1984

Prehistoric fire activity and vegetation near Flathead Lake Montana

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PREHISTORIC FIRE ACTIVITY AND VEGETATION
NEAR FLATHEAD LAKE, MONTANA

by

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B.A., University of Montana, 1978

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1984

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5-1-84
Date

Onken, Todd L., M.S., June 1984 Forestry

Prehistoric Fire Activity and Vegetation Near Flathead Lake, Montana (59 pp.)

Director: Dr. Nellie M. Stark NS

A recent study of fossil charcoal and pollen contained in the sediments of Lost Trail Pass Bog in southwestern Montana concluded that local fire frequency had increased significantly during the last 2000 years. Changing patterns of Indian land use and resource management were thought to be factors contributing to the increase in fire activity. The purpose of this study was to determine if a similar increase in fire activity uncaused by climatic change had taken place in the lower elevational plant communities near Flathead Lake in western Montana.

Fossil charcoal and pollen from a sediment core obtained from Flathead Lake were examined using standard palynological techniques. A statistical test was applied to determine if the mean charcoal influx in 14 samples from sediments deposited since 2000 years before present was significantly larger than that in 15 sediment samples deposited during the interval 2000-4000 years before present. A relative frequency pollen diagram was constructed to aid in the examination of the pollen assemblage for indications of vegetational and climatic change during the last 4000 years.

The mean charcoal influx (and therefore presumably fire activity) was not found to be significantly greater during the last 2000 years. The fossil pollen assemblage lacked definitive trends which indicated vegetational or climatic change during the past 4000 years. The end of an earlier, warmer climatic period, however, may be represented in about the oldest 500 years of sediments.

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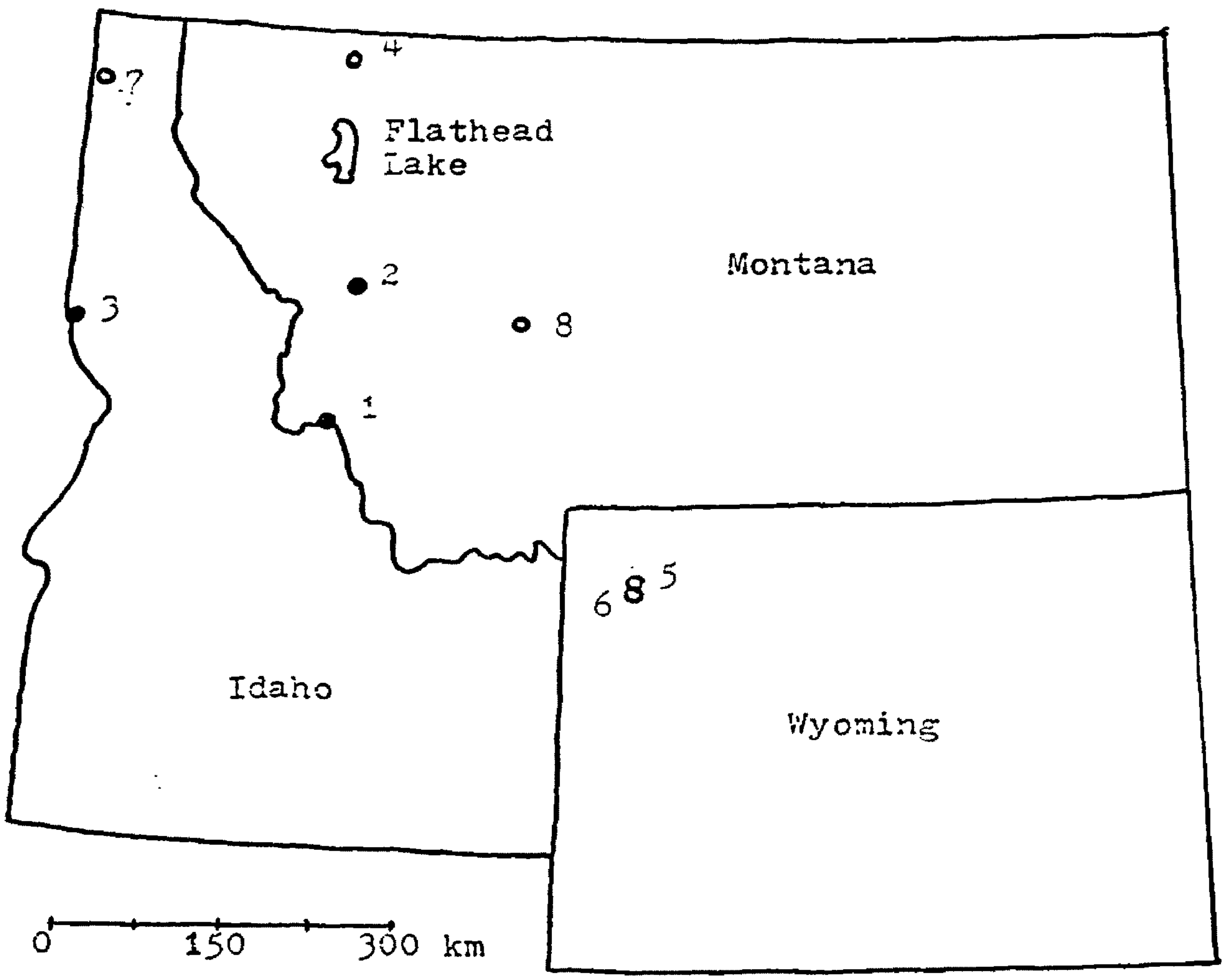
INTRODUCTION

Several palynological studies have been made of lake and bog sediments in the northern Rocky Mountains of western Montana, northern Idaho and northwestern Wyoming (Fig. 1) (Hansen 1948, Waddington and Wright 1974, Baker 1976, Mehringer et al. 1977, Mack et al. 1978a, Brant 1980, Hemphill 1983, Smith 1983). Most of the studies concerned themselves primarily with defining climatic changes based on changes through time recorded in the sediment fossil pollen assemblages. Three of the more recent works, however, also studied the charcoal content of the sediments to learn more about the local fire histories of the surrounding forests (Mehringer et al. 1977, Hemphill 1983, Smith 1983).

The 1977 report by Mehringer and others on the fire and climatic histories derived from the sediments of Lost Trail Pass Bog near Montana's southwestern border was of particular interest to forest fire ecologists. From the pollen record little change was apparent in the vegetation surrounding the bog during the last 4000 years since the end of a warmer climatic period. However, a drastic increase in annual airborne charcoal deposition was found during only the more recent half of the 4000 year period: "More charcoal was incorporated in the sediments during the last 2000 yr than during the preceding 9500 yr and over twice as much as during the relatively warm period from 7000 to 4000 BP" (years before present). Mehringer and others attributed the



•Charcoal and Pollen Studies
°Pollen Only Studies

1 Lost Trail Pass Bog (Mehringer et al. 1977)
2 Sheep Mountain Bog (Hemphill 1983)
3 Blue Lake (Smith 1983)
4 Johns and Fish Lakes (Hansen 1948)
5 Cub Creek Pond (Waddington and Wright 1974)
6 Buckbean Fen (Baker 1976)
7 Hager Pond (Mack et al. 1978a)
8 Telegraph Creek and Forest Lake (Brant 1980)

Fig. 1. Palynological studies reported from the northern Rocky Mountain region of the United States.

charcoal increase to more frequent low to medium intensity fires near the bog during the last 2000 years, the higher fire frequency perhaps due in part to changing patterns of Indian land use and resource management.

The Lost Trail Pass Bog results held some interesting implications for forest fire ecologists and land managers. The results implied that Indians had been an important source of fire ignitions during the pre-settlement period. As such they may have significantly influenced the fire regimes which created and maintained some presettlement vegetation patterns (Barrett and Arno 1982). Such fire regimes are important to forestland managers since "it seems prudent to gear the frequency of prescribed fire on a site to the wildfire frequencies that existed prior to organized fire suppression" (Davis et al. 1980).

Two other studies similar to that conducted at Lost Trail Pass Bog (elevation 2152 m) have been recently completed. Hemphill (1983) reported that the results from a study on 2800 years of Sheep Mountain Bog sediments at 1920 m elevation in western Montana agreed with the interpretation of the charcoal record from Lost Trail Pass Bog. The number of fires was seen to have increased since about 2000 BP near Sheep Mountain, with an even more substantial increase in fire frequency during about the last 1100 years, without fossil pollen evidence of climatic changes. Regional alteration in Indian land use or populations was thought to be responsible. Smith (1983) analyzed 4300 years of sediments accumulated in Blue Lake (1035 m) in northern

Idaho near the forest-steppe ecotone. Like Mehringer and others (1977), Smith found vegetational evidence that a warmer and possibly moister climate had given way dramatically to cooler conditions about 4000 BP. Also like Mehringer and others, Smith reported that fire frequency seemed to have continually increased through the last 4000 years unaccompanied by fossil pollen evidence of major climatic change. An especially apparent increase in the number of low intensity fires over the last 700 years near Blue Lake was attributed to intensified Indian activity including intentional burning of the forest understory.

Of the five regional non-fire history studies identified in Fig. 1, all but one confirmed the presence of the dramatically warmer period which ended about 4000 BP as reported by Mehringer and others (1977) and Smith (1983). Hansen (1948) agreed that the period ended about 4000 BP in Glacier National Park in northwestern Montana, but his evidence suggested that the period was drier as well as warmer than present. Waddington and Wright (1974) concluded that the warmer, but not necessarily drier or moister, period (the "Altithermal interval") ended about 4500 BP in Yellowstone National Park in northwestern Wyoming. Also in Yellowstone, Baker (1976) reported that the Altithermal interval was drier as well as warmer than present, and that it ended about 5000 BP. Mack and others (1978a) in northern Idaho concluded that the warmer and drier climatic conditions ended there only about 3000 BP. Brant's 1980 study of two bogs near the Continental Divide in central Montana did not find fossil pollen evidence of the Altithermal interval. He concluded that frequent fires had held the local plant communities in a disclimax which did not show response to climatic fluctuations.

The purpose of this study is to determine if the conclusion derived from the Lost Trail Pass Bog data is supported by the lower elevational plant communities found near Flathead Lake in western Montana. The hypothesis this study tested was that fire activity in western Montana has increased significantly over the last 2000 years without an equally dramatic change in vegetational composition. The two objectives of the study were (1) to determine if charcoal deposition in Flathead Lake has been greater during the last 2000 years than during the interval 2000-4000 BP, and (2) to determine if palynomorph frequencies in samples taken from Flathead Lake sediments indicate significant vegetational change during the past 4000 years.

Literature Review

The fossil charcoal and pollen contents of lake sediments have been analyzed by several other workers in other regions of North America and, to a lesser extent, in other parts of the world. Davis (1967) was perhaps the first to try to relate microscopic charcoal content of sediments to historic local fire occurrence. The attempt was made in order to establish time to depth relationships within the unvarved sediments from four lakes in Maine for study of the fossil pollen assemblages. At about the same time, Tsukada and Deevey (1967) interpreted fossil charcoal peaks in four Central American lakes as evidence of prehistoric slash and burn agriculture in the tropics.

Waddington (1969) analyzed radiocarbon dated sediments from a small lake in south-central Minnesota. The charcoal content within the sediment core was found to be at its maximum during the period indicated by the fossil pollen assemblage to be the time of greatest prairie expansion. Waddington concluded that the results confirmed the importance of fire in the prairie environment.

Swain (1973) sampled at close intervals annually varved sediments from a small lake in northeastern Minnesota to precisely date charcoal peaks and associated increases in varve thickness. The results allowed him to compute an average fire frequency for the last 1000 years for the area. Swain also used the conifer pollen to sprouting-vegetation-types pollen ratio to better interpret changes in local vegetation which followed each fire. Also in northeastern Minnesota, Bradbury and others (1975) examined the charcoal profile of a sediment core while studying the limnological and hydrological effects of a large wildfire on a nearby lake.

Charcoal and palynological profiles from the sediments of several small lakes in northern Canada were compiled by Nichols (1975). The profiles were compared in an attempt to describe prehistoric displacements of the boreal forest-tundra ecotone due to paleoclimatic changes.

In a major departure from previous studies which analyzed sediments from small lakes, Byrne and others (1977) reported on work done with varved sediments collected from the Santa Barbara Channel off California's coast. Close interval sampling of sediments deposited since 1931 allowed him to develop a charcoal profile which he compared to historical records of nearby wildfires. Preliminary analysis of Sixteenth and Seventeenth Century sediments yielded a prehistoric fire frequency estimate for the area.

Varved lake sediments deposited from about 770 to 1270 AD were examined by Cwynar (1978) in order to establish a prehistoric fire frequency for an area in southern Ontario. Cwynar found that increased erosion in the lake basin following a fire resulted in increased varve thickness and peaks in aluminum and vanadium deposition. Also in 1978, Swain reported the results of a study he had conducted on varved sediments from the last 2000 years from a small lake in north-central Wisconsin:

> The pollen record indicates changes on two different time scales. Short-term changes lasting several decades appear to be superimposed on long-term changes lasting several centuries. The short-term changes are related to individual fires, and the long-term changes result from increases or decreases in the frequency of these perturbations.

Terasmae and Weeks (1979) used radiocarbon dated sediments from four small lakes in the hardwood-conifer forests of southeastern Canada to establish the frequencies of prehistoric fires in the region. They also related recent peaks in the charcoal record to known fire occurrences and interpreted changes in paleoclimate from the fossil pollen assemblages.

Swain (1980), in an expansion of his previous work in northeastern Minnesota (Swain 1973), used the 400 year fossil charcoal and pollen record from two lakes to help determine why one was surrounded by hardwood tree species and the other by conifers. While sediments from both lakes indicated similar local fire frequencies, Swain with the aid of the conifer/sprouter pollen ratio concluded that natural fire breaks near the conifer-surrounded lake helped preserve the more fire susceptible conifer population.

The fossil charcoal and pollen records in varved and unvarved sediments from three lakes in south-central British Columbia were examined by Cawker (1983). The study was conducted in an attempt to determine the importance of _Artemisia tridentata_ Nutt. (big sagebrush) in local presettlement grassland communities.

A few charcoal and pollen studies have recently been completed in Scandinavia, two of which were summarized by Tolonen (1983). In one study, local and regional fire frequencies were determined from varved lake sediments in the _Picea abies_ (L.) Karst. (Norway spruce) dominated forest of southern Finland through differentiation of charcoal fragments by size. Anthropological interpretations of the changes in fire frequency were made. In the other study, varved lake sediments from the eastern Finland _Pinus sylvestris_ L. (Scotch pine) forest region were examined in an attempt to determine the era of earliest local human habitation. Changes in annual varve thickness and in dominant diatoms present in the sediments helped Tolonen distinguish which charcoal influx peaks were from local rather than regional fires. An interesting observation made by Tolonen may also hold true for most North American prehistoric fire studies:

> Both the historic and prehistoric fire frequency in northern regions with combustible vegetation cover has been potentially influenced by man. Consequently, our fire histories may be histories of ancient sources of livelihood rather than climatic histories ....

STUDY AREA

Location, geology and sedimentation

Flathead Lake, the largest freshwater lake in the United States west of the Mississippi River, covers an area of over 500 km^2 at 880 m elevation in the southern end of the Rocky Mountain Trench. The lake formed behind a moraine during the last retreat of Pleistocene glaciation 12,000-14,000 BP (Stoffel 1980, Moore et al. 1982). Since its formation Flathead Lake has received runoff from an 18,400 km^2 watershed which extends into Canada and is bounded on the east by the Continental Divide. The watershed includes several major mountain ranges with peaks as high as 3091 m. Metasedimentary rocks of the Precambrian Belt Supergroup (and sediments derived from them) cover the vast majority of the drainage, while Quaternary to Cambrian sedimentary rocks are exposed in its far eastern and northern parts (Harrison 1972). The watershed is drained primarily by the Flathead River system (Fig. 2). The Flathead River is now the major annual source of total suspended solid sediments for Flathead Lake (Stanford et al. 1981) through a sediment plume which extends from the river's mouth across all or part of the lake in most springs.

Although the Flathead River is the main supplier of total suspended sediments to Flathead Lake, Stanford and others (1981) found that it was the least important of the major sources of suspended

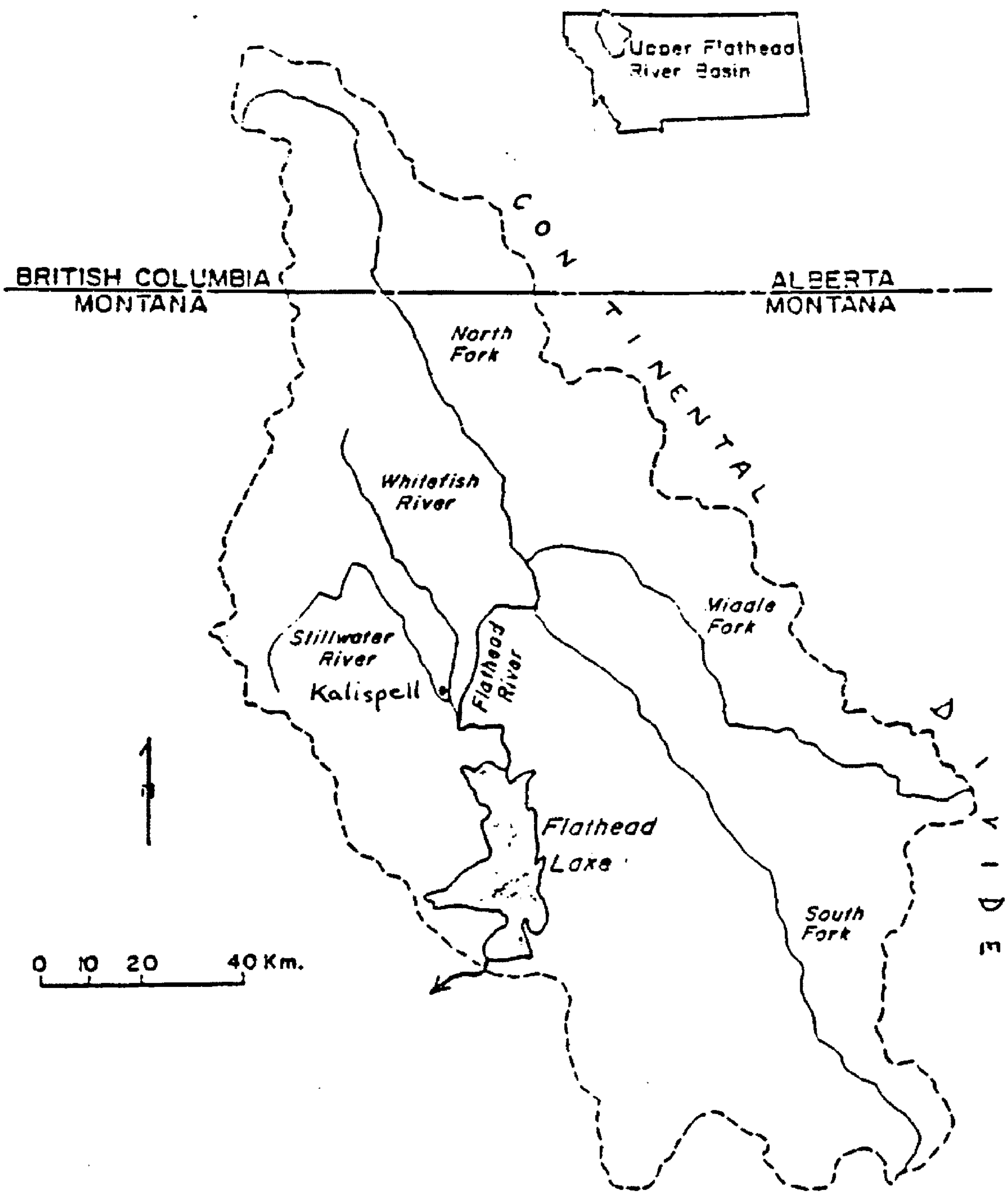


Fig. 2. The Flathead River watershed above Flathead Lake, Montana. (Modified from Moore et al. 1982.)

allochthonous organic material (which would include microscopic charcoal fragments and pollen grains). Most of the allochthonous organic material (77.8%) fell from the atmosphere, either as dry fallout or carried by direct precipitation. The Flathead River delivered most of the remainder (19.2%).

Climate

The area of Montana surrounding Flathead Lake west of the Continental Divide was described by Cordell (1971) as having "a modified north Pacific coast type" climate--relatively mild winters and cool summers with moderate amounts of precipitation distributed fairly evenly throughout the year. Monthly mean temperatures, record maximum and minimum temperatures, and mean precipitation amounts collected by a valley bottom station near the lake are presented in Table 1. Notice that precipitation, while fairly evenly distributed throughout the year, does peak in the late spring. Also notable are the record minimum temperatures (as low as -37°C) caused by occasional spilling of cold artic airmasses during the winter over the Continental Divide from the eastern plains.

As would be expected, temperatures throughout the mountainous watershed tend to be lower with increased distance from Flathead Lake and at higher elevations. For instance, average daily temperatures are near 6°C at the lake (880 m) compared to 3.8°C at Polebridge, Montana at 1207 m, 80 km to the north (Stanford et al. 1981). Precipitation amounts also vary widely within the mountainous region. Arno (1979)

Table 1. Monthly mean temperatures, record maximum and minimum temperatures, and mean precipitation amounts observed at Kalispell, Montana, 21 km northwest of Flathead Lake (Cordell 1971).

	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Mean Temperature (°C)	-6.8	-4.2	-0.1	6.5	11.2	14.8	18.7	17.3	12.6	6.6	-0.6	-3.9	6.0
Record Maximum Temperature (°C)	10.0	13.3	21.7	27.2	31.7	33.9	40.0	40.6	37.2	27.2	17.8	12.2	
Record Minimum Temperature (°C)	-32.2	-30.0	-33.9	-10.0	-5.6	-1.1	0	-0.6	-8.9	-9.4	-33.3	-37.2	
Mean Precipitation Amount (mm)	35	25	24	26	42	56	26	28	26	31	36	34	392

estimated that the average annual precipitation in most of the subalpine forests in the area ranges from 1016 to 1651 mm, compared to the lakeside average of about 392 mm (Cordell 1971). Local wind directions and speeds also vary considerably in the mountainous terrain but regional surface winds in July blow predominantly from the southwest (Baldwin 1973).

Vegetation

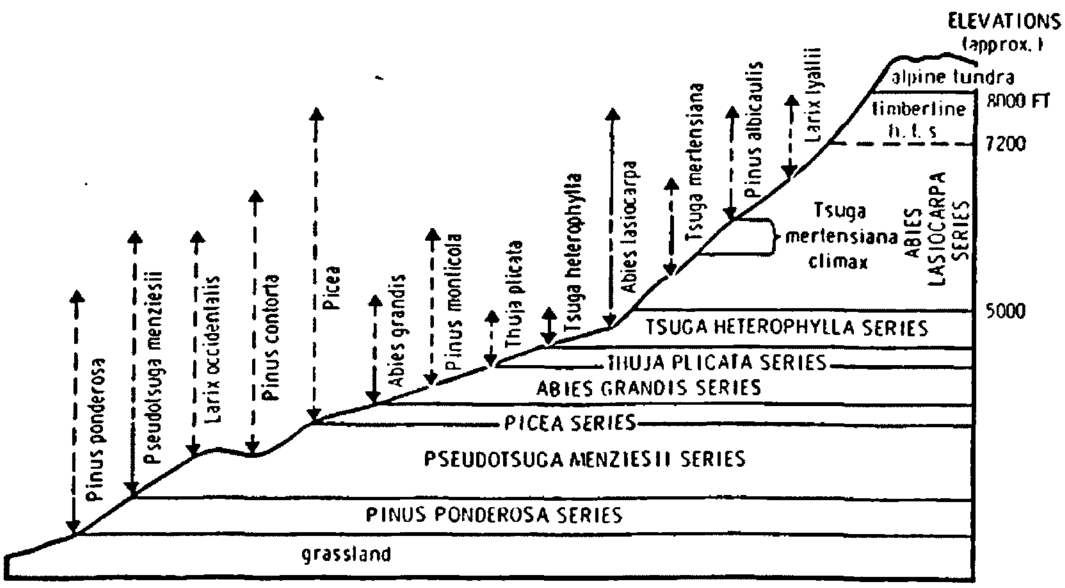
Arno (1979) described the northwest corner of Montana, which includes the Flathead watershed, as the northwestern Montana forest region. The diagnostic feature of the region is an abundance of Pacific Coast tree species in all but the drier valleys. Such tree species include *Tsuga heterophylla* (Raf.) Sarg. (western hemlock), *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock), *Thuja plicata* Donn. (western red cedar), *Abies grandis* (Dougl.) Forbes (grand fir), *Taxus brevifolia* Nutt. (western yew) and *Pinus monticola* Dougl. (western white pine). Associated Pacific Coast type undergrowth species include *Clintonia uniflora* (Schult.) Kunth (queencup beadlily), *Gymnocarpium dryopteris* (L.) Newm. (oak-fern) and *Oplopanax horridum* (Smith) Miq. (devil's club). Perennial grasslands generally prevail on sites below 1065 m to the southwest of Flathead Lake although forests of the *Pinus ponderosa* Dougl. (ponderosa pine), *Pseudotsuga menziesii* (Mirbel) Franco (Douglas fir) and *Abies grandis* climax series (Pfister et al. 1977) extend down to the shore of the lake at 880 m on both its east and west sides. The average elevation of upper timberline is about

2440 m. Fig. 3 shows the distribution of tree species by elevation in an area of the Kootenai River drainage northwest of Flathead Lake which is also within the northwestern Montana forest region. Nearer the lake winter spillovers of cold artic air from east of the Continental Divide limit the frost sensitive species such as Tsuga heterophylla and Thuja plicata to locally sheltered or moderated areas. However, "even in the upper Flathead Valley, tree and undergrowth flora reflect a Pacific influence extending all the way to the Continental Divide itself" (Arno 1979).

Fire ecology

Fire as a natural process has influenced most plant communities in the northern Rocky Mountains (Habeck and Mutch 1973). Two of the region's more abundant seral tree species, Pinus contorta var. latifolia Engelm. (lodgepole pine) and Larix occidentalis Nutt. (western larch), for instance, find their greatest expression in fire-initiated stands (Davis et al. 1980). Fire suppression which began about 1910 and became quite effective during the 1930's however has obscured fire's prehistoric ecological role in many vegetation types.

Fire regimes reported to have existed in forest types present in the northwestern Montana forest region vary tremendously. Recent studies, many of which were summarized by Arno (1980), have determined pre-settlement (pre-fire suppression era) fire frequencies and intensities for many regional plant communities by dating fire scars in living trees and stumps and mapping post-fire tree regeneration age classes. Light



Distribution of forest trees in an area of the Kootenai drainage in northwestern Montana. Arrows show the relative elevational range of each species; solid portion of the arrow indicates where species is potential climax, dashed portion shows where it is seral. (Modified from Pfister and others 1977.)

Fig. 3. Elevational distribution of forest tree species in a part of the northwestern Montana forest region (Arno 1979).

surface fires with mean fire-free intervals of only 5-20 years occurred on the relatively dry sites within the *Pinus ponderosa* climax series. The *Pseudotsuga menziesii* climax series, another major forest series adjacent to Flathead Lake, generally had longer mean fire-free intervals (15-30 years) with an increased chance of moderate to high intensity fires. Spreading fires in higher elevation *Abies lasiocarpa* (Hook.) Nutt. (subalpine fir)-*Picea engelmannii* Parry (Engelmann spruce) stands in the *Abies lasiocarpa* forest climax series, on the other hand, usually occurred less often (150 year or longer mean fire-free intervals) but were of high enough intensity to destroy the stand.

METHODS

During the summer of 1981 Dr. Johnnie Moore of the University of Montana Department of Geology collected several sediment cores from the bottom of Flathead Lake using a gravity piston corer (Moore et al. 1982). Each of the cylindrical cores was 7.5 cm in diameter and contained as much as 6 m of sediment. Dr. Moore used only a longitudinal half of each core for his own sediment geochemistry research so the remaining half of each core was available for other analyses. The core chosen for analysis in this charcoal and pollen study was the one which Dr. Moore felt showed the least sediment mixing and disturbance. Furthermore, the core site lay in the main path taken by the Flathead River sediment plume as it initially travels southward through the lake each spring (Stanford et al. 1981). That particular site was on the western shelf near the center of the lake at a depth of 63 m. Point LC1 in Fig. 4 indicates the location from which the core was collected.

The LC1 sediment core lacked (as did all of the Flathead Lake cores) annual varves for determination of the time to sediment depth relationship. Furthermore, the core lacked pieces of organic matter large enough to date using radiocarbon dating techniques. Therefore the establishment of the time to sediment depth relationship by plotting dated organic matter depth within the sediment core was also

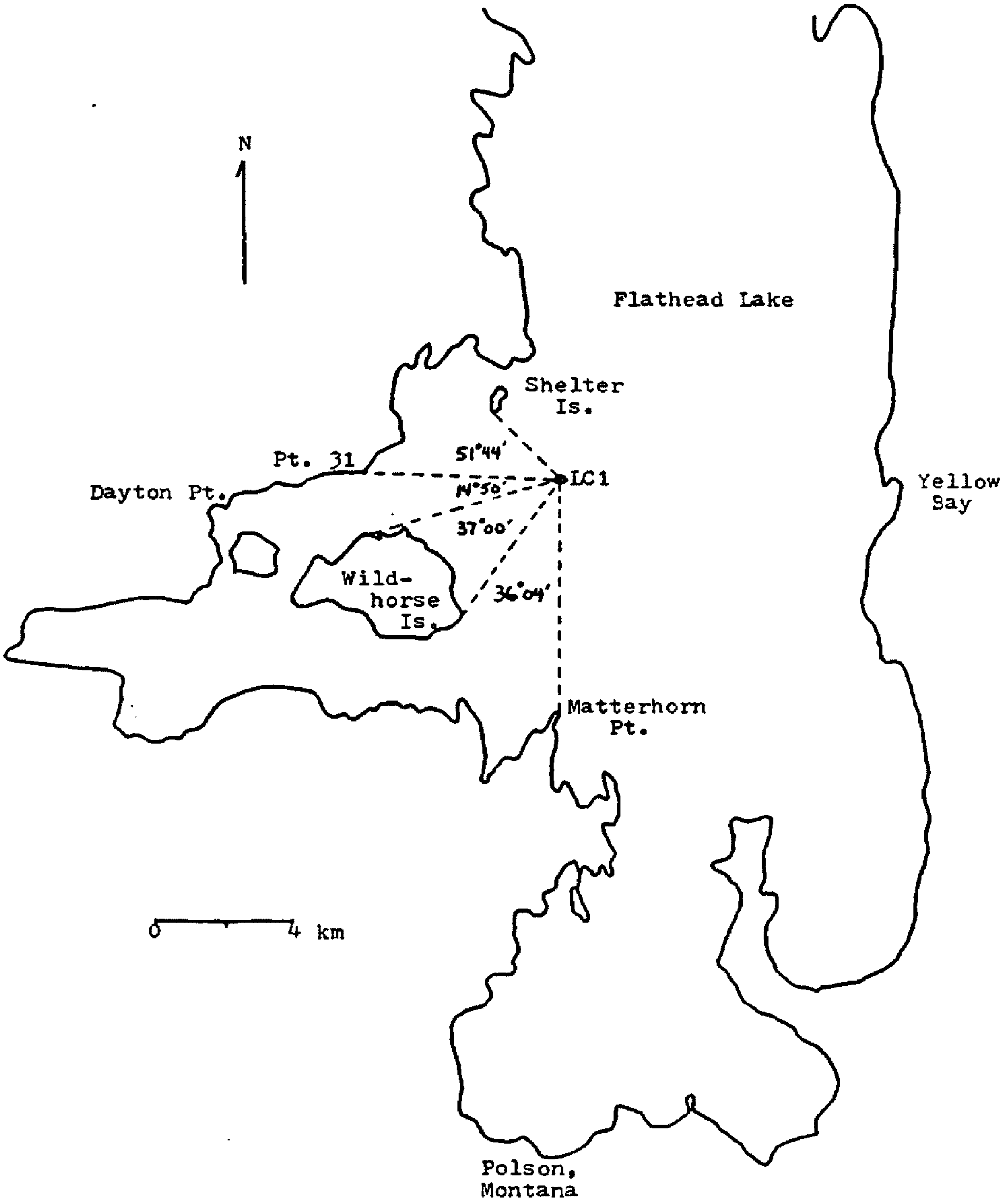


Fig. 4. A map showing the point from which sediment core LC1 was obtained from Flathead Lake, Montana. Sample location courtesy of Dr. Johnnie Moore, University of Montana Department of Geology, Missoula, Montana.

not possible. Attempts to locate the year 1957 sediment depth within the core by searching for the end of Cs^{137} deposition also failed (Dr. Johnnie Moore, 1982, personal communication). Cs^{137} is a radioactive by-product of atmospheric nuclear weapons testing which would not be expected in sediments deposited since the 1957 international ban on atmospheric testing. A layer of volcanic ash from an ancient explosion of Mt. Mazama was recognized as the sole easily datable event within the sediment core.

The explosion of the Mt. Mazama volcano 6600-6700 BP formed present day Crater Lake in west central Oregon. It also spewed into the atmosphere a dense cloud of volcanic ash, much of which was transported by winds and deposited in western Montana (Mehringer et al. 1977, Brant 1980, Hemphill 1983). The 4 cm thick layer of Mazama ash found within the Flathead Lake sediment core was at a depth of about 3.3 m. By dividing that depth by the approximately 6600 years since deposition, an average annual sediment deposition rate of 0.5 mm/yr was estimated. No other method was initially found to relate time to sediment depth as noted above. However Moore and others (1982) located inorganic sedimentary evidence of a regional "mini ice age" known to have occurred 400-500 BP at the appropriate sediment depth assuming the 0.5 mm/yr sedimentation rate. That deposition rate therefore was assumed to be relatively constant throughout the entire 6600 year time period since the Mazama ashfall.

Throughout the top 2 m of sediments in the core which were presumably deposited during the last 4000 years, 29 samples were collected at 7 cm intervals. Fifteen samples were from sediments deposited from 2000-4000 BP. The other 14 samples were from sediments deposited within the last 2000 years. The most recently deposited of the 14 was obtained 4 cm below the core's surface from sediments presumably deposited about the year 1900.

A thirtieth sample was taken from the depth in the sediments (3.5 cm below the core surface) which should have been deposited in the year 1910 based on the assumed annual deposition rate of 0.5 mm/yr. That year was one of unusually heavy fire activity in the northern Rocky Mountains (Cohen and Miller 1978) so an unusually large amount of charcoal was expected in sediments deposited in that year. The thirtieth sample, which came from the presumed 1910 sediment depth, offered a chance to verify the assumption that the 0.5 mm/yr deposition rate was relatively constant throughout the time period since the Mazama ashfall. Data from the thirtieth sample (hereafter referred to as "the 1910 era sample") were not used in testing this study's hypothesis since it would have possibly biased the test.

Each of the 30 samples was obtained with a spatula by taking a 0.5 cm swath centered at each sampling point. Two cubic centimeters were collected at each sampling point. The process used to prepare the samples for microscopic examination generally followed that of Faegri and Iversen (1964).

Lycopodium L. (clubmoss) marker spores were added to each sediment sample. The Lycopodium spore addition is a common palynological practice which aids in absolute charcoal and pollen amount estimation during microscopic examination (Stockmarr 1971). Nine commercially prepared tablets each containing 10,850 ± 200 Lycopodium clavatum L. spores were dissolved in 0.5% potassium hydroxide in each of 30 plastic centrifuge tubes. Following centrifuging and decanting of the liquid fraction, one 2 cc sediment sample was added to each centrifuge tube. Ten percent hydrochloric acid (HCl) was added to fill the 15 ml tubes to about half volume and left overnight to dissolve carbonates. The following day the samples were centrifuged at 2000 rpm for 2 minutes. After decanting, the sediments were washed and centrifuged three times in distilled water with the liquid fraction discarded after each washing.

The samples were then left overnight in tubes filled to about half volume with concentrated hydrofluoric acid (HF) to remove fine-grained silicates. After centrifuging and discarding the liquid fraction, the remaining sediments were washed and centrifuged in 10% HCl twice to remove water insoluable salts, then twice in water.

To remove still more fine-grained silicates, the tubes containing the sediments were once again filled to half volume with concentrated HF and placed in a 90°C water bath for 2.5 hours. After centrifuging and discarding the liquid fraction, the sediments were washed and centrifuged twice in boiling water, then twice in boiling 10% HCl, then once more in water (all liquid fractions discarded).

Acetolysis was required to remove the cellular contents and cellulose walls of the pollen and spores to allow identification. To remove water from the samples, they were washed and centrifuged once with glacial acetic acid in glass 12 ml centrifuge tubes. An acetolysis mixture of one part concentrated sulfuric acid to nine parts of acetic anhydride was added to the remaining sediment to bring each tube to about half volume. The tubes were then placed in a 90°C water bath for 3 minutes. After allowing the tubes to cool slightly, each was centrifuged with resulting liquid fractions discarded. Remaining sediments were then washed and centrifuged with 10% glycerine and allowed to drain overnight. The following day ten microscope slides were prepared from each sample using glycerine jelly as a mounting medium. The remainder of each sample was stored in glycerine jelly in a stoppered vial and retained by the author as a permanent voucher. Slide preparation was finished by 19 March 1982 to lessen the chance of contamination by airborne springtime pollen.

Immediately following slide preparation, a size/frequency distribution curve of the Lycopodium tracer spores was constructed (n=50). This was needed because over time the glycerine jelly mounting medium causes pollen and spores to enlarge. Size increases are proportional among the palynomorphs, so a record of Lycopodium sizes before enlargement aided in size estimation of other palynomorphs after enlargement had begun.

When light microscope examination of the slides from each sample began, a tally was kept of the numbers of charcoal fragments encountered in each of three longest-axis size classes: 25-50 μm, 50-100 μm and greater than 100 μm. Tallying of charcoal fragments continued on slides prepared from the sample until 300 of the *Lycopodium* tracer spores were counted. Also tallied were the numbers of each different pollen type encountered before the three hundredth *Lycopodium* spore was counted. The same number of *Lycopodium* spores was added to each 2 cc sediment sample at the beginning of slide preparation. By examining slides from each sample until 300 *Lycopodium* spores were encountered, it was assured that the same volume of sediments was examined from each sample point.

Methods of data analysis included computing the Pearson correlation coefficient (*r*) and significance of the *r*-value expressed as probability of chance occurrence (*P*) for pair-wise comparisons of the three charcoal fragment size classes. The Pearson correlation coefficient and the related *P*-value were also computed for comparison of the total number of charcoal fragments and total number of pollen grains per sample. A one-tail t-test was applied to determine if the mean charcoal/pollen ratio of the 15 oldest sediment samples was significantly greater than or equal to that of the 14 most recently deposited samples (excluding the 1910 era sample). Similarly, one-tail t-tests were also applied to determine if the mean absolute number of charcoal fragments and mean absolute number of pollen grains in the 15 oldest samples were significantly greater than or equal to those of the 14 most recently deposited samples. The number of grains counted of each pollen type by sample depth (excluding the 1910 era sample) was divided by the total amount of fossil pollen encountered at that depth so that a relative frequency by sediment depth pollen diagram could be constructed.

RESULTS AND DISCUSSION

Charcoal analysis

The number of charcoal fragments by size class tallied in each of the 30 Flathead Lake sediment samples is presented in Table 2. As also reported in several other sediment charcoal studies (Mehringer et al. 1977, Hemphill 1983, Smith 1983), positive correlations exist between the amounts of charcoal in each size class from the Flathead Lake sediment samples, with possibly one exception. Note (Table 3) that only a weak correlation ($r = 0.280$, $P = 0.070$) at best exists between the numbers of fragments found in the smallest (25-50 μm) and largest (>100 μm) size classes. Correlation could suggest that the smaller fragments were pieces broken from the larger fragments during transportation and deposition or during charcoal and pollen extraction (Mehringer et al. 1977). Non-correlation would not necessarily support the inverse assumption that the smaller fragments were not just pieces broken from larger ones, however. Differential settling rates between different sized fragments could also be a factor resulting in non-correlation.

One obvious conclusion can be drawn from the great amount of charcoal fragments distributed throughout the Flathead Lake sediments (Table 2). It is that fire has been a significant regional ecological process throughout the past 4000 years. Absolute amounts of charcoal

Table 2. Charcoal fragments grouped by longest-axis size classes counted in 30 sediment core samples from Flathead Lake, Montana.

DEPTH IN CORE (m)	CHARCOAL FRAGMENTS COUNTED PER 300 LYCOPODIUM SPORES IN EACH SAMPLE 25-50 μm	50-100 μm	> 100 μm	TOTAL
.035*	361	67	8	436
.04	230	43	4	277
.11	255	47	9	311
.18	197	46	8	251
.25	204	29	4	237
.32	333	73	7	403
.39	145	39	8	192
.46	259	37	9	305
.53	248	63	7	318
.60	245	86	14	345
.67	272	72	9	353
.74	261	61	10	332
.81	195	48	3	246
.88	155	33	7	195
.95	275	53	4	332
1.02	98	24	9	131
1.09	134	38	9	181
1.16	84	30	6	120
1.23	176	30	3	209
1.30	232	68	14	314
1.37	237	50	8	295
1.44	212	20	0	232
1.51	307	68	8	383
1.58	121	18	4	143
1.65	209	35	4	248
1.72	146	21	3	170
1.79	127	23	4	154
1.86	293	63	10	366
1.93	134	23	0	157
2.00	191	37	16	244

* 1910 era sample

Table 3. Correlation coefficient (r) and significance of each r-value expressed as probability of chance occurrence (P) from pair-wise comparisons of three size classes of charcoal fragments counted in 30 Flathead Lake sediment core samples.

Size Classes Compared	r	P
25-50 μm and 50-100 μm	0.759	0.000
50-100 μm and >100 μm	0.597	0.000
25-50 μm and >100 μm	0.280	0.070

fragments longer than 25 μm found in the roughly 0.3% of the volume of each of the thirty 2 cc sediment samples varied from 120 to 436. Some minor sediment mixing probably occurred in a lake such as Flathead (Davis 1968). However the fact that these amounts are all of the same order of magnitude suggests that fires were more than just isolated events during the period.

It is not practical to use absolute numbers of charcoal fragments when comparing the amounts of charcoal found within samples to one another to study fire history. Although each of the 0.5 cm thick sediment samples collected from this Flathead Lake core would be expected to contain on the average ten years of sediments, it is not reasonable to assume that each of the 30 samples contained exactly ten years of sediments. A small sampling error or more likely, variations in annual sedimentation rates could increase or decrease the number of years of sediments contained in each sample. If some charcoal was available for deposition each year, charcoal increases or decreases between samples could merely reflect a difference in the number of years represented in the sediment samples rather than an actual change in the ten year charcoal influx.

A charcoal/pollen ratio has been used by virtually all recent palynological studies to correct for variable sedimentation rates (Swain 1973, 1977, 1980, Cwynar 1977, Terasmae and Weeks 1979, Cawker 1983, Hemphill 1983, Smith 1983). Basic assumptions in using the ratio are that roughly the same amount of pollen was available each year for deposition, and that charcoal and pollen produced in the same year were deposited at the same level within the sediments. An increase in fire activity, therefore, would result in a corresponding sediment increase in charcoal compared to pollen independent of the number of years of sediments included in the sample. Such an increase would be reflected in an increased charcoal/pollen ratio.

The total number of charcoal fragments in each Flathead Lake sample is very significantly correlated with the total number of pollen grains (r = 0.728, P = 0.000). This correlation strongly suggests that the charcoal/pollen ratios would be more appropriate for interpreting fire activity in this study than the absolute numbers of charcoal fragments.

Fig. 5 is a graphic presentation of charcoal/pollen ratios found by sediment depth (excluding the 1910 era sample). The mean ratio of the 15 deepest and therefore oldest sediment samples was 1.64. The mean ratio of the 14 most recently deposited samples (again, excluding the 1910 era sample) was 1.80. A one-tail t-test comparison of these two mean ratios yielded a one-tail probability value of 0.26. Such a large value indicates that annual charcoal deposition most likely had not been greater during the last 2000 years than during the interval 2000-4000 BP. This result is contrary to those found by Mehringer and others (1977) (who used annual charcoal influx rates rather than charcoal/pollen ratios) at Lost Trail Bog, Hemphill (1983) at Sheep Mountain Bog and Smith (1983) at Blue Lake.

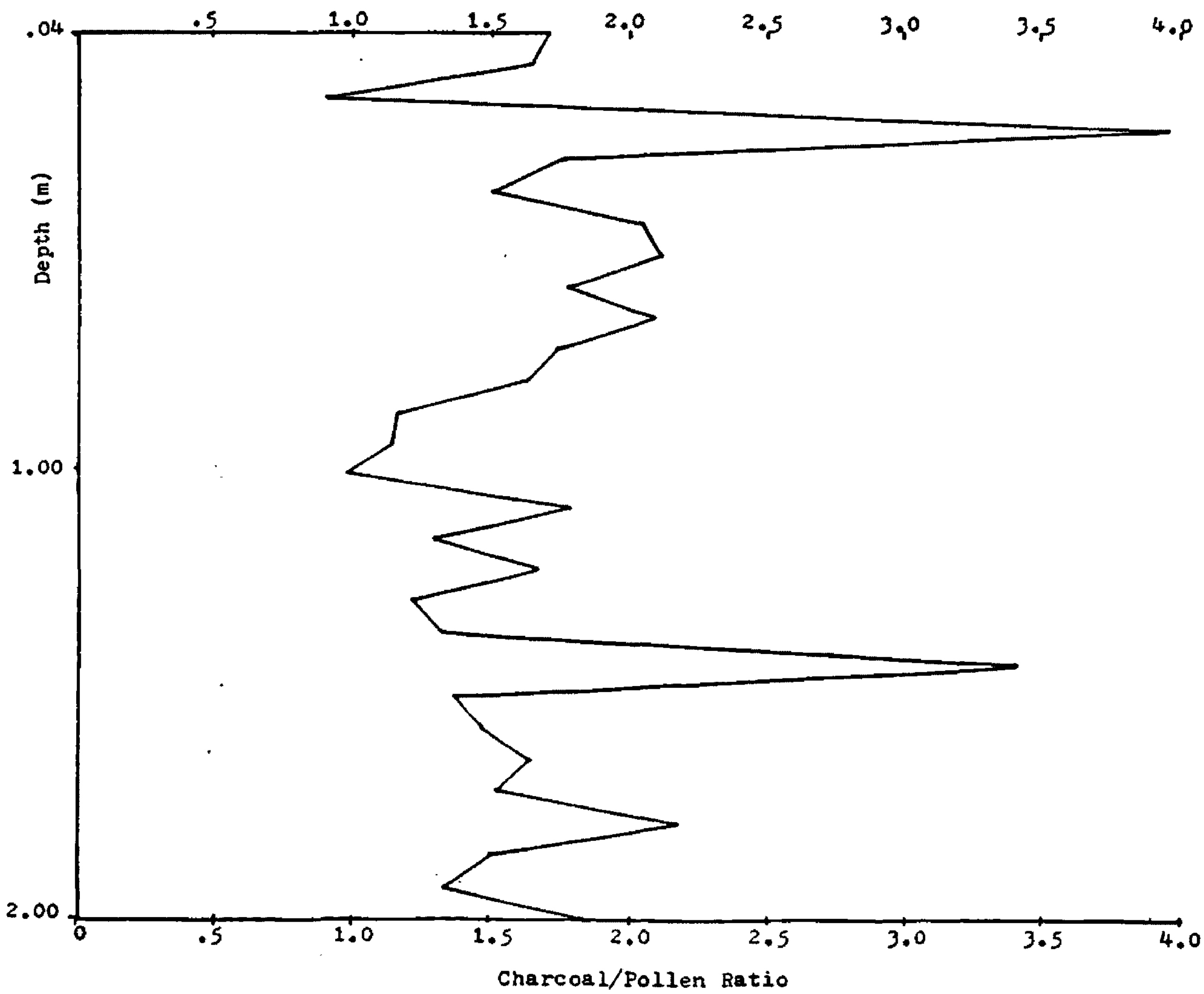


Fig. 5. Charcoal/pollen ratios by depth in a core of Flathead Lake sediments.

It is interesting to note that one-tail t-test comparison of the mean absolute charcoal counts from the 15 lower and 14 upper sediment samples did show a significant charcoal content increase during the last 2000 years ($\underline{P}$ = 0.009). As noted previously, absolute charcoal amounts per sample are probably not valid for comparisons between samples. The absolute charcoal increase during the last 2000 years viewed in the light of no significant charcoal/pollen ratio increase does suggest a decreased average annual deposition rate--that is, more years sandwiched into each sample in the upper reaches of the sediments. However no corresponding significant increase in mean pollen amounts during the last 2000 years was noted ($\underline{P}$ = 0.092).

The possibility of a decreased average annual deposition rate during the last 2000 years is supported by Hemphill (1983) and Smith (1983). Each interpreted from their pollen diagrams a slightly drier period (or at least a period of less effective moisture) which started about 1700 BP and continues to the present. Decreased precipitation during a drier period would have resulted in less overland flow and less sedimentation. Inspection of regional tree-ring growth curves representing the past 1500 years (Shulman 1956) also suggested a drying trend, if indeed any long-term change occurred at all. The occurrence of such a drying trend is not clearly supported or refuted by this study's Flathead Lake pollen analysis, which will be discussed in a later section.

Two peaks in the charcoal/pollen ratios plotted by sediment depths are especially prominent in Fig. 5. The oldest occurs at a depth of 1.44 m which by the 0.5 mm/yr average annual deposition rate corresponds roughly to 2900 BP. The most recent occurs at a depth of 0.25 m in sediments which were deposited about 500 BP. Bradbury and others (1975) and Byrne and others (1977) found peaks in annual fossil charcoal deposition to be evidence of local fires. The background annual charcoal accumulations from which the peaks extended, on the other hand, were seen as reflections of the regional fire regimes. However, such interpretations must be modified for the charcoal peaks found in the Flathead Lake sediments since each sample contained about a decade of sediments rather than just one year. Perhaps, therefore, the two peaks are indications of decades of exceptionally heavy local fire activity, while the background charcoal accumulation rates reflect the local fire activity in more average decades as well as that of the region.

The 1910 era Flathead Lake sediment sample was collected 3.5 cm below the core surface centered around the sediments predicted to have been deposited in 1910 by the 0.5 mm/yr average annual deposition rate. The charcoal/pollen ratio of 1.70 found in that sample falls below the mean ratio in sediments in the upper 1 m of the core. Hemphill (1983) reported a very noticeable peak in the charcoal/pollen ratio from 1910 sediments even though the nearest fire to Sheep Mountain Bog that year was 16 km to the south. Flathead Lake was essentially surrounded by the 1910 fires (Fig. 6). Unusually large amounts of charcoal were available for transport and deposition upwind to the southwest, and upstream to the north and east in the Flathead River watershed. An increase in the charcoal/pollen ratio reflecting an increase in the amount of deposited charcoal would seem to be expected if the sample was collected from the 1910 era sediments.

One of the more likely explanations for the lack of charcoal/pollen ratio increase in the 1910 era sample is simply that the sample failed to include the sediments deposited in 1910. If the 1910 sediments were not included within the 1910 era sample, it is also not likely that the 1910 sediments actually lay immediately below the sample point. The uppermost of the 29 evenly spaced samples was collected at a depth of 4 cm, centered 0.5 cm below the center of the 1910 era sample such that the two samples immediately adjoined each other. The charcoal/pollen ratio of the 4 cm deep sample was the same as that found for the 1910 era sample, a near-average 1.70. The possibility that the 1910 sediments lay above the 1910 era sampling point remains a reasonable alternative. That alternative would be in agreement with the previously mentioned possibility that the average annual deposition rate has decreased in the last 1700 years in response to slightly drier climatic conditions.

Another possible explanation is that the sample did actually include the sediments deposited in 1910 but the sediments did not contain increased amounts of charcoal from the 1910 fires. Byrne and

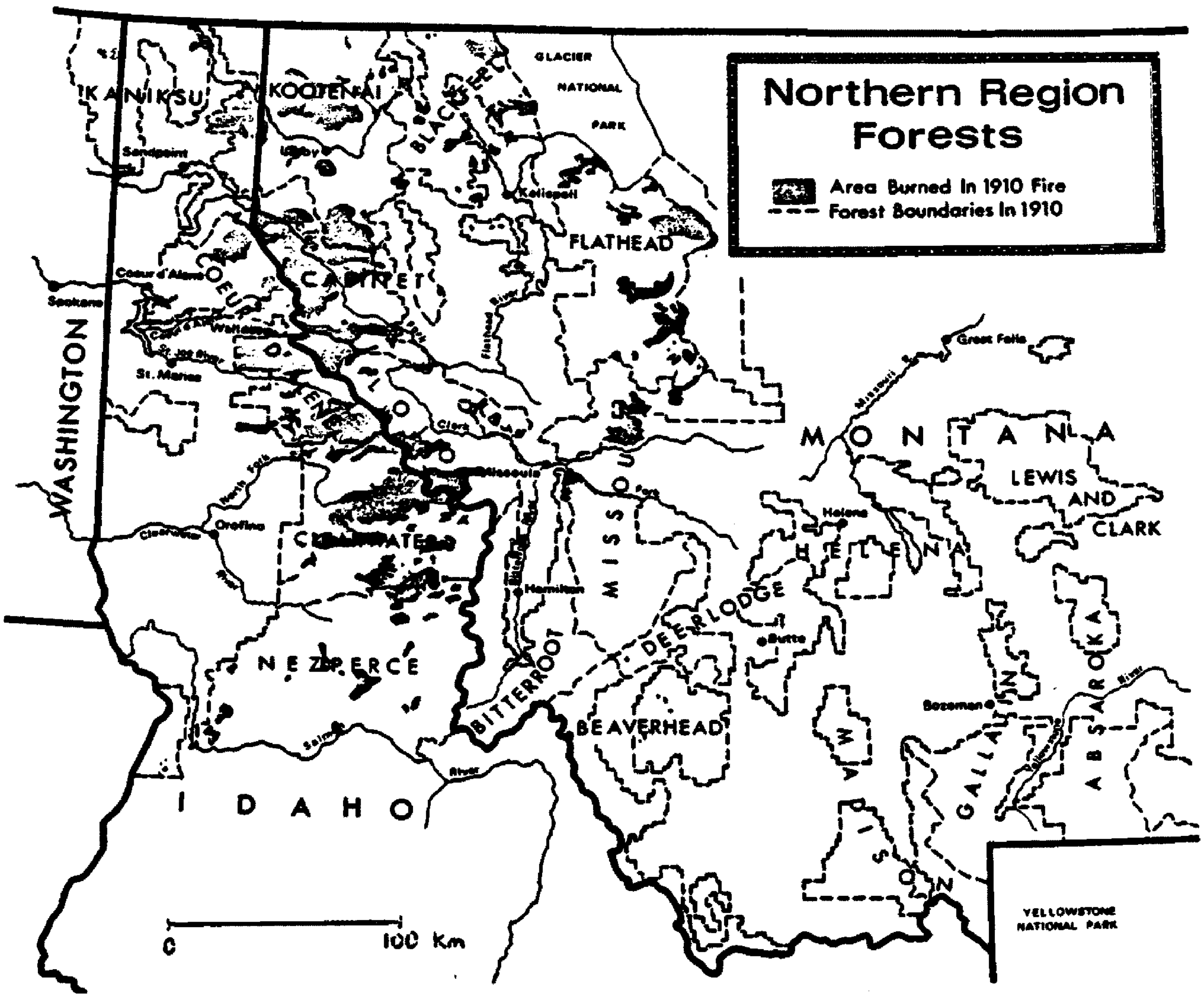


Fig. 6. A map prepared by Cohen and Miller (1978) showing the extent of the 1910 fires (used with authors' permission).

others (1977) reported that only large fires which burned within 50 km of their Santa Barbara Channel core site caused prominent peaks in the charcoal record. Large fires which burned 50-100 km away appeared to have a substantially smaller effect on charcoal influx rates, while fires which occurred more than 100 km from the core site did not measurably affect charcoal influx at all. Note that the bulk of the 1910 fire activity (Fig. 6) took place 75-150 km from Flathead Lake. Thus, there may not have been reason to expect to find a charcoal increase in the 1910 era sediments.

Pollen analysis

Pollen grains were identified through the use of standard keys (Kapp 1969, McAndrews et al. 1973, Moore and Webb 1978) and with the aid of the University of Montana Department of Botany reference collection. Table 4 presents the absolute numbers of each pollen type counted in each of the 30 sediment samples. Fig. 7 is a pollen diagram depicting the relative amounts of each pollen type by sample depth (excluding the 1910 era sample). Most of the pollen grains were differentiated only to family or genus levels, a practice consistent with other regional palynological studies (Waddington and Wright 1974, Baker 1976, Mehringer et al. 1977, Mack et al. 1978a, Brant 1980, Hemphill 1983, Smith 1983). Further differentiation in most cases has not proven reliable although scanning electron microscopy has been used with some minor successes (Kapp 1969, Mack et al. 1978a).

Table 4. Absolute numbers of pollen grains counted at each of 30 depths in a sediment core from Flathead Lake, Montana.

DEPTH IN CORE (m)	PINUS	VESICULATE UNKNOWNS	LARIX-PSEUDOTSUGA	JUNIPERUS	ABIES	PICEA	GRAMINEAE	CHENOPODIACEAE-AMARANTHACEAE	SALIX	ALNUS	ARTEMISIA	OTHER COMPOSITAE	RANUNCULACEAE	ARCEUTHOBIUM	OTHER UNKNOWNS	TOTAL
.035*	100	117	15	2	1	0	2	0	0	0	1	0	1	0	18	257
.04	82	64	3	1	0	0	0	2	1	0	0	0	0	0	10	163
.11	97	80	2	0	3	0	0	0	0	1	0	0	0	0	7	190
.18	130	114	7	2	4	2	2	1	0	0	0	0	0	0	16	278
.25	22	21	0	3	0	0	0	0	2	0	0	0	1	0	11	60
.32	126	44	10	9	5	0	2	3	3	2	1	3	0	0	22	230
.39	79	33	2	2	3	0	1	1	0	0	0	0	0	0	6	127
.46	83	40	1	1	1	0	0	4	1	0	0	3	0	0	15	149
.53	63	27	12	9	0	1	3	8	4	2	0	0	0	1	21	151
.60	103	63	4	3	3	0	4	1	0	0	1	0	1	0	12	195
.67	91	58	2	1	1	0	0	2	1	0	0	1	0	0	13	170
.74	122	28	6	7	0	0	5	3	0	1	1	2	1	0	15	191
.81	64	70	7	1	1	0	1	0	0	0	0	0	0	0	7	151
.88	87	46	10	6	0	0	0	1	0	0	0	0	0	0	17	167
.95	151	92	11	8	1	0	2	2	2	0	0	1	1	0	19	290
1.02	59	40	8	7	2	1	2	1	0	0	2	0	0	0	11	133
1.09	52	29	7	0	0	1	1	1	1	0	0	0	0	0	10	102
1.16	34	45	2	1	0	0	1	0	1	1	0	0	0	0	8	93
1.23	68	26	1	4	1	3	2	2	0	1	0	3	0	0	14	125
1.30	152	58	12	6	6	0	1	2	0	0	0	0	1	0	22	260
1.37	151	35	5	3	2	0	2	4	1	0	0	0	0	0	17	220
1.44	28	10	5	1	0	0	2	2	0	1	0	1	0	0	18	68
1.51	172	45	9	9	0	0	5	2	3	0	0	3	2	0	30	280
1.58	60	13	3	5	0	0	1	2	0	1	0	0	0	0	12	97
1.65	63	44	5	6	0	0	3	3	3	0	0	2	0	0	22	151
1.72	28	44	9	8	2	0	2	2	1	0	1	1	0	0	13	111
1.79	25	25	3	5	0	0	1	2	1	0	0	1	0	0	8	71
1.86	93	69	22	14	4	1	5	3	2	0	0	2	2	0	27	244
1.93	44	21	15	8	0	0	3	2	3	0	1	2	1	0	17	117
2.00	49	25	11	10	0	0	3	2	1	0	0	1	3	1	26	132

* 1910 era sample

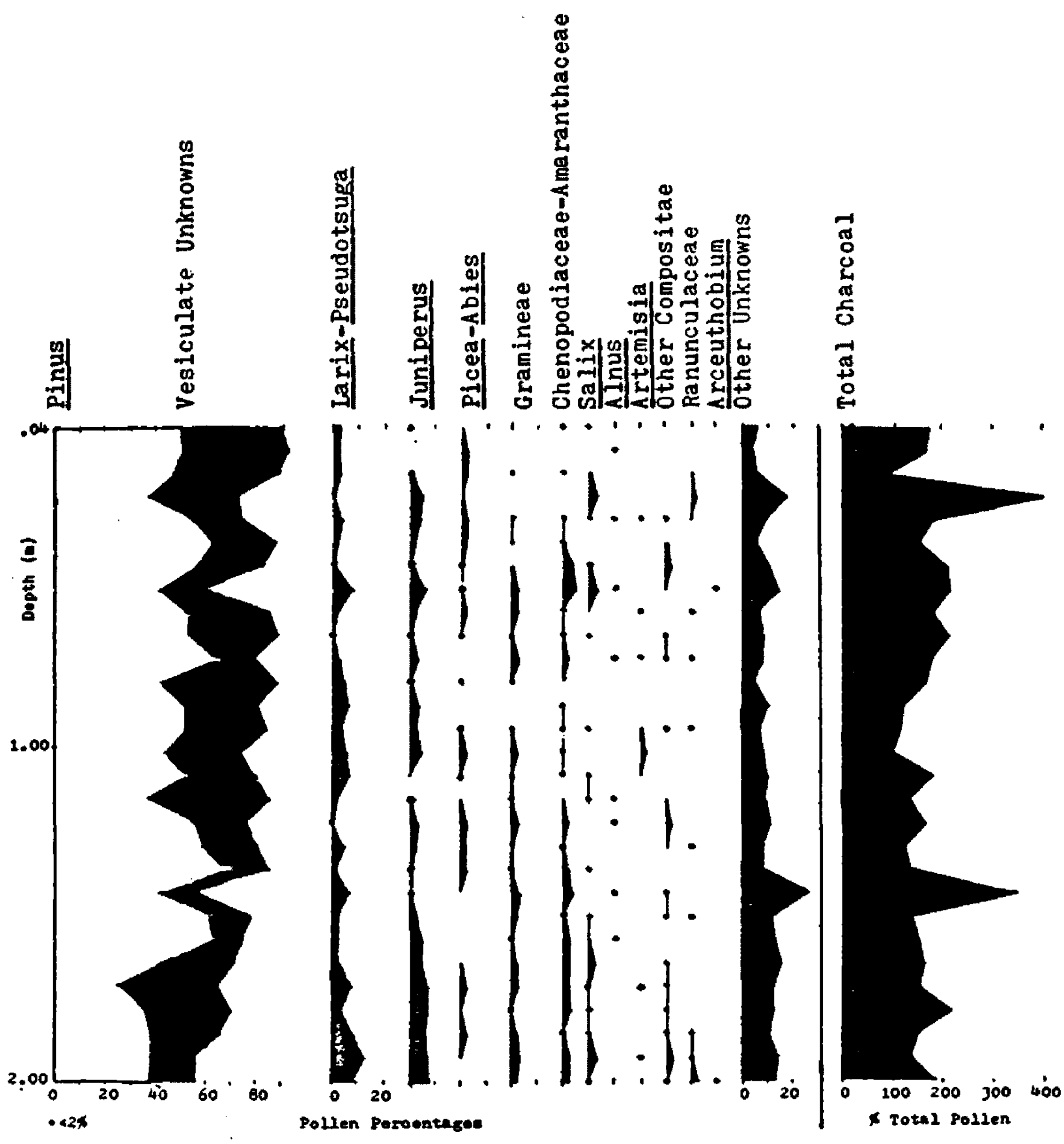


Fig. 7. Pollen diagram presenting the relative amounts of each pollen type and of total charcoal fragments (> 25 μm) found in a core of Flathead Lake sediments. Note that total charcoal expressed as a percent of total pollen is the charcoal/pollen ratio X 100%. The rest of the pollen percentages scale is constant.

Grains from the genus *Pinus* L. (pine) dominate the pollen record throughout the 2 m of sediment core sampled (25-67%). The *Pinus* grains which were intact and oriented correctly in the mounting medium were differentiated as being haploxylon (belonging to the subgenus *Strobus*) or diploxylon (belonging to the subgenus *Pinus*) (Critchfield and Little 1966). The differentiation was made based on the presence or absence of distal verracae or "belly warts" (Kapp 1969). Of the 47 grains which could be differentiated, only three were haploxylon. Therefore the vast majority of the *Pinus* pollen grains counted must have been of the regional diploxylon types, *Pinus ponderosa* and *Pinus contorta* (Harlow and Harrar 1968), both of which are now common near Flathead Lake. The smaller amount of haploxylon pine pollen most likely came from *Pinus monticola*, *Pinus albicaulis* Engelm. (white bark pine) or *Pinus flexilis* James (limber pine) which are all regional species.

Hansen (1948) differentiated fossil *Pinus* pollen from Glacier National Park to the species level using a single measured dimension (width of corpus only or total breadth) and pre-developed size/frequency distributions for each species (Hansen 1947). Of particular interest to this study was Hansen's contention that *Pinus ponderosa* grains were substantially larger than those of *Pinus contorta*, an observation also generally reported by Mack (1971). Hansen's (1947) size/frequency distributions showed virtually no overlap in sizes of pollen grains between the two species with the total breadth of *Pinus* ponderosa grains averaging about 23 μm broader than Pinus contorta grains. Ting (1966) pointed out the many problems associated with using single dimension measurements to determine Pinus species, and Mack (1971) showed that Hansen's technique was unreliable. No other recent northern Rocky Mountain palynological studies used the size differentiation method. However size/frequency distributions were prepared for the measurable Pinus grains found in both the uppermost 1 m and lower 1 m of the Flathead Lake sediments examined by this study (Fig. 8). This was done to see if there was an obvious difference between the two distributions which would suggest that a shift had occurred in species composition; no attempt was made to classify individual grains as one species or another. Non-statistical comparison of the two distributions gives no indication of such a shift.

Between 13 and 48% of the pollen grains in each sample were classified as vesiculate unknowns (Table 4). This group consisted of grains which were recognized as vesiculate (winged) grains, typical of several conifer genera, but which were obscured, mangled or oriented poorly on the microscope slides such that more specific identification was not possible. The glycerine jelly mounting medium, unlike silicon oil, did not allow rotation of the palynomorphs in order to search for identifying characteristics. The vast majority of the vesiculate unknowns was probably of the genus Pinus since of the three vesiculate grain types identified--Pinus, Picea A. Dietr. (spruce) and Abies Mill. (fir)-- Pinus was clearly the most abundant. For that reason the

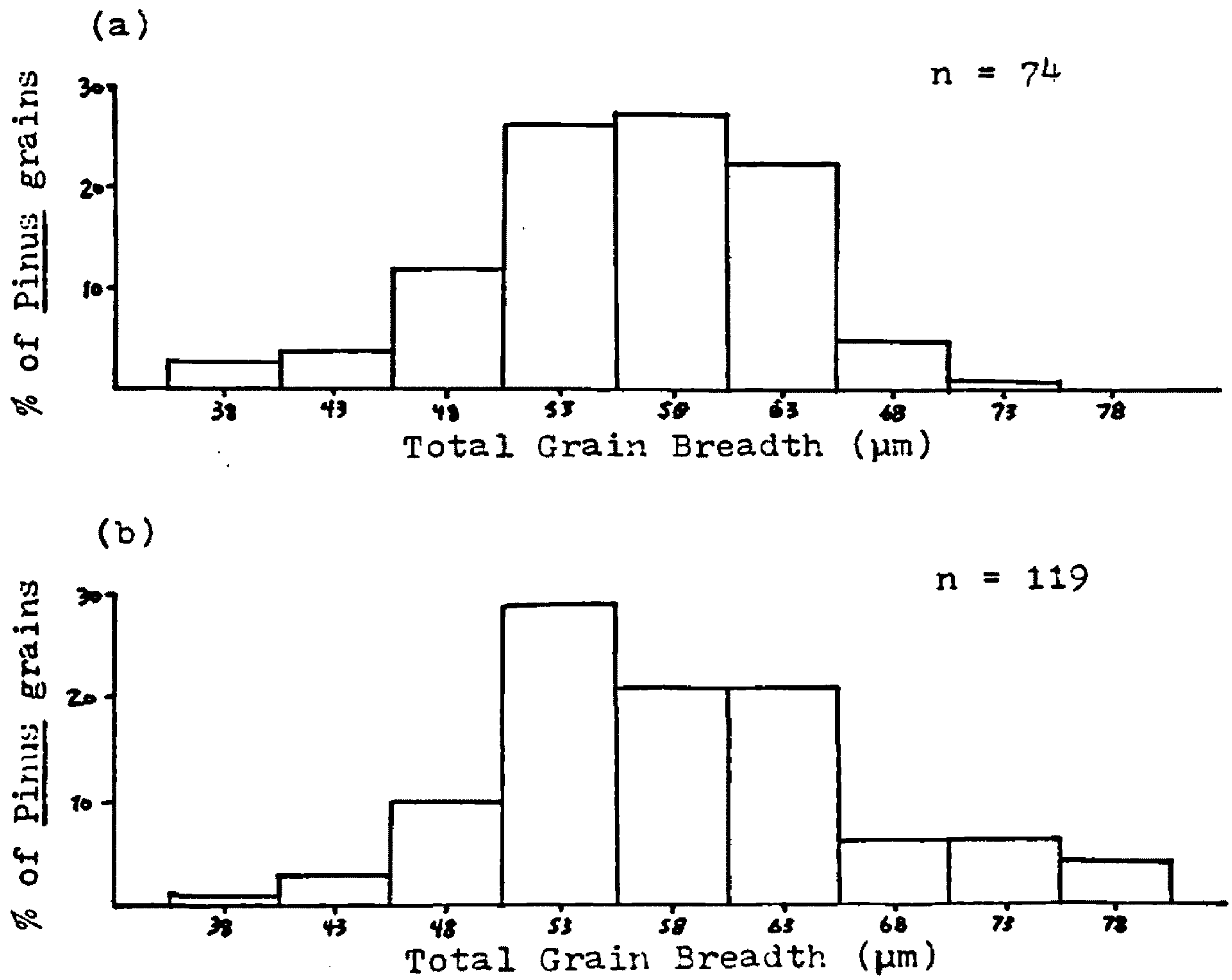


Fig. 8. Percent of measurable diploxylon and undifferentiated *Pinus* pollen grains by size classes found in the upper 1 m (a) and lower 1 m (b) of a Flathead Lake sediment core.

relative amounts of the unknown vesiculate grains have been combined with those identified as Pinus in Fig. 7. The combined category is probably much closer to the true Pinus pollen relative frequencies contained in each sample than just the Pinus category alone.

Pinus pollen has also dominated the pollen records reported by other northern Rocky Mountain palynological studies (Hansen 1948, Waddington and Wright 1974, Baker 1976, Mehringer et al. 1977, Mack et al. 1978a, Brant 1980, Hemphill 1983, Smith 1983). One reason for Pinus dominance is that relatively large amounts of pollen are produced per individual compared to those of other arboreal genera such as Picea (Hansen 1948) and Pseudotsuga Carr. (Baker 1976). Another reason is that Pinus grains are more widely dispersed than most other regional pollen types. McAndrews and Wright (1969) reported Pinus pollen making up as much as 20% of the pollen in duff on grassland sites in North Dakota 400 km from the nearest pine forest. The pollens of Picea, Abies and Pseudotsuga, they reported, travel only a few tens of kilometers beyond their source areas in the western mountains.

Pollen grains of the genera Larix Adans. (larch) and Pseudotsuga were the second most abundant type found. Unfortunately, grains of these two genera are not distinguishable with a light microscope (Mehringer et al. 1977) so they remained undifferentiated during counting. Pseudotsuga menziesii and Larix occidentalis are the two most likely present-day contributors to the Larix-Pseudotsuga pollen count, while Larix lyallii Parl. (subalpine larch) pollen probably makes up the rest. Pseudotsuga menziesii and Larix occidentalis presently grow adjacent to Flathead Lake, while Larix lyallii is generally restricted to the higher elevation forest habitat types in western Montana (Pfister et al. 1977).

The relatively small amounts of Larix-Pseudotsuga pollen (0-13%) cannot necessarily be attributed to lower populations of these genera relative to Pinus. Baker (1976) reported finding less than 1% Pseudotsuga pollen in a surface sample in an open Pseudotsuga forest in Yellowstone National Park. Mack and others (1978b) concluded that "Larix/Pseudotsuga-type pollen is prominent (> 5%) only in stands with high coverage of Pseudotsuga" in eastern Washington and northern Idaho. Several regional fossil pollen studies, however, have generally reported larger amounts (up to 40%) of Larix-Pseudotsuga pollen within their pollen assemblages (Mehringer et al. 1977, Brant 1980, Hemphill 1983, Smith 1983). Relative amounts of Larix-Pseudotsuga pollen would also be expected to vary between samples since regional cycles of heavy pollen cone production in Pseudotsuga menziesii peak about every five years (Allen and Owens 1972).

Picea and Abies pollen grains were each differentiated to the genus level (Table 4). They are represented in a single column in Fig. 7, however, since species of both genera occupy similar ecological niches--relatively moist forest sites (Pfister et al. 1977). Most Picea populations now present in western Montana are the result of Picea engelmannii and Picea glauca (Moench) Voss (white spruce) hybridization (Pfister et al. 1977). The most likely sources of Abies pollen for Flathead Lake are Abies grandis and Abies lasiocarpa. As is the case with the Larix-Pseudotsuga relative pollen amounts, the small Picea-Abies relative frequencies (0-3%) are not necessarily a fair reflection of the genera's contribution to regional forest composition. Picea pollen (and presumably also the larger Abies grains) is not dispersed as far as Pinus pollen (McAndrews and Wright 1969, Waddington and Wright 1974), and Picea individuals do not produce as much pollen as those of Pinus (Hansen 1948). Furthermore, a regional cycle, such as that found for Pseudotsuga menziesii, may also influence annual pollen production in Picea and Abies (Allen and Owens 1972).

The genus Juniperus L. (juniper) is represented in western Montana by Juniperus scopulorum Sarg., a tree species, and by Juniperus communis L. and Juniperus horizontalis Moench, both shrubs. Species of Juniperus have been found in virtually every forest habitat type in the state of Montana (Pfister et al. 1977). Juniperus grains accounted for up to 8% of the pollen encountered in each sample.

Gramineae pollen grains made up 0-3% of the sample pollen totals. Native representatives of the family common in the Flathead Lake region are grasses such as Agropyron spicatum (Pursh) Scribn. & Smith (bluebunch wheatgrass), Festuca idahoensis Elmer (Idaho fescue) and Calamagrostis rubescens Buckl. (pinegrass). The presence of such species is usually indicative of drier forest sites (Pfister et al. 1977).

Chenopodiaceae and Amaranthaceae pollen grains are not commonly differentiated without the aid of a scanning electron microscope (Kapp 1969). Pollen from plants of these two families accounted for up to 5% of each sample's total pollen. Most of the western Montana representatives of these families prefer dry or alkaline sites (Brant 1980). Waddington and Wright (1974) interpreted a reduction in this pollen type as a response to a cooling trend.

The shrub genus Salix L. (willow) is presently represented in western Montana by Salix scouleriana Barrett in generally all of the more mesic forest habitat types (Pfister et al. 1977). Other species of Salix also inhabit moist sites in Montana (Hitchcock and Cronquist 1981). Its presence was indicated by up to 3% of the total pollen throughout the sediments sampled.

Alnus incana (L.) Moench (mountain alder) and Alnus sinuata (Regel) Rydb. (Sitka alder) are the current species of the Alnus Hill (alder) genus found in western Montana. Alnus, like Salix, may be found in all but the driest and wettest forest habitat types (Pfister et al. 1977). Alnus was present in several samples in amounts of 1% or less.

Substantial amounts of Artemisia L. (sagebrush) have been viewed by other northern Rocky Mountain palynological studies to indicate relatively warm sagebrush steppe conditions (Waddington and Wright 1974, Mehringer et al. 1977). Artemisia pollen occurred only in scattered amounts of 2% or less in the Flathead Lake sediments. Artemisia tridentata is a possible constituent of the more xeric forest habitat types in western Montana (Pfister et al. 1977) and is found in the perennial grasslands to the southwest of the lake.

The column labelled "Other Compositae" in Fig. 7 contains the relative frequencies (up to 2%) of all Compositae pollen grains counted, other than those of the Artemisia genus. Hansen (1948) considered the presence of substantial amounts of Compositae pollen (along with that of grasses and chenopods) an indication of xerothermic conditions.

Ranunculaceae pollen grains were found in amounts of 2% and less at several sample levels within the core. Brant (1980) considered the presence of most western Montana members of the family to indicate wet, semiaquatic or aquatic conditions. However, at least one species, Ranunculus glaberrimus Hook. (sagebrush buttercup), is found generally on well-drained soils in sagebrush-grasslands and Pinus ponderosa forests (Hitchcock and Cronquist 1981). The attractive flowers and highly sculptured pollen grains of many members of the family suggest that, as is the case with many other understory plants, insect dissemination of pollen predominates over wind dispersal.

Arceuthobium Bieb. (dwarf mistletoe), depending on species, parasitizes Pseudotsuga menziesii, Pinus contorta or Pinus ponderosa (Baker 1976). All three species are currently present in substantial numbers in the forest surrounding Flathead Lake. Only one grain of the

Arceuthobium genus was found at each of two different sampling levels within the Falthead Lake sediment core.

The relatively large numbers of pollen grains classed as "Other Unknowns" are the unidentified pollen grains excepting the vesticulate unknowns mentioned earlier. These other unknowns may be divided into two groups. The first and largest group contains those non-vesticulate pollen grains which were unidentifiable because they were obscured by extraneous sediments or mangled during transport, deposition or sample preparation. The second group of non-vesiculate unknowns consists of only 3.1% of the total grains encountered and were grains which possibly could have been identified by a more skilled palynologist than myself. In many cases the grains were just oriented on the microscope slides in such a way that I could not positively identify them. As many as one-third of these grains were tricolpate (three furrowed) types similar to many of those of the Cruciferae (mustard) family. These tricolpate unknowns were encountered throughout the depth of sediment core sampled so it is unlikely that their identification would have added significantly to this study.

The two largest peaks in the "Other Unknowns" column occur at the same sediment depths as the two previously discussed prominent peaks in charcoal/pollen ratios. The relatively larger amounts of undifferentiated pollen grains were due in both cases to an increase in obscured grains rather than an increase in potentially identifiable grains. Cwynar (1978) showed that peaks in aluminum and vanadium deposition in lake sediments followed local fires in southern Ontario. Perhaps changes in the chemical composition of the Flathead Lake sediments associated with the charcoal/pollen ratio increases decreased the effectiveness of the charcoal and pollen extraction process.

The lack of obvious trends recorded in the pollen diagram provides no clearcut evidence of major vegetational change during the last 4000 years in which the 2 m of Flathead Lake sediments sampled were presumably deposited. This result is generally in keeping with the results of other palynological studies conducted in the northern Rocky Mountains. None have indicated dramatic changes in vegetation due to climatic change since the end of the Altithermal interval estimated variously at 3000-5000 BP (Hansen 1948, Waddington and Wright 1974, Baker 1976, Mehringer et al. 1977, Mack et al. 1978a, Brant 1980, Hemphill 1983, Smith 1983).

An argument can be made that the pollen relative frequencies in the bottom two to four samples of the 2 m of the Flathead Lake sediments suggest that the samples were deposited during the end of the Altithermal interval. In these samples, relatively smaller amounts of *Pinus* pollen correspond to larger amounts of *Larix*-*Pseudotsuga* pollen while *Picea*-*Abies* pollen is either absent or present in only small amounts. These are two of the more important criteria used by some studies to define the occurrence of the Altithermal interval (Hansen 1948, Waddington and Wright 1974, Mehringer et al. 1977, Mack et al. 1978a). However it must be noted that other (but smaller) increases in the relative amount of Larix-Pseudotsuga pollen occur elsewhere in the pollen diagram, perhaps due to the cyclical nature of Pseudotsuga menziesii's pollen production (Allen and Owens 1972). Pollen of Picea-Abies also was not found at all other sample depths and never was present anywhere in amounts greater than 3%. Other pollen types, such as Gramineae, Chenopodiaceae and Compositae, which would have been expected in greater amounts during a warmer period (Hansen 1948) were not present in greater amounts. Furthermore, if the Altithermal interval was locally drier as well as warmer (Hansen 1948, Baker 1976, Mack et al. 1978a), greater charcoal/pollen ratios might be expected in the bottom samples than in the more recently deposited ones. Qualitative comparison of the charcoal/pollen ratios indicate that is not the case, however. Judging from the Flathead Lake pollen diagram where the Altithermal interval ended (if it is represented at all) would be a subjective process without an idea of what charcoal/pollen ratios and pollen percentages were characteristic of the interval.

The slight drying trend reported to have occurred during the last 1700 years (Hemphill 1983, Smith 1983) is not particularly evident in the Flathead Lake pollen diagram (Fig. 7). The relative frequency of Pinus and unknown vesiculate grains seems to have increased during that time period at the expense of Larix-Pseudotsuga--one of the indications that suggested to Smith (1983) that the climate has been drier. But corresponding decreases in pollen of moist site indicators such as Picea-Abies and increases in pollen of drier site indicators such as

Gramineae and Artemisia do not occur. Such decreases and increases may however have become apparent if a larger amount of each sample was examined.

The beginning of modern agriculture and the subsequent increase in fossil Ambrosia L. (ragweed) pollen (a Compositae) was used by Bradbury and others (1975) and Swain (1980) to date lake sediments in northern Minnesota. Smith (1983) in northern Idaho reported an increase in Artemisia and Chenopodiaceae pollen in recent sediments, possibly a result of agricultural activities below Blue Lake. The late Nineteenth and early Twentieth Centuries were the period during which extensive grazing, logging and some modern agriculture became established in the northern Rocky Mountain region. No relative increases in the fossil pollen of weedy undergrowth species were observed in the two uppermost samples which were collected from Flathead Lake sediments deposited during that era, however (Table 4).

Anthropological implications

Each of the other three charcoal and pollen studies conducted at locations in the northern Rocky Mountains (Mehringer et al. 1977, Hemphill 1983, Smith 1983) reported recent increases in fire frequency not caused by climatic changes. In each study it was suggested that fires set by Indians may have been responsible for the increase. Analysis of the Flathead Lake sediments, however, showed no apparent increase in fire frequency near the lake during the same time frame, 4000 BP until present. This lack of apparent increase must not be viewed as an indication that fires started by Indians did not contribute significantly to the prehistoric fire regime near Flathead Lake. To the contrary, Barrett (1981) has shown that Indian-caused fires were important ecological factors in western Montana's lower elevational forests in recent prehistory.

Man has inhabited the northern Rocky Mountains for at least the last 10,000 years (Malouf 1969), much longer than the 4000 years examined in this Flathead Lake sediment study. Specifically, the Salish Indians (including the Upper Pend d'Oreille tribe whose territory included Flathead Lake prior to 1855) and the Kootenai Indians (who lived northwest of the lake) have been in western Montana since at least 1700, and probably have been in the area much longer (Malouf 1974, Phillips 1974). The possible constant Indian inhabitation of the Flathead Lake area during the last 4000 years coupled with the apparent lack of fire frequency increase during the period and the undisputed importance of Indian burning in the area in recent prehistory suggests to the author that Indian-caused fire activity near the lake was persistent throughout the entire 4000 year period.

CONCLUSIONS

Contrary to the results reported by other regional fossil charcoal and pollen studies, charcoal deposition in Flathead Lake has not been significantly greater during the last 2000 years than during the interval 2000-4000 BP. Fire has, however, apparently been a significant regional ecological process throughout the past 4000 years. Analysis of the Flathead Lake fossil charcoal record also debatably supports the possibility that the average annual sedimentation rate may have decreased during the most recent 1700 years.

The lack of obvious trends recorded in the fossil pollen assemblage from the Flathead Lake sediments provides no clearcut evidence of major vegetational change during the last 4000 years. However, some evidence of the warmer Altithermal interval which ended in the region 3000-5000 BP might exist in as much as the oldest 500 years of sediments sampled. Vegetational changes due to the possible slightly drier period which began about 1700 BP and post-settlement human activities are not particularly evident in the fossil pollen record.

The results suggest that this study's hypothesis--that fire activity in western Montana has increased significantly over the last 2000 years without an equally dramatic change in vegetational composition--is not applicable to the area around Flathead Lake since fire activity, as indicated by the lake's sediment fossil charcoal record, has not increased during the last 2000 years. Rejection of the hypothesis for the Flathead Lake area, however, in no way implies that Indian-caused fires did not contribute significantly to the area's prehistoric fire regime.

ACKNOWLEDGEMENTS

Several persons helped me immensely in the course of this project. I am sincerely grateful to:

My advisor, Dr. Nellie M. Stark, for guiding me through the research and writing of this thesis;

Dr. Charles N. Miller (University of Montana Department of Botany) for the use of his laboratory facilities and materials;

Dr. Johnnie N. Moore (University of Montana Department of Geology) for supplying the Flathead Lake sediment core;

Dr. Ronald H. Wakimoto (University of Montana School of Forestry) for useful discussions and encouragement;

and Dr. Peter J. Mehringer, Jr. and his anthropology graduate students at Washington State University who gave freely of their invaluable technical expertise in palynology.

I thank also Stan Cohen and Don Miller for allowing me to use the map of the 1910 fires from their book, The Big Burn: The Northwest's Forest Fire of 1910.

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