U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

CHARACTERISTICS OF SEDIMENTS FROM SELECTED LAKES OF OREGON AND WASHINGTON AND THEIR POTENTIAL FOR OBTAINING HIGH-RESOLUTION PALEOCLIMATE RECORDS

by

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INTRODUCTION

In September, 1992 we went to the Pacific Northwest to take Ekman box cores of surface sediments from lakes in Oregon and Washington, and longer Livingston piston cores (Wright, 1967) in a few selected lakes. The Ekman box core samples a surface area of 20 cm x 20 cm, and can penetrate the sediment to a depth of 20 cm, but typical penetration is 10-15 cm. With the Livingston, it is common to penetrate at least 10 m of sediment one meter at a time. The purposes of this coring expedition were threefold: First, we wanted to collect piston cores of several lakes that were rotary drilled in 1991 as part of the Correlation of Marine and Terrestrial Records of Climate Change in the Western U.S. Project of the USGS Global Change and Climate History Program (Gardner and others, 1992). To this end, we had made arrangements with David Adam, USGS, Menlo Park, who was in charge of the 1991 rotary drilling project, to meet us in Klamath Falls, Oregon on or about September 9. Second, we wanted to identify additional lakes with annually laminated sediments (varves) in the climatically sensitive Pacific Northwest to provide high-resolution (annual calibration) paleoclimatic records of the Holocene. Our preliminary survey of varved lakes in North America (Anderson and others, 1985) identified several lakes with varved sediments in Washington but none in Oregon. Finally, pollen analyses of the surface sediments will expand the modern-vegetation database from lake and bog sediments being assembled by Pat Bartlein and Cathy Whitlock at the University of Oregon in order to develop climate transfer functions for interpreting late Quaternary lacustrine pollen records of the Pacific Northwest. In addition, the surface sediments will provide baseline data on geochemical and diatom components in Oregon and Washington lake sediments.

Our first stop was at the University of Oregon, Eugene to borrow two canoes from Pat Bartlein who had designed a system of attaching the canoes together to provide a stable catamaran platform for coring lakes, and to review Oregon and Washington lakes with Bartlein and Whitlock for pre-selecting lakes with potential for preserving varved sediments. Basically, we were looking for deep lakes with a relatively small surface area. Our primary references for the latter task were Johnson and others (1985) and Wolcott (1973). The former provides an excellent database for the chemistry, trophic status, access, bathymetry, origin, and general information of all lakes in Oregon. The latter reference is somewhat dated but does provide area, depth, elevation, location, and general information for all lakes in Washington, and bathymetric maps for some lakes. Armed with a coring platform and a list of lakes (Table 1) to sample, we set out for the Cascade Mountains of central Oregon.

Table 1. Lakes in Oregon and Washington sampled during September, 1992 showing location by township (T), range (R), and section (sec); maximum depth (Z) in meters (m) and feet (ft); elevation above sea level in meters (m) and feet (ft); surface area in hectares (ha) and acres (ac); ratio of area to depth (A/Z); pH (in standard pH units); and Specific Conductance (Cond. in microSiemens (μS).

Lake	State	County	Location T	Location R	Location Sec	Maximum Depth (Z) (m)	Maximum Depth (Z) (ft)	Elevation (m)	Elevation (ft)	Surface Area (A) (ha)	Surface Area (A) (ac)	A/Z	pH	Cond. (μS)
Alta	WA	Okanagan	28N	23E	10	24	79	354	1163	76	187	3.1	7.24	299
Big Twin	WA	Okanagan	34N	21E	15	21	70	594	1950	32	79	1.5	7.11	205
Blue	OR	Jefferson	13S	8E	27	96	314	1052	3453	229	54	0.2		
Diamond	OR	Douglas	27S	6E	30	15	50	1580	5183	1300	3214	85.3	6.70	70
Duck	WA	Okanagan	34N	26E	10	20	65	378	1241	16	39	0.8		
East	OR	Deschutes	21S	13E	31	49	160	1942	6370	422	1044	8.7	7.52	377
Elk	OR	Deschutes	18S	8E	5	15	50	1489	4884	164	405	10.8	6.70	48
Gillette	WA	Stevens	36N	42E	17	27	87	963	3160	19	48	0.7	5.77	65
Lake of the Woods	OR	Klamath	37S	5E	3	15	50	1508	4949	464	1146	30.4		
Loon	OR	Douglas	23S	10W	2	30	100	128	420	119	294	3.9	8.64	54
Magone	OR	Grant	12S	32E	7	30	98	1524	5000	12	30	0.4	7.62	89
Miller	OR	Klamath	27S	6.5E	13	18	60	1716	5630	229	566	12.5	8.41	35
Munsel	OR	Lane	18S	12W	14	21	70	27	90	44	110	2.1	6.71	81
North Twin	OR	Deschutes	21S	8E	28	18	60	1323	4339	45	112	2.5	7.59	162
Paulina	OR	Deschutes	21S	12E	34	73	240	1930	6331	620	1531	8.5	8.24	694
Sherry	WA	Stevens	36N	42E	19	26	85	963	3159	11	26	0.4		
Suttle	OR	Jefferson	13S	8E	24	24	80	1048	3438	102	252	4.2	6.84	70
Swan	WA	Ferry	35N	32E	20	29	95	1110	3641	21	52	0.7	6.03	182
Triangle	OR	Lane	16S	7W	20	49	160	212	695	113	279	2.3	8.18	48

ITINERARY- OREGON LAKES

Saturday 9/5/92

Triangle Lake: Diatom Locality # 92:09:05-1

Triangle Lake is a deep (49 m maximum depth) lake in the Coast Ranges west of Eugene, Oregon (Fig. 1). We took one Ekman box core from approximately the deepest part of the lake (ca. 29m). From the Ekman sample, the sediment appears to consist of a black anoxic surface layer several millimeters thick, underlain by several centimeters of olive gyttja, which is underlain by a tan, stiff oxidized layer. The lake is surrounded by steep wooded topography with some clear-cut areas. Increased erosion following logging of this area may have been responsible for the stiff oxidized layer. We took a one-liter surface water sample and two whirlpacks of surface sediment from the Ekman. We also took one large composite sample from the Ekman. A core from edge of a fen at Little Lake near the south-southwestern end of Triangle Lake, taken by Cathy Whitlock and student, had a bottom ^{14}C age of 27ka and a good progression of additional ^{14}C ages. *Myriophyllum* was growing near shore.

Two diatom samples were collected: sample 92:09:05-1a ("surface") = surface sediment composite of the Ekman box core. Characteristic diatoms include *Tabellaria flocculosa, Cyclotella stelligera, Aulacoseira distans, Asterionella formosa, Hannaea arcus, Melosira varians, Stephanodiscus oregonica* (+ecc), *Rhizosolenia, Fragilaria crotonensis, Diploneis fennica, Eunotia.*

Diatom sample 92:09:05-1b ("surface sed")= top 1.0 cm of surface sediment. Sample contains very abundant diatoms dominated by *Tabellaria flocculosa, Asterionella formosa, Fragilaria crotonensis, Synedra acus, and S. parasitica.*

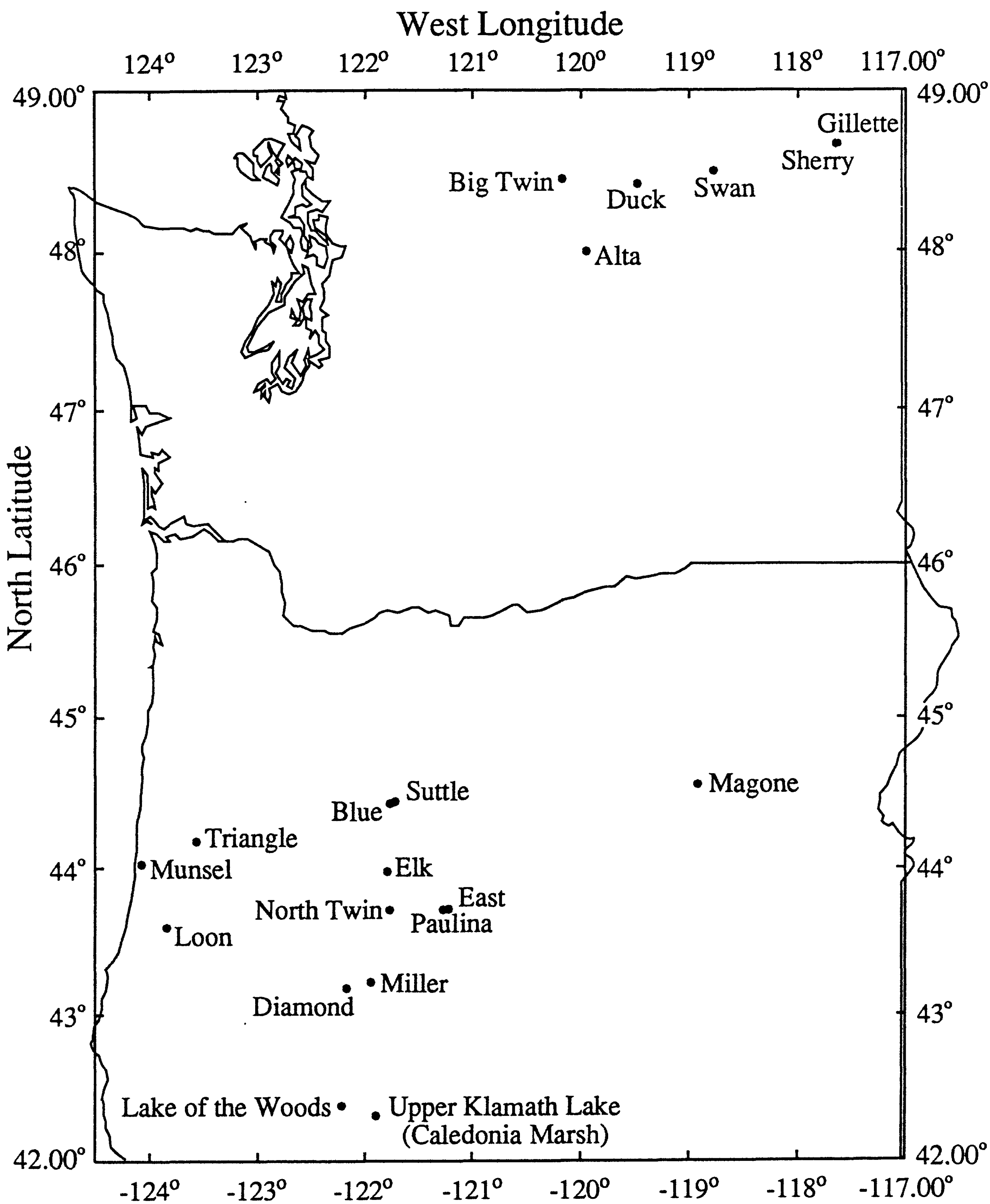


Figure 1. Map of Oregon and Washington showing locations of lakes sampled during September, 1992.

Sunday 9/6/92

Suttle Lake: Diatom Locality # 92:09:06-1

Suttle and Blue Lakes are high (1050 m) Cascade Mountain lakes right next to each other and just off highway 20 on the north end of the Three Sisters Wilderness Area and just west of Sisters, Oregon. From Suttle Lake we took one Ekman box core in center of lake at a water depth of 20 m. Two whirlpacks were filled with surface material and one large bulk Ekman sample was taken. The sediment is a tan, gelatinous, diatom-rich gyttja. The lake is surrounded by steep wooded topography. We took a one-liter water sample.

Diatom sample 92:09:06-1 represents the top 1.0 cm of lake mud. Characteristic diatoms: *Asterionella formosa, Stephanodiscus niagarae, St. oregonica, St. medius?, St. hantzschii / minutulus?, Aulacoseira italica, Fragilaria crotonensis, Synedra ulna danica.*

Blue Lake:

Blue Lake is much smaller (22 ha) than Suttle Lake and much deeper (maximum of 96 m; Table 1). We attempted several Ekman samples by lengthening our 65-m long Ekman chain with rope. However, we were unsuccessful in our attempts to trip the Ekman. The depth of Blue Lake is too deep for our present coring system. There was some difficulty in detecting when the sampler was on the bottom because the bottom apparently is rocky.

East Lake: Diatom Locality # 92:90:06-2

We took one Ekman box core from deepest part (ca. 49 m) of this crater lake in the Newberry Craters west of the Cascades and south of Bend, Oregon. Two whirlpacks were filled with black anoxic surface sediment. After spooning off this surface sediment, the underlying layer appeared lighter in color. Much of the sediment collected by the Ekman appeared to be varved, with millimeter-scale laminae of black and tan material. The varved sediment was in the middle of the Ekman sample, but it was hard to tell if the overlying and (or) underlying few centimeters of sediment also were varved; we need a frozen finger core to determine that. One composite sample of the varved material was collected along with a one-liter surface-water sample. We also collected a sample of littoral (ca. 45 cm water depth) sediment. White material in the littoral zone may be carbonate, but more likely it is pumice. However, white precipitated material on numerous bottles collected from the bottom of the lake near shore, on display in the boat rental office, probably is carbonate (a small sample was scraped from one bottle). This is in line with the reported high conductivity of 310 μSiemens (μS) and alkalinity (ca. 103 ppm) of East Lake from influx of dissolved solids from hot springs submerged along the southwest edge of the lake (Johnson and others,1985). East Lake is surrounded by steep, wooded slopes as might be expected for a crater lake. Paulina Lake, the twin to East Lake in the Newberry craters, contains even higher contents of dissolved solids. East Lake freezes most years with 30 cm or more of ice which usually stays on the lake until the third week in May.

Diatom sample 92:09:06-2 represents top 1.0 cm of lake mud. Characteristic diatoms: *Asterionella formosa, Fragilaria crotonensis, Stephanodiscus minutulus?* (d), *Cyclotella bodanica, Aulacoseira italica.*

Monday 9/7/92

Elk Lake: Diatom Locality # 92:09:07-1

Elk Lake is a high (1490 m) mountain lake in Deschutes Co. southwest of Bend, Oregon. We attempted two Ekman samples from the south end of a long, narrow 16-m trough that constitutes the deepest part of the lake. The first attempt, in 14.5 m of water, recovered only a clump of *Nitella* plants. The second attempt in 15.5 m of water, recovered even more *Nitella*, but also recovered some light olive gyttja. This material was put in a zip-lock bag. The sediment suspended in water in the pan was poured into two zip-lock bags; once the sediment had settled, the contents of the two bags were combined. From our sampling, it would appear that the bottom of Elk Lake contains extensive beds of *Nitella*. We collected a one-liter sample of surface water. Elk Lake is surrounded by wooded slopes of moderate to low steepness.

Diatom sample 92:09:07-1 was collected from olive gyttja surrounding *Nitella*. Characteristic diatoms: *Fragilaria crotonensis* (c), *Asterionella formosa, Fragilaria brevistriat* (a), *Aulacoseira italica, A. ambigua* (r), *A. alpigena* (c), *Aulacoseira species cf. A. lirata, Tabellaria flocculosa, Cyclotella stelligera* (r).

North Twin Lake: Diatom Locality # 92:09:07-2

North Twin Lake is another high (1320 m) mountain lake southwest of Bend. We took two Ekman box cores, one from 14.5 m and one from 16.5 m, with essentially identical results: the jaws of the Ekman were clogged with aquatic moss but some sediment was retained along with moss inside the Ekman. From the shallower of the two cores, we collected two whirlpacks of sediment and one of moss. From the deeper core, we took one composite sample in a ziplock bag. A one-liter surface-water sample was taken. The lake level in North Twin appears to be down at least 1.5 m below dead trees that line shoreline. Trees were probably killed by a high water level that was at least 1.5 m above the base of the trees. The shore of lake is wooded with moderate to low slopes.

Diatom sample 92:09:07-2 a represents a composite sample. Characteristic diatoms: *Navicula radiosa, N. tenella, N. aurora, N. vulpina, Cyclotella michiganiana, Asterionella formosa.* Diatom sample 92:090:07-2b represents mud with moss. Diatoms are rare, but characteristic diatoms are *Eunotia implicata* (cf. *E. pectinalis*) with teratological forms, *Navicula pupula.*

Paulina Lake: Diatom Locality # 92:09:07-3

Paulina is similar to its twin crater lake, East Lake, but is deeper. We took one Ekman box core in 57 m water depth. Most of the sediment recovered in the Ekman was a black, fairly homogenous, soupy sapropel?, but at the bottom, ca. 8 cm below the sediment/water interface, there were two bright green, stiffer layers, each about 1 cm thick, separated by several centimeters of coarse black and tan laminae (not varves). This laminated sediment contained segmented worms (not Chironomids) ca. 2 cm long. We collected two whirlpacks of black sapropel from the very top of the Ekman, and one whirl pack of the lower green layer. We collected one large ziplock bag of the stiffer green sediment from the two lower layers, and one ziplock bag of composited black ooze. We attempted to take an Ekman in water about 67m by attaching a rope to the Ekman chain and nylon fishing line to the messenger on the chain below the splice, but the messenger released prematurely. A one-liter water sample was taken from the surface. The surfaces of *Elodea* leaves in littoral zone are covered with precipitated carbonate which is consistent with an alkalinity of >300 ppm (conductivity >550 µS). However, all of this carbonate is introduced from submerged hydrothermal springs just like it is in East Lake. Therefore, the climatic significance of any carbonate variation is questionable. The obsidian flow just south of Paulina Lake occurred 1.3 ka, and lava flows around Newberry Craters are as young as 1.0 ka. Therefore, the meaningful record obtainable from this lake is likely to be <1500 yr.

Diatom sample 92:09:07-3a represents the lower green layer. Characteristic diatoms: *Stephanodiscus minutulus, S. parvus, Fragilaria crotonensis, Asterionella formosa, Rhoicosphenia curvata, Epithemia hyndmanii.*
Diatom sample 92:09:07-3b represents top 1.0 cm of surface mud. Characteristic diatoms: *Stephanodiscus minutulus, S. parvus, Fragilaria crotonensis, Asterionella formosa, Cyclotella bodanica, Fragilaria consturens + vars, Stephanodiscus medius?, Rhoicosphenia curvata, Epithemia hyndmanii.*

Tuesday 9/8/92

Miller Lake: Diatom Locality # 92:09:08-1

Miller and Diamond Lakes are two high (1716m and 1580 m, respectively) lakes in the southern Cascades near Mt. Thielsen. From Miller Lake, we collected one Ekman box core from a water depth of 38 m. We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of entire box core. Based on the Ekman sample, the sediment in Miller Lake is a tan, oxidized, homogeneous, gelatinous gyttja. A one-liter water sample was taken from the surface. *Isoetes* was growing in the littoral zone.

Diatom sample 92:009:08-1 represents top 1.0 cm of surface mud. Characteristic diatoms: *Synedra acus, Stephanodiscus parvus / minutulus, S. alpinus?, Asterionella formosa, Aulacoseira italica, Fragilaria construens venter, Epithemia,* and assorted benthics.

Diamond Lake: Diatom Locality # 92:09:08-2

Diamond Lake has a low conductivity like most other Oregon Cascade lakes, but unlike most other Cascade lakes is reported to be eutrophic. We collected one Ekman box core from deepest part of the lake (ca. 15 m). We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of the entire box core. Based on the Ekman sample, the sediment in Diamond Lake is a light tan, very oxidized (probably the most oxidized we've seen so far), homogeneous, gelatinous gyttja. We collected a one-liter water sample from the surface. A fairly heavy blue-green algal bloom was in progress when we sampled the lake.

Diatom sample 92:09:08-2 represents top 1.0 cm of surface mud. Characteristic diatoms: *Stephanodiscus niagarae* (c), *S. minutulus ? parvus / hantzschii, Asterionella formosa, Fragilaria crotonensis, Aulacoseira granulata* (r).

At this point, we concluded that even deep Cascade lakes are too dilute, too oligotrophic, and have open water seasons that are too long (too well mixed?) to have much potential for varve formation and preservation. Typical sediment is a tan, oxidized, homogeneous, gelatinous, probably diatom-rich gyttja. We decided to obtain Ekman box cores from moderately deep (20-30

m) lakes near the coast and in the coast ranges, and spent the rest of the day driving to Bandon, Oregon.

Wednesday 9/9/92

Munsel Lake: Diatom Locality # 92:09:09-1

Munsel Lake is an interdune coastal lake due west of Eugene, Oregon. We collected one Ekman box core from a water depth of 22.5 m. We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of the entire box core. Based on the Ekman sample, the surface sediment in Munsel Lake is a dark olive, homogeneous, firm gyttja; firm presumably because of the apparent high content of siliciclastics. A one-liter water sample was taken from the surface. The lake is in a wooded, residential area with access from one public boat-launch and fishing area. The lake appears to be a drainage that was dammed by dunes.

Diatom sample 92:09:09-1 represents the top 1.0 cm of surface mud. Characteristic diatoms: *Cyclotella stelligera, Aulacoseira italica, A. distans* (r), *A. ambigua* (vr), *Asterionella formosa, Synedra nana, Tabellaria flocculosa, Brachysira, Eunotia, Neidium, Pinnularia.*

Loon Lake: Diatom Locality # 92:09:09-2

Loon Lake, at 420 m in the Coast Ranges, is surrounded by heavily wooded, steep-sided shores which is in line with its origin as a landslide lake, perhaps as recently as 1460 years ago. We collected one Ekman core from a water depth of 30 m. We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of the entire box core. The sediment is distinctly layered with alternating black and medium gray to tan bands, both composed of clay. The bands vary in thickness but average about 0.5 to 1.0 cm. The layers may be annual, in which case the black band probably represents a summer organic-rich layer and the gray or tan layer a winter storm layer. If they are annual, then the sedimentation rate in Loon Lake is quite high because the annual couplets average about 1.0 cm.

Diatom sample 92:09:09-2 represents the top 1.0 cm of silty surface mud. Characteristic diatoms: *Asterionella formosa, Fragilaria crotonensis, Aulacoseira granulata* (r), *Tabellaria flocculosa.*

Thursday 9/10/92

Upper Klamath Lake: Diatom Locality # 92:09:10-1, 2

We met Dave Adam and Karen Schiller (both with the USGS in Menlo Park) in Klamath Falls and conducted a reconnaissance of the entire perimeter of Upper Klamath Lake and surrounding wetlands, and former wetlands and lake-floor areas that have been drained for agriculture. In 1991, Dave, using a drilling rig and crew from the USGS, Denver, had taken rotary cores from Caledonia and Wocus Marshes, two areas of reclaimed lake floor, but the recovery of the upper part of the section in both cores was poor (Gardner and others, 1992). Our objective here was to get better recovery of this upper section using a piston core. We decided to take a Livingston piston core from the lake margin on the outer part of Caledonia marsh (which was once part of the lake floor). Before doing that, we rigged the two canoes and took a 1.69-m plastic-tube push piston core from the south side of Howard's Bay about 400 m off the north northeast edge of Caledonia marsh. While we were rigging and taking the push core, Dave and Karen rigged the coring frame which was transported to the edge of Howard's Bay, ready to begin coring the next day.

Diatom sample 92:09:10-1 was collected from an exposed mud flat on the SW margin of Howards Bay, just NE of the highway. Upper Klamath Lake is down about 2 m judging from lake level marks exposed on the highway berm. Characteristic diatoms: *Stephanodiscus niagarae, S. parvus / minutulus, S. oregonica, Aulacoseira ambigua, Asterionella formosa, Melosira varians, Fragilaria construens + vars.*

Diatom sample 92:09:10-2 was collected from diatomaceous mud about 30 cm below the toe of the road berm that contains Caledonia Marsh along its NW margin. The material was exposed with a shovel near the center of the marsh fringe and close to the coring site. Characteristic diatoms: *Fragilaria construens* (d), *Stephanodiscus niagarae, St. oregonica* +- ecc.

Friday 9/11/92

We spent all day collecting a 12.8 m core from the site on the edge of Howard Bay in Upper Klamath Lake (see log, Fig. 2). The coring was accomplished in 17 drives using a 1-m square-rod Livingston piston corer. Coring was stopped by a hard, sandy layer.

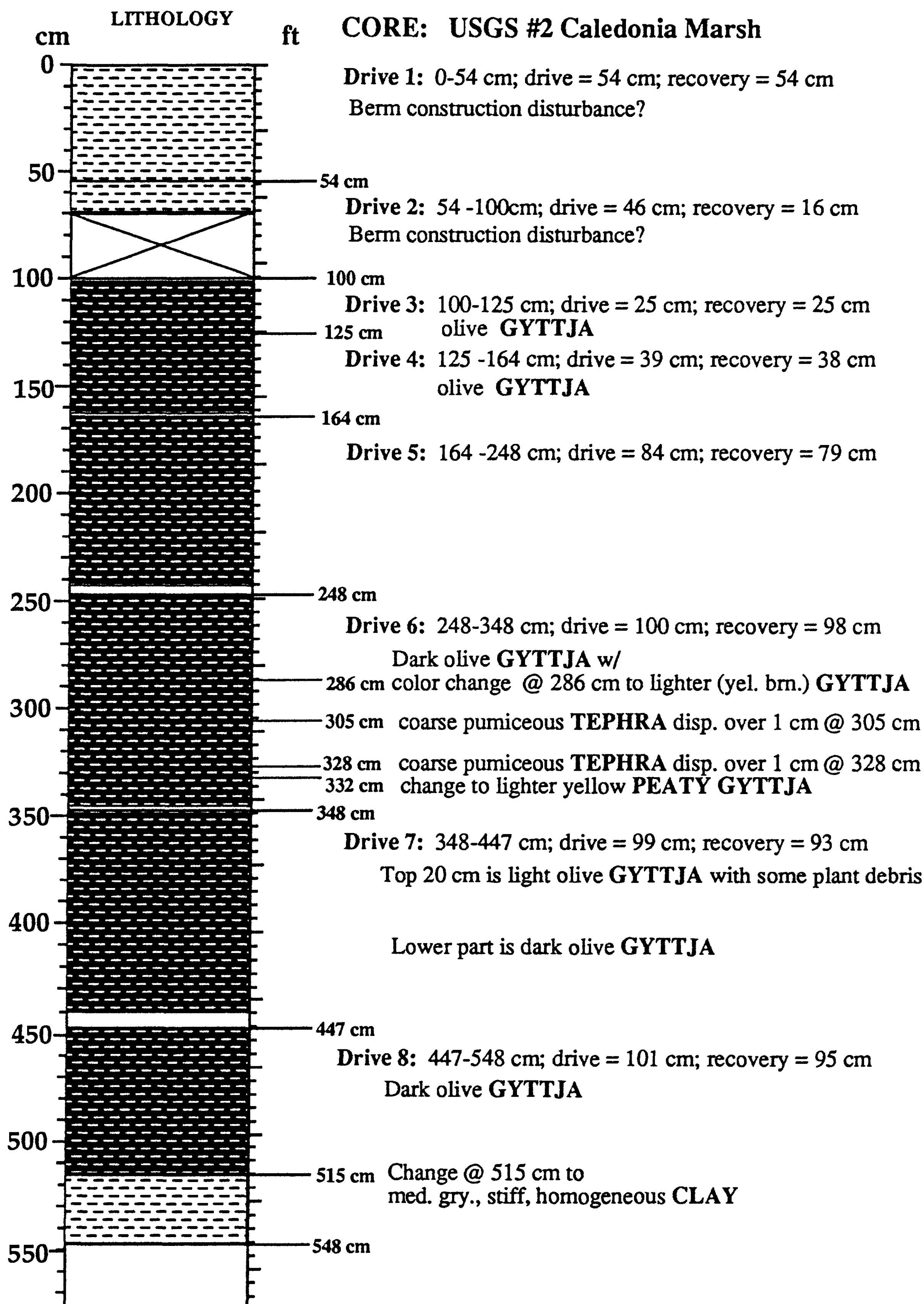
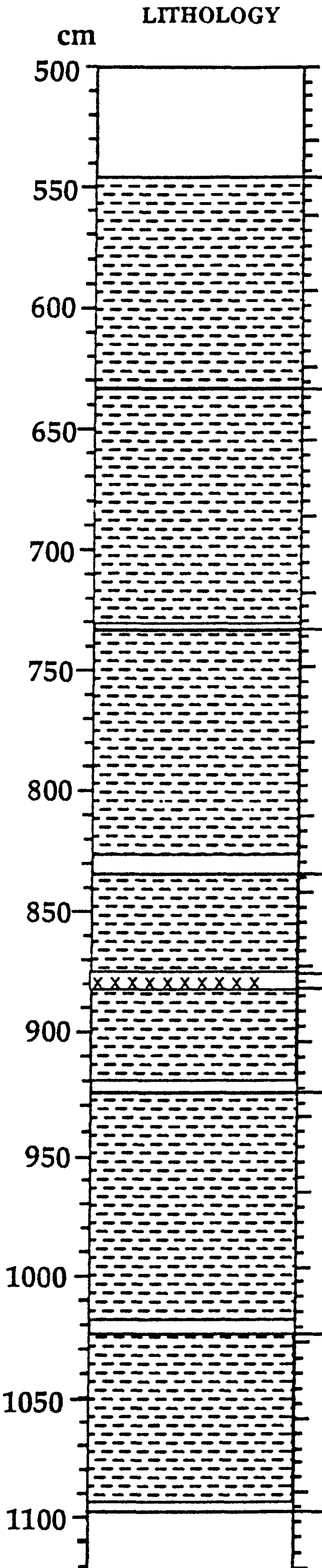


Figure 2. Lithologic log of core USGS #2 Caledonia Marsh from Upper Klamath Lake.

MAA/WED/BBS - 6/92

CORE: USGS #2 Caledonia Marsh



548 cm

Drive 9: 54 8-632 cm; drive = 84 cm; recovery = 84 cm

CLAY - med. gry., stiff, homogeneous (upper 8 cm is soft coring gunge)

632 cm

Drive 10: 632-732 cm; drive = 100 cm; recovery = 98 cm

CLAY - med. gry., stiff, homogeneous, w/ a few coarser, darker layers 1-2 mm thick

732 cm

Drive 11: 732-832 cm; drive = 100 cm; recovery = 96 cm

CLAY - med. gry., stiff, homogeneous, w/ several dark green mottles and layers throughout

832 cm

Drive 12: 832-925 cm; drive = 93 cm; recovery = 88 cm

CLAY - med. gry., stiff, homogeneous as above

876 cm
881 cm
TEPHRA - 2, 1-cm-thick ash layers @ 44-45 cm and 49-50 cm

CLAY - med. gry., stiff, homogeneous as above

925 cm

Drive 13: 925-1023 cm; drive = 98 cm; recovery = 88 cm

CLAY - med. gry., stiff, homogeneous as above; thin, dark layer @ 23 cm may be basaltic tephra.

1023 cm

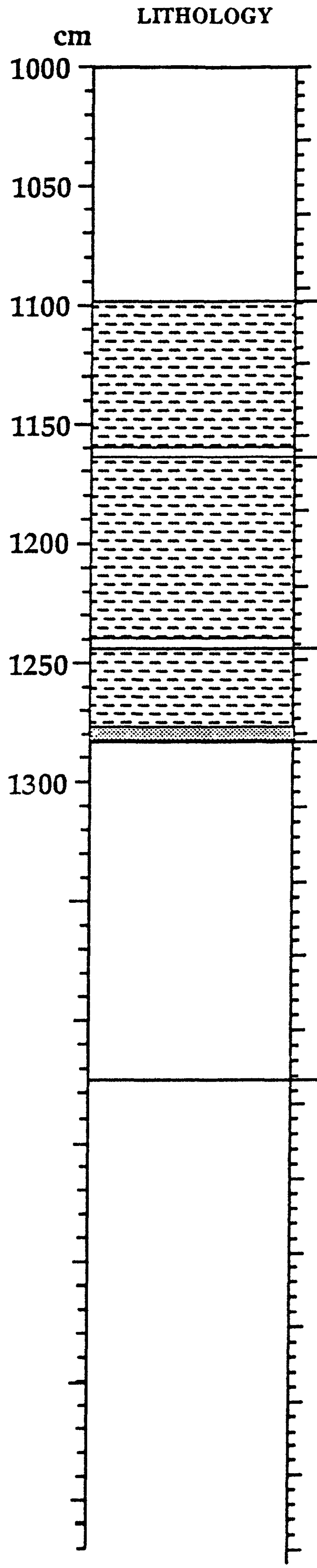
Drive 14: 1023 -1098 cm; drive = 75 cm; recovery = 71 cm

CLAY - med. gry., stiff, homogeneous as above

1098 cm

MAA/WED/BBS - 6/92

CORE: USGS #2 Caledonia Marsh



1098 cm

Drive 15: 1098-1163 cm; drive = 65 cm; recovery = 62 cm

CLAY - med. gry., stiff, homogeneous as above

bottom cm sli. more silty

1163 cm

Drive 16: 1163-1244 cm; drive = 81 cm; recovery = 77 cm

0-14 cm: soft gray CLAY
14-23 cm: firmer, siltier gray CLAY
23-71 cm: stiff, gray CLAY
71-81cm: light gray mottles in darker gray CLAY

1244 cm

Drive 17: 1244-1283cm; drive = 39 cm; recovery = 51 cm

CLAY - med. gry., stiff; sandier at bottom; top 14 cm is soupy

1283 cm
= T.D. for hole

MAA/WED/BBS - 6/92

Saturday 9/12/92

We spent the morning unsuccessfully trying to get deeper in the Howard Bay hole, but we were not able to penetrate any further into the hard sandy layer. We spent the rest of the day sampling Pliocene diatomite outcrops around Klamath Falls.

Sunday 9/13/92

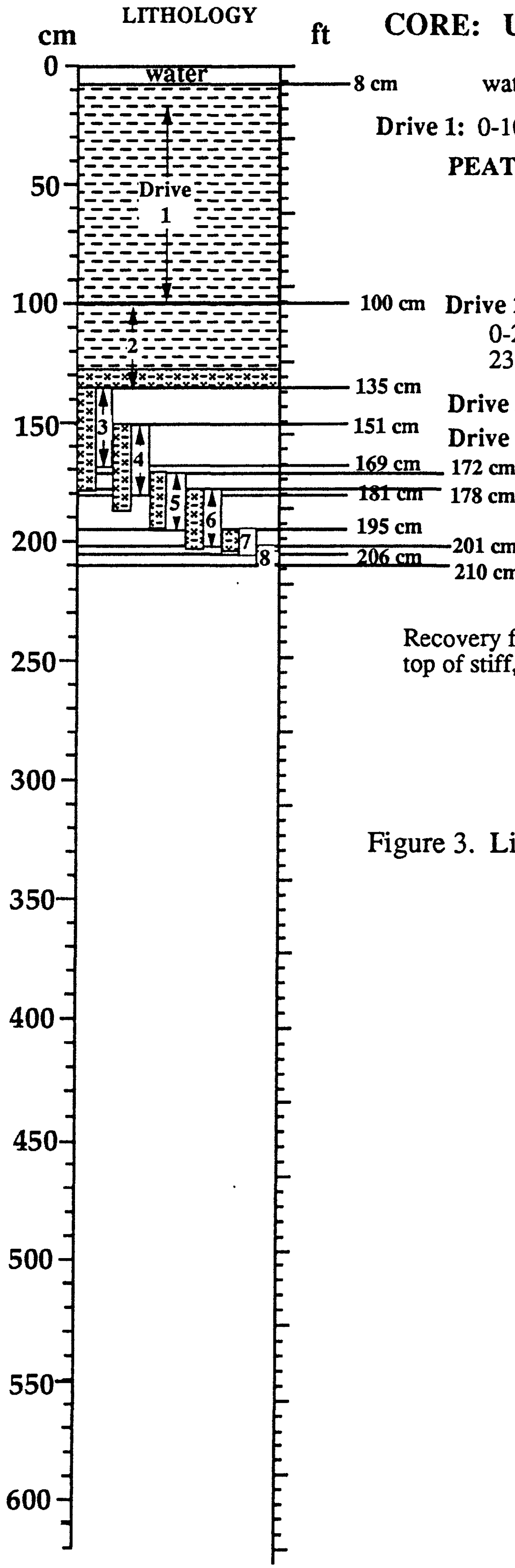
This was field trip day. We were joined by Pat Bartlein and Pat McDowell University of Oregon, Bob Thompson USGS, Denver, and Alexis Levine a graduate student from Humbolt State University doing a master's thesis on cinder cones around Tule Lake. We spent most of the morning doing arm waving and overviews of coring sites and the big picture and the general geologic and limnologic setting around Upper Klamath Lake. In the afternoon we went south to the Tule Lake basin and got an overview of the cinder cones around Tule Lake in Alexis' thesis area.

Monday 9/14/92

Buck Lake:

Dave Adam took a rotary core from near the old shoreline of now-dry Buck Lake in 1991 using a drilling rig and crew from the USGS, Denver (Gardner and others, 1992). We went to Buck Lake to attempt to take piston cores further out in the center of the basin where the drill rig was unable to go a year ago. The principal objective was to resolve the problem of the gravels that were encountered about 3 m down in the rotary hole drilled much closer to the shore. Their presence close to the edge of the basin can be explained by fluvial processes, but if they are present in the middle of the lake basin, how did they get there? We set up the coring frame on the edge of a drainage ditch near the center of the basin. At 123 cm we encountered a sandy, basaltic tephra (Fig. 3). On subsequent drives, this tephra sand continued to wash into the hole complicating recovery of the underlying clay, which was very stiff and extremely difficult to core even without the problems of tephra flow-in. By 200 cm, most of the tephra flow-in had stopped but our ability to penetrate the clay was limited; on the final drive we were only able to penetrate 6 cm.

CORE: USGS #2 Buck Lake



water level is 8 cm below ground level

Drive 1: 0-100 cm; drive = 100 cm; recovery = 94 cm

PEATY CLAY-yel. gray; homogeneous

Drive 2: 100-135 cm; drive = 35 cm; recovery = 35 cm
0-23 cm: **PEATY CLAY**-yel. gray; homogeneous
23-35 cm: **TEPHRA** - basaltic; olive; sandy

Drive 3: 135-169 cm; drive = 34 cm; recovery = 43 cm

Drive 4: 151-181 cm; drive = 30 cm; recovery = 37 cm

Drive 5: 172-195 cm; drive = 23 cm; recovery = 23 cm

Drive 6: 178-201 cm; drive = 23 cm; recovery = 25 cm

Drive 7: 195-206 cm; drive = 11 cm; recovery = 10 cm

Drive 8: 204-210 cm; drive = 6 cm; recovery = 6 cm

Recovery from drives 3-7 consisted of sandy, basaltic **TEPHRA** on top of stiff, gray, inorganic **CLAY**

Figure 3. Lithologic log of core USGS #2 Buck Lake.

MAA/WED/BBS - 6/92

The Buck Lake property is ranched by Hugh Charley and his wife Cathy (Charley Livestock, Inc.). The property is owned by Hugh's mother who can remember as a little girl that there was an extensive lake in the basin. That lake drained south and today there is a substantial channel still draining the basin with a gorge and waterfalls that are overfit for the present drainage. At the outlet, there is also the remnants of a concrete dam indicating that there was at least some attempt to maintain a lake in the basin before they decided to make a meadow out of the basin.

The sedimentation rate in Buck Lake is extremely slow, estimated at 3-4 cm/1000 yr. based on a 500,000-yr ash at 20 m and a 300,000-yr ash at 10 m in the 1991 rotary core. Diatomite, apparently of Holocene age, occurs ca. 30 cm below the present grassy surface of the basin. This diatomite is also found in the gouge at the outlet. A volcanic ash (pumice lapilli) were found ca. 15-20 cm below the present soil surface (= Mount Mazama ash?).

Lake O' The Woods: Diatom Locality # 92:09:14-4

Because we were unsuccessful in obtaining a piston core at Buck Lake, we had some time left in the day and decided to collect an Ekman core from Lake of the Woods on the west side of Mountain Lakes Wilderness Area which forms the western border of Upper Klamath Lake. Lake of the Woods is fairly large (464 ha) and shallow (15 m) so we did not expect to find varve sediments. Our main interest in the lake was for a baseline for pollen and diatoms in a high (1508 m) mountain lake close to Upper Klamath Lake. We collected one Ekman box core from a water depth of 15.5 m on the asymmetrically steep west side of the lake. We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of entire box core. Based on the Ekman sample, the surface sediment is a light olive, homogeneous gyttja. No water sample was collected.

Diatom sample 92:09:14-4 represents the top 1.0 cm of lake mud. Characteristic diatoms (poorly preserved): *Aulacoseira ambigua, A. italica, A. granulata?, Tabellaria flocculosa, Fragilaria brevistriata, Fragilaria crotonensis, Navicula aurora, Eunotia, Cyclotella radiosa.*

Tuesday 9/15/92

Magone Lake: Diatom Locality # 92:09:15-1

On our way north to begin sampling Washington lakes, we decided to take an Ekman box core from Magone Lake (pronounced Magoon), a high (1524 m) mountain lake in the Blue Mountains north of John Day, Oregon, because it is small (12 ha) and deep (30 m) and, therefore, has the morphometric potential for preserving varved sediments. In addition, the Blue Mountains contain Paleozoic carbonate strata so that the lake has a higher alkalinity than Oregon Cascade lakes and, therefore, has the potential for carbonate precipitation. Magone Lake was created by a landslide sometime during the early 1800s. We collected one Ekman box core from a water depth of 24 m from the deep south end of the lake. The deepest reported depth is 28 m, but the water level of the lake is at least 2 m below normal level of the lake judging from the exposed shoreline. We collected two whirlpacks of sediment from the top of the Ekman, and one bulk composite sample of the entire box core. Based on the Ekman sample, the upper 15 cm of sediment is a jet black, very soupy, homogeneous, gyttja or sapropel with some visible plant debris. We also collected a surface water sample.

Diatom sample 92:09:15-1 represents the top 1.0 cm of surface mud. Characteristic diatoms: *Fragilaria crotonensis* (v. fine), *Asterionella formosa, Synedra acus, S. nana?, Navicula oblonga, Nitzschia dissipata?, Amphora ovalis, Rhopalodia gibba, Epithemia, Cocconeis placentula.*

ITINERARY-WASHINGTON LAKES:

Wednesday 9/16/92

Alta Lake: Diatom Locality # 92:09:16-1

Alta Lake is in Alta Lake State Park 6 km southwest of the Pateros, Washington off highway 153. There are two resorts that rent row boats (but not motor boats), one midway on the west shore and one at the northern end. The southern end contains an extensive State Park with camping, swimming beach, and boat launch. We collected one Ekman box core from a water depth of 20 m from the deep central part of the lake. The deepest reported depth is 25 m, but the water level of the lake is at least 1 m below normal level of the lake as evidenced from carbonate staining on rocks above present lake level. There are beds of *Chara* growing in the littoral zone indicating that this is a carbonate-rich lake. Based on a clear plastic subcore collected from the center of the Ekman, the top of the sediment is olive black and the rest of the sediment is banded dark olive with lighter tan bands and laminae. There is one zone with at least 10 distinct mm-scale laminae. There are three very distinct tan-colored laminae. We collected two whirlpacks of sediment from the top of the Ekman, one whirl pack of the distinct tan laminae, and one bulk composite sample of the entire box core sample. The subcore did not travel back to shore very well, and some of the sediment leaked out of the bottom. In the future we should take subcores of Ekman box cores but to do this properly we should have end caps for the plastic tubes. One photo was taken from the boat launch at the southern end of the lake looking north. The east and west shores of the lake consist of very steep scree slopes that extend down to the shore. Most of the shoreline is wooded but most of the valley walls are too steep.

Diatom sample 92:09:16-1a represents the top 1.0 cm of surface mud. Much volcanic ash is present in this sample. Characteristic diatoms: *Fragilaria brevistriata, F. construens, Cyclotella bodanica, C. kuetzingiana?, Nitzschia dissipata.*
Sample 92:09:16-1b was from the tan bands or laminae that proved to be composed almost entirely of diatoms. Characteristic diatoms: *Fragilaria brevistriata, F. construens, Cyclotella bodanica, C. kuetzingiana?, Cyclotella michiganiana.*

Thursday 9/17/92

Big Twin Lake: Diatom Locality # 92:09:17-1

Big Twin Lake, Okanogan Co., is one of many kettle-hole lakes in this moraine-covered part of Washington. It's reported deepest depth is 20 m. The deepest we were able to find was 19 m. Lake is presently about 1.5 m lower than normal according to Mr. Frank Johnson[1] who has lived here all his life and manages the campground on the southwest shore. According to Frank, there is a distinct marl bench that does not show particularly well on the 1946 bathymetric map, made with sounding lines, that is in Wolcott (1973). Also according to Frank, a storm last year created very large waves that washed up at least 20 m on the southwest shore by Frank's house. Such a storm, if they occurred in the past, would have had a vary marked effect on the sedimentary record, such as turbidites from the marl bench. The shores of the lake are fairly low, exposed, and grass covered. Littoral vegetation contained *Elodea* and *Chara*. A water sample was taken from the surface. One photo was taken from the shore looking toward the deepest part of the lake. From this deepest part, we took a plastic-tube, push piston core 147 cm long. Most of the core is distinctly banded with cm-scale lighter gray, more carbonate-rich bands and darker brown, more organic?-rich bands. There are some zones of distinct millimeter-scale laminae, mostly about 2 mm thick. There is a distinct ash lamina at about 91 cm. The core was extruded, and the uppermost part of the top soupy sediment was put into two whirlpacks. The rest of the top 17 cm of soupy sediment was placed in a large ziplock bag. The rest of the sediment was described in detail (Fig. 4), photographed, and wrapped in three segments (147-117 cm, 117-68 cm, and 68-20 cm).

Diatom sample 92:09:17-1 is from the uppermost soupy sediment at core top. Characteristic diatoms: *Cyclotella bodanica, Nitzschia angustata, Stephanodiscus minutulus / parvus, Fragilaria crotonensis, Asterionella formosa, Synedra nana?, Amphipleura pellucida, Cyclotella michiganiana* (r).

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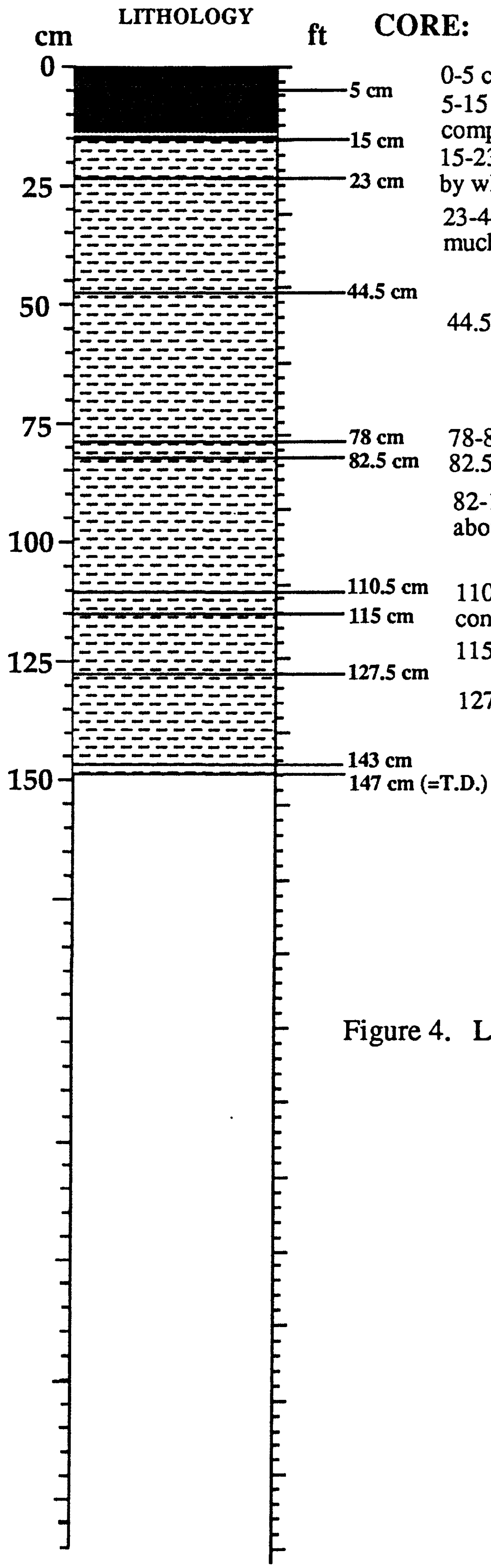
CORE: USGS #1 BigTwin; 19 m water depth; 9/17/92



0-5 cm: olive algal-bacterial (?) floc

5-15 cm: olive algal-bacterial (?) floc as above but more compacted and slightly lighter in color

15-23 cm: CLAY; alt. 0.5-1 cm bands of tan and olive separated by whitish laminae

23-44.5 cm: CLAY; brownish tan; apparently banded but bands much more obscure than above; dist. blk. lamina @ 44.5 cm

44.5-78 cm: CLAY; lt. olive; no bands or laminae

78-82.5 cm: CLAY; dk. gray; no bands or laminae; contact @ 82.5 cm very sharp

82-110.5 cm: CLAY; dk. gray; no bands or laminae; similar to above but darker gray; flecks of ash? @ 89-90 and 87-88 cm

110.5-115 cm: CLAY; tannish gray; no bands or laminae; contact @ 115 cm very sharp

115-127.5 cm: CLAY; tannish gray; same as above

127.5-143 cm: CLAY; lt. tannish gray

143-147 cm: CLAY; tannish gray; similar to above but sli. darker and faintly banded

Figure 4. Lithologic log of core USGS #1 Big Twin Lake.

MAA/WED/BBS - 6/92

Duck Lake: Diatom Locality # 92:09:17-2

Duck Lake (also known as Bide-a-Wee Lake), is a small kettle-hole lake in an extensive outwash plain in the Okanogan River valley, which has well developed kame terraces, particularly on the east valley wall. The shore of the lake consists of low, gently rolling hills typical of outwash plain. The lake is probably subjected to fairly high winds because it is not particularly well protected by trees or topography. The lake reportedly has a maximum depth of 19.8 m but this is when the water level was considerably higher and there was an open channel between Duck lake and Fry Lake. Water depth in the deepest part of the lake where we collected the Ekman box core was 16 m deep on this date. We took a 5-cm--diameter subcore of the Ekman. We then collected two whirlpacks of sediment from the top of the Ekman, one whirl pack of gray clay from the very bottom of the Ekman, and one bulk composite sample of the entire box core. The Ekman sample appeared to be a homogeneous, black sapropel, but the subcore did show a hint of several laminations, as if conditions were right to make and preserve laminations at times. The subcore was not saved.

Diatom sample 92:09:17-2 represents the top 1.0 cm of surface mud. Characteristic diatoms: *Asterionella formosa, Tabellaria flocculosa, Fragilaria crotonensis, Stephanodiscus parvus / hantzschii, Cyclotella ocellata, Cocconeis pediculus.*

Friday 9/18/92

Swan Lake: Diatom Locality # 92:09:18-2

Swan Lake, Ferry Co., is a small, protected lake southwest of Republic, Washington, with access off highway 21. The reported maximum depth of Swan lake is 29 m. The slopes surrounding the lake are not particularly steep but are completely covered with tall coniferous forest. The deepest water we were able to find was 26.5 m, and we took an Ekman from this water depth. A 5-cm-diameter subcore from the Ekman showed that the sediments are distinctly laminated throughout. A top flocculent unit of dark gray and lighter gray laminations with an overall color of dark gray is 5 cm thick. Underlying the dark gray laminated unit was a very gelatinous, light brown sediment set off by distinct laminations of both lighter (light tan to almost white) and darker (darker brown to reddish brown) material, with lighter laminae more abundant than darker. The contact between the two laminated units is very sharp, and the base of the dark gray laminated unit is more silty than the underlying brown laminated unit. Most of the laminae couplets in the lower brown laminated unit average about 2 mm thick, but some are as much as 1 cm thick. These laminae appear to be iron-rich and look similar to those in Lake of the Clouds, Minnesota. The subcore was capped and saved. We took two whirlpacks of the dark gray flocculent surface material, one composite bulk sample of the upper laminated dark gray unit, and once composite bulk sample of the lower laminated brown unit. We also took a surface water sample. Back on shore, photos were taken of the subcore and of laminae in the lower gelatinous brown unit in the bulk Ekman sample that was left in the pan. Several slabs of this material were wrapped in plastic in an attempt to preserve the bulk material. A photo also was taken of the lake from the boat ramp toward the deepest part of the lake.

Diatom sample 92:09:18-2 represents the top 1.0 cm of surface sediment. Characteristic diatoms: *Tabellaria flocculosa, Cyclotella bodanica, C. meneghiniana, C. michiganiana, Stephanodiscus cf* *alpinus, Synedra acus, S. nana?, Asterionella formosa, Navicula oblonga, Mastogloia, Nv. radiosa, Epithemia argus, Amphora ovalis.* This assemblage suggests moderately high alkalinity.

Gillette Lake: Diatom Locality # 92:09:18-3

Gillette Lake is one of a string of small, deep paternoster lakes along the Little Pend Oreille River northeast of Colville in Stevens Co. The reported deepest depth is about 26m, but the lake level appears to be down about 0.5 m judging from the shoreline. We took an Ekman box core from a water depth of 25.5 m. We placed a 5-cm-diameter subcore tube in the center of the Ekman and took two whirlpacks of surface material. We took the unopened Ekman with the subcore in place back to shore where we could open it in a more controlled environment. We did take a surface water sample. Back on shore, the subcore showed that the entire Ekman sample consisted of laminated black sapropel (called sapropel because of its black color although there was no obvious odor of H_2S when the Ekman was first opened). The laminations were difficult to see mainly because they are fine (mostly <1mm) and without much contrast (black vs dark gray), but apparently the entire sediment column recovered is laminated. The laminae were easier to see in the scraped Ekman sample. A bulk composite sample was placed in a large ziplock bag, and two slabs of sediment were placed on a sheet of cardboard to dry and oxidize. We also took a sample of light-colored littoral sediment. Rooted aquatic vegetation (*Potomogeton*) in the littoral zone had a light encrustation of granular $CaCO_3$. Two photos were taken from the boat-launch dock. The shoreline is heavily wooded in coniferous forest, but the shoreline is also fairly heavily developed with private homes. The next lake to Gillette is Sherry Lake which has the same morphometric characteristics and probably also contains laminated sediment.

Diatom sample 92:09:18-3 represents the top 1.0 cm of surface sediment. Characteristic diatoms: *Cyclotella bodanica (radiosa?), C. michiganiana, C. stelligera / pseudostelligera* (p), *Synedra nana, S. acus* (p), *Aulacoseira italica, A. distans, Tabellaria flocculosa, Stephanodiscus parvus* (r), *Asterionella formosa.*

CONCLUSIONS

When we went to Oregon and Washington, we had the simplistic notion that morphometry alone (i.e. deep and small) should be enough to preserve lamination. We learned, however, that it also takes a fairly high level of organic productivity, and a high content of $CaCO_3$ also helps. The high productivity contributes a seasonal organic component, in addition to just the diatom remains, and also produces seasonal anoxia to eliminate bioturbation. In a typical oligotrophic Oregon Cascade lake with diatoms as the main primary producers, the sediment is oxidized (even in very deep lakes) and looks like light brown rice pudding. $CaCO_3$, while not necessary, is helpful to contribute a seasonal $CaCO_3$ lamina.

Oregon:

East Lake in the Newberry Craters (and probably Paulina Lake) have the alkalinity required for carbonate precipitation, but it was derived from sublacustrine hot springs, and, therefore, the carbonate signal would reflect hot spring activity and not so much climate. We also learned from Loon Lake that apparently winter storminess may produce fairly thick (0.5-1 cm) varves if you have something to contrast it with such as a good black organic-rich summer layer which Loon Lake apparently has. Even though Loon Lake would only have about a 1000-year record, this record might contain information about El Niños and winter storms as recorded in the winter layer. Another component that appears to be necessary is greater seasonality. We suspect that the fall and spring overturns in Oregon lakes are too long. What is needed is a period of rapid overturn in the fall and spring followed by fairly rapid stratification. Then, in the summer, the lake needs to have at least moderate organic productivity to bring about anoxia.

The above considerations appear to limit varve formation in the ultraoligotrophic, extremely low alkalinity, relatively warm lakes of Oregon.

Washington

Washington lakes are able to preserve varves even at moderate depths (ca. 25 m). Carbonate apparently precipitates in some lakes (e.g., Big Twin, Swan, and possibly in Gillette) in calcareous glacial drift. Protection from wind also is important to help reduce wind mixing. For example, Big Twin and Swan Lakes are about the same size, but Big Twin is open and unprotected from wind in low rolling hills with no tree cover. Big Twin probably is subjected to considerable wind mixing and does not preserve varves. Swan, on the other hand, is completely surrounded by coniferous forest and is more protected from wind mixing, and does contain laminated sediments. The low elevation Okanogan lakes appear to be well stratified thermally, but we don't have the thermal data to say anything about the dynamics of overturn. Steppe kettle-hole lakes in outwash plains like Big Twin and Duck probably get a lot of wind stress and, therefore, more wind mixing; small, deep lakes in coniferous forest such as Swan and Gillette probably have less wind mixing and, therefore, a more stable stratification. We also don't have data to assess the importance of a continental (versus maritime) climate or the effects of elevation.

Origin of Sapropel

We only sampled two lakes that have sapropel (defined as black, fine-grained, sulfidic sediment), Magone in Oregon and Duck in Washington. A third lake, Gillette Lake, Washington, contained black sediment that might be called sapropel, but did not smell of H_2S, and probably is not sulfidic. Most of the organic matter in Magone Lake probably is terrigenous. Most of the organic matter in Duck Lake probably is autochthonous. Magone, unlike most Oregon lakes, has a fairly high TDS content, derived from Blue Mountain carbonate terranes. Probably the main difference between a good gyttja in a deep, Cascade lake and the sapropel of Magone is the sulfate content of the water; the Cascade lakes can't produce any H_2S whereas Magone can produce some. In any of the Okanogan lakes, sulfate is probably abundant so that although sulfate is limiting pyrite production, it is not limiting H_2S production. Most Oregon lakes are too pure; bacteria don't have a chance.

Potential for Obtaining High Resolution Paleoclimatic Records

One only has to view the satellite images shown on the weather segments of the evening news, particularly during the winter months, to appreciate the importance of the eastern North Pacific Ocean on the weather of the western U.S. The northeast Pacific, dominated by the North Pacific High and the Aleutian Low not only generates the dominat weather and climate of the western U.S., but effects the climate of the entire northern hemisphere (Namias and others, 1988). Paleoclimatic records from lakes in the Pacific Northwest are far fewer than from other parts of the country, particularly the northeast and midwest, and paleoclimatic records from the North Atlantic Ocean far outnumber those from the North Pacific. High-resolution, varve-calibrated paleoclimatic records from the Pacific Northwest are, therefore, badly needed. From our preliminary compilation of varved lake sediments in North America (Anderson and others, 1985), we concluded that lakes in Washington and British Columbia had an excellent potential of providing varve-calibrated paleoclimatic records for comparison with more abundant records that exist in the well-studied north-central and northeastern United States. In that compilation we did not have any sites from Oregon, and our coring expedition in September, 1992 was designed to try to find some. However, for reasons explained above, the potential for varves in Oregon lakes, and, therefore, high resolution (annual) paleoclimatic records, is not very great. Our expedition did, however, confirm the great potential for recovering varved sediments containing climatically sensitive components from lakes in Washington. The main unknown is the quality and completeness of the varved sedimentary records, and this unknown can only become known by obtaining long cores.

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