge, 1955, p. 154). Lane (1898, p. 183) noted that he had "not been able to recognize any material as morainal, that is, deposited by the ice directly, and not rehandled by water, although such may occur on the lee sides toward the southwest of the island buried under rehandled material." During the present study a complex of ice-margin deposits was recognized near the west end of Isle Royale; the nature and distribution of glacial deposits on the island appears to be closely related both to direction of ice movement and to proximity to the ice margin.

On the east half of Isle Royale, where the last ice advance moved approximately parallel with the ridge-and-valley topography, surficial deposits other than talus and slope wash are confined to valleys and smaller depressions, and constructional features of glacial origin are not apparent; outcrops are relatively abundant except in the valleys. Scattered erratics indicate the presence of glacially transported materials, but are not abundant. Beach gravels along the present shoreline are predominantly of locally derived materials. But even at the east end of the island, the beaches contain numerous pebbles, some exotic, reworked from glacial debris. The pebbles most obviously exotic are of granitic rocks from the Canadian mainland and fossiliferous limestone and chert from the Hudson Bay basin.

Near the west end of Siskiwit Lake, where the direction of ice movement was westward and crossed the trend of the ridge-and-valley forms at an angle of about 25°, glacially deposited materials become more abundant; thin till mantles many of the slopes, and outcrops decrease in size and number. Large erratics are numerous.

Till is abundant on the west end of the island, effectively mantling most of the bedrock and subduing the landforms (fig. 3). Large erratics also are abundant (fig. 8). Outcrops are limited mainly to small but prominent knobs and the steep north faces of some ridges. In

FIGURE 8.—Granitic erratic near summit of Feldtmann Ridge (near site of abandoned lookout tower).

many places these exposures have clearly been excavated by wave action during lake stages higher than the present level of Lake Superior. It is on this west, till-covered end of the island that the abandoned shorelines of higher lake levels, discussed in a later section, are so well developed.

DRUMLINS

As the amount of till increases west of Siskiwit Lake, constructional glacial deposits, including drumlins, become apparent. The drumlins range in length from a few feet to nearly 2 miles; the larger ones can be seen on the shaded-relief map (fig. 3) and on aerial photographs (fig. 9) as distinct east-west ridges superimposed upon the bedrock-controlled, northeast-trending ridges. They are most abundant between the west end of Siskiwit Lake and a locale about 5 miles east of Cumberland Point. The drumlins are of the crag-and-tail variety—linear ridges of glacial debris streamed out behind a bedrock knob in the direction of glacial transport. Although outcrops are not visible at the noses of all such features, enough have been seen to suggest that all are of similar origin. In an area west of Siskiwit Bay covering several square miles, the only bedrock present crops out at the heads of these linear till deposits (fig. 9). Glacial striations and drumlins indicate the same direction of ice movement in all cases where both are present.

ICE-MARGIN DEPOSITS

A series of ice-margin deposits, built during a pause in the retreat of the last ice sheet, crosses the island in a northerly direction west of Lake Desor. These deposits define an irregular ice front, controlled by topography, with tongues of ice extending into valleys or low areas in front of the main ice mass. Nested deposits on the south side of Greenstone Ridge indicate a sporadic withdrawal of the ice lobe that extended up the drainage basin of the Little Siskiwit River. Two deposits on the north side of the Big Siskiwit River lowland also may indicate successive stages of withdrawal. In the westernmost of these deposits, there is a small kettle similar to those on Mount Desor noted by Stanley (1932, p. 42).

It is not known if the glacial debris making up the ice-margin deposits shows any sorting or layering, and it is thus uncertain whether the deposits are recessional moraines, kame deposits, or other types of glacial deposits typically formed near the edges of ice sheets. Their physiographic form is distinctive, however, and can be generally characterized as consisting of arcuate ridges roughly transverse to the direction of ice movement, as indicated by striations and drumlins, and not controlled by bedrock structure. Although all ice-margin deposits shown on the map were visited, their geographic extent has been largely determined from topographic form as seen on aerial photographs. Other small related deposits may be present, but none are readily apparent on the aerial photographs, as the part of the island where the deposits occur has an especially heavy timber cover.

POST-VALDERS LAKE STAGES IN THE LAKE SUPERIOR BASIN

Some uncertainty exists as to whether Valders ice completely filled the Lake Superior basin (Black, 1969, 1970; Farrand, 1970; Wright, 1970; Wright and Watts, 1969; Zoltai, 1965). However far the Valders ice advanced, when it retreated it left a series of lakes that progressively filled more and more of the Lake Superior basin. The elevation of water in the lakes was controlled by periodic changes in their outlets, which were at times dammed by glacial ice. Lake levels were further influenced by isostatic rebound, or uplift of the earth's crust as the weight of the ice was removed. The sequential history of the series of lakes has been largely deduced from correlations of their abandoned shorelines around the Lake Superior basin. The most recent comprehensive study of these shorelines is that of Farrand (1960; summarized 1969). This study, together with observations of Stanley (1932) for Isle Royale, provides the basic framework for much of the following discussion. Hough (1958; 1963) presented regional syntheses for the entire Great Lakes system; Kelley and Farrand (1967) gave a nontechnical account of the glacial lakes around Michigan, and Dorr and Eschman (1970) included similar material in their volume on the geology of Michigan.

The first glacial lake (and the highest at 1,085 feet above sea level) to fill a major portion of the Lake Superior basin following the Valders Stade was Lake Du-

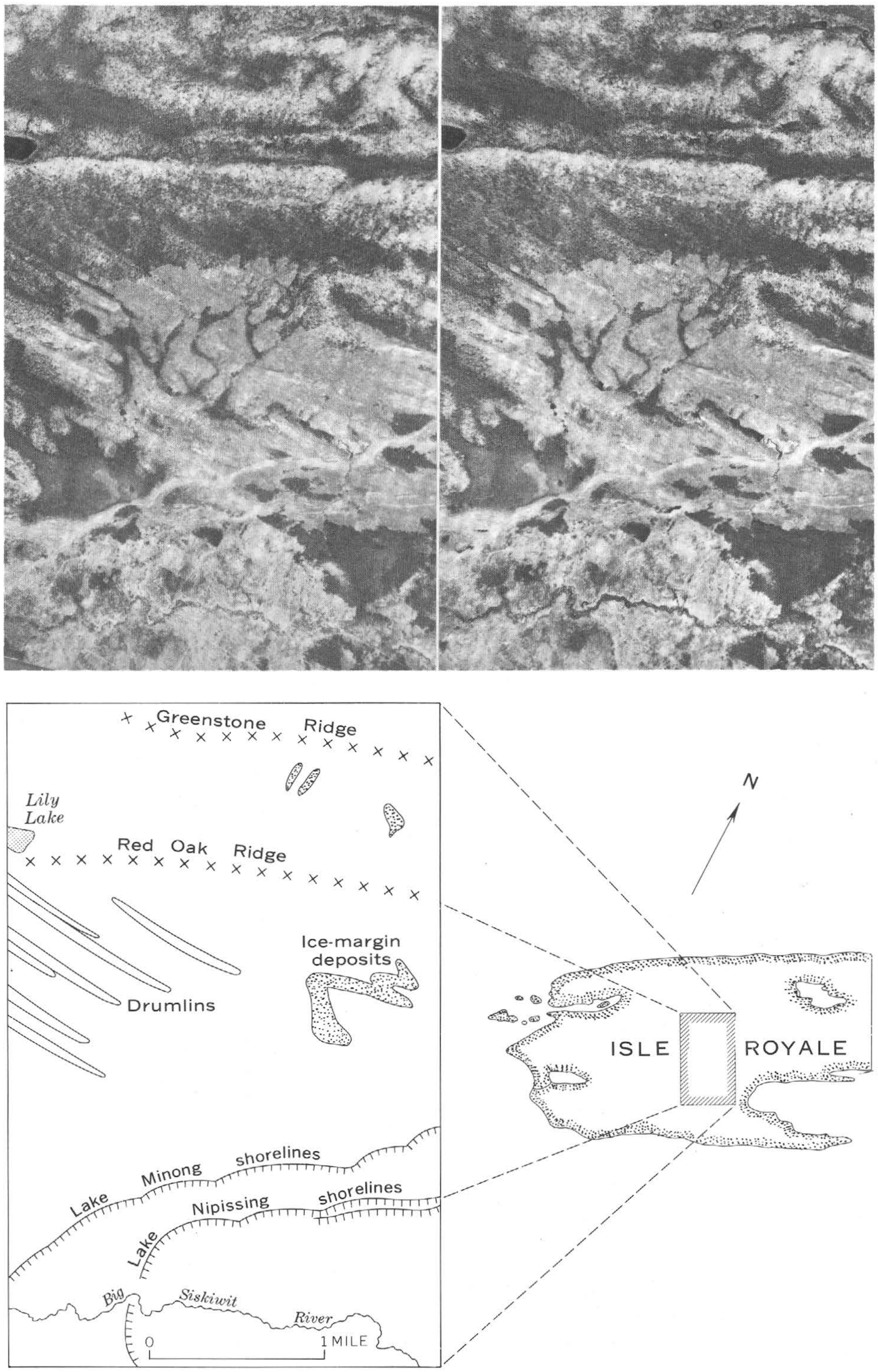

FIGURE 9.—Stereoscopic pair showing drumlins, ice-margin deposits, and abandoned shorelines west of Siskiwit Bay. Sketch map shows area of photograph.

luth (fig. 10). The history of Lake Duluth and subsequent lakes has been concisely summarized by Farrand (1969, p. 194) as follows:

Apparently the ice sheet was in a period of rather rapid retreat when Glacial Lake Duluth formed. The uppermost Duluth beach can be followed some 90 miles northeastward from Duluth along the Minnesota shore and as far east as the base of the Keweenaw Peninsula. Subsequent shorelines of Lake Duluth extend to the international border at the Pigeon River and to Isle Royale. Then the ice front seems to have paused in its retreat; the shorelines of the subsequent Post-Duluth lakes do not extend much farther north and east than those of Lake Duluth itself, although lake level fell some 500 feet during this time [fig. 11]. * * * A number of individual lake stages (named Highbridge, Moquah, Washburn, Beaver Bay, etc.) have been recognized in this interval, but they are mostly weakly developed and apparently mark minor halts in a period of rapidly falling lake level. Another period of relatively rapid retreat of the ice front opened up the entire lake as we now know it, bringing into existence Glacial Lake Minong [fig. 12]. The original altitude of Lake Minong, before rebound, was around 450 feet above sea level, or some 140 feet lower than the present Lake.

An even lower lake, Lake Houghton (375 ft above sea level), followed Lake Minong. Then, during a long period, slowly rising lake levels controlled by glacial rebound resulted about 5,000 years ago in the Nipissing lake stage at 605 feet (fig. 13). As a result of minor changes related to decreasing but continuing rebound, the present Lake Superior, at 602 feet, evolved. Farrand (1969) provided details on changes in outlets that were the immediate causes for the establishment of various lake levels.

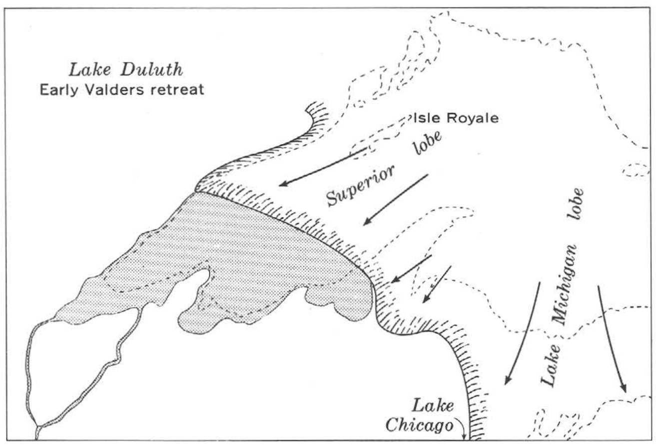

FIGURE 10.—Glacial Lake Duluth and contemporary ice border, about 11,500 years ago (after Farrand, 1969).

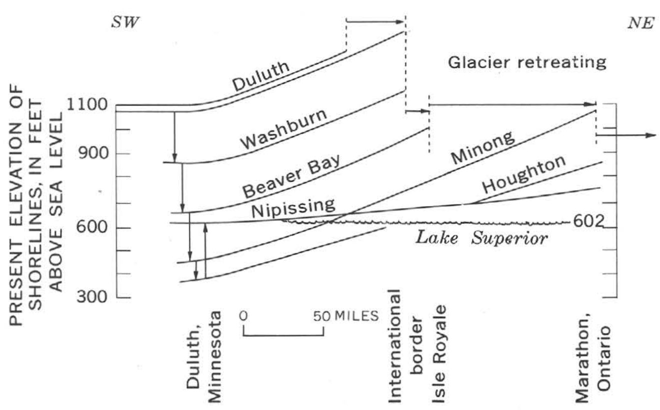

FIGURE 11.—Water-level change and suggested intervals of ice retreat for the Lake Superior basin. Curvature is due to postglacial rebound (uplift), progressively greater to the northeast (after Farrand, 1969).

ABANDONED SHORELINES ON ISLE ROYALE

Abandoned shorelines for a number of the lake stages between Lake Duluth and Lake Superior are evident on Isle Royale, although direct correlations are difficult except for some of the best-developed ones, such as those of the Minong and Nipissing stages. The highest well-developed shoreline features appear to correlate with lake levels between those of Lake Beaver Bay and Lake Minong, according to the profiles of Farrand (fig. 14). Examples include a mile-long barrier beach closing off a swamp slightly above 800 feet elevation[1] near the west

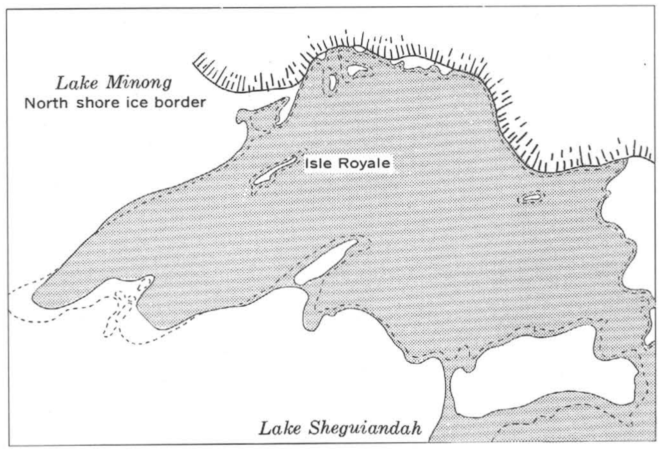

FIGURE 12.—Glacial Lake Minong and contemporary north shore ice border, about 10,500 years ago (after Farrand, 1969).

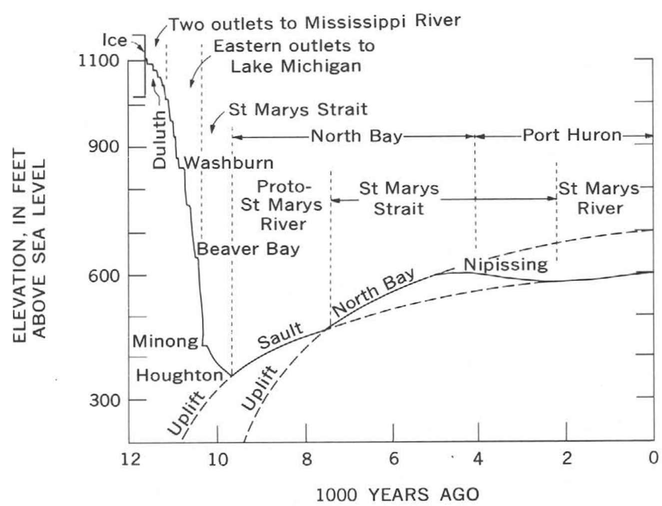

FIGURE 13.—Chronology of lake-level changes in the Lake Superior basin. Note the levels of various outlets for different lake stages and the role played by postglacial rebound (uplift) in controlling lake level since about 10,000 years ago (after Farrand, 1969).

[1] All elevations originating with this report have been obtained by interpolation from a topographic map (20-ft contour interval) after plotting location from aerial photographs and should be considered only approximate.

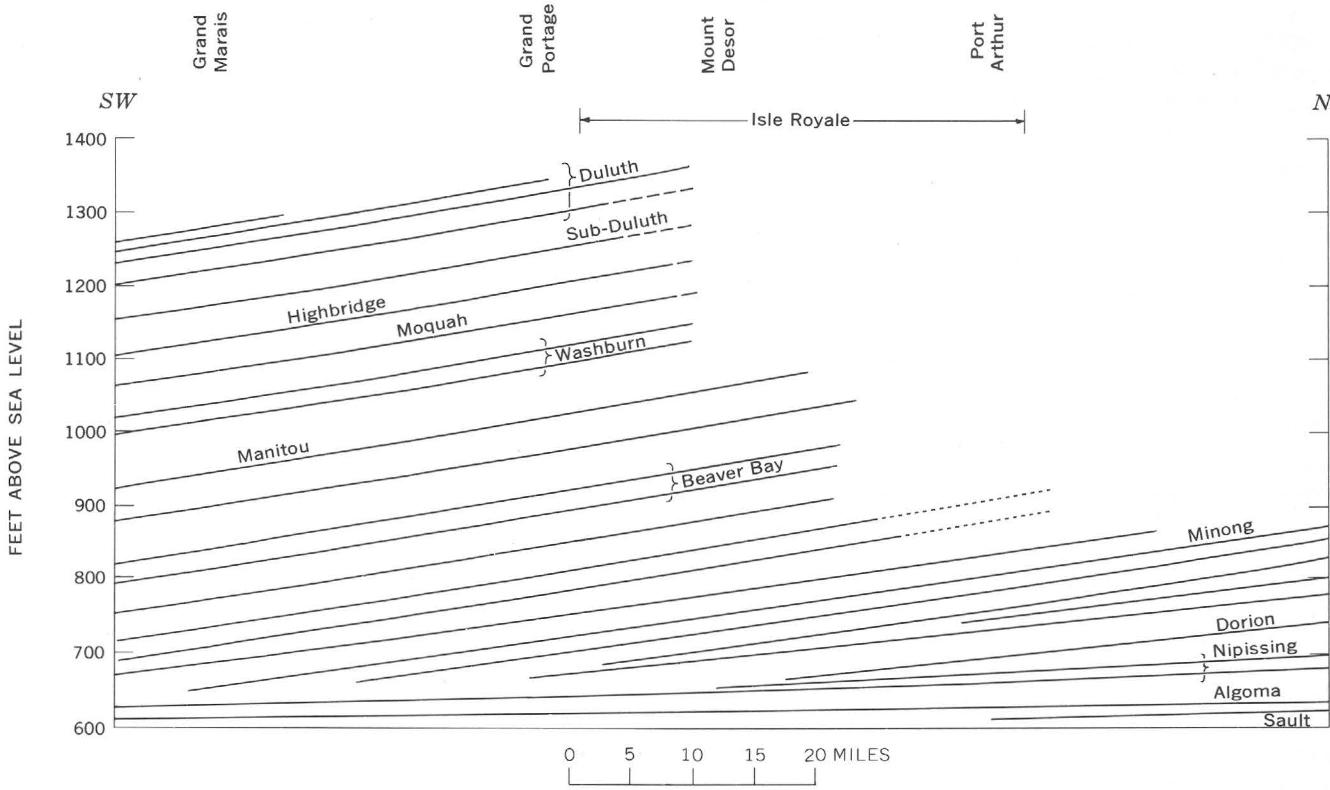

FIGURE 14.—Profiles of former water planes in northwestern Lake Superior basin. The profiles are essentially parallel to the Minnesota shoreline (after Farrand, 1960).

end of Feldtmann Ridge (pl. 1) and a wave-cut cliff with a sea cave at about 810 feet elevation (Stanley, 1932, p. 39) south of Washington Harbor.

The western part of Feldtmann Ridge, which is mantled with easily reworked glacial debris, was well suited for beach development. Study of aerial photographs discloses a series of beach bars, many of which close off swampy areas behind them, between the present lake level at Cumberland Point and the beach previously noted, which is slightly more than 200 feet above the present lake level. No higher beach features can be discerned from the photographs even though glacial debris readily susceptible to beach formation continues to mantle the ridge at higher elevations. If Farrand's profiles are correct with respect to Isle Royale, beaches that might be correlated with Lake Beaver Bay would exist close to 300 feet above the present lake level at this location. One cliff of conglomerate at about 300 feet elevation at the west end of Feldtmann Ridge has a distinct overhang, but it is not clear whether this might be due to undercutting by former wave action or to simple slumping of the rubbly conglomerate making up the cliff face.

On the north slope of Greenstone Ridge near Mount Desor, a series of benches extends nearly to the summit (800 ft above Lake Superior). Unfortunately, the slope is covered by glacial debris, talus, and other surficial materials; no bedrock outcrops or possible beach deposits were noted in several traverses down and along the slope. Stanley (1932, p. 41–42) first interpreted these benches as wave-cut features, but he did not find definitive exposures of beach materials and is not now confident of his earlier interpretations (G. M. Stanley, written commun., 1971). Because Stanley's (1932, p. 80) correlation of these benches with glacial lake stages immediately subsequent to Lake Duluth has been utilized by more recent workers (Farrand, 1960, p. 23; 1969, p. 194), their validity as wave-cut features becomes important.

Relatively level benches are characteristic of the north-facing slopes of all ridges on Isle Royale underlain by more than a single lava flow, including Greenstone Ridge. Near Ishpeming Point, about 5 miles east of Mount Desor, the north slope of Greenstone Ridge has benches very similar to those at Mount Desor. Near Ishpeming Point, however, the mantle of glacial debris is thinner than near Mount Desor, and scattered outcrops can be found along many of the benches. The amygdaloidal texture of the rock of many of these outcrops is typical of that near flow tops, and the benches appear to have been formed by differential erosion of the highly amygdaloidal, less-resistant flow tops within the sequence of flows making up the ridge. While wave-cut features and bedrock-controlled topographic features are not mutually exclusive, there is no need to attribute the formation of the benches near Mount Desor to wave action, and in the absence of supporting evidence such as beach deposits, a non-wave-cut origin appears more probable for these benches. Such an origin is supported by the fact that benches are not cut into ice-margin deposits angling down the slope on the south side of Greenstone Ridge near Mount Desor, which would be readily susceptible to wave erosion. Limited observations from the present study are not sufficient to resolve the problem of the nature and origin of the benches; if wave cut, they would indicate that at least the west end of Isle Royale was free of ice during glacial lake stages in the Lake Duluth–Lake Washburn interval, stages with which such shorelines would correlate (fig. 14).

A few other possible shoreline features higher than 800 feet have been noted by Stanley (1932, p. 43, 71) on the west end of the island east of Washington Harbor and on Feldtmann Ridge. These features are not well developed, however, and as they also consist of benches on north-facing ridge slopes with possible structural control, their significance is uncertain.

Lake Minong is the earliest of the lake stages for which abandoned beaches and other shoreline evidence can be found along the full length of Isle Royale (Stanley, 1932, p. 82–85).[2] Such evidence is most strikingly developed on the west end of the island where the abundance of glacial drift permitted more pronounced development of shoreline features. Beaches from the Nipissing stage also are well developed on Isle Royale, as shown by Nipissing (and Minong) beaches discernible on the aerial photographs of glacial features west of Siskiwit Lake (fig. 9) and by a profile of barrier-bar beaches of the two lake stages between Rainbow Cove and Lake Feldtmann (fig. 15).

On the east end of Isle Royale, where glacial debris is limited and abandoned beaches are less evident, wave-cut features in the bedrock mark old shorelines (fig. 16). Prominent examples are Monument Rock, a stack associated with the Lake Minong shoreline north of Tobin Harbor (fig. 17) and an arch cut through a narrow ridge crest on Amygdaloid Island (fig. 18), probably associated with the shoreline of the Nipissing stage.

In summary, shoreline evidence in itself indicates that the west end of Isle Royale may possibly have been free of glacial ice some time prior to the Lake Beaver Bay stage (see fig. 11) and was definitely free of ice after Lake Beaver Bay. Lake Minong was formed by the retreat of the ice front all the way to the north shore of the Lake Superior basin, and the entire island was, of course, free of ice at that time.

SIGNIFICANCE OF ICE-MARGIN DEPOSITS ON ISLE ROYALE

The distribution of individual ice-margin deposits on Isle Royale indicates all were not formed coevally. And yet the system of deposits as a whole must have been formed by a relatively stable ice front during a pause in its general retreat from the Lake Superior basin. The problem, then, is to attempt to relate this system to a specific glacial lake stage and thus to fix the position of the ice margin with respect to that stage.

Several lines of evidence can be brought to bear upon this problem. First, the sharp topographic nature of the ice-margin deposits strongly suggests that they were deposited by ice on land rather than in a lake possibly marginal to the ice front. Thus any lake present at the time of their formation must have been lower than the lowest ice-margin deposit. Second, the deposits show no evidence of wave erosion, further indicating that they were formed subsequent to glacial lakes at higher levels. Third, ice-margin deposits on both the north and south sides of the island extend down to elevations near 800 feet, giving a rough maximum elevation for shorelines to be correlated with this ice-margin. Fourth, the absence of similar deposits below this elevation suggests that a glacial lake was indeed present at about the elevation of the lowest ice-margin deposit and that subsequent rapid retreat of the ice front prevented formation of lower ice-margin deposits associated with progressively lower lake levels. It is perhaps, then, more than coincidence that the highest unequivocal shoreline occurs at about this elevation on western Isle Royale.[3]

It was noted in the previous section that shorelines somewhat above 800 feet elevation for this part of Isle Royale would correlate with glacial lake stages intermediate to Lake Beaver Bay and Lake Minong, according to the profiles of Farrand (fig. 14). Allowing for subsequent uplift due to rebound, the lake (or lakes) would probably have had an elevation between 500 and 600 feet above sea level. An ice front straddling Isle Royale (fig. 19) during this interval appears compatible with other data presented by Farrand (1960, 1969) for the Lake Superior basin as a whole.

An ice front during post-Beaver Bay time in the position of the Isle Royale complex of ice-margin deposits

[2] In the reference cited, the Minong stage was initially correlated with the Fort Brady stage of Leverett and Taylor (1915) and is so labeled there. See Stanley (1936, p. 1955–1956; 1941, p. 1935) for initial Minong usage.

[3] Shoreline tilt has been neglected in this discussion; for the limited area of western Isle Royale, differences in shoreline elevation attributable to tilt are probably less than the error of estimate for the elevations given. In addition, during the time of formation of the ice-margin deposits, we are most likely dealing with a range of lake levels on the order of several tens of feet, or even more.

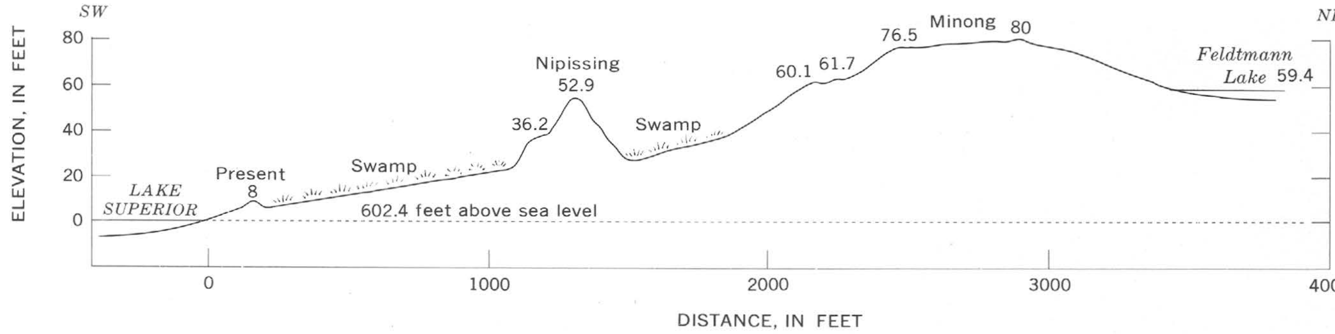

FIGURE 15.—Profile across barrier-bar beaches between Rainbow Cove and Feldtmann Lake (after Stanley, 1932).

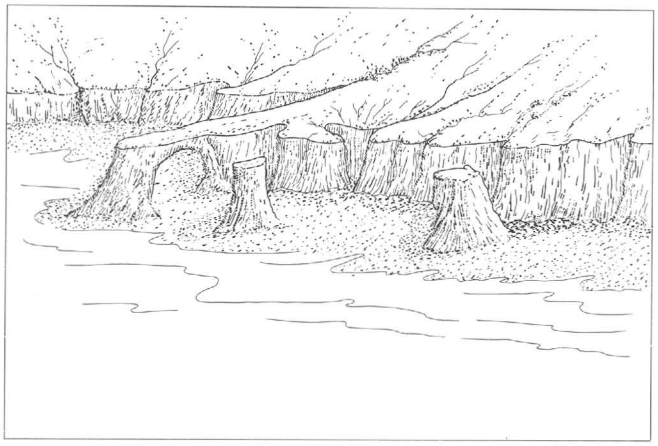

FIGURE 16.—Wave-cut shoreline illustrating development of stacks and arches.

poses another problem concerning the position of the ice margin prior to that time. Alternate conclusions depend upon the validity of evidence for higher level shorelines on the island.

If the evidence for higher level shorelines postulated by Stanley (1932) is valid, especially in the vicinity of Mount Desor, the ice margin must have been well northeast of the complex of ice-margin deposits by at least the later stages of Lake Duluth, and the deposits would indicate a readvance of the ice front during Beaver Bay or post-Beaver Bay time. The higher beaches would have to have been preserved on north-facing lee slopes in front of the readvancing ice margin, and any earlier ice-margin deposits that might have eixsted northeast of the present complex would have been destroyed by the readvance. Farrand (1960, fig. 5, pl. 3; 1969, fig. 8) showed an inferred ice border for Lake Washburn (fig. 11) crossing Isle Royale well northeast of the complex, but this position was based on the data of Stanley (1932). I am not aware of any evidence for a readvance of the ice front during retreat of the Valders ice from the Lake Superior basin.

If it is accepted that the benches near Mount Desor are bedrock-controlled topographic features not formed by wave action, evidence to indicate that any part of Isle Royale was free of ice prior to the Lake Beaver Bay stage would be lacking. According to this interpretation, the ice front would be placed southwest of Isle Royale for all lake stages from Lake Duluth through Lake Beaver Bay, across Isle Royale in the vicinity of the complex of ice-margin deposits sometime during the Beaver Bay–Minong interval, and finally, near the north shore of the Lake Superior basin at the time Lake Minong was formed. While I prefer the interpretation that favors a non-wave-cut origin for the

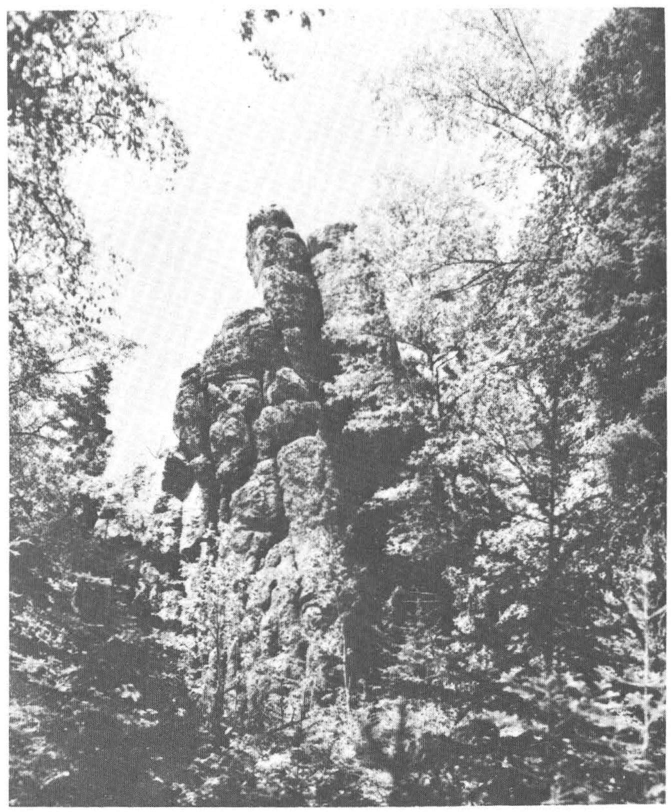

FIGURE 17.—Monument Rock, a stack associated with the shoreline of glacial Lake Minong. Adjacent wave-cut cliff is just out of photograph to right. National Park Service photograph by Tom Haas.

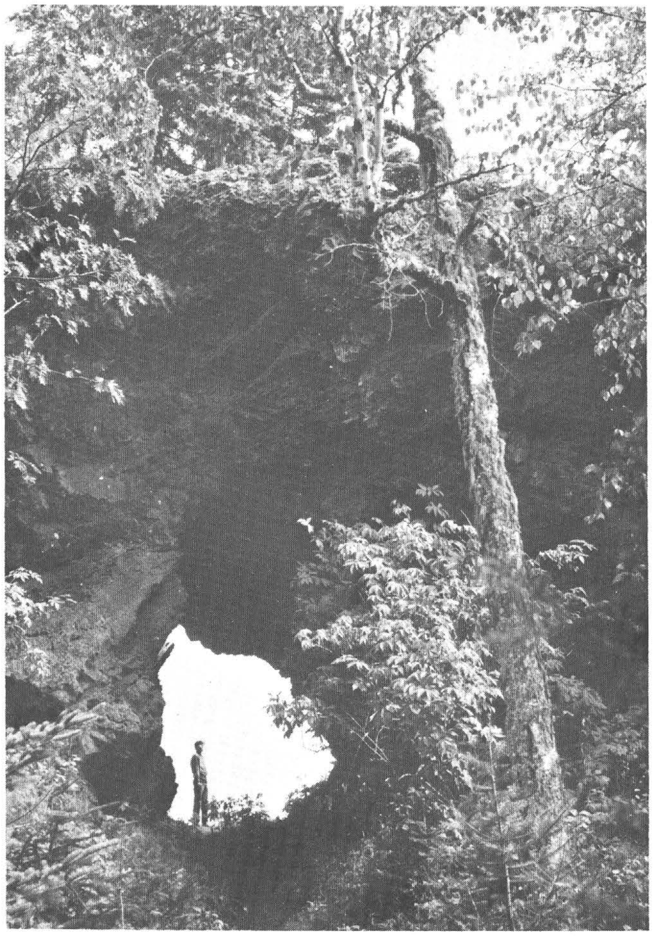

FIGURE 18.—Wave-cut arch on Amygdaloid Island. A short distance west is a collapsed arch.

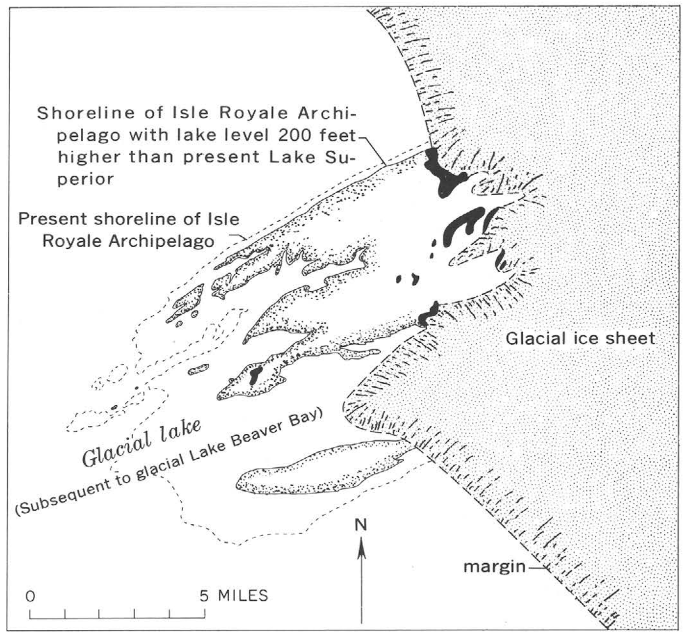

FIGURE 19.—Hypothetical position of glacial ice margin during final stages of deposition of ice-margin deposits on Isle Royale and prior to complete northeastward retreat of ice from the island. Ice-margin deposits shown in solid black.

benches, I cannot unequivocally rule out the possibility that they represent higher level shorelines. Nevertheless, further field study of the Mount Desor area is desirable.

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