ENVIRONMENTAL CHANGES WITHIN THE LAST 5,000 YEARS FROM GEOCHEMICAL AND STABLE ISOTOPIC COMPOSITIONS IN SEDIMENT CORES FROM SWAN LAKE, NEBRASKA, USA

BY

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A DISSERTATION

PRESENTED TO THE FACULTY OF

THE GRADUATE COLLEGE AT THE UNIVERSITY OF NEBRASKA

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

MAJOR: GEOSCIENCES

UNDER THE SUPERVISION OF PROFESSORS

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LINCOLN, NEBRASKA

December, 1998

UMI Number: 9917832

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

DISSERTATION TITLE

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GRADUATE COLLEGE
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ENVIRONMENTAL CHANGES WITHIN THE LAST 5,000 YEARS FROM GEOCHEMICAL AND STABLE ISOTOPIC COMPOSITIONS IN SEDIMENT CORES FROM SWAN LAKE, NEBRASKA, USA

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University of Nebraska, 1998

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Sediment cores recovered from Swan Lake included a sandy silt layer between an upper interval of lake gyttja and a lower interval of marsh sapropel. The gyttja contained 3.9 to 40% calcite and from 5.9 to 32.1% organic matter (OM). Calcite (marl), magnesium-free $CaCO_3$, is present mainly as very fine grains and some aggregates, with ostracod shells in the upper half of the gyttja sections. The sapropel is characterized by up to 60.8% OM with an absence of carbonate. OM in the sandy silt layer provided the radiocarbon age of about 3,900 years before present (YBP) and was characterized by an increase in clastic particles that were enriched in clastic-borne elements relative to sediment above and below. These clastics and their elemental enrichments were most likely deposited during a period of windy and dry climate.

The sediment organic nitrogen-15 to nitrogen-14 ratios ranged from + 0.55 to +3.54 per mil (‰) and are consistent with minimal fraction from an atmospheric source (0.0‰). Ratios of carbon-13 to carbon-12 ($\delta^{13}C$) in bulk sediment OM ranged from 9.7 to -27.2‰ relative to the Peede belemnite (PDB)

standard. The productivity in the lake was initially dominated by C_3 plants such as sedges and cattails, followed by floating macrophytes from 3,950 to 3,830 ± 100 YBP, and later by plankton. Calcite from marl and the ostracod Candona lactea contained high $\delta^{13}C$ values (+ 4.56 to + 20.35‰$_{PDB}$), which are indicative of diagenetic carbonate formed as a by-product of a CO_2 reduction reaction. Insoluble OM (kerogen) in post-3,900 ± 60 YBP sediment had $\delta^{13}C$ values from -10.7 to -22.5‰$_{PDB}$, suggesting that the Swan Lake surface biomass and surface biocarbonate were low at 3,900 ± 60 - 2,810 ± 70 YBP, high at 2,810 ± 70 -1,230 ± 40 YBP, and intermediate since 1,230 ± 40 YBP.

Values of oxygen-18:oxygen-16 ($\delta^{18}O$) in marl and Candona lactea changed from -2.2 to -7.19‰$_{PDB}$. Vertical changes in $\delta^{18}O$ are similar to marl and kerogen $\delta^{13}C$ profiles, suggesting that $\delta^{18}O$ may have been influenced by changes within a carbon reservoir that include temperature, evaporation, and other factors.

The deuterium to hydrogen ratio (δD) in kerogen varied from -143 to -179‰ relative to the Standard Mean Ocean Water (SMOW). These δD variations suggest that the climate was likely warmer from about 5,000 to 3,800 YBP than in later years.

Dedicated

to

My Parents, Sisters, and Brothers

Acknowledgements

I'm indebted to my advisor, Professor Roy F. Spalding, whose tutelage, calmness, sense of balance, and good humor have expanded my scientific imagination in a manner that focuses on infinitesimal matter. Without his moral and intellectual support, I would not have been able to complete my dissertation.

I acknowledge the counsel given by the other respected members of my Graduate Committee, Professors James B. Swinehart, James D. Carr, William J. Wayne, and David M. Harwood. I'm highly appreciative of Drs. Mary Anne Holmes, Eric M. Durrance, and Brian Edie for significant contributions to my study. I acknowledge Professors James D. Carr, Richard M. Kettler, Ronald J. Goble as well as my advisor who have helped improve my understanding of geochemistry. I'm thankful to Professors Norman D. Smith and David B. Loope, and Ms. Ruth H. Ford and Ms. Carol R. Dicks for their helpful support.

Thanks to the staff and graduate students at the Water Sciences Laboratory at the University of Nebraska for their cooperation in several phases of the project. Special thanks to our project assistant, Ms. Lorraine Moon, for her excellent editorial assistance and encouragement. I'm most grateful to the Water Center, the Water Sciences Laboratory, the Nebraska Research Initiative, and the School of Natural Resource Sciences for financing this project.

My family has always been supportive of scholastic aims. My gratitude for their generosity extends as far as I can reach. Thanks can not be completed without giving thanks to God (Allah) for patience, health, and endurance.

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Chapter I

Introduction

1. Previous Investigations

Chemical and isotopic signatures in lake sediment profiles have been used to assess paleoclimate (Dean, 1993; Dean and Stuiver, 1993; Krishnamurthy and Bhattacharya, 1986; Krishnamurthy et al., 1995). An improved understanding of climate during the last few thousand years may provide data on the frequency and extent of past temperature cycles to compare with those initiated since the introduction of greenhouse gases to the atmosphere by human activities. Such information may help in evaluating the reliability of global warming forecasts. Since the last major glaciation, the earth's surface has warmed about 5°C. This temperature rise has been attributed to the Milankovitch Effect, which results in the seasonal flux of solar radiation received by the Earth's surface. This effect produces variations in regional temperature and precipitation (Houghton et al., 1990). About 10,000 years before present (YBP), the Earth's surface temperature became warmer and has remained relatively warm to this day. This period of relative warmth is called the Holocene Interglacial.

According to Crowley (1996), regional temperatures in many places in Europe and North America from 7,500 to 4,000 YBP in the so-called mid-Holocene were warmer than present. Records indicated that this was not a uniformly warm period for the total Earth surface but was more regional in nature. Crowley (1996) noted there was a dramatic increase in precipitation reported in North Africa and the Middle East at the end of the mid-Holocene. Crowley (1996) further said "Neolithic or Late Stone-Age man occupied the Tibesti Massif in what is now the drier part of the Sahara Desert. The

development of agriculture in Mesopotamia and in the Indus Valley of present-day Pakistan and India benefited from the increased moisture", after the mid-Holocene period.

A record of effective moisture during the Holocene has been reported in sediments from Moon Lake, North Dakota (Valero-Garcés et al., 1997). The climate was cool and moist between 11,700 and 9,500 YBP. This was followed by a gradual decrease in precipitation from 9,500 and then 7,100 YBP. Three arid phases occurred at 6,600-6,200, 5,400-5,200, and 4,800-4,600 YBP. Increased moisture generally returned after 4,000 YBP, and only two dry periods were noted between 2,800 and 2,900 YBP and between 1,200 to 8,000 YBP (Valero-Garcés et al., 1997).

Bradbury et al. (1993) said, "The Medieval Warm Period (= Neo-Atlantic, A.D. 700-1200) in the north-central United States was characterized by a northerly position of the Pacific airstream and consequently mild winters and wet summer conditions in the northern Plains". Changes in volcanism and ocean-atmosphere interactions (i.e., El Niño) have been proposed to explain climate oscillations of decadal-to-millennial scale; however, there is less evidence that prolonged clusters of volcanic eruptions can cause temperature changes for decades or longer (Crowley, 1996).

The mid-Holocene is widely recognized in Europe and the northeastern United States as a period that was several centigrade degrees warmer than present. It is referred to as the altithermal, hypsithermal, or climatic optimum (Dean and Stuiver, 1993). However, the interpretations for climatic conditions during the mid-Holocene in the upper midwest of the United States is contradictory. Evidence obtained from modeling of pollen data (Webb and Bryson, 1972; Winkler et al., 1986) suggests that during the mid-Holocene the midwestern United States was considerably drier and as much as 2°C warmer

than present. Ostracod data from Elk Lake (Forester et al., 1987) suggest northwestern Minnesota was drier during the mid-Holocene than at present, but the ostracod populations indicate that it was cooler than at present, at least until about 6,700 YBP. Wright (1976) indicated that the mid-Holocene in Minnesota and South Dakota was dry; however, temperature was not evaluated.

Prairies dominated north-central Iowa from about 8,000 to 3,000 YBP until increased moisture resulted in the present-day forest cover (Baker et al., 1992). They reported that the 5,500 to 3,000 YBP interval was warmer and drier than the surrounding periods, suggesting that maritime tropical air from the Gulf of Mexico blocked the eastward advance of Pacific air in the area.

Late Holocene eolian activity in the Nebraska Sandhills were reported by Muhs et al. (1997). The report suggests that drought-induced eolian sand deposition occurred at least twice in the past 3,000 YBP in three widely separated localities and as many as three times in the past 800 YBP at three other localities.

Mild temperatures during the Medieval Warm Period, reaching maximum warmth in the 12th to 13th centuries, were reported in many places of the world. This period was followed by a colder climate of the Little Ice Age, A.D .1,450 - 1,890, when the global mean temperature may have been 0.5-1.0 °C lower than today (Crowley, 1996).

Swan Lake (Figure 1.1) is comprised of two interconnected basins between two sand dunes more than 30 m high (Wright et al., 1985). west of the Crescent Lake National Wildlife Refuge in the western part of the Sandhills region of Nebraska. The Nebraska Sandhills, an area of sand dunes that covers about 50,000 km^2 in the north-central portion of the state, were developed by wind action during the Pleistocene (Maroney, 1978; Swinehart, 1990). In 1961

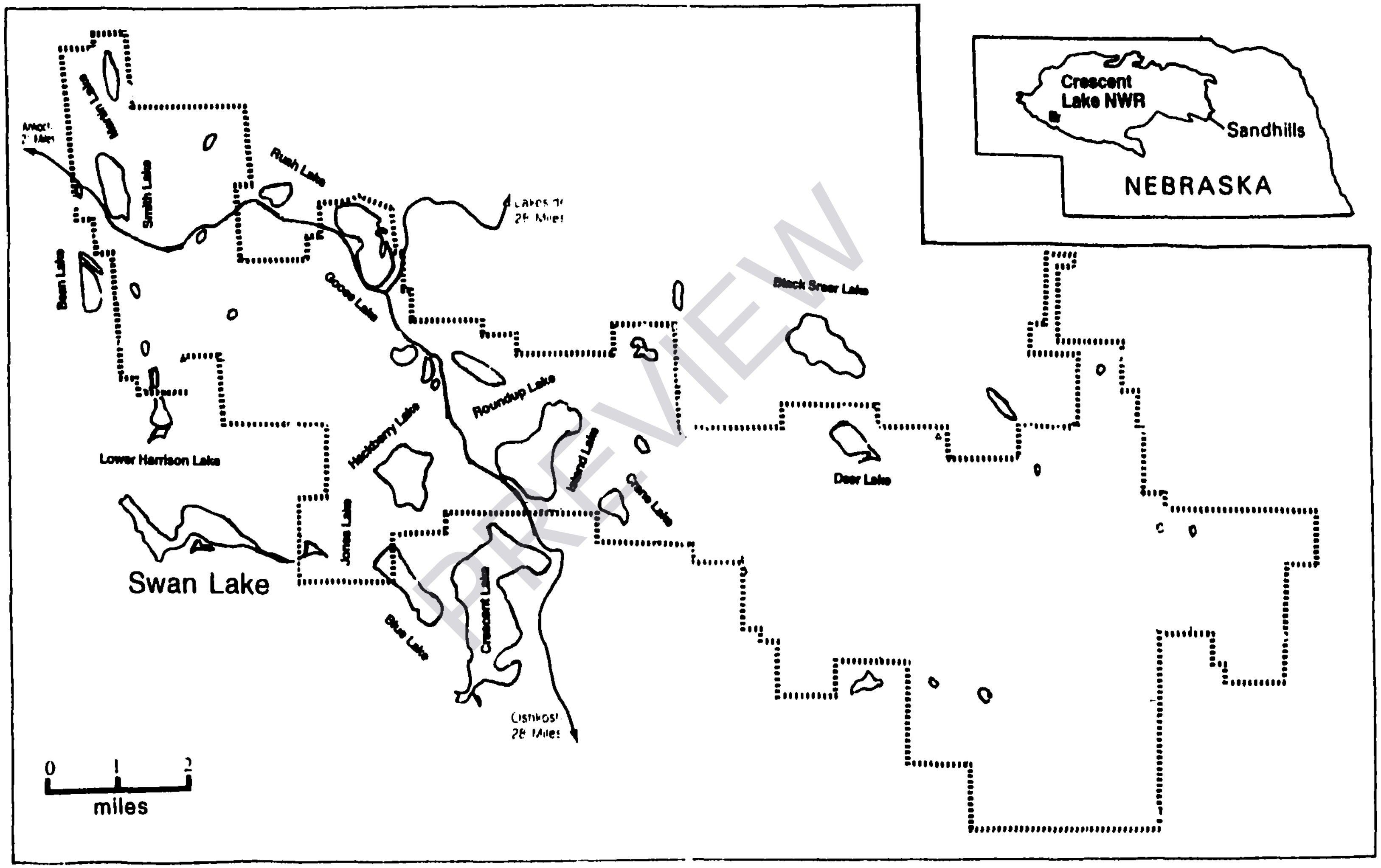

Figure 1.1. Locations of Swan Lake and other lakes in the Crescent Lake National Wildlife Refuge (NWR), the western region of Nebraska.

Steen counted 2,490 lakes, but McCarraher (1977) estimated 1,500 lakes in the Sandhills. The lakes in the eastern Sandhills are predominantly fresh water, and many of them have surface outlets while those in the western Sandhills (Figure 1.2) tend to be shallow, broad, and alkaline (Ginsberg,1985). With the exception of the hypersaline and hyperalkaline closed-basin lakes in the extreme west of the Sandhills, most are water-table lakes. Groundwater is the source of supply for most of the Sandhills lakes. The ground water in the western Sandhills forms part of the High Plains Aquifer, which includes three permeable units: the Arikaree Group, Ogallala Group, and Quaternary deposits (Bleed, 1990). There is no evidence that the Sandhills lakes are undergoing notable changes due to accelerated, natural, or human influence (Steen, 1961).

The sandhills lakes were studied from 1956 to 1972 by the Nebraska Game and Parks Commission. The study included measurements of physical, chemical, and biological parameters at the most accessible lakes. Swan Lake limnological parameters were reported by McCarraher (1977) and listed in Table 1.1. It occupies a surface area of ~151.4 hectares and had maximum and mean depths during 1971 of 1.8 and 1.2 m, respectively. Mason (1995) indicated that the average lake depth was 1.2 m. Throughout the year, the shallow lake water is quite fresh (TDS, 283 to 465 mg L^{-1}). The water's status remains fresh even when sequential increases in TDS occur as a result of evaporation during the warm season. Calcite is the only carbonate phase which was chemically precipitated in the lake bottom (Hassan et al., 1997). Swan Lake is a highly productive (eutrophic) system in which plankton are the primary contributors to the organic-rich sediments. The combination of wind and productivity creates an extremely murky and turbid water.

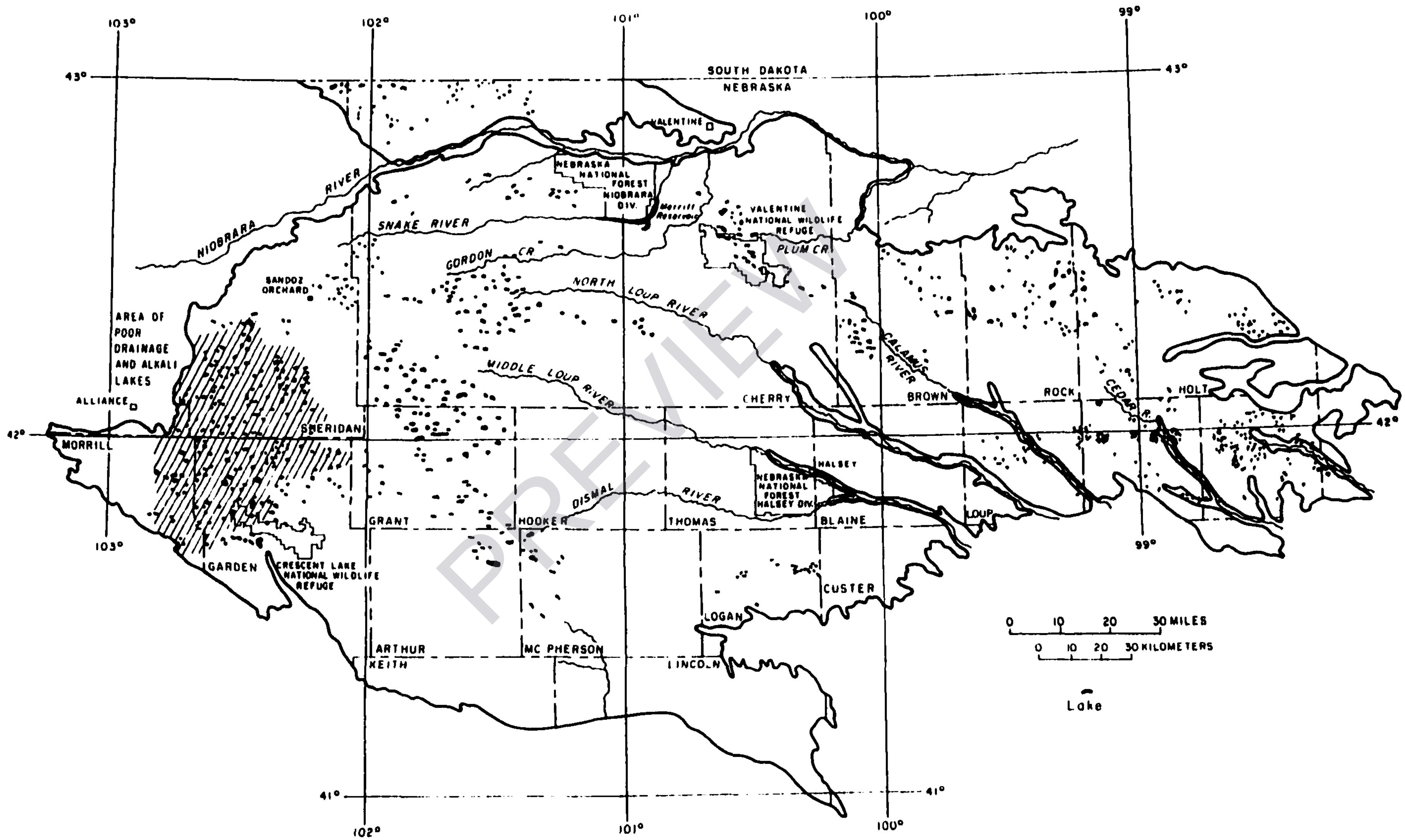

Figure 1.2. The Nebraska Sandhills lakes (After McCarraher, 1977).