INTERPRETATION OF LAKE HISTORY BASED ON DIATOMS AND POLLEN FROM SEDIMENT CORES, MOUNTAIN LAKE, VIRGINIA

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Figure 1. Mountain Lake, Giles County Virginia--Coring Device in Use on Lake-bottom.

INTRODUCTION

Mountain Lake is located near the summit of Salt Pond Mountain (elevation 1177 m / 3860 feet), Giles County, Virginia, in the ridge and valley province of the southern Appalachians (37° 27' 56" N, 80° 31' 39" W). Although small, Mountain Lake is the only natural lake in the unglaciated highlands of the southern Appalachians. Mountain Lake has a maximum depth of 33 m at the north end of the lake; this deep portion consists only of a narrow crack or crevice feature in the bottom of the lake. Most of the deep end of the lake is approximately 24 m deep, shallowing to the south.

Since the 1930s, numerous workers have considered the origin, geology, phytoplankton community, and physical limnology of Mountain Lake. (e.g., Hutchinson and Pickford 1932, Marland 1967, Obeng-Asamoa and Parker 1972, Parker et al. 1975, Dubay and Simmons 1981, Parson and Parker 1989a,b, Beaty and Parker 1994). Deevey, in 1957, produced the first bathymetric map of the lake, using lake soundings and (War Department) aerial photographs (Deevey et al. unpublished 1957; Beaty and Parker 1994). This lake bathymetry has been updated using Sonar by the authors in 1997-1998, and the lake origin is now recognized as related to a regional fracture feature (Cawley et al. in press a). Historical records suggest that the size of the lake has varied periodically through time.

In 1997-1998 the authors undertook a re-evaluation of the water quality, lake history and origins (Cawley et al. in press a, b), and the extant and historical diatom and pollen taxa of Mountain Lake. Sediment coring of Mountain Lake has proved important for interpretation and analysis of the lake's paleoenvironments. Because of the undisturbed nature of the sediments, the lack of permanent stream inputs, and the very low sedimentation rates (presently estimated at about 1mm/yr), Mountain Lake affords a good, albeit challenging subject for coring.

This study examines the diatom, pollen and sedimentary content of ^{14}C dated cores from the deepest portion of Mountain Lake. Water depth and changes in the lake through the past 6100 years are documented, as evidenced by changes in diatom and pollen content, sedimentary erosion features, and the presence of wood fragments, plant fiber, and *Sphagnum* spores. Diatom thanatocommunity contents are identified for selected time periods.

METHODOLOGY

Our recovery included 7 complete cores from the lake. Sediment cores were taken from a transect near the north-south center-line of the lake (Figure 2). Of these, results from the three best deep cores (D, F, and G) are presented here. Frozen cores from the lake were described and correlated; the correlation strategies of Anderson (1986) were used where applicable.

Figure 2. Sonar Bathymetric Map of Mountain Lake in 1997 Showing Core Locations.

Subsamples for diatom and palynomorph extraction consisted of 10 g of lake sediment, selected at intervals of 3-5 cm. The spacing of the subsamples depended on the physical features of the material. Diatoms were oxidized from each sample with hydrogen peroxide (3% H_2O_2) followed by hypochlorite bleach (5.25% NaClO). Maceration methodology for palynomorphs included 1) removal of carbonates by concentrated hydrochloric acid, 2) removal of silicates by concentrated hydrofluoric acid, 3) oxidation by sodium hypochlorite bleach, and 4) acetolation with acetic anhydride. Statistical relative counts of pollen were made via video microscope. Again, counts of 300 were made until consistency of sample contents was verified, after which subsequent counts of 100 were made, with blind recounts.

Two samples for ^{14}C were taken from organic-rich layers in core (G) at 27 and 45 cm. One ^{14}C sample was taken from an organic-rich layer near the bottom of core D, at 45 cm.

Figure 3. Mountain Lake Sediment Cores.

RESULTS

Older diatoms and pollen within shallower lake cores (A, B, and C) were found to be in poor condition . This was not unexpected; these materials have been exposed to repeated subareal exposure during low lake levels. In contrast, preservation of both diatoms and pollen from the deeper cores was generally good. Broken and abraded materials in the deep cores coincided with past periods of low water levels, and periods of subareal exposure. Resolution of sediment structures was excellent in cores D, F, and G. (Core E, which was taken from a sloping portion of the lake bottom, showed evidences of turbidity flow.)

Core F correlates directly to core D (Fig 4-5). Core D was collected from a shallower region of the lake bottom than core F, and shows consistently shallower sedimentary and diatom thanatocommunity structure. ^{14}C dates establish sediment at 45 cm in core D at 1860 $\pm$ 100 bp. The top 15 cm of core G also correlates with D and F. Below 15 cm, however, time and sediment is missing. This is likely due to its location near the lake bottom outflow in the deepest portion of the lake (see Cawley et al. in review b). Older material however, is preserved in core G below this sediment unconformity. ^{14}C dating at 27 cm in core G results in a date of 4220 $\pm$ 50 bp, while the core bottom dates at 6160 $\pm$70 years bp.

Diatoms, pollen, and erosional features in these cores suggest at least 6 extended periods when Mountain Lake has been dry or small in size. These periods occurred at approximately 100, 400, 900, 1200, 1800 and 4100 years bp. The lake shows progressive (albeit slow) eutrophication through time, as well as anthropogenic impacts during the 20th Century.

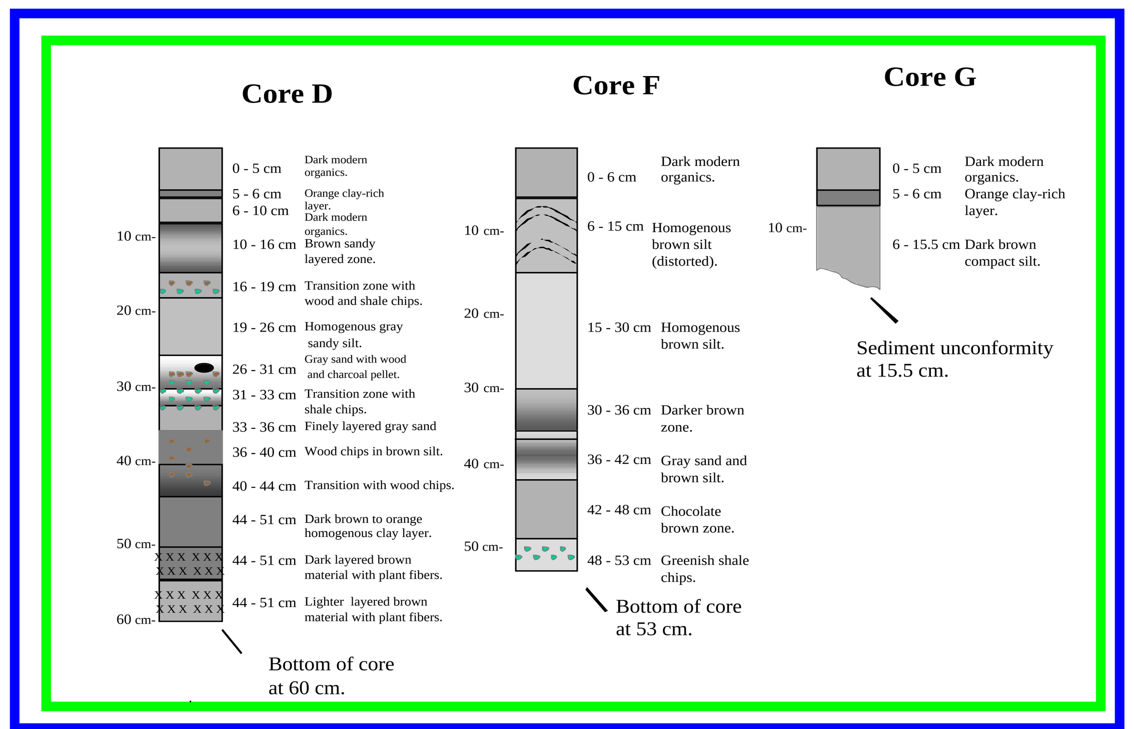

Figure 4. Stratigraphic Column of Sediment Cores D, F, and the top portion of G, Mountain Lake, Virginia.

DISCUSSION

0 to 1800 yrs bp: We have identified 66 taxa of diatoms presently in the lake representing 25 genera. These flora reflect the circumneutral pH and relatively low (oligotrophic to meso-oligotrophic) nutrient conditions of modern Mountain Lake. In the deep portions of the present lake, the planktonic to littoral ratio of diatoms is greater than 10.0 (specifically 12.0 and 15.0 in regions near our core samples.) The present deep-water flora of the lake is dominated by *Stephanodiscus alpinus*, *Cyclotella stellegera*, *Tabellaria fenestrata*, *Nitzschia sinuata* and *Fragilaria* species, together with species of *Eunotia*, *Anomoeneis*, *Navicula*, *Amphora*, *Cymbella*, and *Pinnularia*.

Two of our three cores exhibited a well-defined red-orange inorganic silty layer at 5 to 7 cm depth. This layer had thicker consistency than sediments above and below. We suggest that this inorganic-rich layer represents erosion into the lake at the time the Mountain Lake Hotel and the road skirting the lake were constructed in the early 1930s. At estimates 1 mm/year of sedimentation, an age of approximately 50-70 years bp appears reasonable. This estimate is also supported by the qualitative observation that somewhat more *Castanea* (American chestnut) pollen occurs

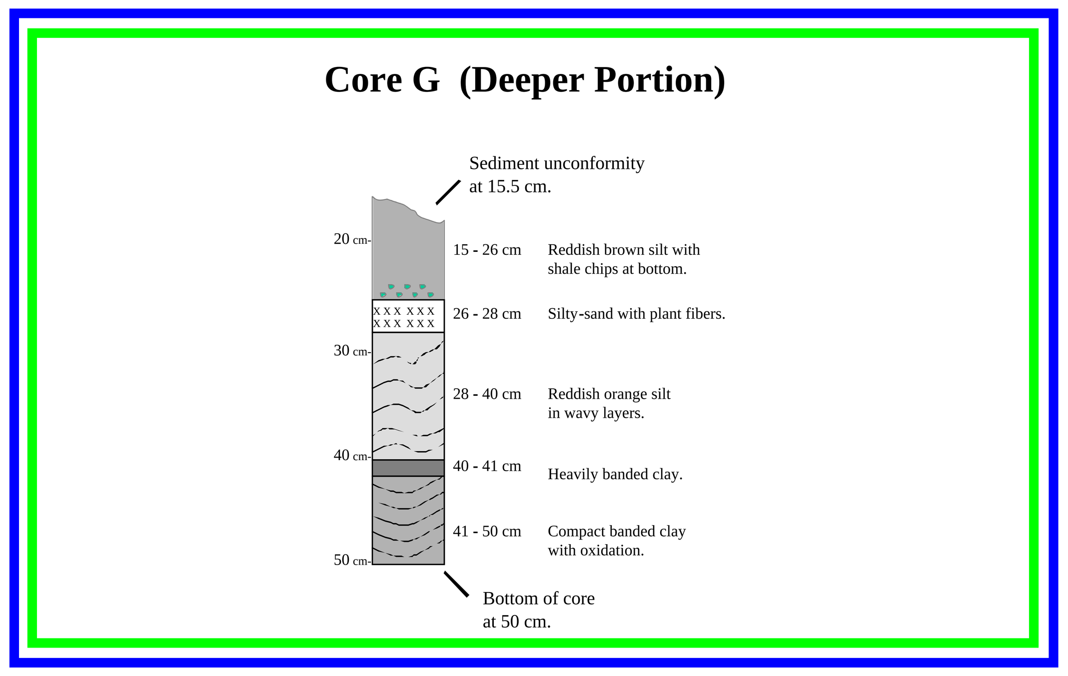

Figure 5. Stratigraphic Column of Lower Portion of Sediment Core G, Mountain Lake, Virginia.

below this layer than above it. The American chestnut blight swept through the southern Appalachians in the 1930s, bringing with it a functional demise of the chestnut forests.

Diatoms at this 5 cm level closely resemble the modern flora, although the density and diversity of diatoms appears generally less. The planktonic to littoral ratio is less than at present; at no time in the past did we see a ratio as high as the ratio of 10 to 15. Tappan (1980) suggested that, if water depth is held constant, an increase in the ratio of centric to pennate diatoms indicates increased eutrophication. We suggest, in light of meso-eutrophic symptomology in the lake (Beaty & Parker 1994), that Mountain Lake has eutrophically "aged" significantly in the 20th Century, primarily due to human activity. We also note that *Stephanodiscus alpinus* is a recent addition to the lake flora, likely associated with eutrophication.

At 10 cm (100 yrs bp) in core F, we find a decrease in diatom density and diversity (at 10 species, down from 23 species in samples below). In addition, *Sphagnum* spores are present at 10 cm in core G. We suggest that the change in diatom community, as well as the presence of *Sphagnum* indicates a relatively short period when the lake was very low or dry. This time-period in the late 1800s corresponds to historical reports that the lake ("Salt Pond") was a small pond used for salting cattle, which then filled after a local earthquake toward the end of the 1890s (Hilda Roberts, pers. comm.). This event underscores the apparent structural role of the regional fault / fracture feature in the lake's periodic loss and reformation through time (Cawley et. al. in press b).

At 17 cm (approximately 400 years before present), we find wood particles and shale frag-

Figure 6. Representative Diatoms from Mountain Lake Sediment Cores.

ments associated with a period of lake-bottom erosion. The 20 cm portion contains virtually no diatoms of any sort. These data suggest an extended period of low water and subareal exposure, during which the area around the lake/pond was at least partially wooded. This interpretation is supported by historical record, as well as a well-preserved portion of yellow pine (*Pinus pungens*) recovered from growth position at a depth of 10 meters in the lake (Parker *et. al.*, 1975). ^{14}C dating of this wood produced an age of 1655 ±80 AD. Tree ring analysis revealed that the tree had grown for 30 years along the shore of a much smaller Mountain Lake. We now suggest that this extended low water period at Mountain Lake may correspond to a dry period co-incident with the Maunder Solar Minimum (Eddy 1977; Parker et al. 1982).

A more noticeable layer of shale fragments and wood particles occurs (primarily in core D) at 31 cm, or about 900 years bp. Here, diatoms are diverse (with 40 species present), suggesting relatively high lake productivity during this time. The planktonic to littoral ratio for core D is 1.2, suggesting shallow conditions. We also find Sphagnum spores at this level, suggesting that the lake was again fairly low or empty at this time, and was surrounded by a peat bog. We note that this time, about 1100 a.d., corresponds with yet another solar minimum, the Sporer Miniumum, when history suggests that agriculture failed in both Europe and the American southwest due to cold and dry conditions. *Sphagnum* continues to be present in the cores downward from 900 years bp to 42 cm, or approximately 1200 bp. At 1200 bp, we again see and erosion surface present in the core

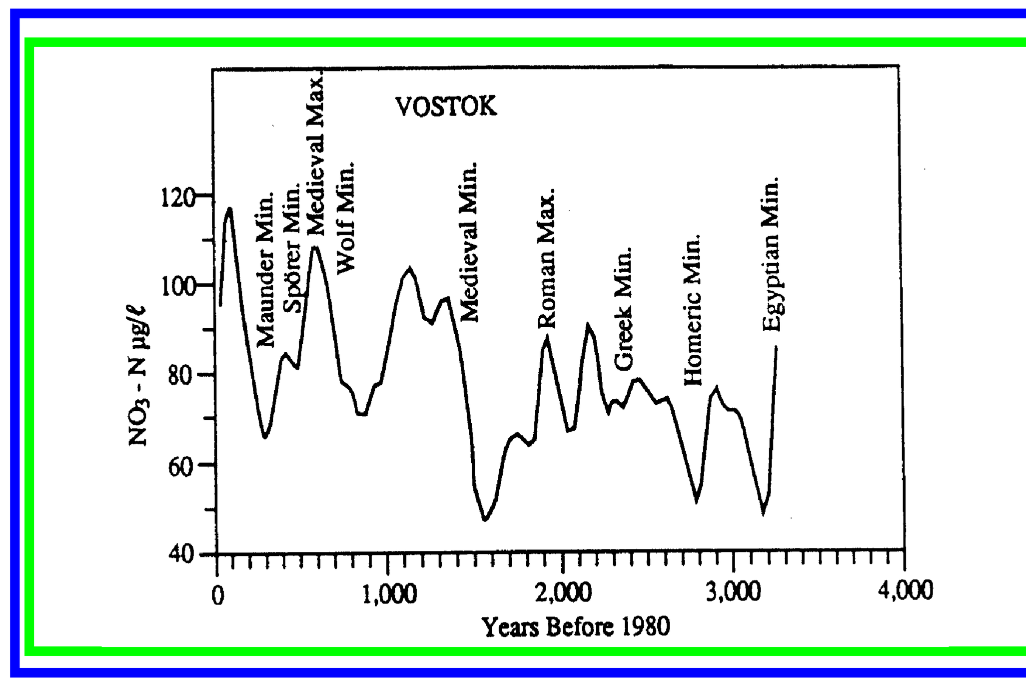

Figure 7. 20-year averages for Nitrate concentration in Vostock firn-ice core showing solar activity (minimum / maximum) events. (after Dreschhoff et al, 1993)

with shale chips, suggesting exposure. The planktonic to littoral diatom ratio, at 0.7 in core D, supports this interpretation.

The layer at 53 cm in core D consists of a mat of plant fiber, which corresponds to abundant *Sphagnum* spores in the samples. This layer produced a ^{14}C date of 1860 $\pm$ 100 years bp. Diatoms here include a reduced fauna , and we find approximately 20% of the *Tabellaria* and *Pinnularia* present to be aberrent morphologic forms. We suggest that these aberrent forms may be produced in acidified conditions of a bog. The ratio of planktonic to littoral diatoms, however, was between 3.4 and 6.6, suggesting that a period of deeper water had likely preceded the low water interval and bog formation.

1800 to 6100 yrs bp (core G): A sediment unconformity occurs in core G at approximately 15 cm depth. The underlying 35 cm of core G predates either core D or F. Less organic material is apparent in this older interval. There is only one prolonged low water event specifically discernible within this section. It seems likely, however, that the periodic short term filling and emptying of Mountain Lake was occurring throughout the interval. At 27 cm in G, a plant fiber layer provided a ^{14}C date of 4220 $\pm$ 50 yrs bp. Diatom flora at this level is reduced; five species are present, being fragmentary remains of few large individuals that may be *Cymatopleura* or *Surirella*. These forms may be mud- or soil-dwellers, and may represent a mud-surface thanatocommunity. *Sphagnum* spores are present although wood particles are lacking, suggesting a less-wooded situation around the lake. At 25 cm, trilete (fern and/or moss) spores are abundant, suggesting an open fern meadow. Pollen counts contain abundant grass pollen, as well as occasional hemlock.

Amphora ovalis var. affinis (Kutz) V. H. ex DeT.
Caloneis ventricosa (Ehr.) Meist. var. ventricosa
Cyclotella meneghiniana Kutz.
Cymatopleura elliptica (Breb) W. Sm.
Cymbella lunata W. Sm var. lunata
Eunotia flexuosa Breb. Ex Kutz. var. flexuosa
Eunotia pectinalis var. minor (Kutz.) Rabh.
Fragilaria brevistriata var. inflata (Pant.) Hust.
Fragilaria contruens var. pumila Grun.
Fragilaria pinnata Ehr. var. pinnata
Fragilaria pinnata var. lancettula (Schum.) Hust.
Gomphonema angustatum (Kutz.) Rabh. var. angustatum
Gomphonema parvulum (Kutz.) var. parvulum
Gomphonema truncatum var. capitatum (Ehr.) Patr.
Gomphonema truncatum var. turgidum (Ehr.) Patr.
Navicula integra (W. Sm.) Ralfs. Var. integra
Navicula mutica Kutz. var. mutica
Navicula pupula var. capitata Skr. & Meyer
Navicula scutiformis Grun. ex A.S. var. scutiformis
Nitzschia linearis (Ag.) W. Sm.
Pinnularia abaujensis (Pant.) Ross var. abaujensis
Pinnularia acuminata var. instabilis (A.S.) Patr.
Pinnularia appendiculata (Ag.) Cl. var. appendiculata
Pinnularia formica (Her.) Patr.
Pinnularia maior (Kutz.) Rabh. var. maior
Pinnularia mesogongyla Ehr. var. mesogongyla
Pinnularia nodosa (Ehr.) W. Sm. var. nodosa
Pinnularia parvula (Ralfs) Cl.-Eul. var. parvula
Pinnularia subcapitata var. paucistriata (Grun.) Cl.
Pinnularia substomatophora Hust. var. substomatophora
Pinnularia viridis (Nitz.) Ehr. var. viridis
Synedra rumpens Kutz. var. rumpens
Tabellaria fenestrata (Lyng.) Kutz. var. fenestrata
Tabellaria quadrisepta Knuds. var. quadrisepta

Figure 8. Diatom Taxa List for Mountain Lake at 6160 ±70 years bp.

At 37 cm in core G, approximately 10 diatom species occur. The planktonic to littoral ratio is 1.8, suggesting shallow waters, and some diatoms are abraded. The thanatocommunity at this level is sparse, with low population density, including *Fragilaria* species, a few *C. kutzingiana*, and occasional *Pinnularia*.Core G below 37 cm consists primarily of finely-banded silty clays.

At 45 cm the bottom clay of the core carbon dates at 6160$\pm$ 70 yrs bp. The interval below 40cm contains a thanatocommunity dominated by *Tabellaria*, including ridged forms of *fenestrata*, as well as *quadrisepta* not seen elsewhere. At 45 cm, the thanato-community contains *C. meneghiana*, the only samples in our study where this species was found. At 45cm the diversity is high, with 21 species; this thanatocommunity does not resemble a pioneering community early in the lake's history. Rather, it appears that by 6100 years bp, Mountain Lake was long established, with productive rather than "hungry" waters. The planktonic to littoral diatom ratio suggests deep and open waters. Pine, hemlock, hardwood and grass pollen suggest that local flora were not significantly different than at present. The deepest samples of G contain occasional grains of hemlock and spruce pollen (compared with extant red spruce pollen from the Spruce Bog), suggesting that, although hemlock was present in the local flora by 6100 years ago, spruce had not yet entirely vanished from around the lake.

CONCLUSIONS

1) The clay / inorganic silt layer at 5 to 6 cm in the lake core reflects human-related sediment from the building of the present hotel and the cutting of 2 roads around the lake in the early 1930s. This is supported qualitatively by a drop in chestnut pollen above this layer.

2) The core record shows Mountain Lake to be aging via eutrophication. Early sediments show few organics and small rates of sedimentation. More recent sediments contain, more organic materials and more diverse diatom thanatocommunities. This eutrophication has accelerated in the past 100 years.

3) A drop in diatom diversity at 10 cm corresponds to the late 1800s when the lake was temporarily low ("Salt Pond") during which the surrounding unforested meadow was used as pasture. This low period is supported by the historical record.

4) Mountain Lake was low or dry for at least 30 years in the mid 1600s. The lake was also low or empty for more extended periods at about 900, 1200, and 1800 years bp. The lake basin tended to develop a peat bog during these periods. Some low water periods may correspond to dry periods associated with solar minima.

5) Low water and a peat bog and fern meadow situation was present in the lake basin at 4200 years bp. Diatoms at this time likely represent mud- or soil-colonizing forms.

6) Layered clays and silts in oldest portions of the core probably represent smaller scale lake water level changes.

7) At 6100 years bp, deep, open waters occurred in Mountain Lake; diatoms were already diverse, productive, and well-established. The lake at that time was surrounded by terrestrial flora not greatly different from the modern, although red spruce and hemlock coexisted around the lake.

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