ICE-LENS MOUNDS, CEDAR BOG, CHAMPAIGN COUNTY, OHIO[1]

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ABSTRACT

Dome-shaped mounds containing lenses of transparent ice were found in a one-half acre area in Cedar Bog, Champaign County, Ohio. The occurrence of ice-lens mounds in temperate latitudes such as Ohio has not previously been reported. Formation of the ice lenses caused heaving of the overlying soil to form small topographic mounds, which remained after the ice had melted. The ground surrounding the area of mounds did not develop ice lenses, either because of standing water or because the water table was too deep to allow ground water to be drawn upward to the freezing surface. Ice-lens formation was apparently controlled by the depth of the water table, by variations in the soil, and by the rate and duration of freezing.

INTRODUCTION

Ice-lens mounds were found during the winter of 1971–72 in a one-half acre area of Cedar Bog, Champaign County, Ohio (fig. 1). The mounds, small dome-shaped features, were formed by the accumulation of a layer of transparent ice in the soil near the ground surface. The mounds were generally ellipsoidal in plan view, with their longest dimensions typically less than 30 inches, and were elevated above the general surface no more than 4 to 6 inches. The lenses of ice had planar bases and convex top surfaces.

When observed in March 1972 ice lenses were intact beneath the mounds, the top of the ice being 3 inches below the surface. By April 1972 the ice had melted, but the mounds had not collapsed.

Lenses of ice in soil have been recognized for at least 65 years (Taber, 1918a, b). Such mounds are common in high-latitude regions where permafrost conditions prevail, but their occurrence in temperate latitudes such as Ohio has not previously been reported. Features similar to the mounds have been described, for example, by Sigafoos and Hopkins (1951), Hopkins and Sigafoos (1954), and Lozinski (1934).

Perhaps the most widely recognized term for ice-heaved mounds is "pingo," an eskimo word first used in a technical sense by Porsild (1938). Pingo refers to structures that are much larger than those at Cedar Bog and that have formed under vastly different physical conditions. The term "frost-heaved tussock" was used by Sigafoos and Hopkins (1951) and Hopkins and Sigafoos (1954) to describe matted ball-like masses of living and dead plant material on marsh surfaces in Massachusetts and on the Seward Peninsula, Alaska. These small hummocks are apparently due to alternate periods of plant growth and ice heaving. Foreign literature (Tolstichin, 1935; Andreiev, 1937) contains descriptions of similar features, using the term "hydrolaccoliths." Lozinski (1934) described peat mounds in bogs of northern Europe and Siberia; he used the term "palsen" for these features. Sharp (1942) reported the presence of "ground ice mounds" in Arctic and sub-Arctic regions; these mounds were generally a few feet high and tens of feet in circumference.

Features described by these terms generally result from the same process of ice heaving and segregation described by Taber (1929), but each reference describes a slightly different product.

LOCATION AND SETTING

Cedar Bog is 45 miles west of Columbus, Ohio, between Urbana and Spring-

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field. The Bog is located (fig. 1) in the Mad River valley in the SW$\frac{1}{4}$ of section 32 and the NW$\frac{1}{2}$ of section 31, Urbana Township (Urbana West, Ohio, 7$\frac{1}{2}$-minute quadrangle) at 40° north latitude. Figure 2A is an aerial view of the western part of Cedar Bog, and figure 2B is a ground view of the mounds as they appear at the surface. The area of ice-lens mounds is to the right in figure 2A. The locations of the lenses in 2B are obvious, because they have pushed the soil up through the cover of leaves on the ground.

This paper reports the occurrence of the ice-lens mounds, details observations made by the author at Cedar Bog, and discusses the formation of the ice lenses. The intent of the paper is to document the presence of rather than to theorize about the occurrence of the mounds.

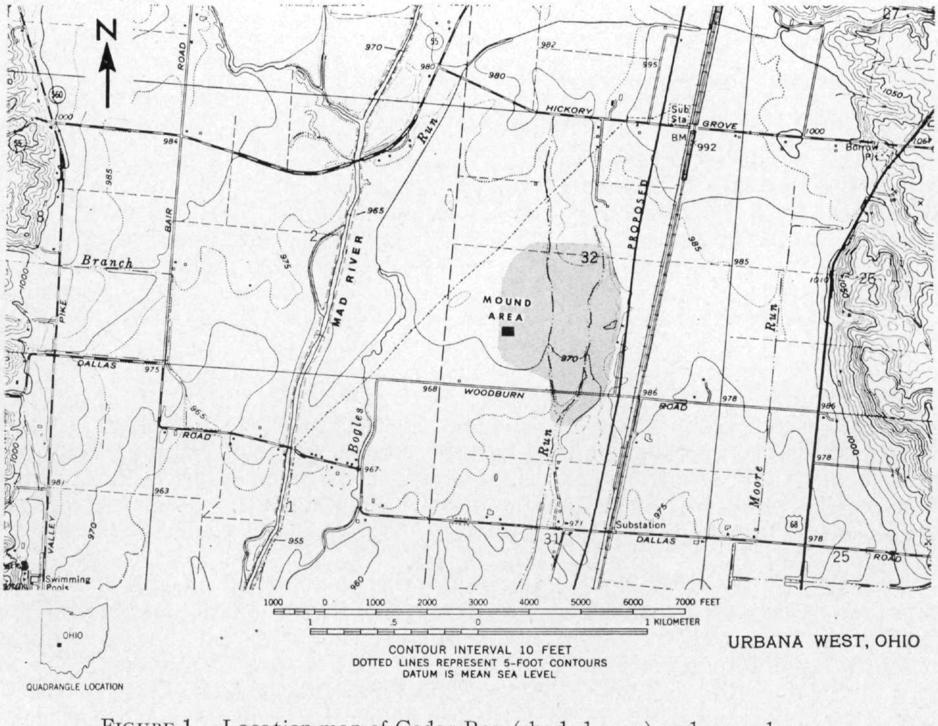

FIGURE 1. Location map of Cedar Bog (shaded area) and mound area.

OCCURRENCE OF MOUNDS AT CEDAR BOG

Dachnowski (1912) described several soil profiles from Cedar Bog. He found between 2 and 4 feet of compact blackish-brown peat, underlain at places by a 3-foot layer of fine-grained cream-colored calcareous marl. Glacial outwash sands and gravels occur beneath these units in the bog. Several test pits were dug in 1972 in the area of the ice-lens mounds to learn about subsurface conditions. Glacial outwash deposits were encountered in the area at depths of 18 to 24 inches. Cobble-size fragments of siltstone, and metamorphic and igneous rocks were found within the gravel zone.

The ice-lens mounds were contained entirely within the peat layer; no intermixing with or turbation of the underlying granular material was detected. The clear ice within each mound had a sharply planar base and a convex upper surface. The ice-lens appeared to comprise about two-thirds of the raised mound. The

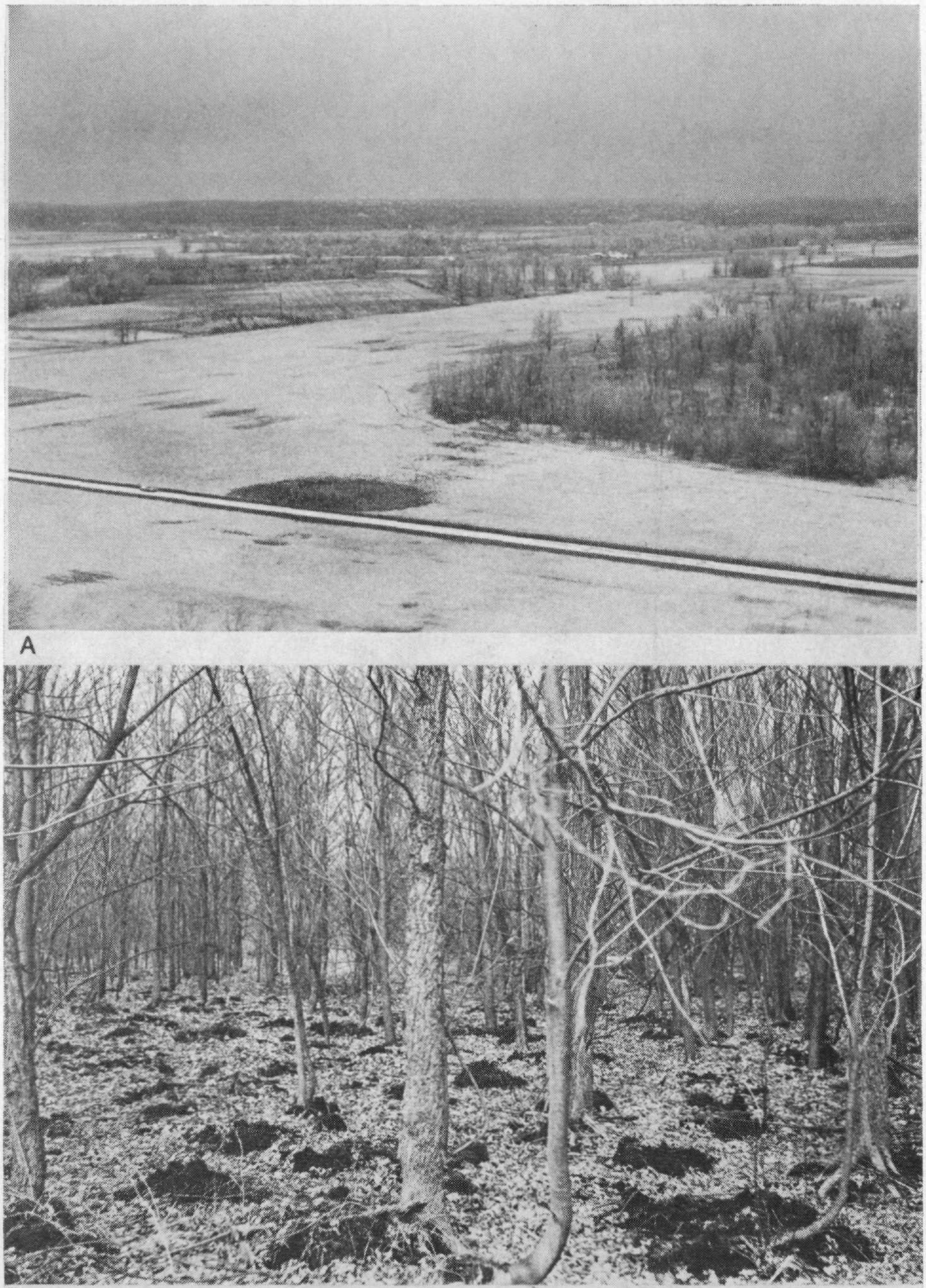

FIGURE 2. A, Aerial view of western side of Cedar Bog; the area of the ice-lens mounds is within the trees to the right of the picture. B, Ground view within ice-lens mound area.

dimensions of the ellipsoid-shaped mounds rarely exceeded 30 inches length and 24 inches width. Heaving raised the mounds to an average height of 4 inches, increasing the original volume of a unit weight of peat. Figure 3 is a generalized sketch of a cross section of one of the mounds.

Mounds were counted in two 24-by-24-foot grids marked off in the area of the mounds. The first grid contained 48 mounds and the second grid had 45 mounds; approximately 25 percent of each grid was occupied by mounds.

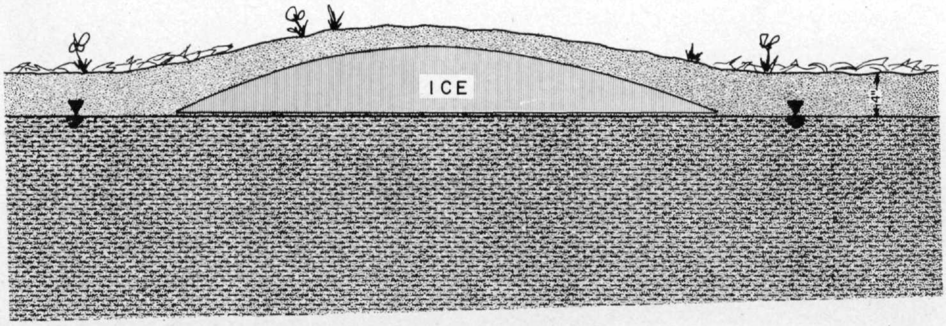

FIGURE 3. Generalized sketch of ice-lens mound.

SOIL CHARACTERISTICS AND GROUND WATER

Two samples of the peat in the area of study were collected in March 1972 and analyzed to determine weight and volumetric percent of organic matter present in the soil. The first sample was taken from between two ice-lens mounds at a depth of approximately 4 inches. The second sample was taken 120 feet south of the mounds area at a depth of 16 inches (at the water table). Table 1 provides a summary of the results.

The soil profile at the area of ice-lens development is composed of about 18 inches of blackish-brown peat underlain by silty sands and gravels. Between 18 and 30 percent of the total volume of the peat was organic matter. Clay minerals present in the peat and identified by X-ray diffraction included kaolinite, illite,

TABLE 1

Results of processed samples[1]

	Carbonate content (%)	Silt-size quartz and clay particles content (%)	Organic content (%)	Inorganic content (%) of volume of solids)	Organic content (% of volume of solids)	Inorganic content (% of total volume)	Organic content (% of total volume)
Sample inside mound area	13	41	46	25.8	74.2	10.3	29.7
Sample outside mound area	5	76	19	55.8	44.2	22.3	17.7

[1]Assumed density of organics............0.8 g/cc
Assumed density of inorganics............2.7 g/cc
(assumed densities are based on densities of cellulose and quartz)
Percentage voids of total volume = 60%

chlorite, and montmorillonite. Clay particles and silt-size (0.03 mm) quartz grains accounted for 10 to 22 percent of the total volume, the remainder being pore space.

In order to establish the percentage of total volume of solids for both the inorganic fraction and the organic fraction of both samples, densities of 2.7 g/cc and 0.8 g/cc, respectively, were assumed. The porosity of the peat was determined by use of an air pycnometer to be 60 percent.

The level of standing water in the test pits in the mounds area was 4 to 6 inches below the ground surface. To the east of the mounds area, water levels were progressively closer to the surface; about 30 feet east of the ice-lens mounds, water 1 to 2 inches deep was present at the ground surface. Water levels west and south of the mounds were significantly lower, as much as 2 feet below the surface of the ground. In March 1972 the ice lenses were still intact beneath the mound surface, and the water table in the area of the ice-lens mounds was uniformly about four inches below ground surface.

An infinite supply of water is available to the growing ice lens unless the difference in elevation between the freezing ice surface and the water table is so great that resistance to the upward-migrating water prevents replenishment to the lens surface. Jumikis (1956) noted that, if the water table is deep, water will not be drawn up to the height necessary to intercept the freezing plane surface.

The distribution of the ice-lens mounds at Cedar Bog is apparently controlled by the depth to the water table. In areas surrounding the ice-lens mounds, where the depth to the water table is greater than about 4 inches, water is apparently not able to move up to the surface in sufficient quantity to form lenses of ice. Where the water level is significantly closer to the surface than 4 inches the relatively warm ground water (53° to 57°F) restricts freezing. Small pools of water east of the mounds area were observed to be free of ice or to contain only a thin rim of ice along the edges of the pools.

TEMPERATURE VARIATIONS AND FREEZING CYCLES

Winter air temperatures at Cedar Bog fluctuate considerably above and below 32°F. This oscillation in daily temperatures results in numerous freeze-thaw cycles. A report by the Clark County Audubon Society (1972) states that air temperature variations at Cedar Bog are more extreme than at the Urbana weather station, located 3 miles north of the bog. Average minimum air temperatures at the bog are as much as 7°F lower than at the weather station. More importantly, at least within the past 7 years, there have been 37 to 82 fewer frost-free days per year in the bog than at the Urbana weather station. Each freezing period brings more water in the form of ice near the surface, resulting upon thawing in a close supply of ground water for the next freeze. Taber (1929) recognized that freezing concentrates water near the surface and that, with each successive freeze, greater segregation of ice occurs than in previous freezing periods. He conducted laboratory experiments on clays which contained too little water to form ice lenses on the first freezing, but which, after several freezing and thawing cycles, formed lenses near the surface.

FORMATION OF ICE LENSES

Taber (1918a, b, 1929, 1930), in a series of classical experiments, formed lenses of transparent ice in soil. Two aspects of Taber's work are apparently fundamental to the process of ice segregation. He (1918a, b) noted that the amount of heaving was commonly greater than the 10 percent volumetric increase accompanying the phase change from water to ice and concluded, after experimentation, that water was drawn by capillary movement or suction to the growing ice lens.

Taber (1929) was the first to recognize that upward displacement of overlying soil is due to heat conductance being most rapid in that direction, thereby determining the direction of ice crystal growth. Previously, upward displacement by frost heaving was attributed only to less resistance to expansion in a vertical direction. A lens will continue to grow as long as there is sufficient water supply and the temperature is low enough to cause freezing. Because the freezing point of water decreases with increased pressure, the freezing temperature of water decreases as heaving continues. This decrease may partially account for the much larger ice-lens features found in permafrost areas.

Taber (1930) showed also that during the formation of an ice lens a thin adsorbed water layer must be present on the surfaces of the soil particles in order for ice to segregate from the particles. This water layer makes frost heaving a reversible thermodynamic process.

The properties of the water-ice interface are critical to the explanation of frost heaving. It is at this surface that pressure is developed and transmitted. Because porous soil contains some air, a soil-water-ice-air system exists; this system is constantly changing to maintain thermodynamic equilibrium.

As water freezes at the ice-liquid interface, a temperature gradient is develloped and moisture is removed from the soil and replaced by surrounding water molecules in order to reestablish equilibrium. The formation of ice is accompanied by a pressure deficiency initiated by the nonequilibrium conditions established at the interface. Water from the surrounding soil pores flows instantly when water freezes to ice at the freezing plane. This is because of the change in pressure and corresponding loss of water from the balanced system. Therefore both temperature and pressure gradients are developed at the interface. The pressure deficiency, directly proportional to the amount of temperature change, allows the freezing front to advance downward through the soil pores by triggering an upward flow of water; there is a corresponding upward loss of heat from the unfrozen layer.

Temperature graidents were considered to be a driving force by Jumikis (1956) and by Gold (1957). Heat is transferred by the soil particles and by the upward-moving water that is present in the system as microscopic films of moisture. If the amount of heat loss exceeds the amount of heat addition, ice crystallization and growth of ice lenses occur. This is a function of soil porosity and permeability, soil moisture content, and pressure gradient. At the point where conditions change so that heat loss balances heat supply, thermodynamic equilibrium is established and growth stops.

CONCLUSION

The one-half acre of Cedar Bog where the ice-lens mounds occur is interpreted as a local topographic high where the porous texture and the saturated condition of the peat and the critical distance between the ground surface and the water table relative to the depth of freezing are conducive to ice lens formation. The limited areal extent of the mounds suggests that the balance between the water, climate, and soil factors is a delicate one.

ACKNOWLEDGMENTS

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Conservation of Natural Resources, 4th Edition. *Guy-Harold Smith,* Editor. John Wiley and Sons, Inc., New York. 1971. xiii+685 p. $11.95.

The third edition of this well-organized compilation of papers discussing environmental topics appeared in 1969 and has been used as a textbook in many geography and conservation courses. People in charge of these courses will welcome an up-to-date revision of the book in the form of the recently released 4th edition.

All the same topics are covered (soil, land, water, minerals, plants, wildlife, and planning, etc.), although the order and organization of the different topics is somewhat different, albeit in a very reasonable and meaningful order. Many of the separate chapters are very little changed, through most have minor changes which bring them up to date and which represent the change in national emphasis from soil erosion and agriculture to water quality, and urbanization, and regional planning. Others contain considerable additions, which both update and enlarge them, in some cases somewhat redirecting their emphases, and a few are completely revised or new. Topics which are completely revised in this edition are those on soils, soil conservation, irrigation, waterways, forests (Diller's two sections are replaced by material prepared by Lee M. James), fisheries (Howard W. Martin's contribution is replaced by one by coauthors Guy-Harold Smith and Donald W. Lewis), and regional planning (handled in this volume by James A. Spencer, rather than by Harold V. Miller). Topics new in this edition are Conservation of the Atmosphere (i.e. air pollution) by Robert M. Basile, and water pollution by Carl H. Strandberg.

In general these changes represent improvements. However, the soil section, while presenting the new soils classication, that of the 7th Approximation (which is now in general use by soils scientists), does not mention the old classic Great Soil Groups at all; it would have helped if these Great Soil Group names and their coorelation in the new classication had been included.

Type size in the new volume is the same, but the type is slightly thinner, appearing less dark, so, though it is easy to read, one gets the impression of more white surface on the page than formerly. One bad feature is that the ink used in this new edition, both for printing the typed material and for the figures, appears to have a sort of greenish cast, so that the type is less dark and contrasty, and the figures, especially the half-tones, are somewhat less bright and clear. The poorer quality of the figures, however, is offset by the improved and up-to-date additions to the text.

As in the earlier edition, references are listed at the end of each separate chapter. In addition, there is a list of 108 general references on conservation at the back of the book, followed by a lengthy 25-page index. The book is almost the same size as the previous edition, except for being about 20 percent thicker.

This book provides a good systematic survey of all aspects of conservation and would make a good textbook in this field at the introductory level in college or the 12th grade. It would also be a good reference book for others interested in general considerations of conservation. It is not sufficiently detailed or specific to provide answers for most of the modern problems of environment or pollution, but it presents a good overall introduction to the different areas of conservation.

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