Journal of Ecology (1986), **74**, 1103–1117

HYDROLOGY, WATER CHEMISTRY AND ECOLOGICAL RELATIONS IN THE RAISED MOUND OF COWLES BOG

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SUMMARY

(1) The Cowles Bog National Natural Landmark and the wetlands between the dunes near the south shore of Lake Michigan, in Indiana, contain plant species that are typical of circum-neutral fens.

(2) The distribution of eight, rather sharply delineated, vegetation types correlates most strongly with water level variations resulting from the presence of a 4·1-ha convex peat mound.

(3) A network of shallow ground-water wells installed in the wetland has identified an upwelling of water under artesian pressure at sites underlying the mound.

(4) The well-buffered water, containing high concentrations of inorganic solutes, is derived from an aquifer that is recharged on an upland moraine and is confined beneath a clay till sheet.

(5) A breach in this clay layer beneath the mound allows water to flow upward and radially outward as the hydraulic head is dissipated in the overlying marl and peat.

(6) The marl and organic lake sediments in the wetland were formed during the Nipissing level of ancestral Lake Michigan (4000–6000 years ago) when the wetland basin was probably a small bay of the lake.

(7) The peat mound developed when the lake level fell from the Algoma through to modern times. This increased the difference in hydraulic head and increased spring flows, which in turn induced peat formation.

INTRODUCTION

The Cowles Bog Wetland Complex (CBWC) is a mixture of various wetland and peatland communities that occupies approximately 80 ha of the basin between the Calumet and Tolleston dunes on the southern shore of Lake Michigan in Porter County, Indiana (Reshkin 1981) (Fig. 1). A 22-ha area of peatland (fen) within the complex was designated as Cowles Bog National Natural Landmark (CBNNL) in 1966—the same year that the entire wetland complex was incorporated into the authorized boundaries of Indiana Dunes National Lakeshore. Professor Henry Chandler Cowles led his classes as well as the 1913 International Phytogeographic Excursion to this site (Tansley 1913). Although Cowles is not known to have conducted his pioneering studies in plant ecology in the peatland, it has borne his name since the early 1920s (Brennen 1923; Kurz 1923).

Early research on the natural resources of Cowles Bog includes two papers by one of Cowles' graduate students (Kurz 1923, 1928), and descriptions of the area were provided by Tansley (1913), Bailey (1917), Brennen (1923), Lyon (1927) and

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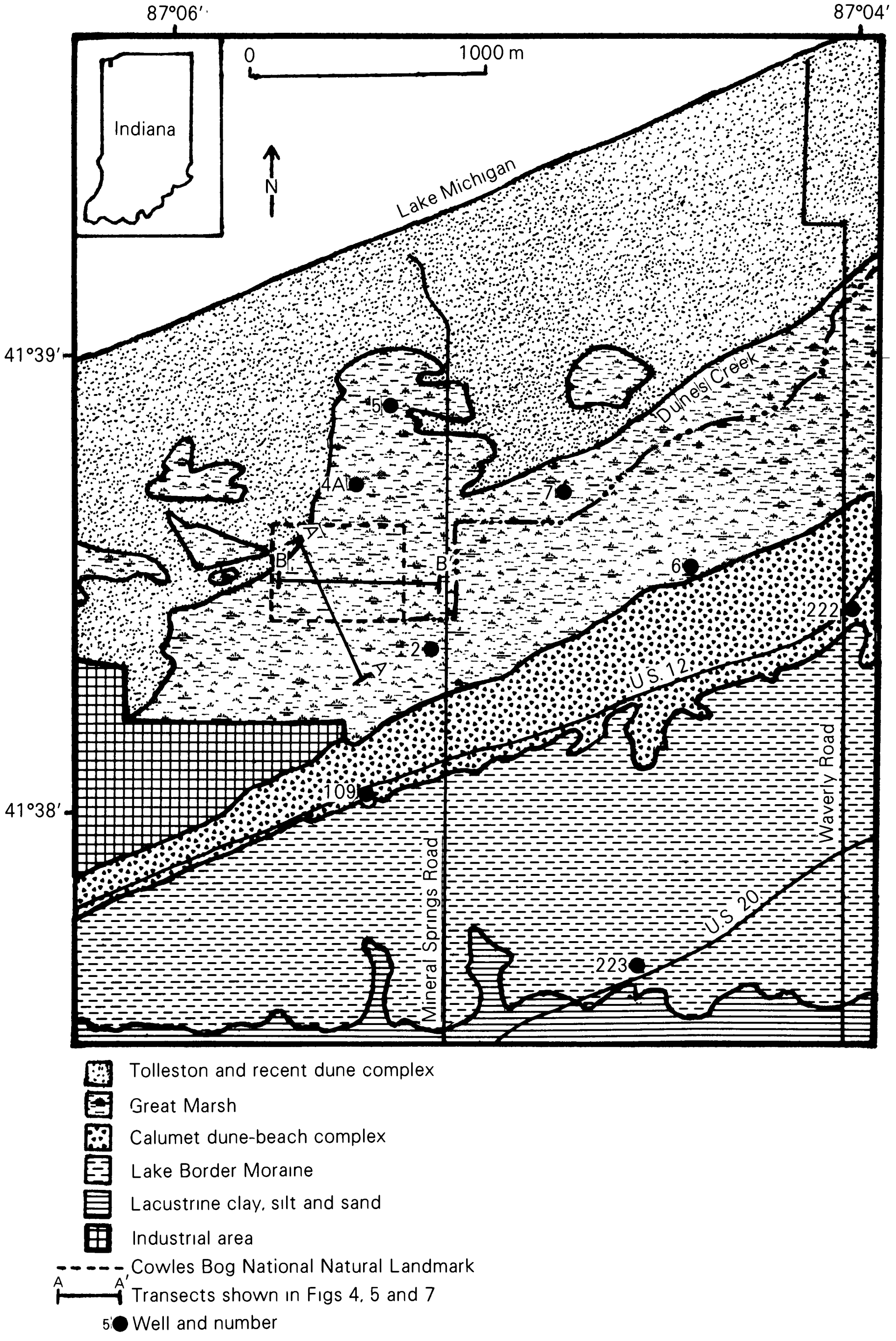

FIG. 1. Map of Cowles Bog Wetland Complex and surrounding area, showing geomorphic features, surface geology, coring transects and locations of perimeter wells.

Cressey (1928). Little work was done in Cowles Bog until the mid-1970s, when nearby industry potentially threatened the hydrology of the wetland. The U.S. Geological Survey studied the hydrologic implications of seepage from fly-ash settling ponds at the site of a coal-fired generating station about 2 km west of the site, and of ground-water pumping at the construction site of a planned nuclear power plant at the same place (Marie 1976; Meyer & Tucci 1979; Gillies & Lapham 1980). Other recent studies have been on water quality (Arihood 1975; Hardy 1981), soils (Boelter 1978; Patterson & Fenn 1978), vegetation (Wilhelm 1980; Wilcox, Apfelbaum & Hiebert 1984) and more general ecological relationships in the Cowles Bog Wetland Complex (Texas Instruments Ecological Services 1974–81; Carter & Stottlemyer 1978; Hendrickson & Wilcox 1979; Apfelbaum *et al.* 1983). None of these studies, however, comprehensively examined the very localized hydrology, topography, stratigraphy and water chemistry that resulted in the raised peatland and its unusual assemblage of vegetation (Table 1), which includes the only stand of northern white cedar (*Thuja occidentalis* L.) in Indiana (Deam 1953). This paper examines the relations between these factors.

METHODS AND MATERIALS

The vegetation of the Cowles Bog Wetland Complex was previously mapped from aerial photographs taken between 1938 and 1982 (Wilcox, Apfelbaum & Hiebert 1984). During the current study, maps of the Cowles Bog National Natural Landmark were brought up to date with 1983 colour infrared aerial and 1984 colour aerial photographs coupled with extensive ground surveys. The vegetation types mapped were: *Typha* marsh; *Phragmites*/*Typha* marsh; *Carex*/*Calamagrostis* marsh; shrub swamp; *Larix laricina* swamp; *Thuja occidentalis* swamp; *Acer rubrum* swamp; and upland *Quercus velutina* woodlands. The vegetation types represent an elaboration of those mapped for the entire CBWC (Wilcox, Apfelbaum & Hiebert 1984) and also identified by Apfelbaum *et al.* (1983). All plant names used conform to the nomenclature of Swink & Wilhelm (1979).

A stratigraphic cross-section was constructed from cores collected with soil augers and a modified Livingston piston corer (Brown 1956) at 30-m or lesser intervals along a 600-m transect perpendicular to the long dimension of the basin (see Fig. 1). Continuous cores collected with a vibra-corer (Finkelstein & Prins 1981) as part of a regional sedimentology study (Thompson 1985) provided additional stratigraphic data. The topography of a 400 m × 150 m convex peat mound in the wetland was mapped using a survey level. Radiocarbon dates were obtained from five peat and marl/organic fractions of a core collected from the *Acer rubrum* swamp.

Ground-water observation and sampling wells were installed along east-west and north-south transects that intersected at the greatest height on the mound. These ten wells consisted of 5-cm diameter stainless-steel slotted screens, 80 cm long, attached to stainless-steel casing. The wells were hand-driven into the underlying sands to depths ranging from 2·3 to 6·5 m from the surface. Three more wells were driven at site 4C on the mound to create a group of four wells at different depths in different strata. Additional wells were installed at several perimeter sites in the wetland. The altitudes of the tops of all wells were established (the casings protruded above the soil surface), and water levels were measured at least quarterly from 1980 to the end of 1984.

Analyses for specific conductance, pH, alkalinity, total hardness, tritium, calcium, magnesium and sulphate were conducted on water samples from the wells, from shallow

TABLE 1. The dominant (d) and rare or particularly interesting (r) plant species found in each vegetation type in the Cowles Bog National Natural Landmark. Based on Hendrickson & Wilcox (1979), Wilhelm (1980) and Apfelbaum *et al.* (1983).

Species	*Carex/ Calamagrostis* marsh	*Typha* marsh	*Phragmites/ Typha* marsh	Shrub swamp	*Thuja occidentalis* swamp	*Larix laricina* swamp	*Acer rubrum* swamp
Acer rubrum					d		d
Aralia nudicaulis					d		
Betula lutea				r	d r	r	d r
Betula papyrifera							r
Betula pumila				r			
Calamagrostis canadensis	d						
Carex seorsa							r
Carex stricta	d						
Coptis groenlandica							r
Cornus canadensis							r
Cornus stolonifera				d	d	d	
Galium trifidum	r	r			r	r	
Impatiens capensis	d	d	d	d			
Larix laricina						d	
Leersia oryzoides						d	
Lindera benzoin						d	
Lonicera dioica						r	
Maianthemum canadense							d
Mitchella repens							r
mosses						d	d
Myosotis laxa							r
Osmunda cinnamomea							d
Parthenocissus quinquefolia						d	d
Peltandra virginica		r		r			
Phragmites communis			d				
Pinus strobus					r		
Polygonum arifolium pubescens	r	r					
Potentilla palustris	r						
Prunus serotina							d
Rhamnus alnifolia						r	
Rhus vernix		r	r		d r	r	
Rosa palustris				d			
Salix candida	r						
Salix sericea	r						
Salix spp.				d			
Sarracenia purpurea		r					
Symplocarpus foetidus					d	d	d
Thalictrum dasycarpum			d				
Thuja occidentalis					d r		
Trientalis borealis							r
Typha angustifolia	d	d	d				
Typha latifolia		d					
Vaccinium atrococcum							r
Viola pallens					r	r	r
Vitis labrusca				r	r		

excavations in the peat at each well site (interstitial peat pore-waters) and from surface waters in the marsh. Samples were analysed by standard U.S. Geological Survey laboratory procedures (Brown, Skougstad & Fishman 1970).

RESULTS

Vegetation

Eight vegetation types were mapped that generally were sharply separated (Fig. 2). The *Quercus velutina* (black oak) woodland is on upland dunes, and the *Acer rubrum* (red maple) swamp is in a band adjacent to the upland sites. *Typha* (cattail) marsh

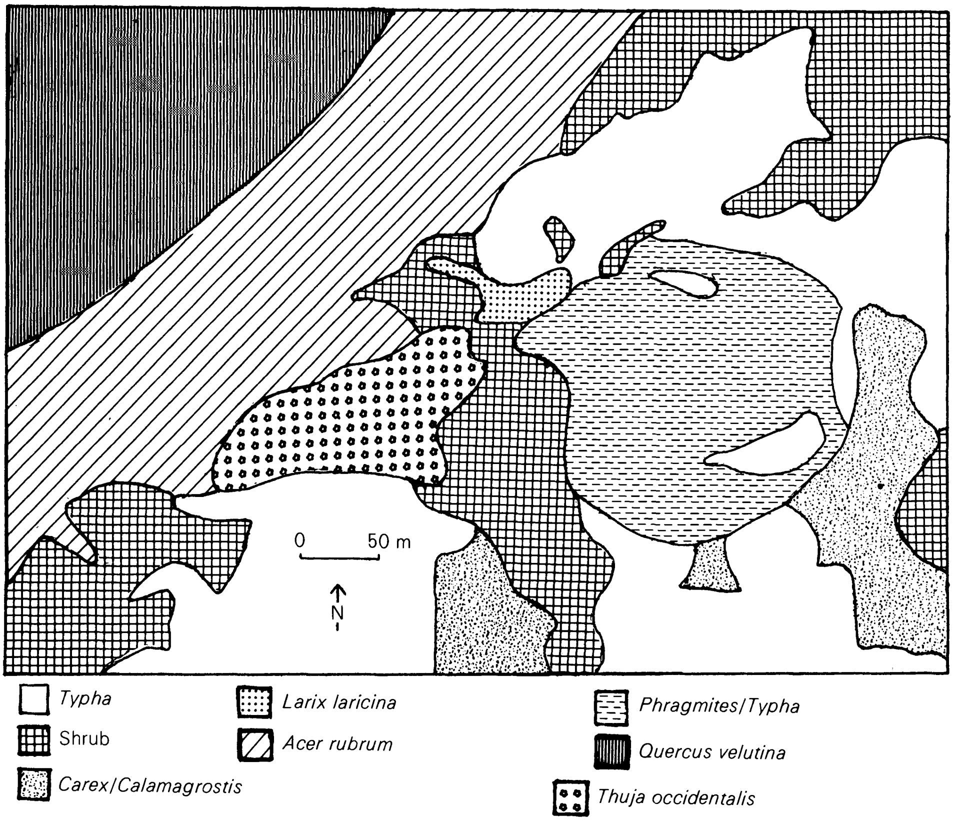

FIG. 2. Map of vegetation types in Cowles Bog National Natural Landmark.

and shrub swamp zones appear as a mosaic, which seems to be invading the *Carex/Calamagrostis* marsh, as previously reported by Wilcox, Apfelbaum & Hiebert (1984). The remaining vegetation types are clumped in the wetland. The *Thuja occidentalis* (northern white cedar) swamp occurs on a site that is somewhat drier than most of the wetland, and the *Larix laricina* (tamarack or larch) swamp is in an area where soils are saturated throughout the year. The *Phragmites/Typha* marsh is on a drier site and has also been classed as an invader of the *Carex/Calamagrostis* marsh (Wilcox, Apfelbaum & Hiebert 1984).

Topography and stratigraphy

The drier wetland sites in the CBNNL are on a 4·1-ha convex mound in the wetland that rises as much as 1·4 m above the surrounding marsh water levels (Fig. 3). The mound is bisected by the remnant of a drainage ditch that was constructed in the early 1900s. The *Phragmites/Typha* vegetation type occupies the eastern part of the mound, whereas *Thuja occidentalis* dominates the western part.

In a stratigraphic cross-section of the entire CBWC basin perpendicular to its long axis (A–A′) (see Fig. 1), the mound is shown to be an 80-m wide topographic anomaly on an otherwise nearly flat wetland surface (Fig. 4). The northward-sloping surface of the sand that overlies the clay layer probably represents the near-shore lake bottom

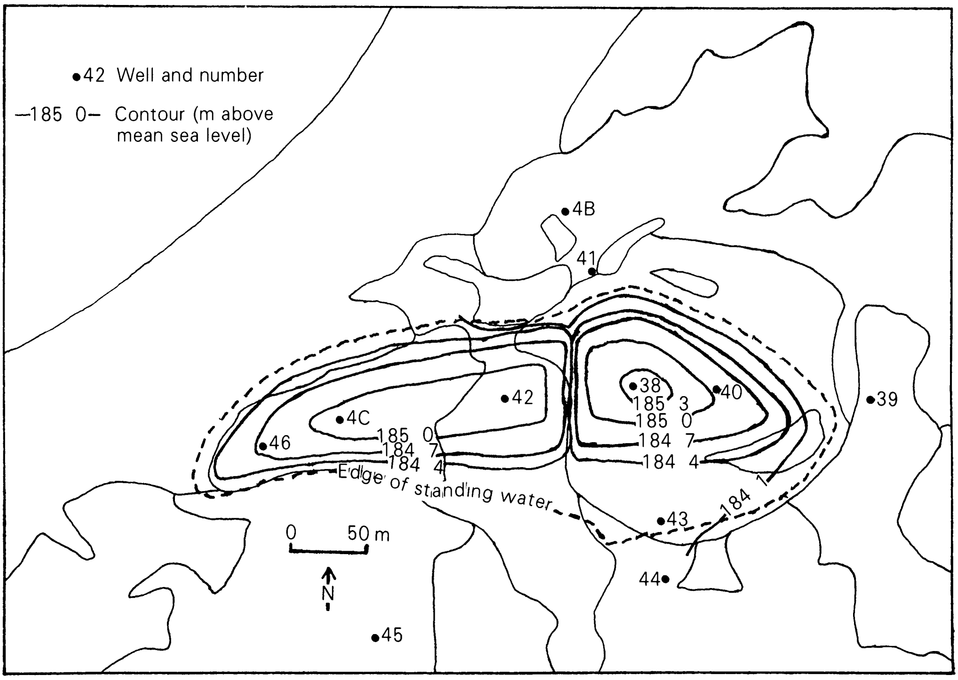

FIG. 3. Well locations and surface topography of mounded peatland superimposed on the outlines of vegetation types in Cowles Bog National Natural Landmark. See Fig. 2 for vegetation types.

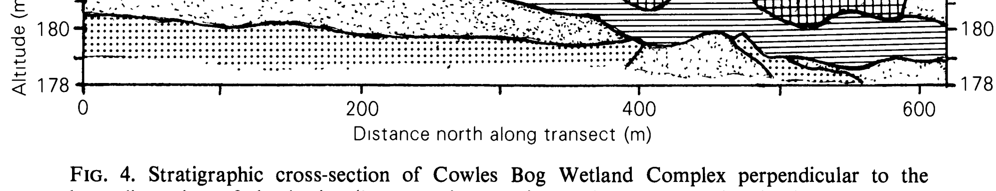

FIG. 4. Stratigraphic cross-section of Cowles Bog Wetland Complex perpendicular to the long dimension of the basin. (From various coring and gamma-ray logs.) Line of transect (A–A′) is shown in Fig. 1. The vertical exaggeration is ×20.

of the Calumet stage of Lake Michigan (Bretz 1951). The CBWC basin is bounded on the north by dunes that formed and migrated southward during a period of lower lake levels after the Calumet stage.

At the northern edge of the basin, beginning at a point 470 m along the transect, a clay layer is present that is probably the sub-surface extension of the till surface of the Lake Border moraine (which crops out and forms an upland south of the CBWC).

The till surface was not detected beneath the mound along this transect and, because of the thickness and depth of the sand, it was not detected south of the mound using manual coring methods. However, the till was recovered in several vibra-core holes made south of the mound, and its extension to the south in Fig. 4 is inferred from these holes. The deepest part of the above-sand basin contains a layer of marl interbedded with layers of sand. Most of the marl beds also contain admixed sand and carbonate shells. The marl layer is much thicker beneath the mound than it is in adjacent areas. Well-decomposed (sapric) peat and organic lake sediments overlie the marl, and they are overlain by the poorly-decomposed (fibric) peat that forms the convex surface of the mound.

Radiocarbon dates of organic materials extracted from the marl place the age of the above-sand CBWC basin at about 6200 years B.P. Deposition of marl continued until around 4500 years B.P., when organic lake sediments began to accumulate. The more fibrous peat began to accumulate about 2000 years ago.

An east-west stratigraphic profile (B–B′) that crosses the mound (see Fig. 1) was constructed from descriptions of seven vibra-cores. In this profile (Fig. 5), the till is again found adjacent to the mound and even extends beneath it for about 100 m at the west end. However, the till is absent beneath most of the mound. Marl deposits are thicker

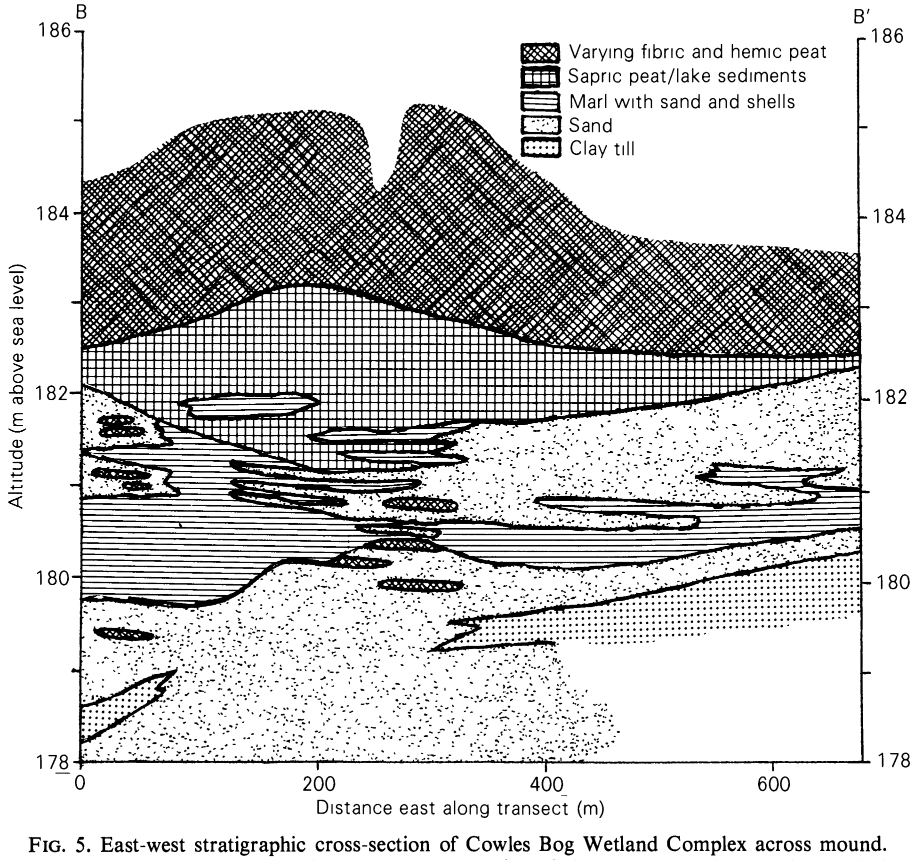

FIG. 5. East-west stratigraphic cross-section of Cowles Bog Wetland Complex across mound. (From vibra-core descriptions.) Line of transect (B–B′) is shown in Fig. 1. The vertical exaggeration is ×80.

beneath the mound than in adjacent areas in this cross-section also. In addition, the continuous cores obtained with the vibra-corer showed the detailed inter-fingering of sand and peat within the marl. In this east-west profile, the surface of the underside of the peat mass is convex.

Hydrology

The water levels in wells extending down into the sand beneath the mound were higher than the peat surface of the mound (Fig. 6). However, no natural spring flows were observed. Water levels in wells beneath the highest parts of the mound were generally higher than in wells at the perimeter of the mound. Water level in wells that were away from the mound were at about the same height as the corresponding water surface in the marsh. Water levels varied seasonally, but retained a similar well-to-well pattern.

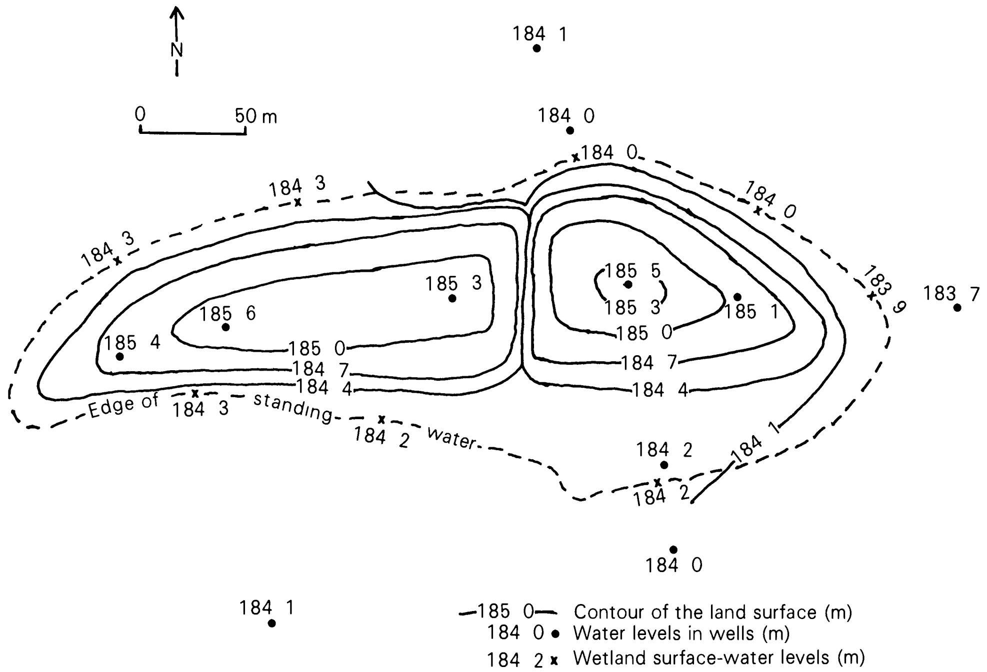

FIG. 6. Altitudes of water levels and surface topography of mounded peatland in Cowles Bog National Natural Landmark, April 1980. (Altitudes in metres above sea level.)

The deposits of sand, marl and peat that overlie the till surface of the Lake Border moraine form a multilayered near-surface aquifer. In the CBWC, the till is underlain by a complex sequence of interbedded sand and clay that forms an aquifer confined below the till. Water in this artesian aquifer seeps upward into the overlying sand of the surface aquifer. However, the breach in the till beneath the mound connects the two aquifers directly. This improved connection is reflected in the higher water level in wells on the mound.

Water levels in the group of four wells at site 4C indicate an upward flow from the sub-till aquifer to the peat mound that is also shown by the inferred flow lines near site 38 in Fig. 7. Upward flow into the peat is through both the breach in the till and the partly confining layer of marl and sand. Most of the difference in water pressure between the sub-till aquifer and the water table on the peat mound is dissipated through the marl layer. The head contours in Fig. 7 give a general picture of the head distribution beneath the mound. For this reason and because the thickness and depths of the various strata change along the long dimension of the mound, the head contours shown in the figure cross stratigraphic boundaries.

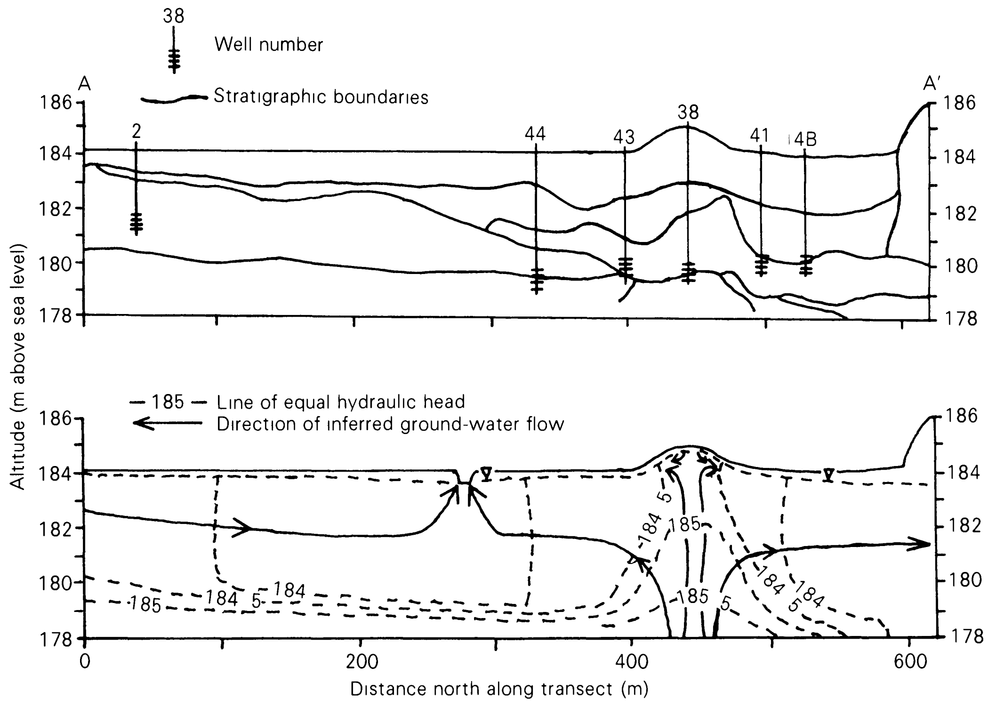

FIG. 7. Hydrogeologic cross-section of Cowles Bog Wetland Complex perpendicular to the long dimension of the basin showing well locations, contours of hydraulic head and ground-water flow paths. Line of transect (A–A′) is shown in Fig. 1. Vertical exaggeration is ×20. The cross-bars on the well symbols show the section from which water is drawn into the well.

The flow diagram also illustrates that the water table is higher in the peat mound than in the surrounding wetland. This causes a radial pattern of shallow ground-water flow away from the peat mound in all directions (Shedlock 1983). Because the peat mound is in the headwaters of Dunes Creek, which flows east, all the shallow flow paths that originate in the mound eventually curve toward the east.

Water chemistry

All of the waters analysed from the CBWC were dominated by calcium and magnesium bicarbonate (Table 2). At sites on or near the raised peat mound, the waters are well-buffered and maintain circum-neutral pH values. The specific conductance is quite high for a peatland and indicates a highly mineralized water source.

TABLE 2. Selected mean water chemistry values (and standard deviations) for well and peat pore-waters collected at sites on the mound, near the mound and away from the mound in the Cowles Bog Wetland Complex. See Figs 1 and 3 for well locations.

Site	Specific conductance (μS cm^{-1})	pH	Alkalinity (m-equiv. l^{-1})	Ca (mg l^{-1})	Mg (mg l^{-1})	SO_4 (mg l^{-1})
Well waters						
On mound (46,4C,38,43)	832 ± 42	7·44	7·56 ± 0·56	82 ± 8	46 ± 3	93 ± 4
Near mound (4B,41,39,44)	768 ± 50	7·37	7·48 ± 0·40	68 ± 10	45 ± 7	50 ± 44
Away from mound (4A,5,6,7)	363 ± 177	5·89	1·70 ± 0·58	35 ± 3	12 ± 5	50 ± 36
Peat pore-waters						
On mound (46.4C,38)	862 ± 89	7·16	9·58 ± 1·64	90 ± 12	50 ± 5	37 ± 23
Near mound (4B,39,44)	827 ± 106	7·03	9·22 ± 0·94	85 ± 11	45 ± 2	15 ± 14
Away from mound (4A,5,6,7)	190 ± 136	5·51	1·20 ± 1·48	22 ± 13	8 ± 6	27 ± 9
Confined aquifer site						
Ground-water (2)	671	7·1	6·62	87	36	62

Waters from wells on or near the mound that take their water from sands beneath the peat and marl have significantly higher (paired *t*-test, $P = 0{\cdot}01$) specific conductance, alkalinity and concentrations of total hardness, calcium and magnesium than waters from shallow wells 0·5–1·4 km from the mound. The values of these variables in peat pore-waters on and near the mound are significantly higher than in peat pore-waters away from the mound. These hydrochemical differences are probably a function of position in the ground-water flow system.

The chemistry of well and peat pore-waters on or near the mound is similar to that of water from one of the wells at site 2 (Table 2). Independent geophysical techniques (logging of natural gamma radiation) used at this site on the southern edge of the CBWC basin have shown that the well reaches a sub-till confined aquifer. The water pressure and the similarities in water chemistry to the confined aquifer indicate that both the shallow ground-water and peat pore-water on and near the mound are derived mainly by upward leakage from the confined aquifer. Sites away from the mound (see Fig. 1) represent areas where shallow ground-water comes from the surface aquifer that is recharged in the dunes at the margins of the wetland (Shedlock 1983). Flow paths and residence times of this water are short, and thus the water has lower concentrations of inorganic solutes than that in the confined aquifer.

Isotope analyses also confirm that the confined aquifer is the source of water supplying the mound. Waters from wells in the confined aquifer on the moraine and wells on the mound all had very low tritium concentrations (Table 3)—an indication that the aquifer was recharged prior to atmospheric nuclear testing in the early 1950s. Waters from wells away from the mound or in the unconfined aquifer on the moraine all had high concentrations of tritium, whereas wells near the mound had rather low concentrations. Moderate values for tritium concentration in the peat pore-waters on and near the mound indicate the mixing of old and new waters.

TABLE 3. Tritium concentrations in well and peat pore-waters in and around the Cowles Bog Wetland Complex. See Figs 1 and 3 for well locations.

	H^3 (pCi l^{-1})	
Site	Well waters	Peat pore-waters
On mound		
38	2·2 ± 1·3	28·6 ± 1·7
4C	0·1 ± 1·3	27·4 ± 1·8
46	2·0 ± 1·3	18·5 ± 1·5
Near mound		
4B	1·8 ± 1·2	39·8 ± 2·3
39	12·8 ± 1·5	—
44	5·8 ± 1·3	63·2 ± 3·0
Away from mound		
7	153 ± 6	120 ± 5
4A	150 ± 7	—
Upland (moraine)	*Confined aquifer*	*Unconfined aquifer*
222	0·3 ± 1·3	116 ± 5
223	0·3 ± 1·2	—
109	5·0 ± 0·5	—

DISCUSSION

Terminology

Although, by definition, bogs are isolated from regional ground-water flow and their water is derived from ion-poor precipitation (Boelter & Verry 1977; Gore 1983), the term has been mis-used in naming a wide variety of peatlands in North America. Peatlands such as Cowles Bog, which derive most of their water from ion-rich ground water, are actually fens by definition. They are typically minerotrophic, with waters rich in calcium and magnesium bicarbonates and circum-neutral pH values (Boelter & Verry 1977; Curtis 1959). Cowles Bog not only meets these conditions, but also seems to meet the specific conditions described by Moore & Bellamy (1974) for a spring mire: a peatland formed over spring heads, which 'may exhibit a convex profile, the height of the convex peat mass being a function of the hydrostatic head of the spring and the containing volume of the peat'.

Hydrology of CBWC and similar wetlands

Mounded fens may form in two different physiographic positions: hillsides and valleys. Hillside fens, supplied by 'artesian' or confined aquifer waters under pressure, have been reported by Friesner & Potzger (1946), Havas (1961), Kukla (1965), Holte (1966), Lahermo, Valovirta & Sarkioja (1977) and Kratz, Winkler & DeWitt (1981), and may be hydrologically similar to Cowles Bog.

Artesian-fed, mounded fens in valley bottoms or other flat terrains, which are physiographically more similar to Cowles Bog, have been reported by several investigators (Gordon 1933; Bitner 1958; Ciolkosz 1965; Holte 1966; Colhoun, van de Geer & Mook 1982). The hydrologic data in these papers are scanty, but Colhoun, van de Geer & Mook and Bitner report spring flows that percolate upward through layers of marl in fens of Tasmania and Poland, respectively. This is consistent with our model of seepage through the marl and into the peat mound at Cowles Bog. Bitner also identified a heavy, greenish-blue clay that pinches out beneath the edge of the peat mound and morainal clay in the adjacent valley slopes. This is consistent with the concept of a discontinuous clay confining-layer overlying the artesian aquifer beneath the wetland.

Valley Fen 7 in Iowa (Holte 1966) is the most similar to Cowles Bog in topography and stratigraphy of all the mounded fens that have been reported. The blue clay layer confining the sand aquifer is discontinuous beneath the mound and is overlain by alternating strata of sand and sand–soil mixtures, marl, sapric peat and fibric peat. The bed of peat is biconvex, as in Cowles Bog. The upward flow of water to the peat mound is confirmed by the water level in a single well, where water rises about 0·5 m higher than the peat surface.

Relationship of vegetation to hydrology and water chemistry

The distribution pattern and species composition of the vegetation types mapped within the CBNNL appear to be correlated with the topography, stratigraphy, hydrology and consequent water chemistry of the wetland. Lahermo, Valovirta & Sarkioja (1977) observed similar correlations in the study of spring-fed peatlands in Finland. As is common for a number of habitats, Holte (1966) found that plant zonation in Iowa fens is correlated with height above the water table and, hence, with aeration, soil moisture and pH.

Certain plant communities and individual species are also commonly associated with hard and soft water types (Moyle 1945; Coombe & White 1951), and particularly with pH and calcium and magnesium concentrations (Lahermo, Valovirta & Sarkioja 1977; Sjörs 1950). Kurz (1928) noted differences in pH between the alkaline open mat and the more acidic forested portion of Cowles Bog in his early work there. These differences have also been confirmed in later work (Hendrickson & Wilcox 1979). Holte (1966) found that community zonation on spring-fed peatlands was not determined by water chemistry, but that species occurrence seemed to be related to water chemistry and temperature.

Within the CBNNL, the dominant and rare or particularly interesting plants in the different vegetation types (Table 1) are primarily species of minerotrophic peatlands. Boelter & Verry (1977) give this classification to such Cowles Bog species as *Betula papyrifera*, *Thuja occidentalis*, *Cornus canadensis*, *Potentilla palustris*, *Calamagrostis canadensis* and *Phragmites communis*. *Larix laricina* and *Sarracenia purpurea* are common to both minerotrophic and ombrotrophic sites. Many plant species found in Cowles Bog have also been identified in the mounded peatlands of Silver Lake Fen in Iowa (Anderson 1943; van der Valk 1975) and in Cabin Creek Raised Bog in Indiana (Friesner & Potzger 1946; Starcs 1961).

The vegetation types in the CBNNL strongly resemble those identified for Cedar Bog in Ohio (Frederick 1974), even though there is no evidence of gradient-like zonation in Cowles Bog. The species distribution patterns can, however, be assessed in relation to hydrology and water chemistry. The northern white cedars of Cowles Bog grow only on the peat mound, where improved soil aeration may be beneficial (U.S. Department of Agriculture 1965). In Cedar Bog, northern white cedar grows in alkaline, spring-fed areas of a marly fen (Dachnowski 1910; Collins, Perins & Vankat 1982)—a habitat often associated with this species (U.S. Department of Agriculture 1965; Swink & Wilhelm 1979). The *Phragmites* that grows with *Typha* on the eastern part of the mound in Cowles Bog may also thrive better in more aerated soils. However, on the basis of historic vegetation analyses (Wilcox, Apfelbaum & Hiebert 1984), *Phragmites* is considered to be a recent invader of the *Carex*/*Calamagrostis* marsh. At Silver Lake Fen in

Iowa, the raised peat mound of the spring discharge zone is dominated by *Phragmites communis* (van der Valk 1975).

The stand of *Larix laricina* in Cowles Bog is adjacent to the peat mound, where water chemistry is similar to that in the mound but where the soil is more saturated. These are conditions that this species can tolerate (U.S. Department of Agriculture 1965; Tilton 1977). Red maple and its associates are commonly found in wet habitats ranging from swamps to bogs (Swink & Wilhelm 1979). The *Acer rubrum* swamp in the CBNNL is found along the northwestern edge of the wetland overlying the clay layer. It is, therefore, influenced less by the upwelling of hard ground-water and has water of somewhat lower pH (5·0–6·75) than that of the mound (Kurz 1928; Hendrickson & Wilcox 1979).

The *Carex*/*Calamagrostis* marsh of Cowles Bog once dominated much of the unforested wetland (Wilcox, Apfelbaum & Hiebert 1984). It would characteristically have occupied an area where seasonal flooding occurred, but the water table would have been near the soil surface much of the year (Curtis 1959). The invasion of *Typha* and shrubs in Cowles Bog may be partly successional, but it is also related to hydrologic disturbance in the wetland watershed, which increased and stabilized water flow to the lower-lying lands (Wilcox, Apfelbaum & Hiebert 1984). The oak woodlands in the CBNNL are obviously an upland community.

Development of the Cowles Bog Wetland Complex

The development of the CBWC was largely in response to the sequence of events in glacial geology that formed the Lake Michigan basin. The northward-sloping sand surface underlying the wetland is probably the near-shore lake bottom of the Calumet stage, which ended about 11 000 years ago. This surface overlies interbedded sand and clay till layers that are part of the Lake Border moraine and other lake deposits. About 6200 years B. P., water levels rising to the Nipissing stage (184 m above sea level) created a backwater area between the Calumet and later dunes that may have been connected to the lake by the Dunes Creek drainage. Marl formed in the stagnant, hard-water environment—probably by both chemical and biogenic precipitation. Marl deposition was greater in the area surrounding the breached clay confining-layer, where ground-water high in calcium and bicarbonate concentrations entered the basin. Marl deposition continued until about 4500 years B.P., when organic sediments of lacustrine origin began to dominate the deposits of a shallower, more vegetated basin.

As the basin became filled with organic mud and marsh peat, lake levels declined through the Algoma stage (181 m). The open water in the basin gradually disappeared and, about 2000 years ago, the water table was near the surface of the peat. Lake levels continued declining to the Lake Michigan stage (177 m), which caused a greater head difference between the water table at the peat surface and the confined aquifer at the breach in the clay. Peat accumulation continued around the upwelling, but not throughout the remainder of the wetland, and a mound gradually formed. As the peat accumulated to greater heights, the head gradient consequently declined and any spring pools that were present became covered with peat (Lahermo, Valovirta & Sarkioja 1977). This, in turn, further dissipated the head and resulted in a mounded peatland without flowing springs.

The valley fens reported by Holte (1966), Colhoun, van de Geer & Mook (1982) and Bitner (1958) probably have origins similar to Cowles Bog. Bitner's speculation on formation is the most consistent with that of Cowles Bog. He found that marl and lake sediments has developed in a narrow valley and then partly eroded as the natural areas provided the proper environment for peat development, with greater peat formation at sites with highest hydraulic heads. In Cowles Bog, a catastrophic event was not necessary to cause water levels in the backwater area to decline; the declines of Lake Michigan provided the necessary drainage of the basin.

ACKNOWLEDGMENTS

We thank D. Early and W. Maines for assistance in installing wells; D. Cohen, T. Imbrigiotta, L. Watson and J. Payton for assistance in data collection; R. Futyma for collection of samples for radiocarbon dating; T. Thompson for allowing us to inspect the vibra-cores from Cowles Bog; M. Mueggler and K. Edwards for preparing the figures; and M. Pittman for typing the manuscript. We also thank V. Carter and E. S. Verry for their helpful reviews of the manuscript.

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(Received 3 January 1986)