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Pilot Study of Sediment Accretion Methods and Rates in Prairie Potholes

by William N. Pizzolato, Barbara A. Kleiss, Miriam L. Fearn

July 1995 – Final Report

Wetlands Research Program

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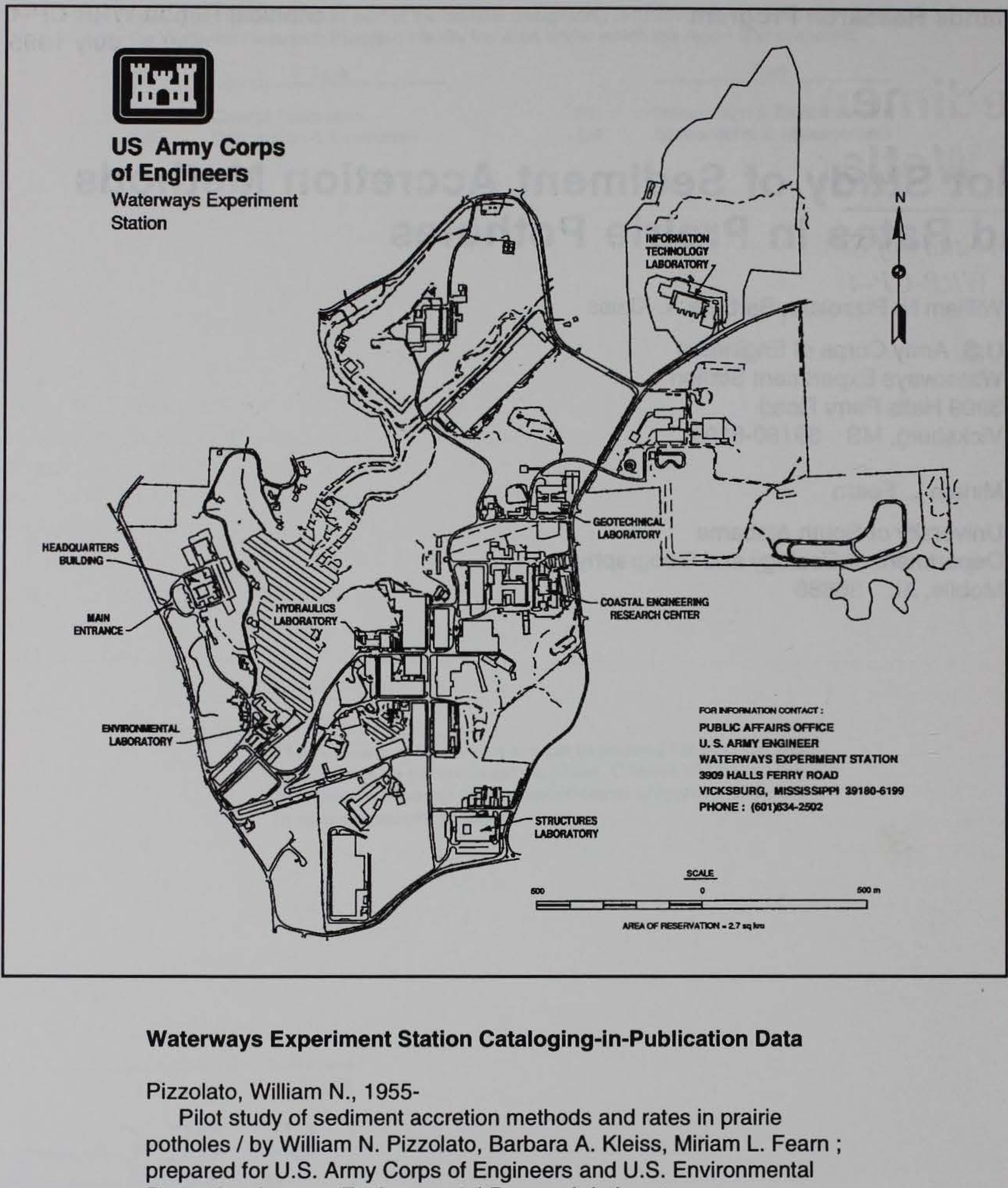

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Corps of Engineers Research Report Summary, July 1995

Sediment Accretion in Wetlands

Pilot Study of Sediment Accretion Methods and Rates in Prairie Potholes (TR WRP-CP-4)

ISSUE:

It is commonly believed that excess sediment deposition is accelerating the filling of prairie pothole wetlands and stressing these systems. To help address this issue, methods that will quickly and effectively measure the rate of sedimentation in these systems need to be examined.

RESEARCH:

Replicate cores were taken from three potholes in the vicinity of Jamestown, ND. One of the potholes was surrounded by agricultural fields, a second was ringed by a well-established buffer strip, and the third was located in the Cottonwood Lake study area, where the watershed was primarily native grasses. The cores were studied using physical descriptions, including particle size, loss on ignition, and color, ^{137}Cs measurements, and a preliminary palynological assessment.

SUMMARY:

There was no indication that settlement or increased rates of sedimentation could be detected from the physical characterization of the cores. The ^{137}Cs measurements compared favorably with a concurrent shift in the pollen assemblages and may provide a tool that could substitute for cesium measurements. For the potholes sampled, the geomorphologic setting of the pothole appeared to play a role in sedimentation rate equal to that of watershed land use.

AVAILABILITY OF REPORT:

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About the Authors:

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Critical Processes Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32802, "Field Investigations of Wetland Functions" for which Dr. Barbara A. Kleiss was the Technical Manager. Mr. John Bellinger (CECW-PO) was the WRP Technical Monitor for this work.

Mr. David Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, U.S. Army Engineer Waterways Experiment Station (WES), was the Wetlands Program Manager. Mr. Jack E. Davis, WES, was the Task Area Manager.

Partial funding for this work was received from the U.S. Environmental Protection Agency, Duluth Laboratory, where Dr. Glenn Guntenspergen, Dr. Naomi Detenbeck, and Mr. William Sanville supervised and contributed to the project. Several members of the National Biological Survey, Northern Prairie Science Center, particularly Dr. Chip Euliss, helped with the fieldwork and background information associated with this project.

This work was performed by Mr. William Pizzolato, a Contract Student at WES; Dr. Kleiss, an Ecologist in the Wetlands Branch (WB), Ecological Research Division (ERD), Environmental Laboratory (EL), WES; and Ms. Miriam Fearn, who is an instructor in the Geology and Geography Department at the University of South Alabama. The work was conducted under the general supervision of Mr. E. Carl Brown, Chief, WB, Dr. Conrad J. Kirby, Chief, ERD, Dr. Edwin A. Theriot, Assistant Director, EL, and Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

Prairie potholes are small, shallow, ponded depressions of glacial origin (Sloan 1972) comprising approximately 1 million ha of wetlands in North Dakota (Bigler and Richardson 1984). Potholes occur within the rolling terrain of glacial deposition as a series of closed or poorly drained basins. Prairie potholes serve as productive freshwater wetlands, providing primary waterfowl habitat for half the annual migratory waterfowl in the Mississippi Flyway (Smith, Stoudt, and Gollop 1964). They also provide water storage and groundwater recharge.

Agricultural land use impacts prairie potholes by creating mobile sediments that can fill these wetlands. Nutrients and sediments from cultivated watersheds entering pothole basins promote the growth of vegetation that in turn traps additional sediment. Such anthropogenic effects may modify and reduce wetland habitat through the filling of the pothole basin (Martin and Hartman 1986), causing changes in hydrology and vegetation composition.

Objectives

The intent of this study is to conduct a preliminary examination of methods to measure the vertical accretion of sediments subsequent to the agricultural development of the area. In an attempt to find markers in the soil profile, cesium measurements, the description of physical characteristics of the soils, and palynology were used. Sediment cores were taken from prairie potholes representing a range of watershed land-use conditions. This was done to determine how the various methods characterize pothole sedimentation and evaluate variation in sediment accretion in watersheds with different land uses.

Study Area Characterization

Triplicate soil cores were collected in August 1992 from three prairie potholes near Jamestown (Stutsman County), ND. The selection criteria for the prairie pothole sites were outlined by the U.S. Environmental Protection Agency, in cooperation with the National Biological Survey, Northern Prairie Science Center. The wetlands selected have similar hydrologic characteristics, low salinity, similar watershed:wetland size ratios, similar soils, similar grazing histories, and similar watersheds composed of highly erodible soils.[1] The prairie pothole sites selected consist of (a) a wetland with a grassland buffer within a cultivated watershed (Figure 1-462A), (b) a wetland without a buffer within a cultivated watershed (Figure 1-462B), and (c) a wetland located within a tillage-restricted, grassland watershed (Figure 2-P1). In 462A and 462B, the agricultural watersheds produce wheat, oats, rye, sunflowers, and alfalfa. The watershed for wetland P1 has not been cultivated nor tilled since 1965.[2] Prairie pothole P1 is part of a National Waterfowl Production Area, which protects wetlands for wildlife habitat.

Each site is classified as a Class IV wetland (semipermanent ponds and lakes) as defined by Stewart and Kantrud (1971), and the potholes are approximately 7 to 15 ha in area. Prairie pothole 462A has a native-grass buffer surrounding the site (Figure 3); the deep marsh contains open *Typha* (cattail) vegetation, but lacks submerged vegetation. Prairie pothole 462B has its western one-half tilled to the edge of the wetland and the eastern one-half tilled to a deep marsh buffer (Figure 4). A dense stand of *Typha*, *Scirpus* (bulrush), and *Potamogeton pectinatus* (sago pondweed) comprise the deep marsh vegetation, and the wetland supports an abundant waterfowl habitat. Prairie pothole P1 is within a grassed watershed and has a narrow band of *Typha* vegetation (Figure 5). The prairie pothole sites are poorly drained and frequently ponded; however, each of the wetlands lacked standing water at the time of coring. The maximum slope in each of the watersheds ranges from 1 to 3 percent.

The soils comprising the prairie potholes are derived from water-sorted, glacial drift deposited into depressions, swales, and drainage ways. The soil is mapped as Southam clay loam (U.S. Soil Conservation Service, unpublished technical guide 1990) and is typified by areas of open water and wetland marsh vegetation (Bigler and Richardson 1984). The Southam soil series (fine, montmorillonitic (calcareous), frigid Cumulic Haplaquolls) consists of deep, slowly permeable soils that formed in local alluvial sediments from glacial drift on slopes less than 1 percent. Site and soil core descriptions are found in Appendixes A and B. The average soil-erodibility (K index) for the Southam soil series is 0.37 (U.S. Soil Conservation Service, unpublished technical guide 1990), and the rainfall

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1 Personal Communication, 1992, U.S. Environmental Protection Agency.

2 Personal Communication, 1992, Northern Prairie Science Center.

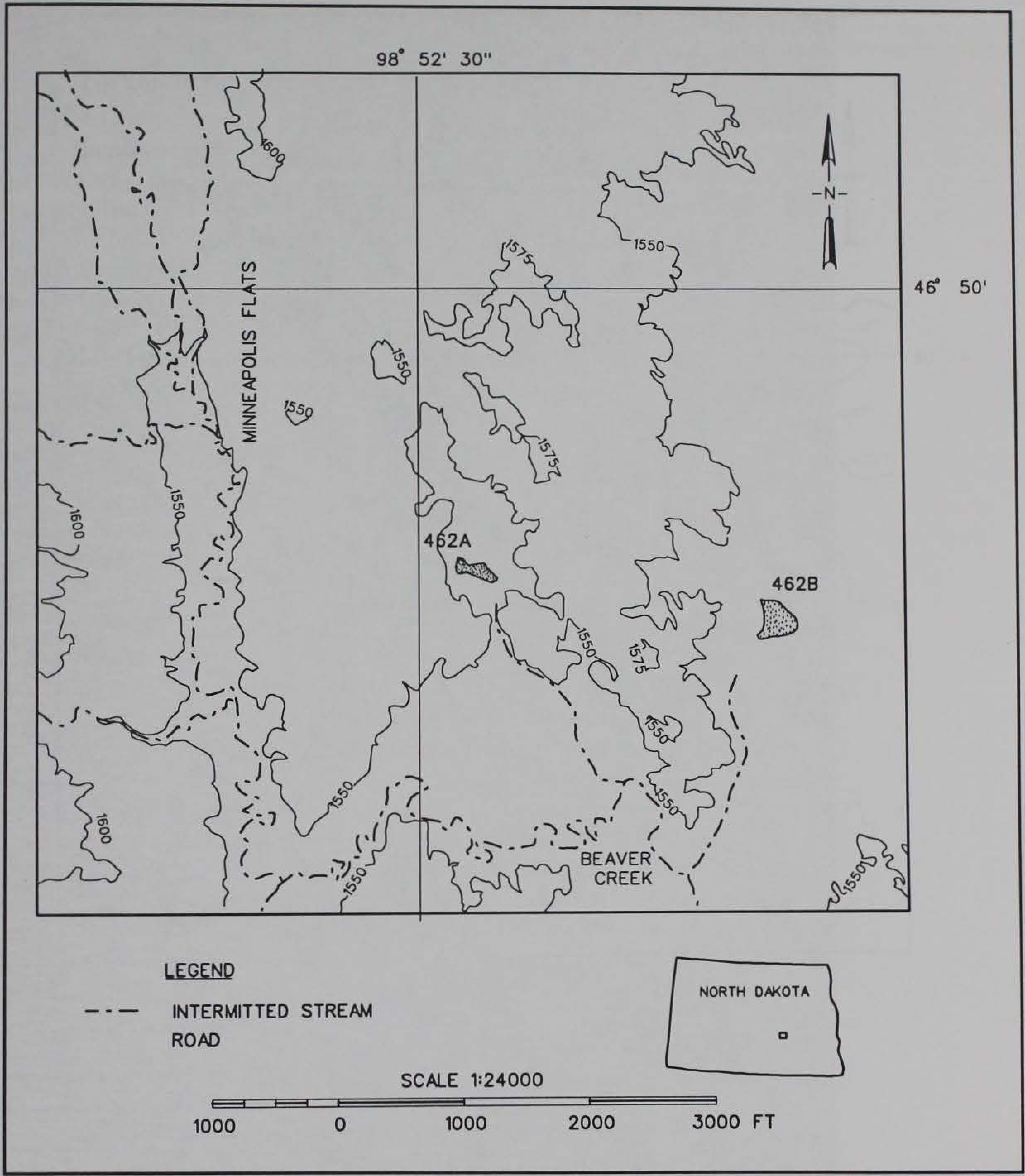

Figure 1. Topographic map showing locations of wetlands 462A and 462B (Source: USGS Topographic map, Eldridge SE and SW, North Dakota, 1951, 1952)

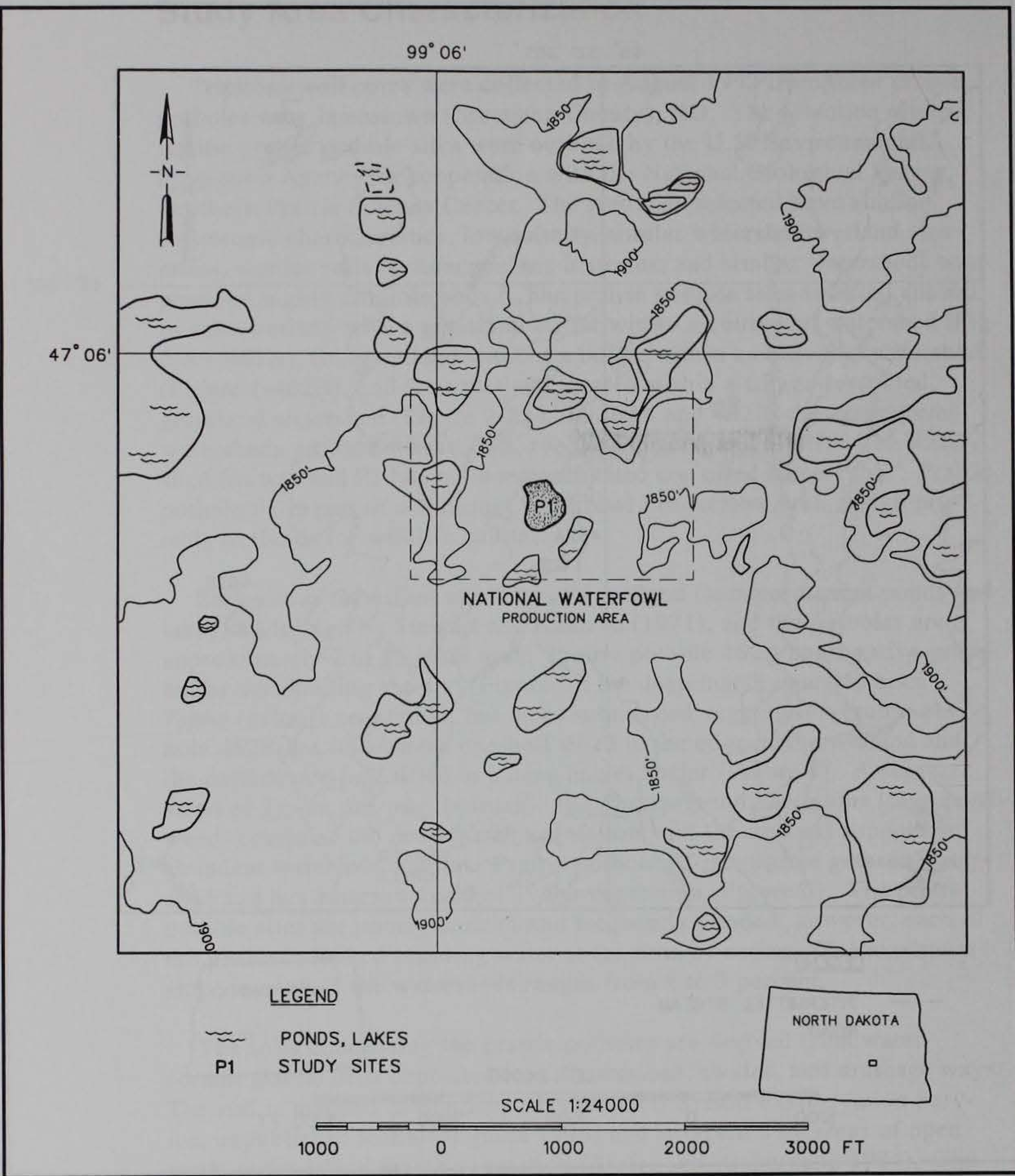

Figure 2. Topographic map showing location of wetland P1 (Source: USGS Topographic map, Goldwin SE, North Dakota, 1986)

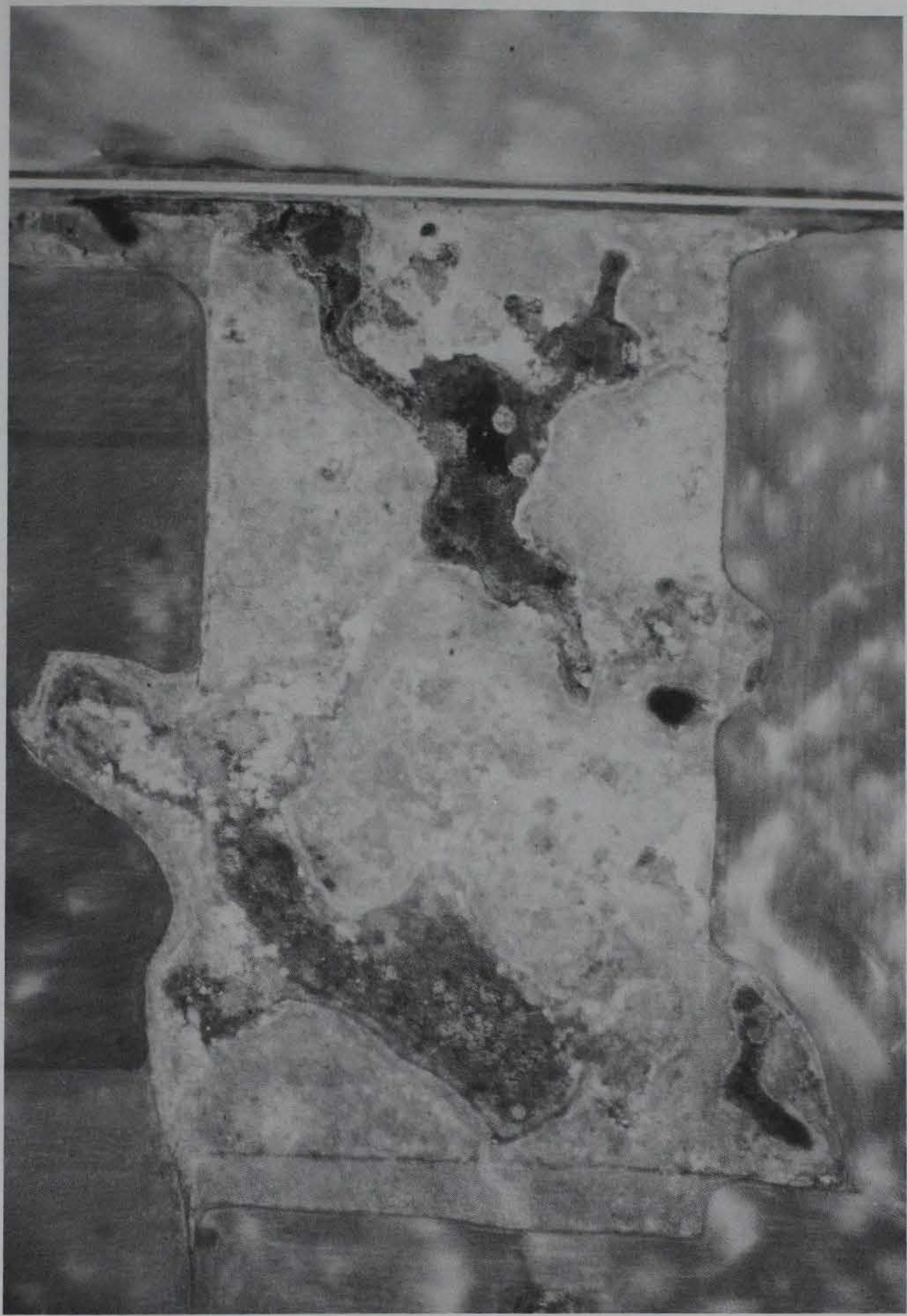

Figure 3. Photograph of wetland 462A illustrating buffer area surrounding wetland

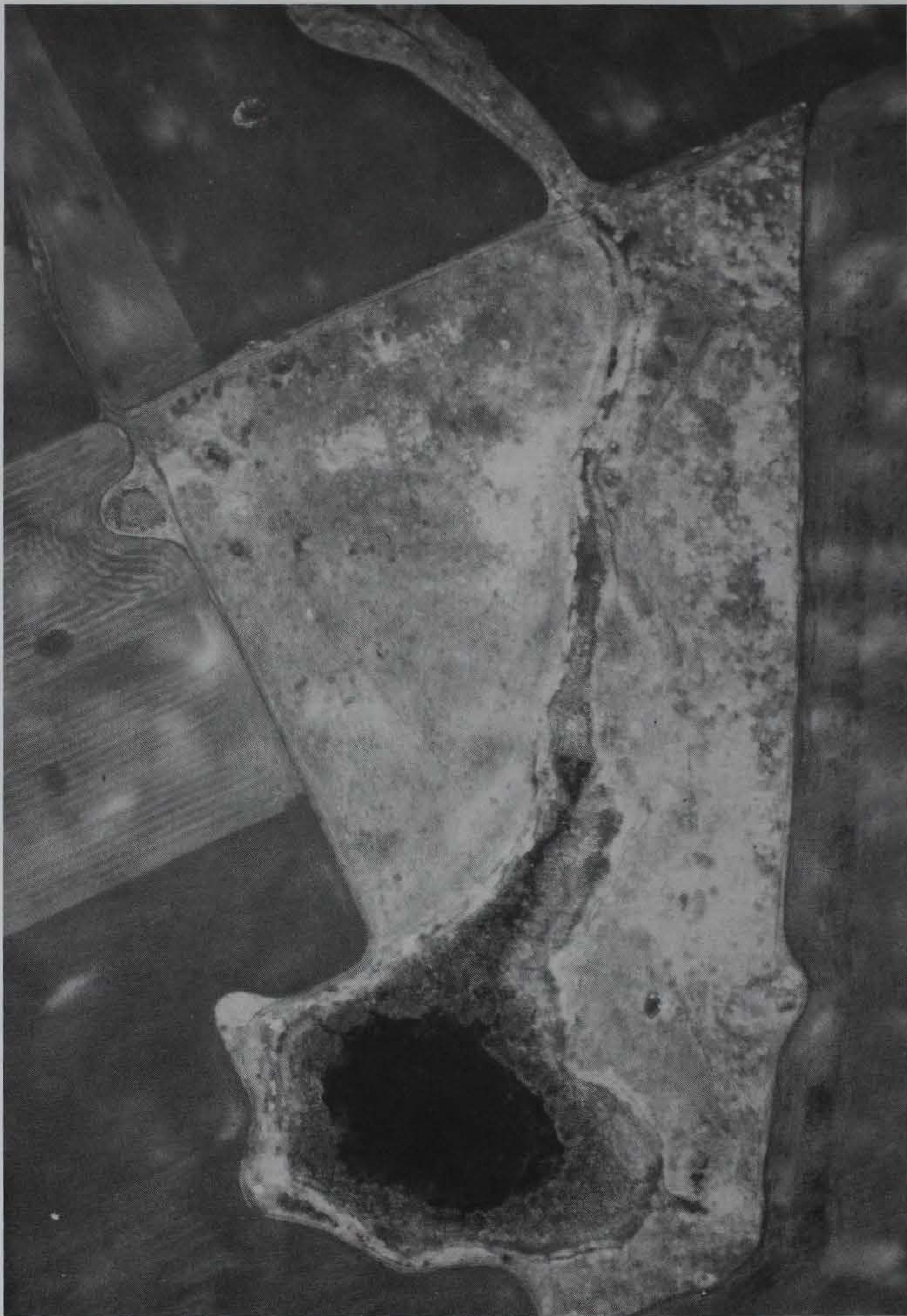

Figure 4. Photograph of wetland 462B illustrating agricultural tillage immediately adjacent to wetland

Figure 5. Photograph of wetland P1 illustrating native prairie grasses surrounding wetland

erosion (R index) is 68 for Stutsman County (Wischmeier and Smith 1978). This classifies the Southam series as a nonhighly erodible soil.

Surface Geology of Stutsman County, North Dakota

Winters (1963) described the geology of Stutsman County. The following section is a synthesis of portions of the publication that apply to this prairie pothole study.

Two morpho-stratigraphic units comprise the cored prairie potholes: 462A and 462B are in the Drift Prairie, a Late Pleistocene (Wisconsin) glacial landscape formed by an orderly retreat of the Millarton and Eldridge end moraines; P1 is in the Coteau du Missouri, an early Wisconsin glacial landscape formed by extensive stagnation of the ice sheet left by the deposition of the Streeter moraine.

Prairie potholes 462A and 462B (Lippert Township T. 139 N., R. 65 W., Sections 34 & 35) are within former meltwater channels at the distal end of Eldridge moraine. These drainage channels routed glacial meltwater from the southwest and west flanks of the Millarton moraine glacier retreated northward. During the Eldridge phase, outlet meltwater channels through the Minneapolis Flats were partially diverted southeast via Beaver Creek (Figure 1) to the James River basin, but were abandoned early in the Eldridge phase. With the retreat of the Eldridge glacier to the north, Minneapolis Flats and Beaver Creek drainage ceased to be significant meltwater conduits at the start of the Buchanan phase. While both prairie potholes 462A and 462B have distal drainage outlets south to Beaver Creek, only pothole 462A has a proximal drainage inlet from the eastward overflow of the Minneapolis Flats.

Prairie pothole P1 (Round Top Township T. 142 N., R. 66 W., Section 19) is part of the morainal topography of the Missouri Plateau between the Missouri Escarpment and the Missouri River. The study pothole lies within the Coteau du Missouri complex and is one of eight kettle depressions within the Cottonwood Lake region (Figure 2). The hummocky stagnation moraine, the predominant topography of the Coteau du Missouri, is higher in elevation than the Drift Prairie to the east. The potholes formed in place from the stagnation of the ice sheet, which resulted in a random pattern of angular to circular depressions of varying dimensions. Present topography of the Coteau du Missouri shows a youthful glacial morphology devoid of interconnected drainage or large valleys. Runoff enters directly into prairie pothole P1 and is devoid of any surface water inlet or outlet, unlike the study potholes of the Drift Prairie.

The age of the Coteau du Missouri surficial drift was radiocarbon dated at 11,070 ± 300 years before present (b.p.) from postglacial pelecypod shells. This radiocarbon date indicates that the Streeter moraine had completed its last advance by this date, although the period of time for the development of the hummocky stagnation moraine is not known. The Millarton and Eldridge moraines preceded the Streeter moraine. The Millarton and Eldridge moraines were radiocarbon dated at 9,900 to 10,050 ± 300 years b.p. from wood samples in the eastern part of Stutsman County.

Introduction to Palynological Investigations

Pollen analysis of lake sediments provides a method of identifying and quantifying vegetation that had existed in an area during the past. The methods work because pollen is produced in vast quantities, is small enough to be widely dispersed by air currents, is identifiable often to the genus level, and is well preserved in waterlogged acidic environments such as lake sediments (Moore and Webb 1978). Studies of modern pollen rain confirm its direct relationship to vegetation and to catchment size (Webb 1974; Webb and McAndrews 1976). In general, the smaller the lake the more the pollen assemblage is dominated by the local component, that is, vegetation growing within 20 m of the site (Anderson 1967; Jacobson and Bradshaw 1981; Bradshaw and Webb 1985). Because land-use practices associated with settlement have a dramatic influence on the vegetation, a definite shift occurs in the pollen rain within the catchment and an easily detectable change in the pollen is preserved in the sediments. For much of North America after European settlers cleared the land, tree pollen declined and opportunistic plant pollen increased (Davis 1976). The most noticeable species is ragweed (*Ambrosia* in the family Compositae), and the "*Ambrosia* rise" is a well-documented feature of pollen studies associated with the settlement horizon (McAndrews 1966; Webb 1973). In prairie regions where low percentages of arboreal pollen and high percentages of grass (Gramineae and Compositae, members of the grass and sunflower families) pollen are the rule, the "*Ambrosia* rise" may be less dramatic. In such cases, the settlement horizon can often be detected by the appearance of pollen from introduced plants (Behre 1981). Strong (1977) found marked increases in pollen from species such as the Chenopodiaceae-Amaranthaceae families (Cheno-Am) and *Taraxacum* (dandelion) associated with settlement of the shortgrass prairie in southern Alberta, and Van Zant et al. (1979) detected an increase in *Cannabis/Humulus* (hemp) pollen in sediments from two Iowa lakes.

Introduction to ^{137}Cesium-Derived Sedimentation Rates

This method measures the vertical distribution of ^{137}Cesium (^{137}Cs $t_{1/2} = 30.2$ yr), a radioactive isotope generated as a result of atmospheric nuclear weapons testing. Beginning in the early 1950s, ^{137}Cs dispersed globally through the stratosphere, and measurable amounts began to accumulate in soil profiles during 1954 (Wise 1980). Two major weapon testing periods (1959 and 1963) produced significant radioactive fallout, and atmospheric nuclear testing ended with the ratification of the 1963 Limited Test Ban Treaty (Ritchie and McHenry 1985). The majority of ^{137}Cs deposition occurred in the 1962 to 1964 period, with the peak fallout occurring between 1 April and 30 September 1963, when the ^{137}Cs fallout rate was twice that observed in either 1962 or 1964 (De Jong, Villar, and Bettany 1982).

^{137}Cesium deposition occurs as dry fallout or in precipitation. Upon contact with soil or sediments, the isotope becomes strongly adsorbed by organic and clay particles (Robbins and Edgington 1975). Some downward ^{137}Cs migration in soil profiles occurs by microbial organic decomposition and dissolution of organic C compounds via percolating water. Preferential migration of this isotope by organic decomposition and removal of fine particles may lead to enrichment with depth. ^{137}Cesium can be mobilized shortly after deposition if the exposed, uppermost surface containing fresh organic material is subject to temperatures in excess of 30 °C (Tegan, Dörr, and Münnich 1991).

2 Methods and Procedures

Wetland Coring and Core Treatments

Field crews took sediment cores from the center of three prairie potholes using a hand-driven 7.6-cm piston-corer for the upper sediments and a hammer-driven 5.1-cm piston-corer for the lower sediments. Coring devices driven into the mudflats of the potholes encountered glacial parent-material at 1.4- to 2.0-m depths. After field extraction, the hand-driven cores compacted 6 to 21 percent, while the hammer-driven cores compacted 27 to 50 percent. Three cores were extracted and wrapped in plastic and aluminum foil for transport to the laboratory.

Two cores from each site were selected for soil characterization analysis, from which ^{137}Cs and pollen profiles were produced. The third core was left intact for any additional procedure replication.

One core used for ^{137}Cs analysis was sectioned into 1-cm intervals to a depth of 30 cm. Soil bulk density samples from the ^{137}Cs core were oven-dried at 105 °C for 24 hr and weighed to the nearest 0.01 g. The second core was used for soil descriptions and pollen processing. Moist samples were collected from alternating 1-cm intervals and, at 30 cm, the sample intervals were increased to 2 cm for the remainder of the core.

Soil Characterization

Standard field procedures (Soil Survey Staff 1951) were used to describe soil color, texture, structure, consistence, free carbonates, and roots.

Soil color is the dominant color, or, if more than one color is present, a percentage of mottling or codominant color is noted. Soil color was examined under direct sunlight and compared with Munsell Soil Color Charts. Soil color (moist and dry) was reported with color names and Munsell notation. Mottles were described in terms of abundance, size, and contrast.

Soil texture is characterized by the proportion of particle-size groups of sand, silt, and clay in a soil and was determined using texture-by-feel analysis (Foss, Wright, and Coles 1975). A ball of moist soil is formed into a ribbon of uniform thickness and length by pressing between the thumb and forefinger. The ribbon is observed until breaking under its own weight and its length noted. The soil is then wetted, rubbed into the palm of the hand with a forefinger, and described in terms of grittiness or smoothness. The quality of organic material present was described in terms of fibric, hemic, or sapric by the degree of identifiable plant remains (Soil Survey Staff 1975).

Soil structure describes the arrangement of soil-particles grouped into stable aggregates and held together by organic materials, carbonates, iron oxides, clays, and/or silica (Miller and Donahue 1990). Aggregates of soil or peds are described by three characteristics: grade (strength of cohesion), size, and type (shape). In cores, where the soil aggregate is a cohesive mass, the ped is described as structureless. This is due, in part, to compaction and to the saturated condition of the soils. Where observable peds are seen, the soil is visibly compared with scaled soil-structure diagrams.

Consistence is the degree of adhesion of a soil mass and its resistance to deformation (stickiness and plasticity) based upon a wet moisture state (Miller and Donahue 1990). The quality of consistence for evaluation is measured by using texture-by-feel analysis. The soil material is pressed between the forefinger and thumb and the relative adherence is noted in terms of stickiness. Rolling the soil material to form a wire determines soil plasticity. When a soil is in its moist state (between air-dried and field capacity), the terms of loose, friable, or firm consistence are applied.

Soil reaction is the relative amount of calcium carbonate in the soil. Using 10-percent hydrochloric acid, the formation of bubbles confirms the presence of calcite or dolomite in the soil. The degree of effervescence indicates the relative amount of carbonates, including whether the reaction occurs throughout the ped or locally, as in the case with shell material.

Soil pH is an indication of the hydrogen ion concentration of the soil and determines the solubility of minerals. A pH meter was used to measure the soil pH in a 1:1 soil/water ratio. Fifteen grams of moist soil and 15 ml of distilled water were well mixed and allowed to settle. The pH meter was allowed to stabilize for several minutes before the measurement was recorded (Peech 1965).

Plant root observations, particularly very fine and fine roots, indicate the physiological maturity of perennials at the time of collection. Roots were described in terms of quantity, size, and location within the soil profile.

Additional information not directly measured in the field (i.e., drainage and permeability classes, land use, and vegetation) was obtained from unpublished technical reports. Additional information about the area that was useful in understanding the hydrogeomorphic setting of each of the potholes is in Appendix A. Complete soil descriptions are listed in Appendix B.

Bulk density

Bulk density is the natural density for a volume of soil and includes any voids occupied by air and water within the soil. An organic soil will have a lower bulk density than a mineral soil. Bulk density is used to calculate soil porosity (when the particle density is known), as well as evaluate soil layers for water storage capacity and root penetration (Miller and Donahue 1990).

A soil core was cut into 2- to 4-cm sections for the entire length of the profile (Figure 6). The soil bulk density was calculated from the oven-dry weight of the soil and the volume of the sediment sections.

Particle size analysis

Discrete particle size analysis generated a soil textural classification for each core sample. The soil profile was sectioned at depth intervals every 2 to 4 cm, and the samples were air-dried at room temperature, then hand-sieved through a 2.0-mm screen. Any gravel remaining was weighed and recorded as weight percent of the sample interval.

Each soil sample (20.0 g) was then treated with a 1 M sodium acetate (buffered with acetic acid to pH 5.0) solution, followed by 30-percent hydrogen peroxide (Gee and Bauder 1986). The moist treated sample was mixed for 5 min with a 0.5-g/ℓ solution of sodium hexametaphosphate (Gee and Bauder 1986). These treatments serve to (a) disaggregate the soil into constituent particles by removing soluble cements and humus from the soil and (b) remove flocculating agents that attract particles together.

The suspension was first wet-sieved through a 230-mesh sieve, and the sand fraction (<2.0 to 0.063 mm) was transferred to a weighed beaker and oven-dried. The suspension was then transferred to a settling cylinder and brought up to 1,000 ml with the sodium hexametaphosphate solution, and a temperature reading of the suspension was measured. Stokes' Law (Miller and Donahue 1990) is the theoretical basis used for determining the settling velocity of the silt (<0.063 to 0.002 mm) and clay particles (<0.002).

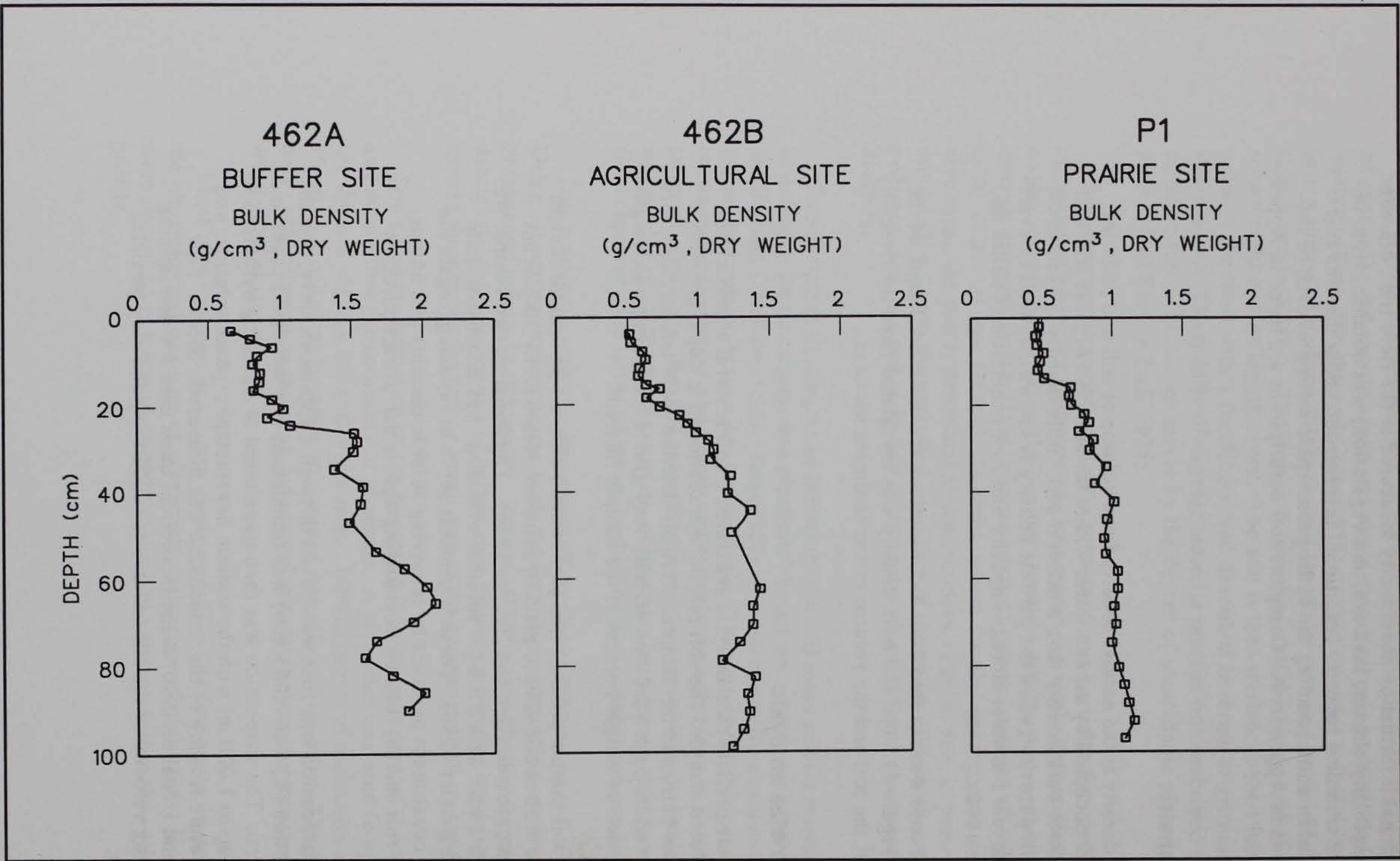

Figure 6. Bulk density changes with depth for sediment cores from three prairie potholes

The suspension was stirred for 2 min, allowed to settle for 20 sec, and the first pipette withdrawal (20 ml) sample was taken at 20 cm. This represents the total mass of particles in suspension. The suspension was then restirred, and the silt-size interval was pipetted at the appropriate time and depth with the clay fraction being the last withdrawal. All pipette withdrawals were transferred to weighed beakers and oven-dried overnight at 105 °C. After drying, the sample beakers were allowed to equilibrate to room moisture for 2 hr before weighing on an analytical balance (Folk 1974).

The weight percent of sand is calculated as 100 S/(S + F), where S is the weight of the sand caught on the 230-mesh screen and F is the first pipette withdrawal, which represents the total weight of the sample in suspension minus the weight of the dispersant (Folk 1974). The subsequent withdrawals are calculated as 100 (S + F - P)/(S + F), where P is the cumulative weight percent of the silt and clay fractions. The final cumulative weight percent is subtracted from 100 and is the mass of the finest particles still in suspension.

Loss on ignition

Organic material and carbonate were determined by ignition in a muffle furnace (Dean 1974). The soil profile was sectioned at 2-cm intervals, placing 10 g of moist soil in a weighed crucible and drying the sample at 105 °C for 24 hr. The soil samples were reweighed, after cooling, to the nearest 0.0001 g, then heated to 550 °C for 1 hr. The soil gravimetric weight after cooling represented the percent of organic matter for that interval. The samples were then reheated to 1000 °C for 1 hr and weighed after cooling for the carbonate determination.

Pollen Processing

A practical application of palynological methods is to use the "*Ambrosia* rise" as a marker horizon in the sedimentary record (Webb 1973; Mathews and D'Auria 1982). The identification of this marker horizon and the historical records of settlement can provide an average postsettlement sedimentation rate. More detailed information on postsettlement land-use changes and sedimentation rates can be obtained using pollen analysis in conjunction with ^{210}Pb or ^{137}Cs dating (Brugam 1978; Davis 1989).

Forty-four 0.9-ml moist sediment pollen samples were taken from the upper 30 cm of each core at 2-cm intervals. These samples were processed using standard techniques (Faegri and Iverson 1975). The procedure included hydrochloric acid treatment to remove carbonates, potassium hydroxide to break organic bonds and remove humic acids, hydrofluoric acid to remove silica, vortex mixing and decanting to separate sand, and acetolysis to remove cellulose. The pollen sample was dried with tertiary butyl alcohol, stained with safrarin red, and mounted on glass slides in silicone oil. The addition of exotic *Lycopodium* (clubmoss) markers provided a means of calculating pollen concentrations in each sample (Stockmarr 1971). Counting was done at 400X magnification except where pollen was scarce. In these cases, the slides were scanned at 200X and grains were identified at 400X. On slides with adequate pollen counts, at least 200 grains exclusive of *Lycopodium* were counted. Slides with low pollen concentrations and poorly preserved grains were not counted to the 200 grain number. In no case were less than 50 *Lycopodium* markers counted.

^{137}Cesium Analysis

^{137}Cs activity (pCi/g) within the soil profile was measured at the Louisiana State University Wetland Biogeochemistry Institute. The upper 30 cm of each core was sectioned into 1-cm intervals. Oven-dried soil samples were ground to a powder, weighed, and sealed in plastic bags. Because of the high organic content and low sample mass, most samples were combined into 2-cm intervals. The ^{137}Cs activity was measured by a lithium-drifted germanium detector and a multichannel analyzer. Samples were counted in order of increasing depth until samples had nearly undetectable activity.

Sedimentation rates were calculated from two periods: (a) 1954 to the sampling date, and (b) 1963 to the sampling date. The depth at which ^{137}Cs was first detectable corresponds to the 1954 deposition. Another peak occurs at 1959 (Pennington, Çambray, and Fisher 1973), but this ^{137}Cs marker horizon is not always present because of its close proximity to the 1954 and 1963 horizons. Maximum activity appears as a spike in the ^{137}Cs soil profile and corresponds to the 1963 deposition. The 1963 peak provides the best stratigraphic horizon for determining sediment accretion since there is less pronounced activity associated with the 1954 peak (De Laune et al. 1989).

3 Results

Soil Characterization

Soils in each of the three potholes were identified as belonging to the Southam soil series and are considered hydric soils. Soil colors were uniform for each site in the upper horizon, and mottles became more numerous with depth. Soil matrix chromas ≤2 and values ≥4 below the dark surface layers indicated that saturated and reducing conditions have occurred as a result of an aquic moisture regime. In pothole 462A, between 42- to 109-cm depth, mottle hues ranged from 2.5 YR to 7.5 YR and chroma was >4 (Appendix B). These mottle colors indicate iron concentrations of lepidocrocite and ferrihydrite (Schwertmann 1993) and are characteristic of contemporary redoximorphic features (Vepraskas 1992). Both potholes 462A and 462B had intermittent gastropod horizons and soil values (>6) related to accumulations of calcium carbonate at depths between 34 to 101 cm. Pothole P1 appears to have been continuously saturated throughout its history by the presence of shell fragments in all horizons and the absence of calcium carbonate deposits.

All the soil profiles showed increasing bulk density with depth (Figure 6). Potholes 462B and P1 had similar bulk densities of >0.5 g/cm^3 from the surface to a depth of 25 cm, which were related to the high percentage of organic matter. The higher and more variable bulk densities of pothole 462A were related to a lower percentage of organic matter and the presence of gravel in some sections.

Particle size classes (sand/silt/clay) were plotted against soil depth to illustrate the textural variation of each sediment core in Figures 7, 8, and 9. The buffer pothole, 462A, ranged from silty clay to clay in its upper horizons, grading to sandy clay loam lower in the soil profile. Pothole 462A had over 20-percent gravel in two horizons. Pothole 462A also had the largest and most variable sand content of the three potholes, with a median sand texture of fine to medium sand (0.1 to 0.5 mm). Potholes 462B and P1 had a narrower spread of soil textures, ranging only from clay to silty clay, and their median sand texture consisted of very fine sand (<0.1 mm).

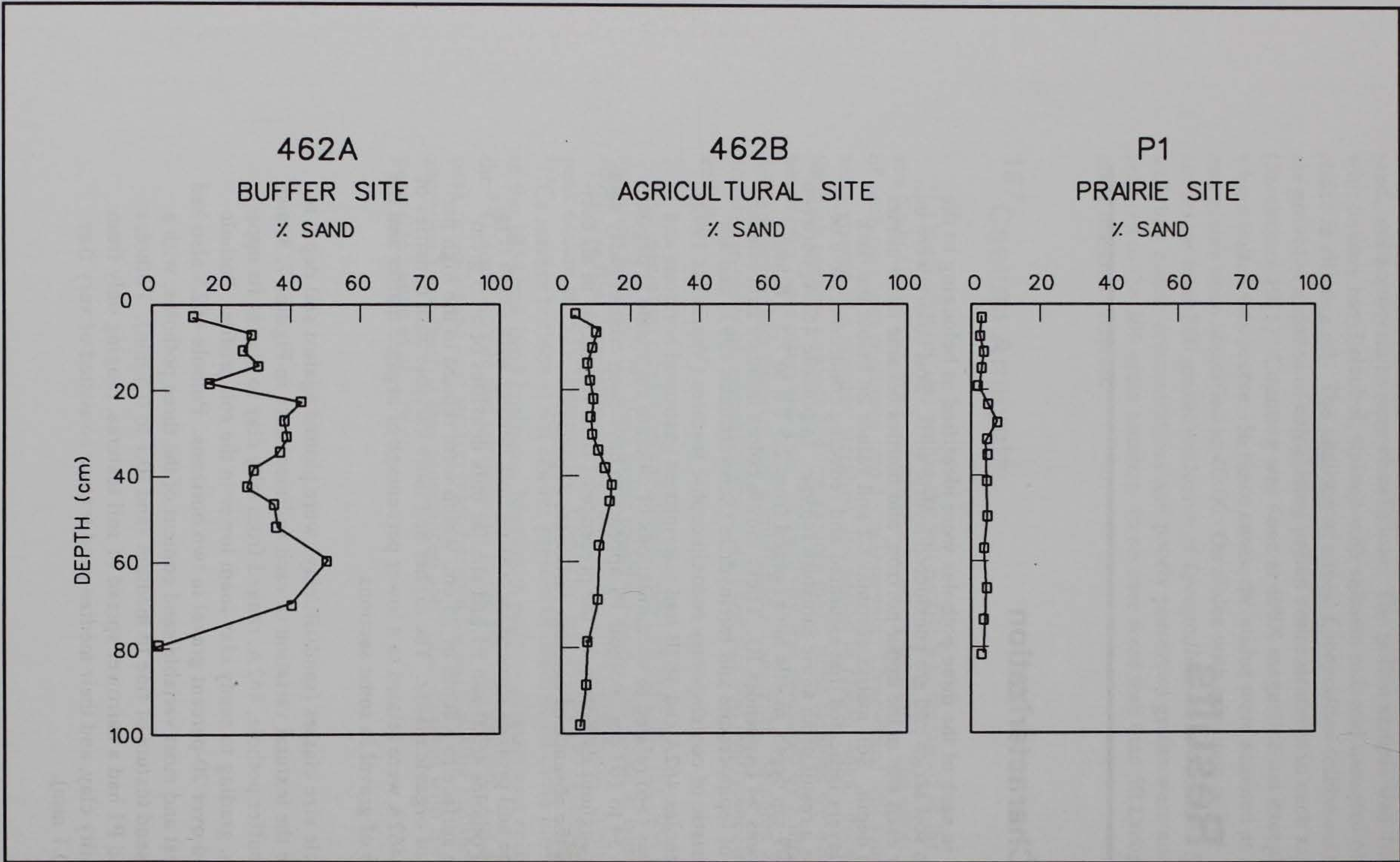

Figure 7. Changes in percent sand composition with depth for sediment cores from three prairie potholes studied

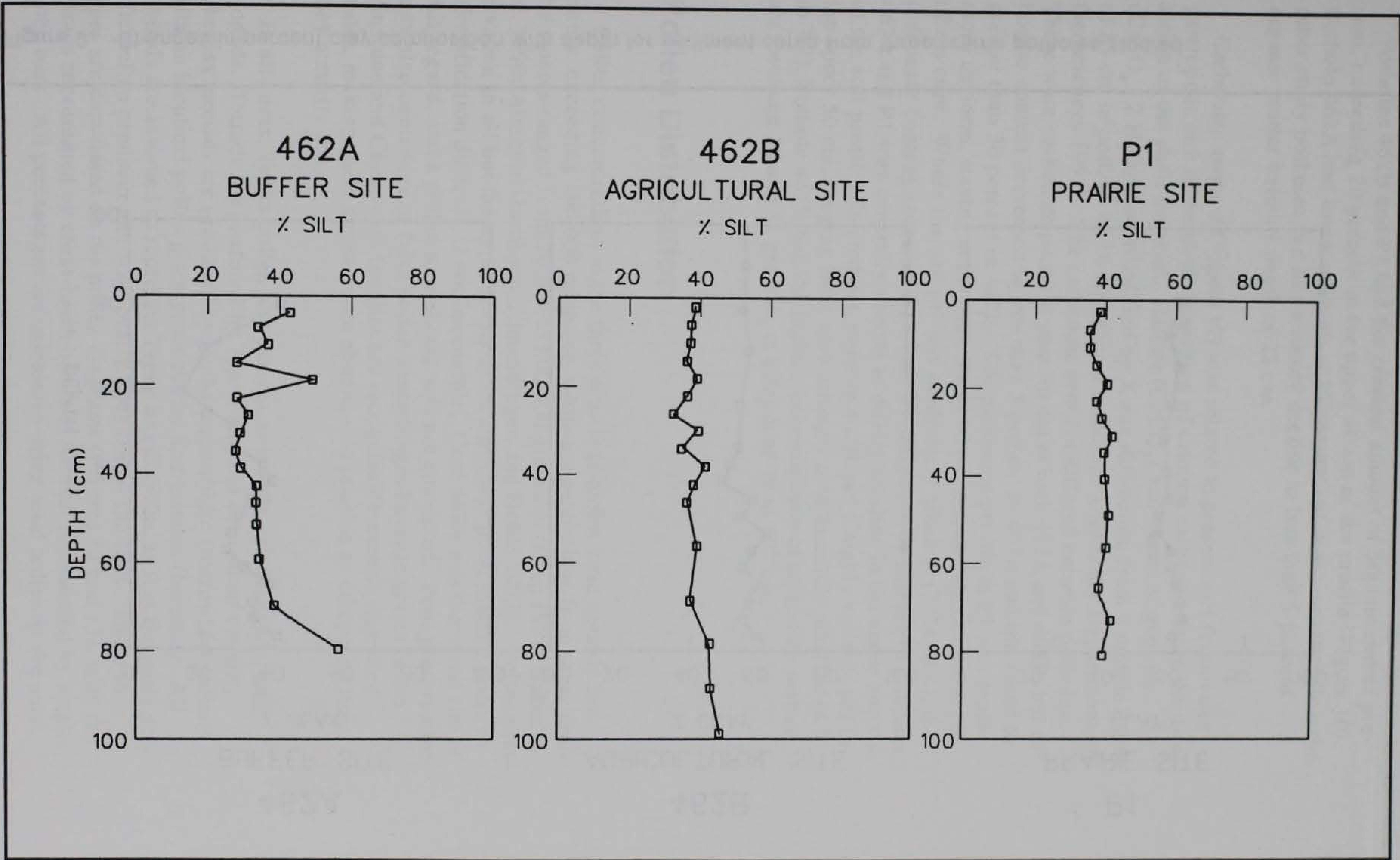

Figure 8. Changes in percent silt composition with depth for sediment cores from three prairie potholes studied

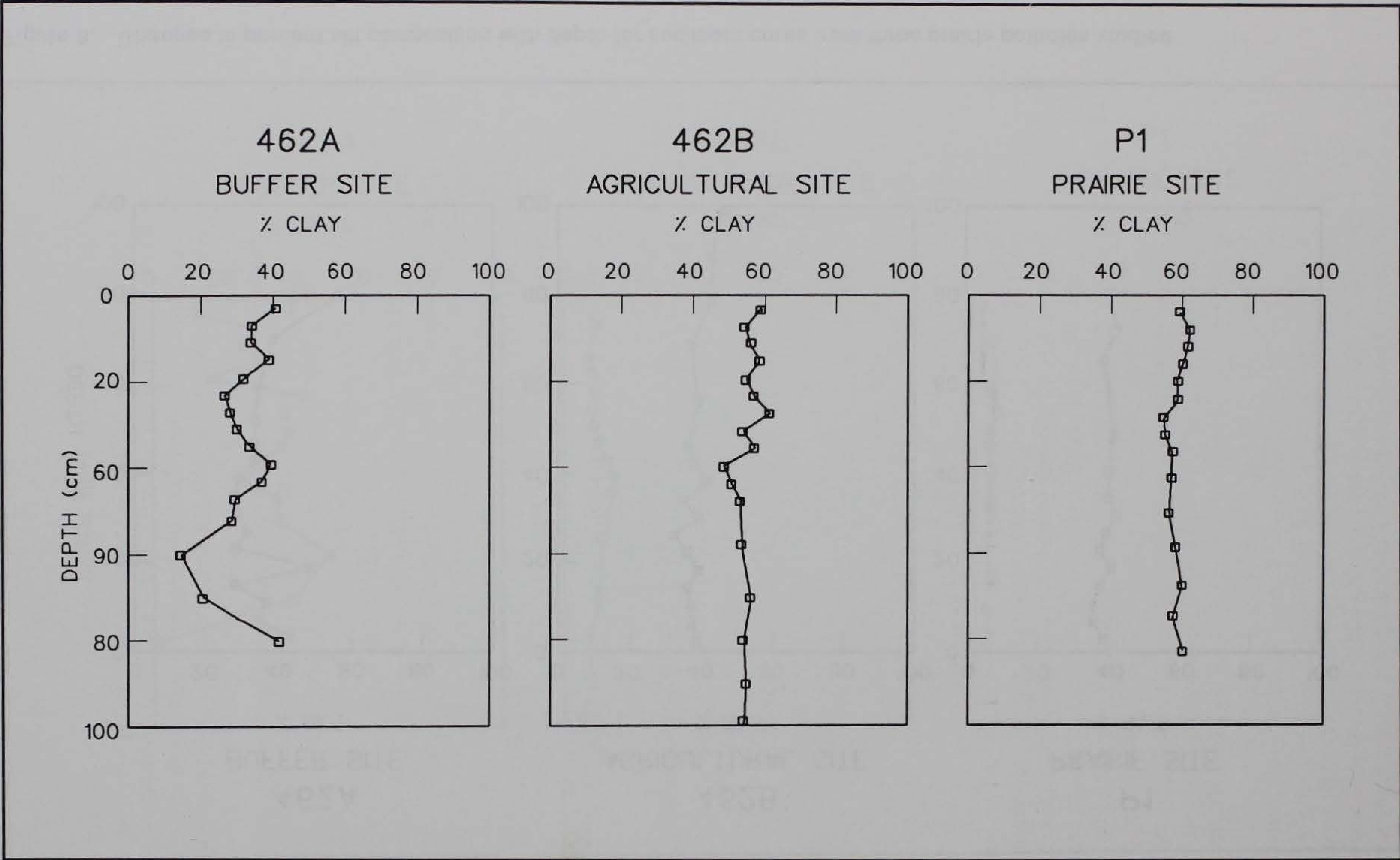

Figure 9. Changes in percent clay composition with depth for sediment cores from three prairie potholes studied

Potholes 462B and P1 had the greatest amount of organic matter present, exceeding 20 percent in the upper 10 cm of the profile (Figure 10). Pothole 462A had lower amounts (<15 percent) of organic matter than the other study potholes and had a steady decline to less than 5-percent organic matter below a depth of 22 cm.

Carbonate content (Figure 11) was related to presence of freshwater gastropods and subsequent deposition of calcium carbonate from the dissolution of the shell material. Calcite ($CaCO_3$) and traces of gypsum ($CaSO_4 \cdot 2\,H_2O$) were identified by X-ray diffraction from a sample depth of 85 cm in pothole 462B (Northeast Louisiana University Department of Geosciences 1991). The carbonate profiles differed between potholes. There were carbonate peaks at near 40 cm at both 462A and 462B, but carbonate content decreased to less than 5 percent in 462A and increased to greater than 30 percent in 462B. The carbonate profile in P1 was much more uniform, staying at between 5 and 10 percent throughout the depth of the core. Where the soil pH was moderately alkaline (7.9 to 8.4), the carbonate content exceeded 5 percent by weight. The soil pH of potholes 462A and P1 was generally neutral to mildly alkaline in the upper horizon of the soil profile. In contrast, pothole 462B had a highly variable pH in the upper 50 cm, ranging from very strongly acid to mildly alkaline (4.9 to 7.7). Pothole 462B had the highest concentration of carbonate materials, between 14 and 31 percent, at a depth of 79 to 107 cm.

Pollen Distribution

Pollen concentrations at the three prairie potholes were notably low, rarely exceeding 100,000 grains/cc, while concentrations from other prairie studies ranged from 20,000 to 600,000 grains/cc (King 1981; Baker et al. 1990; Almquist-Jacobson, Almendinger, and Hobie 1992). Pollen preservation in all but the upper levels of all cores was poor, making positive identification difficult, if not impossible. Core 462A was the worst site in this regard, and a pollen assemblage was not attempted. Poor preservation may also contribute to false pollen assemblages because grains in the Pinaceae and Cheno-Am families are recognizable even in degraded states, making them appear more abundant in relation to other taxa than they actually are.

In all cores, *Typha* pollen was present as tetrads, triads, dyads, and monads. Tetrads are produced by *Typha latifolia* (broadleaf cattail), whereas monads are produced by *Typha angustifolia* (narrowleaf cattail), with an identical pollen grain produced by *Sparganium* (burreed). All monads are assumed to represent *Typha angustifolia*, as it is the more prolific pollen producer and was locally abundant at the sites. These four types are cumulated on the pollen diagrams (Figures 12 and 13), with the tetrads represented by cross-hatch bars and the rest represented by single hatch bars. All percentages are calculated using total pollen as the sum;

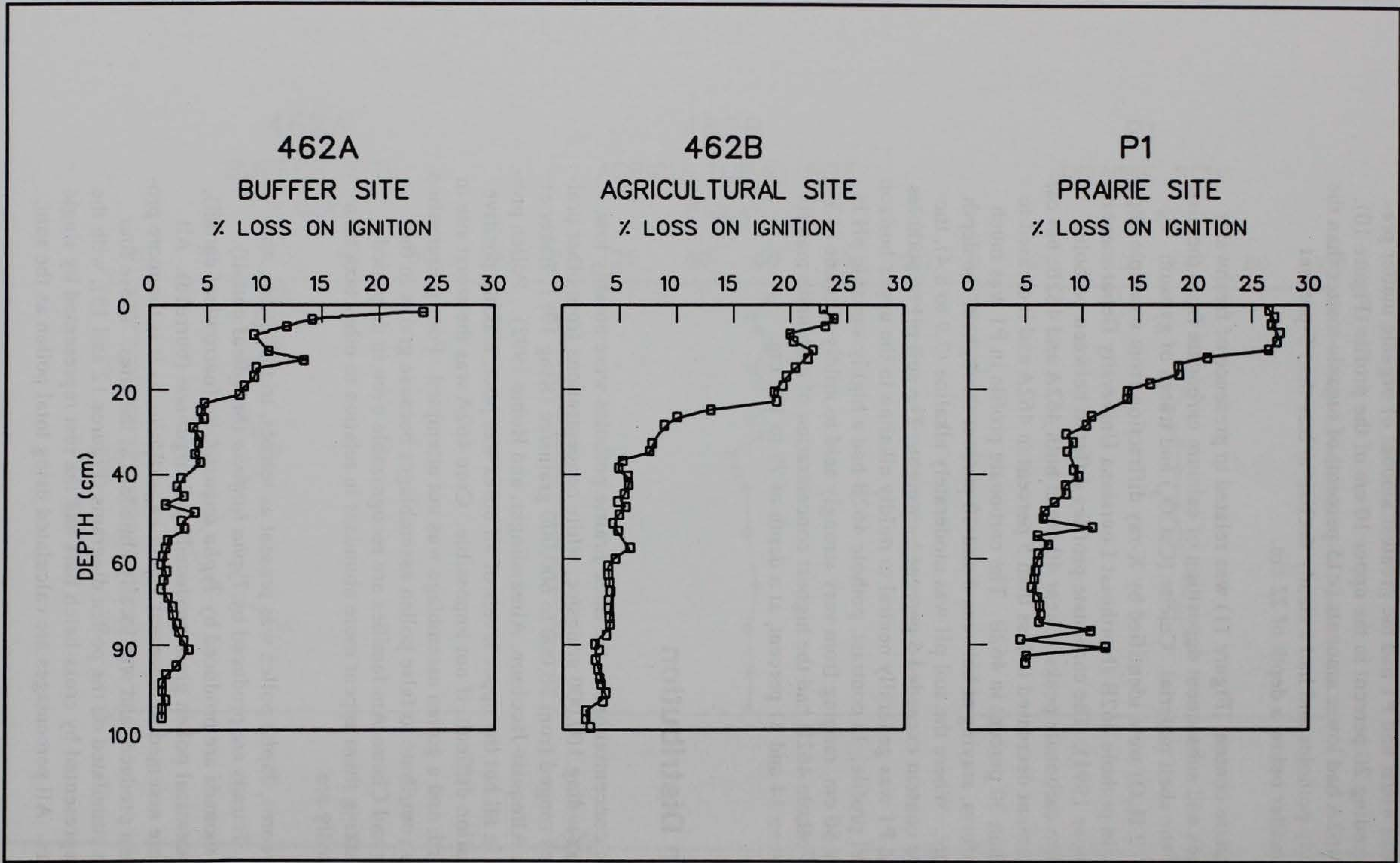

Figure 10. Changes in percent loss on ignition values with depth for sediment cores from three prairie potholes studied

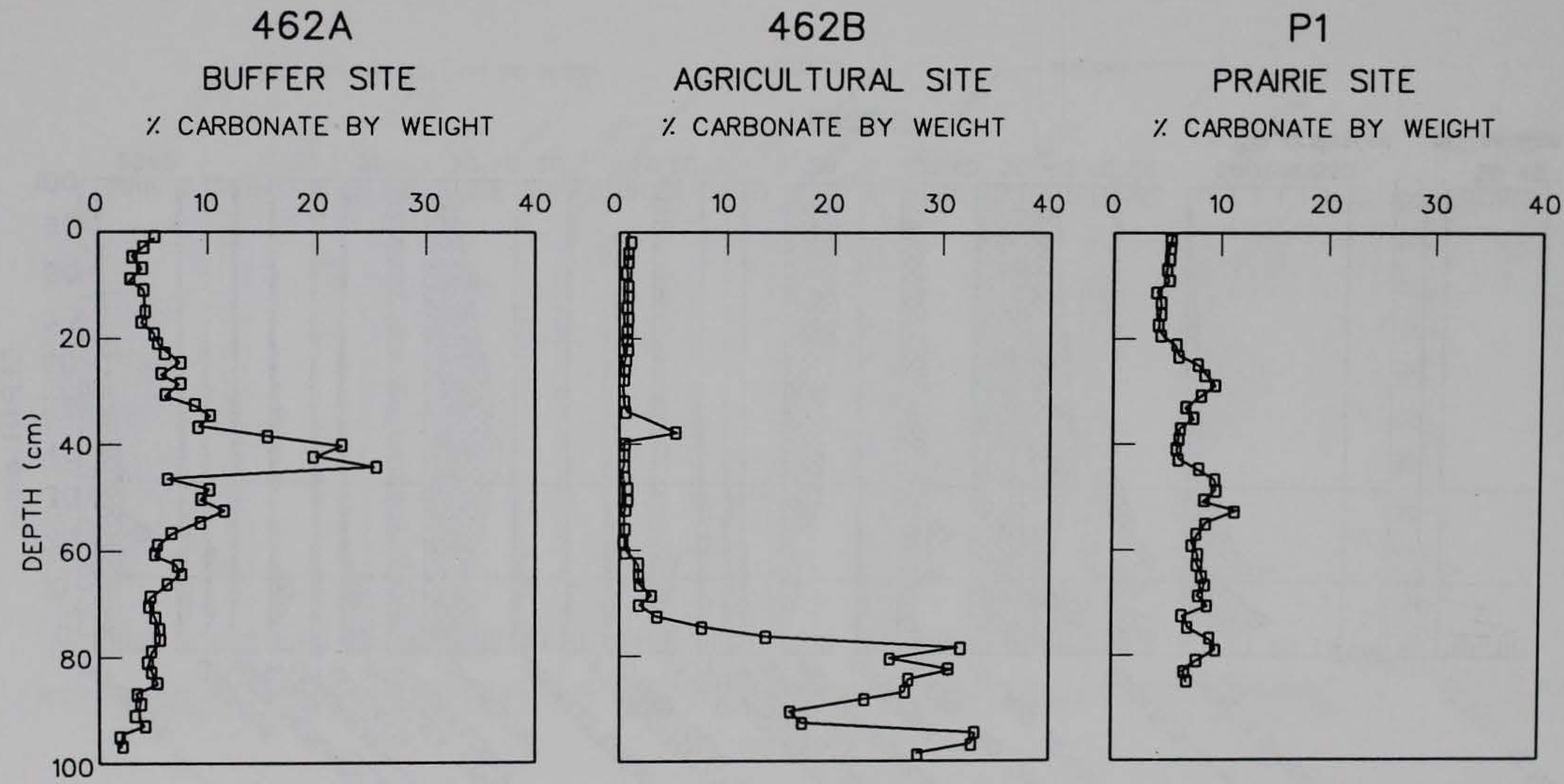

Figure 11. Changes in carbonate values with depth for sediment cores from three prairie potholes studied

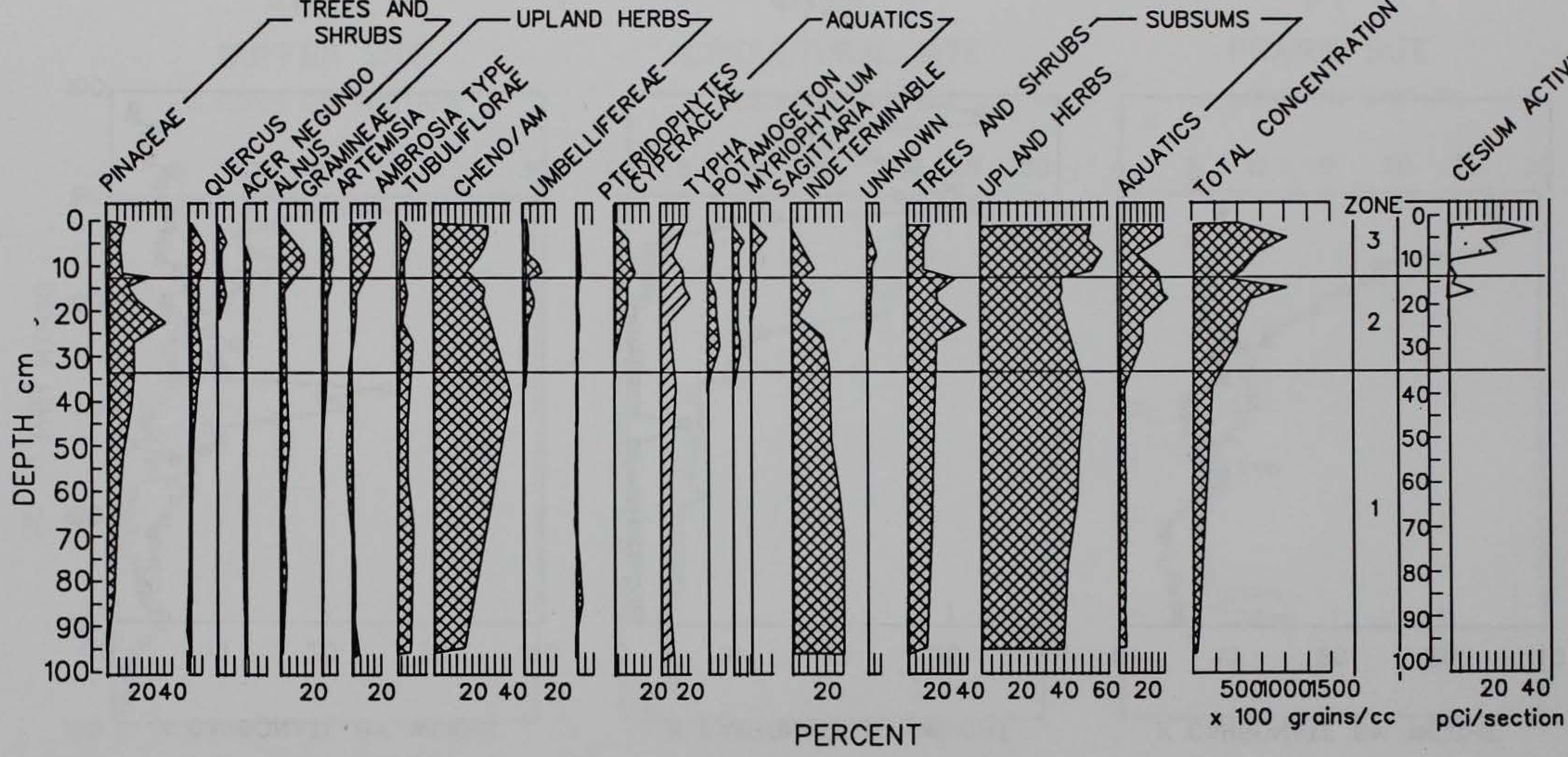

Figure 12. Pollen diagram for prairie pothole 462B

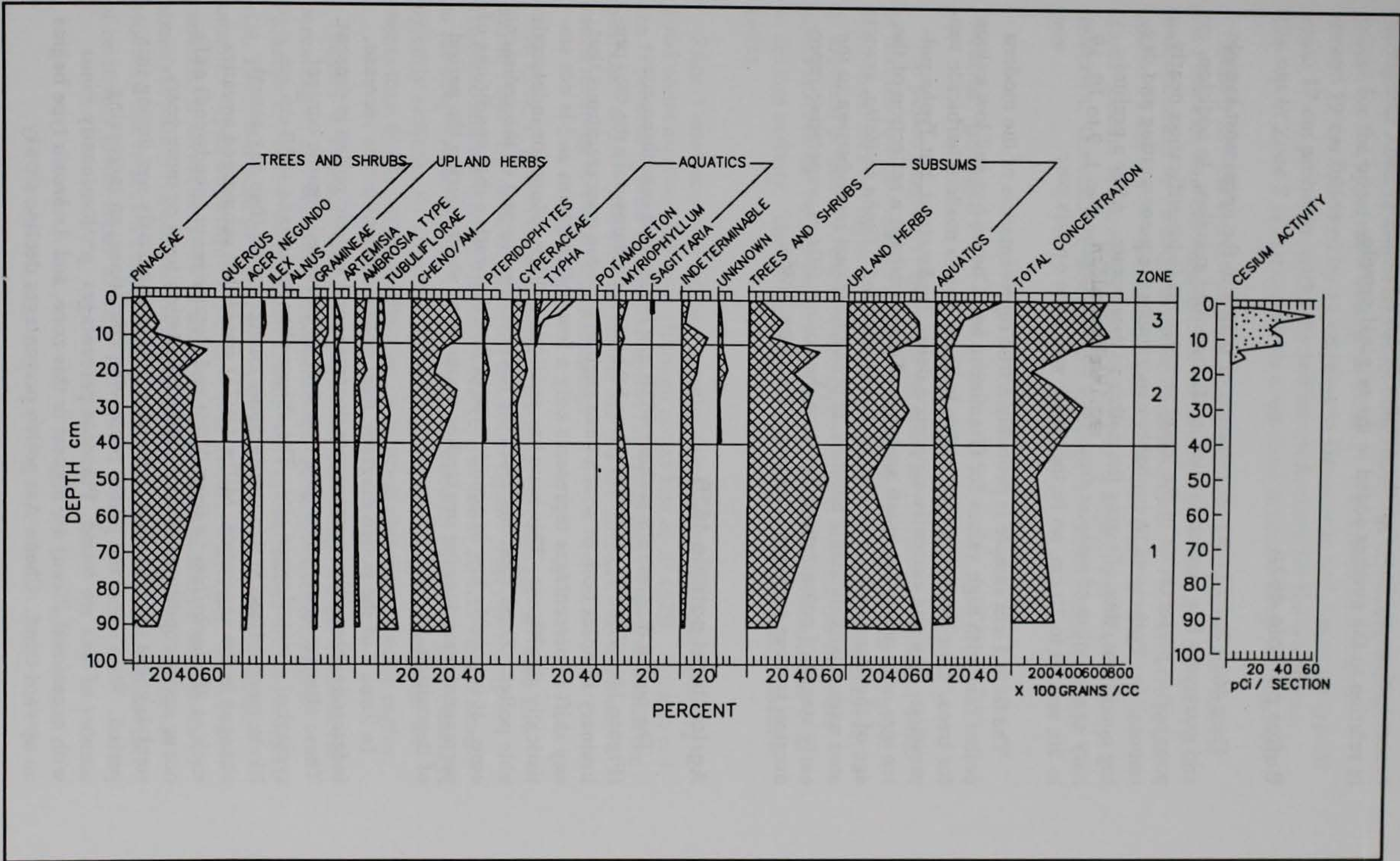

Figure 13. Pollen diagram for prairie pothole P1

concentrations are based on the number of *Lycopodium* markers counted in relation to the number added to the original sample.

Buffer pothole 462A

Core 462A has a high concentration of pollen in the uppermost sample and extremely low concentrations in all the lower samples. In addition, poor pollen preservation in the lower samples made identification nearly impossible. Pothole 462A probably experiences frequent wetting and drying conditions, thus allowing the pollen to deteriorate. After a preliminary examination of samples from core 462A at depths 0 to 1, 9 to 10, 19 to 20, and 29 to 30 cm, no further work was done on this core.

The 0- to 1-cm sample is probably a true representation of the modern pollen rain with high values for Gramineae and Cheno-Am and low values for trees. Low *Ambrosia* type pollen is likely due to modern herbicide suppression. The site currently supports a dense *Typha* stand, but *Typha* pollen was only present in small amounts. This is perhaps a reflection of the age of the stand and the species of *Typha* involved. *Typha latifolia*, associated with relatively stable habitats, is prone to sexual reproduction in the early stages of colonization; but once the colony fills in, vegetative reproduction is more common (Grace and Harrison 1986).

Agricultural pothole 462B

The pollen diagram for pothole 462B can be divided into three zones (Figure 12). Zone 1, the lower part of the core, contains only the two preliminary samples both of which have such low pollen concentrations that any shift in percentages represents only a few pollen grains and is not statistically significant. This zone has predictably high values for indeterminable pollen. Zone 1 encompasses the lower inorganic part of the sediment core. It is notably low in aquatic type pollen, indicating that conditions of permanent waterlogging or standing water were absent during the period of deposition.

In Zone 2 of the pollen diagram, total pollen concentrations increase, indeterminable pollen percentages decrease, and aquatic pollen is present. These changes occur in conjunction with an increased organic content, typical of a waterlogged site. The abrupt changes in taxa at 30 cm are likely more related to this stratigraphic change rather than any actual changes in the vegetation. Millar (1973) stated that submerged aquatics such as *Myriophyllum* (watermilfoil) and *Potamogeton* (pondweed) only occur under conditions of continuous inundation for 4 or more years, implying that the pothole was more or less continuously wet during this period. With improved pollen preserving conditions, an increasing number of taxa are found. Pinaceae percentages (predominantly *Pinus* with occasional *Picea*) are highest in this zone, and *Ambrosia* type begins an upward trend. Cheno-Am pollen percentages decline slowly throughout Zone 2; however, actual concentrations are above normal except for the uppermost sample in Zone 2. A decrease in Pinaceae around 19 cm followed by an increase in Gramineae and *Ambrosia* type at about 17 cm probably marks the settlement horizon for the watershed. The top of Zone 2 is marked by an even more dramatic drop in Pinaceae.

Zone 3 has the highest percentages for upland herb pollen, the lowest for Pinaceae, and the highest total concentrations. Note that the total pollen concentration closely follows the introduction of ^{137}Cs activity in the core at 17-cm depth. A shift between "Trees and Shrubs" and "Upland Herbs" occurs at almost the exact level where significant ^{137}Cs activity increases. Overall, the changes at 12 cm are the most dramatic in this core.

"Prairie" pothole P1

The pollen diagram (Figure 13) for pothole P1 resembles that of 462B in that the lowest concentrations are associated with the lower inorganic sediments, and the highest levels of nonarboreal pollen and lowest levels of arboreal pollen are found in the upper samples. Again the most dramatic shift in the pollen percentages occurs in conjunction with the peak in cesium activity. This pollen diagram is also divided into three distinct zones.

Zone 1 contains only the two samples from the preliminary counting. Total concentrations are low, although not as low as in 462B. Aquatic pollen is present in both of these samples, implying that P1 was wetter in the past than 462B. Still concentrations are too low in Zone 1 to attribute much meaning to the pollen assemblage.

In Zone 2, pollen concentration increases; percentages of "Tree and Shrub" and "Upland Herb" pollen are about equal. There is a drop in Pinaceae and a slight rise in *Ambrosia* type at about 20 cm. This is similar to the drop in Pinaceae at 19 cm in 462B, probably related to land clearing by early settlers. P1 consistently had higher percentages of arboreal elements than 462B, perhaps reflecting its location closer to a source region.

Zone 3 is characterized by low arboreal percentages, high nonarboreal percentages, and high total concentrations. Actual concentrations of Pinaceae are below normal, and Cheno-Am concentrations are above normal. There is a peak of *Typha angustifolia* type pollen in the uppermost sample. *Typha angustifolia* is common in disturbed habitats. Like most ruderals, it invests heavily in sexual reproduction, making it the source of abundant pollen (Grace and Harrison 1986). The high pollen values are probably due to recent colonization of the pond, perhaps as a direct result of relatively lower water levels.

^{137}Cesium Profile Distribution

^{137}Cs-derived sedimentation rates are listed in Table 1. Both potholes 462B and P1 had a maximum activity at depth 3 cm (corresponding to the 1963 horizon) and nondetectible ^{137}Cs activity at depths 17 and 15 cm, respectively. Pothole 462A had a maximum ^{137}Cs activity at a depth of 10 cm and was nondetectible below 28 cm (Figure 14).

Table 1
^{137}Cs-Derived Sediment Accretion Rates

Core	1963-1992 cm year^{-1} (Corrected for compaction)	1954-1992 cm year^{-1} (Corrected for compaction)
462A Buffer site	0.41	0.63
462B Agricultural site	0.12	0.25
P1 "Prairie" site	0.12	0.32

The ^{137}Cs activity corresponding to the 1954 horizon was variable in depth, ranging from 20 cm for buffer pothole 462A, 8 cm for agricultural pothole 462B, and 11 cm for "prairie" pothole P1 (Figure 14). The 1954-1992 sedimentation rates showed a much higher rate of accretion than the 1963-1992 rate. A higher accretion rate is seen if estimates are made from the 1954 horizon, which may be evidence of ^{137}Cs migration. However, it is clear from sedimentation rate estimates from both dates that 462B and P1 are similar, while 462A has experienced a higher rate of sediment accretion.

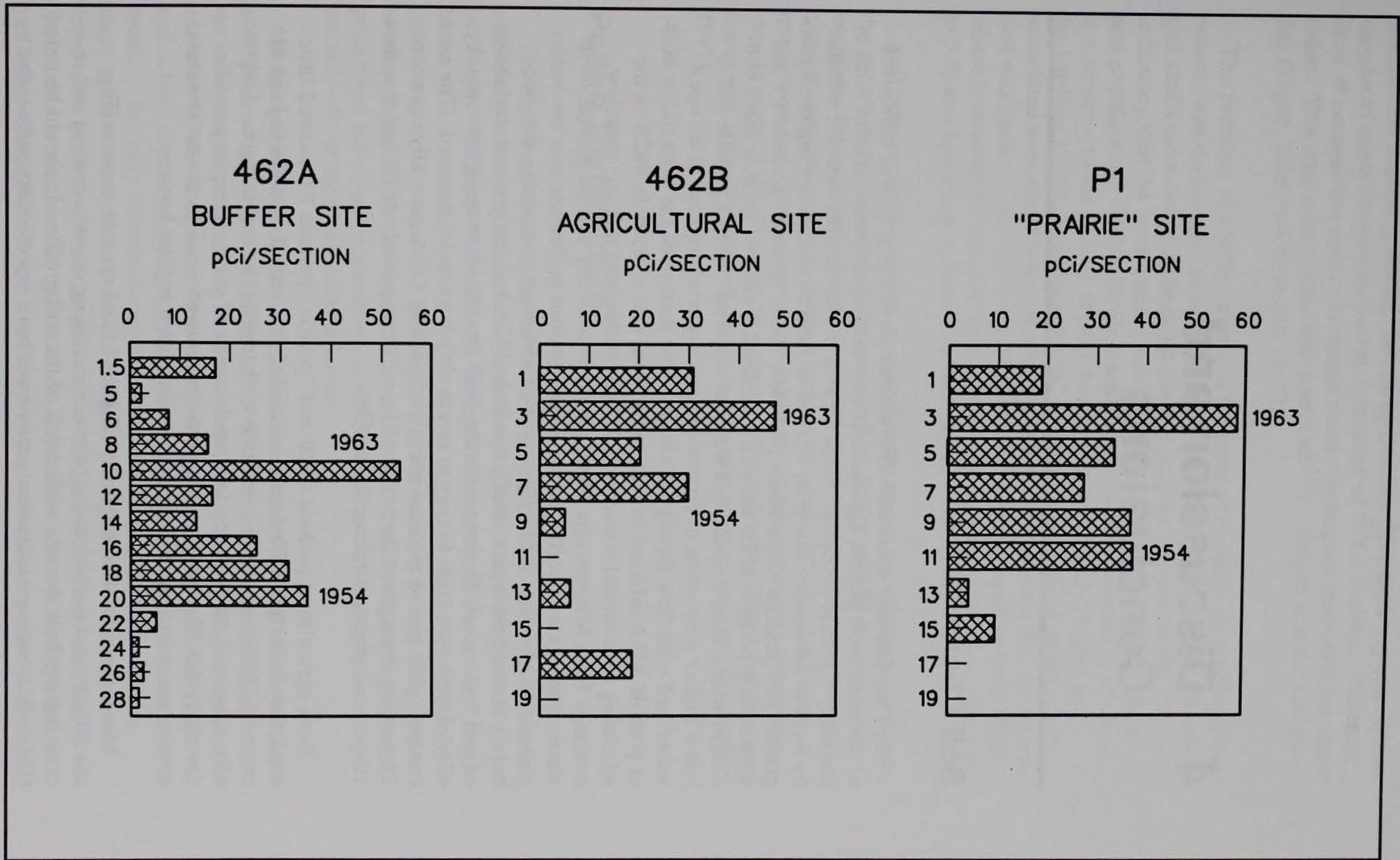

Figure 14. ^{137}Cs profiles for three prairie potholes (not corrected for compaction)

4 Discussion and Conclusions

Soil Characterization

Soil morphology characteristics did not yield any practical indicators of the settlement period, agricultural conversion, or sedimentation rates in the study's prairie potholes. Rather, particle-size determinations, whether by field or laboratory analysis, were most helpful characterizing the hydrogeomorphic regime of the study potholes. Both "prairie" pothole P1 and agricultural pothole 462B showed a uniform profile of particle sizes consistent with a closed watershed's parent material. Buffer pothole 462A had a higher proportion of coarse-grained materials typical of an open watershed with flow through drainage. The texture of the material in buffer pothole 462A differed considerably from that of pothole 462B in the adjoining agricultural watershed. It is hypothesized that the overflow drainage from Minneapolis Flats, which historically carried glacial meltwater, transported poorly sorted, coarse-grained sediments into the buffer pothole 462A and is the likely source of sediment comprising this pothole's varied lithologies. Buffer pothole 462A had the greatest variability of soil textures of the three potholes soils examined, ranging from mucky silty clay to clay loam to clay to sandy clay loam to loamy sand. The sand content (plus fine to medium gravel) of pothole 462A generally exceeded 20 percent throughout the soil profile, whereas pothole 462B had less than 10-percent sand throughout its profile.

Both agricultural pothole 462B and "prairie" pothole P1 showed little departure in texture with depth, indicating that recent changes in land-use practices did not result in a detectable change in the soil texture. Additionally, there was no evidence for translocation of clays. Despite periodic drying cycles, the study prairie potholes showed weak to absent structural development and an absence of a well-defined argillic horizon.

Measurements of bulk density (Figure 6) and organic content (Figure 10) showed a relationship between declining organic content and increasing dry bulk density with depth of the soil profile. It should be noted that bulk density measurements may have been unavoidably influenced by compaction occurring during the coring process. The high organic content may be of some concern in the interpretation of ^{137}Cs profiles. Different rates of compaction occur as organic matter undergoes microbial decomposition. This may result in the movement of ^{137}Cs deeper into the soil profile (Tegen, Dörr, and Münnich 1991).

The presence of $CaCO_3$, either in the form of biogenic or lithologic carbonate, was distributed throughout the soil profiles (Figure 11). Gastropod shells were found throughout the soil profiles (Appendix B), indicating that the environment was sufficiently moist to support gastropod populations. $CaCO_3$ limits the dispersion and translocation of clays, contributing to the lack of argillic horizons in these soils (Bigler and Richardson 1984). Soil pH reflected a moderately alkaline environment associated with the calcareous nature of the soil (Appendix B). An exception was found in the upper organic horizon of agricultural pothole 462B where intermittent intervals were strongly to very strongly acidic (pH 4.9 to 5.2) and hydrogen sulfide odor was noted.

Soil color could be used to distinguish the upper organic horizons from the parent material lower in the soil profile. In the middle to lower soil horizons, the soil color ranged from dark gray to very dark gray and indicated that gleying or reducing conditions were present. Rust-colored mottles, an indicator of iron segregation in waterlogged soils, were common in each of the three study potholes (Appendix B). These features are consistent with a hydric soil series in an aquic moisture regime (Vepraskas 1992).

Pollen Distribution

The high concentration of pollen at the surface of buffer core 462A and extremely low concentration at lower levels indicate that the pothole may be subject to flow during the late spring/summer, which could flush much of the year's accumulation of pollen out of the basin. More than 55 percent of the total annual precipitation (Jamestown) falls during the months of May, June, July, and August (Winters 1963). This low concentration of pollen and poor pollen preservation suggested that 462A should be excluded from the final pollen analysis.

Pollen percentage diagrams for cores from agricultural pothole 462B and "prairie" pothole P1 exhibit similar shifts in pollen assemblages, with the most dramatic occurring at about 12 cm in each core. This shift is concurrent with the abrupt rise in cesium activity associated with the 1950s and is best explained by the expansion of mechanized agriculture. Unfortunately, the only information available on land-use practices near the study potholes is that land use fragmented during the 1930s drought and depression years, with the property later being resold to new owners. It is reasonable to assume that mechanized agriculture was not widespread until after World War II and that this pronounced shift in pollen probably followed that introduction. The dramatic shift in pollen percentages at the Zone 2 to Zone 3 boundary (^{137}Cs appearance) can be quickly detected by counting only the easily recognized pollen grains of Pinaceae and Cheno-Ams (Figure 15). This might eliminate the need for more costly cesium analysis. The other factor both potholes have in common is the drop in Pinaceae pollen that occurs around 20 cm in each core (Figures 12 and 13). In P1, this decrease is concurrent with, and in 462B, is preceded by, a slight rise in *Ambrosia*-type pollen. This probably represents the true settlement horizon.

Unfortunately, poor pollen preservation, lack of information about early land-use practices, and lack of dating control below the cesium horizon are limiting factors in this study. Pollen stratigraphy and grain integrity are best preserved under waterlogged, acid, and anaerobic conditions (Bryant 1989; Anderson 1986). The alternate wet and dry regimes that likely exist in the prairie potholes are detrimental to pollen preservation (Bryant 1989). During periods when the water table drops, these sites are subject to pedogenic processes as evidenced by their "soil" type profiles and the accumulation of cesium and pollen at about 16 cm in 462B. Under a soil regime, small particles, pollen included, are selectively removed from the A horizon and transported downward in the soil profile (Dimbleby 1961). In addition, drying subjects pollen to processes that destroy the most fragile grains first leading to a false pollen assemblage as found in Zone 1 of each core.

McAndrews, Stewart, and Bright (1967), in a study of Woodworth Pond, also located in Stutsman County, North Dakota, detected a similar shift between Pinaceae and Cheno-Am pollen percentages at about 9 cm, with poor preservation in the levels below 15 cm. In the absence of dating control, they attributed this to a hydrologic change in the early 1900s. If the cesium profiles reflect the actual time of sediment deposition, the hydrologic change may instead be related to the end of the 1930s drought.

^{137}Cesium Sedimentation Profiles

^{137}Cs-derived sedimentation rates measured in this study show that sediment accumulation in the study potholes was relatively low. Using the 1963 peak, prairie pothole 462A had the highest rate of vertical accretion of 0.41 cm/year. Both agricultural pothole 462B and "prairie" pothole P1 had identical 1963-1992 sedimentation rates of 0.12 cm/year. This identical rate occurred in spite of the fact that pothole P1 has a grassed watershed with a drainage area ten times smaller than the corresponding agricultural watershed of pothole 462B. Buffer pothole 462A had the highest sedimentation rate of the three potholes examined. This rate may reflect the close proximity of the watershed to the Minneapolis Flats drainage and the deposition of a coarser, poorly sorted, particle-size fraction from this drainage course.

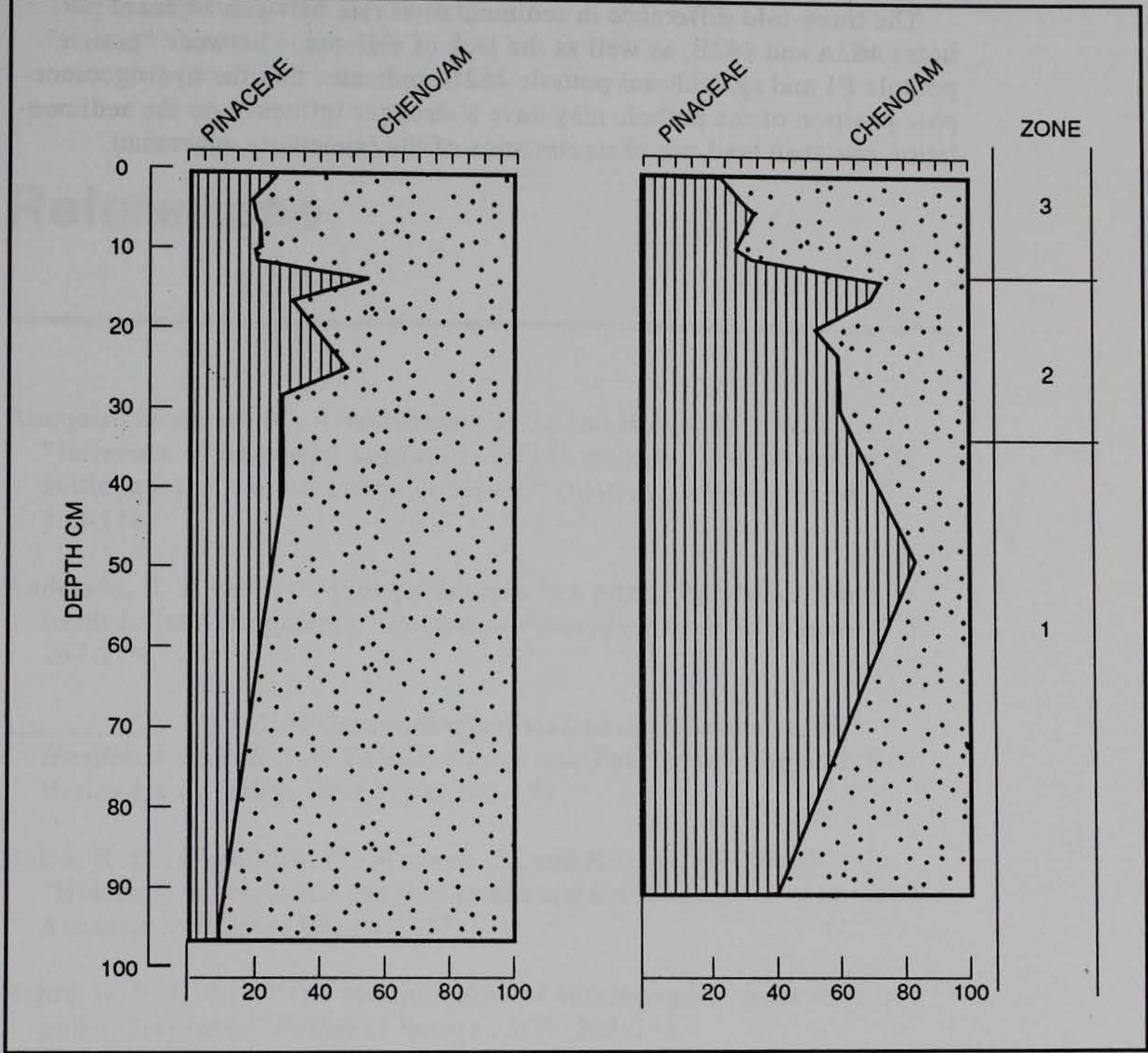

Figure 15. Pinaceae:Cheno-Am pollen ratio

The three-fold difference in sedimentation rate between adjacent potholes 462A and 462B, as well as the lack of difference between "prairie" pothole P1 and agricultural pothole 462B, indicates that the hydrogeomorphic position of the pothole may have a stronger influence on the sedimentation rate than land-use characteristics of the immediate watershed.

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Appendix A
Prairie Pothole Site Descriptions

Pothole ID #: 462A

Correlated Name: Buffer Pothole

Quadrangle: Eldridge SE, North Dakota (1951)
Lippert Township
T.139 N R.65 W Section 34 NE¼ NW¼

Location: 10.3 km (6.4 miles) south of Eldridge, ND
220 m (722 ft) south of paved road

Latitude: 46° 49' 05" N
Longitude: 98° 52' 05" W

Soils Series: Southam
Classification: fine, montmorillonitic (calcareous), frigid Cumulic Haplaquoll
Geographically Associated Soils: Parnell, Tonka

Physiography: end moraine in glaciofluvial landform
Geomorphic Position: on a slope and in a depression of an interfluve, 1.6 km (1 mile) from Minneapolis Flats drainage
Microrelief: depression
Slope Characteristics: northwest facing concave horizontal
Elevation: 471 m (1,544 ft) MSL

Precipitation: 43 cm (17 in.) ustic moisture regime

Water Table Depth: not observed
Hydraulic Conductivity: low to moderate
Drainage Class: poorly drained
Runoff: ponded

Air Temperature: Annual 5.6 °C (42 °F) Summer 18.9 °C (66 °F)
Winter -12.2 °C (10 °F)

Watershed Use: agricultural cultivation with an opal grass cover surrounding a prairie pothole

Parent Material: alluvium from mixed material over from glacial till plains and end moraines
Erosion: none

Vegetation: *Typha* ssp. (cattail)

Diagnostic Horizons: 0 to 33 cm (0 to 13 in.) mollic
33 to 89 cm (13 to 35 in.) cambic
89 to 109 cm (35 to 43 in.) glacial alluvium

Pothole ID #: 462B

Correlated Name: Agricultural Pothole

Quadrangle: Eldridge SE, North Dakota (1951)
Lippert Township
T.139 N R.65 W Sections 34, 35 centerline

Location: 10.3 km (6.4 miles) south of Eldridge, ND
200 m (656 ft) west of unimproved dirt road

Latitude: 46° 48' 37" N
Longitude: 98° 50' 26" W

Soil Series: Southam
Classification: fine, montmorillonitic (calcareous), frigid Cumulic Haplaquoll

Geographically Associated Soils: Parnell, Tonka

Physiography: end moraine in a glaciofluvial landform
Geomorphic Position: on a sideslope of a depression at the head of a drainageway.
Microrelief: depression
Slope Characteristics: southwest facing concave horizontal

Elevation: 465 m (1,524 ft) MSL

Precipitation: 43 cm (17 in.) ustic moisture regime

Water Table Depth: 76 cm (30 in.) at time of coring
Hydraulic Conductivity: very low
Drainage Class: very poorly drained
Runoff: ponded

Air Temperature: Annual 5.5 °C (42 °F)
Summer 18.9 °C (66 °F)
Winter -12.2 (10 °F)

Watershed Use: agricultural crop production surrounding a prairie pothole

Parent Material: alluvium from mixed material over from glacial till plains and end moraines.
Erosion: none

Vegetation Code(s): *Typha* ssp. (cattail), *Scirpus* ssp. (bulrush), *Potamogeton pectinatus* (sago pondweed)

Diagnostic Horizons: 0 to 50 cm (0 to 20 in.) mollic
50 to 79 cm (20 to 31 in.) cambic
79 to 107 cm (31 to 42 in.) glacial alluvium

Pothole ID #: P1

Correlated Name: "Prairie" Pothole

Quadrangle: Goldwin SE, North Dakota (1958, 1986)
Round Top Township
T.142 N R.66 W Section 19 SE¼ SW¼

Location: 22.5 km (14 miles) west of Buchanan, ND
244 m (800 ft) southeast from unimproved dirt road

Latitude: 47° 05' 53" N
Longitude: 99° 05' 54" W

Soil Series: Southam
Classification: fine, montmorillonitic (calcareous), frigid Cumulic Haplaquoll

Geographically Associated Soils: Parnell, Tonka

Physiography: kettle pothole in a stagnation moraine landform
Geomorphic Position: on a slope and in a depression
Microrelief: closed depression
Slope Characteristics: northwest facing concave horizontal, concave vert
Elevation: 559 m (1835 ft) MSL

Precipitation: 43 cm (17 in.) ustic moisture regime

Water Table Depth: not observed
Hydraulic Conductivity: very low

Air Temperature: Annual 5.6 °C (42 °F)
Summer 18.9 °C (66 °F)
Winter 12.2 °C (10 °F)

Drainage Class: very poorly drained
Runoff: ponded

Watershed Use: tillage restricted National Waterfowl Production Area

Parent Material: alluvium from mixed material over from glacial till plains and end moraines
Erosion: none

Vegetation: *Typha* ssp. (cattail)

Diagnostic Horizons: 0 to 56 cm (0 to 22 in.) mollic
56 to 100 cm (22 to 40 in.) cambic
100 to 117 cm (40 to 47 in.) glacial alluvial

Appendix B
Soil Descriptions

462A-(Buffer Pothole)

0 to 18 cm (0 to 7 in.)—black (N 2/) mucky silty clay to mucky silt loam, dark gray (10YR 4/1) dry; organic content is high (>10 percent); common, fine *Typha* stems in the surface layer and many to common, fine to very fine roots; structureless; slightly sticky, slightly plastic; the surface is stained dark reddish brown (5Y2/2) to a depth of 0.5 cm and nonsticky by humus, many, fine to medium gastropod shells and fragments and is strongly effervescent in microsites; neutral to mildly alkaline (pH 7.0 to 7.6); abrupt smooth boundary.

18 to 26 cm (7 to 10 in.)—black (N 2/) mucky silty clay loam to clay loam, dark gray (10YR 4/1) dry; structureless; slightly sticky, slightly plastic; many, fine shell fragments; common to few, very fine roots; strongly effervescent in microsites; mildly to moderately alkaline (pH 7.8 to 7.9); clear smooth boundary.

26 to 34 cm (10 to 13 in.)—black (N 2/) sandy clay loam to clay loam; few to many, fine prominent brownish yellow, light brownish gray to dark gray (10YR 6/8, 10YR 6/2, and 10YR 4/1) mottles; structureless; slightly sticky, slightly plastic to plastic; many to common, fine shell fragments; common to few, very fine roots; 1 to 5 percent fine, angular gravel; strongly effervescent in microsites; moderately alkaline (pH 7.9 to 8.0); clear smooth boundary.

34 to 42 cm (13 to 16 in.)—dark gray (10YR 4/1) clay loam to clay; many, fine distinct black (N 2/) mottles; structureless; slightly sticky, plastic; few, very fine roots; 3 percent fine, angular gravel; strongly effervescent throughout; moderately alkaline (pH 8.1 to 8.3); clear smooth boundary.

42 to 59 cm (16 to 23 in.)—light grayish brown (10YR 6/2) clay loam to stony sandy clay loam; many, prominent black (N 2/) and few, fine, prominent olive yellow (2.5YR 6/8) mottles; structureless; slightly sticky to nonsticky, plastic to slightly plastic; 5 to 22 percent fine angular gravel; no shell fragments except for one planispiral gastropod; calcareous; strongly

effervescent throughout; moderately alkaline (pH 8.2 to 8.4); abrupt smooth boundary.

59 to 89 cm (23 to 35 in.)—light grayish brown (10YR 6/2) to reddish yellow (7.5YR 6/8) and brown (10YR 5/2) stony sandy loam to loam to silty clay; many to common, fine, prominent dark brown (7.5YR 3/2), common, medium to fine, prominent reddish yellow (7.5YR 6/8), common, fine, prominent dark reddish brown (5YR 3/2), and common, fine, prominent very dark grayish brown (2.5YR 3/2) mottles; structureless; nonsticky, nonplastic; clear to opaque sand grains and 4 to 21 percent fine to medium gravel (up to 8-mm diam) at the top to iron concretions (up to 5-mm diam) and Fe-stained sand grains in the middle and bottom of the horizon; very slightly effervescent in microsites; mildly to moderately alkaline (pH 7.6 to 8.3); clear smooth boundary.

89 to 109 cm (35 to 43 in.)—reddish yellow (7.5YR 6/8) to yellowish brown (10YR 5/4) loamy sand; structureless; nonsticky, nonplastic; common, fine to medium gravel (up to 1-cm diam); common clay concretions.

462B-(Agricultural Pothole)

0 to 23 cm (0 to 9 in.)—black (N 2/) sapric clayey muck, dark gray (10YR 4/1) dry; common, fine reeds, leaf fragments in the upper half layer; structureless; slightly sticky, nonplastic to slightly plastic; the surface is stained dark reddish brown (5Y2/2) to a depth of 1 cm; common, fine (1 mm) gastropod shells and fragments; many to few, fine to very fine roots; slightly effervescent in microsites; strongly acid to neutral (pH 5.2 to 7.0); abrupt smooth boundary.

23 to 50 cm (9 to 20 in.)—black (10YR 2/1) mucky clay to mucky silty clay; dark gray (10YR 4/1) dry; very fine to fine, subangular blocky; slightly sticky to nonsticky, slightly plastic to plastic; this horizon contains few, fine shell fragments; common to few, fine to very fine roots; very slightly effervescent in microsites; very strongly acid to mildly alkaline (pH 4.9 to 7.7); clear smooth boundary.

50 to 79 cm (20 to 31 in.)—black to very dark gray (10YR 2/1 to 10YR 3/1) mucky clay to mucky silty clay; few fine prominent yellowish brown (10YR 5/4) mottles; very fine subangular blocky; nonsticky, plastic; many to common, fine planispiral gastropod shells (3 to 5 mm) and fragments in the bottom of this horizon; strongly effervescent in microsites; neutral to mildly alkaline (pH 6.8 to 7.7); abrupt smooth boundary.

79 to 101 cm (31 to 40 in.)—gray (10YR 4/1) to white (10YR 8/2) to very dark gray (10YR 3/1) silty clay; common, threadlike prominent olive (5Y 4/6) mottles at the bottom of this horizon; few, thin to medium platy concretionary layers aligned in vertical bands of silt and clay; slightly sticky to nonsticky, plastic to nonplastic; this horizon resembles a burrow tube 4

to 5 cm in diam, with two concentric bands of noncalcareous (gypsum?) material, weakly cemented silt containing common gastropod shells (3 mm) and fragments and is banded with thinner vertical walls of clay; the silt bands are strongly effervescent, but discontinuous; the clay is non-reactive; moderately alkaline (pH 7.9 to 8.4); clear smooth boundary.

101 to 107 cm (40 to 42 in.)—grayish brown (10YR 5/2) sandy clay loam; structureless; slightly sticky, slightly plastic; few fine gravels few 1-cm diam Fe concretions.

P1-("Prairie" Pothole)

0 to 20 cm (0 to 8 in.)—black (N 2/) sapric clayey muck, dark gray (10YR 4/1); many, fine fibers and leaf fragments; fine, common distinct dark brown (10YR 2/2) mottles in the middle of the horizon; structureless; non-sticky, slightly plastic; surfaces stained dark brown (10YR 4/3) to 2 cm; many to common, fine to very fine roots; few, fine (1 mm) gastropod shells and common to many shell fragments; strongly effervescent in microsites; mildly alkaline (pH 7.4 to 7.5); abrupt smooth boundary.

20 to 54 cm (8 to 21 in.)—black (10YR 2/1/) mucky clay to mucky silty clay; dark gray (10YR 4/1) dry; structureless; nonsticky to slightly sticky, slightly plastic; common to few, fine to very fine roots; many to common, fine shell fragments; very strongly effervescent in microsites; mildly to moderately alkaline (pH 7.5 to 7.9); clear smooth boundary.

54 to 100 cm (21 to 39 in.)—very dark gray (10YR 3/1) mucky silty clay to clay; many to common prominent dark yellowish brown (10YR 4/6) mottles in the upper half of the horizon; structureless; slightly sticky to sticky, plastic; common to few, fine gastropod shells and fragments; strongly effervescent in microsites; mildly to moderately alkaline (pH 7.8 to 7.9); clear smooth boundary.

100 to 119 cm (30 to 47 in.)—dark grayish brown (2.5Y 4/2) silty clay; common, medium to fine distinct olive brown (2.5Y 4/4) and few, fine, prominent dark gray (10YR 3/1) mottles; structureless; slightly sticky, plastic; common to few, very fine shell fragments, strongly effervescent in microsites.

Appendix C
Pollen Percentages and Selected Concentrations for 462B

Level, cm	0.5	3.5	7.5	11.5	13.5	16.5	18.5	24.5	28.5	38.0	96.0
Pinaceae	10.1	7.5	8.3	4.9	26.7	13.3	14.7	32.5	13.5	17.1	2.4
Quercus	1.0	0.8	1.3	0.8	0.8	0.0	0.9	0.0	2.8	0.0	4.9
Ostrya/Carpinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Betula	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Salix	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.3	0.0	0.0	0.0
Acer negundo	1.0	2.4	0.0	0.0	0.0	2.8	1.8	0.0	0.0	0.0	0.0
Ilex	1.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.0	0.9	1.6	0.0	0.0	0.0	0.0	0.0	0.0	4.9
Gramineae	10.1	4.7	14.8	10.6	6.9	1.7	0.9	1.3	1.4	2.4	4.9
Artemesia	0.0	3.2	2.2	3.3	1.5	2.2	0.9	0.0	0.0	2.4	0.0
Ambrosia type	14.1	7.1	14.8	11.4	9.2	2.8	1.8	5.3	1.4	0.0	9.8
Tubuliflorae	2.0	5.5	3.9	3.3	2.3	5.6	5.3	2.6	7.1	7.3	9.8
Cheno/Am	31.3	34.0	30.0	18.7	22.9	30.0	28.4	34.4	35.5	43.9	24.4
Opuntia	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Umbelliferae	2.0	1.6	0.9	12.2	0.8	2.8	6.2	0.0	2.8	0.0	0.0
Pteridophytes	0.0	0.8	0.4	0.0	0.8	0.0	0.0	1.3	0.0	0.0	4.9
Cyperaceae	2.0	5.5	4.8	10.6	6.1	7.2	8.9	6.6	2.8	0.0	0.0
Typha 4-3-2	0.0	0.8	0.0	0.0	0.0	0.6	1.8	0.0	0.0	0.0	0.0
Typha monad	10.1	4.7	1.7	7.3	10.7	10.6	12.4	1.3	1.4	2.4	4.9
Typha Total	10.1	5.5	1.7	7.3	10.7	11.1	14.2	1.3	1.4	2.4	4.9
Utricularia	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	3.0	3.2	1.7	0.8	0.0	2.2	2.7	2.6	5.7	0.0	0.0
Myriophyllum	4.0	5.5	0.0	0.0	1.5	0.6	0.0	0.0	4.3	0.0	0.0
Sagittaria	4.0	6.3	0.0	0.8	1.5	1.7	2.7	0.0	0.0	0.0	0.0
Indeterminable	3.0	4.7	8.7	11.4	4.6	12.8	9.8	6.6	21.3	24.4	29.3
Unknown	0.0	1.6	5.7	2.4	1.5	2.8	0.9	2.6	0.0	0.0	0.0
Trees & Shrubs	13.1	10.7	10.4	7.3	29.0	16.7	17.3	35.1	16.3	17.1	12.2
Upland Herbs	59.6	56.1	66.5	59.3	44.3	45.0	43.6	43.7	48.2	56.1	48.8
Aquatics	24.2	26.1	8.3	19.5	19.8	22.8	28.4	10.6	14.2	2.4	4.9

Level, cm	0.5	3.5	7.5	11.5	13.5	16.5	18.5	24.5	28.5	38.0	96.0
All concentrations	100 grains/cc										
Total Conc.	483	1,061	772	611	388	1,050	656	482	526	180	104
Pine Conc.	48.8	79.7	63.8	29.8	103.7	140.0	96.2	156.4	70.9	30.7	2.5
Ch-Am Conc.	151.2	360.7	231.6	114.3	88.9	315.0	186.6	166.0	186.5	79.0	25.4
Pine Z score	-0.6	0.1	-0.2	-1.0	0.6	1.4	0.5	1.8	-0.1	-1.0	-1.6
Ch-Am Z score	-0.2	2.0	0.6	-0.6	-0.9	1.5	0.1	-0.1	0.1	-1.0	-1.5

Appendix D
Pollen Percentages and Selected Concentrations for P1

Level, cm	0.5	5.5	9.5	11.5	13.5	15.5	19.5	23.5	29.5	49.0	91.0
Pinaceae	7.4	17.1	13.4	19.0	51.7	37.0	28.4	44.9	42.2	49.4	21.5
Fraxinus	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus	0.0	2.1	0.0	2.5	0.0	2.7	1.9	1.1	1.2	0.0	0.0
Ulmus	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ostrya/Carpinu	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Betula	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Acer negundo	0.0	0.0	0.0	1.2	0.0	5.5	2.8	0.0	0.0	9.6	3.1
Ilex	0.9	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	1.4	1.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Gramineae	7.9	7.1	8.0	2.5	2.8	8.2	4.7	1.1	1.2	4.8	3.1
Artemisia	0.5	2.9	4.0	0.0	1.4	2.7	1.9	1.1	2.4	4.8	7.7
Ambrosia type	5.1	4.3	4.0	6.1	2.8	2.7	1.9	1.1	3.6	0.0	3.1
Tubuliflorae	2.3	3.6	2.0	7.4	4.1	2.7	7.4	4.5	8.4	0.0	15.4
Cheno-Am	25.0	33.6	33.8	36.8	19.3	16.4	26.0	30.3	27.7	9.6	29.2
Petalostemon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0
Pteridophytes	0.5	2.9	0.0	0.0	0.0	0.0	0.9	1.1	1.2	0.0	0.0
Cyperaceae	6.9	5.7	3.0	11.0	6.9	0.0	8.4	4.5	2.4	7.2	0.0
Typha 4-3-2	4.6	0.7	1.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	3.1
Typha monad	25.5	7.1	2.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0
Typha Total	30.1	7.9	3.0	0.0	0.0	0.0	0.0	1.1	1.2	0.0	3.1
Potamogeton	0.0	0.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Myriophyllum	5.1	2.1	4.0	2.5	0.0	0.0	1.9	1.1	0.0	7.2	10.8
Sagittaria	0.5	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0
Indeterminable	6.0	2.9	18.9	9.8	9.7	13.7	10.2	4.5	6.0	7.2	3.1
Unknown	1.4	2.1	3.0	1.2	1.4	5.5	2.8	2.2	1.2	0.0	0.0
Trees & Shrubs	8.8	24.3	14.4	22.7	51.7	45.2	34.0	47.2	43.4	59.0	24.6
Upland Herbs	40.7	51.4	51.7	52.8	30.3	32.9	41.9	38.2	44.6	19.3	58.5
Aquatics	42.6	16.4	11.9	13.5	6.9	2.7	10.2	6.7	3.6	14.5	13.8

All concentrations × 100 grains/cc											
Level, cm	**0.5**	**5.5**	**9.5**	**11.5**	**13.5**	**15.5**	**19.5**	**23.5**	**29.5**	**49.0**	**91.0**
Total Conc.	698	626	710	322	423	306	437	323	530	195	335
Pine Conc.	51.7	107.4	95.3	61.2	218.8	113.2	124.0	145.1	223.6	96.5	72.3
Ch-Am Conc.	174.6	210.2	240.1	118.4	81.7	50.3	113.9	97.9	147.0	18.8	98.1
Pine Z score	-1.2	-0.2	-0.4	-1.1	1.8	-0.1	0.1	0.5	1.9	-0.4	-0.9
Ch-Am Z score	0.8	1.4	1.9	-0.1	-0.7	-1.1	-0.1	-0.4	0.4	-1.6	-0.4

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13. ABSTRACT ***(Maximum 200 words)***

It is commonly believed that excess sediment deposition is accelerating the filling of prairie pothole wetlands and stressing these systems. To help address this issue, the U.S. Army Engineer Waterways Experiment Station, the U.S. Environmental Protection Agency, Duluth Laboratory, and the National Biological Survey, Northern Prairie Science Center, jointly conducted a pilot study to compare methods for determining the rate of sediment accretion in prairie potholes and to compare rates of deposition in prairie potholes that differed in watershed land use. Replicate cores were taken from three potholes in the vicinity of Jamestown, ND. One of the potholes was surrounded by agricultural fields, a second was ringed by a well-established buffer strip, and the third was located in the Cottonwood Lake study area, where the watershed was primarily native grasses. The cores were studied using physical descriptions, including particle size, loss on ignition, and color, ^{137}Cs measurements, and a preliminary palynological assessment. There was no indication that settlement or increased rates of sedimentation could be detected from the physical characterization of the cores. A pronounced shift in the easily recognized Pinaceae and Chenopodiaceae-Amaranthaceae pollen occurred concurrently with the appearance of ^{137}Cs. This suggested that pollen procedures could be substituted for the more costly cesium analysis in the prairie pothole area. For the potholes sampled, the geomorphological setting of the pothole appeared to play a role in sedimentation deposition equal to that of watershed land use.

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