Supplemental Data for:

Kelsey, H.M., Nelson, A.R., Hemphill-Haley, E.M., and Witter, R.C., 2005, Tsunami history of an Oregon coastal lake reveals a 4600 yr record of great earthquakes on the Cascadia subduction zone: Geological Society of America Bulletin, v. 117, p. 1009–1032, doi: 10.1130/B25452.1.

This supplemental data for Kelsey et al., (2005) includes photographs and descriptions of stratigraphic units in 21 cores from Bradley Lake (pdf format, listed separately in folders for each core [click "Tree" tab above listed files]) used to make the interpretations of lake history discussed in the paper, a preliminary interpretation of the correlation and genesis of core stratigraphic units in much more detail than could be presented in the published paper (pdf format, below), and tabulations of smear slide data for key units in cores (xlsx format, listed separately by core, lithology, and disturbance event). This data is in addition to the table of radiocarbon ages, table of sedimentation rates, and two figures in the supplemental data for the original paper in the Geological Society of America Data Repository (https://doi.org/10.1130/2005105).

Diatom data used for interpretation in the Kelsey et al. (2005) paper are explained and tabulated in: Hemphill-Haley, E.M., and Lewis, R.C., 2003, Diatom data from Bradley Lake, Oregon: Downcore analyses: U.S. Geological Survey Open-File Report 03-190, 138 p. (https://pubs.usgs.gov/of/2003/0190/pdf/of03-190.pdf).

A previous attempt to use infrared optical luminescence to date some of the tsunami-deposited sand beds in the lake cores is described in Ollerhead, J., Huntley, D.J., Nelson, A.R., and Kelsey, H.M., 2001, Optical dating of tsunami-laid sand from an Oregon coastal lake: Quaternary Science Reviews, v. 20, p. 1915-1926, https://doi.org/10.1016/S0277-3791(01)00043-9.

A 2021 paper discusses new radiocarbon ages and Bayesian age models for Bradley Lake disturbance events, and new (unsuccessful) optically stimulated luminescence ages for 8 samples of tsunami-deposited sand from the lake:
Nelson, A.R., DuRoss, C.B., Mahan, S.A., Gray, H.J., Engelhart, S.E., Witter, R.C., Hawkes, A.D., Horton, B.P., Kelsey, H.M., and Padgett, J.S., 2021, Megathrust earthquake and tsunami recurrence at the central and southern Cascadia subduction zone—reassessing dated coastal evidence: Quaternary Science Reviews 261, https://doi.org/10.1016/j.quascirev.2021.106922.

Detailed preliminary interpretation of disturbance events in Bradley Lake cores

2 June 1999

These preliminary notes refer to the photographs of Bradley Lake cores in pdf format. Text in regular font was written October 1996 through January 1997 with a few very minor changes in January 1998 based on additional smear slides. Italics text is additional comments of January through May 1999 based mostly on interpretation of DE5-6 by Harvey dated 6/2/98 and diatom email messages and graphs from Eileen throughout 1998. **Note that I have renumbered the DEs with the new system (17 DEs) but retained the old numbers in parentheses (15 DEs) in the header for each DE section.** For core locations within Bradley Lake, see Figure 3 of Kelsey et al. (2005).

Here is my proposed new terminology to use in publications. The old terms, however, are used in notes on the core photographs and below.

OLD	NEW
normal lake sediment	laminated mud or massive mud or faintly laminated mud or intermittently laminated mud
tan or gray layer or laminae (gl)	light laminae (light-colored)
brown or black laminae (bl)	dark laminae (color or other modifier, such as "organic-rich" is fine if referring to specific laminae)
microlaminated gyttja cap (mlgc)	finely laminated gyttja
gyttja capping layer (gcl)	massive gyttja (coarse or fine)
debris layer (drm)	debris-rich layer
sand (sd)	sand (muddy sand, sandy mud)

for this series of papers, "laminae" could be <3-5 mm and "beds" > 5 mm???

I. Comments on core lithologies based on semi-quantitative estimates of components in smear slides

The relative abundance of major components was estimated using 7 classes: absent, rare (<1%), occasional (<1-5%), common (5-25%), abundant (25-50%), dominant (50-80%), and highly dominant (>80%; see Birks and Birks, 1980, and Abby and Berglund, 1986). Class assignments were made from estimates of the percent area of the sediment-covered parts of the smear slide. Components consisted of clay, silt, sand fractions, diatoms plus spicules, coarse (>0.1 mm) or fine (<0.1 mm) palynowafers or brown debris (plant fragments), amorphous plant remains, other palynomorphs (such as pieces of foraminifera, theocamebians, fungi, algae, spores, seeds, large pollen, etc.), and black debris (opaque). Pyrite was identified with reflected light. Terminology is a lumping of the classification

system of (Boulter and Riddick, 1986). Any fragments with clear plant structure are included with palynowafers. Most brown debris consists of fragments that are too thick or too opaque to be translucent or that have a lot of clay adhering to them. There is probably no genetic difference between brown debris and palynowafers—brown debris is just thicker. Amorphous is very gradational with brown debris; less so with small palynowafers.

These estimates are pretty crude because the density and distribution of sediment on the slides varies greatly and because different components have different thicknesses. One medium sand grain might be a third of the weight of a sample but only cover a very small area of the slide. Plant debris is much thicker than grains of silt and clay and so my "sediment-covered area" estimates greatly underestimate the proportion by volume of the debris (organic material). My estimates are somewhat closer to those based on weight because plant debris is much lighter than mineral grains. Another serious problem is that mineral clay is pretty hard to distinguish from amorphous matter. Despite these problems, the estimates of the relative proportions of the major components should be comparable. In most slides with little sand, the proportion of the major components, as measured by the semi-quantitative scale, is very similar. Sediment from the upper 140 cm of core X is highly compacted and of uncertain correlation and therefore these slides are hard to interpret.

Black laminae (bl)

Black laminae are characterized by their black color (5Y-2.5Y-10YR 2/2-2/1), high organic content, and soupy, high-water-content texture. These laminae are easily disturbed, quickly compacted, and soon oxidized to brown or orange laminae after splitting. In the best preserved cores, black laminae are horizontal and of uniform thickness (<1-2 mm). Few cores retain well preserved black laminae more than a few weeks after splitting. Because most are <1 mm thick, the laminae are particularly difficult to sample without getting some of the adjacent laminae with higher clay contents mixed into the sample. There are no obvious differences in the content of continuous black laminae, discontinuous black laminae, fine black mottles, black laminae in mlgcs, black laminae in "Black soupy" (below), etc. Smear slides of black laminae were made from cores J (12 slides from black soupy, DE1, DE2, and DE3) and T (1 slide) and S (7 slides from DE1 and DE2). Slides were also made from 8 mlgcs in core X (10 slides), but most of these samples are probably mixtures of black, gray, and brown laminae.

Most black laminae are dominated by fine (<0.1 mm), decomposed plant fragments with common to abundant diatoms (many as chains in some slides from core J). All slides examined have less clay and silt (<50%, usually <30%) than most other lithologies. Most of the plant fragments in most black laminae appear more decomposed than in other types of sediment, although the proportion of amorphous matter is similar to that in other types of sediment. In many black laminae spherical pyrite is occasional to abundant. Pyrite is obviously forming within many large plant fragments. The pyrite is probably what makes the laminae black. There are very few silt-or-larger-sized fragments in these or

most other smear slides that could be charcoal. Many small opaque fragments (black debris) that are not pyrite are dark brown in reflected light and so appear to be plant fragments. Except for the mlgc of DE3 in core J, black laminae contain little sand. Those that do have only 1-2 grains of very fine sand.

Black laminae must have formed during periods when conditions at the bottom of the lake were very anoxic and very little mineral sediment was being deposited. If these are seasonal laminae, this was probably during summer and fall, but it seems odd that so little mineral sediment was deposited during seasons when winds should have stirred up the shallow sediment around the lake.

Gray laminae (gl)

Gray laminae are distinct from other lithologies in having high color values (2.5Y-5Y 5/1-6/1) and consisting mostly of clay (>60% and commonly >80%) with few plant fragments (commonly rare or occasional) or diatoms (commonly rare or absent) and little or no sand or pyrite. A few slides of gls have occasional to common diatoms suggesting lower deposition rates or, perhaps, diatom blooms. Slides of some of the lightest colored laminae (or those most carefully sampled) show almost nothing but clay. Examination under a binocular scope of sections of wet sediment that span 3 vertical cm of mlgcs in DEs 4 and 5 in core BB also indicates that gray laminae consist mostly of clay. However, grain-size analysis of "Big stormy" (the thickest gray laminae) yielded 22% silt, and so it may be hard to distinguish <25% fine silt in the smear slides dominated by clay. Gray laminae occur in a wide variety of thicknesses (0.1-20 mm), but single laminae are of uniform thickness and are horizontal unless deformed. Because of their light color and uniform composition many laminae clearly show folding or faulting of core sediments. Gray laminae occasionally mark truncation surfaces on underlying laminae. Gray laminae were examined in slides from cores X (5 slides), J (11 slides), S (2 slides), and T (2 slides).

Gray laminae record rapid influxes of clay with much lesser amounts of silt, probably during winter or spring floods on China Creek. Low organic and diatom percentages indicate high deposition rates. Gray laminae occur within other lithologies including gcls (except sand)--another indication of rapid deposition. The variable thicknesses and irregular vertical spacing of gray laminae indicate a variable process, such as flooding, rather than a seasonal process of about the same length and intensity each year. Thickness measurements of some of the more widely traceable gls in many cores might locate the turbidity maximum during floods marked by the laminae. The percentage of silt might increase toward the creek. The presence of gray laminae also show which sections of sediment were less turbated (mixed) than others. "Turbation" processes may include mixing by roots of aquatic plants or bottom dwelling animals, either in the same year as deposition or much later, or slight erosion, resuspension, and settling of sediment by gentle currents (for example, during lake turnover) within a few years after it was deposited. Massive sections of sediment in the cores indicate zones that have been turbated rather than intervals of time when gray laminae were not deposited.

The lack of clay in black laminae and the lithologic contrast between black and gray laminae suggest that black-gray pairs are annual couplets. Unless there were periods of one or more years when almost no clay or silt was deposited in the deeper, central part of the lake, the black laminae probably record summer or fall deposition. Counts of black-gray couplets in the upper 1.5 m of the cores yield sedimentation rates of 1-2 mm/yr, but the bulk of the weight of the sediment in couplets is in the gray laminae. Below this depth, liberal counts in the best preserved mlgcs give rates of 0.6-0.7 mm/yr. These rates are primarily a measure of compaction; the actual rate is probably about 2 mm/yr or perhaps a little higher.

Brown (tan) laminae, laminated sediment, and massive sediment ("normal" lake sediment)

Although they are lithologically quite variable, no consistent differences among brown laminae, tan laminae, laminated lake sediment, and massive lake sediment are evident in the smear slides. The only exceptions are samples of well laminated lake sediment that contain a high proportion of gray laminae; they tend to be dominated by clay. All these types of sediment seem gradational between the end members of black laminae and gray laminae. Five slides of brown laminae were examined in cores X, J, and T. Three slides of laminated sediment in core X and 2 in J and 9 samples of massive (or very faintly laminated) sediment in core X and 1 in J show the same range of lithologies.

Brown laminae and laminated lake sediment vary considerably in their shades of brown or tan and this variability seems reflected in their composition. In these sediments clay is always abundant and usually dominant, silt is common, plant fragments of variable sizes and variable stages of decomposition are common. Diatoms are occasional to common in all samples of brown laminae, laminated sediment, and massive sediment. Examination with a binocular scope of sections of wet sediment that span 3 vertical cm of mlgcs in DEs 4 and 5 in core BB suggest that most darker laminae have more organic material or more highly decomposed plant fragments with pyrite and less clay than lighter laminae; these observations are consistent with the compositions seen in the smear slides.

Where brown laminae are interbedded with black laminae, as in many mlgcs, they suggest moderate rates of deposition of clay, plant fragments, and some silt. Perhaps they mark years with minimal flooding. As with the gls, where brown laminae are finely interbedded with black laminae each brown-black pair probably is an annual couplet because it's hard to see how the the black-laminae type of sedimentation could persist from year to year.

Over most of the section spanned by the cores, black laminae either did not form or were incorporated into the sediment by disturbance of the sediment-water interface through shallow bioturbation or perhaps by gentle mixing due to sediment loading and/or slow currents. In either case, the brown lake sediment characteristic of most of the cores is a variable mixture of clay, silt, and plant fragments in various stages of decomposition.

The sections that are strongly laminated with gls indicate episodic flooding, but there is no reason to think that all the gls are annual. Where gls are separated by brown laminae about 0.5-1.0 mm thick, the brown-gray couplets may well be annual because deposition rates measured from mlgcs (assumed to be annual) in the middle parts of the cores suggest deposition rates of about 0.6-1.0 mm/yr. In many places the gls are much more widely spaced and there are no obvious sediment characteristics that record annual cycles of deposition.

The distinctness of the gl laminae within the brown lake sediment varies greatly and must reflect at least several factors (see also later comments about tan laminae at the tops of gcls). The factors probably include the intensity, duration, seasonal timing and number of floods, flood sediment load and rates of stream and lake transport, transport mechanism of plumes in the lake, extent of resuspension of clay and silt in shallow water (wind), and the extent of bioturbation at the sediment-water interface or perhaps post-depositional infaunal bioturbation. Some and perhaps many massive sections of lake sediment were once laminated but have been more turbated than the other sections. However, the sections with only one or two gls in otherwise massive sediment suggest that turbation processes have not always been major factors in the center of the lake and that there really were times when prominent gls were not deposited (reduced flooding). If so, maybe we could get some paleoclimate funding for further study of the cores(!).

Micro-laminated gyttja caps

Mlgcs are finely laminated zones of black-gray or black-brown (occasionally tan) couplets that commonly overlie gcls. When I prepared the 8 slides of mlgcs from core X and 4 from core J, I wasn't especially careful about sampling individual laminae. Thus, most of these slides are apparently mixtures of black, gray, and/or brown laminae. A few of the slides apparently include only sediment from black laminae or gray laminae, but most have proportions of components similar to those in brown laminae (even in slides from mlgcs that lack brown laminae). The mlgcs from DE3 in core J have rare very fine and fine sand, but other mlgcs lack any sand.

Conclusions from the SEM analysis of the mlgc sediments in DE 7 of core BB(245-248, core Y) are consistent with the observations of smear slides, as long as the "dark" laminae are brown rather than black laminae (they look brown on the core photo). The light laminae were finer grained and had fewer diatoms--the main characteristics of gray laminae. The dark laminae were coarser (minerals or organics?) or at least had more coarse particles (plant fragments??) and had either the same or a higher concentration of diatoms. As outlined above, my observations of wet slabs of mlgcs under a binocular scope suggest mostly a difference in proportions of the main components of laminae between light (gray) and dark (brown) laminae rather than a qualitative compositional difference. The main question is: Were black laminae destroyed by the SEM preparation process? My feeling is that because the black, gray, and brown laminae typically have very different

densities due to different proportions of mineral and organic sediment that the proportions of components will be differentially affected by the differing preparation procedures for SEM, diatom analysis, and smear slides (a run-on sentence). Black laminae could probably not survive acetone. The orientation of the SEM section is probably also a factor.

Mlgcs mark times when the bottom was so anoxic that black laminae could form in between gray or brown laminae and syndepositional bioturbation was non-existant. These conditions seem most common following gcls, but there clear occur at some other times as well. More comments about mlgcs occur under various DEs.

Gyttja capping layers

Like brown laminae, massive sediment, and laminated sediment, gyttja capping layers (gcls) are variable in lithology--more variable than any other sediment type. As discussed later under DEs, within the wide range of lithologies permitted for gcls, the distinction between gcls and underlying dls is commonly based as much on the *relative* proportion of organic material as it is on overall lithology. All gcls contain common to abundant plant fragments, most typically of both coarse and fine sizes. Gcls also typically contain some much larger plant fragments than other types of lake sediment. Gcls tend to have higher ratios of silt to clay and more diatoms than laminated sediment. In many gcl slides there is a greater diversity of components than in the other lithologies. For example, highly decomposed plant fragments containing abundant pyrite may co-ocur with undecomposed fragments. In core X, many gcls contain loose (not within plant fragments) spherical pyrite crystals, which are probably reworked from older black laminae. Diatoms seem particularly common near the tops of some gcls (DE 7/8 in X, DEs 1 and 3 in J). Sand also occurs in some of the slides, particularly those sampled from near the boundary between a gcl and a debris layer or sand layer. I examined all the gcls in core X (18 slides), 14 slides of gcls in DEs 1-3 from core J, and 4 slides of gcls from DEs 3-5 in core T.

All but one of the above characteristics are consistent with rapid deposition following a major disturbance event in the lake. Common to abundant diatoms do not seem consistent with deposition during hours to days, although a few gcls may have coincided with diatom blooms. Considering the variable characteristics of various gcls dicussed below, "rapid" may mean hours for some gcls and months for others. Tan gls within or at the top of some gcls imply deposition over weeks to months.

Psuedo-gyttja capping layers

Because these beds all differ from each other, they are discussed individually under each DE.

Debris layers

The 12 slides of debris layer sediment in core X (8), J (3), and T (1) examined are much like the the gcl samples into which these units grade. The only difference is that very fine and fine sand is rare to common in these samples and some dls contain rare medium sand. In several slides the plant fragments are especially fresh and large.

Sand

Most of the 8 sand samples examined in cores X and J are dominated by fine sand. One sample from DE 2 in core J has >50% medium sand and 2 samples from X are muddy with common to abundant clay and plant fragments.

Marsh sediment

Six slides of the peaty mud at the base of cores X and E are similar to many gcl slides. A wide variety of materials are found and large plant fragments are common to abundant. These slides, however, seem to have more silt than most other slides; the ratio of silt to clay is probably close to 1.

II. Interpretations of the DEs.

(based on a review of all data for cores V, W, T, R, B, C, H, G, P, D, J, I, BB, L, K, E, X, F, N, M, and O, especially correlation of photos using the yellow dots)

Old mill (J14, E22)

It is difficult to say much about "Old mill" because it wasn't recovered in cores V, W, T, C, B, P, X, and probably not in BB or R. Although it is quite disturbed in most cores in the eastern third of the lake, Old mill is a 1.0-2.7-cm-thick zone of 1-2-mm, discontinuous, black and brown laminae with a few gls near the top. These are best developed in cores D and J. It has a much lower proportion of black laminae and the zone is thinner than "Black soupy." This may be partly the effects of compaction on younger, gooeyer sediment. Disturbance of the zone is probably due to coring through the angular wood fragments with needles and cones that are found within the zone in cores L, E, F, N, O, M, and G. Where wood is absent the laminae are horizontal. This zone may be present in some cores, but the uppermost core sediments are too compacted and the distinctive black laminae may be too few for the zone to be recognized. In cores L, E, F, O, and M the zone has a trace of sand. The sediments above and below Old mill are massive, or in a few cases, very faintly laminated. Thus, when this zone was deposited, lake conditions must have changed a bit from before and after it was deposited. In two smear slides from core J, a gl in Old mill has significantly more clay (>50% vs. <25%) and more organic debris, particularly large (>0.1 mm) debris, than a black laminae just below it.

The wood fragments, especially the bark in core E, suggest an input of large, angular wood fragments very unlike the debris layers found in lower DEs. Except for core G, wood is restricted to the eastern third of the lake. The traces of sand in many of the cores from the eastern third of the lake are hard to explain unless the sand fell off of floating timber. Sand can be blow in, but there is little noticeable sand in most other sections of the cores and none from this zone in the cores nearer the dunes. If DE1, at an average depth of about 50 cm, is 300 years old, a constant sedimentation rate would suggest Old mill (depth about 12-13 cm) formed about 70-80 years ago. Sedimentation rates calculated from older laminated sections give similar results. Thus, the hypothesis that the wood fragments are from cut timber being floated across the lake in the early 1900s seems reasonable. Whether the formation of Old mill laminae had something to do with settlement of the area in the late 1800s is hard to determine. Similar laminae formed in many older parts of the cores, for example, Black soupy and many mlgcs.

The black laminae suggest a period when either less sediment was being supplied to the lake throughout the year or there was less mixing of the upper few mm of sediment. I don't think Old Mill was sampled for diatoms, as my green dots on core E lie above and below the dark zone labeled Old Mill. BHC diatoms are present in the sample from Old Mill's upper contact and in the sample about 5 cm above that. However, because the upper segment of core E is disturbed, I think there is a good chance that the stratigraphic equivalent of the Old Mill black laminae seen in cores D and J actually falls near 13 cm in core E, at the top of the first long segment of core. If so, then Old Mill shows BHC diatoms just like Black soupy (see below). We need to explain why these taxa apparently did so well during parts of this historic period of the lake(???).

Using the "Black soupy" sedimentation rate used in the analysis of ages from BL (1.8+/-0.25 mm/yr) and core E thickness, Old Mill is 119+/-17 years old (from AD 1994 when core was collected!). Using thicknesses from other cores where Old Mill is less disturbed (14.5 cm) yields ages of about 82+/-12 years. Because the Black soupy rate is probably too low for the Old Mill zone (because of the compaction gradient), the older age is almost certainly a maximum. Keeping in mind that we really don't know the errors on these estimates, the younger age is probably more accurate unless more than a few centimeters of soupy sediment was not recovered in most of the Livingston cores. This would suggest an age of around 1910 for Old Mill. Someone could probably find out to within a few years when the first major timber was harvested from around the lake.

Black soupy (E26, J23))

"Black soupy" is characterized by its black color (5Y-2.5Y-10YR 2/2-2/1), high organic content, and soupy, high-water-content texture. Because of its low viscosity it is disturbed and compacted in most cores. The cores where it seems least compacted and most distinct are G, H, D, J, and possibly M. Using core G as a guide, Black soupy consists of: about 2 cm of discontinuously laminated black and brown laminae grading up into 2 cm of brownish-black ooze with some silt and clay. The upper half of the ooze has more silt and clay and is browner and more distinct in some cores. Interestingly, in core M the

equivalent of the upper half of the ooze is actually a nice gcl. Above it in core G is the "true black soupy", a 1-2 cm layer of totally black ooze with a very high water content. Above the true ooze is a 1-3 cm mlgc composed of black, brown, and some gray laminae. In cores such as D, J, and even M, 3 gls are particularly prominent just above the ooze. In some cores, the laminated sections continue upward for several more cm with black laminae gradually becoming less prominent, just as in the mlgcs on older DEs. However, in many cores the contact between the mlgc of Black soupy and the overlying massive or faintly laminated sediment is irregular and diffuse, as if bioturbation had mixed younger sediment into parts of the mlgc or promoted the oxidation of black laminae. In core N this diffuse contact is highly irregular and looks like root casts extending into the mlgc. The thickness and depth measurements on Black soupy are not particularly accurate because on some cores they refer to only the "true black soupy" whereas on others both black ooze layers or their disturbed equivalents have been included.

Black soupy is really just an unusual concentration of black laminae that accumulated gradually over many years. This is especially evident in core J where many black laminae are well preserved in the upper 1.5 m. In the few cores where it is well preserved, Black soupy is not a 1-cm-thick bed but a layer of black, brown, and gray laminae, as in many other parts of the cores. But the proportion of black laminae is much higher in Black soupy than in other similar layers. In core T there are at least 10 couplets in true black soupy. In H there is a 4-mm-thick gl in the middle of true black soupy. The one grain-size sample from Black soupy is from the compacted part of BB and the sand and wood at that level suggest that a correlation with Old mill is more likely than Black soupy. Semi-quantitative estimates of components in smear slides from the black laminae of Black soupy in cores T and J show that the sediment is dominated by fine (<0.1 mm), highly decomposed plant fragments with common to abundant diatoms (many as chains in J) and abundant spherical pyrite. There is less silt and clay in these laminae than in any other units, probably <30%. The gray laminae within black soupy have much more clay (>50%) with less plant fragments and far fewer diatoms, and little or no pyrite. After the cores have been split for several months, Black soupy oxidizes to a bright orange color, confirming its high iron content.

The problem of how to interpret the gcl in Black soupy in core M remains. The gcl-mlgc couplet looks a lot like the similar couplet of DE1 in the same core. Perhaps this is not really an equivalent of the browner part of the lower ooze in other cores. It could be turbidity sediment deposited from a small localized slump off the delta that just happened to have been deposited in the middle of true black soupy. This gcl unit may also be present in core O, but it does not occur in the other cores.

Note: The depths on my core E photos do not match exactly with the depths mentioned for Black soupy in Eileen's email of 27 Aug 1998. I have the top of Black soupy at 26.3 cm and the gradational base at 33.4 cm. She mentions samples at 25, 30, and 35 as being part? of Black soupy. However, on her figures she shows only sample 30 as from Black soupy, which is the way I interpret it.

In addition to coring technique, the better preservation of Black soupy in some cores may have something to do with undetected microtopography on the floor of the lake. In any case, the gradual changes observed in the best cores suggests that this interval of core records non-sudden changes in lake floor environment. The correspondence between a higher proportion of black laminae relative to brown or gray laminae (lower sediment input during seasons when black laminae form) and BHC diatoms (one sample at 30 cm in core E and one sample at 9.5 cm in core C) is striking. If we understood this connection better, we could be more confident about our interpretation of the meaning of mlgcs. Particularly during the historic period, could reduced sediment input be a reflection of changes in the drainage basin well above the lake (seems like it should be the reverse)? How would that effect the shallow water diatoms? Could the lake turnover enough to mix the saline lens at the bottom of the lake with the surface waters but still not produce currents strong enough to disturb the very fragile laminae?? This doesn't seem likely and would not seem to agree with the abundant pyrite spheres in some black laminae. A marine geochemist at GSA told me that pyrite cannot form in a freshwater lake (insufficient sulfur), but possibly the spheres could be reworked and would have a particularly high concentration in years with low sediment input. Overall, its hard to argue that the lake wasn't more brackish during Black soupy—we just need to think of a mechanism! Black soupy and Old Mill could be best investigated further in cores D and J, and perhaps in F, O, and M.

Using the Black soupy sedimentation rate and the mean depth of Black soupy in 16 cores (26.9+/-3.2 cm) yields an age of 155+/-39 years (AD 1800-1878). Thus, Black soupy may date from just prior to settlement of the area.

DE1 (alias "Wimp"; J41, J46, F53)

In most cores, DE1 follows Harvey's model of erosional emplacement of a sand bed and/or debris layer (dl) overlain by a gyttja-capping-layer (gcl) overlain by a micro-laminated gyttja cap (mlgc), as long as allowance is made for the complex patterns of erosion and deposition that must have prevailed during most disturbance events.

A distinctive feature of this DE is the lack of sand in all cores except B (5 mm thick). Traces of sand are found in dls and gcls in 10 of 19 cores. Usually these are near the base of the dl or gcl but not always (cores D, H, I, T). Apparently, only a small volume of sand was deposited as a distinct bed during this DE. Sandy intervals within dls and generally thick (2.2-9.4 cm) gcls suggest multiple slumps of sandy beds soon after a surge. If most sandy intervals are due to multiple surges, the gcls were largely deposited within a few hours of the first surge.

Apparent erosion (relative to core M) of the lake floor during DE1 can be measured with reference to correlation point F53. Except for less than 0.3 cm of missing section in core J, measurements range from about 0.8-2.6 cm with no obvious axial or across-the-lake trends.

Dls and gcls are lithologically gradational and so the lack of dls in some cores (V, P, J, K, F, and M) probably does not reflect any major difference in depositional process. Like the irregular distribution of sand during DEs, dls appear only where coarse organic debris was deposited probably during or immediately after surges moved back and forth across the lake (dls do not show upward trends in sorting). Gcls were deposited more slowly (hours to weeks??) and uniformly from less coarse-grained debris suspended in the water column around much of the lake. However, despite 9-cm-thick gcls in cores P and J, cores B, R, and T lack gcls. This suggests that little less-coarse-grained debris (gcls) was deposited in the western third of the lake during DE1 and, therefore, that many gcls were deposited too rapidly for the less-coarse-grained debris to be disbursed evenly throughout the lake. Again, some of these differences are semantic—many dls grade very gradually upward into gcls and some gcls consist of finer-grained facies overlying coarser-grained (cores O, I, K, M). Isopach maps of the DE1 dl and gcl are not very informative, but a map of the combined thickness of these units shows 1-2-cm thicknesses near the western end of the lake, increasing to 7-10 cm in the central part, and then decreasing to 3-5 cm near the eastern end. The dls and gcls are probably produced primarily by debris derived from the erosion, slumping, and resuspension of nearby shallow-water sediment, which was apparently focused into the deepest and narrowest central part of the lake.

The apparent occurrence of gcls *below* dls is a different matter. This apparent stratigraphic relation is distinct in core R, and may occur in core B, although the latter is poorly described and photographed. If both gcls and dls were deposited by the processes inferred above, this relation would imply a lake-wide disturbance at least many hours and perhaps days after the deposition of the basal gcl. However, the "gcls" in these cores are fine-grained compared to other gcls and the lower contact in R is gradational rather than sharp. On the basis of comparisons with the many well developed DEs (i.e, distinct beds that nicely fit the model) at this level in other cores, we interpret the lower gcl in R as turbated "normal" (originally at least faintly laminated) lake sediment deposited over many years. For example, in core O, a dl erosionally overlies a brown gyttja mud that is lithologically identical to the gcl above the dl. Our best guess for core B is that the "gcl" is a mud clast at the top of the sd.

DE1 is missing in core W and possibly in cores BB and X, but the upper sections of the latter two cores are so compacted that correlations are very uncertain. The most likely explanations for core W are that 1) no distinctive gcl or mlgc was deposited during DE1, or, more likely, 2) later slumping eroded whatever thin beds had been deposited during the DE. Color changes on the photos suggest an unconformity of 5-20 cm at about 65 cm depth (depending on the amount of compaction).

All the cores in which DE1 can be confidently identified have mlgcs overlying a gcl or dl, but the degree of preservation of mlgcs varies greatly. The thickness of mlgcs is more uniform than implied by the measured range in thicknesses (0.8-3.6 cm) because the horizontal lamination of some mlgcs are measured and/or preserved only as far upsection as a prominent gl (J46) whereas others are measured to as much as another cm above it. Here I limit the mlgc to the 1.3-1.8-cm-thick section between J46 and the top of the underlying gcl or dl. In the cores where it is best preserved (G, D, J, I, K), this mlgc has distinctive

alternating black and brown-to-gray laminae in 8 or 9 couplets. Two of the lower couplets are marked by light gray gls. Above J46, black laminae are much less distinct in all cores and in more than half, laminae are disturbed or turbated. In cores N, O, and L this disturbance extends down into J46 and, in core R, probably throughout the mlgc. The least compacted cores (J, D) show that periods of anoxic conditions implied by the black laminae in the DE1 mlgc perhaps lasted longer during the deposition of the mlgcs than afterwards, but that they still persisted for many decades to hundreds of years. This suggests a gradual rather than rapid change in lake environments following the DE; the "top" of the mlgc is defined more by the prominent gl (J46) than by a sudden change in lithology. Some of the deformed J46 gls look like the truncation surfaces found in some older mlgcs, but I didn't see any consistently truncated laminae in DE1.

The above evidence indicates a lake-wide disturbance event that involved large slope failures on the dune at the western end of the lake and in shallow water around the lake and slight erosion and resuspension of material in the deepest parts of the lake. The ecology of the lake may have changed for at least 8 years following the DE. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (by at least several meters above lake level) and lake-wide slope failure (without a tsunami), probably induced by strong ground motion. The volume of sand spread onto the floor of the lake is too small to distinguish tsunami-deposited sand from sand flows from a dune-slope failure.

The following is from my analysis of BL AMS ages: Wide fluctuations in the radiocarbon calibration curve for the past few hundred years prevent the ages from DE1 from telling us more than that the DE0-1 interval records less than 550 years (exhibit B). For the later OxCal analyses, I correlated DE1 with the 9PM earthquake (AD 1700), a correlation we will almost certainly make in our papers. The mlgc-derived sedimentation rate age for DE1 is 291 years using the core E thickness. But because the compaction "gradient" in the DE0-1 interval must be much steeper than that in other intervals, the sedimentation rate for "Black soupy" is almost certainly a better estimate of the rate for the whole interval than is the average of the Black soupy and DE1 rates (as on table S1). If we use the Black soupy rate (1.8+/-0.25 mm/yr) from the cores with the most distinct laminae, the DE0-1 interval spans about 258+/-37 years with the core E thickness, and 278+/-60 years with the average axial core thickness. Both ages overlap AD 1700.

The section between DE1 and Black soupy is mostly laminated in most cores with a few distinctive gls. The least compacted, least turbated cores (D, J) show clear laminations throughout the section. Much of the same section in core O is massive, perhaps because bioturbation is more common in the shallow water where it was collected. Correlation of this section in the upper parts of the vibracores is difficult because of variable compaction.

Freshwater diatoms are rare in the dl of DE1 in core E, but large, mostly freshwater benthic diatoms and sponge spicules are common in the overlying gcl, consistent with redeposition of biogenic debris from shallow areas. MM and MD marine diatoms are not found in the gcl, but rather in massive (formerly laminated but disturbed by premature

placing of casing during collection of core E) lake mud above the gcl at 48 and 50 cm. (from Eileen, see also Eileen's email of 7 Jan 98). I remain confused as to why MM diatoms would only be found above the mlgc of DE1, especially as BHC diatoms are not found within it or above it until Black soupy. Nevertheless, I guess we will conclude that an incursion of saline water about the time of DE1 brought MM diatoms into the lake and either allowed them to reproduce or concentrated them along the axis of the lake through reworking for 60-90 years. Reviewers will want a better argument than this. The obvious approach would be to look at another core, but that has already been done (core C shows a similar pattern). Can the sand volume be used to suggest tsunami inundation?

DE2 (J99, J123, F99)

DE2 is one of the more consistent DEs in terms of following the model. In almost all cores (DE2 is severely compacted and possibly misidentified in cores BB and X) a sand bed (0.6-58 cm thick) is overlain by a gcl or dl which, in turn, is overlain by a mlgc. Sharp, irregular contacts at the base of the sand in all cores suggest erosion of underlying lake sediment.

Except for the anomalously thick sand in core B (58 cm, filled channel?) and disturbed sands in BB and E, sand thickness shows a nice west to east decrease from 35 cm in core T to 0.6 cm in core O (enclosed sketch map). I have not done calculations, but I think this volume of sand is far too large to have come entirely from slumping of the distal face of the dune. I also doubt that slumping could deposit sand at the far end of the lake, but again I have no numbers to show this. Concentrations of mud clasts and to a lesser extent organic debris in some cores suggest multiple pulses of sand deposition. Clasts are found near the top and bottom of the sand in cores V, T, B, and C. Beds of clasts and/or debris that extend horizontally across cores in cores B, H, G, and L suggest as many as four (core H) multiple pulses. Some other cores (I, T) have thin lenses of debris or clasts that are weaker evidence for multiple pulses (more discussion of such evidence is needed). Coarse clasts (>1 cm) are found only in the western third of the lake where erosion was greater. What do the clasts say about currents? Correlation points can be identified in the large clasts in core T that show what part of the section they came from. Because any large wave, whether from a tsunami or a large slump, would have washed back and forth across the lake, multiple pulses do not require multiple tsunami surges. Hand lens examination of some thick sands in some cores (W, R, B, C, and G) show they fine subtly upward from medium and fine sand to fine sand. The very subtle fining trend reflects the very uniform grain size of the source material. A 5-mm-thick, irregular sand bed was injected (?) into the horizontally deformed mlgc in core C; it may be evidence of liquefaction or lake-side slumping long after DE2. The dated material from this sand is clearly reworked and its14C age also suggests that it is older than this level in the core.

Apparent erosion (relative to core D) of the lake floor during DE2 can be measured with reference to correlation point E119 (J123 or F110 would be better but can't be identified in many cores). As the lower sand contact in D is sharp and irregular, all measurements are minimum values. Values from the vibracores include a lot of compaction. Except for

less than 0.3 cm of missing section in core J, measurements range from about 1-9 cm with much variability. In general, erosion was greater in the western part of the lake than the eastern part.

Comments about gcl and dl lithologies and inferred processes in the DE1 discussion will not be repeated here. Combined thickness of gcls and dls for DE2 (0.4-7.1 cm) shows less range for DE2 than for DE1, but thickness trends are similar: <2 cm near the western end of the lake, increasing to 3-7 cm in the central part, and then decreasing to 1-4 cm in the eastern part. These trends and the presence of thick dls (>1 cm) only in cores H, C, G, and I suggest focusing of organic debris into the deepest and narrowest central part of the lake. Some gcls are divided into two units based on the coarseness of debris (cores P, I, F, and G). Sandy gcls are found in cores J E, and F.

As in DE1, "pseudogcls" (using "gcl" as a genetic term) complicate interpretations of DE2, but only in a few cores. I judge several beds of identical color and lithology to some fine-grained gcls to be massive (turbated) lake sediment deposited over many years because exactly equivalent beds in other cores are well laminated. Two typical examples are found in core L at 70 cm and 88 cm and in core H at 89 cm. In cores O and G, a 1-cm-thick "gcl" appears above the mlgc, but this same section is very well laminated in a number of other cores. Perhaps small slumps or unusual currents occasionally stir up small, localized parts of the lake bottom to a depth of 1 cm. If so, the currents must be too slow to remove most of the resuspended sediment, which apparently settles back down to form a massive bed. This same explanation may apply to many massive zones in other parts of the cores. I'm fairly amazed that so much of the section in so many cores appears to have escaped such processes.

In DE2, mlgc laminations and preservation are more consistent than in DE1. The location of the top of the mlgc is, however, just as arbitrary. I place the top at a prominent gl because it is easy to trace from core to core and because the darker laminae of couplets are generally blacker and thicker in couplets below that gl than above it. Also, the laminae below the gl are well preserved in most cores, whereas those above it are commonly deformed (cores W, R, C, P, D, J, K, E) or turbated (cores W, F, N). Although laminae at the top of the mlgc appear truncated in a few cores (T and ?), most are not, particularly in the cores with the best preserved mlgcs (H, G, J, I, L, M). A flat peat clast (?) appears above the mlgc in core D. The thickness of mlgcs is quite uniform (1-2 cm in all but two problem cores); 14-21 couplets were counted in the mlgcs, with 20-21 in the best preserved beds. Sedimentation rates within mlgcs are 0.7-1.5 mm/yr. The lack of consistent changes in lithology or other characteristics of laminae near the top of mlgcs, or in the 1-2 cm of section above them, suggests to me a gradual rather than rapid change in lake environments in the 2-4 decades following DE2. As in DE1, I attribute most of the variation in mlgcs to post-depositional modifications that affected different cores to different degrees.

The maximum limiting age for DE2 from the OxCal AMS age analysis is 995-920 cal yr BP using either the core E thickness or mean axial core thickness (as explained in the 14C analysis notes of 4 June 98). This is probably a close maximum age because three of

five ages used in the final analysis are almost identical and one of the three is a high quality, delicate (A, Table 1) sample. Two of the five ages were considered to be on re-worked material (see above for one) and so were eliminated from later analyses. Both of these ages were older than the mean age for DE3.

The above evidence indicates a lake-wide disturbance event that involved transport of much sand into the lake from the west, major erosion and resuspension of lake sediment in deep as well as shallow water, and probably large slope failures on the dune at the western end of the lake and in shallow water around the lake. Black laminae in the mlgcs suggest that the ecology of the lake may have changed for at least 21 years following the DE. The volume of sand spread onto the floor of the lake seems too large for this event to have been produced by anything except a local tsunami.

MM diatoms, including delicate species, in several samples from the gcl of DE2 (from Eileen) confirm that marine water entered the lake about the time the gcl was deposited. So why no MM diatoms in the gcl of DE1 and no BHC diatoms in or above the mlgc of DE2?

The section between DEs 1 and 2 is mostly laminated in most cores with a number of distinctive gls. The least compacted, least turbated cores (D, J) show faint to clear laminations throughout the section. Correlation of this section in the upper parts of the vibracores is difficult because of variable, occasionally severe compaction.

DE3 (alias "Sneaker"; E119, E125)

DE3 is probably the most subtle of all the DEs—it was not recognized as a DE in the original descriptions of many cores and is identified on the photos of cores C, L, X, and M only through detailed correlation with other cores where it is more distinct. DE3 looks like Harvey's DE model described for DE1 only in cores D and J where thick, coarse dls overlie an obviously erosional contact and very thick mlgcs are well preserved. The dl of DE3 in core D is slightly sandy, especially near its base, but sand was not found in DE3 in any other core. A gcl for DE3 is identified in all cores, although compaction and poor photographs in this part of core X make correlations uncertain.

Correlation of point E125 among the cores indicates that there was no significant (>0.5 cm) apparent erosion of the lake floor during DE3. The lower contact of the gcl or dl is sharp enough to suggest slight erosion only in cores V, W, G, P, D, J, I, N, and O. In other cores, the contact appears gradational (particularly in cores T, B, R, C, H, and M), probably because there is little contrast in lithology between the fine-grained, low-organic-content gcls and underlying laminated lake sediment.

Dls were found only in cores G, D, J, I, N, O, and as a thin, discontinuous lens in core L. Gcl thicknesses were about 1-2 cm in most cores, but ranged from 0.4 (N) to 4.4 (E). The fine-grained texture of most of the gcls of DE3 makes them much like some of the thin turbated zones elsewhere in the cores mentioned earlier. The lower half of some gcls (W,

T, P, and E) is lighter in color and perhaps slightly finer-grained and/or lower organic content than their upper halves—characteristics that are difficult to explain with the DE model. But the lack of laminations in beds in the same stratigraphic position in any core and the obvious correlation of most of these gcls with the gcls in the well developed DEs in cores J and D shows that gcl gyttja was deposited lake wide during DE3. Combined thickness of gcls and dls show no obvious pattern; the greatest thicknesses (4.4-5.0 cm) are in Livingston cores D, J, and E. Comments about gcl and dl lithologies and inferred processes in the DE1 discussion will not be repeated here.

The mlgc of DE3 never ends. That is, in the better preserved mlgcs (cores D, J, V, P) there are no characteristics that suggest a rapid change of lake bottom conditions before the section is terminated by the erosional contact at the base of DE2. A deep, V-shaped truncation surface cuts into the mlgc in cores J, D, and N. This could be used to arbitrarily mark the top of the mlgc in these cores, but such surfaces were not found in most other cores. Conditions immediately following the deposition of the gcl may not have as anoxic as the times following DEs 1 and 2. In most cores, the couplets overlying the gcl are browner and lighter in color than the mlgcs of DEs 1 and 2 and than 2-3 zones containing blacker laminae overlying the lighter zone in DE3. In many cores, the mlgc of DE3 is partially (N, E, G, H, B, I, and F) to almost completely (M, K, L, X, BB, and O) obscured by turbation, but does not seem to be deformed except in core K. "Turbation" refers to mixing and resulting oxidation of laminae during (1) bioturbation by organisms or roots of aquatic plants, and (2) erosion, resuspension, and settling of a few mm of recently deposited laminae by gentle bottom currents, such as those that occur during turnover of the lake. Sometimes processes (1) and (2) can be identified by the sharpness and geometry of the tops of the mlgcs, but usually this in not the case. Both processes probably explain the termination of some mlgcs. A thick tan lamiae separates almost all gcls from the overlying mlgcs. The large amount of clay and lack of large palynowafers in a smear slide from this laminae in core J suggest it is a gl deposited about the time gcl deposition ended. This idea raises the possibility that some of the coarse gcls in some DEs were deposited in a few hours, whereas others, such as in DE3, may have required weeks or months.

Conservative counting of laminae couplets by Rob in core T indicates at least 33 couplets, whereas more liberal counting in the longest section between DEs 2 and 3 in core D suggests as many as 106. In most other parts of the cores, counting of well preserved couplets in short sections of the cores yields sedimentation rates that agree better with the liberal counting of the longer sections, such as here in core D. Sedimentation rates based on liberal counting of the better preserved mlgcs between DEs 2 and 3 (V, W, T, R, H, P, D, and J) are about 1 mm/yr. In deeper parts of the cores, the best preserved mlgcs yield rates of 0.6-0.8 mm/yr.

The maximum limiting age for DE3 from the OxCal AMS age analysis is 1130-980 cal yr BP using either the core E thickness or mean axial core thickness (Table1, as explained in the 14C analysis notes of 4 June 98). This is probably a close maximum age because two of three ages used in the final analysis are almost identical and one of the three is a high quality, delicate (A, Table 1) sample. One of the three ages was 200 years older

than the others; because it may be on reworked material it was eliminated from the final analyses.

The above evidence indicates a small disturbance event that involved lake-wide resuspension of organic debris from shallow water into the deeper parts of the lake. The ecology of the lake does not seem to have changed in a major way following the DE. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, perhaps induced by strong ground motion. The sand in core D suggests that sand may have been spread onto the floor of the lake, but far too little sand was found to distinguish between a tsunami and a dune-slope failure.

The gcl of DE3 contains abundant, large freshwater benthic diatoms and sponge spicules, but there are no marine diatoms either above or below the gcl (from Eileen). So, even though this DE in one core contained a little sand, this DE did not involve tsunami inundation. Comparison of the data for this DE with that of most others makes our story much stronger.

DE4 (alias "Rogue"; E154, E149, J182)

DE4 is another subtle DE similar to DE3, but with thicker gcls. DE4 is particularly difficult to identify where it is partly deformed at the tops of Livingston core segments in cores G and F and where compacted in vibracore X. DE4 follows Harvey's DE model described for DE1 only in core D and to a lesser extent in I and V, where dls overlie an erosional contact and are overlain by thick gcls, and where thin mlgcs are preserved. The dl of DE4 in core D is slightly sandy, especially near its base; the gcl of BB is sandy and that of L has a 1-mm-thick sand parting at its base, but sand was not found in DE4 in any other core except W. In W, correlation points above and below DE4 show that sand has been intruded as a sill between the thin gcl and mlgc, and large clasts with horizontal laminae make up most of the DE (as in DE2 in some cores). Despite extraordinary efforts, measurement errors resulted in the section containing DE4 not being cored at the site of core K, and being recovered twice at the site of core M.

As with DE3, only a few of the basal DE units show erosional contacts but those that do (D, I, N, O) are very clear. There is no distinct correlation point immediately below DE4 that can be correlated easily among most of the cores to show apparent erosion. The thickness of sediment between point J182 and DE4 in cores in the western half of the lake suggests about 1-3 cm of possible erosion or differential compaction relative to cores J and H. Correlation of point J182 is less certain in the eastern part of the lake; cores N and M appear to have sections about 3 cm shorter than other nearby cores.

Dls were found in cores D, J, I, N, O, and reach thicknesses of 2.6 and 3.3 cm in cores O and D. Gcl thicknesses were mostly about 3-4 cm, but ranged from 1.2 (N) to 6.9 (E) cm. As in DE3, in two-stage gcls in the western half of the lake the lower half of some gcls (V, T, R, C, H) is lighter in color and/or finer-grained and/or lower organic content than

their upper halves—characteristics that are difficult to explain with the DE model. However, in other cores (D, J, I, M, N, and O) units with finer-grained organic material overlie coarser gcl or dl units, as would be expected. What is this telling us about "gcl" depositional processes? Are more models needed? The fine-grained texture of some of the gcls of DE4 (L, N, C) makes them much like some of the thin turbated zones discussed above. For example, in core N a thin "pseudogcl" overlies a tan laminae that marks the base of the mlgc (discussed below). Based on correlations, I interpret this higher "gcl" as the turbated mlgc of DE4 in this particular core. Combined thickness of gcls and dls show no east-west trend; the greatest thicknesses (5.6-7.3 cm) are in Livingston cores D, X, and E along the axis of the lake, suggesting focusing of gcl sediment into its deep axial part (core BB gcl, 2.8 cm, is probably compacted). Other comments about gcl and dl lithologies and inferred processes in the DE1 discussion will not be repeated here. It is interesting that dls in DE4 occurred in the same cores (except for G) as the dls for DE3; this may suggest that dls are largely derived from slumping of nearby shallow-water lake sediments rather than from suspension and deposition of coarse organic debris that is distributed throughout the lake during a tsunami that surges back and forth across the lake. Relative thickness of gcls in DEs 3 and 4 is also similar in most but not all cores.

In contrast to DE3, DE4 is characterized by a very thin mlgc that is only well(?) preserved in a few cores (T, V, H, and L). I define the DE4 mlgc as only that part of the finely laminated sediment above the gcl with prominent black laminae. This criteria makes the mlgc only 2-6 mm thick in most cores (9 mm in core M). Although black laminae are important for defining mlgcs in many DEs, applying the black-laminae criteria for DE4 to DE3 in many cores would result in most having no mlgc. This state of affairs serves to emphasize several points: (1) most well preserved mlgcs (those not subject to turbation) do not have distinct tops that record a rapid change in lake conditions, rather they grade upward into overlying laminated lake sediment, (2) where mlgcs do appear to have distinct tops the tops mostly are due to prominent gls or to turbation extending downward into the mlgc, and in a few cases to truncation (erosional) surfaces (possible in cores T, R, H, and P) cut by bottom currents, and (3) black laminae may be characteristic of mlgcs but they decompose and compact (BB, O, N) so easily that I can't be sure that they haven't disappeared from some laminae before they were described. In DE4 in some cores (I, H, J, and X), the black laminae seem to be much thicker than or to completely overwhelm the light laminae, as in Black soupy. As in DE3, a thick tan lamiae separates almost all gcls in DE4 from overlying mlgcs. If the seasonal timing of earthquakes is random, why would a tan laminae occur at exactly the same stratigraphic position in both DEs? What is this relation telling us about gcl depositional processes? Are tan laminae really just organic-rich versions of gls or do they imply some additional process?

By far the most distinctive section of laminated sediment in the cores occurs between DEs 3 and 4. The variation in thickness of gls, particularly in this section of the cores, is probably the result of clay plumes of different concentrations and durations deposited during major floods on China Creek. Conservative counting of laminae couplets by Rob in cores T and R indicates at least 183 and 238 couplets between these DEs, whereas more liberal counting in the longest section between DEs 3 and 4 in *cores R, T, V, and J suggests as many as 268 (Table S2 of OxCal analysis of 4 June 98).* If we assume that

the light-colored, clay-rich laminae deposited during floods will not be separated by an organic-rich laminae deposited much more slowly more than once a year, then the number of couplets gives the number of years with floods (minimum number of years of deposition). Sedimentation rates using these assumptions for these sections and for the same section in core BB, counted by Harvey, yield sedimentation rates of 1.1-1.25 mm/yr. Sedimentation rates based on my liberal counting of mlgcs with preserved laminations between DEs 3 and 4 (T, R, D, J and L) are 0.8 mm/yr.

The maximum limiting age for DE4 from the OxCal AMS age analysis is 1510-1330 cal yr BP using the core E thickness and 1500-1320 cal yr BP using the mean axial core thickness (Table1, as explained in the 14C analysis notes of 4 June 98). This is probably a close maximum age because all four of the averaged ages overlap at the one sigma level (Table 1). All ages were used in the final OxCal analyses.

The above evidence indicates a lake-wide disturbance event that involved slope failures on the dune at the western end of the lake and in shallow water around the lake and slight erosion and resuspension of material into the deepest parts of the lake. Although the volume of sand was small relative to DE2, sand occurs in some cores as far east as core L. The ecology of the lake probably changed for at least 5-6 years following the DE. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, probably induced by strong gound motion. The sand in cores W and D suggests that sand was spread onto the floor of the lake, but far too little sand was found to distinguish between a tsunami and a dune-slope failure. The apparent intrusion of sand in core W is suggestive of liquefaction, but this must have occured *after* the gcl was deposited (by aftershocks?).

Rare marine diatoms are found in 3 of 4 samples of the gcl of DE4 in core E and in the immediately overlying mlgc and laminated lake mud. Concentrations of rare BHC diatoms are similar to those in samples in laminated mud above and below DE4, but in situ freshwater diatom concentrations are lower (from Eileen). Is this evidence for reduced benthic habitat following shallow water sediment disturbance that produced the gcl? Anyway, the microflora once again suggests at least moderate tsunami inundation.

DE5/6(5) (alias "Big guy"; E183, E187, J218, E214)

DE5/6 (formerly DE5) is by far the most dramatic of the DEs in many cores and it corresponds well to the DE model, at least in general *(double nature of this DE is explained below)*. In all cores an usually thick sand bed (1-177 cm) is overlain by a gcl which, in turn, is overlain by a mlgc. Mlgc thickness and character are quite consistent from core to core, whereas gcls and sands have a wider range in thickness and character. For example, many gcls in the western part of the lake are thin and very fine-grained compared to those of other DEs. The rare dls are thin and tend to be interbedded with sand. Sharp, irregular contacts at the base of the sand in all cores show erosion of underlying lake sediment.

Sand was spread throughout the lake during DE5/6. Total sand thickness shows a west to east decrease from more than meter in all cores from the western part of the lake (V, W, T, R,B, and C) to 0.6 cm in core M (enclosed map; let's measure sand thickness in Y, Z, and AA, too). The volume of sand is far too large to have come entirely from slumping of the distal face of the dune. Concentrations of large and small mud clasts and to a lesser extent organic debris in many cores suggest multiple pulses of sand deposition. Beds of clasts and/or debris that extend horizontally across cores suggest multiple pulses. Possible numbers of pulses are: 11 (W), 9 (T), 7 (R), 5 (V, H, D, J), 4 (C, K, F), 3 (P, I, E, X, G?), 2 (BB, M, O), and 1 (N). Most cores have thin lenses of debris or clasts that are weaker evidence for multiple pulses. The thickness of sand units deposited during some of the initial pulses are similar in some cores but not in others in the western part of the lake. Of course, later pulses may have eroded earlier ones and pulses are difficult to identify in cores where clasts or debris were not deposited near the end of a pulse. Muddy beds with debris a few mm thick are interbedded with clean sand near the upper parts of some cores (V, T, I, F,); the muddy beds would be classified as dls if they graded into gcls, but few of the gcls in DE5 are directly underlain by such beds. Except in core E, large clasts (>1 cm) are found mostly in the western half of the lake (cores D, J, H, W, R, V, and T) where erosion was greater. What do the large and small clasts say about the strength and timing of currents? Because any large wave, whether from a tsunami or a large slump, would have washed back and forth across the lake, multiple pulses do not necessarily require multiple tsunami surges. Hand lens examination of the thick sands in many cores shows that some pulses within the sands fine subtly upward from medium and fine sand to fine and very fine sand. The very subtle fining trend reflects the very uniform grain size of the source material. (I leave further analysis of pulses to Harvey.)

An interpretive problem for DE5/6 in core M can best be explained by poor coring technique (culprits = Alan and Rob). In this core, a typical mlgc, gcl, and underlying sandy dl are underlain by a slightly deformed mlgc containing about 11 couplets, which, in turn, is underlain by an identical gcl and two 5-mm sand beds. The mlgc sandwiched between the two gcls is evidence for a decade-long interval between the deposition of the two gcls. But no other core shows any evidence of two closely spaced DEs at about the time of DE5/6. Although field notes make no mention of such problems during the collection of segment 3 of core M, the Livingston corer was probably pushed to the stratigraphic level of the upper sandy dl, raised about 6 cm without losing more than 1 cm of sand, and pushed down again through part of the mlgc-gcl sequence as far as the base of the segment. Alternatively, interbbeded sands and thin gcls could have been deposited during the same DE--but a mlgc could not. And the possibly that evidence of two DEs would appear in only one of the 21 studied cores seems remote. *Harvey's careful observations of May 1998 show that, in fact, Alan and Rob are not as sloppy corers as implied by this 1996 text—DE 5/6 really is one DE(6) superimposed on another (5), but clear evidence of this stratigraphic relation is found only in core M (discussed below).*

Apparent erosion (relative to core M) of the lake floor during DE5/6 can be measured with reference to correlation points E214, E221, and E232, but not very accurately. Point

E232, the only point common to most cores, is far below the base of DE5/6 in many cores. Because of differences in sedimentation rates, compaction during vibracoring, and errors in measuring depths during Livingston coring, errors in measurements of the section between E232 and DE5/6 relative to core M may be as large as 8-10 cm. For example, correlation point E214 shows that erosion in core E was greater than in core K, but my measurements from point E232 in both cores show 7.5 cm more erosion in core K than core E. Unfortunately, point E214 is preserved in only a few cores. As the lower sand contact in M is sharp and irregular, all measurements are also only minimum values. With these problems in mind, 15-20 cm of relative erosion (measurement for core G is not accurate because of problems matching depths on segments 2 and 3 of this core) was measured in the western two-thirds of the lake and about 7-15 cm in the eastern end. Stratigraphic comparisons among cores (F, M, and O) with the least erosion suggest that erosion in the eastern part of the lake is actually about a third of what our measurements indicate, probably about 1-5 cm relative to core M. I conclude that some erosion occurred throughout the lake during DE5/6 and that erosion was 5-10 cm greater in the western half of the lake than in the eastern half.

A notable difference among DE5/6 and other DEs is the range in thickness and lithology of the gcls in DE5/6. Probably these differences in some way reflect the scale of this DE relative to other DEs. Particularly in the western end of the lake, gcls are very thin (0.5-1.3 cm), fine-grained, organic-poor, and tend to grade gradually downward into or be interbedded with sands or sandy dls (cores V, W, T, R, and G). In contrast, gcls are very thick (5.0-14.5 cm) in the central part of the lake (H, C, P, J, and D), and decrease to more typical thicknesses (1.6-6.5 cm) in the eastern part. Nevertheless, two cores (K, G) in the central and eastern parts have gcls <1 cm thick. The gcls in cores H, P, and C are unusual in having a 3-5-mm-thick, lighter-colored cap, which is similar to some of the thinnest gcls in the western part of the lake. Because many gcls are so organic-poor compared to the more typical gcls of some other DEs, it is difficult to distinguish possible gcls interbedded with sand from muddy lens of clasts and fine debris (discontinuous dls) at the tops of sands (cores J, I, V, W, R, K, E, F and H). No foraminifera were found in the lower part of the gcl for DE5/6 in core BB. The gcl in core N has coarse organic material near its upper contact, but other gcls have little coarse material. Possibly the disturbance of the lake during DE5 was so great that almost all coarse debris from shallow water around the lake was entrained during the initial surges and deposited within sands or on top of them during the wanning phases of each surge. Because this debris was so dispersed it did not form thick dls though local slumping of thick debris accumulations in shallow water. Another possibility is that there was much less coarse debris in shallow water at 1700 BP than at present because the lake shore was not forested 1700 years ago. However, I doubt if the latter makes sense in terms of climate reconstructions for the region. For some unknown reason, little fine-grained organic debris was available to settle out of the water column in the west, whereas much more was deposited in the central and eastern parts. Perhaps sand deposition (through slumping and flows??) continued much longer in the western part of the lake than in the eastern part, periodically eroding gcls in the western part. This senario could explain why only the light-colored cap of the gcls seen in cores H and P is apparently preserved in some of the cores with the thinnest gcls.

In DE5/6, mlgc laminations and preservation are more consistent from core to core than in most other DEs. Again it is difficult to decide where to place the top of the mlgc. For measurements, I arbitrarily place the top of the mlgc at the first prominent gl because it is easy to trace from core to core. However, most cores show well laminated sections with dark laminae extending upward as much as 50% farther than the thickness of the mlgc below the prominent gl. Counts of couplets of laminae in cores V, W, and R suggest the complete mlgc lasted 60-80 years. Dark laminae end in many cores where the mlgc is eroded (K, G, W, and D), deformed (J, K, and L), or obscured by turbation (M, L, I, T, B, P, E, F, and O). Thus, the thickness of mlgc units in most cores is more likely the result of post-depositional changes that affect the preservation of laminae to different degrees in different cores rather than sudden changes in lake ecology. Lake turnover could, of course, erode mlgcs to different depths in different cores, but the tops of few mlgcs show good evidence of this process. In cores, such as V, R, and C, where these processes have not obscured the top of the mlgc, the dark laminae rapidly grade upward into a laminated section with lighter, browner laminae, suggesting a change to less anoxic lake-bottom conditions over a period of 5-15 years. The thickness of mlgcs (to the gl) is quite uniform (2.2-3.5 cm in all but one core, M); 28-77 couplets were counted in the mlgcs; the higher numbers are probably more accurate. Sedimentation rates within mlgcs are 0.5-1.1 mm/yr, with most 0.7-0.9 mm/yr. As in DEs 3 and 4, a thick tan lamiae separates almost all gcls in DE5/6 from overlying mlgcs. But in contrast to the later DEs, a thinner tan gl also occurs in the lower third of the mlgc. This relation shows that tan gls are not always associated with the end of a gcl and that there may be some ecological change or difference in seasonal timing that produces tan gls.

The above evidence indicates a truly catastrophic disturbance event that involved transport of very large amounts of sand into the lake from the west, major erosion and resuspension of lake sediment in deep as well as shallow water, and much erosion and slope failure of the dune at the western end of the lake and of shallow-water sediment around the lake. A series of strong currents, probably successive tsunami surges each of which may have washed back and forth across the lake several times, laid down as many as 11 beds of sand and debris in the western end of the lake. Black laminae in the thickest mlgcs suggest anoxic conditions at the bottom of the lake for roughly 80 years following the DE. The amount of erosion and the volume of sand spread onto the floor of the lake seems too large for this event to have been produced by anything except a large local tsunami overtopping the lake outlet by at least several meters and completely inundating the lake.

Harvey's observations of May and early June 1998 of the DE5/6 interval in cores M, E, X, and K argue convincingly that DE5/6 is two separate disturbance events closely spaced in time. In most cores, evidence for the earlier event was eroded during the later event.

insert Harvey's one-page summary of evidence dated 6/2/98 (I don't have the WORD file) here

In core M the evidence is pretty clear (my core M depths differ from Harvey's by 26 cm). I attributed this evidence to repeat-section coring several years ago. If, as we argue elsewhere, the mlgc laminae are annual, the 11 laminae in the lower gcl (DE6) show at least 11 years between DE5 and DE6.

At 199 cm, core X shows a smooshed bed of probably laminated sediment that could be the mlgc and upper part of the gcl of DE6. Getting this core out and looking at successive vertical sections through that part of the core might confirm this. A similar, but thicker equivalent bed occurs at 203 cm in core E (core is too messed up to be worth getting out), although this bed was originally described as "massive" and interpreted as a mud clast. These beds in cores X and E could well be the remains of DE6, but because the laminations are so faint and disturbed this evidence is weak compared with that in core M.

I do not agree, however, that the sandy mud bleb at 157 cm (J281) in core K is the dl or sand of DE6. This bleb does occur only 2 cm below the stratigraphically equivalent level in core E (E214), which also contains sand partings and blebs, but point E214 is clearly below the evidence for DE6 in cores M and X. Unfortunately, point E214 seems to have been eroded in most other cores and so it is impossible to determine if sand was widespread at the time of point E214, well before DE6. Thus, if evidence for DE6 is preserved in core E, I think that it is higher in the section than argued by Harvey in June 1998. This interpretation leaves direct stratigraphic evidence for DE6 (two DEs) only in core M, and quite possibly in E and X.

A later DE superimposed on an earlier one would help explain some unusual features of DE5/6. Particularly in the western part of the lake, a gcl and overlying thin mlgc would not likely survive the erosive forces of a large sand-laden tsunami. Two DEs could help explain the substantial sand/dl thicknesses of DE5/6 in many cores and the inconsistent patterns, thicknesses, and number of pulses in many cores. The unusually thin gcls of DE5 in many cores (see 1996 discussion above) may be the result of a fairly powerful DE6 suspending most of the soft gyttja in shallow water so that little new gyttja was present for suspension when DE5 came along a decade or two? later. Inconsistencies in the thickness of DE5 gcls and their low organic contents might also reflect prior massive disturbance of the lake bottom during the earlier DE.

AMS dating is no help in distinguishing DEs 5 and 6 because (1) DE5 occurred too few years after DE6 for AMS ages to distinguish them, (2) we can't distinguish DE5 sediments from DE6 sediments in most cores, including all cores sampled for 14C, and (3) all dated samples are detrital and so any of the ages on them could correspond to the time of DE5, the time of DE6, or an earlier time.

The wide range in ages from DE5/6 makes estimating even the century of DEs 5 and difficult. The initial age of 1610+/-60 for DE5 is more than 300 years younger (more than 2 SDs) than any of the other 6 ages for that DE, most of which are on higher quality (=expected to yield younger ages) materials. The dated sample is from the middle of the DE sand sequence in core C rather than its lower part. This young age is on a single root

fragment and we had a lot of problems coring through the DE5 sand with Cathy's Livingston, so it is conceivable that the dated fragment was dragged down from a younger level in the core. Yes, this is grasping at straws, but it's all I can think of right now. Ignoring the 1610 age and averaging the three next youngest of the remaining six ages (the only ones that which meet the criteria of Ward and Wilson [1986]) yields an OxCal-derived maximum age (with core E thickness) of 2020-1870 cal yr BP for DE5/6.

MM diatoms certainly show marine inundation throughout DE5/6. Is the high concentration of MM in the mlgc of DE5 due to reworking of detrital tests from shallow water or marine guys reproducing in saline water in the lake? If we could find obvious laminations in the lower muds of DE5/6 in core E then the MM diatoms that we see in the lower part of DE5/6 would be evidence for marine inundation during DE6 as well as DE5. A look at a series of samples through both DEs of core M would be even more instructive.

The section between DEs 4 and 5/6 is mostly laminated in most cores with 2-4 distinctive gls. The least turbated cores (V, T, and W) show faint to clear laminations throughout the section. Rob's couplet counts in cores V, W, T, and R of 100-201 couplets yield sedimentation rates for this section of 1.2-2.5 mm/yr. Such rates are higher than rates measured in the best preserved mlgcs, probably because the couplet counts are much lower than the total number of years of deposition. Such reasoning would argue for using maximum couplet counts in the best preserved sections to estimate the number of years between DEs *(see Tables S1 and S2 of June 1998).*

DE7(6) (E296, BB225, E316)

DE7 (formerly DE6) is reached in only 10 cores (T, R, P, D, I, BB, E, X, F, and N), but it is one of the most consistent DEs and follows the DE model as well as any other DE. All cores that reach the sand of DE7 show sand overlain by a well developed gcl (and a dl in 4 of the 9 cores), which is, in turn, overlain by a finely laminated mlgc of very uniform thickness. Core T recovered only the mlgc and gcl of DE7. Sharp, irregular contacts at the base of the sand in all but one core (F) suggest erosion of underlying lake sediment.

There is less than a 3-cm difference between the base of DE7 and correlation point E316 in the 7 cores where the point is reached. Thus, although an erosional contact occurs at the base of DE7 in all cores (except possibly F), there is probably less than 2 cm of differential erosion from one core relative to the others.

Thick (11 and 12.7 cm) beds of sand with beds of sandy mud and large and small clasts in cores R and P from the western part of the lake suggest two pulses of sand deposition during DE7. Muddy beds a few mm thick in the thinner sands (1.5-2.8 cm) of other cores (D, BB, and E) may also record multiple pulses. In the eastern part of the lake, sand thins to 1.5 cm or less (cores E, X, and F) and is only 2 mm thick in core N (see discussion below). I have not done calculations, but I think this volume of sand is too large to have come entirely from slumping of the distal face of the dune. I also doubt that slumping could deposit sand at the far end of the lake, but again I have no numbers to show this.

In considerable contrast to most of the gcls of DE5, those of DE7 are organic-rich gyttjas that tend to fine upward. Some gcls are divided into two units based on the coarseness of debris (cores P and F), and others (BB, X, E and I) are underlain by sandy dls with coarse organic debris. Combined thicknesses of gcls and dls for DE7 are somewhat greater (5.6-7.5 cm) for 3 (P, D, BB) of the 4 cores in the central part of the lake than for those to the west (2.1-4.2 cm; T and R) or east (3.0-5.3 cm; E, X and F). As in earlier DEs, this may indicate focusing of organic debris into the deepest and narrowest central part of the lake. No foraminifera were found in samples from the lower part of the gcl in core BB. Smear slides in core X show that the gcl contains many large and small plant fragments and more clay, diatoms, and pyrite than the underlying dl and sd.

In DE7, mlgc thickness (1.0-1.7 cm), laminations, and preservation are more consistent than in any other DE. Following earlier reasoning, I place the top of the mlgc at a prominent gl near the point at which black laminae end in most cores. Particularly in cores in the eastern half of the lake, laminations above the gl are obscured by turbation (F, X, E, D, I, and BB); erosion is probable just above the gl in D, I, and F. However, other cores at the western end of the lake (P, R, and T) show that laminations were produced for many years after the deposition of the gl, although the black laminae typical of mlgcs do not extend upward beyond it. Thus, once again, I think that turnover or other processes that may produce erosion by gentle bottom currents are not necessarily contemporaneous with the tops of mlgcs. At the tops of many mlgcs it is difficult to determine whether the laminae are really truncated by erosion or by bioturbation. Where best preserved, the tops are gradual and probably record a return of the lake bottom to less anoxic conditions that took at least a few years. Counts of couplets of laminae in DE7 are very consistent (10-18 couplets) suggesting sedimentation rates of 0.65-1.0 mm/yr; the lower rates probably show the degree of compaction more accurately. No tan laminae were found in gcls or mlgcs.

DE7 cannot be positively identified in core N. The section between DEs 5/6 and 8 in this core is one of the most turbated sections of the cores, with some indistinct, uncertain correlation points; the section is also much thinner than in nearby cores F and E. An irregular, 1-to-2-mm-thick sand bed with a 1-cm-thick, blotchy zone of dark, massive gyttja above it is probably the remains of DE7 in core N. Turbation may explain the destruction of DE7 in this core, but DE8, which is only 23 cm below it, is well preserved.

The other unexplained anomalously young age from the BL DEs is an age of 2440+/-50 on fresh-looking spruce needles from the top of the DE7 sand in core BB. More fragile material from the same sample gives an age of 2735+/-95 and two other ages for this DE from cores E and P give similar ages. Thus, unless I argue that almost all our ages on this DE (and by analogy the other DEs) are hundreds of years older than the times of the DEs that they come from, I must attribute the age of 2440 to the statistical variation inherent in AMS analysis. Another age on wood from the same sample as the spruce needles is 3205+/-70, indicating substantial reworking. The average of the three other ages used in the OxCal analysis give a maximum age interval of 2855-2750 cal yr BP for DE7 using either the core E or the axial cores thickness.

The above evidence indicates a lake-wide disturbance event that involved transport of much sand into the lake from the west, erosion and resuspension of lake sediment in deep as well as shallow water, and probably slope failures on the dune at the western end of the lake and in shallow water around the lake. Black laminae in the mlgcs suggest that the lake bottom may have been strongly anoxic for 17-18 years following the DE. The volume of sand spread onto the floor of the lake seems too large for this event to have been produced by anything except a local tsunami that inundated the lake by several meters.

MM diatoms found in DE7 in core E are quite convincing of marine inundation. Therefore, it was a tsunami. Why no BHC diatoms?

The long section between DEs 5/6 and 7 is more difficult to correlate than higher sections. In many cores parts of this section are massive or only faintly laminated, distinctive gls are less frequent and not as easily traced from core to core as in higher parts of the cores, and there is more variation in sedimentation rates among cores than in higher parts. Cores D, R, and X and have the best laminated sections with as many as 15 correlation points. Counts of laminae by Rob in the outstanding section between DEs 5 and 6 in core R yields a mean of 338 couplets and a maximum of 361. These counts give a very low sedimentation rate of 0.2 mm/yr. Is this low rate the result of unusual compaction in this vibracore or hopelessly minimum counts of laminae in other sections of the cores? Are my "liberal" counts in many mlgcs lower in the cores far too conservative?? Massive gyttja between correlation points E228(221) and E232(237) in a few cores (E, F, X, BB) was initially described as a possible gcl, and therefore, a DE. However, these gyttja units have no other beds associated with DEs above or below them and the equivalent section is discontinuously laminated in cores T, R, L, K, I, D, H, G, and P. Thus, this "gcl" is probably the result of turbation of originally laminated lake sediment deposited over many years. The circular brown massive zone in core H is particularly suggestive of a root cast or burrow fill. The former would imply a period of much shallower water before DE5/6.

DE8(7) (E332, E326, E345)

DE8 (formerly DE7) is also very consistent in the 7 cores that reached it (P, D, BB, E, X, F, and N) and follows the model well. All cores that reach the sand of DE8 (6 of 7) show sand overlain by a well developed dl, overlain by a gcl, overlain by a partially obscured mlgc of uniform thickness. Sharp, irregular contacts at the base of the sand in all 6 cores indicate erosion of underlying lake sediment. Core N recovered only the mlgc, gcl, and dl of DE8.

There is less than a 3-cm difference in the thickness of sediment between the base of DE8 and correlation point E345 in the 5 cores that reach the point. Thus, although an erosional contact occurs at the base of DE8 in all 6 cores, there is probably less than 2 cm of differential erosion from one core relative to the others.

A thick (23.9 cm) bed of sand with 11-cm-diameter clasts in core P from the western part of the lake suggests extensive erosion during DE8. Muddy beds a few mm thick in the upper part of this core and in the thinner sands (2.8-9.3 cm) of other cores (D, BB, and E) may record two or more pulses of sand deposition. The sand in core X, and probably most of the other cores, fines upward. Small mud clasts also form muddy beds at the base of the sand in cores BB and F. Sand is much thicker in the 3 western cores (4.3-23.9 cm; P, D, and BB) compared to the 3 eastern cores (1.0-2.8 cm; E, X, and F), but thicknesses in only 6 cores provide few clues to sand distribution. I have not done calculations, but I think this volume of sand is too large to have come entirely from slumping of the distal face of the dune. I also doubt that slumping could deposit sand at the far end of the lake, but again I have no numbers to show this.

DE8 has a sandy, coarse organic dl beneath the gcl of each core except core D. The gcls are also typical in being organic-rich gyttjas that tend to fine upward; the gcl in core N is divided into two units based on the coarseness of debris. A thin (0.5 mm), indistinct tan gl occurs at the top of the gcl only in cores E and X. Combined thickness of gcls and dls for DE8 are 3.1-4.5 cm, except for core D (0.9 cm) and core BB (7.2 cm) in the central part of the lake. No foraminifera were found in samples from the gcl in core BB. Smear slides in core X show that the gcl contains many large and small plant fragments and more clay, diatoms, and pyrite than the underlying dl and sand.

DE8 has a very thick mlgc (5.0-6.5 cm) with much variation in the darkness of laminae and the thickness of gls within it. We place the top of the mlgc at correlation point E326 where there is a prominent gl, although 4-5 similar couplets of black and light laminae extend above it in cores P and D. In the other cores, couplets above E326 are so turbated and oxidized that the laminae cannot be counted. It is possible that some of these upper laminae are truncated by erosion in some cores, but if so, the latter processes have obscured the truncation surfaces. Although the black laminae of the mlgc do not extend upward much beyond point E326, there are beds of browner laminae within the mlgc that look the same as beds of laminae above it (cores D and BB). The beds at the base and the top of the mlgc contain fine laminated couplets of black and light laminae, but several beds within it look similar to beds in finely laminated sections between DEs in other parts of the cores. In this way, this mlgc is similar to the mlgc of DE3. The mlgcs of DEs 3 and 8 and the similar dark laminated beds between DEs, such as at E316, show that the fine, continuous, black and light laminae that are the main characteristics of mlgcs occasionally formed at times of no disturbance in the lake. Such beds tell us something about DEs because they almost always (no black laminae occur at base of the mlgc of DE) occur above gcls. The processes and ecological changes they record, however, are not unique to DEs. The laminae in the lower part of the mlgcs in cores BB, F, X, and N are slightly deformed; gls of variable thickness suggest slight erosion during this period and parallel folds in these and other gls indicate later deformation, probably during coring. The sand in tiny sand partings in the mlgc in core N may have fallen off of the roots of a floating tree trunk. Sand could also be blown off the dune into the lake during large storms, but there is little or no similar sand in the normal (massive and laminated) lake sediment in cores from the central and eastern parts of the lake (hand textures in the lab).

This suggests wind blown sand is rare. Grain-size analysis of samples in core BB show 0-2% sand in normal lake sediment, but 2% sand is apparently too low a percentage to feel in hand textures. Counts of couplets of laminae within DE8 suggest sedimentation rates of 0.68-1.15 mm/yr. Laminae are too disturbed for accurate counts of laminae through the complete thickness of the mlgc; maximum counts of 71-78 couplets in cores D and BB suggest 80-90 years of mlgc deposition following DE8.

The three AMS ages for DE8 are within 20 years of each other. The OxCal-derived maximum age interval for this DE is 3260-3090 cal yr BP using the core E thickness and 3250-3060 using the axial cores thicknesses.

The above evidence indicates a lake-wide disturbance event that involved transport of much sand into the lake from the west, major erosion and resuspension of lake sediment in deep as well as shallow water, and probably slope failures on the dune at the western end of the lake and in shallow water around the lake. The volume of sand spread onto the floor of the lake seems too large for this event to have been produced by anything except a local tsunami that inundated the lake by several meters. Black laminae in the lower part of the mlgcs suggest that the lake bottom may have been strongly anoxic for 12-15 years following the DE and during several similar intervals over the next 60-80 years.

The distribution of MM and BHC diatoms for DE8 is about as good as it gets, nicely showing marine inundation and the brackish-loving guys hanging on through most of the mlgc. Definitely a tsunami.

The 20-25-cm section between DEs 7 and 8 is massive to faintly laminated with less frequent distinctive gls than in higher parts of the cores. Cores D, P, and X and have the best laminated sections with 3-4 correlation points; the section in core O lacks laminations. Two 1-cm-thick beds in the middle of the section show couplets of fine black and light laminae that are partly destroyed by bioturbation. The best preserved of these beds in core D (at E316 and above it) look like the mlgcs of DE8 in cores E and F. Too few laminae are preserved to make counting them useful for estimating the number of years between DEs 7 and 8.

DE9(7/8) (alias "Phantom"; E345)

At correlation point E345 in cores BB, E, X, and F, the remains of a 1-2-cm-thick mlgc overlies a 4-12-mm fibrous gcl. Both units are partly to almost completely obscured by post-depositional bioturbation. We did not recognize these units as part of a DE in our original descriptions of cores F and X. Fragments of couplets in the mlgc in core F suggest a sedimentation rate of about 1 mm/yr. A possible thicker (2-3 cm) gcl underlies the fibrous gcl in cores E and BB, but its organic-poor lithology and faint laminations in parts of the same section in cores F and X show this possible gcl to be a pseudogcl, as found in DE2 and discussed earlier. Smear slides in core BB show some very fine sand and more diatoms in the gcl than in the underlying unit. No hint of a dl or sand was noted in this potential DE in lab descriptions of cores BB, E, X, or F, but its gcl has more coarse-

grained organic material in cores BB, X, and F than the gcl of DE3 and all 4 cores are in the eastern part of the lake where sand was not deposited during DEs 1, 3, or 4. Furthermore, at the base of core D, a 5-mm-thick disturbed dark unit overlies 2 cm of mud with 1-2-mm-thick blebs of sand--possibly the remains of a fine-grained gcl mixed with underlying sand. The gouge-core-within-a-Livingston-core section of core D lies directly below the blebs of sand and its upper part contains two 10-cm-thick beds of clean sand. I hesitate to draw any conclusions about the sand in core D, however, because of the likelyhood of severe disturbance during reverse gouge coring inside a segment of Livingston core.

We need a consensus about whether or not to bestow official DE status on DE9 (formerly DE7/8). If, like DE3, it had been recovered in 20 cores, I think we would draw the same conclusions about it that we do for DE3. If it is a DE, it should be labeled DE9 in publications and the DEs below it renumbered.

Based on Harvey's email of 5 Aug 98 and a lack of dissent to the above statements of early 1997, I award official "disturbance" status to DE9 (formerly called DE7/8).

Two consistent ages from DE9 yield an OxCal-derived maximum age interval for this DE of 3390-3220 cal yr BP using the core E thickness and 3400-3210 using the axial cores thicknesses.

The above evidence indicates a small disturbance event that probably involved lake-wide resuspension of organic debris from shallow water into the deeper parts of the lake. The probable thin mlgc suggests at least a small change in lake ecology for maybe 10-20 years following the DE. Only freshwater and reworked diatoms were found in samples near DE9 in core E, but MDM diatoms were found in a sample from the gcl in core BB and rare marine diatoms and some BHC diatoms in the overlying mlgc in core BB (Eileen's email of 4 Aug 98). Apparently this DE involved some tsunami inundation(??).

The 4-6-cm-thick section between DE8 and DE9 is massive to faintly laminated with no distinctive gls or other features.

DE ?? (alias "Eileen's"; F367, F370)

In 1997 I wrote: A huge clast of peaty freshwater mud spans 33 cm of core E and a gyttja-like mud that could be a gcl overlies the clast. Unfortunately, correlation points E354 and E357 and three unlabeled gls below them indicate that the "gcl" above the clast is about 11 cm stratigraphically higher than the mlgc of DE8 (now 10) in cores BB, X, and E. The clast apparently was deposited at least a century after DE8 (now 10). Erosion during emplacement of the clast removed the section down to correlation point F387 in core E, including the beds of DE8 (now 10).

This previously unnumbered DE consists of a 1.5-3-cm-thick, massive gcl in cores X, BB, and F, as well as a probable gcl in core E, and is capped by a distinctive gl at F367. The

base of the gcl is indistinct, suggesting little or no erosion during its deposition. In core E, a 3-cm-thick gcl overlies a coarser 2-cm-thick gcl/dl at the top of the peat clast (which spans 368-401 cm). The gl at the top of the gcl in core E at 363 cm is probably correlation point F367.

Apparently the peat clast was deposited at the same time that the gcls below point F367 were deposited in the other cores.

Eileen's data highlights this DE (which, if it is a DE, requires the subsequent renumbering of everyone's figures and text). Her samples of the 360-368-cm interval in core E (??) show a distribution of MM and BHC diatoms similar to DEs 5/6 and 8, although the diatom concentrations are lower. Doesn't this more or less require marine inundation (tsunami)? So, now we finally have an explanation for what induced the peat clast to slump into the center of the lake. Note lots of BHC above the gcl but no mlgc (Why??).

The peat clast yielded top and bottom AMS ages only 40 years apart. The calibrated average of these two ages is 4150-3920 cal yr BP. This age, which is older than DE10, is not surprising from a detrital peat clast. These two ages were not used in the OxCal analyses because they are obviously older than the probable disturbance that deposited the peat clast. Interpolating between the average OxCal ages for DEs 9 and 10 gives a age of about 3500 cal yr BP for DE(?).

The 15-to-20-cm section between DEs 9 and ?? is quite well laminated with 3 correlation points and distinctive gls in its lower half to two thirds.

DE10(8) (alias "Shy guy"; F370, F387)

Its hard to draw conclusions about DE10 (formerly DE8) because it's only well preserved in two cores (BB and X). In core F dark photos, a gap between two Livingston segments within the gcl of DE10, and probable sluff at the top of the lower core segment confuse this investigator. Correlation points E357, E360, F367, and E418 show that DE10 is present in the gouge-within-a-Livingston segment of core D, but the photos are very dark and all that can be concluded is that a thick gcl is probably sandwiched between a mlgc and a 0.5-cm-thick dl.

In cores BB and X, a thick (4.8-6.0 cm), two-stage gcl is overlain by a 1-cm-thick mlgc. No real dl is present but organic material in the gcls grades upward from coarse to fine and the lower part of the gcls in cores BB and F are sandy (7% in BB). Three smear slides in the gcl of DE10 in core X and one in core F show the same trends. Possibly, the sand in the gcl in core F could have been mixed into it during deformation of the top of the core segment during coring. In all three cores the base of the gcl is gradational with massive brown lake sediment (which is similar to the pseudogcls discussed for higher DEs)--no erosive contact is obvious. A tan gl occurs at the top of the gcl in all three cores.

Thin (0.8-1.1 cm), dark mlgcs overlie the gcl in cores BB, X. and E. Laminae are most distinct in core BB (14 couplets), although laminae of the mlgc in core BB are only slightly darker than overlying laminae, whereas in X and E the black laminae of the mlgc are distinctly darker. The tops of the mlgcs in cores X and E appear partly engulfed by turbation rather than being eroded. Couplets in the mlgc in core BB yield a sedimentation rate of 0.78 mm/yr.

The two ages from DE10 are within 50 years of each other. OxCal analysis of the two averaged ages gives a maximum age interval of 3830-3630 for DE10 using either the core E thickness or the axial core thicknesses.

The above evidence is suggestive of a lake-wide disturbance event that might have involved slope failures on the dune at the western end of the lake and in shallow water around the lake and resuspension of material into the deepest parts of the lake. Analogies with other DEs suggest the sand in the gcls came from the west but with only two good cores not much can be said about sand distribution. Neither the character of the contact at the base of the gcls nor the uniform thickness of sediment between the base and correlation point F387 suggest any erosion during DE10. The ecology of the lake probably changed for at least 14 years following the DE. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, possibly induced by strong gound motion. Far too little sand was found to suggest a major tsunami.

Rare MM and BHC diatoms in the gcl of DE10 suggest possible marine inundation, but I am not sure that this is enough evidence for a tsunami. Are the diatom concentrations high enough to rule out just strong shaking or a landslide into the lake?

The 3-5-cm interval between the top of the mlgc of DE10 and the base of the gcl of DE?? is only preserved in cores X and BB. The interval is faintly laminated.

DE11(9) (E438, E435, E447)

DE11 (formerly DE9) is well preserved and undeformed in all 4 of the deep cores (BB, E, X, and F), although the photos of core F are dark and its mlgc is only faintly laminated. All cores show a dl-gcl-mlgc sequence. The dl of core BB has 11% sand, but only a trace of sand was found in the dl of one other core (X).

A 0.7-1.1-cm-thick dl in the 4 cores is darker and has slightly more coarse organic material than the overlying gcls. In three cores (BB, E, and X) the base of the dl is gradational with massive brown lake sediment that looks like a gcl. Faint, discontinuous laminae just below the dl in core F, however, show that this section is a pseudogcl as discussed for some earlier DEs. The gcls (2.1-4.7 cm thick) overlying the dls are interesting in that they grade downward rather then upward, with more clay, less organic material, and lighter color in their lower thirds. These characteristics are less pronounced in the gcl in

core BB, but this gcl shows faint interbedding of lighter, more clay-rich zones with sandier, more organic-rich zones. The interbedding is suggestive of pulses of deposition; if related to tsunamis the pulses would have had to have occurred within hours. The lighter parts of the other gcls apparently were deposited during an influx of clay to the lake, as might occur if a landslide had suddenly exposed much clay-rich sediment in the drainage basin of China Creek. A tan gl caps the gcl in all 4 cores. Are tan gls at the tops of gcls in other DEs a record of much smaller or more distant landslides?

The mlgcs that overlie the gcls in all 4 cores are darker than overlying sediment and extend upward to correlation point E435 where they are truncated by turbation. 5-8-mm beds of lighter (browner) and darker laminae can be seen in mlgcs of BB, E, and X, with some of the lightest laminae at the base of the mlgcs. The mlgc in core F is too turbated to see distinct laminae. The tops of the mlgcs are engulfed by turbation and are fairly planar in cores BB and X and wispy in cores E and F. 5-10 mm of massive brown sediment overlies the mlgcs and a similar bed is found within the mlgc of core X. In both cases we interpret the brown sediment as turbated, formerly laminated sediment. Counts of couplets in the mlgc in core BB yield a sedimentation rate of 0.72 mm/yr.

The three ages from DE11 are within 25 years of each other. OxCal analysis of the three averaged ages gives a maximum age interval of 4230-3990 cal yr BP for DE11 using the core E thickness and an interval of 4280-4000 cal yr BP using the axial core thicknesses.

The above evidence is suggestive of a lake-wide disturbance event that might have involved slope failures on the dune at the western end of the lake and in shallow water around the lake and resuspension of material into the deepest parts of the lake. Analogies with other DEs suggest the sand in the dls came from the west, but because sand was found in only two cores not much can be said about sand distribution. Neither the character of the contact at the base of the dls nor the uniform thickness (5-7.5 cm) of sediment between the base and correlation point F387 suggest erosion during DE11. The ecology of the lake probably changed for at least 60 years following DE11. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, possibly induced by strong ground motion. Far too little sand was found to suggest a major tsunami.

Marine diatoms in the gcl and mlgc of DE 11 in core E and a high concentration of BHC diatoms in one sample from the mlgc show a distibution of diatoms similar to those for other DEs where we have made a marine inundation interpretation. Thus, this must have been a tsunami.

The 30-cm section between DEs 10 and 11 is massive to well laminated with 3 gl correlation points. The best laminations and most distinctive gls are in the middle of the section. Chief among these is "Big stormy", the thickest of the gls in the lake sequence, at correlation point at E418. Big stormy appears to be a single massive gl in core BB, but in the other cores its upper and lower parts are much more diffuse, as if it was partially mixed with overlying and underlying units. The smear slide of big stormy is almost entirely

clay and it contains mostly pine and other upland forest pollen typical of the drainage basin rather than the shore of the present lake (Cathy Whitlock, written communication, 1996). Laminae are visible through the "fog" of Big stormy in cores E, X, and F, so perhaps it represents a multiple-year period of massive flood-type clay input to the lake. How could this happen? A clear V-shaped channel is eroded into the gl at E422 in core BB; without the prominent gl or distinct laminae such features are hard to distinguish.

DE12(10) (E458, E475)

DE12 (formerly DE10) is similar to DE7 in being very consistent among the 4 deep cores (BB, E, X, and F) and following the model well. The cores show clean sand overlain by a dl (3 of 4 cores), overlain by a gcl, overlain by a thick, burrowed mlgc. Sharp, irregular contacts at the base of the sand indicate erosion of underlying lake sediment.

There is a 7-cm difference between cores BB and X in the thickness of sediment between the base of DE12 and correlation point E475, suggesting at least this much erosion of core X relative to BB. Similar measurements for cores E and F suggest about 3 cm of erosion relative to core BB. A clast in core X was probably eroded from the mlgc of DE11. If so, a total of at least 16 cm of sediment was eroded at some other spot in the lake.

The sands of DE12 show a nice west-to-east decrease in thickness (5.4 cm to 1.2 cm) and contain small mud clasts in 3 of the 4 cores. I have not done calculations, but, as with DEs 2, 6, and 7, I think this volume of sand is too large to have come entirely from slumping of the distal face of the dune. I also doubt that slumping could deposit sand this far east in the lake, but again I have no numbers to show this. Clasts occur near the top (BB), base (E), and throughout (E and X) the sand beds; in core E discontinuous layers of clasts suggest 2-3 pulses of deposition. The sand in core X, and possibly the other cores, fines upward. Sand fills probable burrows (BB) or possible fissures (F) beneath its erosional contact in two cores.

DE12 has a sandy (4% in core BB), organic dl (0.3-2.6 cm thick) beneath the gcl of 3 of the 4 cores. The gcls are also typical in being organic-rich gyttjas that tend to fine upward; the gcl in core F is divided into two units based on the coarseness of debris. Smear slides in core X show that the gcl contains many more small plant fragments and less sand than the underlying dl. Combined thickness of gcls and dls for DE12 are 3.6-6.2 cm, very similar to thicknesses for later DEs in the central part of the lake. No tan gl was noted at the top of the gcls. In core E, a 1-6-mm-thick sand bed occurs between the gcl and the mlgc. Gls in the basal part of this mlgc are deformed, perhaps because of differential compaction over the sand. It is difficult to explain how a clean sand laminae could be deposited in the eastern part of the lake after the gcl was deposited. A small sand flow from slumping near the dune would probably have deposited much muddier sand. A clast of sand must have been dropped into its present position, or possibly later liquefaction injected sand upward to this level.

Like DE7, DE12 has a very thick mlgc (5.0-6.9 cm) with variation in the darkness of laminae and the thickness of gls within it. Much of the distinct lamination in the mlgc seems to be the result of thick gls rather than dark, black laminae; the two most prominent gls are 2-3 mm thick. Although the top of the mlgc is burrowed in all 4 cores, the top seems to occur at about the same stratigraphic position. The mlgc of core BB is severely deformed by a 2.5-cm-thick, triangular-shaped clast of gcl sediment that was apparently dropped at least 14 years (14 couplets) after the gcl was deposited. In cores X and F, the top of the mlgc seems to grade more evenly into overlying faintly laminated sediment, whereas in the other cores the top shows a strong blotchy, burrowed pattern. Nevertheless, burrows are as distinct in DE12 as in any other DE; they suggest a limited period of shallower water when plant roots or animals could intrude into older sediment. However, the period was apparently short enough to prevent most of the sediment in the DE from being turbated. Counts of couplets of laminae within DE12 suggest sedimentation rates of 0.9-1.0 mm/yr. Maximum counts of 56-66 couplets in parts of the mlgc in cores D and BB suggest 70-80 years of total mlgc deposition following DE12.

Three of the four ages from DE12 meet the criteria of Ward and Wilson and so were averaged for the OxCal analyses. The fourth age is >200 older than the others and so was assumed to be seriously reworked. OxCal analysis of the three averaged ages gives a maximum age interval of 4420-4240 cal yr BP for DE12 using the core E thickness and an interval of 4410-4230 cal yr BP using the axial core thicknesses.

The above evidence indicates a lake-wide disturbance event that involved transport of much sand into the lake from the west, major erosion and resuspension of lake sediment in deep as well as shallow water, and probably slope failures on the dune at the western end of the lake and in shallow water around the lake. The volume of sand spread onto the floor of the lake seems too large for this event to have been produced by anything except a local tsunami that inundated the lake by several meters. Dark laminae in the mlgcs are lighter than in many mlgcs, so the lake bottom may not have been as strongly anoxic following DE12 as for some other DEs. The many prominent gls in the mlgc suggests 70-80 years of mostly annual flooding following DE12.

Marine diatoms in the gcl and mlgc of DE 12 in core E and a high concentration of BHC diatoms in one sample from the mlgc show a distribution of diatoms similar to those for other DEs where we have made a marine inundation interpretation. Thus, this must have been a tsunami. The high BHC diatoms are shown at different depths in one of Eileen's diagrams (454 cm) versus her email of 27 April 98 (460 cm). I'm guessing the latter depth is correct.

The 11-20-cm section between DEs 11 and 12 is faintly to well laminated with some distinctive gls and 2 correlation points. Many parts of the sections are partially burrowed with broken gls, however, and too few laminae are preserved well enough to make counting them useful for estimating the number of years between DEs 11 and 12.

DE13(11) (E484, F454)

DE13 (formerly DE11) is a subtle DE similar to DE3 with no dl, a very thin gcl, and a thick mlgc. Sand was not noted in any descriptions of this DE, but grain-size analysis showed 4% sand in the gcl in core BB. The irregular lower contact of the gcl (marked by a prominent gl at the top of the normal lake sediment) in 3 of the 4 deep cores (BB, E, X, and F) suggests slight erosion. The 4-6 cm of section between DE13 and DE14 in the 4 cores suggests <2 cm of differential erosion among the cores.

A very thin (0.8-1.3 cm), fine-grained, two-stage gcl characterizes DE13 in the 4 cores. The upper 1/4 to 1/2 of the gcls are lighter in color and perhaps slightly finer-grained and/or lower organic content than their lower halves. This relation is obscured at the break between two core segments near the top of the gcl in core E. In cores X and F, the light upper part of the gcl looks similar to the tan gl at the tops of the gcls of some other DEs and to the thin, light gcls of DE5 in some cores in the western part of the lake. These thin, light-colored gcls were probably deposited much more slowly than thicker gcls with coarser organic material.

The thick (4.6-6.7 cm), finely laminated mlgc of DE13 is well preserved in 3 cores; in core E it's lower part is deformed by coring. The mlgc ends at correlation point F454. Prominent gls highlight the middle part of the mlgc. Although some laminae near the top are obscured by turbation, the tops of the mlgcs in cores BB and E are gradational, whereas the upper parts of the mlgcs in cores X and F are clearly burrowed. As in DE12, dark laminae are more brown than black compared to the mlgcs of some younger DEs. Laminae counts in 3 cores indicate a sedimentation rate of 0.7 mm/yr over about 90 years.

Only the two of three ages from DE13 that meet the criteria of Ward and Wilson were averaged for the OxCal analyses. The third age is 170 years older than the next oldest age and may be reworked. OxCal analysis of the two averaged ages gives a maximum age interval of 4650-4420 cal yr BP for DE13 using either the core E thickness or the axial core thicknesses.

The above evidence indicates a small disturbance event that involved resuspension of organic debris from shallow water into the deeper central parts of the lake. A thick, well laminated mlgc suggests deep water and/or moderately anoxic bottom conditions for about 90 years following the DE. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, perhaps induced by strong gound motion. With only 4 cores it is not clear whether or not this DE affected the entire lake.

Marine diatoms are common to abundant in the upper, light-colored half of the gcl and in the mlgc of DE13 in core X (see Eileen's email of 6 Jan 99). They are also common in the gcl of core E. Few are found in the dark, lower half of the gcl. BHC diatoms are also abundant in the mlgc of DE13 in core X and present in the mlgc of core E. Thus, these

distributions sound as convincing as any for evidence of marine inundation of the lake (=tsunami) during this DE (I have not seen any of Eileen's diagrams for DE13.).

The 7-11-cm section between DEs 12 and 13 is very faintly to well laminated with some distinctive gls and 3 correlation points. Parts of the section are partially burrowed with broken gls, however, and too few laminae are preserved well enough to make counting them useful for estimating the number of years between DEs 12 and 13.

DE14(12) (E493, E499)

DE14 (formerly DE12) is a subtle and unusual DE that does not seem to correspond to the model of tsunami inundation and sand deposition from the west used to interpret many younger DEs. In 3 of the 4 deep cores it consists of a thin gcl over a thin dl; in core E there is only a gcl, unless a light-colored bed beneath it is a different type of dl from those described previously. Basal contacts of the gcl are sharp in 3 cores but too smooth to suggest erosion, except possibly in core F. Sand was not noted in any descriptions of this DE. The 3-5 cm of section between DE14 and correlation point E499 in the 4 cores suggests <2 cm of differential erosion among the cores.

A very thin (0.4-1.2 cm) dl underlies a thin (0.7-1.7 cm) gcl in 3 cores. The dls are darker (especially in cores X and F) and contain slightly coarser, fibrous organic fragments than the gcls. Smear slides of the dl in cores BB and X have many organic fragments, a little more sand, and less silt and clay than most fine-grained gcls. The dl-gcl pairs are similar to some two-stage gcls in younger DEs. A prominent gl at the top of the gcl is broken by burrowing.

Possible traces (1-2 mm thick) of a former mlgc can be found near the edges of cores BB and E, but they are so thin and indistinct that the existence of a former mlgc is in considerable doubt. Considering the similarities between DE14 and DE15 (discussed below), it is more likely that a mlgc never formed than that it has been completely obscured by turbation. Perhaps water depths were too shallow to preserve the laminations of a mlgc.

Underlying DE14 in all cores is a thin (0.3-1.0 cm), light-colored, porous mud with common coarse plant fragments but little fine-grained organic material. The mud differs from the pseudogcls indentified beneath some younger DEs, in being lighter in color, having less fine-grained organics, and more coarse plant fragments. Roughly equal proportions of silt and clay in smear slides in cores BB, X, and E suggest that the light color is due to a mineral content twice that of the overlying dl and gcl. In core E, this mud has more coarse organic material than the overlying gcl and was sampled for radiocarbon. It is difficult to determine how the mud formed. One idea is that coarse organic material was moved into it by burrowing of the gcl and mlgc. This, however, does not explain why the contacts of the DE are more distinct than would be expected in a highly burrowed unit, and why the gl at the top of the gcl has not been totally obscured by burrowing. A more likely possibility is that the mud is a dl that records a large influx of light-colored silt and clay (floods?) mixed with organics from lake shore slumping. The greater ratio of silt to

clay in smear slides of this unit than in normal lake sediment supports this idea. But if so, the lower contact of the mud is very gradational and shows no sign of erosion. Why this type of unit isn't found in younger DEs is a BIG mystery. These differences in lithology may reflect differences in depositional processes or the setting of the lake that require a model different from the one used to explain most DEs.

The three ages from DE14 are within 30 years of each other. Only two of the ages were averaged for the OxCal analyses because some uncertainty remains about whether or not the sample for the third age came from DE14 (see OxCal analyses notes of 4 June 98). OxCal analysis of the two averaged ages gives a maximum age interval of 4780-4560 cal yr BP for DE14 using either the core E thickness or the axial core thicknesses.

The above evidence indicates a small disturbance event that involved resuspension of organic debris from shallow water into the deeper, central part of the lake. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, perhaps induced by strong ground motion. With only 4 cores it is not clear whether or not this DE affected the entire lake.

DE14 was sampled for diatoms in both cores E and X. Neither core showed marine or BHC species indicative of brackish water (Eileen's email of 12 Jan 99). Thus, this DE apparently did not involve marine inundation and so there was no tsunami. The absence of an mlgc for this DE agrees nicely with the lack of brackish/marine diatoms.

The 4-6-cm section between DEs 13 and 14 is only faintly laminated with 1-2 distinctive gls and no correlation points. Why this section is so well turbated and the mlgc directly above DE13 is so well preserved is yet another mystery. Too few laminae are preserved well enough to make counting them useful for estimating the number of years between DEs 13 and 14.

DE15(13) (E536, E543)

DE15 (formerly DE13) is similar to but thicker and less subtle than DE14. Like DE14, it does not correspond to the model of tsunami inundation and sand deposition from the west used to interpret many younger DEs. In 2 of the deep cores it consists of a dark-colored gcl over a light dl, but in core BB a two-stage dark-over-light gcl overlies a dark dl. The lower part of a dark gcl and possible dl in core F are obscured by 3 cm of apparently missing section between two core segments. Basal contacts of the gcl are sharp and irregular enough in all cores to suggest erosion. Sand was not noted in descriptions of this DE, although as much as 5% fine and very fine sand were observed in a smear slide of the dl in core BB. The thickness of the section between DE15 and correlation point E543 in the 4 cores differs by <1 cm; therefore, no differential erosion is evident among the cores.

Like DE14, DE15 has a light-colored, fine-grained unit with coarse plant fragments in its lower half in cores E and X (labeled as dls). In core BB the light-colored unit is sandwiched between two darker beds (labeled as a two-stage gcl over a dl). Combined thicknesses of gcls and dls are 5-6 cm. Hand textures and smear slides in cores X, E, and BB suggest that the dark color is due to very fine-grained organic fragments and the light color to higher silt and clay contents. However, in considerable contrast to most upward fining gcls from younger DEs, at the hand lens scale most of the light beds seem to have more coarse plant fragments than the darker, more organic-rich dark beds (X and E). In smear slides, however, the opposite seems to be the case—the gcls have more >0.1 mm as well as <0.1 mm plant fragments than the lighter units. Although the matrix lithology and color of the light beds is the same as underlying normal lake sediment, these beds are too thick and have too much coarse organic fragments to have been formed by the incorporation of fragments into them through burrowing. They must record the mixing and deposition of shallow and deep water sediments along the axis of the lake, probably through slumping of shallow water deposits. The light color of some of these beds is most likely the result of mixing of recently deposited sediment containing prominent gls. Several such slumps could explain the dark-light-dark sequence of beds in core BB. Perhaps the lighter colored units are turbidity flows induced by rapid deposition of flood sediments near the east end of the lake. Light-colored, subhorizontal blebs in the upper parts of the gcls in cores BB, E, and X look like small clasts, whereas more irregular blebs in core F look more like animal burrows. Recent excavation in core E indicates that at least those blebs are clasts. A prominent broken gl caps gcls in core F, but in core BB the gcl seems to extend above it. The tops of the gcl are probably turbated in all cores, but the tops are less irregular and gradational in cores E and F than in BB and X.

No evidence of a former mlgc was noted in any of the cores. Transitional zones at the tops of the gcls in cores BB, X, and F differ from overlying normal lake sediment only in their slightly darker color. Because partially turbated gls remain distinct in the normal lake sediment above and below DE15, it seems very unlikely that a former mlgc would have been completely obscured by turbation in all 4 cores. It is much more likely that one never formed. Perhaps water depths were too shallow to preserve the laminations of a mlgc.

Only two of the three ages from DE15 meet the criteria of Ward and Wilson and so were averaged for the OxCal analyses. The third age is >500 years older than the others and so is obviously reworked. OxCal analysis of the two averaged ages gives a maximum age interval of 5590-5320 cal yr BP for DE15 using the core E thickness and an interval of 5600-5320 cal yr BP using the axial core thicknesses.

The above evidence indicates a small disturbance event that involved resuspension of organic debris from shallow water into the deeper central part of the lake. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, perhaps induced by strong ground motion. With only 4 cores it is not clear whether or not this DE affected the entire lake.

No marine or BHC diatoms were observed in the dl or gcl of DE15. I am extremely pleased with these results because they confirm that DEs 14 and 15 are real oddballs, as indicated by the lithology and smear slide data. Maybe they reflect small landslides around the lake, floods following large landslides in the basin of China Creek, or failures on the China Creek delta. Regardless, their differences from other DEs are much easier to explain because we won't be attributing these DEs to tsunamis.

The 40-50-cm section between DEs 14 and 15 is massive to moderately well laminated with a number of distinctive gls and 5 correlation points. All parts of the section are at least faintly laminated in at least one of the 4 deep cores. Burrowing has broken many gls and too few laminae are preserved well enough to make counting them useful for estimating the number of years between DEs 14 and 15.

DE16(14) (E598)

DE16 (formerly DE14) is the winner of the strangest DE award, if two separate mlgcs deserve to be included within it. This sequence of beds probably reflects a DE similar to DE15 followed by a series of lake level changes over several hundred years. The only sand noted was a trace in the gcl of core X. The section immediately above DE16 in core F is obscured by deformation at the top and bottom of adjacent core segments. Although there are no correlation points just below DE16 with which to measure apparent relative erosion, the section between DEs 16 and 17 is twice as thick in cores BB and E as it is in cores X and F, suggesting significant erosion of the section in the latter.

The sequence begins with a dark dl or gcl on an erosive contact in 3 of the 4 deep cores. Only thin gcls (1.5 cm) are found in cores BB and F, whereas dark dls (0.9-2.5 cm) underlie the gcls (1.5-1.8 cm) of cores X and E. As is true for many DEs, the lithologic characteristics of dls versus gcls are somewhat relative to each other--smear slides show that the gcl of core X has a coarse organic composition similar to that of the dls in many other DEs, but it is underlain by an even more organic-rich dl. But in smear slides from core E the only significant lithologic difference between the gcl and the dl is a few percent very fine to medium sand near the base of the gcl. The tops of all the gcls are clearly burrowed and grade upward into light-colored, massive to faintly laminated sediment about 3 cm thick. Smear slides of the light sediment are similar to many fine-grained gcls, except for higher concentrations of diatoms and a few percent very fine to fine sand. Overlying this light sediment in cores BB and E is a thin (0.4 cm) mlgc, which seems to be completely turbated in the other cores. Above the mlgc is another 2-3 cm of massive, light-colored sediment and this, in turn, is overlain by a thick (5 cm), finely laminated mlgc, which is so clearly burrowed in its upper 2/3 that is wins the "Best Burrows" award for Bradley Lake. Both mlgcs contain mostly black laminae and prominent gls and a smear slide from the thick mlgc contains abundant pyrite. Above the mlgc is more massive sediment with light and dark blotches (E and BB) indicating extensive burrowing.

I interpret the dls and gcls of DE16 in the same way as those of DE15. The base of the gcl in core BB is gradational and the dls are dark rather than light, but other characteristics are similar between these two DEs. The massive to faintly laminated light-colored sediment over the gcls is probably normal lake sediment that has been turbated, probably by plants, animals, and currents in water much shallower than the present sites of these cores. Lake turnover could probably accomplish this by itself if water depths were less than 5 m. In contrast, the thin and thick mlgcs show that bottom sediments were anoxic and undisturbed during the periods when the mlgcs were deposited, probably because the water was much deeper, close to today's depths. It is enlightening to observe that despite extensive burrowing by roots or large animals, both mlgcs can still be identified in cores BB and E and the thick mlgc is obvious in all 4 cores. This suggests to me that later bioturbation is unlikely to have completely erased most mlgcs that formed previously in other parts of the cores, for example, above the gcls of DEs 14, 15, and 16. This process cannot generally be called on to explain the absence of mlgcs. Where there is no sign of a mlgc, bottom processes were probably too energetic or insufficiently anoxic to form mlgcs. Couplet counts in the best developed laminae in the thick mlgc of cores E and X give sedimentation rates of 0.74-0.83 mm/yr.

The three ages from DE16 meet the criteria of Ward and Wilson and so were averaged for the OxCal analyses. OxCal analysis of the three averaged ages gives a maximum age interval of 6520-6310 cal yr BP for DE16 using the core E thickness and an interval of 6510-6310 cal yr BP using the axial core thicknesses.

The above evidence indicates a small disturbance event that involved resuspension of organic debris from shallow water into the deeper central part of the lake. Without clear evidence of marine inundation (microfossils) it is difficult to distinguish between a tsunami inundating the lake (probably just barely above lake level) and lake-side slope failure, perhaps induced by strong ground motion. With only 4 cores it is not clear whether or not this DE affected the entire lake. Using the sedimentation rates from the thick mlgcs, I infer that about 40 years of normal lake sedimentation followed the DE but the water was much shallower than at present. A short period (<10 years?) of deeper water followed, which was followed, in turn, by another 30 years of normal sedimentation in shallower water. Finally, the lake once again became deeper for a period of 60-70 years, before becoming shallow again. I restrain myself from speculating here about the causes of the water level changes.

Marine diatoms occur in the thick mlgc well above the dl and gcl of DE16, but not apparently in the 6 cm of faintly laminated sediment of thin intervening mlgc beneath it. Nor are any found in the underlying dl or gcl. Marine water must have gotten into the lake during the time of the thick mlgc, but no sand, dl, or gcl (diagnostic criteria for tsunami) occurs at this level in any of the four cores. Nevertheless, the lake was clearly deep (>5m) and anoxic when the thick mlgc formed, which suggests that the lake became deeper about the time that marine diatoms entered the lake. Could this be due to subsidence and a tsunami just barely poking into the lake? With coseismic subsidence one would expect substantial shaking and yet there is no gcl at this level in any of the four cores. Please explain.

BHC diatoms suggest a high conductivity environment during deposition of most of the sequence of beds labeled DE16. I guess this means that brackish/high conductivity water must have had episodic access to the lake during this entire period (dl, gcl, faintly laminated sediment, thin mlgc, thick mlgc). In fact, the distribution of BHC diatoms extends through much of the DE16-DE17 interval suggesting an environment where brackish water could mix occasionally with the lake water for much of that time. The diatoms don't tell us much about the amount of water level change during the DE16 time interval, but the changes between faintly laminated and mlgc sediment suggest at least a few meters of lake level fluctuation over at least a century and a half. I understand from Eileen's comments of 11 Feb 98 that BL has always been a lake rather than a lagoon. But don't the BHC guys suggest that the lake elevation was fairly close to sea level for much of the DE16-DE17 interval? Certainly tsunamis would have favored BHC productivity, but perhaps large storm surges did as well. If multiple tsunamis were the BHC helpers, why do we only see one dl-gcl pair at the base of DE16? Because we have the dl-gcl pair and BHC diatoms in the overlying faintly laminated sediment, a tsunami seems the reasonable explanation for the lower part of DE16 (but no marine diatoms). But could this part of the sequence have formed from shaking during a non-tsunamigenic earthquake offshore followed by a large storm surge a few years later?? For this reason, BHC diatoms in the dl and gcl of DE16 may not be particularly diagnostic evidence of a tsunami during this interval of time.

Perhaps the above is way overinterpreting the limited number of diatom samples(?).

The 45-55-cm section between DEs 15 and 16 is massive to moderately well laminated with a number of burrowed but distinctive gls and 4 correlation points. Massive zones in all the cores and dispersed fragments of plants suggest shallower water than that represented by most younger cores sediments. Burrowing has broken many gls and too few laminae are preserved well enough to make counting them useful for estimating the number of years between DEs 15 and 16.

DE17 (E629, E640)

DE17 is not a lake disturbance event and so would not be expected to correspond with the model of tsunami inundation and sand deposition from the west used to interpret many younger DEs. It represents a rapid change from a freshwater marsh environment to a pond, small lake, or possibly even an occasionally intertidal lagoon.

Sand was erosionally emplaced in cores E and F, but occurs only as laminae a few mm thick in cores BB and X. Interestingly, by far the thickest sand (8.7 cm) was found in the easternmost core (F). This sand contains a 1-cm-thick peaty bed of mud and plant fragments (the peaty parts are probably clasts) and much thinner (1-2 mm) discontinuous lenses of sandy mud and organic debris. No obvious dl occurs at the top of the sand in cores E and F; the sand grades upward through lenses of muddy sand and sandy mud into massive mud (1-4 cm thick). A thin sand lens (1-3 mm) was also found in the upper part

of the massive mud in core F. The interbedded sand and mud indicate alternating periods of high and low energy deposition, perhaps extending over years.

No gcls were found. A smear slide from the massive mud overlying the sandy laminae in core X contains fewer plant fragments, more diatoms, and more silt than most gcls in other DEs. Smear slides from mud beds above and below the sand in core E are similarly silty, but have fewer diatoms. The texture and organic content of these beds in the other cores is similar to that of normal lake sediment rather than to a gcl. The mud beds were probably deposited in a pond or freshwater lagoon in water too shallow to preserve or originally form laminae. Despite burrowing, a distinct gl occurs in the upper part of the mud in core F. A gl within the mud suggests that it took more than one flood season to deposit the mud. As a gl would probably not be preserved in a pond, a small lake must have formed by the time that the gl was deposited.

Because no gcls are present, the thin (1.1-1.5 cm) mlgcs 1-4 cm above the sandy beds are not part of a DE. Although highly burrowed, remnants of enough fine light and black laminae are preserved in cores E and X to identify these beds as mlgcs. Apparently, water depths had increased rapidly to the point where fine laminae were preserved at the bottom of the newly formed lake. Estimates from mlgc thickness and fragments of laminae suggest the mlgcs took at least 15-20 years to form. Deformation of the mlgc in core BB was caused by the core catcher.

The two ages for DE17 were not used in the OxCal analysis because the sediments between DEs 16 and 17 span a long interval of time and the lack of laminations or a reliable mlgc for DE17 make it difficult to estimate sedimentation rates for this interval. The calibrated age for the average of the two ages (which meet Ward and Wilson criteria) is 7390-7220 cal yr BP.

The above evidence indicates the flooding of a freshwater marsh in the former stream valley of Bradley Lake, probably due to a dune or beach berm blocking the stream. The erosional emplacement of the sand suggests a large storm (or tsunami?) may have thrown up a berm, although if dune sand was present along the stream the stream may have redeposited some the sand during higher flows. In either case, RSL was probably closer to the lake level than it is now. There is no evidence of significant slope instability or resuspension of organic debris from shallow water into the center of the lake during DE17, perhaps partly because there was no earlier (deep) lake for detrital organic debris to accumulate in. Even if diatom analyses show marine inundation, it may be difficult to distinguish between storm surges creating a barrier and occasionally overtopping it and a tsunami inundating the lake. It is also not clear where the western end of the lake was during this period, as the westernmost core is east of the center of the lake. A year or more after the lake formed it became quite deep and stayed that way for at least 15-20 years.

On 10 Feb 98 Eileen said: Bradley Lake was probably a fresh marsh up to this point. The first appearance of planktonic diatoms occurs at 628-230 cm, suggesting that the lake began deepening about that time. Marine diatoms are present in the sand at 634 cm, and are particularly abundant in the gcl at 632 cm. The marine diatoms (both modern

and from the Neogene diatomites) occur against a background assemblage of freshwater diatoms; therefore DE-17 represents an inundation event into a freshwater environment, rather than deposition in an estuarine environment. At 628 cm and 630 cm there is evidence for a change in lake chemistry, with an increase in species that prefer brackish water or water with increased conductivity. The indicative species would likely grow in the shallow areas of the lake.

On 11 Feb 98 Alan said: If RSL was close to the BL freshwater marsh about the time of DE17, the sand could easily have been deposited during a storm or series of storms. The berm formed during the storm(s) could have ponded water behind it to form the lake. There are several sand beds in core F, but if the peat bed between them is really a clast, then only one storm is needed. Such sands are deposited on many coasts every year.

The detrital peat and overlying mud at 635-638 in core E shows that some water was already ponded on the marsh well before the sand. Lithologically the mud above and below the sand is identical in core E, and has much less organics than younger, typical gcls. Thus, the DE17 gcl is only a "gcl" on the basis of its position between the sand and the mlgc, not on the basis of any lithologic (smear slide) characteristics. Furthermore, there was no deep lake with steep sides from which to derive the "gcl" just above the sand, as there was for most of the rest of the DEs. Thus, I don't consider the "gcl" to be a "true" (genetic) gcl.

A small storm or the wind could have thrown up enough of a bar to partly block the stream valley and form ponds or an initial lake behind the bar. Then a bigger storm could have spread some sand into the ponds and that or a later storm could have built a higher berm that completely blocked the valley. A later storm that built an even higher berm would help explain why brackish diatoms occur at 632, but not higher in the core. Occasional high tides or storm surges might have topped the initial berm formed at the same time as the sand, and this would allow occasional influxes of brackish water. The later storm could have built a higher bar that kept out the sea completely (as RSL gradually fell) and deepened the lake. Below 632 I see nothing that requires any subsidence. The diatoms are particularly helpful in showing that freshwater ponds were not suddenly down-dropped into the intertidal zone, forming a lagoon, as would be expected if RSL was just below lake level.

The odd part about DE17 is the apparent mlgc above the non-gcl. The laminations suggest that at 632 the lake became rapidly much, much deeper, probably >5-7 m if some of our earlier reasoning applies to this DE. Although the laminations are too burrowed and oxidized to count, the thickness of the mlgc suggests at least 15-20 years of deposition. The brackish species in the mlgc suggest rare marine inundations (note sand laminae within basal mlgc in core F). Subsidence is not a reasonable explanation for making the lake a lot deeper (>5 m), although it could be part of the answer. How could the lake get so deep so fast and still be close enough to the sea for rare storm surges to enter the lake? Perhaps there is a disconformity at 632. Or maybe RSL was lower than I am suggesting and the brackish diatoms in the mlgc record the odd tsunami that did not spread sand into the lake?

To summarize, I would argue that DE17 cannot be that similar to many of the younger DEs because the geomorphology of the site was different, at least at the time that the sand was deposited. Neither subsidence nor tsunamis are required to explain the sand and "gcl", but they might be helpful (but not adequate) in explaining the mlgc.

On 11 Feb 98 Eileen said: Bradley Lake started off as a freshwater marsh, which we know from the peaty mud and diatoms at the base of core 94E. There could have been standing water, but it wouldn't have been consistently deep enough to support planktonic diatom populations, nor exclude vascular plants from the lake bottom. What is this change in depth? We can estimate from the modern lake. I don't remember exactly, but the vascular plants seem to grow in maybe a half meter of water, perhaps a bit more (Might have to take a drive over to the lake to check this out). But for the sake of argument, lets say the maximum water depth at site E prior to DE-17 was 0.5 m. Doesn't the fact that there was already an extensive FW marsh at the BL site, and not just a stream following its bed, imply that there was already some kind of barrier impounding water at this locality? Then let's say there's at least 0.5 m of subsidence. Wouldn't that help to deepen the lake beyond the range of vascular plants, and also push an existing sand barrier further landward?

On 12 Feb Harvey said: Similar to Alan, I am vexed by how the lake got so deep so fast in order to preserve the mlgc at 630.5-632. I am especially interested in the explanation for rapid deepening because prior to DE17, site E must have been close to the beach (elevationally and distance from the beach) so that a marine incursion of some form could bring in sand with marine diatoms (and if the mechanism is storm, then we are talking of a setting similar to Euchre Creek in terms of ocean proximity). My assumption is that the physical mechanism for why the lake got deep fast was first, the stream outlet was dammed by sand, and second the sand barrier then built up quickly.

At the time of DE 17 time (ca. 6,000 14C years ago), global sea level studies tell us that there was a deceleration in the rate of post-glacial sea level rise. Globally, this affected coasts because relative sea level stability enabled barrier beaches to form that could not form when sea level was rising rapidly. Southern coastal Oregon was not immune from this global affect: the barrier built up and China Creek was dammed. A deceleration in the rate of global sea level rise probably contributed to the damming.

Against this background of changing coastal stability, great subduction zone earthquakes are happening every 600 years or so, subsiding the coast and generating tsunamis. So, while I wholeheartedly agree that we should interpret what happened at Bradley Lake from the Bradley Lake stratigraphy and biostratigraphy and not from general models, I think the background setting in the above two paragraphs is pertinent.

The way to get the lake deep quickly is to dam the creek outlet and/or drop the creek bottom down relative to sea level (causing relative sea level rise). Ground water levels will rise as sea level rises, so if you subside the bottom a meter or two deeper, the marsh (or lake) becomes a meter or two deeper.

One way to drop the lake bottom down relative to sea level is subsidence. Is subsidence a viable interpretation from the data for getting the marsh to be 1-2 m deeper overnight and thus start the chain of events that turned the marsh into a deep, freshwater lake? Eileen said in her initial email that, ""DE17 represents an inundation event into a freshwater environment rather than deposition in an estuarine environment". While this statement is not the same as saying there was subsidence, it does not negate it. Also, the diatom evidence is consistent with the lake getting deeper just above the DE17 sand (is it not?). We do not need to document that a brackish marine or estuarine environment overlies the freshwater marsh in order to call on subsidence. The site getting more deeply inundated is also consistent with subsidence. Indeed, that's the interpretation we invoke at the Sixes estuary ca. 300 years ago to explain the diatom biostratigraphy. There was tsunami and subsidence but the diatoms record a freshwater environment throughout, with the environment wetter (deeper) after the subsidence event.

As far as mechanisms for how to quickly get the barrier dune higher so that the dam is higher: I have a hypothesis (albeit it difficult to test): if subsidence triggered formation/deepening of the lake, and the dunes were beginning to build up independently of the subsidence (because of deceleration of sea level rise), then maybe the subsidence was a trigger for rapid increase in lake depth. The subsidence caused the closing off of a China Creek (which barely had the stream power to continue to erode through the dunes in any case) and once the creek was closed, the dunes quickly filled in the stream valley that had been cut in the dunes to a depth of ca. 4 (?) m. The filling in of the steam valley with wind blown sand effectively built up a substantial barrier (4-6 m high?) in a matter of years to less than a decade.

The above scenario would leave open whether the DE sand was deposited by tsunami or storm.

On 3 June 99 Alan said: The following comment on the above applies to some other DEs as well. I have no problem with subsidence occurring during most of the DEs at BL, but I don't feel that there is any stratigraphic or fossil evidence from BL itself that requires subsidence. For the BL papers I would prefer to see us discuss first what we can and cannot conclude directly from the evidence at BL. In a later section of various papers we can bring in published evidence from elsewhere that bears directly on distinguishing among the alternative explanations developed for evidence at BL. Documented subsidence at the Sixes (assuming its published) would certainly qualify. Evidence from marshes in northern Oregon and elsewhere might not because it has never been clear whether or not the southern Oregon coast responds to great earthquakes in the same way as coasts in some other parts of the subduction zone (determining this is the point of our study, not the other way around).

My main question about coseismic subsidence at BL causing major stratigraphic changes involves the scale of subsidence. From Rob's thesis I get the impression that coseismic relative sea-level rises were about 0.5-1.0 m. But I don't think that a 0.5-1-m rise would

be the primary factor in causing most of the changes that we make much of in our DE interpretations, especially changes from non-laminated to very well laminated sediment and increases in BHC diatoms. Wouldn't a series of wet winters, dune slumps, or changes in dune morphology near the outlet due to wind, storms, or tsunamis be much more likely to cause a meter of lake level rise than subsidence? I'm not saying that subsidence couldn't have contributed a little, but I don't see how it could be the primary factor or even the trigger for most such changes, which think may reflect meters of lake level change.

The 15-25-cm section between DEs 16 and 17 is massive to very faintly laminated with 1-2 distinctive gls and only one correlation point. All parts of the section show evidence of extensive burrowing and few laminae are preserved.

Marsh peat (E640+)

The 55-95 cm of peaty mud beneath DE17 in cores E, X, and F is freshwater marsh sediment (confirmed by diatom analysis), deposited along the former stream occupying the Bradley Lake valley. Many discontinuous lens of peat and muddy peat occur irregularly throughout the section of mostly peaty mud. Smear slides of this material differ from normal lake sediment and some gcls only in having somewhat less decomposed plant fragments and more silt, and in some cases a few percent sand. The upper part of the section, only 2 cm in core E but 20 cm in cores X and F, is siltier (2 smear slides) with less peat and is lighter in color than the lower 2/3 of the section. The gray color, particularly in core X, is probably due to an influx of silt and clay during a period of more seasonal floods, like those that produced distinctive gls later in the valley's history. A smear slide at the top of the peat in core X has <5% very fine to medium sand. The 10 cm of sand at the top of the deepest segment of core F is sluff pushed into the corer from higher in the section.

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