Diatom, pollen, and geochemical evidence for the palaeosalinity of Medicine Lake, S. Dakota, during the Late Wisconsin and early Holocene*

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Abstract

Medicine Lake is a highly saline meromictic lake in eastern South Dakota. A lithostratigraphic and biostratigraphic study of the late-glacial and early post-glacial sediments shows that it was a relatively deep dilute freshwater lake during the period of the *Picea* pollen zone. When spruce forest changed to a *Betula* and then to a *Quercus/Ulmus* woodland in the early post-glacial period, the lake water became more concentrated but remained fresh. However, during the subsequent rapid transition to prairie in the early Holocene, when Gramineae, *Ambrosia*, and *Artemisia* dominated dry-land vegetation, the freshwater diatom flora was progressively replaced by a saline assemblage characterized by *Cyclotella quillensis, Chaetoceros,* and eventually *Cyclotella caspia.* The lake became permanently saline at about 9000 yr BP. A comparison of the fossil diatom assemblages with surface-sediment samples from a range of lakes in the Dakotas indicates that the change involved an increase in conductivity from about 500 μS cm^{-1} in the late-glacial period to > 10000 μS cm^{-1} in the early Holocene. This rapid change is also marked by an abrupt increase in sulphate concentration in the sediment, the first appearance of bands of gypsum crystals, and the beginning of a well-laminated core sequence that continues through the remaining sediment record. Conditions of high salinity have prevailed to the present day.

Introduction

Lake sediment records are potentially useful as a means of reconstructing changes in lake-water levels (Richardson, 1969; Bradbury *et al.*, 1981; Digerfeldt, 1986). In the prairie forest border region in the upper mid-west USA past water-level fluctuations have been inferred from macrofossil analysis (Watts & Winter, 1966; Watts & Bright, 1968) and diatom analysis (Haworth,

1972; Brugam, 1980). These studies have shown that low-water levels occurred in this region in the mid-Holocene, a time when pollen evidence indicates an eastward migration of the prairie/forest border (McAndrews, 1966), probably in response to climatic warming associated with the hypsithermal period (Wright, 1976).

Until now studies in this region have been confined to lakes with open drainage. In the prairie environment closed (saline) lakes are common. Lake-level fluctuations can be accompanied by major changes in water salinity, and associated
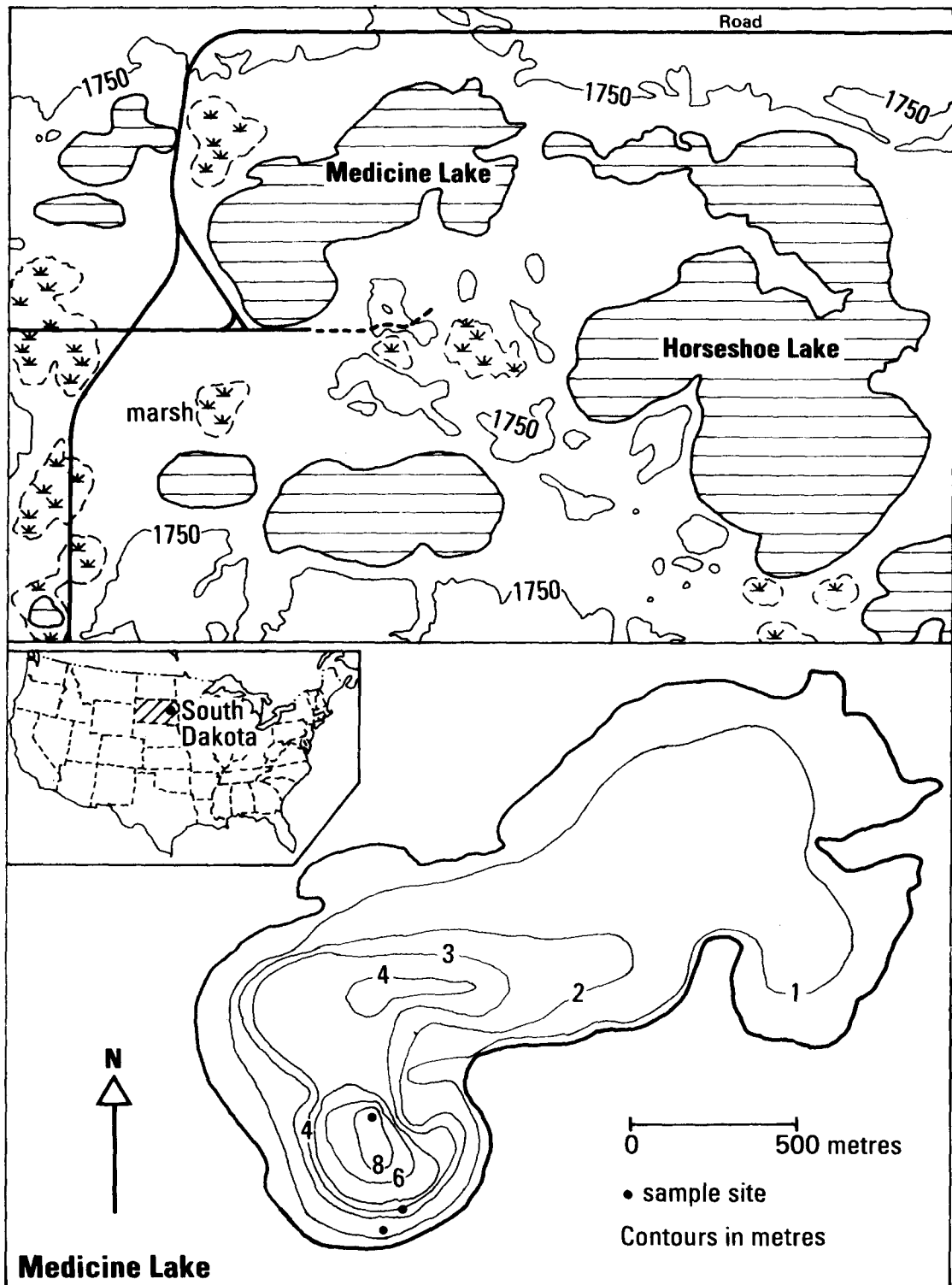
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Fig. 1. Medicine lake: location, bathymetry, and coring site.

biotic and chemical responses can be clearly recorded in the sediments (Bradbury et al., 1981; Last & Schweyen, 1983, 1985). Diatoms are probably the most useful microfossils for salinity reconstruction, and in cases where adequate modern analogue samples are available (cf. Fritz & Battarbee, 1988) attempts can be made to quantify past changes in lake salinity. In this paper we use diatom analysis, supplemented by geochemical analysis, to reconstruct early-Holocene changes in salinity in Medicine Lake, a saline lake in the eastern Great Plains. Associated changes in the surrounding vegetation are traced by pollen analysis.

Site

Medicine Lake in Codington County in northeastern South Dakota (Fig. 1) is part of a chain of lakes that occupy an outwash channel filled with 11 to 20 m of partially collapsed sand and gravel. The region is blanketed by 150–250 m of calcareous glacial till and outwash containing fragments of Paleozoic carbonate and local Cretaceous bedrock, predominantly shale (Flint, 1955; Tipton, 1958, 1975). The natural vegetation of the area is tall-grass Prairie, but the lake catchment is now mainly pasture. Soils are molisols – black and typically alkaline, developed under deep-rooted tall grasses. The climate is semi-arid, with an average annual precipitation and evaporation of 52 cm and 84 cm respectively (Bavari,

1971). Average daily temperature is − 12 °C during January and 22 °C during July.

The lake has an approximately oval surface area of 100 ha, with a drainage basin of about 350 ha (Fig. 1). Maximum depth is 9 m in a small sub-basin located towards the southwest corner of the lake. The lake has no outlet, and the hydrologic budget is controlled by direct precipitation, groundwater inflow, and surface evaporation. The present chemistry of the lake is shown in Table 1 (D. R. Engstrom, pers. comm.).

Methods

The deepest basin of the lake (Fig. 1) was cored from the ice surface in February 1980 with a square-rod piston corer, 5 cm in diameter (Wright, 1967). The 13.4 m core ended in grey inorganic silt. Core recovery was generally nearly complete except for the dense stiff basal sediments. The core was refrigerated and subsampled in the laboratory within two months of collection. Each core segment was split in half lengthwise to facilitate measurement of the laminations and crystal bands. Pollen and diatom samples and material for ^{14}C dating were taken from one core-half, which was then cut into 4-cm segments. These segments were homogenized to provide material for chemical analysis and determination of organic content. Depth measurements in the core refer to depth below ice surface rather than sediment surface. Only the lowest 3.4 m of the core (1900–2240 cm) are described in this paper.

Dry weight, organic content, and carbonate content were calculated from successive measurements of weight loss after heating to 110, 550 and 1000 °C respectively (Dean, 1974). Sulfate analysis was based on a modification of the methods used by Jackson (1958) and Thomas (1954), in which sulfate is precipitated with barium and the resulting turbidity measured spectrophotometrically at 380 nm. Concentrations were calculated with reference to serial dilutions of potassium sulfate standards. Sediment Ca and Mg concentrations were determined by atomic absorption following extraction in 0.3N HCl at 95 °C modified from Engstrom and Wright (1984).

Table 1. Chemistry of Medicine Lake, October 1985.

pH	8.92
cond. (μS cm^{-1})	27,900
salinity (g l^{-1})	38.56
Na^{+} (mg l^{-1})	3100
K^{+}	511
Mg^{++}	5750
Ca^{++}	360
SO$_4^{-}$	28120
Cl^{-}	533
HCO$_3^{-}$	216
CO$_3^{=}$	31

Samples for diatom analysis were treated with HCl to remove carbonates and HNO_3 with potassium dichromate to remove organic matter. Slides were prepared by the method of Battarbee (1973), and a minimum of 500 valves were counted at each level. In the case of *Chaetoceros* both cysts and valves were counted. Cyst counts were multiplied by 2 to represent valves, and the higher of the two numbers was included in the percentage calculations. Stratigraphic zonation of the diatom data was carried out with the SPLITINF and SLITSQ programs of Gordon & Birks (1972). Conductivity estimates for the core samples are derived from a suite of modern diatom assemblages and water chemistry of 32 Dakota lakes ranging from $1000\ \mu S\ cm^{-1}$ to $60000\ \mu S\ cm^{-1}$ (cf. Fritz & Battarbee, 1987). The modern samples were grouped using the program CLUSTER, and objective comparisons between samples were carried out by Correspondence Analysis on a combined data set of core samples and modern surface-sediment samples for species with an occurrence greater than 2%.

Pollen samples were prepared following Faegri and Iversen (1975). Pollen concentration was calculated from the ratio of added *Eucalyptus* marker grains to the total pollen counted. Grains of all taxa, excluding obligate aquatics, were included in the pollen sum, which consisted of 300 or more grains. Pollen identifications were made with keys and illustrations in McAndrews *et al.* (1973), Faegri & Iversen (1975), and Kapp (1969) and by comparison with slides in the pollen reference collection of the Limnological Research Center.

Results

Radiocarbon Dates

Radiocarbon dates for the whole core are shown in Table 2. The basal date was from a sample of woody material, whereas other dates were from mud samples with a high carbonate content. Because the dates for these latter samples might be too old, corrections were attempted by comparison with more reliable dates in two ways. First, the uppermost date was compared with the historical rise in *Ambrosia* pollen, which occurs at 1040–1044 cm and has a ^{14}C date of 1130 ± 70 yr B.P. (Radle, 1981). Because settlement in this region occurred in 1880, the ^{14}C date is 1030 years too old. Using the same approach Waddington (1969) found a 1000-year correction at Rutz Lake in central Minnesota. A correction factor may also be obtained by determining the difference between wood and gyttja at the same stratigraphic level. A layer of woody detritus, including needles and seeds of *Picea*, in a matrix of calcareous gyttja near the base of the Medicine Lake core was dated as $10\,940 \pm 135$ yr B.P. and the gyttja matrix dated as $12\,610 \pm 120$ years B.P., a difference of 1670 years. The three intermediate dates in the Medicine Lake core, taken from calcareous gyttja, were corrected by substracting 1350 years, the mean of the corrections used at the top and bottom of the core. The 14C date of 8750 ± 100 yr B.P. for the 1954 cm level was corrected to 7400 yr B.P. (Fig. 4), and linear interpolation between this date and the basal

Table 2. Radiocarbon dates

Sample number	Depth below ice surface	Date (yr B.P.) (uncorrected)	Date (yr B.P.) (corrected)	Material
WIS-1244	1040–1042	1130 ± 70	100	gyttja
WIS-1242	1352–1356	2700 ± 70	1350	gyttja
WIS-1245	1644–1652	5050 ± 80	3700	gyttja
WIS-1246	1952–1956	8750 ± 100	7400	gyttja
WIS-1227	2210–2217	$10,940 \pm 135$	10,940	wood
WIS-1225	2210–2217	$12,610 \pm 120$	10,940	gyttja

wood date was used to yield estimated ages for the portion of the core considered in this paper.

Lithostratigraphy

The core sequence from 2240–1900 cm can be divided into three general lithostratigraphic units based on sedimentary texture and color (Fig. 2). These units correspond to zones based on pollen stratigraphy (see below).

2240–2218 cm

The lowest portion of the core is a high-density, grey silty clay with low (3%) organic content. This material is thought to be glacial outwash and is separated from the overlying organic material by an 8-cm thick layer of woody detritus.

2218–2100 cm

These sediments consist of sticky brown clay gyttja overlain by dark silty-gyttja with blacker bands at the top. The transition may be missing because of incomplete core recovery at this depth.

2100–1900 cm

The very dark grey to black marly sediments in this part of the core contain numerous fine white laminations at the bottom that increase in frequency towards the top. Several layers of gypsum crystals are also present, the thickest occurring between 1952 and 1940 cm.

Chemistry

Figure 2 shows the results of the chemical analyses. A dividing line is placed at 2100 cm, the boundary between pollen zones ML-2 and ML-3 (see below).

2218–2100 cm

This section corresponds to pollen zones ML-1 and ML-2. Sulfate concentrations are lowest at the base of this section, but rise gradually towards the top. The carbonate concentration is fairly high at the bottom, declines slightly and rises to a peak at 2130 cm. The calcium curve matches the carbonate curve nearly point for point, while the magnesium values are low and fairly uniform.

2100–1900 cm

At 2100 cm sulfate concentration rises abruptly to a maximum. Smaller peaks occur near the top of this section but the concentration never falls to the level of the basal sediments. Carbonate content is low at the bottom of this section but several peaks near the top correspond to declines in the sulfate curve. Calcium values fluctuate with each peak corresponding to either a sulfate or a carbonate peak. Magnesium concentration is uniformly low throughout with a minimum at 2080 cm.

Diatom stratigraphy

Figure 3 shows the stratigraphy of the main planktonic taxa, expressed as percentages of the plankton total. The diagram is divided into 5 zones.

Diatom zone DML-1; 2212–2194 cm

This zone coincides with the late-glacial *Picea* zone (see below). The sediment is a uniform silty gyttja.

The zone includes only 3 widely spaced samples since diatoms were present in very low concentrations. Only 31, 7 and 15 valves were counted in the respective samples. The counts are not represented in Fig. 3 partly because of the low numbers and partly because very few planktonic diatoms were encountered. The species present include *Fragilaria construens* and varieties, *F. pinnata*, *F. brevistriata*, *Navicula scutelloides*, and *Achnanthes lanceolata*.

Diatom zone DML-2; 2194–2122 cm

This zone is approximately coincident with the *Betula – Quercus – Ulmus* pollen zone. The diatom concentrations are considerably higher, and sample counts range from 43 to 565 valves. In this zone a freshwater plankton flora occurs, dominated by *Stephanodiscus* spp., *Fragilaria crotonensis*, *Tabellaria flocculosa* and a range of *Cyclotella*
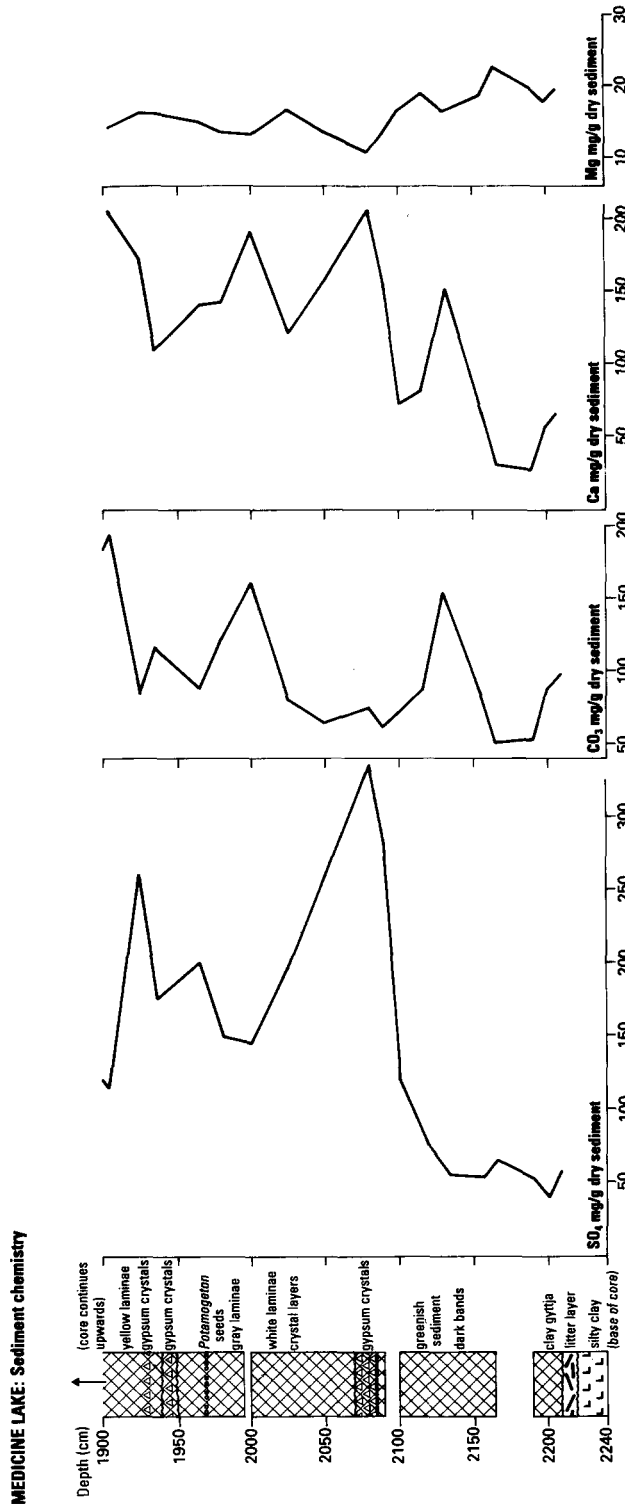
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Fig. 2. Litho- and chemical stratigraphy of late-glacial and early-Holocene sediments of Medicine Lake. Concentrations in mg g^{-1} dry sediment.
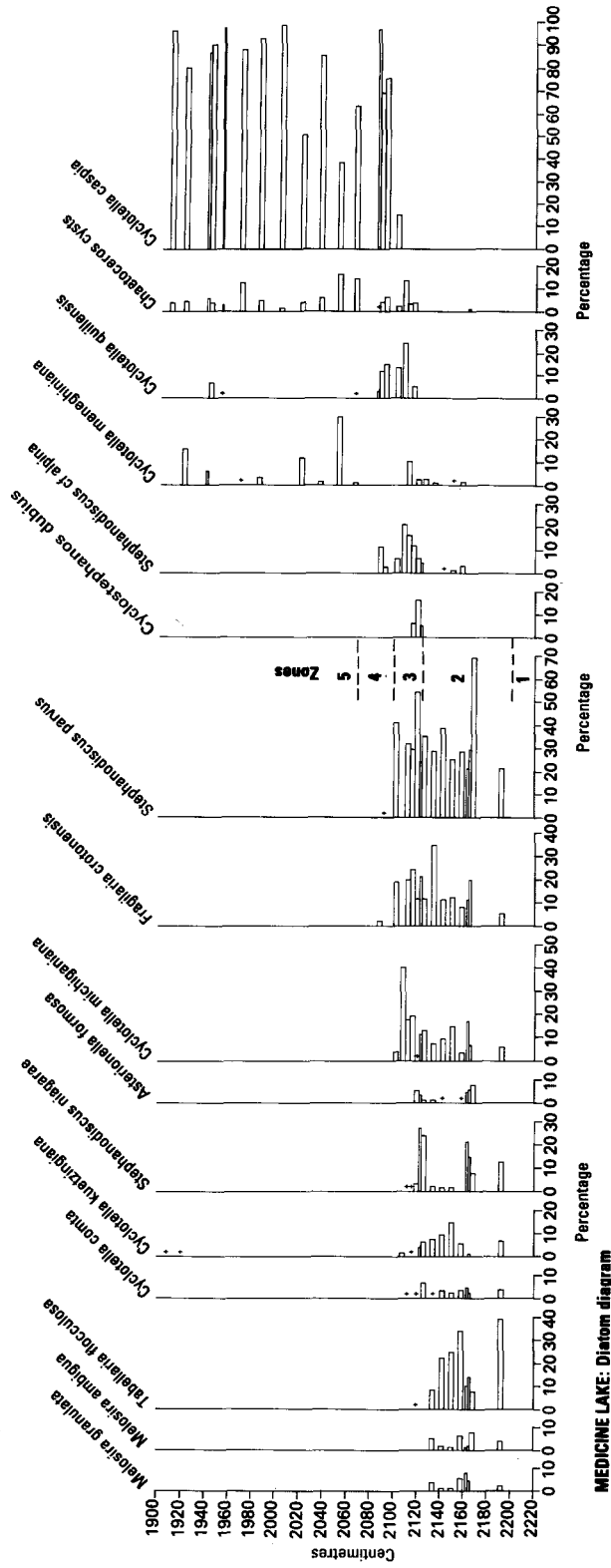
Fig. 3. Diatom percentage diagram: late-glacial and early-Holocene sediments of Medicine Lake. Only planktonic taxa are shown.

taxa. The most abundant non-planktonic forms are *Mastogloia smithii* v. *lacustris, Navicula scutelloides, Amphora perpusilla,* and *Gomphonema intricatum.*

Diatom zone DML-3; 2122–2100 cm.
This zone is a transitional one in which the assemblage changes rapidly from one of wholly freshwater composition to one with saline species. Figure 3 shows the progressive loss of *Melosira* spp., *T. flocculosa, Cyclotella comta, C. kutzingiana, Asterionella formosa, Stephanodiscus niagarae,* and *C. michiganiana.* These species are replaced by *Cyclostephanos dubius, Stephanodiscus* cf. *alpinus, Cyclotella meneghiniana, Chaetoceros,* and *Cyclotella quillensis.* The *Chaetoceros* resting spores are probably *C. elmorei* or *C. muelleri* (Rushforth & Johansen, 1986). Both these taxa and *C. quillensis* are found only in saline environments. *Stephanodiscus parvus* is dominant throughout the zone.

Diatom zone DML-4; 2100–2084 cm.
The most significant division identified by the zonation programs occurs between samples at 2090 and 2100 cm, and it is related to the abrupt decline of *S. parvus* and the rise of *C. caspia.* Towards the end of the zone *S. alpinus* and *C. quillensis* decline.

Diatom zone DML-5; 2084–1906 cm.
This zone is dominated by the saline species *Chaetoceros* and *C. caspia* and by the euryhaline species *C. meneghiniana.* Freshwater diatoms are no longer present. This assemblage, or variations of it, remains throughout the whole of the ensuing post-glacial period, of which only the earliest period is represented in Fig. 3.

Salinity reconstruction

A major shift in the salinity of Medicine Lake is clearly representeed by the change in diatom assemblages, from a flora typical of alkaline freshwater to one found in lakes where salinity is greater than approximately $3 \, g \, l^{-1}$ (Williams,

1981). In an attempt to quantify the salinity shift the core data have been compared with a series of sediment samples taken from a range of lakes of differing salinity in the Dakotas. These sites form part of an increasingly large data set currently being compiled for the Northern Prairie region of the Dakotas, Manitoba and Saskatchewan (Fritz & Battarbee, 1988).

Simultaneous ordination of the fossil and modern data sets using Correspondence Analysis (Fig. 4) shows there is considerable variation on both axes 1 and 2 and that there are very few fossil samples similar to modern samples. The few exceptions include the stratigraphic samples 12–16 in zones DML-2 and DML-3, which have floras similar to Roy L. and E. Oakwood L. with conductivities of 1413 and 2267 $\mu S \, cm^{-1}$ respectively, and the samples in zone DML-5, dominated by *Cyclotella caspia,* which have some similarity with L. George, conductivity 17 000 $\mu S \, cm^{-1}$. The lack of overall similarity is probably related to differences in ionic composition, nutrient concentration, and water depth.

Pollen stratigraphy

The pollen sequence of the basal sediments of the Medicine Lake core can be divided into 3 distinct zones (Fig. 5).

Zone ML-1, Picea zone: 2218–2190 cm
Zone ML-1 overlies grey silt of unknown thickness containing only a few poorly preserved pollen grains. Above the silt is a 7 cm layer of wood fragments along with needles, stigmata, seeds of *Picea, Potamogeton richardsonii, Najas flexilis, Alisma* sp., and *Ceratophyllum* and shells of mollusks. The pollen assemblage above this litter layer is dominated by *Picea* pollen (maximum 56%) and includes *Larix* (1.5%) and *Fraxinus nigra* (5%). Gramineae and Cyperaceae occur in amounts less than 10%. *Artemisia* decreases from 14% at the base of the zone to 6% at the top. NAP ranges ftom 40 to 20%.

Zone ML-2, Betula-Quercus-Ulmus zone: 2190–2100 cm

This zone has been further divided at 2146 cm into subzones 2a and 2b. Sub-zone ML-2b has high percentages of *Betula* which rise to a maximum of 27% and largely replaces *Picea*, which drops to 2%. In sub-zone 2a *Betula* is replaced in turn by *Quercus* and *Ulmus*, which expand to peaks of 25%. Values for other deciduous tree taxa reach maxima in this zone. Arboreal pollen accounts for over 80% of the total until the end of the period, when tree pollen percentages decline rapidly and the percentages of Gramineae, *Ambrosia* and *Artemisia* increase.
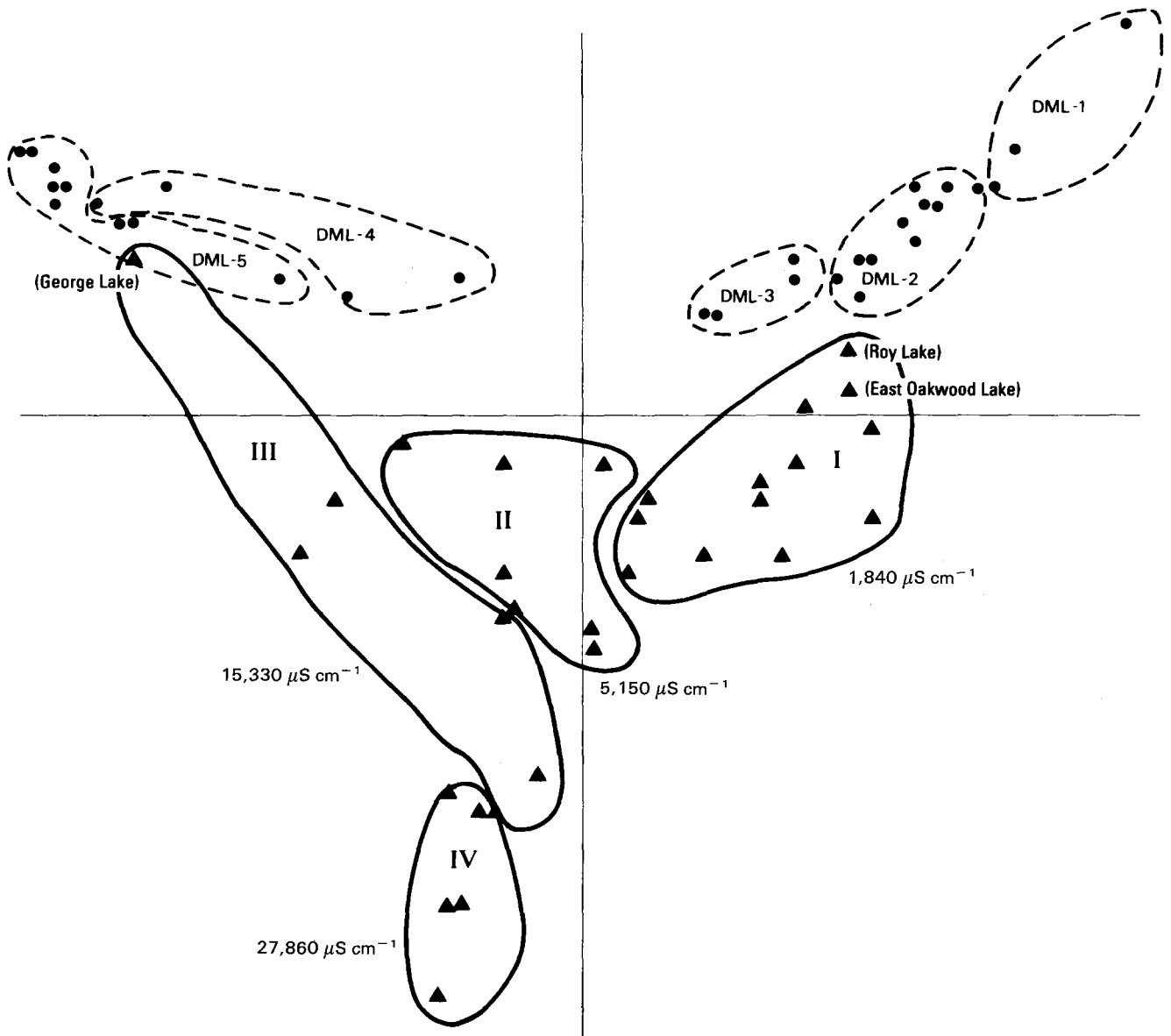

Fig. 4. Ordination of diatom assemblages from Medicine Lake core (Fig. 3) with surface sediment samples from a range of Dakota lakes. Only species with occurrence > 2% are included; ● fossil samples, ▲ modern samples. Clusters of fossil samples (DML-1 – DML-5) were identified using the stratigraphically constrained methods SPLITINF and SPLITSQ (Gordon & Birks, 1972), and the modern groups (I–IV) were identified using the program CLUSTER.
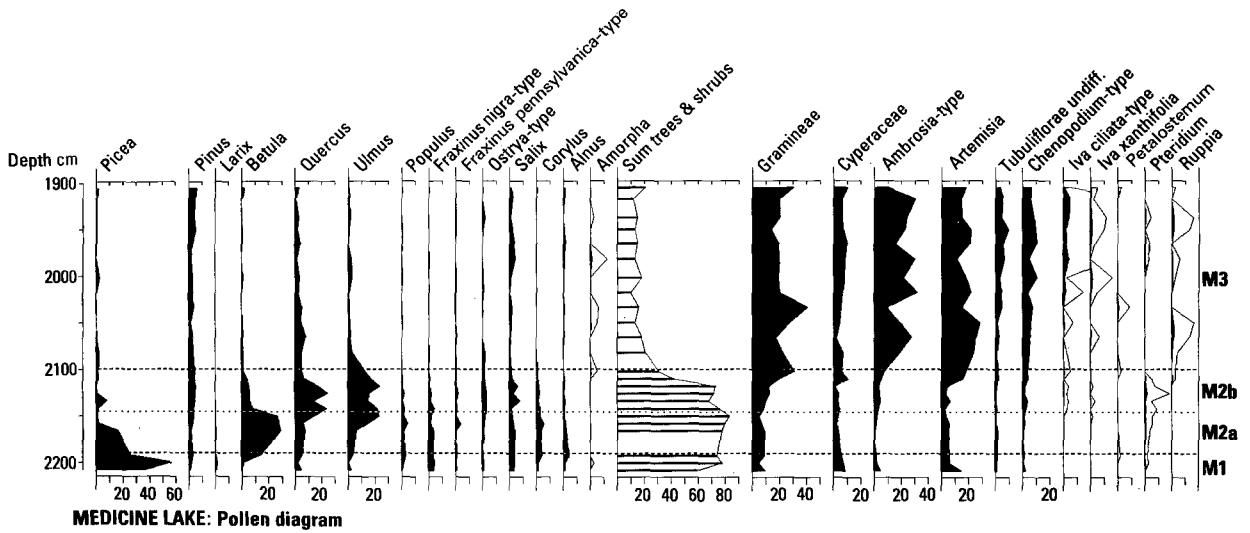
Fig. 5. Pollen percentage diagram: late-glacial and early-Holocene sediments of Medicine Lake. Only the major taxa are shown.
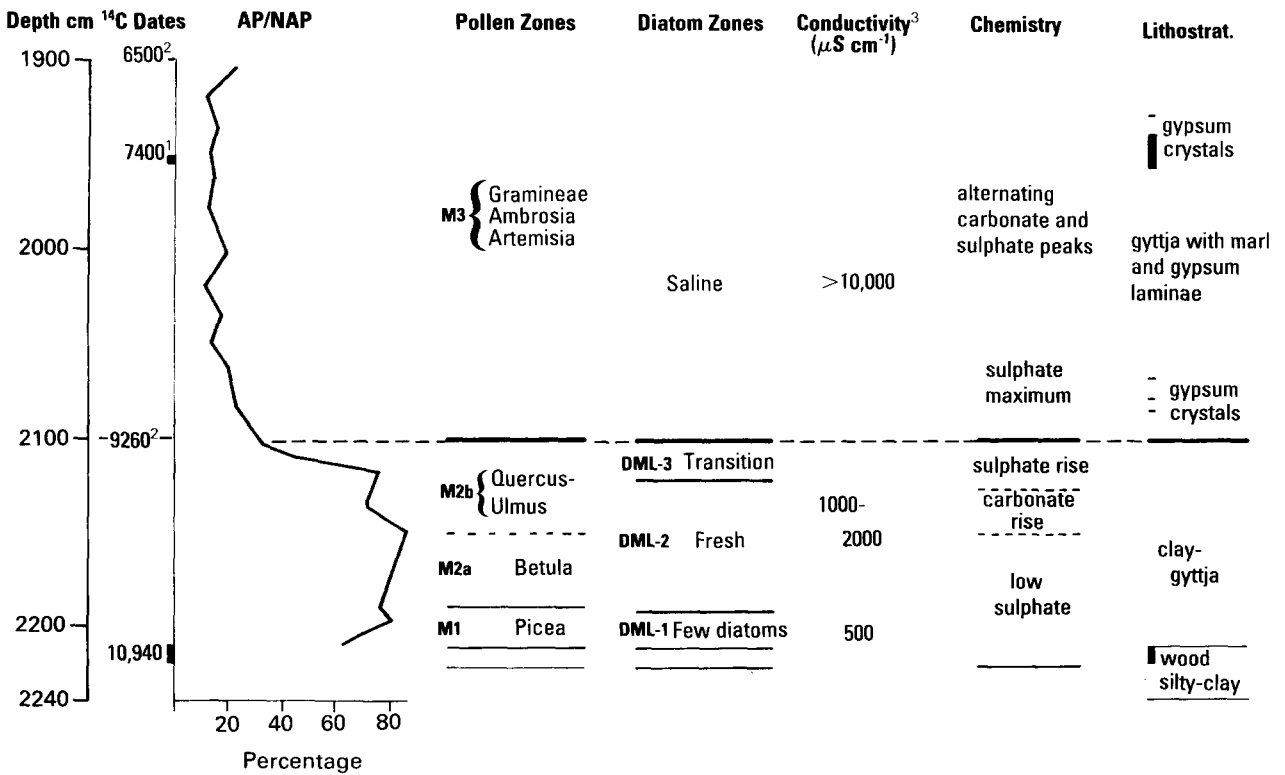

Fig. 6. Summary diagram. [1] corrected date (see Table 2), [2] interpolated dates, [3] inferred from diatoms.

Zone ML-3, Gramineae-Ambrosia-Artemisia zone: 2100–1900 cm

Zone ML-3,dated at 9260–6500 yr B.P., is dominated throughout by herb pollen, especially Gramineae, Cyperaceae, *Ambrosia, Artemisia,* Compositae (Tubuliflorae), and Chenopodiaceae, all of which rise sharply at the base of the zone to increase the total NAP from 30 to 85%. Tree pollen drops to 15–20%, with the major contributors being *Pinus* and *Quercus. Iva ciliata, Iva xanthifolia,* and *Petalostemum* are present in small quantities, and pollen of the brackish/saline aquatic macrophyte *Ruppia maritima* is relatively abundant. Although not presented here, pollen data for the remainder of the core show that this assemblage continues through to the historic period that began about 100 years ago (Radle, 1981).

Discussion

Comparisons of all the data presented in Figs 2–5 and summarized in Fig. 6 suggest that the early salinity history of Medicine Lake can be divided into two main phases. In the core this division occurs at approximately 2100 cm. A linear interpolation between the radiocarbon date on woody material close to the base of the core and the corrected date at 1952 cm gives a date of 9260 BP for the boundary.

Early freshwater phase: 11,100–9260 BP

The clearest evidence for salinity change in the early history of Medicine Lake is shown by the diatom assemblages. The basal lake sediments (2198–2212 cm) contain an alkaline freshwater flora for which there is no modern analogue in the data set of Fig. 4. However the taxa in the assemblage are common in Minnesota lakes with conductivities of about 500 μS cm^{-1} (Brugam, 1983). The presence of freshwater molluscs in the litter layer, macrofossils of freshwater aquatic plants throughout the lowest sediment, and the low sulfate and carbonate values (Fig. 2) are consistent with this interpretation.

The freshwater character of the lake during this early period is not unexpected. The pollen record indicates that the lake was initially surrounded by *Picea* forest, and the litter layer at the base of the core suggests that the lake was formed by the melting of a buried ice block (Florin & Wright, 1969). The presence of *Fraxinus nigra* and *Larix laricina,* along with the high percentage of *Picea* pollen and a number of *Picea* macrofossils, indicates that the climate was relatively cool and moist, with boggy areas and watter-logged soils around the lake. The forest was probably similar to the present-day boreal forest with the exception that *Pinus* was absent (the low percentages in zone ML-1 probably represent long-distance transport) and that the forest contained more openings, as indicated by the high non-arboreal pollen percentages. Similar pollen assemblages have been observed at other prairie sites during this period (Watts & Bright, 1968; McAndrews *et al.,* 1967; Ritchie & Lichti-Federovich, 1968).

The decline of the spruce forest is dated ca. 10650 yr B.P. at Medicine Lake, comparable to dates at other prairie sites. The climatic amelioration associated with the spruce decline and the subsequent expansion of birch (Zone ML-1/ML-2b) appears to have had little effect on the character of the lake sediment or the bulk sediment chemistry, but it is reflected in the diatom assemblages by the emergence of a planktonic flora (DML-2). This change probably represents both an increase in available nutrients and an increase in the total solute concentration in the lake. Comparison with the modern diatom data set suggests that conductivities increased to over 1000 μS cm^{-1} during this period (Fig. 4).

Midway through pollen zone M2 the *Betula* assemblage is replaced by a deciduous woodland flora dominated by *Quercus* and *Ulmus.* This change is a feature also recorded by van Zant (1979) from nearby Lake Okoboji, Iowa. At Medicine Lake, as *Betula* decreases the calcium and carbonate curves begin to rise, probably reflecting a sequential chemical precipitation of alkaline-earth carbonates (e.g. low-Mg calcite, high-Mg calcite, aragonite) and a move towards a somewhat lower lake level (Eugster & Hardie, 1978). Despite this evidence for a decrease in

water level the diatom data indicate that there was little increase in salinity at this stage. It is possible, therefore, that the replacement of *Betula* by *Quercus* and *Ulmus* may have been related to immigration and forest succession as well as to climatic warming.

At the 2130 cm level an important period of change in lake salinity and lake water level begins. *Melosira granulata, M.ambigua,* and *Tabellaria flocculosa* disappear from the diatom record, and the sulfate curve begins to rise, indicating a switch from carbonate to sulfate precipitation as the lake water became saturated with respect to gypsum (Eugster & Hardie, 1978).

An acceleration in the trend towards higher salinities occurs from about 2122 cm. Percentages of tree pollen, especially *Quercus* and *Ulmus,* begin to decline and are replaced by pollen of herbs. Several diatom taxa abruptly decline at the same level (Fig. 3), the euryhaline taxon *Cyclotella meneghiniana* appears and subsequently expands, and two planktonic taxa characteristic of saline lakes, *Chaetoceros* and *C. quillensis* also appear. The flora of this 'transitional' diatom zone (DML-3, Fig. 6) has no modern analogue, since it contains a mixture of freshwater and saline taxa representing two distinctly different communities that are unlikely to have occurred together at the same time. The freshwater component of the assemblage, *Stephanodiscus* spp., *Fragilaria crotonensis,* and *C. michiganiana,* represent relatively dilute conditions, whereas the saline flora represents a water salinity of at least $3 \, g \, l^{-1}$ ($> 3000 \, \mu S \, cm^{-1}$) (cf. Battarbee *et al.,* 1983). This assemblage as a whole probably indicates a lake oscillating between fresh and saline in response to short-term hydrological and climatic cycles. In this condition oligohalobous taxa (e.g. those of DML-2) would be excluded, and halophilous freshwater taxa would alternate with saline species. Although the sediment samples are continuous the 20–40 years represented by each sample is inadequate to resolve the periodicity of the cycles implied.

Despite this probable loss of resolution, the longer term directional change towards increased salinity is clear. The diatom change occurs in phase with the vegetational change recorded by the pollen data at the end of zone ML-2 and suggests that the precipitation: evaporation ratio was decreasing, probably as a consequence of climatic warming. Increasing values of herbs (15–20%) indicate the expansion of prairie-like openings in the forest, and plants characteristic of the modern prairie such as *Iva, Petalostemum, Ambrosia,* Tubuliflorae, and *Amorpha* either first appear or expand. The development of a more mesic prairie and increased fire frequency is also indicated by the appearance of large amounts of charcoal.

These pollen changes at Medicine Lake are similar to those described at Pickerel L. (Watts & Bright, 1968), Woodworth Pond (McAndrews *et al.,* 1967), and L. Okoboji (van Zant, 1979) all of which have high herb percentages during the period equivalent to ML-2. Farther north at the Glenboro site, Ritchie & Lichti-Federovich (1968) describe an assemblage with spruce and deciduous trees on mesic sites, elm and ash in wet sites, and herbs and shurbs in well-drained sites. Farther east the NAP percentages are lower, indicating the forest had fewer openings.

The freshwater-saline transition and the Early Prairie Period, 9260–6500 BP

The point at which Medicine Lake became a saline lake is clearly indicated in the sediment at 2100 cm by the abrupt decline of *Stephanodiscus parvus* and the appearance and rapid expansion of *Cyclotella caspia.* The lack of exclusively freshwater species from this stage onwards suggests that any short-term climatic fluctuations that may have occurred were not sufficient to dilute the lake to a salinity of less than about $3 \, g \, l^{-1}$, and it can be confidently inferred that the lake became permanently saline at this stage. The change is clearly indicated in Fig. 5 by the substantial distance between zone DML-3 and DML-4, and the ordering of samples within these zones suggests that a continuous increase in salinity took place to values greater than $10\,000 \, \mu S \, cm^{-1}$ before stabilizing at high levels in zone DML-5, a zone that

has a diatom flora similar to that of Lake George, with a conductivity of 17000 μS cm^{-1}. The diatom flora in this upper zone is dominated by C. caspia, a taxon that seems to be more common than C. quillensis in waters of high salinity, although the ecology and distribution of these taxa are poorly understood.

The appearance of Ruppia and Iva pollen in levels above 2100 cm also indicates saline waters. The sulfate and calcium curves rise to a peak, indicating the precipitation and deposition of gypsum. Layers of euhedral gypsum crystals with sharp unabraided faces occur in the sediment at this level. Because the laminae adjacent to the crystal layers are undisturbed, it is assumed that the crystals did not form by post-depositional intra-sediment growth but rather by precipitation in the water column.

The transition from a freshwater to a saline lake coincides with the pollen boundary ML2/ML3, which indicates a rapid change in vegetation from an open deciduous woodland to a Gramineae, Ambrosia, and Artemisia prairie. A climatic amelioration is indicated, as conditions became too warm and dry for most trees, and prairie vegetation expanded around the lake. Pinus and Quercus were probably not present in the area, and their pollen most likely represents long-distance transport from forests in the east (McAndrews, 1966). This early prairie zone represents the maximum warmth of the Hypsithermal and the expansion of prairie discussed by Wright et al. (1963), Watts & Bright (1968), Van Zant (1979), and others. Salinity was probably at a maximum during the early Holocene, although both the diatom and chemical data show fluctuating values within the period. Peaks in sulfate alternate with carbonate peaks, suggesting that cycles of evaporative concentration and freshwater dilution may have been taking place in response to shorter-term climatic changes.

The full pollen and diatom diagrams for Medicine Lake (Radle, 1981; Keister unpub.) are not presented here. They indicate that conditions throughout the ensuing 6500 year period have remained similar, with oscillating conductivities almost always in excess of 10000 μS cm^{-1} and a landscape dominated by open prairie.

Precise conductivity and salinity levels for Medicine Lake cannot yet be reconstructed, although a reliable guide to the range of probable values can be inferred by analogy with modern Dakota lakes. These reconstructions can be refined in the future as the regional diatom/salinity database is expanded (Fritz & Battarbee, 1988). Together with improvements in dating the development of a diatom–salinity transfer function should allow accurate salinity reconstructions to be established for a range of lakes in the Northern Great Plains and should by extension allow regional trends in water level and climatic history to be inferred with some confidence.

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