Late-Quaternary Vegetational History of the Yellowstone Region

by

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POSTGLACIAL FIRE FREQUENCY AND ITS RELATION TO LONG-TERM VEGETATIONAL AND CLIMATIC CHANGES IN YELLOWSTONE PARK

ABSTRACT

In ongoing research, we are studying the vegetational history of Yellowstone and Grand Teton Parks and the long-term response of vegetation to changes in climate and fire frequency. A pollen record from Slough Creek Pond provides information on the development of plant communities on Yellowstone's Northern Range. The late-glacial pollen sequence suggests a progression from tundra vegetation with birch and juniper to spruce parkland to open forest of lodgepole pine and whitebark or limber pine. The early and middle Holocene record is dominated by mixed pine forest. The late-Holocene record indicates a gradual replacement of pine forest to more open Douglas-fir forest and grassland in the last 3000 yrs.

The fires of 1988 in Yellowstone provide a set of conditions that help disclose the relationships between vegetation, climatic change, and fire frequency on short and long time scales. Field and laboratory studies are underway to monitor some of the biological and sedimentological inputs into lakes in the aftermath of the recent fires. The calibration of these inputs--sedimentary charcoal, pollen, and magnetic minerals--with size and type of burn are the basis for reconstructing past fire conditions from the stratigraphic record.

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INTRODUCTION

The sediments of lakes preserve a rich record of past environmental change, not only those that occurred within the lake but also changes in the surrounding terrain. Cores from natural lakes and wetlands offer a continuous stratigraphic record of sediment, microfossils, and charcoal that can be used to reconstruct a landscape history. The chronologic framework for paleoecologic interpretations comes from radiometric dating of the sediments or individual plant remains and from identification of tephra layers that have been radiometrically dated elsewhere. Fossil pollen is the most widely used data base to study long-term changes in plant communities, vegetation, and climate. Charcoal contained in lake sediments offers indirect information on fire frequency, which can be linked with pollen records to study the disturbance history of a watershed. Stratigraphic records of diatoms provide information on past variations in pH, water temperature, and water chemistry often related to lake-level fluctuations. The paleomagnetic properties of sediments are used to study clastic input and thus the erosion history of the watershed. When considered together, the biological and physical components of lake sediments are powerful tools for tracing the history of vegetation, slope processes, disturbance, lake conditions, and climate within a region.

To understand an ecosystem's response to different fire intensities requires information on the natural variability of

fire under different vegetational and climatic regimes. Determination of the prehistoric fire frequency over a long time range can take two approaches. The first involves the study of fire-scarred tree rings on surviving trees, along with an analysis of stand ages for trees that depend on fire for regeneration (Heinselman 1973). This method has been applied by Romme and Despain (Romme 1982, Romme and Despain 1989) and Taylor (1969, 1973) to the Yellowstone Plateau and by Houston (1973) to the northern part of the Park.

The second approach is to analyze the frequency of charcoal particles in lake sediments (Swain 1973). The calibration of charcoal with known fire events is improved when charcoal is studied in lakes with annually laminated (varved) sediments (Clark 1988a,b,c). In the absence of annually laminated lake sediments, the sedimentation rate and thus the chronology can be determined by lead-210 analysis, a dating method for the last 150 years. Older sediments in a core can be dated by the radiocarbon method, which is useful back to 35,000 years. Thus charcoal analysis of contiguous samples from a radiometrically-dated or an annually laminated record permit the natural frequency of local fires to be determined over hundreds or thousands of years of forest history.

Objectives of research

The primary research objective has been to study the vegetational history of Yellowstone and to examine its sensitivity to changes in climate and fire frequency. To

accomplish this objective, a network of radiocarbon-dated pollen records has been analyzed from different types of vegetation within the Park. This database is used to reconstruct the long-term vegetational and climatic changes in the region over two time spans--the Little Ice Age (ca. A.D. 1200-1850), when the climate is believed to have been cooler and wetter than the centuries before or afterward, and the last 13,000 years since the end of the Pinedale Glaciation. To add to the network of sites, a pollen record was studied this year from Slough Creek Pond to document the vegetational changes in the Northern Range during the last 11,000 years.

We are also examining the frequency of prehistoric forest fires in Yellowstone through a study of charcoal, pollen, and paleomagnetic minerals in lake sediments. The fire history is based upon relationships between the fire inputs into lakes from the 1988 fires (e.g., charcoal, pollen, magnetic minerals) and the characteristics of the burned catchment. The fire research is divided into three parts:

1. A study of the depositional processes that incorporate charcoal into lake sediments. We are sampling biannually a set of lakes in the 1988 burned region to calculate charcoal abundance with respect to water depth. These measurements are compared with charcoal distribution in lakes that lie outside the burned region in order to calibrate charcoal abundance and particle size as a function of distance from a fire.

2. An analysis of the last 200 years of sediments from lakes on the Central Plateau to determine if sedimentary charcoal records correlate well with the fire chronology based on dendrological studies (Romme 1982, unpublished data). In this part, charcoal abundance, pollen composition, and paleomagnetic characteristics are examined at closely spaced intervals in meter-long cores.

3. An analysis of soils in the burned catchments to determine if soil mineralogy was altered by high temperatures during the 1988 fires. Identification of new mineral phases will allow us to reconstruct the temperature of soil heating.

Significance

The paleoecologic record provides unique insights into the response of communities to environmental perturbations of different duration and intensity. Climate is a primary agent of environmental change and its long-term effects on the vegetation of the Yellowstone/Grand Teton are revealed in a regional network of pollen records. Fire frequency is controlled by climate, and as climate changes so too will the importance of fire in shaping and maintaining spatial patterns of vegetation. The prehistoric record of Yellowstone's Northern Range, for example, shows the response of vegetation to the absence of major fires in the last 150 years (Whitlock et al. in press, Engstrom et al. in press). In longer records spanning the last 13,000 years, periods of frequent fires are suggested by sediments containing high percentages of lodgepole pine and Douglas-fir and abundant charcoal (Barnosky et al., 1987). At present, quantitative estimates of fire frequency in the Park are limited to dendrological data from forest stands no older than 400 years. These records are not adequate for estimating long-term fire variability with respect to postglacial climate change. Longer records from lake sediments will help determine whether 300-year fires are not in fact millennial scale events.

Results of this study should also assist in the prediction of fire frequency in the next 50 years, when the anticipated increase in global temperature may result in enhanced droughts and lightning ignitions. If the climate of the last few years is indeed a response to elevated carbon-dioxide levels, we can expect two consequences in continental interiors: drier/warmer summers and more-frequent fires (Rind et al., 1989). Fires themselves release significant amounts of carbon dioxide and other gases and thus are an inextricable part of the greenhouse cycle. If the 1988 conflagration portends the fire regime of the next several decades, it is important to have a better understanding of fire history on millennial time scales, when the range of climatic change and vegetational response was greater than that provided by the historic record. The fossil record contained in dated lake sediment cores is a proven way to obtain this paleoenvironmental information.

STUDY AREA

Fossil pollen records have been studied from a transect of six lakes in the Pinyon Peak Highlands, extending from northern Jackson Hole to the southern boundary of Yellowstone Park. The lakes are Hedrick Pond, Lily Lake and Fen, Fallback Lake, Divide Lake, Emerald Lake, Mariposa Lake (Fig. 1; Barnosky 1986, 1987). In addition records have been analyzed for Cygnet Lake on the Central Plateau (Barnosky 1989), and Slough Creek Pond on the Northern Range (Fig. 2; this report).

Pollen records have also been described from Cub Creek Pond (Waddington and Wright 1974), Buckbean Fen (Baker 1976), and Blacktail Pond (Gennett and Baker 1986); the paleolimnology of Alder Lake has recently been inferred from a postglacial diatom record (Barnosky 1989, Sherrod 1989).

The fire-history study has focused on six lakes in the 1988 burned region (Grizzly Lake, Cascade Lake, Blacktail Pond, Duck Lake, Goose Lake, and Lake of the Woods) (Fig. 2). Surface sediment has also been collected from Dryad Lake, Sylvan Lake, and Wrangler Lake in the unburned region. Short cores have been collected from Mallard Lake, Duck Lake, and Dryad Lake.

METHODS

Field

Pollen cores from Slough Creek Pond were collected with a 5-cm-diameter piston corer from a floating platform. Two sets were taken (a) to ensure that the deepest part of the basin was sampled; and (b) to provide sufficient material for pollen and plant macrofossil analyses, radiocarbon dating, and tephra analyses. Surface sediment was collected with a gravity sampler from an inflatable raft and from the ice surface. Local vegetation was noted, along with the topographic and geologic setting.

Charcoal samples were collected from Duck Lake, Goose Lake, Grizzly Lake, Cascade Lake, and Lake of Woods in October 1988, March and August 1989, and March 1990 along a transect from

shallow to deep water. Samples were taken at 0-1 and 1-2 cm depth at every 2 m (or less) of water depth. In March 1990 the sampling interval along the transect was changed to 0-2 and 2-4 cm sediment depth, because of the increasing importance of bioturbation with time.

One-meter cores were collected with a piston corer from Mallard, Duck, and Dryad lakes to study the last 200 years of fire history. The cores were extruded and sampled at 1-cm intervals in the field.

Soil samples were taken in the catchments of Duck Lake, Grizzly Lake, and Blacktail Pond to examine the changes in magnetic mineralogy that might be associated with soil heating. At each sampling site, oxidized, charred, and unburned sediment was collected.

Laboratory

POLLEN

The cores from Slough Creek Pond were sliced longitudinally and each core segment was described. Samples of 0.5 cc size were taken at regular stratigraphic intervals for pollen and sediment analyses; 50 levels were sampled, with particularly close sampling of late-glacial and early-Holocene sediments. One set of samples was used to determine the percentage of organic carbon and carbonate in the cores by measuring the weight-loss after ashing the samples at 550°C and 900°C.

Samples from the short cores were taken every 5 cm, and at 1-cm intervals above and below levels with abundant charcoal;

All pollen samples were treated to standard laboratory procedures (Faegri and Iversen 1975, Cwynar et al. 1979). A tracer of Eucalyptus pollen was added to each sample to calculate pollen concentration (grains/cm^3) and pollen accumulation rates (grains/cm^2/yr). Preparations were mounted in silicone oil and examined at magnifications of 400 and 1000X. Identification of fossil pollen was based on published atlases and the pollen reference collection at Carnegie Museum of Natural History. Between 300 and 500 terrestrial pollen grains were identified and tallied per stratigraphic level. Pollen percentages were calculated for each sample. A denominator of total terrestrial pollen was used to calculate the percentage of each terrestrial pollen type. The sum of all pollen and spores (including aquatic taxa) was used to calculate the percentage of aquatic and fen taxa.

AGE DETERMINATIONS

Radiocarbon dating of the sediment is the main method for calculating the age of pollen stratigraphic and lithologic boundaries. Five samples from Slough Creek Pond were sent to the NSF-Arizona AMS Facility for accelerator dating; two samples from the Duck Lake were submitted to Beta Analytic, Inc. (Table 1).

The lead-210 method was used to date the last 150-200 years in short cores from Duck, Dryad, and Mallard lakes. Lead-210 was measured through its granddaughter product ^{210}Po, with ^{208}Po

added as an internal yield tracer. Dates and sedimentation rates were determined by Dr. William Schell (Department of Radiation Chemistry, University of Pittsburgh), using the c.r.s. (constant rate of supply) model (Appleby and Oldfield 1978).

Some of the cores also contained tephra layers of known age: Mt. St. Helens ash--A.D. 1980, Mt. Mazama ash--ca. 6700 yr B.P., Glacier Peak ash--ca. 11,200 yr B.P. These layers provided useful time markers independent of the radiocarbon and lead-210 dates.

CHARCOAL

Charcoal analysis was confined to macroscopic particles. Surface sediments were sampled volumetrically and the dry weight was calculated. The samples were disaggregated in a dilute Calgon solution and gently sieved through successively finer mesh screens (1 mm, 0.5 mm, 0.25 mm, 0.125 mm). Sediment <0.125 mm was also saved. Charcoal for each size fraction was tallied under a binocular microscope. The charcoal quantities were calculated as number of charcoal/cm^3 and number of charcoal/gm for the different size fractions. The results were converted to charcoal flux (number of charcoal/cm^2) by multiplying charcoal concentration by depth of core sample. Charcoal analysis is undertaken by Sarah Millspaugh (Department of Geology and Planetary Sciences, University of Pittsburgh), as part her M.S. thesis research.

Contiguous charcoal samples were taken from the short cores at 1-cm intervals. They were prepared and analyzed with the methods described above.

MAGNETIC ANALYSES

Magnetic susceptibility measurements were taken every cm for the uppermost 50 cm and analyzed by Dr. William Harbert (Paleomagnetic Laboratory, University of Pittsburgh). A continuous-core magnetic susceptibility sensor was used to allow rapid nondestructive measure of magnetic susceptibility of the sediment.

Soil samples were analyzed for magnetic susceptibility and thermal remanence magnetism.

RESULTS

Postglacial vegetation history near Slough Creek Pond

A preliminary pollen record from Slough Creek Pond provides information on the history of the parkland communities on Yellowstone's Northern Range (Fig. 3). Prior to ca. 11,000 yr B.P. the pollen record is dominated by high percentages of Artemisia (sagebrush) and moderate percentages of Juniperus-type (juniper) and Betula (birch). The birch species is identified from macrofossils to be dwarf birch (B. glandulosa). Various herbaceous pollen taxa are also present in small amounts, including grasses, sedges, species of Rosaceae, Compositae, and Ranunculaceae, as well as Stellaria, Shepherdia, Rumex, and Polygonum bistortoides. Pine (Pinus)

and spruce (Picea engelmannii) are represented by low pollen percentages.

Percentages of Picea pollen increase and decline ca. 11,000 yr B.P. This peak is followed by increased percentages of Haploxylon-type Pinus (either whitebark pine [P. albicaulis] or limber pine [P. flexilis]) and Diploxylon-type Pinus (probably lodgepole pine [P. contorta]). Pine pollen is abundant and occurs with Picea, Abies (fir), Artemisia, and Chenopodiineae pollen until ca. 7000 yr B.P. The presence of needles of both lodgepole pine and limber pine indicates that they were both growing in the Slough Creek Pond watershed. After 7000 yr B.P., Pinus percentages decrease, Gramineae (grass) pollen increases, and pollen of Pseudotsuga (Douglas-fir) and Populus (probably aspen) are present in small amounts. Juniperus-type pollen and Betula pollen occur in moderate amounts between ca. 6700 yr B.P. (Mazama time) and ca. 3000 yr B.P. After ca. 3000 yr B.P. grass percentages increase and alternates in abundance with Pinus and Artemisia percentages. Cyperaceae (sedge) pollen is more common in the last ca. 2000 years, when it is associated with abundant fruits of bulrush (Scirpus) and cattail (Typha).

In many respects the pollen record from Slough Creek Pond is similar to others from Yellowstone and Grand Teton Parks. Most records begin with a prominent herb phase (>10,000 yr B.P.) composed of pollen types typically found in modern pollen samples from subalpine parkland and alpine tundra

environments. _Juniperus_-type pollen is present in small percentages and attributed to _J. communis_, which grows to high elevations in dry areas with few competitors. _Betula glandulosa_ also grew on the landscape, probably on poorly drained substrates. Comparison with modern pollen data suggests that this phase was a period of alpine parkland and meadow communities with few if any trees in the Yellowstone/Grand Teton region. The herbaceous phase is followed by high _Picea_ percentages ca. 11,000 yr B.P. Needles of _P. engelmannii_-type are usually associated with this pollen assemblage, confirming that Engelmann (or possibly white) spruce was among the earliest conifers to move into the deglaciated region. Percentages of _Pinus_ (Haploxylon-type) increase toward the end of the spruce phase. Whitebark pine (_P. albicaulis_)is the likely contributor of Haploxylon-type _Pinus_ pollen, although limber pine cannot be ruled out as another pollen source. _Abies_ pollen is present in moderate amounts at many sites at ca. 11,000 yr B.P. It is present in the Slough Creek Pond record at about this time, but only in trace amounts. The mixture of conifer pollen suggests the establishment of a subalpine forest not unlike the present-day spruce-fir-whitebark pine forest at higher elevations and on andesitic substrates in Yellowstone.

Following the spruce-fir-whitebark pine phase, most sites show a dramatic increase in Diploxylon-type _Pinus_ at 10,000 yr B.P., attributed to the expansion of lodgepole pine forest.

Likewise, the early-Holocene record at Slough Creek Pond suggests a widespread pine forest, dominated by lodgepole pine, but with spruce, limber pine, and possibly whitebark pine also present. Moderate amounts of sagebrush pollen and low percentages of Chenopodiineae, Juniperus-type, Betula, and Gramineae pollen imply the presence of forest openings. These taxa indicate warmer conditions than before. Warming is also inferred by an increase in algal productivity, measured by the high organic and carbonate content of the sediment.

The pine period is accompanied by low percentages of Pseudotsuga pollen. Modern pollen data suggest that this pollen type is present only when Douglas-fir is common in the local vegetation (Barnosky 1987). In the Grand Teton region, pollen of Shepherdia canadensis (buffaloberry) and Populus tremuloides-type (aspen) are also at their highest values between 8000 and 4000 yr B.P. The increase in pollen of low-elevation taxa suggests that their range extended to higher elevations than it does today. This biogeographic extension implies a longer growing season and probably more frequent fires than before.

At Slough Creek Pond and nearby Blacktail Pond (Gennett and Baker, 1986), grass became important an constituent of the vegetation after 4500 yr B.P., and especially after 3000 yr B.P. Its increase, along with the better representation of Pseudotsuga pollen at that time, suggests the introduction of more severe summer drought in the late Holocene and the

development of open Douglas-fir forest. Aspen groves were also present on the landscape in late-Holocene time, although aspen was not pollinating in greater abundance than today. Between 2000 and 800 yr B.P., lodgepole pine and sagebrush percentages increase slightly at the expense of grass percentages. This interval may reflect a period of slightly cooler and/or wetter conditions and lower fire frequency. It is interesting to note that Douglas-fir pollen is most abundant in the topmost sample at Slough Creek Pond, which suggests that it has never been more common on the landscape than it is today. This conclusion was also reached in a detailed pollen study of the last 200 years (Engstrom et al. in press).

Characterization of the 1988 fires and their input into lakes and wetlands

CHARCOAL DEPOSITION

The first task has been to determine the most useful size fraction of charcoal for identifying a local fire event in the lake sedimentary record. The abundance of charcoal for different size fractions was examined in lake surface sediments from burned and unburned regions. Charcoal <125 mu in size was found to be abundant in lakes from both burned and unburned watersheds; for that reason, we decided that the small particles were not a good tool for distinguishing between local and extralocal events. Charcoal ranging in size

from 125 to 250 mu was abundant in lakes with burned watersheds and poorly represented in lakes that lay more than 5 km from the fire limit. Larger charcoal pieces (>250 mu) were present regularly in burned watersheds but were uncommon in all samples. Based on these preliminary results, we directed our analysis towards charcoal pieces between 125 and 250 mu in size. This size class seems to be well represented in sites where the catchment was burned and its abundance decreases dramatically in lakes that lie more than 5 km from a fire. Sampling of additional lakes from outside the 1988 fire region is underway to test further our assumptions.

The next step has been to study charcoal distribution within a lake. Does, for example, charcoal from a deep-water sediment core reliably record all local fire events? Or, is it necessary to collect cores from the periphery of the lake to detect major fires in the past? Analysis of the charcoal from Duck Lake provides some preliminary information (Fig. 4). A transect of surface samples taken from shallow to deep water shows the movement of charcoal in the basin following the 1988 fires. The movement of charcoal from shallow- to deep-water sediments occurred in several stages. Most charcoal was introduced during the fire as airborne fallout. Although some charcoal was deposited in deep water in 1988, much of it resided in the water column and was carried to shallow water by subsequent wind and wave action. Additional charcoal was introduced to the lake by slopewash processes after the 1989

snowmelt, as suggested by the increase of charcoal in shallow-water samples in August 1989. Charcoal abundance in deep water seems to have been fairly constant during the first two years, which suggests that the deep-water sediments at Duck Lake provide an integrative record of local fires with little time lag. We hypothesize that charcoal from the 1988 fires will stabilize at all sites during the next two years, after which time the amount and size distribution of charcoal in the deep water will not vary significantly.

MAGNETIC PROPERTIES OF BURNED SOILS

Soil minerals become magnetized to different degrees during a fire depending on the intensity of the burn. Anomalous values of magnetic parameters caused by the presence of fire-induced magnetic minerals can be detected in cores from variations in susceptibility (X), saturation isothermal remanent magnetization (SIRM), saturation magnetization during heating (Js-T), and thermal demagnetization experiments. Fire-induced magnetization results in a significant increase in sample susceptibility and the presence of very fine-grained (<1mu) magnetite or maghaemite (LeBorgne 1955). Studies elsewhere have successfully utilized the identification of magnetic minerals produced by fires to constrain fire location, type, and intensity (Runnery et al. 1983, Thompson and Oldfield 1986).

Magnetic susceptibility measurements of the burned soils at Grizzly, Blacktail, and Duck lakes showed a significant

difference between oxidized (severely burned) soils and charred (modereately burned) and unburned soils (Fig. 5). These data imply some alteration of the soil minerals as a result of the 1988 fires. The thermal remanence magnetism of the samples was studied to examine in more detail the nature of this alteration. At Duck Lake changes in the magnetic moment during the heating and cooling of the samples indicated a low-temperature magnetic phase at 350°C. Mossbauer analysis is underway to identify this mineral and determine the temperature of soil heating.

Comparison of lake-sediment records with historically dated fires

Charcoal and paleomagnetic analyses are completed for Duck and Dryad lakes; charcoal analysis and lead-210 dating has been completed for Dryad Lake. At Duck Lake, the charcoal record shows major peaks of charcoal at 11-13 cm, 38-39 cm, 44-45 cm, and 50-51 cm depth (Fig. 6). These depths also registered high values of magnetic susceptibility, which we interpret as evidence of increased clastic material during fire-related erosion within the catchment (Fig. 6). Lesser peaks of charcoal at 8-9 cm, 34-35 cm, and 60-62 cm are not accompanied by increases in magnetic susceptibility. These peaks may represent extralocal fires (and hence no erosion in the watershed). Alternatively the charcoal may come from early summer fires that did not result in significant erosion.

This situation would be comparable to the 1971 Little Sioux fire in Minnesota, which occurred in May and produced a negligible fire signal in catchment lakes (Wright 1976, Bradbury 1986).

Lead-210 dates from Dryad Lake suggest a sediment accumulation rate of 7 yrs/cm. Thus our resolving power for dating fire events in nonvarved sediments is on the order of a decade. The Dryad Lake charcoal record shows a major fire event at 11-12 cm, which dates between A.D. 1882 and 1890 (Fig. 7). This peak corresponds well with Romme's evidence for a fire in the region 110-114 years ago. When the lead-210 dating is completed for all the sites, we will compare the short core data more closely with the dendrologic record.

CONCLUSIONS

The following conclusions can be drawn from this year's investigation of the prehistory of the Greater Yellowstone region:

1. The pollen record from Slough Creek Pond offers new information of the history of the Northern Range. Tundra communities occupied the region until 11,000 yr B.P. After 11,000 yr B.P. spruce, whitebark pine, and lodgepole pine were present on the landscape. With continued warming at 10,000 yr B.P., a forest predominately of lodgepole pine developed. Spruce, limber pine, and possibly whitebark pine were present in minor amounts, and forest openings supported sagebrush,

grass, and chenopods. Douglas-fir became a component of the forest after 6700 yr B.P. and especially after ca. 4500 yr B.P. Stands of aspen are also recorded after ca. 6700 yr B.P. Beginning 3000 yr B.P. grasslands expanded at the expense of forest and sagebrush communities. Inasmuch as grasses are favored over sagebrush wherever fires are frequent (recurrence interval of <25 years), the pollen record implies a shift towards more frequent fires well as increased summer drought beginning 3000 years ago. Lodgepole pine and sagebrush pollen increase slightly between 2000 and 800 yr B.P., perhaps as a result of cooler and/or wetter conditions and less-frequent fires than before. The record of the last 800 years shows a slight increase in Douglas-fir and grass, suggestive of more severe drought and frequent fires. Analysis of the macrofossil and charcoal record from Slough Creek Pond is underway to provide more detail on the vegetational changes and to clarify the fire history.

2. Small lakes in Yellowstone preserve a sedimentary record of the 1988 fires that can be used to interpret past fire events. Sampling of charcoal in lake surface sediments has been done regularly to trace the introduction and movement of charcoal in the lakes. Charcoal particles between 125 and 250 mu in size provide a good index for separating local from extralocal fires--this size range seems to be abundant in burned watersheds but not in unburned ones. Charcoal from the 1988 fires apparently enters the study lakes from two sources.

Much of it was introduced directly from atmospheric fall-out during the fire event. An additional component entered the system from subsequent snow-melt and from focusing of charcoal from the shallow-water to deep-water sediments. The relative importance of these sources seems to vary with each lake. At Duck Lake, for example, the amount of charcoal in deep water has not significantly changed, although there is considerable variability in charcoal abundance in the shallow-water sediments. Further sampling will determined whether the concentration of charcoal in the deep-water sediments has stabilized, and whether a core from the deep water will provide a good record of all fire events within the catchment.

3. Soils that were oxidized by the 1988 fires show alteration of their mineralogy and the formation of an intermediate magnetic mineral phase. Identification of this mineral phase is underway to determine the temperature of soil heating at those sites.

4. Short cores from Duck and Dryad lakes show charcoal peaks that represent fires in the catchment during the last 200 years. The largest charcoal peaks at Duck Lake correspond with peaks in magnetic susceptibility measurements, which indicate an input of clastic material. The combined charcoal/magnetic susceptibility signal is interpreted to be a local fire event that introduced abundant charcoal and caused erosion within the catchment. We hypothesize that smaller peaks of charcoal represent either distant fires, which

introduced only airborne charcoal into the system, or early summer fires that were not accompanied by significant erosion. Peaks of magnetic susceptibility not associated with charcoal suggest non-fire related erosion events. This hypothesis will be tested by examining short cores from the other study sites.

4. Lead-210 dating has been completed for Dryad Lake. A major charcoal peak between A.D. 1882 and 1890 matches well with the dendrological record of a major fire 110-114 years ago. Similar comparisons will be conducted for the remaining study sites, when the lead-210 ages are available.

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REFERENCES CITED

Appleby, P.G. and Oldfield, F. 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena 5: 1-8.

Baker, R.G. 1976. Late-Quaternary vegetation history of the Yellowstone Basin, Wyoming. U.S. Geological Survey Professional Paper, 729-E, 48 p.

Barnosky, C.W. 1986. Late-glacial and postglacial vegetation and climate of Jackson Hole and the Pinyon Peak Highlands. Annual Report to the UW-NPS Research Center, 25 pp.

Barnosky, C.W. 1987. Late-glacial and postglacial vegetation and climate of Jackson Hole and the Pinyon Peak Highlands, Wyoming. Annual Report to the UW-NPS Research Center.

Barnosky, C.W. 1989. Late-Quaternary vegetational and climatic history of the Yellowstone/Grand Teton region. Annual Report to the UW-NPS Research Center.

Barnosky, C.W., Anderson, P.M., and Bartlein, P.J. 1987. The northwestern U.S. during deglaciation; vegetational history and paleoclimatic implications. in Ruddiman, W.F., and Wright, H.E., Jr., eds., North American and adjacent oceans during the last deglaciation: Boulder, Colorado, Geological Society of America. The Geology of North America, v. 3.

Bradbury, J.P. 1986. Effects of forest fire and other disturbances on wilderness lakes in northeastern Minnesota II. Paleoelimnology. Archiv fur Hydrobiologie 106, 203-217.

Clark, J.S. 1988a. Particle motion and the theory of

stratigraphic charcoal analysis. Quaternary Research 30, 67-80.

Clark, J.S. 1988b. Stratigraphic charcoal analysis on petrographic thin sections. Quaternary Research 30, 81-91.

Clark, J.S. 1988c. Drought cycles, the "little ice age", and fuels: a 750-yr record of fire in northwestern Minnesota. Nature 334, 233-235.

Cwynar, L.C., Burden, E., and McAndrews, J.H. 1979. An inexpensive method for concentrating pollen and spores from fine-grained sediments. Canadian Journal of Earth Sciences 16, 1115-1120.

Engstrom, D.R., Whitlock, C., Fritz, S.C., and Wright, H.E., Jr. In press. Recent environmental changes inferred from the sediments of small lakes in Yellowstone's Northern Range. Journal of Paleolimnology.

Faegri, K. and Iversen, J. 1975. Textbook of pollen analysis. Munksgaard, Copenhagen.

Gennett, J.A. and Baker, R.G. 1986. A late Quaternary pollen sequence from Blacktail Pond, Yellowstone National Park, Wyoming, U.S.A. Palynology 10, 61-71.

Heinselman, M.L. 1973. Fire in virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3, 329-382.

Houston, D.B. 1973. Wildfires in northern Yellowstone National Park. Ecology 54, 1111-1117.

Le Borgne, E. 1955. Susceptible magnetique anormale du sol

superficiel. Ann. Geophysics 11, 399-419.

Rind, D., Goldberg, R., and Ruedy, R. 1989. Change in climate variability in the 21st century. Climate Change 14, 5-37.

Romme, W.H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs 52, 199-221.

Romme, W.H., and Despain, D.G. 1989. The Yellowstone fires. Scientific American 261, 37-46.

Runnery, T.A., Bloemendal, J., Dearing, J., Oldfield, F., and Thompson, R. 1979. The persistence of fire-induced magnetic oxides in soils and lake sediments. Ann. Geophysics 35,103-107.

Sherrod, B.S. 1989. Paleolimnology of Alder Lake and its implications for Holocene tectonics in Yellowstone National Park, Wyoming. M.S. thesis, University of Pittsburgh, 47 pp.

Swain, A.M. 1973. A history of fire and vegetation in northwestern Minnesota as recorded by lake sediments. Quaternary Research 3, 383-396.

Taylor, D.L. 1969. Biotic succession of lodgepole pine forests of fire origin in Yellowstone National Park. Unpublished Ph.D. dissertation. University of Wyoming, Laramie.

Taylor, D.L. 1973. Some ecological implications of forest fire control in Yellowstone National Park, Wyoming. Ecology 54, 1394-1396.

Thompson, R., and Oldfield, F. 1986. Environmental Magnetism: Allen and Unwin Ltd., London. 227 pp.

Whitlock, C., Fritz, S.C., and Engstrom, D.R. In press. A prehistoric perspective on Yellowstone's Northern Range. in Examining the Greater Yellowstone Ecosystem: land and resource management (M.S. Boyce and R.B. Keiter, eds). Yale University Press.

Wright, R.F. 1976. The impact of forest fire on the nutrient influxes to small lakes in northeastern Minnesota. Ecology 57, 649-663.

TABLE 1. RADIOCARBON DATES FOR YELLOWSTONE SITES, 1989

Site	Depth (m)[1]	Age (yr B.P.)	Lab No.	Comments
Slough Creek Pond				
	0.85-0.95	1840 ± 70	AA-4519	
	3.05-3.15	4550 ± 80	AA-4520	
	4.55-4.65	9585 ± 100	AA-4521	
	5.45-5.55	11,725 ± 140	AA-4522	Glacier Pk ash
	5.95-6.05	12,060 ± 130	AA-4523	
Cub Creek Pond[2]				
	Upper ash	9965 ± 110	AA-4517	Date on terrestrial plant debris
	Upper ash	13,000 ± 150	AA-4518	Date on sedge debris
	Lower ash	2560 ± 55	AA-4516	Date on wood; should be ca. 11,200 yr B.P.
	Lower ash	10,666 ± 185	Beta-21580	Date on Carex and plant debris
			ETH-3110	should be ca. 11,200 yr B.P.

[1]Depth from mud surface

[2]Taken from 5 core sets; samples correlated by stratigraphy

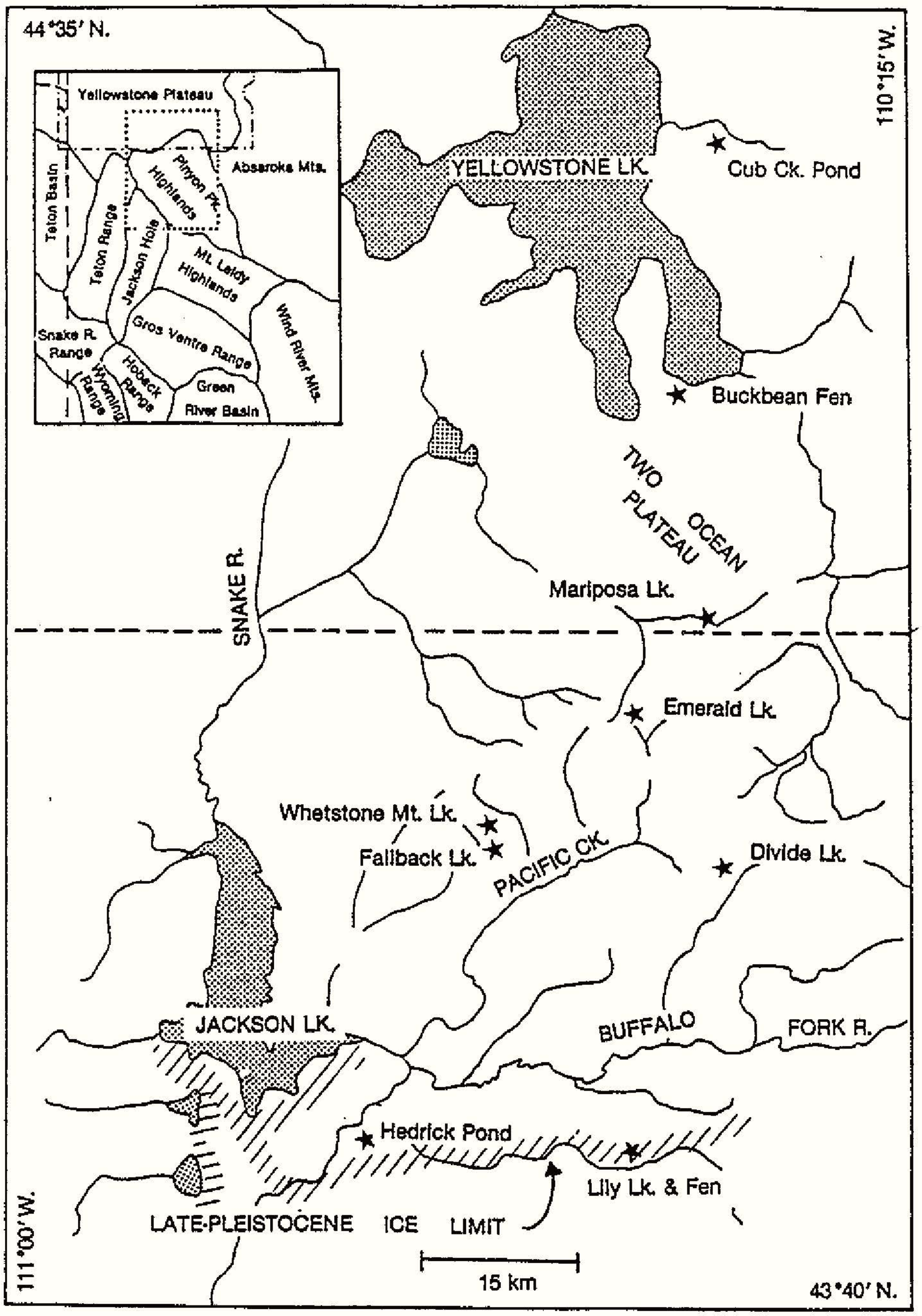

Figure 1. Location of fossil pollen sites from the Pinyon Peak Highlands, described in Barnosky (1986).

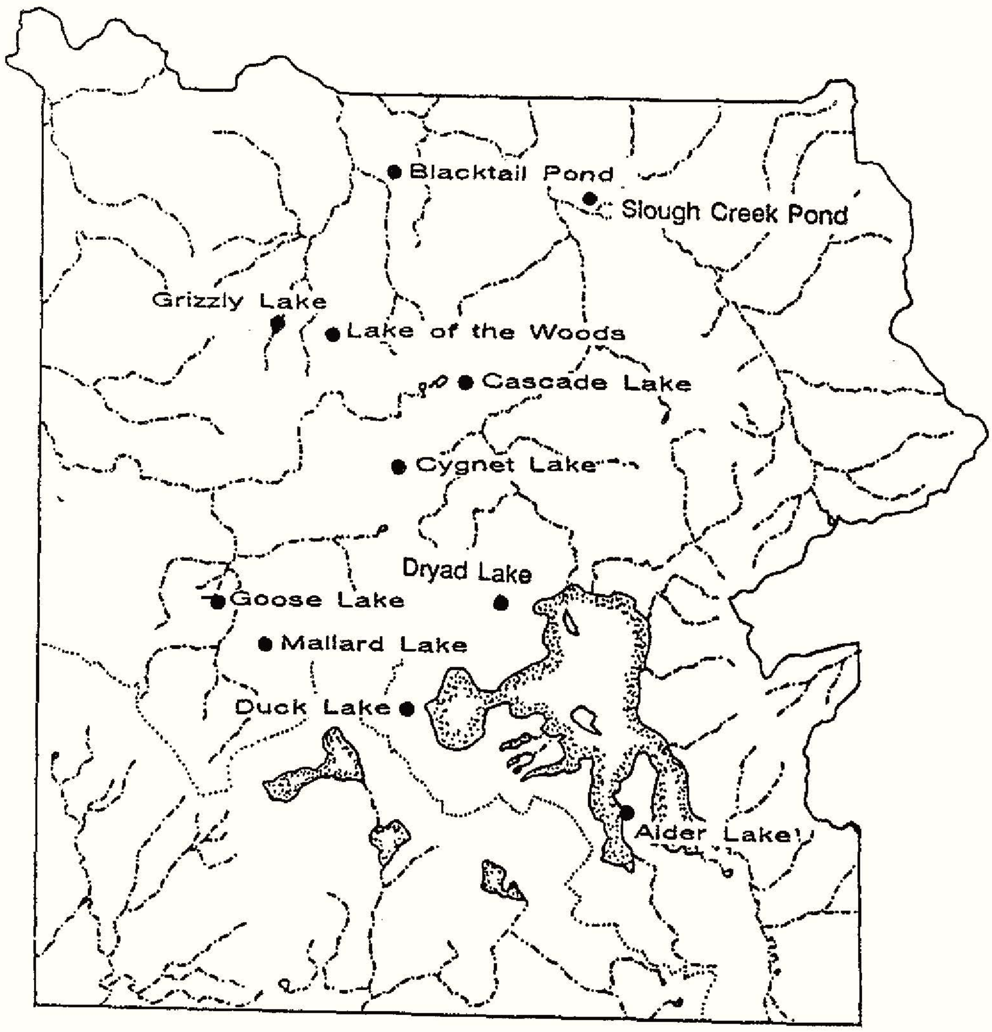

Figure 2. Location of Yellowstone sites discussed in text.

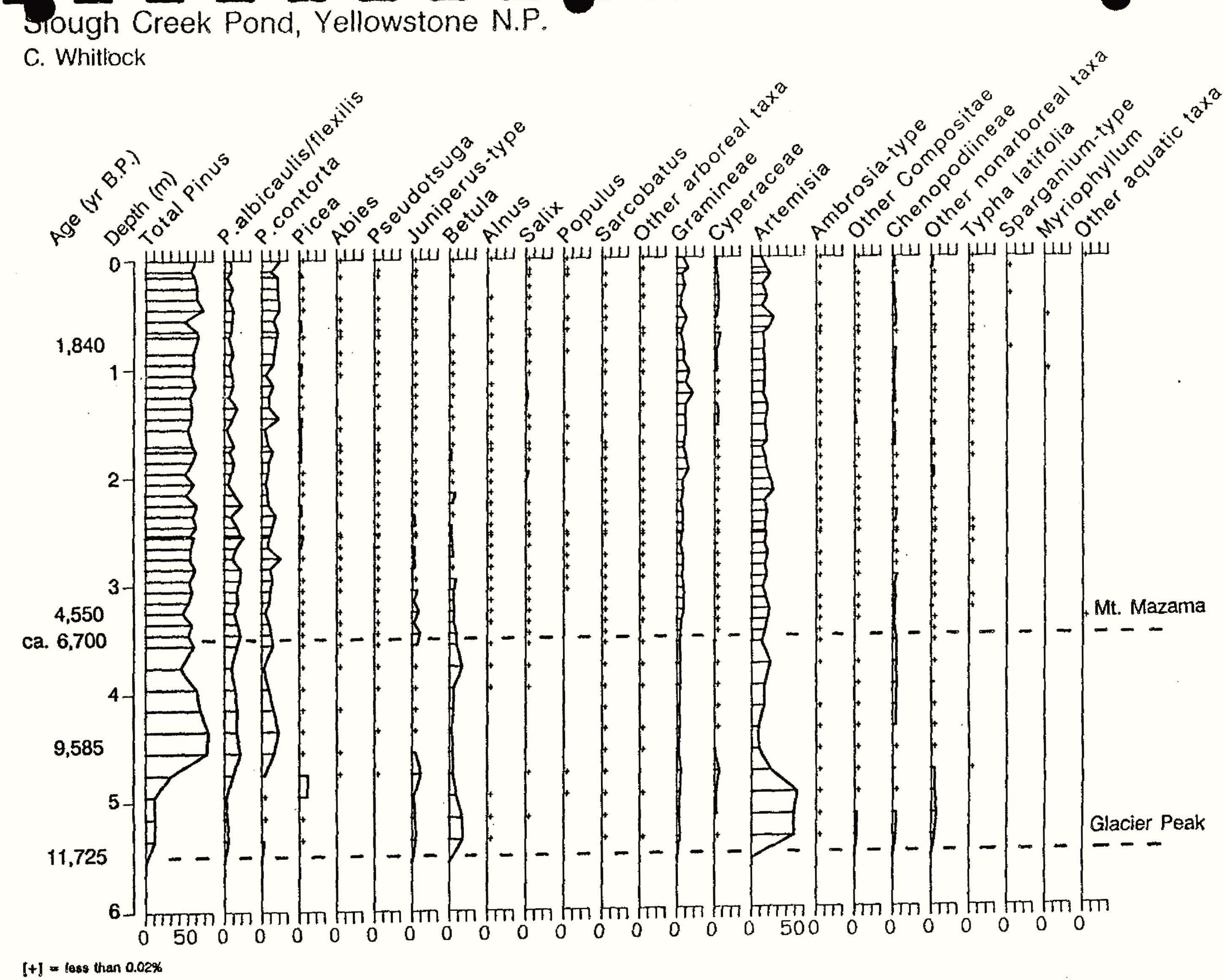

Figure 3. Preliminary pollen percentage diagram: Slough Creek Pond, Yellowstone

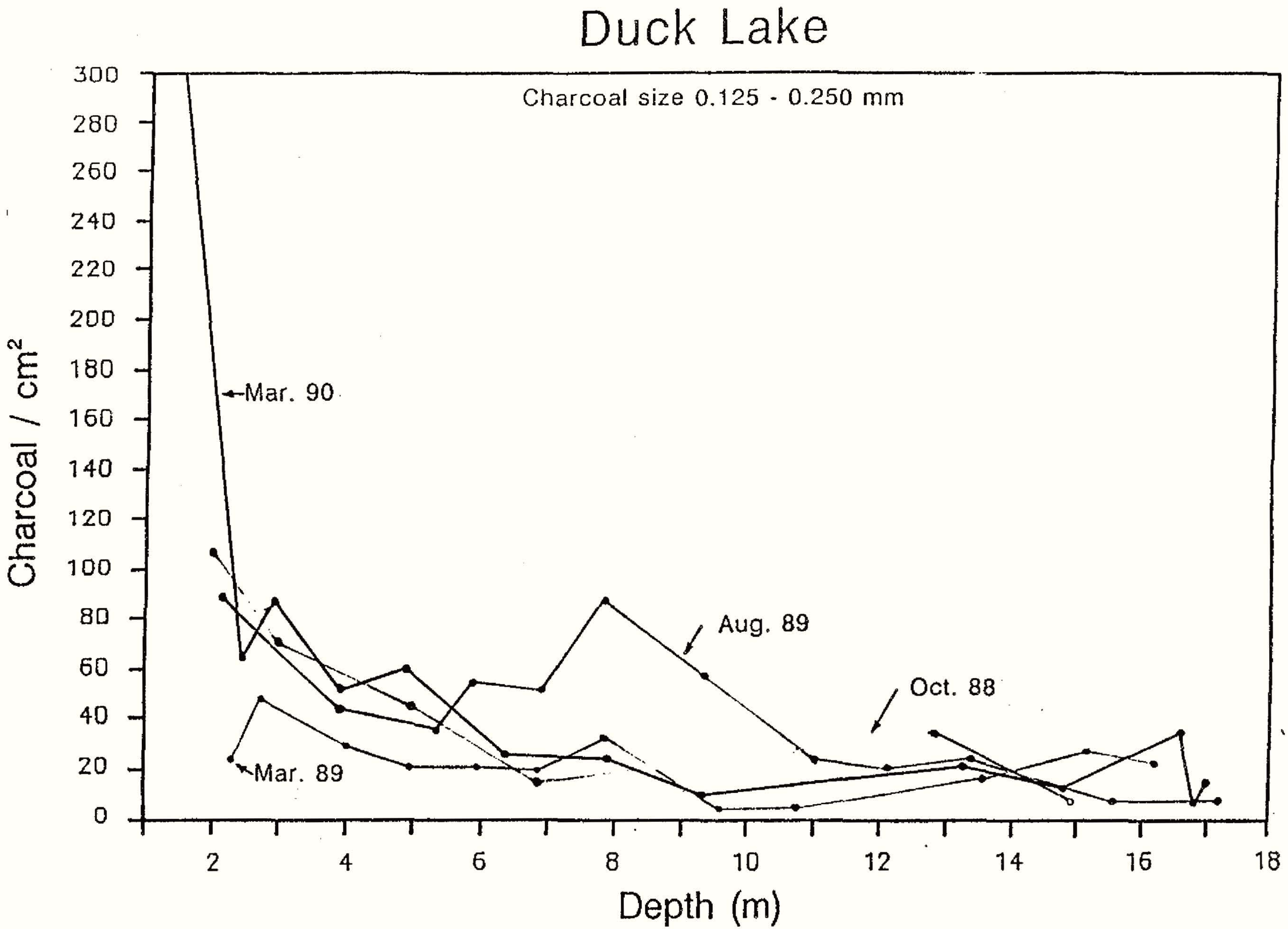

Figure 4. Abundance of charcoal (number/cm^2) in the surface sediment at different water depths in Duck Lake during four samplings between October 1988 and March 1990.

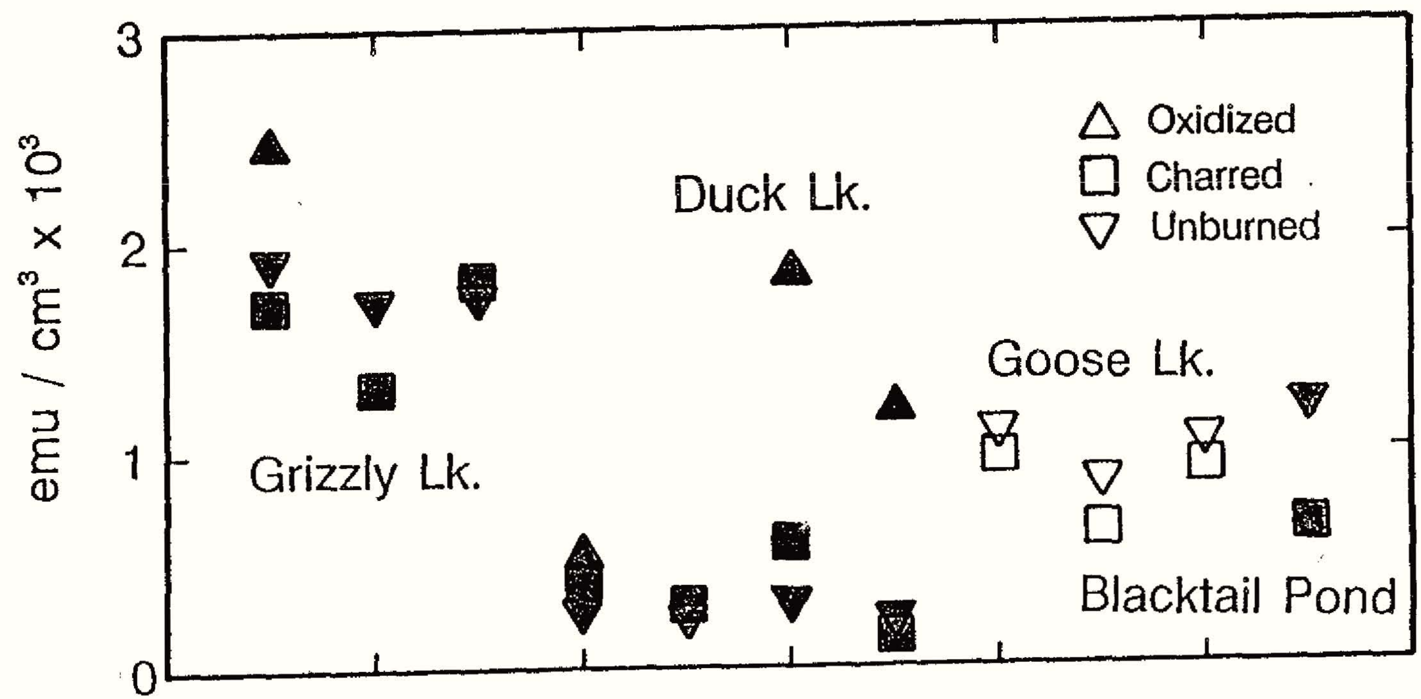

Figure 5. Magnetic susceptibility measurements on burned soils from the study catchments.

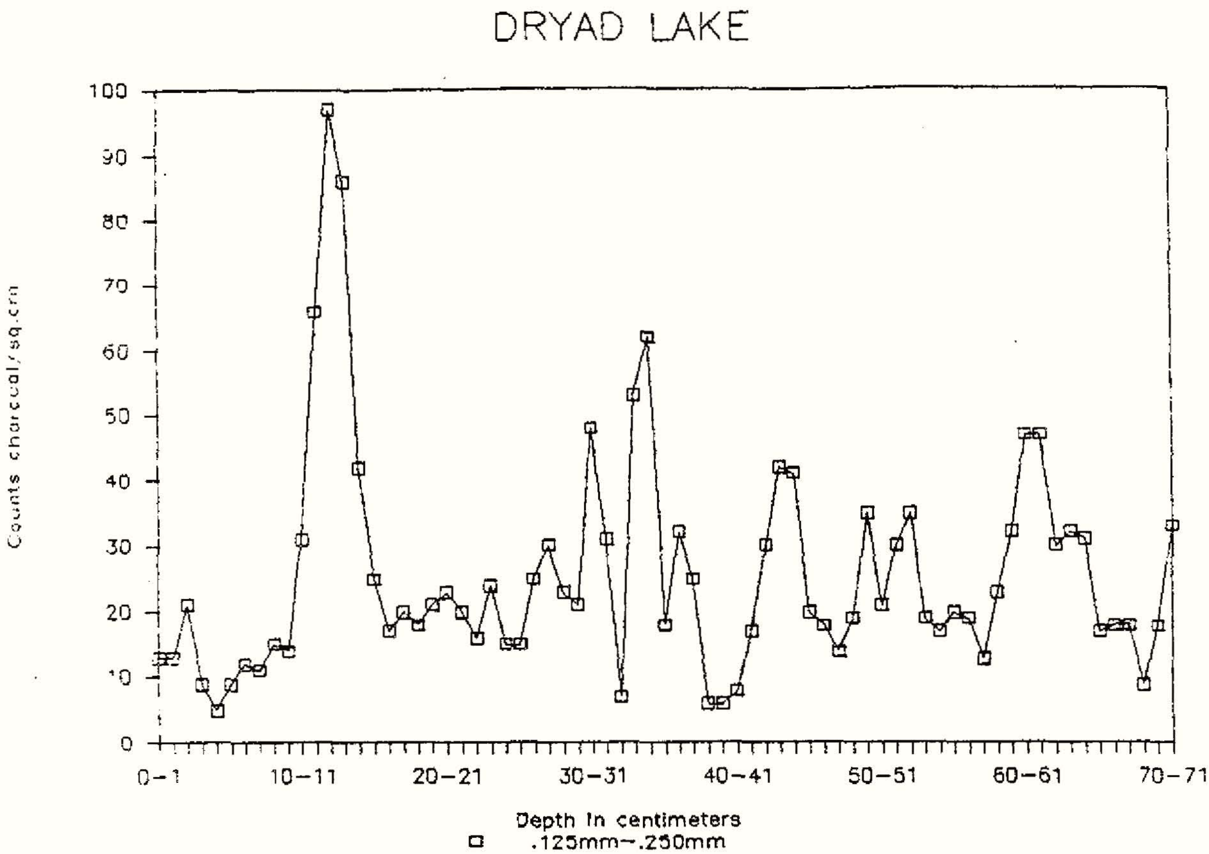

Figure 7. Charcoal analysis from the Dryad Lake short core.

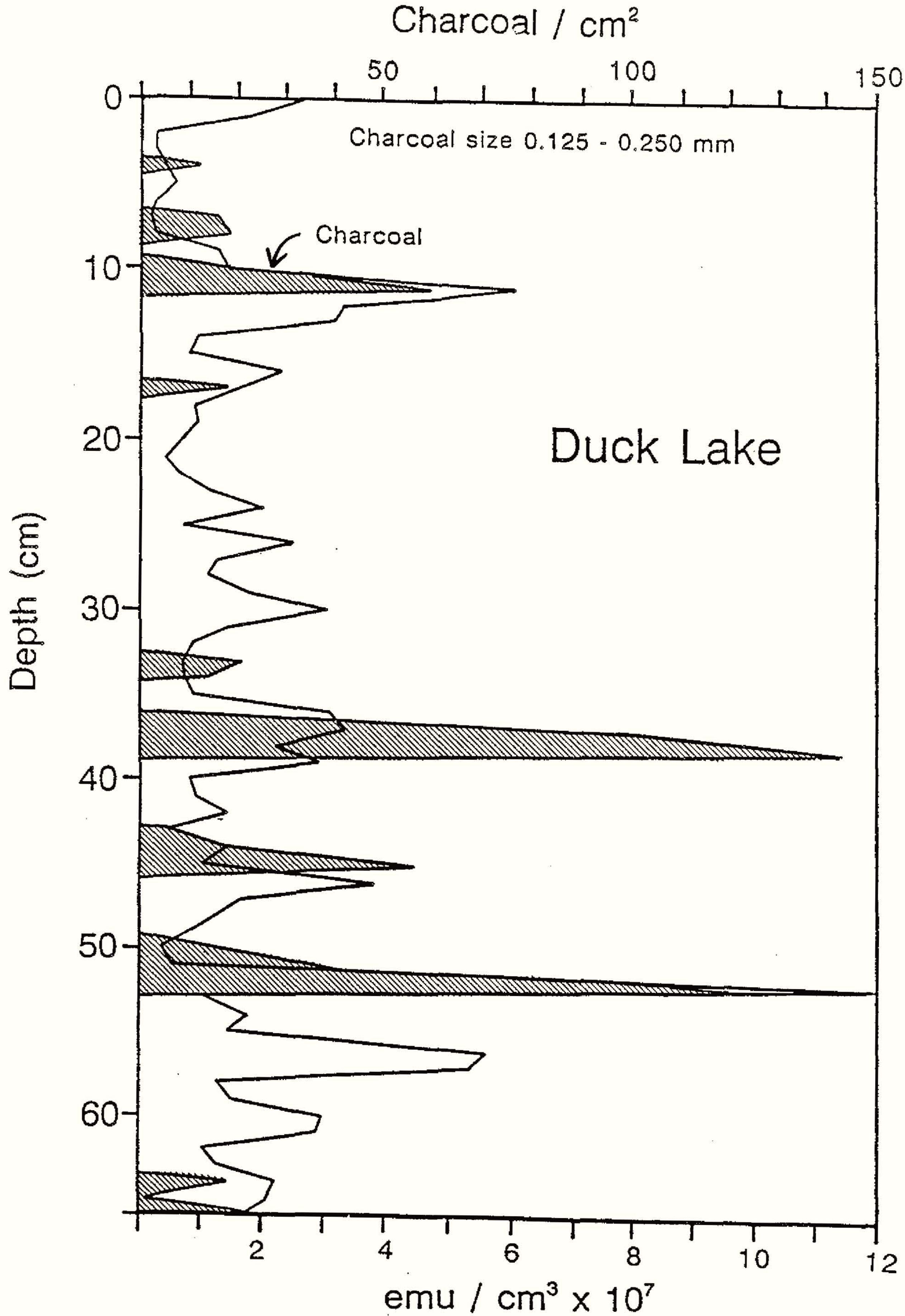

Figure 6. Charcoal analysis and magnetic susceptibility measurements from the Duck Lake short core.