CHAPTER 13

EFFECT OF ICE ON SHORE DEVELOPMENT

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INTRODUCTION

During the course of investigations of ice forms on the Great Lakes bordering the state of Michigan, the writers had occasion to observe several shore areas under winter conditions. The following paper is a general consideration of these casual observations and includes suggestions of the probable relationship between ice conditions at the shore line and in the surf zone to the normal shore processes effective during the ice-free year.

No systematic investigations of ice and its role in shore processes have been made by the writers; it is to be emphasized that the data recorded here were obtained in connection with other investigations not directly concerned with the processes of beach development, and are presented here only because they seem to indicate a field in which little or no previous studies have been made.

GENERAL ICE CONDITIONS OF THE GREAT LAKES BORDERING MICHIGAN

None of the Upper Great Lakes (Superior, Michigan, and Huron) is known to have frozen over completely within historical time, although the ice-free part of the lakes may be of greater or lesser areal extent in different years. Some bays freeze over entirely, and frequently an ice cover will form along a straight coast for a considerable distance out from shore. The thickness of this ice cover is also variable but usually ranges from 6 inches to 2 feet, depending on latitude and local climatic factors. The ice season begins in late November or December, reaches a peak sometime in late January or February, and ends in late March or April. One can thus expect ice conditions to prevail during a period of 3½ to 4½ months of the year.

Between 1949 and 1953, the writers have observed segments of shore under normal winter conditions of Lakes Superior, Michigan, and Huron as a by-product of investigations sponsored by the Snow, Ice, and Permafrost Research Establishment (SIPRE) of the U. S. Corps of Engineers. On Lake Huron, observations in the vicinity of Alpena, Rogers City, Cheboygan and Mackinaw City were made (fig. 1). On Lake Michigan, ice conditions on the north shore between St. Ignace and Manistique were seen; and in Lake Superior, winter shore conditions were recorded for the south shore of Whitefish Bay between Brimley and Point Iroquois.

FORMATION OF ICE-FOOT

The geographic location of the upper Great Lakes and their unusual size combine to produce a characteristic winter condition along "normal" shores. Normal shores are those with an underwater profile approaching equilibrium conditions, that is, they are not of the type bordered by steep bedrock cliffs, nor are they of the unusually flat and swampy kind.

Beginning with the period of sub-freezing temperatures, spray produced in the surf zone is blown onto the foreshore and frozen. Eventually, through a continuation of this process, the frozen spray produced a mass of ice firmly attached to the foreshore. This is called the ice-foot (fig. 2A).[1] Requirements for its formation are twofold: (1) sub-freezing atmospheric temperature; (2) open water bodies that, because of their size, remain ice free well into the season of sub-freezing temperatures. The second factor precludes any formation of an ice-foot on inland lakes, even large ones such as Houghton, Mullet and Black; because the time between the beginning of sub-freezing temperatures and the time of the complete freeze-up of the lake is not sufficiently long to permit the development of an ice-foot.

After the ice-foot becomes firmly established, it may be subjected to some modification by wave action. This involves either continued accretion of frozen spray or erosion by waves. Eventually, however, the water surface in contact with the base of the ice-foot may become frozen so that all further processes effective against the foot will cease. At the water edge of the ice-cover that now extends out from shore, a new ice-foot may develop. Sometimes the new ice-foot is initiated by the presence of an ice ridge formed by the shingling or jamming of broken ice blocks along the open water edge of the sheet ice. Spray on this ridge cements it firmly together, thus producing a new ice foot. For the purposes of easy reference, this second type of ice-foot is called the off-shore ice-foot in contrast to the shore ice-foot (fig. 2B). If the ice-foot borders expanse of open lake water, it is an active ice-foot; an ice-foot locked firmly in frozen lake ice is inactive (fig. 2C).

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1 The term ice foot was used to designate "the part of the fast-ice (ice in situ along a seacoast) immediately close to shore that is not affected by the rise and fall of the tide." Parentheses are ours. Although this definition is not strictly applicable to fresh water ice, it is the only term previously used that seems appropriate for the ice form herein described as the ice-foot.

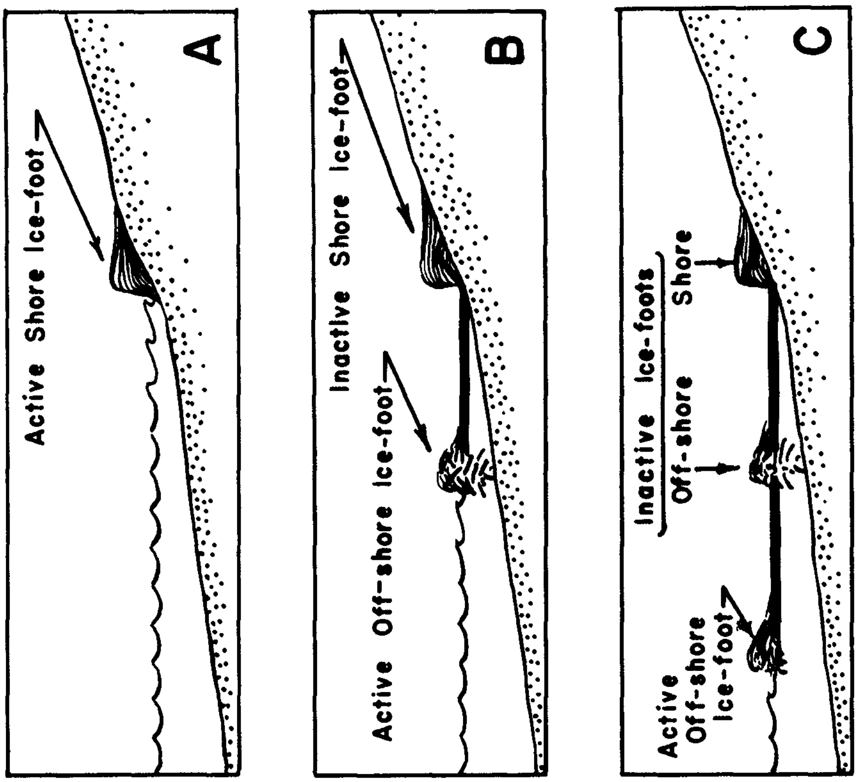

Fig. 2 Diagramatic sketch showing the development of the various types of ice-foots.

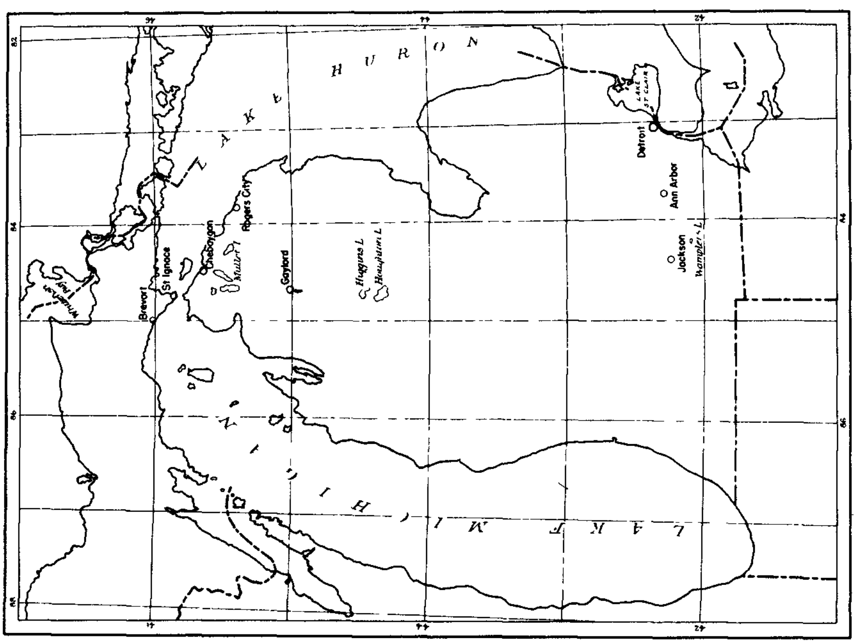

Fig. 1 Index map.

In shallow water of the surf zone the off-shore ice-foot may be grounded. Furthermore, the off-shore ice-foots may be multiple, since the first off-shore foot is liable to stabilization in the same manner as the shore ice-foot, thus permitting growth of a second off-shore foot at some point further out. It is not known whether the position of the off-shore ice-foots is controlled by water depth, or whether their place of occurence is a random event.

POSSIBLE EFFECT OF THE ICE-FOOT ON SHORE PROCESSES

Waves breaking on shore or currents moving parallel to the shore account for most of the processes of shore development. The extent to which the presence of an active ice-foot of the shore or off-shore type modifies normal shore development is not well known, but some theoretical considerations are noteworthy in that they have been supported by casual observation.

Effect of ice-foot on wave attack — Once established, the active shore ice-foot can be regarded as a protective feature since it takes the bulk of the impact of the breaking wave. Sandy beaches and beaches consisting of unconsolidated bedrock are thus given some degree of protection against wave attack. The protective action of the ice-foot is not entirely effective, however, because sand grains imbedded in the ice-foot indicated that some wave scour does take place at the base of ice-foot. This sand is apparently derived from the bottom of shallow water zones and is incorporated in the ice-foot by waves breaking against it. Even on the active off-shore ice-foots, similar evidences of wave scour have been noticed.

The question arises as to the magnitude of this scour in comparison with the scour that is produced under ice free conditions. One conclusion seems justified, even on theoretical considerations alone; the development of multiple ice-foots is tantamount to the moving of the zone of wave scour away from the shore line. Or conversely stated, no wave scour is possible on an inactive ice-foot.

The presence of an active shore ice-foot must upset the equilibrium of the subaqueous profile, because it renders a large part of the available sand immobile as far as movement by direct wave or current action is concerned. This condition requires a readjustment of the bottom profile, since less sand is available for the wave system than during ice-free periods.

Assuming, then, that the profile is altered because of the presence of an ice-foot, the question immediately arises as to the degree of alteration and permanency of the change. Is the change in profile insignificant insofar as the "normal" profile is concerned? How quickly is the altered winter profile reverted to the profile of the ice free year? Is it possible that the conditions imposed upon the regimen of the wave system by the ice-foot could have permanent effects on the general nature of the shoreline? In other words, how do shore lines, formed under conditions of a three to four month ice season, differ from shore lines formed under exactly the same conditions except for the ice?

A closer examination of ice-foots as well as an investigation of ice conditions in general with respect to the shore processes might yield the necessary data to permit the answering of these and other questions.

REFERENCES

Transehe, N. A. (1928). The ice cover of the Arctic Sea, with a genetic classification of sea ice: Problems of Polar Research, American Geographical Society, Spec. Pub. No. 7, p. 115