Journal of the Iowa Academy of Science: JIAS

Volume 99 | Number 2-3 | Article 4

1992

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Jour. Iowa Acad. Sci. 99(2-3):53-59, 1992

Geology of Iowa Fens[1]

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Fens are peatlands which are dependent on groundwater discharge to provide nutrient enrichment. Fens are found in a variety of landscape positions and in most Iowa landform regions. This paper presents a classification system for Iowa fens based on landscape position, stratigraphy, and hydrologic factors. Iowa fens can be separated into six categories: 1) fens along valley wall slopes; the groundwater source for these fens is sand and gravel buried between glacial tills (inter-till); 2) fens in hummocky topography on the northwestern margin of the Des Moines Lobe landform region; the water source is sand and gravel buried within glacial till (intra-till) which exhibits artesian flow; 3) fens on ridges of exhumed sand and gravel on the Iowan Surface; the water source is the exposed sand and gravel; 4) fens on benched alluvial terraces or glacial outwash settings; the water source is sand and gravel exposed at the surface; 5) fens recharged by bedrock aquifers; and 6) fens in abandoned channel areas whose water source is either sand and gravel exposed at the surface or bedrock aquifers.

The lithology, weathering characteristics and thickness of the deposits in the fen's groundwater basin influence infiltration rate, and thus recharge to the fens. The constancy of the water source and the rate of flow to the fen are important both in the long-term maintenance of the fens and in controlling their vulnerability to hydrologic and chemical disturbance.

INDEX DESCRIPTORS: Fens, peat, geology, Iowa

Peatlands, or mires, are characteristic of circumboreal and circumsubarctic regions (Gore, 1983). In North America, the distribution of most peatlands coincides with the distribution of the boreal forest. It may be surprising then to find that there are peatlands in Iowa on the edge of the Great Plains. Their occurence has been documented since the early 1900's (Pammel, 1908; Byer, 1908; and Shimek, 1915), and there have been several studies focused primarily on their vegetation since that time (Anderson, 1943; Eickstaedt, 1964; Holte, 1966; van der Valk, 1975; and Nekola and Lammers, 1989). However, there is a paucity of research on the basic geology of these peatlands.

Because of their prevalence in northern climes, peatlands have long been the subject of study in northern North America, Europe, and the Soviet Union. In each country a scheme has been developed to classify the mires typical of that region, and, as a result, there are a wide array of schemes as well as a diversity of methods available for mire classification. Moore (1984) commented that the classification of peatlands is complicated "by the fact that most of the available criteria — are not discontinuous, but continuous variables, hence the perfect definition of discrete units is impossible..." Gore (1983) recognized four types of classification systems based on ontogeny, biology, chemistry, and a combination of these variables. Moore (1984) listed seven criteria which have been used as the basis for classification: floristics, vegetation structure and physiognomy, morphology, hydrology, stratigraphy, chemistry, and peat characteristics.

Peatlands can be subdivided into two groups: bog and fen, with the subdivision being made on the basis of "the origin and chemistry of their respective water supplies" (Gore, 1983). Thus, the term "fen" has long been used to describe a peatland dependent on a source of water in addition to atmospheric precipitation and with a minero- or mesotrophic status. Fen topography and associated floristic components add a further basis for classification of fen types. Eurola et al. (1984) divided Finnish fens into three major types with a total of 37 subdivisions based on a combination of trophic status, nutrient influence, and peat topography. Central European fens are divided into two major types with 11 subdivisions based primarily on mire vegetation (Rybníček, 1984). The Canadian classification system divides fens into fourteen types based largely on topographic position (Rubec and Pollett, 1979). At present there is no U.S. classification scheme for peatlands, although Crum (1988) has attempted to develop a classification for peatlands of the Upper Midwest. Even this is inadequate for the types of peatlands found in Iowa and other parts of the Lower Midwest and Prairie States.

The growing interest in preservation of these peatlands has led to the realization that the development and maintenance of fens, and the rare plant communities they support, is closely linked to the integrity and stability of their groundwater source. Existing classification schemes do not consider the geology of the recharge basin nor the infiltration/recharge relationships in the basin and are therefore largely inadequate for Iowa fens, particularly if we wish to assess their vulnerability to hydrologic disturbances.

In this paper, we review the geologic settings in which Iowa fens are found, discuss the geologic factors which control their distribution, and develop a classification system based on landscape position, stratigraphy, and inferred hydrologic relationships. We also discuss the vulnerability of these sites with respect to the geologic factors that control groundwater recharge and discharge to the fens.

METHODS

Twenty fens located across northern Iowa were chosen for detailed study however, information from other fen sites across Iowa was also considered (Fig. 1). Landscape position was determined from visual inspection. Land use was mapped in the field and supplemented with information from 1:80,000 color-infrared, high-altitude aerial photos. Well logs on file at the Iowa Department of Natural Resources-Geological Survey Bureau (IDNR-GSB) and other drilling logs were examined for information on the geology in the vicinity of the fens. Soil type and shallow substrate composition were determined from published county soil survey maps. The character of the deposits and stratigraphic relationships at selected fens were determined from intact cores obtained with a Giddings hydraulic soil coring machine. Cores were wrapped, boxed, and returned to Iowa City where they were described using modified U.S. Department of Agriculture Soil Conservation Service terminology (Soil Survey Staff, 1981). Nineteen fens were mapped using standard stadia techniques. To ascertain the geometry of the peat body, the fens were cored with a one-inch diameter hand probe. Additional cores were collected from the fens with an Eijelkamp peat sampler to determine peat characteristics.

GENERAL CHARACTERISTICS OF IOWA FENS

Fens in Iowa occur in a variety of landscape positions, but the majority are situated on hillslopes. The peat is usually saturated to the surface, and although standing water is not usual, shallow pools may be present. Biogenic carbonate can be abundant, often coating the plant remains. Discharge zones are often recognized by red flocs, created as anoxic groundwater discharges from iron-rich sediments,

[1]Iowa Quaternary Studies Group Contribution no. 44

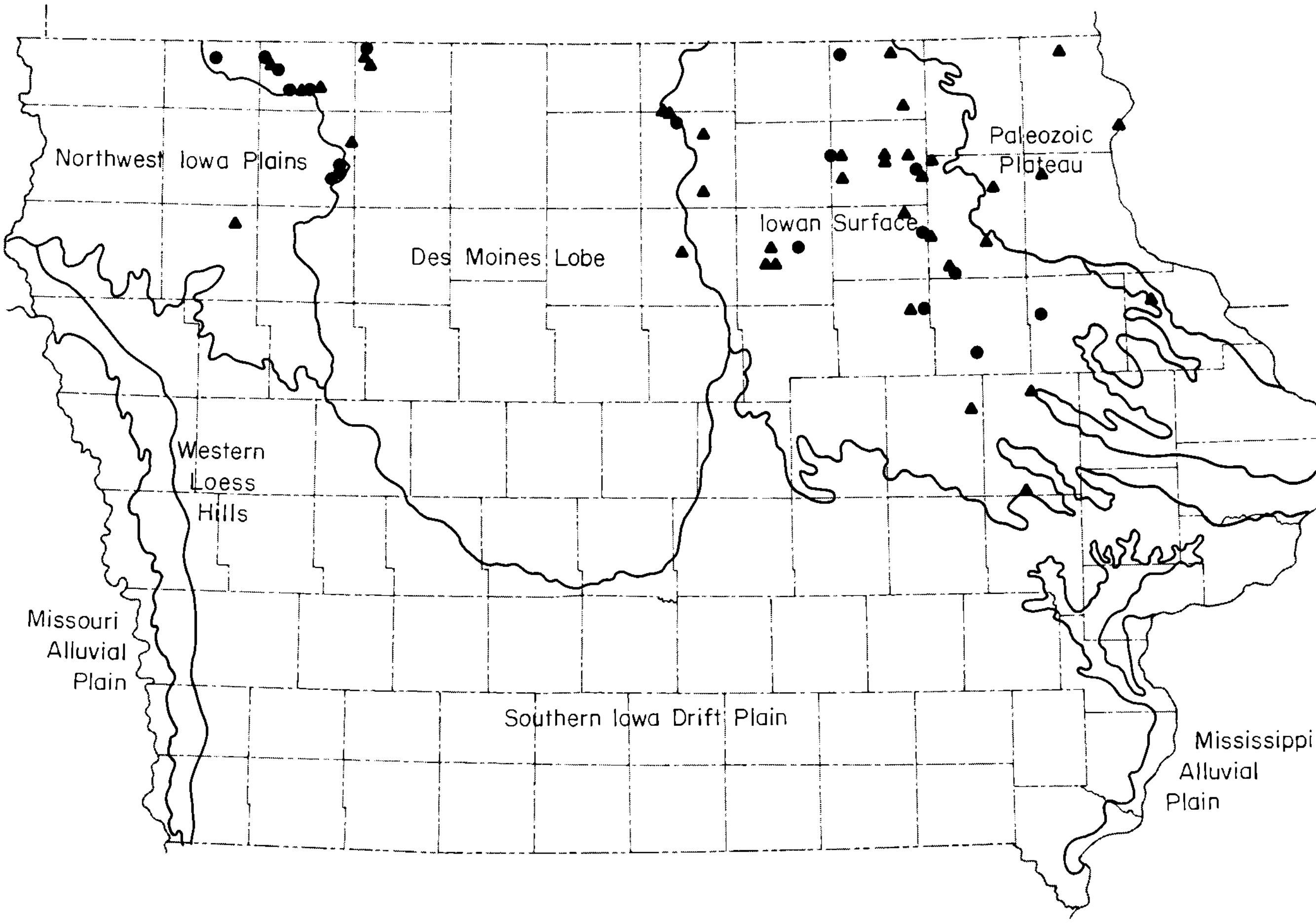

Fig. 1. Locations of selected Iowa fens. Closed circles represent those sites studied in detail.

and "oil" films, from diatoms in the water. Tufa can form lenses in the peat body; at some sites biogenic carbonate is dispersed throughout the peat giving a gray cast to the peat matrix.

The majority of peat in Iowa fens is fairly well-decomposed with few identifiable plant remains (Oa in Everett, 1983; H8-10 Von Post scale in Clymo, 1983). In some fens, layers of more fibrous peat are present (Oe, H6-7), often right above the contact with the underlying mineral substrate. Downslope movement of mineral sediment into the fens results in a denser peat and discrete lenses of sand-sized material are often present. Maximum thicknesses of peat in the fens range from 1.5 meters to in excess of 4.5 meters with an average around 2 meters.

Fens are maintained by groundwater which provides a constant source of water inflow and continual nutrient replenishment, even through the winter months. The source of this groundwater inflow for most fens in Iowa is a sand and gravel layer in contact with a less-permeable deposit such as till. The less-permeable unit inhibits downward movement of water and promotes lateral flow in the sand and gravel. Groundwater is discharged at the surface where the sand and gravel has been exposed by erosion. Most of the sand and gravel deposits associated with fens are shallow and show a direct and often rapid response to precipitation. This response varies with the size of the recharge area and the recharge rate, which is controlled in part by the permeability and storage characteristics of the sediments surrounding the fens.

DISTRIBUTION OF IOWA FENS AND REGIONAL GEOLOGY

Fens are present in all of Iowa's landform regions, though are common only on the Iowan Surface and the Des Moines Lobe regions (Fig. 1). Fens on the Iowan Surface and the Paleozoic Plateau are associated with Pre-Illinoian-age deposits that accumulated during several glacial and interglacial periods extending from about 2 million to 500,000 years ago (Hallberg, 1986). Subsequent to their accumulation several episodes of erosion, oxidation, and soil formation significantly altered the deposits. The most significant alterations include deep oxidation, development of an extensive interconnected network of vertical fractures (joints) that extend to the base of the oxidized zone, deep leaching of primary carbonate minerals, and subsurface secondary accumulations of carbonate as well as iron and manganese oxides. The fracture network provides an avenue for rapid infiltration of surface water deep into the subsurface and appears to be the primary path for groundwater recharge.

Along the northwestern margin of the Des Moines Lobe landform region, fens are found in areas of hummocky topography associated with lateral moraines marking the westernmost advances of the late Wisconsinan Des Moines Lobe glacier (Ruhe, 1969; Kemmis, 1983). These fens are either associated with sand and gravel enclosed within and between Wisconsinan-age tills, or with sand and gravel in outwash benched-terrace settings where the sand and gravel is the surficial deposit. These Late Wisconsinan glacial deposits have undergone slight to moderate weathering during the last 12,000 years. Net effects of these changes are oxidation of the deposits to variable, but generally shallow depths, the development of a network of vertical fractures (joints) that usually do not extend deeper than the zone of oxidation, and slight leaching of primary carbonate minerals from the upper few tens of centimeters. The joint system of Des Moines Lobe deposits is not as well-developed as that of deposits in the Iowan Surface and, although still providing an avenue for groundwater recharge, often does not permit as rapid a response in the water table position.

The geologic setting of fens in the Western Loess Hills and Northwest Iowa Plains landform regions is poorly understood. Two that the authors are aware of are located along valley wall slopes in association with small drainageways north of Sioux City where Cretaceous-age bedrock (limestone and shale) is buried by a mantle of Wisconsinan loess. In both instances, water feeding the fen moves along the contact between either limestone or loess and the underlying, less-permeable shale. The loess and limestone in this area are oxidized and contain vertical fractures that permit rapid infiltration of surface water deep into the deposits. These deposits have not been deeply leached and primary matrix carbonates are usually present at shallow depths.

Only three fens are known to exist in the Southern Iowa Drift Plain landform region. The lack of fens in this landform region is enigmatic and remains an area for further study.

A HYDROGEOLOGICAL CLASSIFICATION OF FENS

Iowa fens can be separated into six categories on the basis of landscape position, and the stratigraphy and hydrology of the water-bearing deposit that recharges the fen. The categories are: 1) fens developed along valley walls where sand and gravel between glacial tills (inter-till) is exposed (Fig. 2a); 2) fens in hummocky topography on the northwestern margin of the Des Moines Lobe that are recharged by sand and gravel buried within glacial till (intra-till), and which exhibit artesian flow (Fig. 2b); 3) those located on the lower slopes of ridges of exhumed sand and gravel on the Iowan Surface (Fig. 2c); 4) fens at the base of benched alluvial terraces or glacial outwash deposits (Fig. 2d); 5) fens recharged by bedrock aquifers (Fig. 2e), and 6) fens occupying abandoned channel areas (Fig. 2f).

The majority of Iowa fens are located on valley wall slopes and are recharged by inter-till sand and gravel (category 1). In this setting the water-bearing deposit is exposed along a valley wall (Fig. 2a). Fens in this category are associated with both large and small valleys and both steep and gentle slopes. They are found on the Iowan Surface, Paleozoic Plateau, Des Moines Lobe, and parts of the Northwest Iowa Plains and Western Loess Hills landform regions (Prior, 1991). Recharge of the aquifers feeding the fens as well as constancy of the water source is partially controlled by the geologic and hydrologic characteristics of the deposits at each site. Because of the diverse settings which this category is found in, generalizations are not possible.

Fens with intra-till water sources (category 2) are restricted to areas of hummocky topography along the northwestern margin of the Des Moines Lobe in Dickinson County. The geometry of the water-bearing deposits are poorly understood for this category of fens. The sand and gravel is apparently contained within Des Moines Lobe glacial deposits and is therefore referred to as "intra-till" (Fig. 2b). Water levels in the sand and gravel are above the surface of the peat indicating confined or artesian conditions. The sand and gravel is often overlain by a low-permeability deposit and upward flow into the peat occurs at a breach in this confining layer. The recharge area and the extent of the sand and gravel deposit is unknown.

Fens in category 3 are located along the lower slopes of ridges of exhumed sand and gravel on the Iowan Surface landform region (Fig. 2c). These ridges are divides that form the highest points on the local landscape. Originally the sand and gravel comprising the ridges was located in an inter-till position in Pre-Illinoian deposits, having originated as englacial channel sediment during glaciations, or as river channel sediment during glacial or interglacial periods. The sand and gravel was exhumed during a Wisconsinan erosion episode that produced the distinctive landscape of the Iowan Surface. Water-bearing sand and gravel at these fens overlies till and recharge occurs by percolation of precipitation through the sand and gravel ridge. The sand and gravel ridges are often dissected, thus limiting the recharge area and the amount of water held in storage. Fluctuations in the water table occur rapidly in response to precipitation patterns.

Category 4 fens are located at slope breaks on benched terraces and at scarps formed by small valleys cutting into outwash plains (Fig. 2d). Fens in this category are above the level of surface-water flooding. All fens in this category are associated with surface or near surface sand and gravel along valleys and outwash plains and most are located on or close to the Des Moines Lobe. Groundwater discharging to the fens flows in the sand and gravel along the contact with underlying deposits consisting of fine-grained alluvium or till. The sand and gravel deposits are slightly weathered, usually contain primary matrix carbonates at a relatively shallow depth, and are generally fully saturated. The contact between the water-bearing sand and gravel and underlying less permeable deposits can be nearly horizontal in the case of terraces (e.g., White fen in Emmet Co.), or exhibit pronounced relief in the case of outwash plains that bury pre-existing valleys (e.g., Barton fen in Clay Co.). Like category 3, recharge to the fens occurs by infiltration of precipitation through surficial sand and gravel deposits and is significantly influenced by climatic variations. Those fens that are located on benched terraces in valleys may also be recharged, in part, by slow groundwater flow through valley wall deposits.

Fens maintained by groundwater flow from a bedrock aquifer comprise category 5 (Fig. 2e). This category has not been studied in detail and has only been recognized in the Western Loess Hills and on the Iowan Surface. Fens in category 5 are usually located on slopes where water-bearing fractured carbonate rock (bedrock aquifer) is underlain by an aquitard (less permeable bedrock unit). Loess, sand, and till can overlie the carbonate aquifer. Groundwater recharge to shallow bedrock units is primarily by precipitation through the overlying deposits, but regional flow systems may also provide water to these fens. The stability of the groundwater discharge to fens in this category is unkown. A second type of bedrock fen is located in abandoned meanders carved in bedrock. These fens are supplied by water flow through the bedrock aquifer, but are similar to category 6 fens in their landscape position.

Category 6 fens are located in abandoned channels where they are associated with various-age deposits and stratigraphic situations. Presently known examples occur in valleys on the Iowan surface and areas in the Iowa-Cedar Basin in southeastern Iowa. In category 6 fens, the outside curve of the abandoned channel cuts into a higher terrace or bench exposing the water-bearing deposit that recharges the fen (Fig. 2f). Ground water flows laterally to the fen through sand and gravel along a zone of low permeability (till, fine-grained alluvium, etc.). Recharge of the water-bearing deposit for these fens occurs by infiltration of precipitation through deposits comprising the upper parts of the terrace (sand and gravel, sand, loess, etc.). This fen category occupies the most dynamic landscape setting in which fens are found. The abandoned channels containing these fens are slightly higher than the normal flood stage, but there is still significant interaction between the river and the fens by way of baseflow.

Although there are some fens that do not fit well within a category, this classification system is still useful for an evaluation of geologic setting and for identifying management issues. Table 1 lists 65 of Iowa's high quality fens classified according to this scheme. Locations of these sites are shown on Figure 1.

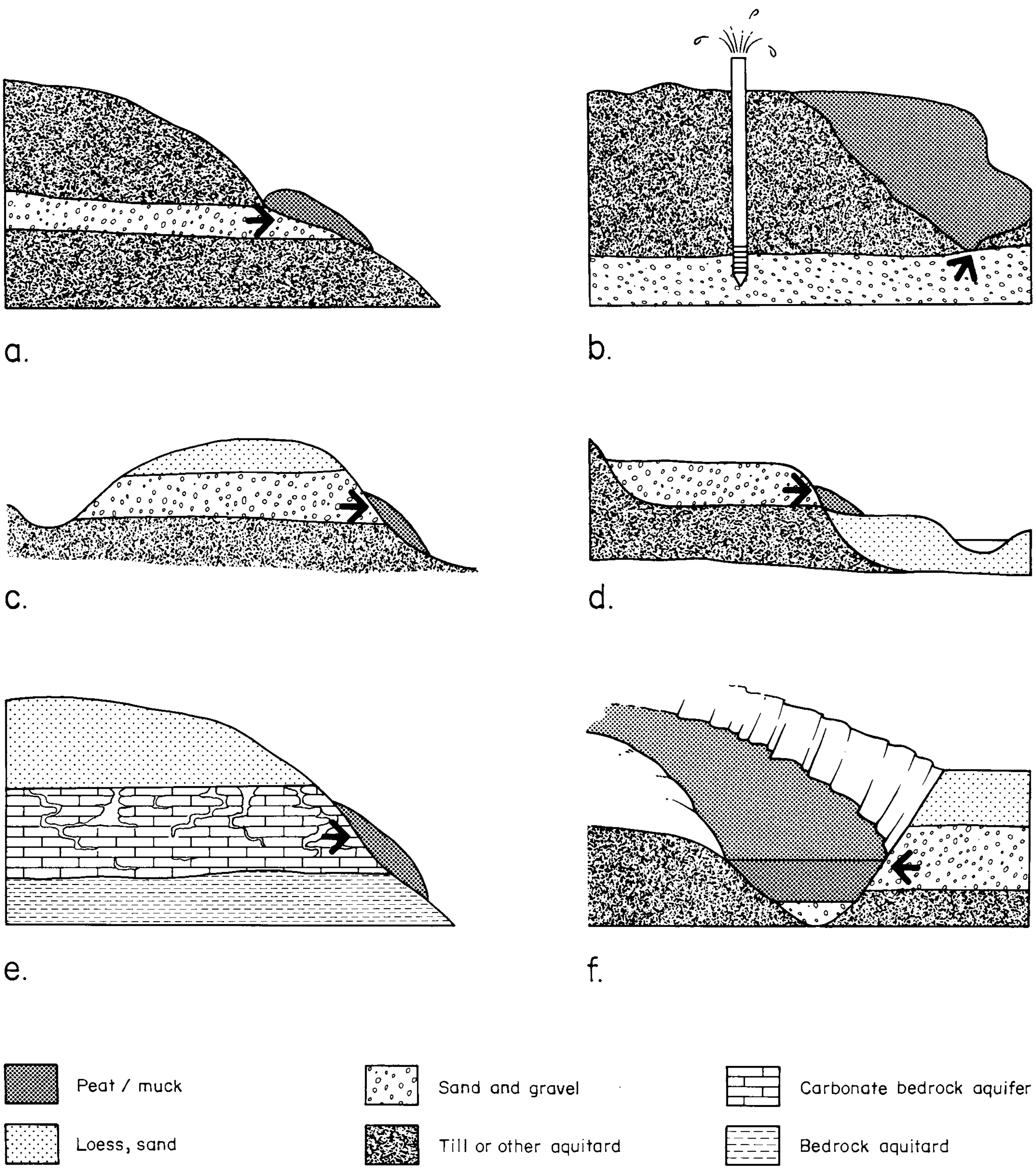

Fig. 2. Schematic diagrams showing geologic settings of Iowa fens: a) Inter-till (Category 1); b) Intra-till (Category 2); c) Gravel ridge (Category 3); d) Terrace, Outwash (Category 4); e) Bedrock (Category 5); f) Abandoned channel (Category 6). Arrows represent approximate direction of flow into fen.

Table 1. Geologic classification of selected fen sites

Fen Name	County	Landform Region	Geologic Classification	
Lindstrom-Simons	Clay	DML/NWP	1	Inter-till
Kinney-Lindstrom	Cerro Gordo	IS	1	Inter-till
Excelsior	Dickinson	DML	2	Intra-till
Silver Lake	Dickinson	DML	2	Intra-till
Schumann	Howard	IS	1	Inter-till
Roose	Butler	IS	1	Inter-till
Buffalo Slough	Cerro Gordo	IS	5,6	Bedrock, channel
Pethick	Cerro Gordo	IS	1	Inter-till
Wander	Cerro Gordo	IS	5,6	Bedrock, channel
Lincoln 15B	Cerro Gordo	IS	1	Inter-till
Sindt	Dickinson	DML	1,2	Inter- or intra-till
Emmet 21A	Emmet	DML	1	Inter-till
Boeding-Tank	Chickasaw	IS	1	Inter-till
Brayton	Bremer	IS	1	Inter-till
Hangartner	Fayette	PP		Indeterminate
Berning	Dickinson	DML	4	Terrace
Beardmore	Floyd	IS	1	Inter-till
Delaney	Allamakee	PP		Indeterminate
Park Fen	Cerro Gordo	IS	5	Bedrock
Ripley 8A	Butler	IS	4	Terrace
Cutshall	Buchanan	IS	4,6	Terrace, channel
Barber	Black Hawk	IS	1	Inter-till
Rowley	Buchanan	IS	3	Gravel ridge
New Hampton 5	Chickasaw	IS	1	Inter-till
Jacksonville 32B	Chickasaw	IS	1,6	Inter-till, channel
Fremont 6A	Fayette	IS	1	Inter-till
Valen	Emmet	DML	4	Terrace
Barton	Clay	DML/NWP	4	Outwash
Fairfield 5	Grundy	IS	1	Inter-till
Geneseo 10	Cerro Gordo	IS	1	Inter-till
Argall-Pollath	Chickasaw	IS	1	Inter-till
White	Emmet	DML	4	Terrace
Miller	Black Hawk	IS	4,6	Outwash, channel
Chapman	Fayette	IS	1	Inter-till
Andera	Howard	IS	1	Inter-till
Kauten	Fayette	IS	1	Inter-till
Rockhill/Berringer	Clay	DML	4	Outwash
Stone	Fayette	IS	1	Inter-till
Halbur	Dickinson	DML	1	Inter-till
Cedar Hills Preserve	Black Hawk	IS	4	Outwash
Anderson	Linn	IS	1	Inter-till
Kristiansen	Chickasaw	IS	1	Inter-till
Kleiss	Chickasaw	IS	1	Inter-till
Stevenson	Chickasaw	IS	1	Inter-till
Kleve	Osceola	DML	4	Outwash
Berends	Butler	IS	1	Inter-till
Lincoln 9B	Cerro Gordo	IS	1	Inter-till
Leith	Dickinson	DML	4	Terrace
Evans	Clay	DML/NWP	1	Inter-till
Schulte	Delaware	IS	1	Inter-till
Estherville Gravel	Emmet	DML	4	Terrace
Cedar 23	Benton	IS	1	Inter-till
Barclay 8A	Black Hawk	IS	1	Inter-till
Feldman	Butler	IS	1	Inter-till
Swab	Linn	IS	1	Inter-till
Lincoln 5B	Cerro Gordo	IS	6	Channel
Forest City 27	Howard	IS	1	Inter-till
Spring 30	Cherokee	NWP	4	Terrace
Deerfield 33	Chickasaw	IS	1	Inter-till
Schneider	Clayton	PP	1	Inter-till
CSM	Dickinson	DML	4	Outwash

Table 1 (Con't)

Fen Name	County	Landform Region	Geologic Classification	
Fremont 6B	Fayette	IS	1	Inter-till
Oran 13	Fayette	IS	1	Inter-till
Marion 26A	Franklin	IS	1	Inter-till
Seehausen	Butler	IS	1	Inter-till

HYDROLOGICAL AND CHEMICAL RESPONSES OF IOWA FENS

The geologic settings outlined in the proposed fen classification system can be used for assessment of the vulnerability of fens to hydrologic disturbance, both physical and chemical. Fens in eastern Iowa are apparently subjected to greater and more rapid fluctuations in water supply than those in western Iowa. During a drought period in 1989, eastern Iowa fens were drier than those in the west. This is in contrast to the long-term climatic pattern in Iowa in which moisture generally increases eastward across the state. In the summer of 1990, a different pattern was observed. Most western fens were drier than in the east, despite above average rainfall across Iowa in the spring and early summer in 1990. This suggests a lag in precipitation response at the western sites.

The differences in weathering profiles and secondary fracture patterns of the geologic materials surrounding the fens may provide a partial explanation for the observed differences in the amount and timing of groundwater discharge to the fens. The more weathered, extensively fractured deposits at eastern Iowa fen sites promote rapid infiltration and flow-through of water to the sand and gravel and into the fen. Water levels and weathering profiles in the Pre-Illinoian sand and gravel deposits in eastern Iowa show that they are not usually fully saturated. Thus, even though more infiltration may occur, there is apparently only short-term storage in the sand and gravel of this excess water to discharge to the fen in drier times. Even seasonal fluctuations will affect the supply of water to the eastern sites.

The precipitation lag observed in western Iowa fens in the inter- and intra-till categories, is also related to infiltration and storage characteristics of the deposits in the recharge basin. Less fracturing and shallow weathering profiles in the Des Moines Lobe deposits at western Iowa fens result in slower infiltration rates. Both the sand and gravel and the enclosing till deposits at these sites are also fully saturated thus providing greater groundwater storage. The result of both of these factors is that the effects of climatic variations are reduced and delayed.

The size of the recharge areas and the size of the sand and gravel deposits feeding the fens are other important factors. If both are large, recharge will be less affected by short-term climatic fluctuations. Local topographic patterns which influence the relative balance between runoff and infiltration may also have an effect. For example, areas of subdued topography and poorly developed drainage patterns, as occur on the northwestern margin of the Des Moines Lobe, inhibit efficient runoff and favor infiltration.

Climatic changes may influence fens in other ways. Most extant fens are in active pastures. During dry periods, cattle walk further onto the site to reach water and considerable compaction can occur. Such disturbance was evident at many fens during the drought years of 1988-89. This compaction also may influence hydrologic patterns. Paths worn into the peat can change its permeability and alter flow paths. These pathways can develop into surface drainages when wetter conditions return and may act to drain the fen.

Our classification scheme also permits a preliminary assessment of the vulnerability of fens to chemical contamination. Sand and gravel units at or near the surface which are the water sources for fen categories 3 and 4 are vulnerable to surface-derived contaminants. The recharge area for these fens can be estimated from published soil surveys and topographic maps.

The vulnerability of category 1 and 2 fens fed by inter- or intra-till sand and gravel deposits is more difficult to assess. At best, soil maps show only the outcrop area of the sand and gravel with no indication of the lateral extent of the water-bearing deposit. Thus, in this situation, soil maps are inadequate for evaluation of the recharge areas. Some additional information might be gained by review of well log data, but these are rarely close enough to a site, nor do they cover enough of the area around a site to provide detailed information about lateral extent or thickness of the sand and gravel. The only way to accurately determine the extent of these sand and gravel deposits is by drilling.

For category 1 and 2 fens, there are also differences in vulnerability which are related to the weathering of the enclosing tills. In general, shallow groundwater from sand and gravels buried within Wisconsinan-age tills shows lower concentrations of chemical contaminants than that from areas of older Pre-Illinoian tills (C.A. Thompson, unpublished data). The distinction between Pre-Illinoian and Wisconsinan deposits can obviously be made on a first evaluation of site location. However, the recharge characteristics and thus the vulnerability are also dependent on the thickness and characteristics of weathering zones and fractures in the till, characteristics which are not easily mapped, but can often be determined by drilling and or observation in the local area.

Land use practices aimed at improving or maintaining the quality of infiltrating water are useful only if effected in the recharge areas for the fens. The geologic classification presented above allows for an early assessment of characteristics of recharge basin deposits that control a fen's vulnerability to groundwater contamination. Use of the classification scheme will aid planners and managers in determining suitable management practices for extant fens. The classification also points to significant gaps in our understanding of fen geology and hydrology, as well as the difficulties inherent in determining the recharge area and hydrologic vulnerability of most fens in Iowa.

ACKNOWLEDGEMENTS

We appreciate the assistance of the many colleagues who helped in data collection, particularly Matt Culp, K.D. Rex, Darwin Evans, Benton Birchard, Jean Prior, Lynette Seigley, Brenda Nations, and Paul VanDorpe. Figures were prepared by Patricia Lohmann. This project was partially funded by a grant from the U.S. Environmental Protection Agency.

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