A POSTGLACIAL RECORD OF CLIMATE CHANGE FROM EAST CROOKED LAKE AND TOFTE LAKE, MINNESOTA

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KELLY MICHAEL WENDT

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Abstract

The postglacial Holocene climate history of Minnesota is characterized by a cool postglacial period beginning about 10 ka and lasting until about 8 ka when dryer conditions ushered in a Prairie Period which lasted until about 4 ka at which time moisture increased. From about 4 ka to the present climate conditions have remained relatively stable. This history of Minnesota climate has been observed by Dean and colleagues in numerous studies at Elk Lake, Minnesota. In these studies the researchers looked at pollen, geochemistry, diatoms, magnetic properties, and isotopes.

This study uses sediment cores from nearby East Crooked Lake to see if scanning X-ray fluorescence results are comparable to classic inorganic geochemistry results from Dean at Elk Lake. A sediment core from Tofte Lake near Ely, MN is also compared to see if the results from Elk Lake and East Crooked Lake are regional in extent.

The results confirm that scanning XRF is comparable to the classic, time consuming geochemistry methods used by Dean at Elk Lake and that the postglacial Holocene history recorded at Elk Lake was also recorded at East Crooked Lake. The timing of events at Elk Lake and East Crooked Lake are adjusted to correlate with the more accurate dating of events at Steel Lake, MN. The findings do not support that the climate events at Elk Lake and East Crooked Lake are regional in their extent to Tofte Lake. Tofte Lake did not experience a dryer Prairie Period.

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Chapter 1: Introduction

The scientific community is in agreement that the earth is warming; the effects that this will have on local climate patterns are not fully understood. Minnesota is predicted to become warmer during the next century and is also predicted to become wetter (IPCC, 2007). The temperature change is not in question and has already been observed to some extent, but the precipitation change is less certain. A change in precipitation would cause a change in natural ecosystems, but perhaps more important to society is the effect it would have on the business of agriculture in the region. Negative effects could be mitigated with appropriate preparation for changes in precipitation.

One way to better predict what these changes could be is to look at the postglacial Holocene history of climate in Minnesota. Studies using pollen (Nelson and Hu, 2008), geochemistry (Dean and Gorham, 1976), diatoms (Laird et al., 1996), magnetic properties (Geiss et al., 2003), and isotopes (Schwalb et al., 1995) have been done on lakes across Minnesota in order to understand the history of the regional climate system. Work by Dean and colleagues (1993) have used all of these methods at Elk Lake, MN. Dean (1993) produced records of mineralogy and elemental abundances using X-ray diffraction, X-ray fluorescence spectrometry, atomic absorption spectrophotometry, and optical emission spectroscopy.

Classic geochemical analyses are expensive and time consuming. New developments in scanning X-Ray fluorescence (XRF) show promise for rapid, inexpensive analyses that can provide comparable information. This study is designed to test this idea, as well as the extent that climate interpretations from a given lake can be used to represent a larger region. To accomplish this lake sediment cores from two lakes in different regions of MN were analyzed by XRF to look for events or horizons that are comparable, in particular extreme dry periods where large amounts of dust would have been blown in from the Great Plains.

A major dry period in Minnesota is known as the Prairie Period and is observed by Dean and others as lasting from about 8 to 4 thousand years ago (ka) in the cores from Elk Lake (Dean, 1993). The use of ka in this paper is defined as thousands of years before present (present = 1950 AD). This Prairie Period is one stage in a succession of pollen sequences observed in Minnesota Lakes. The succession of ecological changes that has been recorded by Minnesota lakes was first discovered by McAndrews (1966) and since then has been seen throughout lakes in north central Minnesota by numerous researchers(Nelson and Hu, 2008; Webb et al., 1983; Whitlock et al., 1993). The pollen sequence observed in these lakes begins with spruce and/or tundra shrub at the base, followed by a dominance of pine, which transitions into a dryer period where prairie plants dominate, followed by wetter conditions and a transition back to deciduous and pine forests (Webb et al., 1983).

Chapter 2: Background

2.1 Present Day Climate

Minnesota covers a large area with a variety of ecosystems and geology. Centered in Minnesota is the confluence of three major air masses that drive the weather for much of North America: the Arctic from the north, the Pacific from the west and the Gulf of Mexico from the south (Dean and Schwalb, 2000). Droughts occur when the Pacific air mass dominates as most of the moisture for the region is brought from the Gulf of Mexico. This sets up an east-west precipitation gradient across the state, with annual precipitation in the eastern half of 70-80 cm and 50-70 cm in the western half (Dean and Gorham, 1976).

This can also be seen in the ionic composition of lake waters. Lakes in Minnesota have been classified into five groups based on conductivity (figure 1), which increases from east to west along with changes in ionic composition. The conductivity ranges from <29 pmhos*cm^{-1} at 25°C up to 73,000 pmhos*cm^{-1} at 25°C in group V lakes. The dominant cations shift from Ca^{2+} to Mg^{2+} to Na^{+} and anions shift from $HC0_3^-$ to SO_4^{2-} from east to west; this is due to both a westward increase in climatic aridity, and partly a westward shift in the composition of glacial drifts from noncalcareous to calcareous and then to calcareous with abundant sulfur-bearing minerals. These boundaries do not coincide with the vegetation boundary between prairie and forest (Gorham et al., 1983).

Minnesota lakes have also been classified into three categories based on the composition of their sediments, which also change from northeast to southwest (figure 2). The group I lakes in the northeast are defined by having almost no sedimentary calcium carbonate, large amounts of clastic material, and high to low amounts of organic material. Group II lakes in central MN contain large amounts of calcium carbonate and lesser amounts of organics and clastic material. Group III lakes in southwestern MN contain mostly clastic material with an average of 12% organic and 20% calcium carbonate. These boundaries are due to differences in geology (glacial drift composition) superimposed on the precipitation gradient (Dean and Gorham, 1976).

Minnesota is split into two dominant ecosystems, the prairie and the forest. In the southwestern half of the state prairie dominates and in the northeastern half the forest. This boundary is due to the positive precipitation/evaporation balance in the northeast and the negative precipitation/evaporation balance in the southwest. There is also a temperature gradient with mean annual temperatures ranging from 2 °C in the northeast to 8 °C in the southwest (Dean and Gorham, 1976).

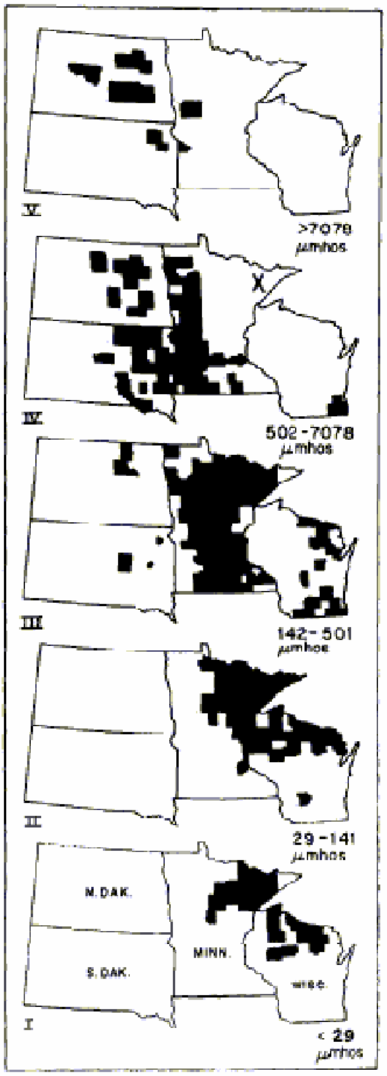


Figure 1. Division of regional lakes into five groups based on conductivity (Gorham et al., 1983).

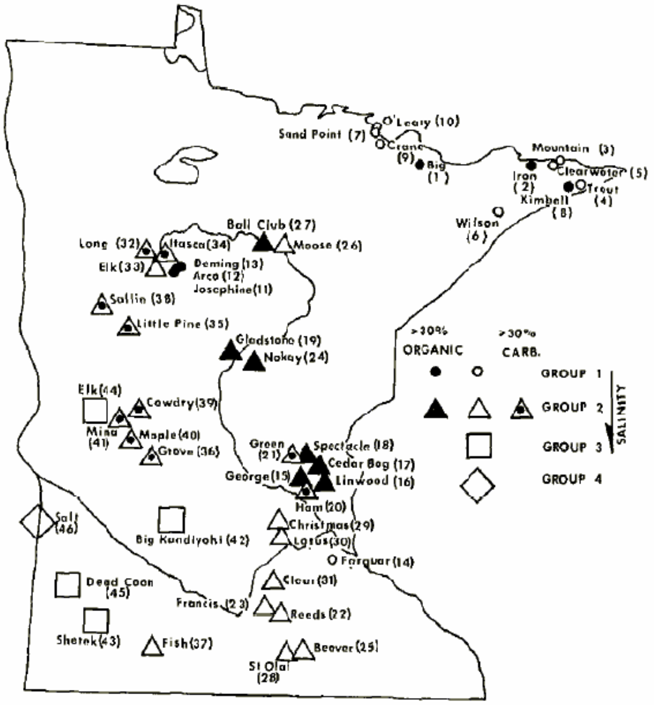


Figure 2. Divisions of MN lakes into three groups based on clastic, organic, and carbonate composition. Also shows increasing salinity of lakes from NE to SW ranked 1-46 with 1 being the least saline and 46 being the most saline (Dean and Gorham, 1976).

2.2 Holocene Climate

One of the icons of past climate in Minnesota is the 10 ky paleoclimate record from Elk Lake (Dean, 1993). The lake is located near the modern prairie/forest ecological boundary and it has been affected by the three air masses that dominate the region (Dean and Schwalb, 2000). Pollen records from Elk and other lakes in the region have shown the migration of the prairie/forest boundary with changing aridity; moving east with dryer conditions and west with wetter conditions (Whitlock et al., 1993; Wright et al., 2004). Na and Al profiles from Elk Lake cores have been interpreted to reflect increased aeolian transport corresponding with dryer conditions during both the Little Ice Age (LIA) and to a lesser extent the Dust Bowl (figure 3) (Dean, 1997).

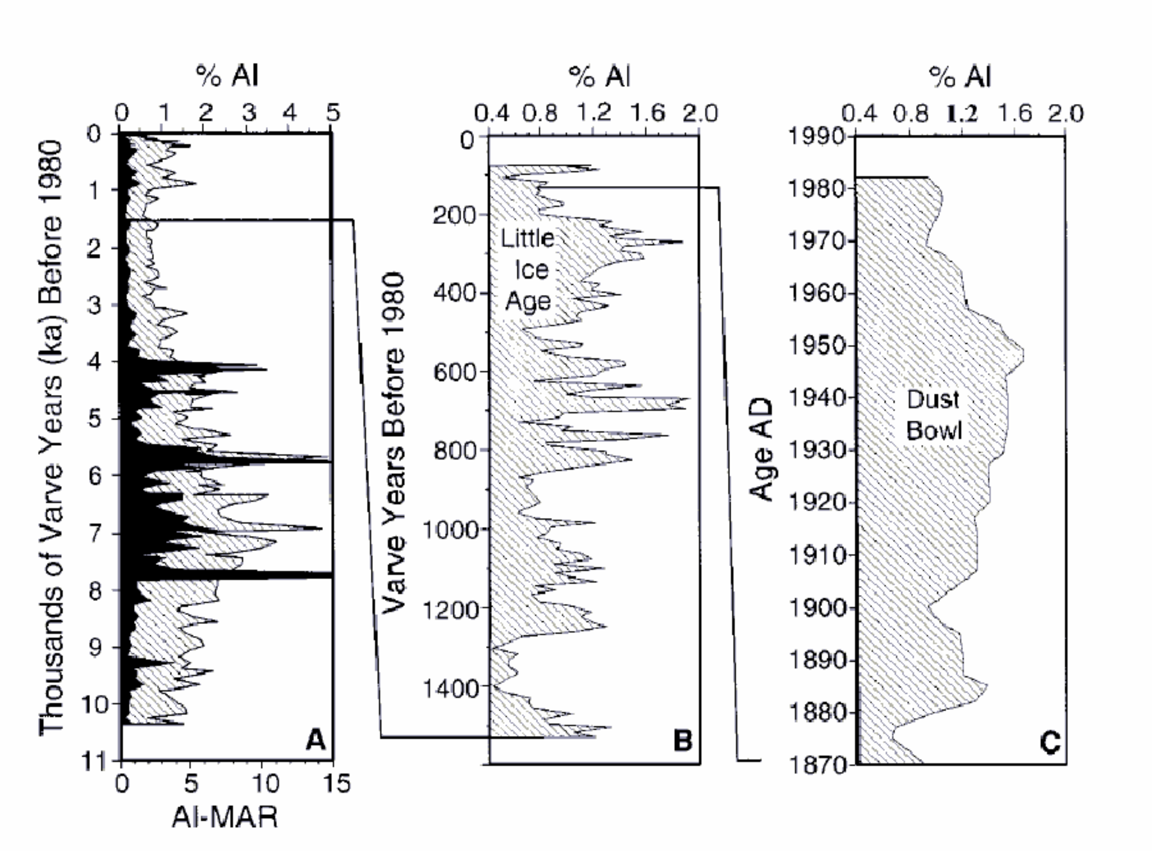


Figure 3. Al records from Elk Lake interpreted as dust influx from the Great Plains (Dean, 1997).

Currently Elk Lake is surrounded by the pine-hardwood forest but from about 8-4 ka it was surrounded by prairie. There was also an increase in elements associated with detrital clastic material such as Na, Al, Ti, and K in the lake sediment, which most likely represented wind transport because no permanent streams enter Elk Lake. Lake sediments from this same time also show increased magnetic susceptibility. Al accumulation was at its highest between about 7.8 and 5.5 ka. Na was also high during the Prairie Period and is used as a proxy for weathering of plagioclase feldspar with decreased weathering during dry periods and increased weathering during wet periods (Dean et al., 1984). There is both a 400 and 84yr cycle in the Al data from 1500ka to present (Dean and Schwalb, 2000).

Another Holocene climate record for Minnesota developed by Wright et al,. (2004) focuses on the vegetational changes recorded in a core from Steel Lake, just 50 km south of Elk Lake in central Minnesota. Steel Lake shows the classic pollen sequence found in Minnesota lakes. Prior to 11.2 ka a spruce forest dominated, this was succeeded by a pine forest which thrived until 9.4 ka. During a transition period from 9.4-7.9 ka a mixed savanna and pine parkland emerged, which was followed by the Prairie Period lasting until 3.4 ka. From 3.4-2.7 ka a birch forest dominated and then transitioned into the pine forests of today. To the west this change in vegetation would have happened 1-2 ky sooner than in central Minnesota and to the northeast these changes would have occurred 1-2 ky later (Wright et al., 2004).

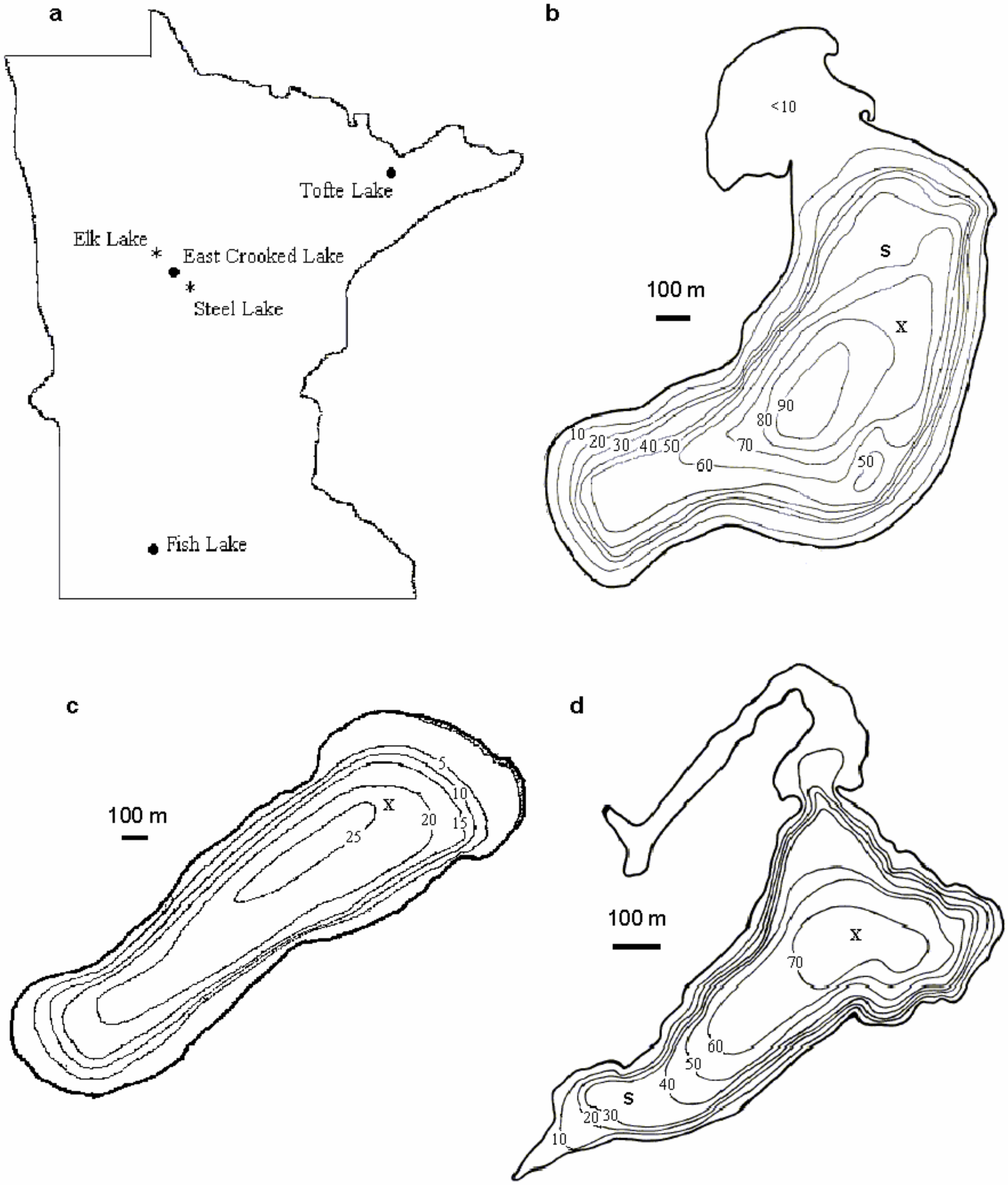


Figure 4. (a) locations of lakes cored for this study and those mentioned in the text (*). (b) bathymetric profile of East Crooked Lake. (c) bathymetric profile of Fish Lake. (d) bathymetric profile of Tofte Lake. Analyzed core sites are marked X, secondary core sites are marked S. Contours are in feet. Bathymetric maps were obtained from the MN DNR lake finder website <http://www.dnr.state.mn.us/lakefind/index.html>.

Chapter 3: Methods and Procedures

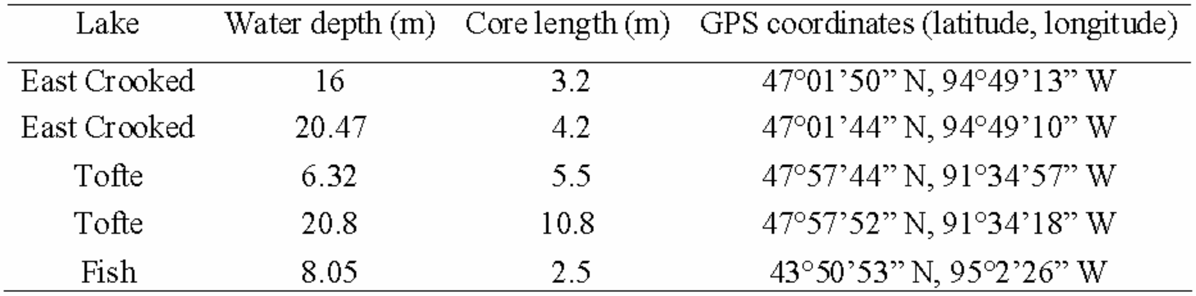
3.1 Core Recovery and Logging

Three lakes were chosen for this study to determine whether signals of climate change are detectable and coherent across the entire state: Tofte Lake located in Lake County, East Crooked Lake located in Hubbard County, and Fish Lake located in Jackson County. These lakes form a rough transect from northeast to southwest Minnesota (figure 4). These lakes were selected because they are all deep and likely not to have dried up during the Holocene, and because they are also relatively small in area having a small fetch. Both of these factors would improve the likelihood of forming varved sediments which provide the potential for an accurate annual record. A reason for selecting the lakes in a transect across the state is that this transect goes across the conductivity gradient, precipitation gradient, prairie/forest boundary, and also spans the three categories of lakes based on sediment composition (Dean and Gorham, 1976).

All cores were taken with a Bolivia-type drive rod piston corer which utilizes 7 cm diameter polycarbonate tubing for a barrel. Multiple 1.5 m drives in the same hole were used to retrieve the full length of the cores. This was possible using 4” diameter PVC pipes as casing that extended from the lake surface to a maximum depth of 1 m into the sediment. Cores were recovered following the procedure outlined by the Limnological Research Center <http://lrc.geo.umn.edu/livingstone-bolivia.pdf>. Single cores were taken at each location so unfortunately there are no overlapping cores.

Cores from East Crooked Lake and Tofte Lake were recovered during the winter when thick ice provided a stable coring platform. There was inclement weather during one day of coring at East Crooked Lake which caused minor difficulties with ice buildup on some of the equipment. Coring at Fish Lake occurred in the summer, using a pontoon boat as the coring platform. The anchors for the boat proved to be insufficient to handle the wind on the lake and prevent drifting of the coring platform. As a result, the cores obtained from Fish Lake are unlikely to be a complete sample of the post-glacial sediment sequence.

Cores of 3.2 m and 4.2 m length were recovered in water depths of 16 m and 20.47 m respectively on March 8-9, 2008 from East Crooked Lake north of Nevis, MN (table 1). Cores of 5.5 m and 10.8 m length were recovered in water depths of 6.32 m and 20.8 m respectively on March 15, 2008 from Tofte Lake east of Ely, MN (table 1). A core of 2.5 m length was recovered in 8.05 m of water on August 28, 2008 from Fish Lake southeast of Windom, MN (table 1).



Lake	Water depth (m)	Core length (m)	GPS coordinates (latitude, longitude)
East Crooked	16	3.2	47°01’50” N, 94°49’13” W
East Crooked	20.47	4.2	47°01’44” N, 94°49’10” W
Tofte	6.32	5.5	47°57’44” N, 91°34’57” W
Tofte	20.8	10.8	47°57’52” N, 91°34’18” W
Fish	8.05	2.5	43°50’53” N, 95°2’26” W

Table 1. Water depth, core length, and GPS coordinates for core sites.

All cores were transported to the core lab at the Limnological Research Center on the University of Minnesota, Minneapolis campus for preliminary processing. All cores were scanned using the Geotek Multi-Sensor Core Logger (MSCL) which detects magnetic susceptibility, wet bulk density, and natural gamma emissions. The cores were then split into archive and working halves, and the archive halves were imaged digitally with a DMT CoreScan Colour system. At this time initial core descriptions were also made by visually inspecting the split cores at the macroscopic scale and observations were also made of smear slides from characteristic layers.

Of the five total cores taken from the three lakes only three were chosen for further analysis. Cores were taken at relatively shallow and deep sites at both East Crooked Lake and Tofte Lake. The cores from the deep sites were chosen for further analysis because they were longer and would provide higher resolution records of the lake history and were more likely to have been sites of continuous deposition during any low lake stands. Only one core was recovered from the deep site at Fish Lake.

3.2 Radiocarbon dating

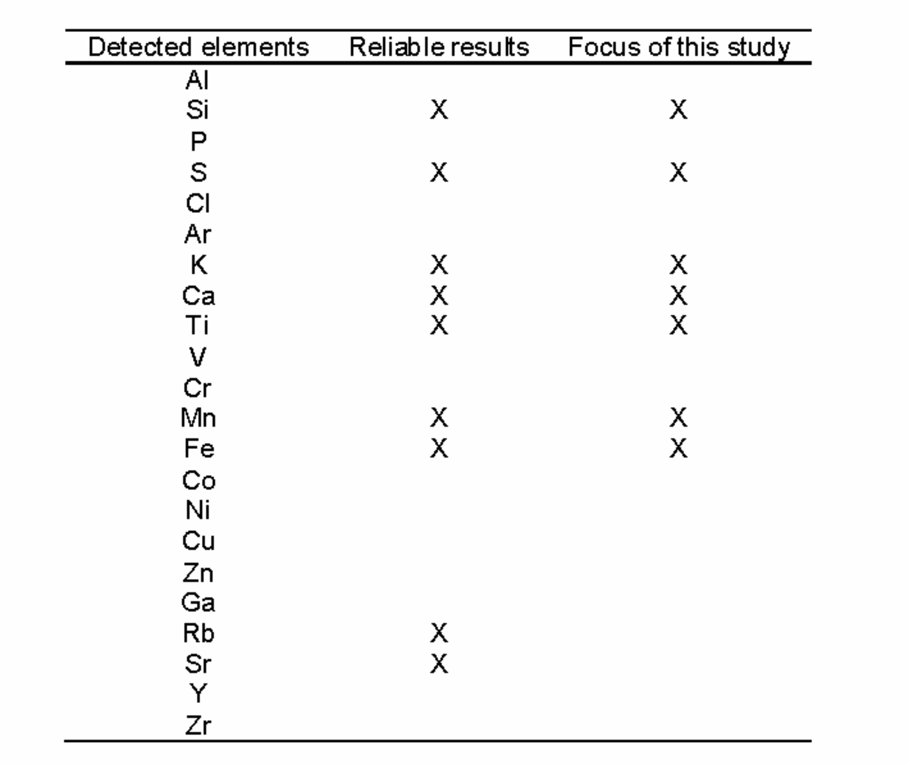
Samples of about 1 cm^3 were taken from five depths in the East Crooked Lake core, five depths in the Tofte Lake core, and three depths in the Fish Lake core for radiocarbon dates. Samples were selected based on the results of the XRF scans, described in the following section, to determine as accurately as possible the timing of major shifts in sediment composition. All sampling was done at the LacCore lab at the University of Minnesota, Minneapolis campus. Samples were placed in small ashed, glass jars, packaged and mailed overnight to the Beta Analytic testing facility in Miami, Florida for radiocarbon dating by the accelerator mass spectrometry (AMS) method on bulk organic carbon.

3.3 X-ray Fluorescence (XRF)

The archive halves of the three cores were scanned with a second generation ITRAX core scanner at the Large Lakes Observatory to determine the abundances of 22 elements (table 2). Several of the elements did not yield reliable results, either due to their signal being overpowered by an element with similar fluorescence properties or in most cases due to the amount of the element detected being very low.

All of the cores were scanned with a Mo tube at the same energy levels, but with different sampling intervals. The settings for the Tofte Lake cores were 30kV, 20 mA, a scanning step size of 2 cm, and an exposure time of 120 seconds. The settings for the East Crooked Lake cores were 30kV, 20mA, a scanning step size of 1 cm, and an exposure time 60 seconds. The settings for the Fish Lake cores were 30kV, 20 mA, a scanning step size of 2 cm, and an exposure time of 120 seconds. The reason for the longer count time for Fish Lake and Tofte Lake cores was that there was more visible organic material present in these two cores than in the East Crooked Lake core. The longer count time helped produce larger peaks that wouldn’t be drowned out by the background noise due to interference by organic materials.

The results produced by the XRF were measured in counts per minute (cpm) and as such are semi-quantitative. Along with the elemental abundances, the ratio of incoherent to coherent scatter was also measured during scanning, providing a qualitative proxy for the abundance of organic matter in the sediment (Burnett et al., 2010).



Detected elements	Reliable results	Focus of this study
Al		
Si	X	X
P		
S	X	X
Cl		
Ar		
K	X	X
Ca	X	X
Ti	X	X
V		
Cr		
Mn	X	X
Fe	X	X
Co		
Ni		
Cu		
Zn		
Ga		
Rb	X	
Sr	X	
Y		
Zr		

Table 2. Elements detected by XRF and their reliability for the cores scanned for this study

3.4 Coulometry

Discrete sediment samples of about 1 cm^3 were taken from the three cores at 10 cm intervals to be analyzed for % total inorganic carbon (TIC) and % total carbon (TC). They were freeze dried, powdered, and heated in an oven at 60 °C overnight to remove any remaining water. A portion of each sample was then placed in a vial, weighed and the inorganic carbon was volatilized with 2N HCl in a CM 5130 acidification module. The released CO_2 was measured by an infra-red detector in a UIC Inc. Coulometrics CM 5014 CO_2 coulometer. Another portion of each sample was placed into a small platinum boat which was then fired in a CM 5300 furnace apparatus at 950 °C to burn all the carbon present. This CO_2 also went to the coulometer and the amount was measured. The total organic carbon (TOC) could then be determined by subtracting the TIC from the TC for each sample.

Chapter 4: Results

4.1 Sedimentology

The upper 2.6 m of the East Crooked Lake core consists of massive dark olive gray sapropelic mud that overlie 0.6 m of massive dark gray diatomaceous silty clay with admixed very fine calcareous sand (figure 5). The 0.5 m below this consists of 2 cm thick, semi-laminated layers of dark gray to very dark gray, very fine calcareous sandy clay. This in turn overlies 0.4 m of semi-laminated black to olive carbonate mud with layers ranging in thickness from a few mm up to 6 cm. The bottom meter of the core is massive gray to black calcareous sand and gravel with pebbles up to 2 cm in diameter (figure 5).

The upper 5 m of the Tofte Lake core consists of faintly laminated (~1 mm thick), olive black, diatomaceous sapropelic mud (figure 5).   This overlies 2 m of faintly laminated (~1 mm thick), olive to gray, diatomaceous sapropelic mud with a few irregularly spaced white laminae that are also about 1 mm thick. The 1.7 m section below this is massive dark gray silt with numerous black, very fine calcareous sandy silt specs and laminae interspersed irregularly throughout; it is interrupted near its center by a 0.25 m layer of massive dark gray silt (figure 5). The underlying 0.7 m consists of 2 mm thick laminations of gray to dark gray clay, below which is 0.3 m of massive dark gray clay (figure 5). The bottom of the core is a series of glacial varves with varying thickness from 2 mm up to 4 cm consisting of gray to dark gray clay with the overall trend of varves being thicker with depth (figure 5). The silt and clay layers, particularly the glacial varves, show up well in x-radiograph images for the lower half of the Tofte Lake core.

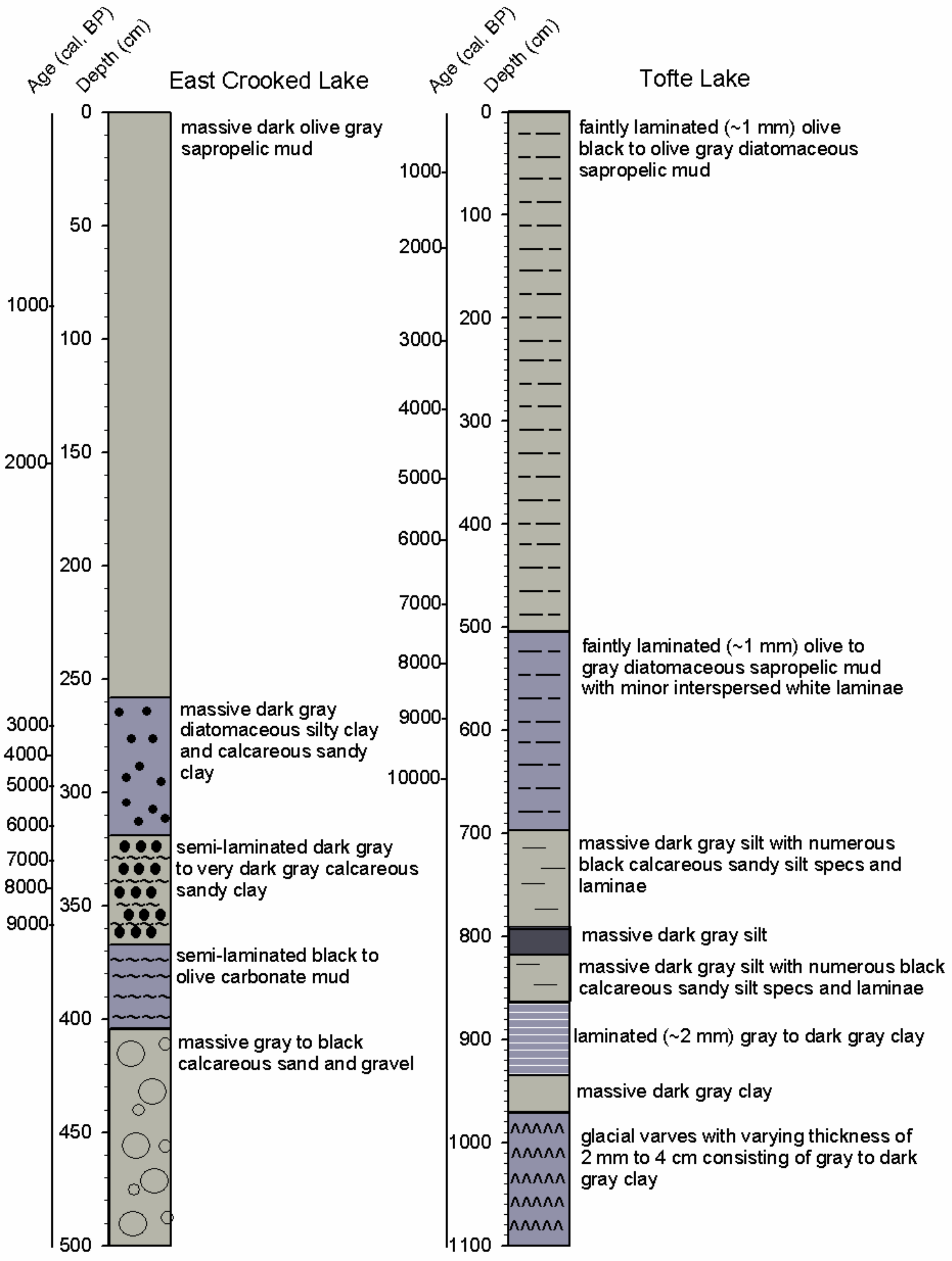


Figure 5. Sedimentology of East Crooked Lake and Tofte Lake.

4.2 Chronology

A total of thirteen samples were sent in for dating from the three cores in two separate shipments. Samples for the first shipment were selected based on major changes in scanning XRF results; samples for the second shipment were selected to refine the geochronology. All ages were on bulk organic carbon after the sediment was treated at the dating facility with HCl acid washes to remove any carbonates.

The samples selected for East Crooked Lake were based on the Ti XRF results (figure 6). A sample from 106 cm was taken just below a Ti peak. Samples from 254 cm and 359 cm bracket the major Ti concentration. The second set of samples from East Crooked Lake include one at 70 cm, the top of the core scanned by XRF, and one at 292 cm where there is a dip in Ti concentration.

Samples for Tofte Lake were selected based on the XRF results of the ratio of K/Ti (figure 6). Of the first three samples, 240 cm and 492 cm were low points in K/Ti; the sample at 600 cm is where Ti concentrations dropped to typical Holocene values (figure 6). The second set of samples include one at 29 cm, the top of the core scanned by XRF, and one at 168 cm which is located at another low point of K/Ti.

The three samples for Fish Lake were selected based on the Ti XRF results (figure6). Samples from 60 cm, 144 cm, and 208 cm all coincide with relatively low Ti concentrations. The Fish Lake results were problematic in that they displayed a total range of ages from 780-1050 cal. BP with all three ages being quite similar (table 3). This problem could be circumnavigated by dating pieces of plant debris or charcoal found in the core. Due to the equivocal dates and the operational difficulties in the recovery of the Fish Lake core itself, there was no further radiocarbon analysis done on the core.

The results of the dating (table 3) were used to develop age-depth profiles for East Crooked Lake and Tofte Lake (figure 7). In the development of these profiles a constant linear sedimentation rate was assumed between dates. Ages were converted to calendar years before present using the Pretoria calibration procedure program by Beta Analytic.

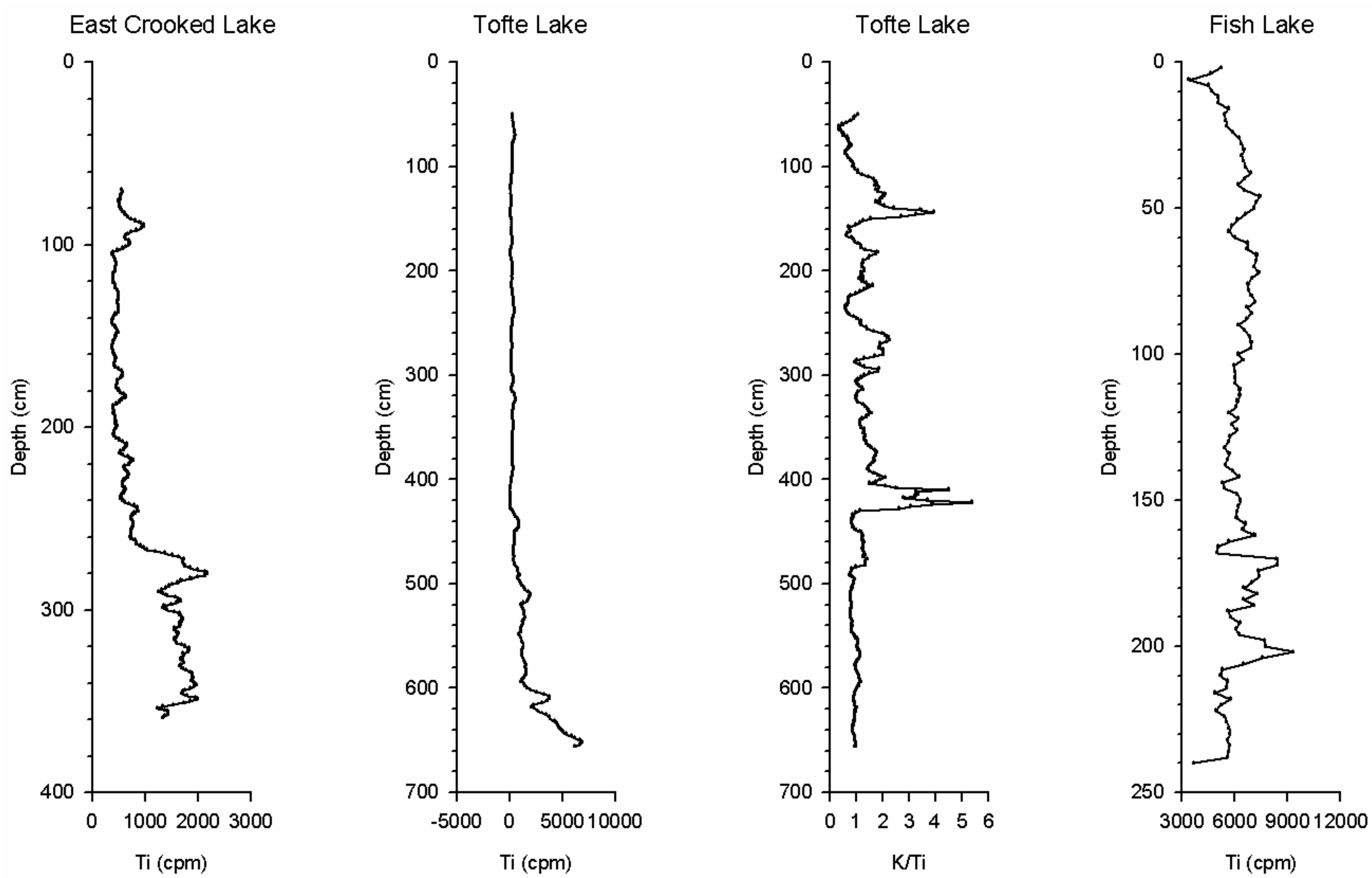


Figure 6. XRF profiles used in the selection of radiocarbon dating samples. Ti profile for East Crooked Lake, Ti and K/Ti profile for Tofte Lake, and Ti profile for Fish Lake.

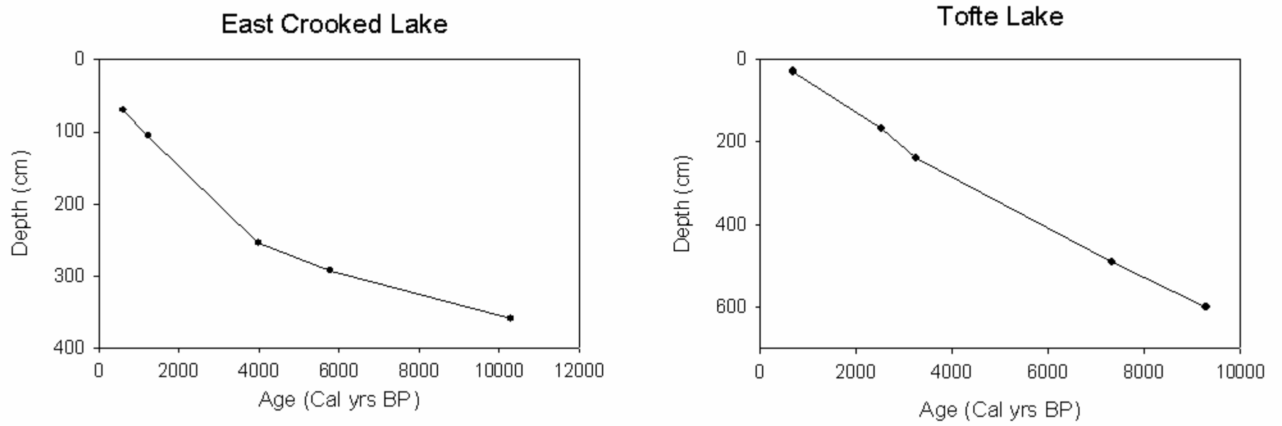


Figure 7. Age vs. depth profiles for East Crooked Lake and Tofte Lake.

Beta lab reference #	Lake	Core	Depth (cm)	AMS ^{14}C dates (yr BP)	Calibrated dates (cal. BP)
267740	East Crooked	TLX-ECR08 3A-1B-1	70	650 ± 40	610 (550-670)
259930	East Crooked	TLX-ECR08 3A-1B-1	106	1350 ± 40	1238 (1240-1320) & (1190-1200)
259931	East Crooked	TLX-ECR08 3A-2B-1	254	3600 ± 40	3983 (4050-4060) & (3830-3990)
267741	East Crooked	TLX-ECR08 3A-2B-1	292	5030 ± 40	5780 (5660-5900)
259932	East Crooked	TLX-ECR08 3A-3B-1	359	9100 ± 60	10295 (10190-10400)
267738	Tofte	TLX-TFT08 1A-1B-1	29	750 ± 40	695 (660-730)
267739	Tofte	TLX-TFT08 1A-2B-1	168	2430 ± 40	2530 (2630-2710 & 2350-2620)
259925	Tofte	TLX-TFT08 1A-2B-1	240	3040 ± 40	3255 (3150-3360)
259928	Tofte	TLX-TFT08 1A-4B-1	492	6320 ± 50	7323 (7400 & 7160-7330)
259929	Tofte	TLX-TFT08 1A-5B-1	600	8290 ± 50	9280 (9120-9440)
259924	Fish	TLX-FSH08 1A-2B-1	60	1040 ± 40	1000 (1030-1050 & 920-1000)
259926	Fish	TLX-FSH08 1A-2B-1	144	960 ± 40	860 (780-940)
259927	Fish	TLX-FSH08 1A-2B-1	208	1050 ± 40	985 (920-1050)

Table 3. AMS radiocarbon dates. All Samples were bulk sediments and provided sufficient carbon for analysis.

4.3 XRF

The abundances of Ti, K, Ca, Si, Mn, Fe, and S are the XRF signals examined in this study. Ti and K have been used as indicators of clastic input, and in this region of central Minnesota much of this clastic input is thought to have come in the form of wind blown dust from the Great Plains (Dean, 1993). K is more susceptible to chemical weathering than Ti, so the ratio of the K/Ti can be used as an indicator of moisture and chemical weathering. Rapid changes in K/Ti can indicate changes in source area for clastic material. Ca can be used as proxy for carbonates. Si is also often an indicator of clastic input, but can also be representative of diatom productivity within a lake. In East Crooked Lake and Tofte Lake S is thought to represent primarily organic S and can then be used as an indicator of the abundance of organic matter, and perhaps of primary productivity within the lake. All XRF curves were smoothed using a simple 5 point moving average.

The Ti profile in East Crooked Lake shifts from relatively high concentrations (~1800 cpm) between 2.6 m and 3.5 m to about 400 cpm in the upper part of the core (figure 8). The major shift that occurs at 2.6 m coincides with the change in lithology from massive dark gray diatomaceous silty clay with admixed very fine calcareous sand below this depth to massive dark olive gray sapropelic mud above (figure 5). The change in lithology from massive dark gray diatomaceous silty clay with admixed very fine calcareous sand to layers of dark gray to very dark gray, very fine calcareous sandy clay at 3.2 m can be seen as a minor shift in the Ti profile (figure 8). The changes in lithology at 3.7 m and 4.05 m are not seen in the Ti profile as they are both occur below the scanned portion of the core.

The Ti profile in Tofte Lake displays minimal abundance (<1000 cpm) in sediments above 4.4 m and low to intermediate (1000-4000 cpm) values in sediments between 4.4 m and 6.1 m (figure 9). Sediments below 6.1 m have the highest (>4000cpm) Ti concentration (figure 9). The change in lithology at 5.05 m can be seen as a shift in Ti at that same depth (figure 5).

The K profile in East Crooked Lake is similar in form to the Ti profile; it shifts from relatively high concentrations (~2000 cpm) between 2.6 m and 3.5 m to about 500 cpm in the upper part of the core (figure 8). The major shift at 2.6 m also coincides with a visible change in lithology (figure 5). The change in lithology at 3.2 m can be seen as a minor shift in the K profile.

The K profile for Tofte Lake shares the same general features of the Ti profile; it displays minimal abundance (<600 cpm) in sediments above 4.4 m and low to intermediate (600-3200 cpm) values in sediments between 4.4 m and 6.1 m (figure9). Sediments below 6.1 m have the highest (>3200 cpm) K concentration (figure 9). The change in lithology at 5.05 m can be seen as a shift in the K profile (figure 5).

Ca in East Crooked is low (<2 kcpm) in the upper 2.6 m of the core, below which the Ca concentration is high (~100 kcpm) (figure 8). The transition to higher values at 2.6 m coincides with the change in lithology at this depth (figure 5). The change in lithology at 3.2 m coincides with a minor transition in Ca values.

In Tofte Lake the Ca profile is similar to both the Ti and K profiles; it remains low (<4 kcpm) above 4.4 m and low to intermediate (4-10 kcpm) between 4.4 m and 6.1 m (figure 9). Sediments below 6.1 m have the highest (>10 kcpm) concentration (figure 9). There is a transition in Ca at 5.05 m which coincides with a change in lithology (figure 5).

The Si profile for East Crooked Lake is very similar to the Ti and K profiles; it shifts from relatively high concentrations (~250 cpm) between 2.6 m and 3.5 m to about 100 cpm in the upper part of the core (figure 8). The major shift at 2.6 m also coincides with a visible change in lithology (figure 5). The change in lithology at 3.2 m can be seen as a minor shift in the Si profile.

In Tofte Lake the Si profile remains relatively consistent (~700 cpm) for the entire core (figure 9). It does fluctuate from higher to lower values six times, approximately every 0.8 m (figure 9). The change in lithology at 5.05 m coincides with a transition in the Si profile (figure 5).

The Mn profile for East Crooked Lake remains low (~200 cpm) from the surface down to 2.4 m at which point it increases steadily until it peaks (6800 cpm) at 3.2m and gradually declines below this point (figure 8). The change in lithology at 2.6 m coincides with the increase in Mn at the same depth.

In Tofte Lake the Mn profile remains low (~7 kcpm) from the surface down to 4 m with the exception of slightly elevated values (~11 kcpm) from 1.4-1.9 m (figure 9). From 4-5.4 m Mn is more variable with average values of 15 kcpm (figure 9). Below 5.4 m Mn remains variable and has the highest average values at about 30 kcpm (figure 9). The lithological transition at 5 m coincides with a transition to lower Mn at the same depth.

The Fe profile for East Crooked Lake is very similar to the Ti and K profiles; it shifts from relatively high concentrations (~120 kcpm) between 2.6 m and 3.5 m to about 40 kcpm in the upper part of the core (figure 8). The major shift at 2.6 m also coincides with a visible change in lithology (figure 5). The change in lithology at 3.2 m can be seen as a minor shift in the Fe profile.

In Tofte Lake the Fe profile is similar to both the Ti and K profiles; it remains low (~70 kcpm) above 4.4 m and low to intermediate (70-200 kcpm) between 4.4 m and 6.1 m (figure 9). Sediments below 6.1 m have the highest (>200 kcpm) concentration (figure 9). There is a transition in Fe at 5.05 m which coincides with a change in lithology (figure 5).

S in East Crooked Lake is high (~400 cpm) from the surface down to 2.6 m and below that is much lower (~100 cpm) (figure 8). S also has a significant peak (400 cpm) at 3.25 m (figure 8). The transition from high to low S at 2.6 m coincides with the change in lithology at that depth (figure 5). No other changes in lithology coincide with the S profile.

In Tofte Lake the S profile is similar to the Si profile; it remains relatively consistent (~1300 cpm) for the entire core (figure 9). It does fluctuate from higher to lower values six times occurring approximately every 0.8 m (figure 9). The change in lithology at 5.05 m does coincide with a transition in the S profile (figure 5).

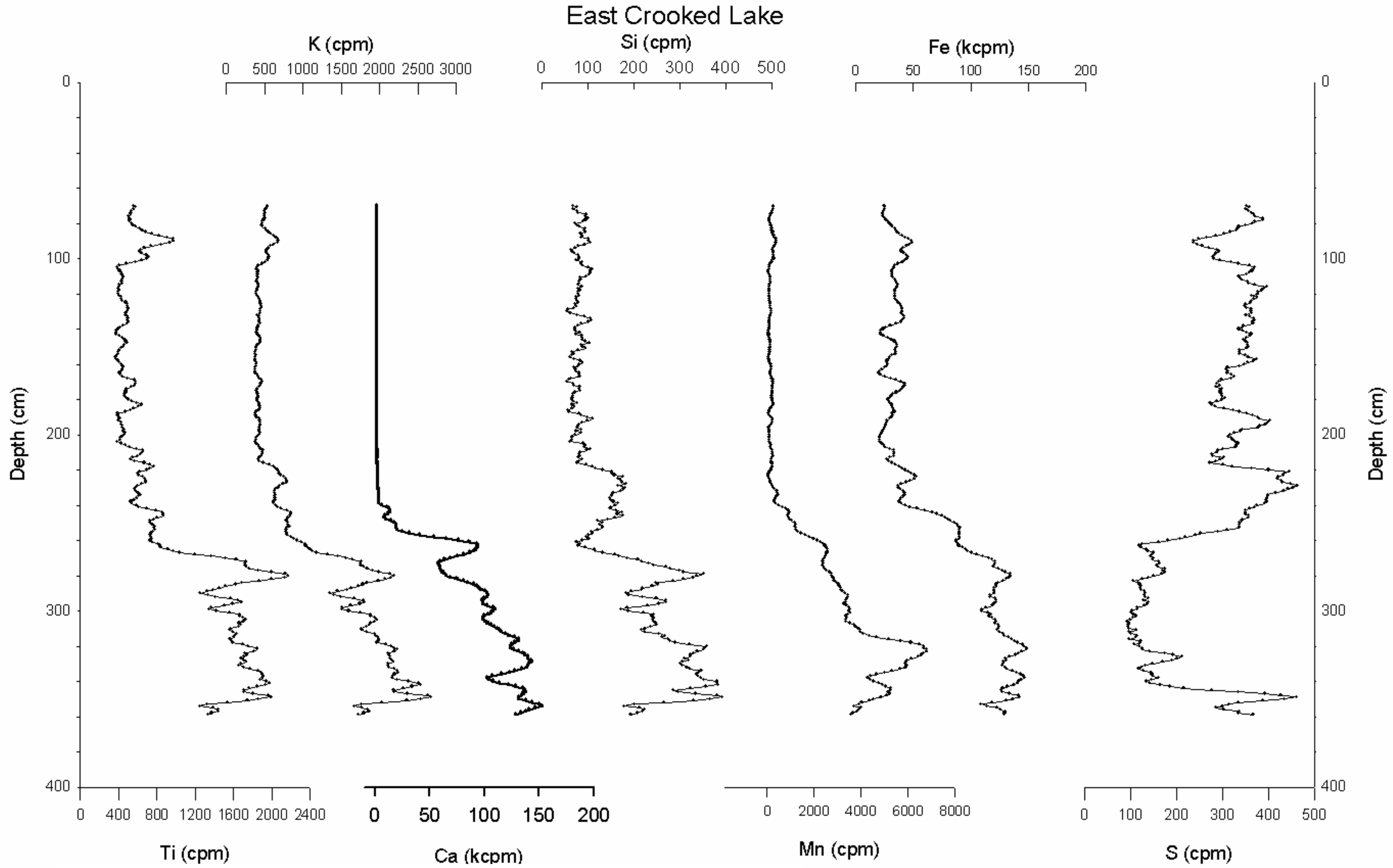


Figure 8. Ti, K, Ca, Si, Mn, Fe, and S XRF profiles vs. depth for East Crooked Lake.

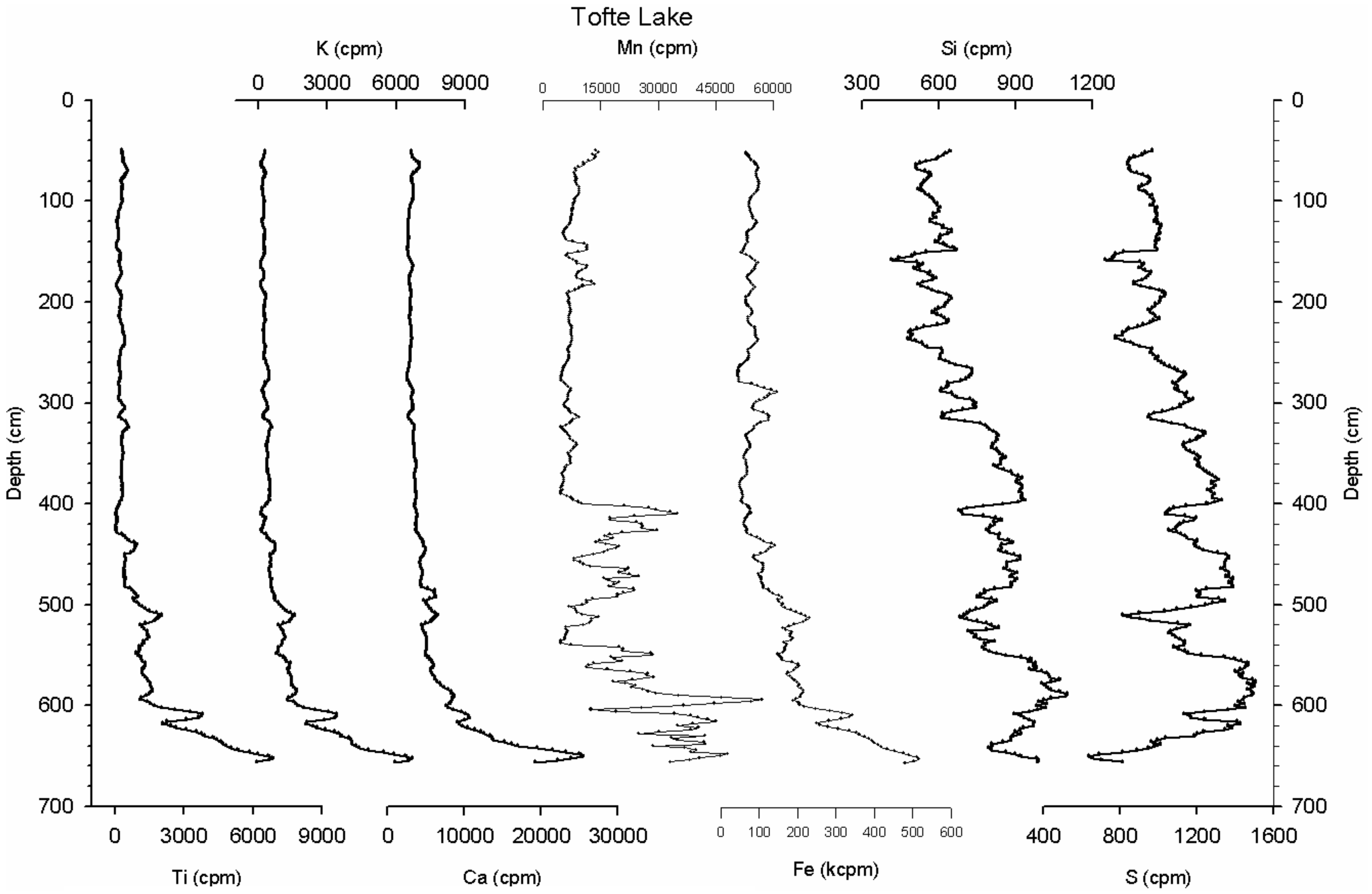


Figure 9. Ti, K, Ca, Si, Mn, Fe, and S XRF profiles vs. depth for Tofte Lake.

4.4 Coulometry

The TIC profile for East Crooked Lake has relatively high values (~6%) from 2.5 m to 3.6 m and is near 0% from 2.5 m to the surface (figure 10). A peak TIC of 7% would correspond to 58% $CaCO_3$ (Dean, 1999).

The TOC profile for East Crooked Lake has relatively low values (~3%) from 2.5 m to 3.6 m and from 2.5 m to the surface has average values near 30% with one notable exception at about 0.9 m where values drop to 20% (figure 10). The increase in organic matter from 2.5 m to the surface results in an increased sedimentation rate which can be seen in figure 7. This increased sedimentation rate of organic matter causes the clastic input from Ti, K, Ca, Si, Mn, and Fe to become diluted which can be seen in figure 8.

The TIC profile for Tofte Lake remains at near 0% throughout the core with the largest peak of 0.7% located at 4.5 m (figure 10). The largest peak of 0.7% would correspond to 5.8% $CaCO_3$ (Dean, 1999).

The TOC profile in Tofte Lake has moderate (~17%) values from 5 m to 6.4 m and then increases and maintains higher (~29%) values from 5 m to the surface (figure 10). From 5 m to the surface the TOC values have a slight oscillation from higher to lower values occurring approximately every 0.8 m (figure 10). It is no surprise that TIC values remain near 0% in the upper portion of both cores as the TOC values are above 12% at which point the effect of decomposing organic carbon is believed to lower the pH of the pore water and dissolve $CaCO_3$ (Dean, 1999).

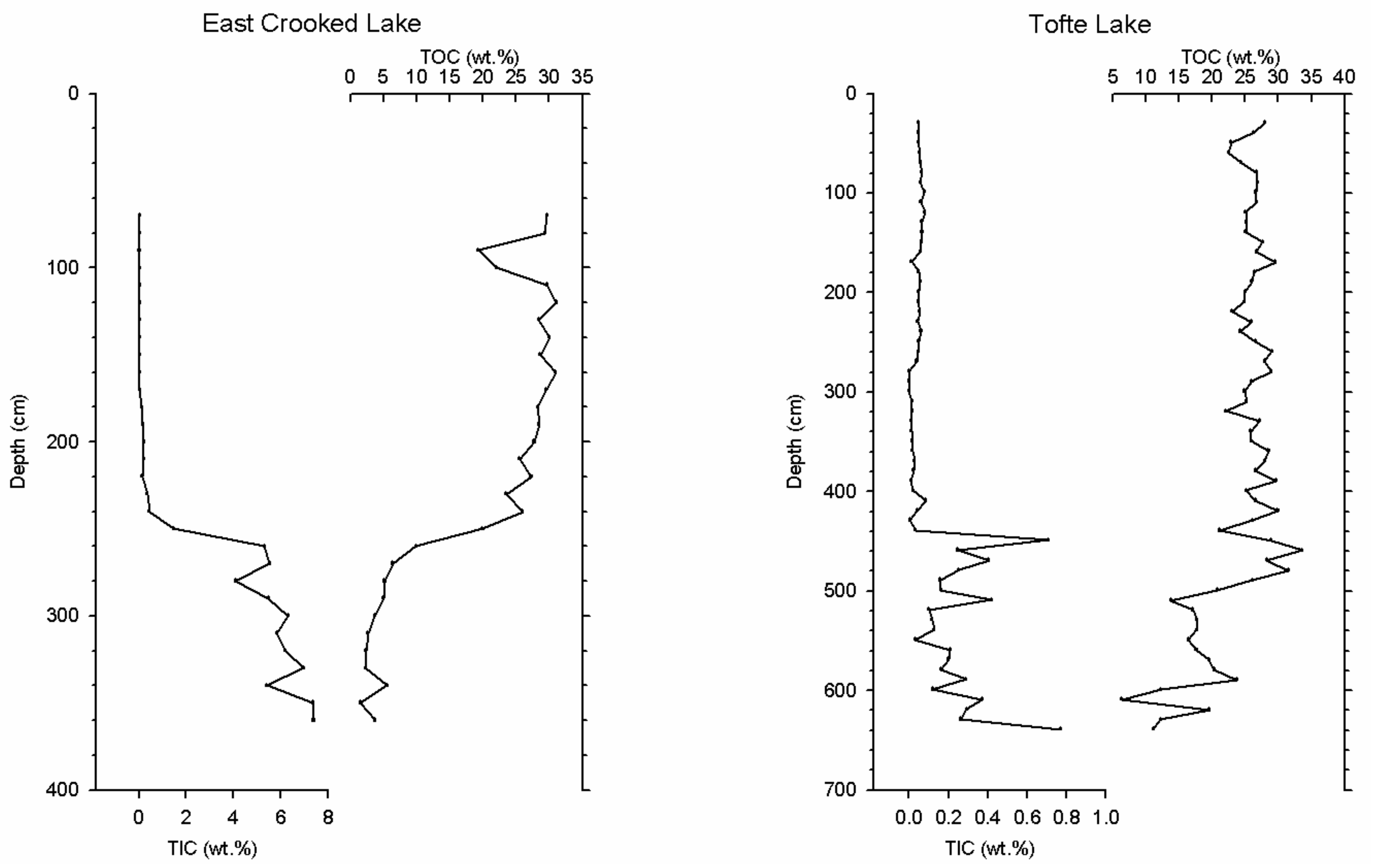


Figure 10. Coulometry results for East Crooked Lake and Tofte Lake showing total inorganic carbon (TIC) and total organic carbon (TOC).

Chapter 5: Discussion

5.1 East Crooked Lake vs. Elk Lake

Elk Lake, which has a sedimentary record that may be considered an icon of Minnesota paleoclimatology (Dean, 1993), is located within Itasca State Park just 35 km NW of East Crooked Lake. Both its depth of 28.3 m and surface area of 305 acres are comparable to those of East Crooked Lake (29.3 m and 365 acres, respectively). These two lakes located in such close proximity would have been affected by the same regional climatic forcing through the Holocene.

This study relied on radiocarbon ages to develop a timescale for East Crooked Lake. The timescale developed for Elk Lake by Dean (1993) and co-workers is based on a varve chronology. Radiocarbon dates were also taken for Elk Lake but were not used in developing the timescale because they were believed to be contaminated with old carbon (Anderson et al., 1993). If the ^{14}C ages are applied to construct the Elk Lake history, then the major peaks in East Crooked Lake based on our ^{14}C chronology and Elk Lake profiles match well (figure 11). Comparing the varve timescale to the radiocarbon timescale for Elk Lake shows a difference in the timing of events by 1 ky or more (figure 11). This could be due to the Elk Lake varve chronology having an imprecision associated with it of up to 12% (Sprowl, 1993).

Another possibility is that both timescales are in error. With varves there can be missing segments, poorly defined laminations, and human error in counting, and with bulk radiocarbon dating it is always possible to have some older carbon mixed in. Steel Lake, located just 50 km southeast of Elk Lake and only 12 km southeast of East Crooked Lake, has the best radiocarbon timescale constructed for this region to date. Wright et al. (2004) used 26 ^{14}C dates from terrestrial macrofossils from Steel Lake to construct a timescale going back 11.2 ka.

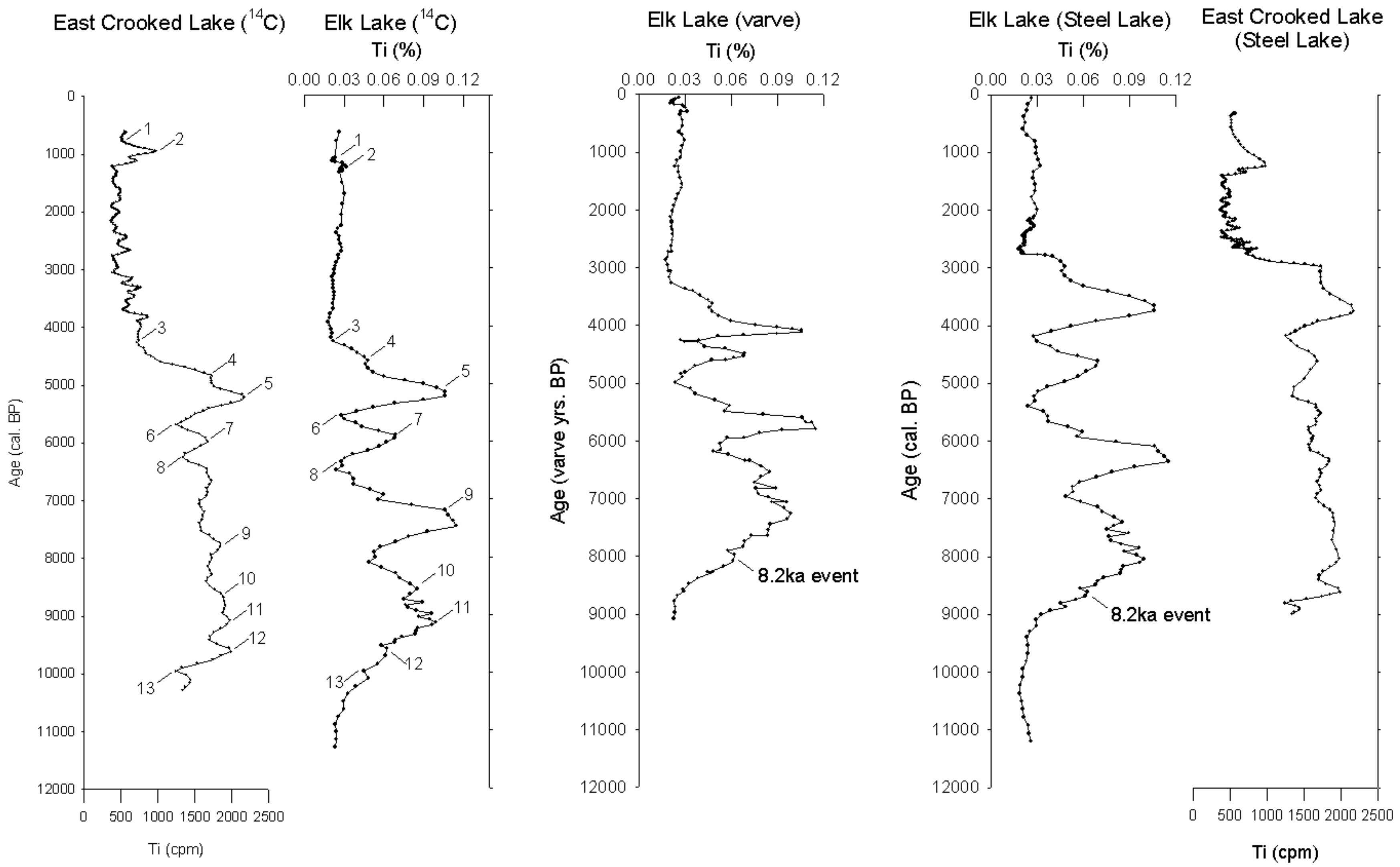


Figure 11. Ti XRF spectroscopy data from Elk Lake compared using three different timescales: radiocarbon dates from Elk Lake, varve counts from Elk Lake, and pollen stage boundaries and peaks from Elk Lake matched to Steel Lake pollen stage boundaries and peaks. Also Ti scanning XRF data from East Crooked Lake plotted on a radiocarbon based timescale with 13 selected points to correlate with the Elk Lake radiocarbon timescale. These 13 points were used to adjust the East Crooked Lake timescale to the Steel Lake pollen based timescale.

A detailed pollen analysis of the Elk Lake core divided it into five pollen assemblages (Whitlock et al., 1993) which can be correlated with the pollen assemblages in Steel Lake, although in the Steel Lake study the pollen assemblages are further divided. By using the pollen stage boundaries as a point of reference along with four other distinct peaks in pollen, a new timescale was developed for Elk Lake based on the more accurate timescale of Steel Lake (figure 12, 13; table 4).

The four pollen boundaries (B, D, F, and H) from Elk Lake were chosen as points of reference because those same four boundaries were also well defined in the Steel Lake study (Wright et al., 2004) (figures 12, 13). Tie point A is a distinct peak in *Pinus strobus* in both lakes, tie point C is a distinct peak in *Betula* in both lakes, tie point E is a distinct peak in *Quercus* in both lakes, and tie point G is a distinct peak in *Pinus banksiana* in both lakes (figures 12, 13). All further graphs of Elk and East Crooked Lakes will be based on the new Steel Lake timescale. On this new timescale it appears the varve chronology is too old from 4 ka to the present and too young prior to 4 ka. The most distinct result of the Steel timescale is that it stretches out the Prairie Period making it slightly longer than previously represented. The new timescale would also change the timing of the 8.2 ka event that has previously been linked to cooling in the Greenland ice cores to 8.75 ka (figure 11) (Dean et al., 2002). The 8.2 ka event in the Elk Lake core is a peak in clastic minerals (Ti, K, Al, and Si) as well as a change in internal chemical and biological signals, Mn, Fe, P, diatoms, and plant pigments (Dean et al., 2002).

Tie Point	Pollen Type/Assemblage	Steel Lake Age (yrs. BP)	Elk Lake Age (varve yrs. BP)
A	Peak: *Pinus strobus*	2,100	900
B	Pollen Stage: 6: *Pinus strobus*	2,700	3,000
C	Peak: *Betula*	2,800	3,500
D	Pollen Stage 4: *Quercus-Gramineae-Artemisia*	3,400	4,000
E	Peak: *Quercus*	7,400	6,500
F	Pollen Stage 2: *Pinus banksiana/resinosa*	9,000	8,500
G	Peak: *Pinus banksiana*	9,400	8,800
H	Pollen Stage 1: *Picea*	11,200	10,000

Table 4. Tie points between Steel Lake and Elk Lake pollen records with corresponding Pollen types/assemblages and both Steel and Elk Lake ages.

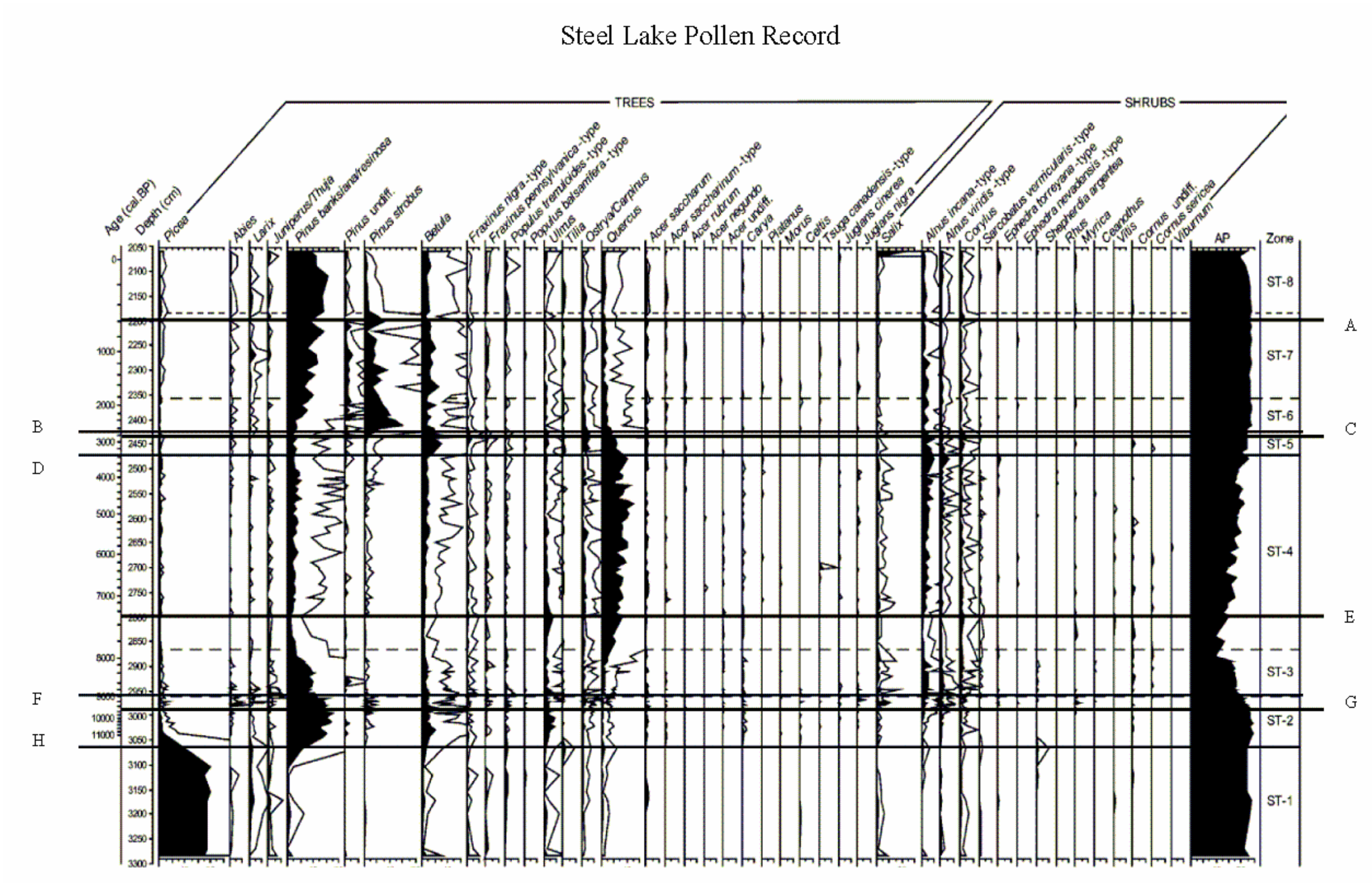


Fig. 12. Steel Lake pollen record. Pollen is plotted in % ∑ P= AP+ NAP. Lines and letter A-H indicated tie points between Steel and Elk Lake pollen records used for development of the Elk Lake Steel chronology, refer to table 4. (from Wright 2003).

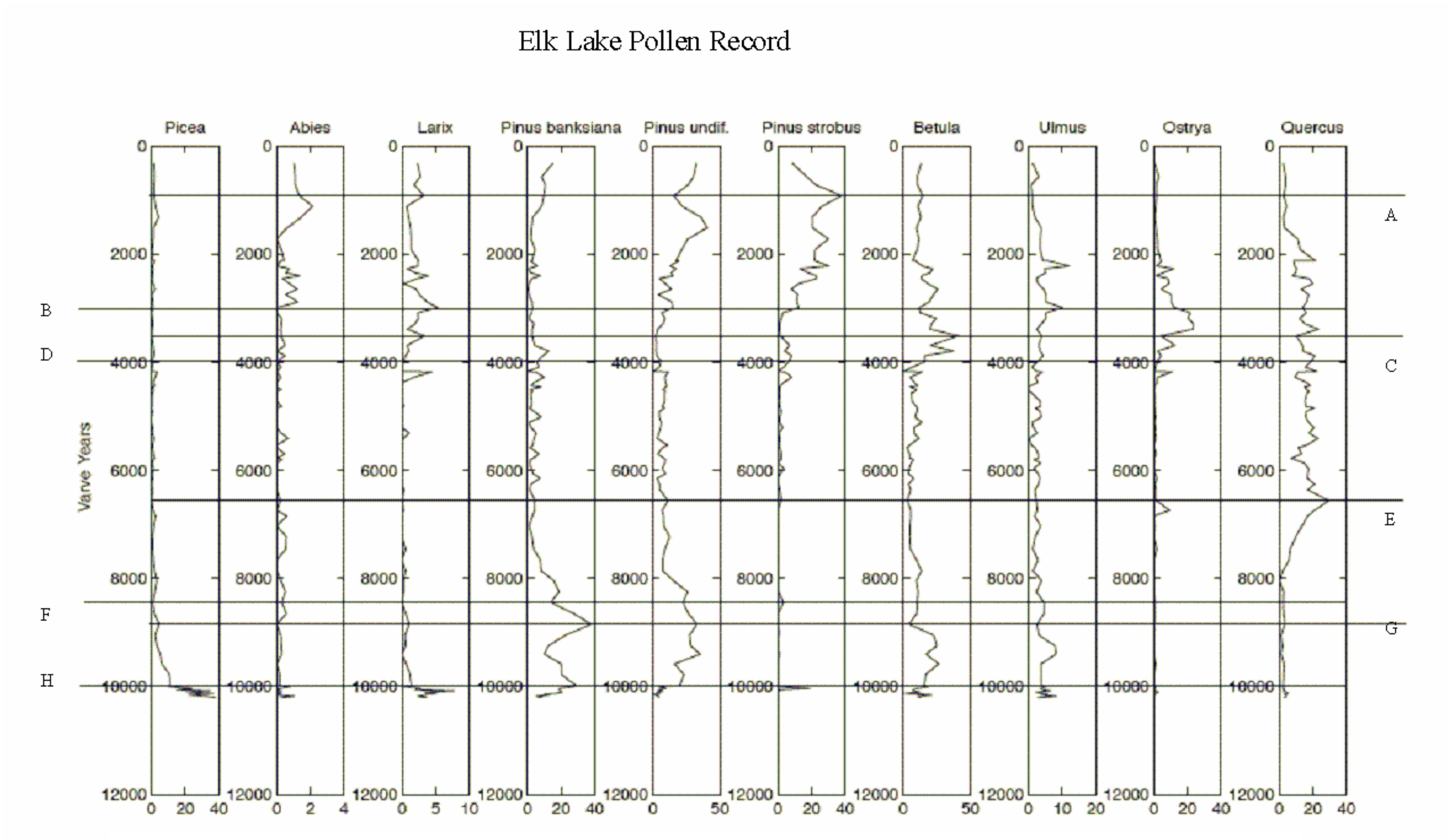


Fig.13. Elk Lake pollen record plotted in % ∑ P= AP+ NAP. Letters A-H refer to tie points between the Elk and Steel Lake pollen records for the development of the age scale of this study and and the application of Steel Lake AMS radio carbon dates to the Elk Lake geochemical record in Dean (1993). Letters/tie points refer to table 4. (from Whitlock 1993).

There are a number of similarities in the sediment profiles of the two lakes. The organic fraction in Elk Lake sediment is variable and relatively low between 11 and 3 ka, and then increases at 3 ka although not as dramatically as in East Crooked Lake (figure 14). This same increase in organic matter has also been seen at Williams Lake 15 km southeast of East Crooked Lake (Schwalb et al., 1995). The Ti, K, and Si profiles for East Crooked Lake and Elk Lake are high from 3-9 ka and drop off to modern values at 2.7 ka (figure 11, 14).

The Mn and Fe profiles for East Crooked and Elk Lake appear to be almost opposite (figure 15). Both Mn and Fe in East Crooked Lake are low from 3 ka to the present and high from 3-9 ka comparing well with the clastic input represented by Ti, K, and Si (figure 15). In Elk Lake Mn and Fe are high from 3 ka to the present and relatively low from 3-9 ka and compare well with TOC (figure 15). Possible reasons for these differences could be varying degrees of groundwater input which Dean (1993) cites as primary source for Mn and Fe at Elk Lake and also oxygenation of the bottom sediments, Elk Lake having varves as evidence of anoxic bottom waters and East Crooked Lake having no varves.

The strong correlation between profiles of Ti, K, and Si in the Elk Lake and East Crooked Lake cores shows that XRF can yield similar results to the traditional methods (inductively coupled plasma emission, atomic absorption spectroscopy) used at Elk Lake. Although XRF data are mainly semi-quantitative in nature, they are generated without sampling and destroying the core and in a fraction of the time, hours instead of weeks or months required by traditional methods.

The climate history recorded by Elk Lake cores begins with a postglacial period when the lake first formed, followed by a relatively dry period from 8-4 ka (varve yrs) known as the Prairie Period (Dean, 1993). From 4 ka (varve yrs) to the present the lake experienced a wetter climate comparable to modern conditions. With the new Steel Lake timescale the Prairie Period would be lengthened, extending from 8.6-3.4 ka. The East Crooked Lake data generated by this study display the same millennial scale features as the Elk Lake record when they are compared on their respective radiocarbon (not varve) timescales and also when converted to the Steel Lake timescale.

Although there are matching peaks at 3.7 ka and 4.6 ka there are also some discrepancies such as the difference in millennial-scale variability between 6.5 and 8 ka (displayed in the Elk Lake but not in the East Crooked Lake records) and the somewhat more variable record seen in East Crooked Lake from 2.7 ka to the present (figure 11, 14). It is not possible at this point to determine if the East Crooked Lake core contains a record of regional climate events such as the Little Ice Age or Dust Bowl as Dean (1997) has reported for the Elk Lake record. This would require detailed XRF scans with a scanning step size of 2 mm for the top 1 m of the East Crooked Lake core in order to achieve similar resolution to Dean's 5 to 10 yr composite samples for the past 1500 yrs in Elk Lake (Dean, 1997).

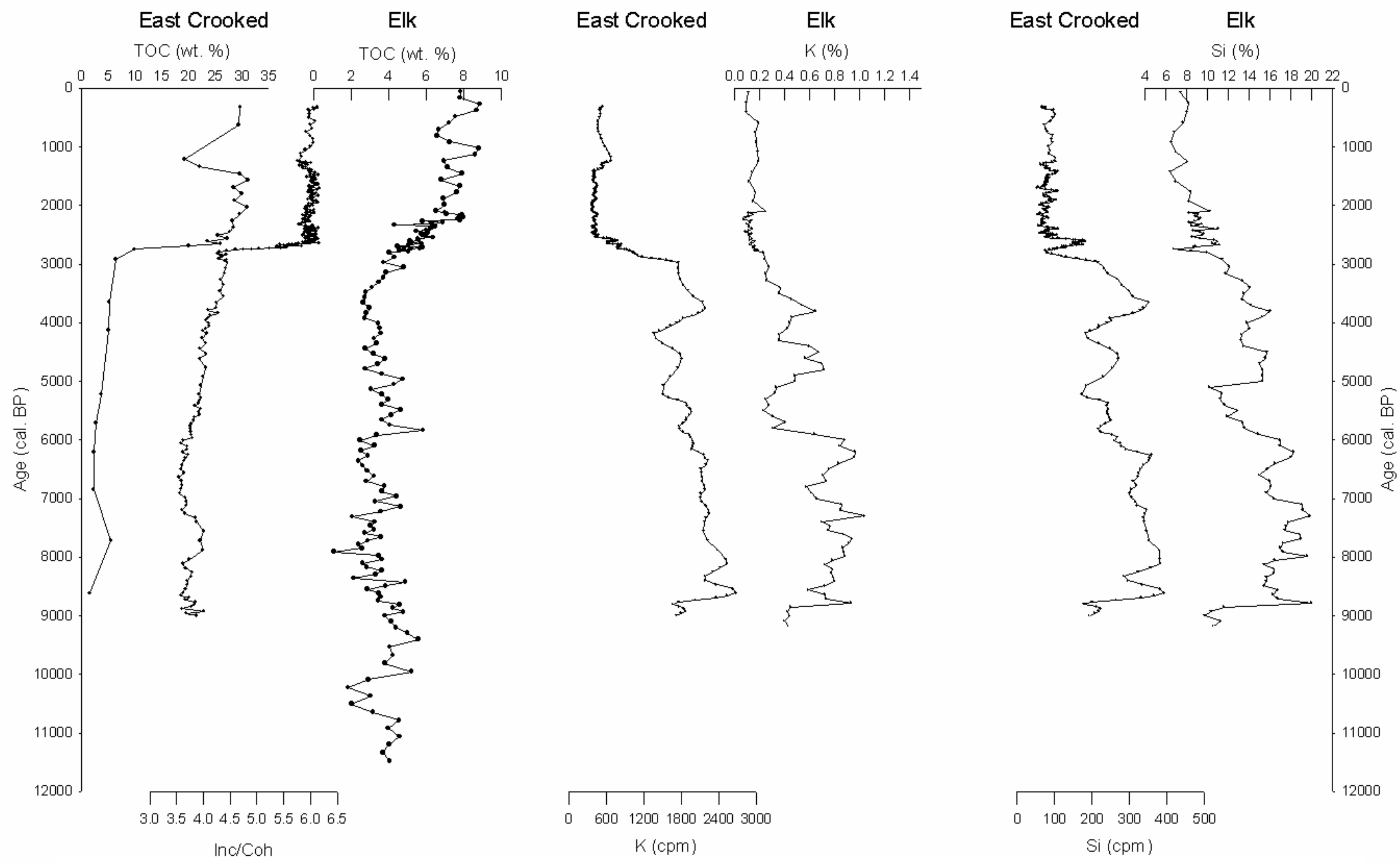


Figure 14. TOC and Inc/Coh for East Crooked Lake and TOC for Elk Lake. K and Si scanning XRF profiles for East Crooked Lake compared to corresponding XRF spectroscopy and optical emission spectrophotometry profiles for Elk Lake.

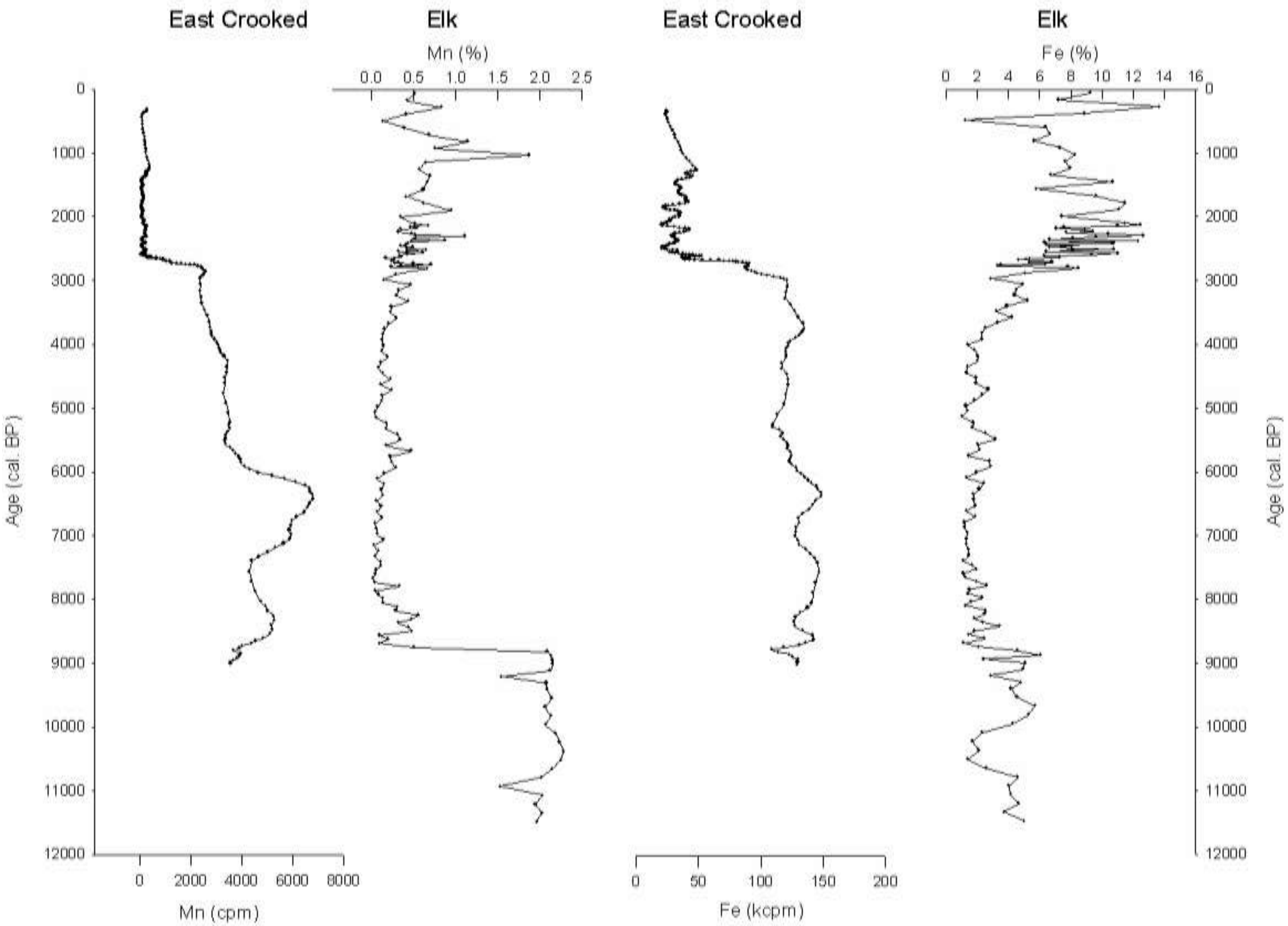


Fig. 15. Mn and Fe scanning XRF profiles for East Crooked Lake compared to corresponding optical emission spetrophotometry profiles for Elk Lake.

5.2 East Crooked Lake vs. Tofte Lake

East Crooked Lake and Tofte Lake were chosen for this study because they share similar features. Both are relatively small lakes with surface areas of 365 and 155 acres respectively, and both are relatively deep with max depths of 29.3 m and 22.3 m. Both lakes are also similar in that they have no inlets and only minor outlets. They are both young lakes having formed after the most recent glacial retreat from the region around 10 ka. In a broad sense they share in the climate of the upper Midwest, experiencing cool dry winters and warm wet summers. Annual average temperature near East Crooked Lake is 4 °C and at Tofte Lake is 3 °C; annual average precipitation is 64 cm and 69 cm respectively (National Climatic Data Center). Both lakes are also located within the dominant ecosystem of NE Minnesota, the conifer forest.

On the surface these lakes may appear quite similar, but their differences become apparent after a cursory glance at their sediment. The 4.2 m core from East Crooked has 2.5 m of organic rich material overlying and grading downward into clay and sand layers that culminate in an extremely coarse gravel sequence (figure 5). The 10.8 m core from Tofte Lake has nearly three times as long an organic-rich section and below this grades into organic-poor clays and silts and sequences of glacial varves. While the history of TOC accumulation in the two lakes appear very similar, starting off near 0% and then over a short interval rising to near 30%, this transition happens 5 ky earlier in Tofte Lake than in East Crooked Lake (figure 16). The inc/coh ratio is a statistically significant proxy for organic carbon with r^2 values of 0.95 and 0.67 for East Crooked and Tofte Lakes, respectively (figure 17).

Titanium (Ti) and potassium (K) are two elements that can be used to represent the clastic input into lakes. The XRF data for East Crooked Lake show consistently high values for the both Ti and K from 3-9 ka that drop off to low counts at 2.6 ka and remain low for the rest of the core (figure 18). Ca appears to be recording largely clastic input as well (figure 19). Ca for East Crooked Lake and Tofte Lake also appears to be an accurate proxy for TIC, although in Tofte Lake the low TIC values make the coulometry data more variable (figure 19).

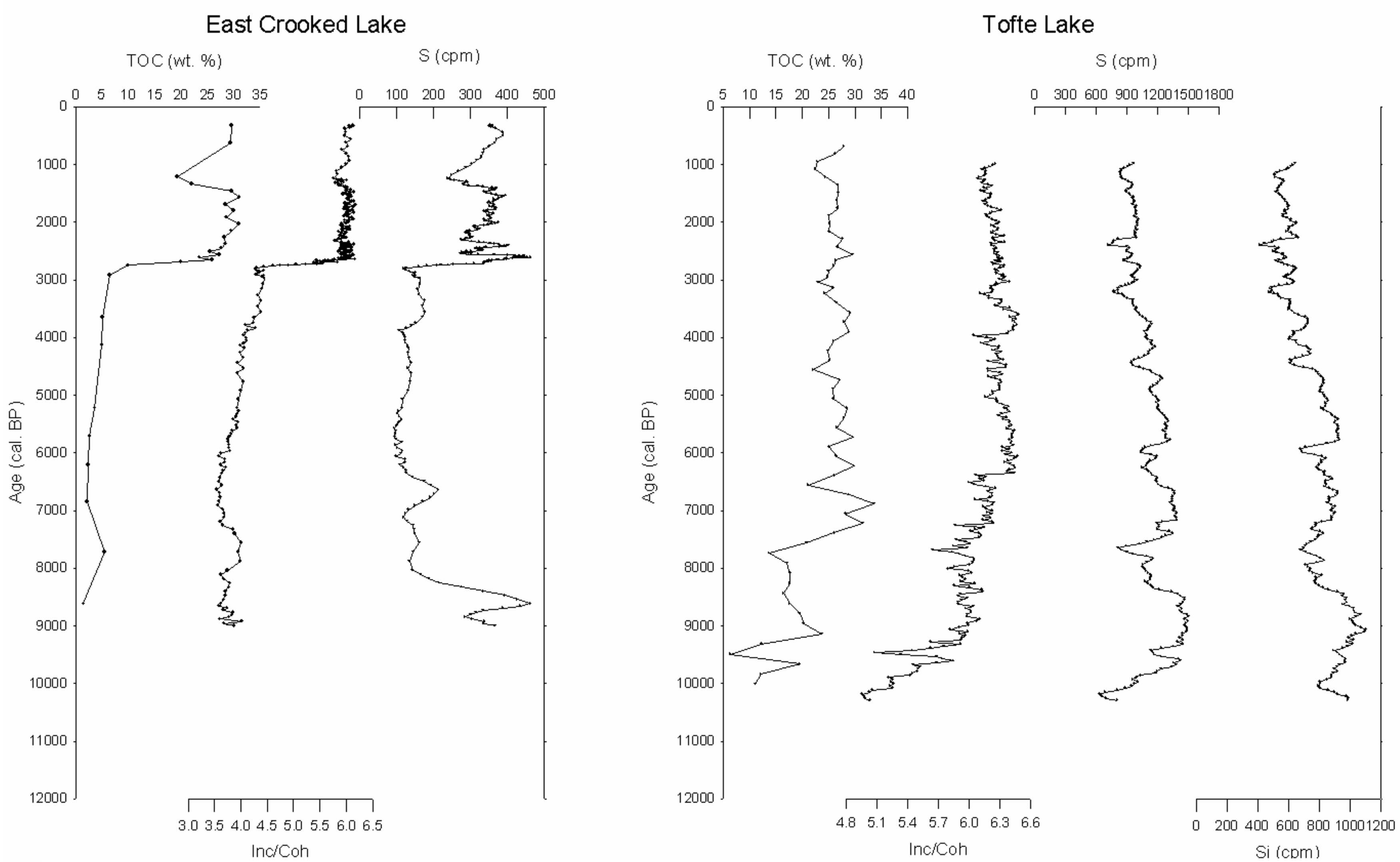


Figure 16. Total organic carbon (TOC) compared to the ratio of incoherent/coherent scatter and XRF S profiles for both East Crooked and Tofte Lake. Also Si XRF profile for Tofte Lake.

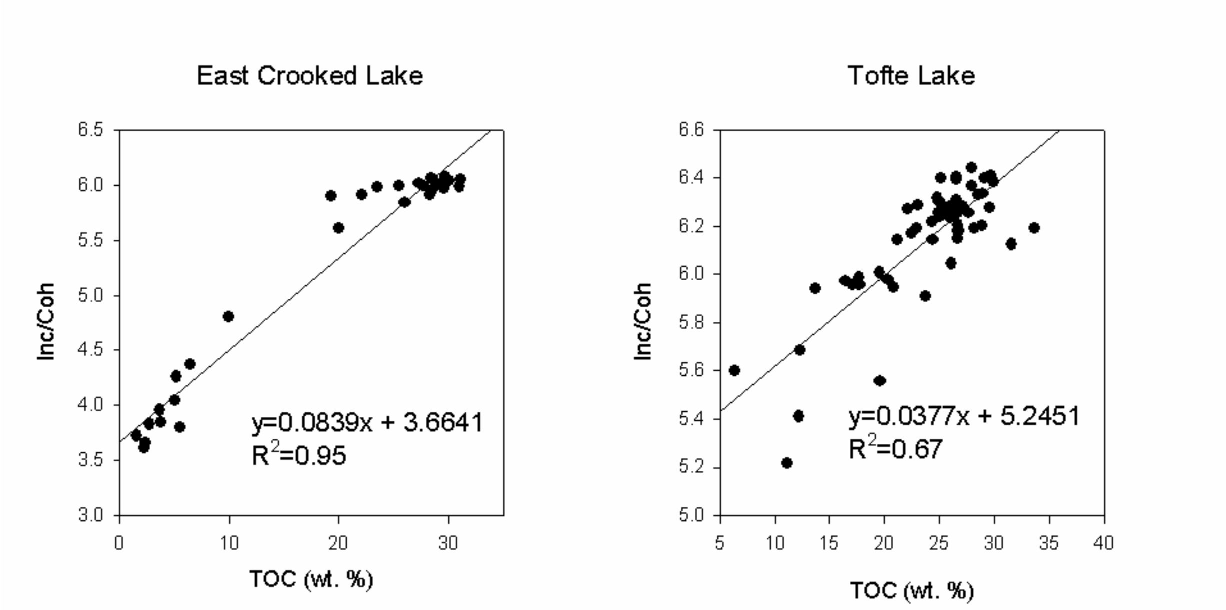


Figure 17. Scatter plots of incoherent/coherent scatter vs. TOC for East Crooked Lake and Tofte Lake.

Both Mn and Fe in East Crooked Lake are similar to the Ti results, they are high from 3-9 ka and relatively low from 3 ka to the present (figure 20). Mn differs somewhat in that it has elevated values from 6-7 ka that are not seen in Ti (figure 20). Si in East Crooked also compared well with Ti and K and is representative of dominantly clastic input rather than diatoms (figure 14). Diatom input can be inferred from the ratio of Si/Ti and correlates well with the increased organic productivity seen after 3 ka. (figure 20).

Sulfur (S) can be used to represent organic input in lake sediments; it compares well with TOC (figure 16). Both TOC and S in East Crooked Lake show the inverse of the Ti results; they remain relatively low until 3 ka at which point there is a rapid increase to modern values. The rather abrupt shift in sediment composition at 3 ka is due in part to the dilution of the clastics by increased TOC and is likely due to a climate shift from a dry unproductive period prior to that time to one of wetter conditions that increased nutrient delivery and productivity within the lake.

The Ti and K values for Tofte Lake are high prior to 10 ka due to glacial influx; they subsequently drop rather dramatically to very low values by 6.4 ka, with superimposed brief peaks centered at ~9.5, 7.8, and 6.4 ka (figure 18). Ca also appears to be recording clastic input as it tracks closely with both Ti and K, having high values prior to 10 ka and lower values after that with the same peaks at 9.5, 7.8, and 6.4 ka (figure

19). Both Mn and Fe also appear to record clastic input as they share the same general trend found in both Ti and K and also have matching peaks (figure 20). One notable difference in Mn is that it has higher peaks and is more variable than Ti (figure 20).

The TOC and S in Tofte Lake remain relatively the same from their increase at 8 ka until the present; however there does seem to be a slight oscillation in their values with an approximate 2 ky period (figure 16). The substantial rise in TOC at 8 ka does not appear as a distinct horizon in the core, but rather as a visible transition from gray to olive/black diatomaceous sapropelic mud (figure 5). The Si profile in Tofte Lake is very similar to both the TOC and S profiles, which suggests that Si is primarily recording diatom abundance and not clastic input (figure 16). Tofte Lake experienced an inflow of glacial silts and clays which dominated its early history, as the glacial inflow began to wane signs of productivity in the lake increased and the glacial inflow ceased; this occurred gradually over a period of several hundreds of years centered on 8 ka.

There are no correlations between Ti, K, Ca, Mn, Fe, or the TOC and S signals between the two lakes. Comparing XRF scans of the other elements has also yielded no similarities between the intensity of the peaks. If the 3 ka rise in TOC at East Crooked Lake was a regional climate event, it is not recoreded as far to the NE as Tofte Lake. The early Holocene history of Tofte Lake may have differed from that of East Crooked Lake because of its proximity to a melting glacier and glacial outflow until about 8 ka, and presumably due to a wetter climate at Tofte Lake than at East Crooked Lake up until 3 ka.

The ratio of K/Ti, a proxy for moisture and chemical weathering rates, also yielded no comparable results between the two lakes (figure 18). A low K/Ti ratio represents increased moisture and increased chemical weathering of K-silicate minerals, whereas a high value would indicate the opposite. East Crooked Lake results show an overall trend going from dry to wet, but with rapid fluctuations beginning around 3 ka and continuing to the present. The rapid changes in K/Ti would represent a change in sediment provenance rather than a change in chemical weathering rates.

The K/Ti trend at Tofte Lake remains relatively stable over time with the exception of four major peaks at 2, 2.8, 3.7, and 6 ka (figure 18). These large peaks could be associated with a change in provenance most likely influenced by wind direction, but are more likely due to extremely low values in Ti for the upper part of the core. The ratio of Si/Ti which is used as a proxy for diatom abundance shows the same trend as K/Ti lending further support to the likelihood that changes in both ratios are dominated by the low Ti values (figure 20). It is possible that some of the centennial scale shifts in K/Ti after 3 ka are coeval in the two lakes, for example the shifts to high values around 2.2 and 3 ka, but many of the peaks and valleys in the two profiles are not aligned.

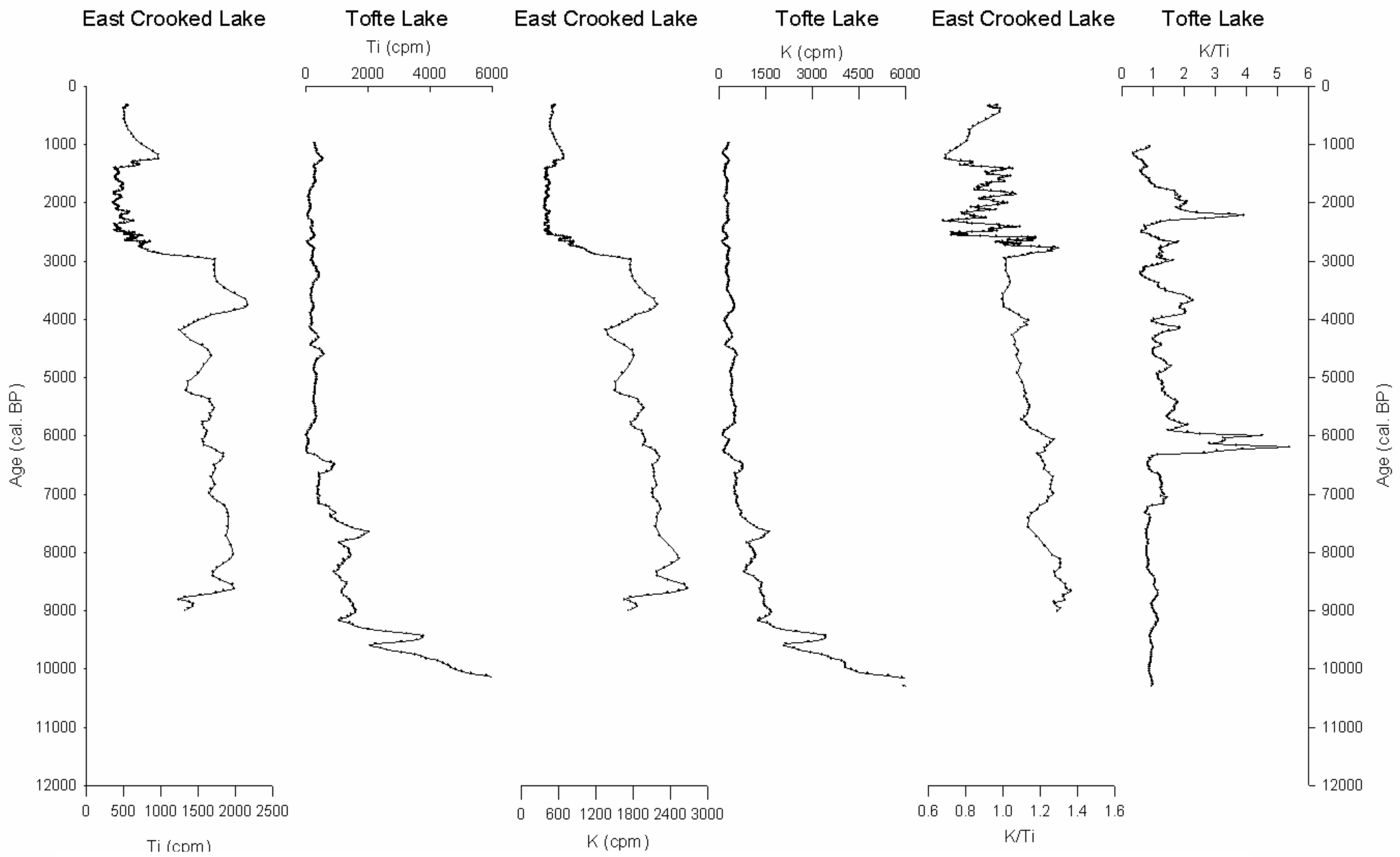


Figure 18. XRF Ti and K profiles for East Crooked Lake and Tofte Lake. The ratio of K/Ti for East Crooked Lake and Tofte Lake.

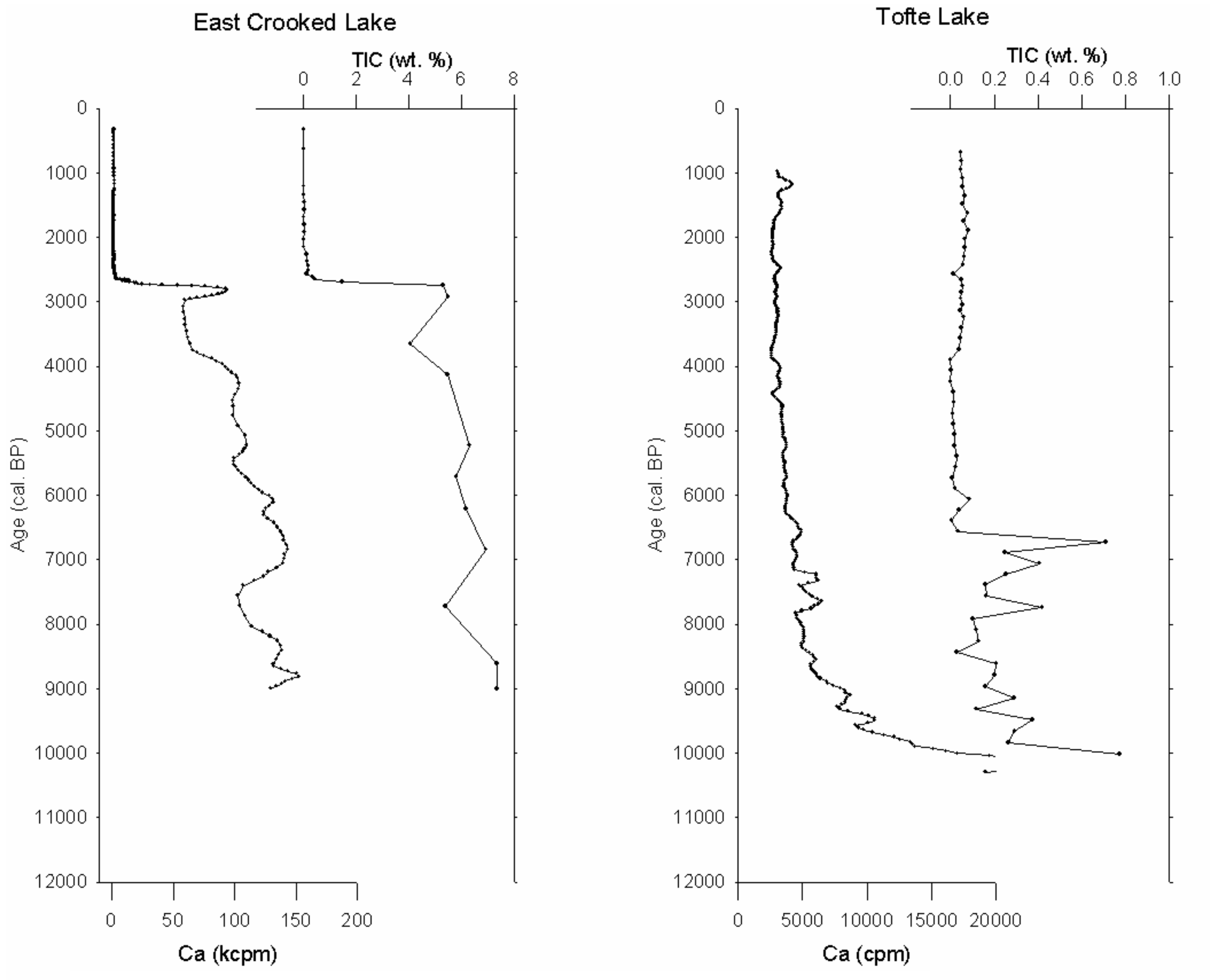


Figure 19. XRF Ca profiles and TIC profiles for East Crooked Lake and Tofte Lake.

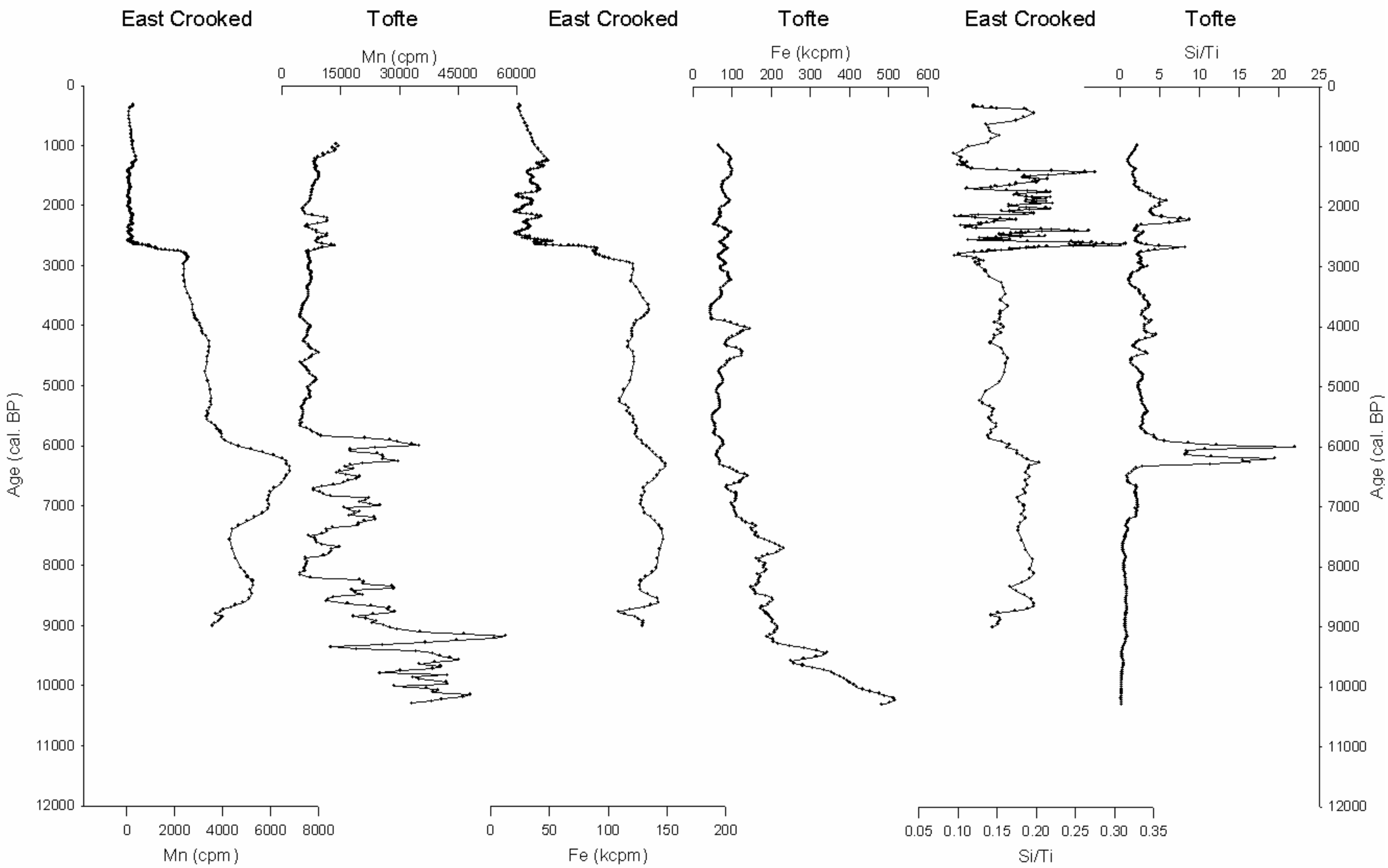


Fig. 20. XRF Mn and Fe profiles for East Crooked Lake and Tofte Lake. The ratio of Si/Ti for East Crooked Lake and Tofte Lake.

Chapter 6: Conclusions

This study set out to determine if the scanning XRF technology could produce climatic records comparable to those created by more traditional time-consuming methods employed by Dean (1993) in the well known Elk Lake core. The results confirm that scanning XRF can do so and in a fraction of the time. Comparisons between the Ti, K, and Si profiles from East Crooked Lake and Elk Lake not only show the same general trend, but also have a number of matching peaks and valleys. This shows that the dry events that are recorded at Elk Lake also affected other nearby lakes. Further high resolution XRF scans from the upper portion of East Crooked Lake could reveal a record of more recent climate events (Little Ice Age and Dust Bowl) recorded at Elk Lake.

One issue not fully resolved by this study is that of the timing of events at Elk Lake. It has been noted by several researchers (Schwalb and Dean, 2002; Wright et al., 2004; Nelson and Hu, 2008) that the timing at Elk Lake differs from that of other regional lakes by about 1 ky. The Elk Lake timescale developed in this study by pollen comparisons to Steel Lake is not meant to be the definitive timescale for Elk Lake. XRF scans for Steel Lake might provide a better means of stratigraphic comparison within the pollen derived periods. Magnetic profiles have also been used to compare the timing of major events at Steel Lake to other Minnesota Lakes and could be used again here (Geiss et al., 2003). A new series of radiocarbon dates on terrestrial macrofossils would provide the best timescale for Elk Lake and perhaps resolve the inconsistency between its chronology and those of other regional lakes. The major effect of this new timescale was lengthening the Prairie Period by ~1 ky.

XRF profiles from East Crooked Lake and Tofte Lake provided an opportunity to look for widespread regional climatic events. The Prairie Period at East Crooked Lake was a distinct feature, along with the transition to wetter conditions at 3 ka. There is no evidence of dust deposition at Tofte Lake during the Prairie Period indicating that dust from the Great Plains was not transported to NE Minnesota. Conditions at Tofte Lake have remained relatively wet from 8 ka to the present. The only similarity between the two locations is found by comparing their K/Ti ratios, which both show an increased variability after 3 ka and some possible century scale coincidences of drought. Increased frequency and intensity of drought has been reported by others for this same time period, i.e., from 3 ka to the present (Fritz et al., 2000; Laird et al., 1996; Tian et al., 2006; Yu and Ito, 1999).

The ratio of incoherent/coherent scatter is an accurate proxy for TOC with the major advantage of increased sampling resolution and decreased time for analysis compared to the use of coulometry. S also proved to be a good proxy for measuring TOC. Ca proved an accurate proxy for TIC in East Crooked Lake and Tofte Lake; however in Tofte Lake the low TIC values make the coulometry data more variable.

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Appendix I: All sediment cores collected

Lake	Core ID	Water depth (m)	Depth below lake floor (m)	Age (cal. BP)
East Crooked	TLX-ECR08-1A-2B-1	16	0.47-1.92	
East Crooked	TLX-ECR08-1A-3B-1	16	1.92-3.08	
East Crooked	TLX-ECR08-1B-1B-1	16	0-1.37	
East Crooked	TLX-ECR08-1C-1B-1	16	0-1.05	
East Crooked	TLX-ECR08-1C-1B-2	16	1.05-1.57	
East Crooked	TLX-ECR08-1C-2B-1	16	1.57-3.2	
East Crooked	TLX-ECR08-1D-1B-1	16	0-1.46	
East Crooked	TLX-ECR08-3A-1B-1	20.47	0.7-2.19	320-2567
East Crooked	TLX-ECR08-3A-2B-1	20.47	2.19-3.57	2567-8923
East Crooked	TLX-ECR08-3A-3B-1	20.47	3.57-4.2	8923-
East Crooked	TLX-ECR08-3B-1B-1	20.47	0-1.37	
Tofte	TLX-TFT08-1A-1B-1	20.8	0.29-1.56	695-2373
Tofte	TLX-TFT08-1A-2B-1	20.8	1.56-2.84	2373-3965
Tofte	TLX-TFT08-1A-3B-1	20.8	2.84-4.34	3965-6387
Tofte	TLX-TFT08-1A-4B-1	20.8	4.34-5.54	6387-8446
Tofte	TLX-TFT08-1A-5B-1	20.8	5.54-7.02	8446-
Tofte	TLX-TFT08-1A-6B-1	20.8	7.02-8.5	
Tofte	TLX-TFT08-1A-7B-1	20.8	8.5-9.96	
Tofte	TLX-TFT08-1A-8B-1	20.8	9.96-10.8	
Tofte	TLX-TFT08-1B-1B-1	20.8	0-1.18	
Tofte	TLX-TFT08-1B-1B-2	20.8	1.18-1.63	
Tofte	TLX-TFT08-2A-1B-1	6.32	0-1.04	
Tofte	TLX-TFT08-2A-2B-1	6.32	1.04-2.55	
Tofte	TLX-TFT08-2A-3B-1	6.32	2.55-4.05	
Tofte	TLX-TFT08-2A-4B-1	6.32	4.05-5.5	
Tofte	TLX-TFT08-2B-1B-1	6.32	0-1.33	
Fish	TLX-FSH08-1A-1B-1	8.05	0-0.42	
Fish	TLX-FSH08-1A-2B-1	8.05	0.42-1.7	
Fish	TLX-FSH08-1A-3B-1	8.05	1.7-2.5	
Fish	TLX-FSH08-1B-1B-1	8.05	0-1.12	