The laminated sediments of Crawford Lake, southern Ontario, Canada

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1. CRAWFORD LAKE VARVES

Crawford Lake (43°28.1'N, 79°56.9'W) is situated in Silurian Guelph-Amabel dolomite, one kilometer west of the Niagara Escarpment and 65 kilometers southwest of Toronto (Fig. 1). The lake probably originated as a cavern formed in the dolomite bedrock (Fig. 2). Crawford Lake has an area of 2.5 ha, a maximum depth of 24 m and a sediment thickness of at least 4.5 m (Fig. 2 , 3).

Testing of the deep water sediment in 1970 showed it to be banded with alternating light and dark laminae (Fig. 4,5). Each light lamina is followed gradually by the overlying dark lamina, but the latter formed a sharp boundary with the overlying light lamina. This repetition indicates that the lower light layer and overlying dark layer are related and form a "couplet". A light carbonate-rich layer was observed at the sediment-water interface in summer (June) and a dark organic-rich lamina overlay it the following winter (March, Fig. 5). This indicates that a complete couplet is probably deposited each year.

The geological setting, limnological features and characteristics of the couplets are similar in Fayetteville Green Lake, New York (Ludlam 1969) and Crawford Lake. Since the Fayetteville Green Lake couplets are known to be true varves the argument that the Crawford Lake couplets are annual is probably correct.

2. CARBONATE-ORGANIC VARVE FORMATION

The couplets in Crawford Lake are identical to those described from the deep water sediment of Fayetteville Green Lake (Ludlam 1969). Both lakes are meromictic. The water in the deep basin is stratified permanently. Incomplete mixing preserves a lower, more dense layer (monimolimnion) below a circulating or mixing layer (mixolimnion). The density gradient between these layers is the chemocline which contains a characteristic dense bacterial plate. Laminated sediments in both lakes were collected only from that part of the basin below the chemocline. The constantly cold and quiet anoxic water of the monimolimnion permits undisturbed accumulation of seasonally deposited sediments. Meromixis insures against mixing of the sediment by bottom feeding fauna and spring and fall turnover (Davis 1967; Davis 1968). The deposition is uniform and simultaneous, as indicated by the lateral continuity of "marker" bands (Ludlam 1969).

Annual deposition provides an explanation for the abundance of calcite in the light laminae and its paucity in the dark laminae. According to Brunskill (1969) the seasonal input of calcite, regulated by temperature, is the variable responsible for couplet formation in Fayetteville Green Lake. In May or early June, calcite crystals reach the sediment, initiating couplet formation. This sudden calcite precipitation would explain the

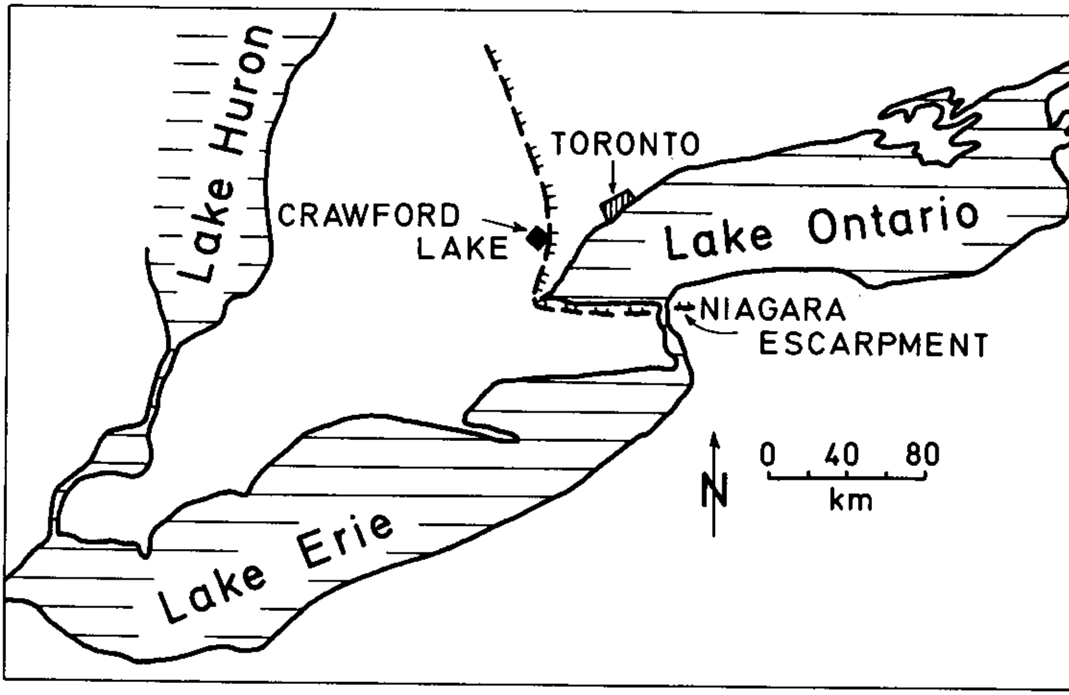

Figure 1. Schematic map of southern Ontario with location of Crawford Lake

sharp contact with the underlying dark lamina in Crawford Lake. Calcite rich materials are deposited until midsummer when the rate of calcite supply decreases slowly in relation to the organic matter and clastic material that are deposited throughout the year. This could explain the gradual contact between a pale lamina and its overlying dark lamina.

In Fayetteville Green Lake photosynthesis played only a secondary role in couplet formation (Brunskill 1969), and after Ludlam (personal communication) photosynthesis is not responsible for varve formation. This is not necessarily true in Crawford Lake. Tippett (1964), who has worked with varved sediments from McKay Lake and Little Round Lake in eastern Ontario, felt that biological agents such as Chara and phytoplankton were the principle cause of calcite precipitation. The role of photosynthesis in calcite precipitation should be examined more closely in Crawford Lake.

There is one major difference between the sediments of Crawford Lake and Fayetteville Green Lake. In the latter lake, there is a marked frequency of "massive" layers between sections of laminated sediment. These are attributed to turbidity currents and slope of the basin (Ludlam 1969). They are rare or absent in Crawford Lake.

3. VARVE-DATED POLLEN RECORD

Direct observations and analogies to known varved sediments indicate that the sequential couplets in Crawford Lake each represent one year's accumulation of sediment. The annual pollen rain is locked into the couplets which provide an absolute chronology.

The layered sediments from Crawford Lake were collected by freezing the sediments in situ with a frigid finger sampler (Swain 1973). The frozen sediment was embedded in Carbowax 1540 and 200 couplets were counted backwards from the sediment-water interface of 1971 (Fig. 4,5). A comparative study was made of this 200 year interval using the pollen record of the sediment and the hi-

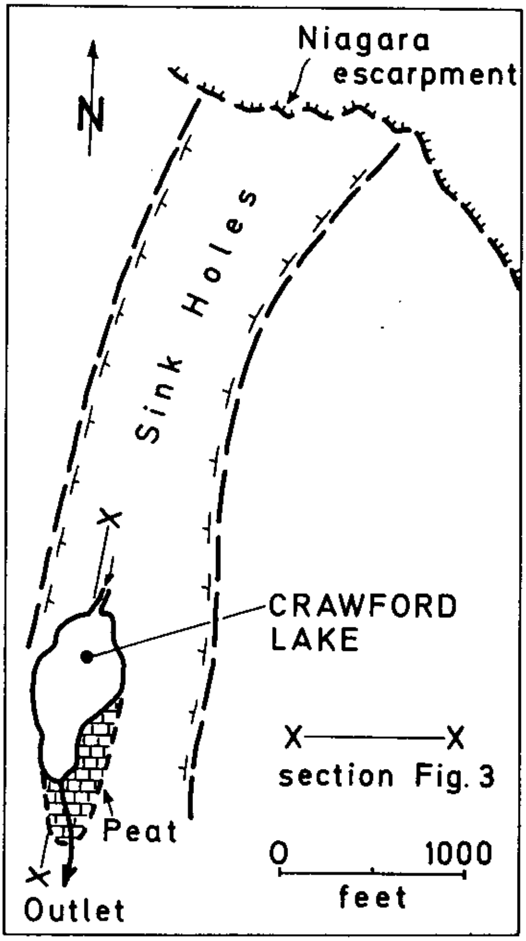

Figure 2. Crawford Lake - situated in a sinkhole area close to the Niagara Escarpment

story of European settlement derived from land patent records and written records of forest clearance (Boyko 1973). Pollen analyses were performed by two individuals (author and J.H. McAndrews) each working separately on alternate five-couplet segments and independently of the historical records. The latter records complemented or aided in explaining the interpretation derived from the varve dated pollen record.

It is generally accepted that European weeds accompanied the spread of settlement from the western shores of Lake Ontario northward at the beginning of the nineteenth century. One of these weeds, Rumex acetosella (sorrel) appears in the Crawford Lake sediment in the early 1820's. Settlement started in the 1790's. The approximate 30 year difference is explained by the type of settlement practices, that is, land grants with absentee landlords as opposed to actual settlement, and by the rate of spread of sorrel. Sorrel was possibly introduced as a crop seed contaminant, as were many other introduced weeds, and spread as fields were cleared.

The distinct rise of native Ambrosia (ragweed) and its subsequent increase is identified in all recent sediments in the lower Great Lakes region and it is attributed to European settlement. The Ambrosia rise has never been dated. At Crawford Lake it begins in the mid-nineteenth century (1846-1851).

In southern Ontario the distribution of native ragweed depends largely on soil disturbance. The appearance of Ambrosia after Rumex acetosella in the pollen record suggests that the latter weed had a greater chance of success in the initially cleared fields, probably because it was sown with the crop. Native Ambrosia had to spread from its sparse, naturally disturbed habitats such as river banks and bluff slopes. Historical records indicate that about 35-40 % of the surrounding study area of 3885 sq km was cleared of forest when Ambrosia began to appear consistently in the pollen record.

A sharp decline in total pollen influx after 1871 corresponds to near maximum forest clearance in the surrounding area. The woody plants provided the majority of the pollen rain (over 90 %) before European settlement and once these were removed the succeeding herbs, including crops and weeds, were poorer pollen producers, mainly because the majority of them are insect-pollinated and/or they reproduce vegetatively.

After World War II there was a general movement of people from the farms to the cities. Consequently the area of farmland was reduced and in the pollen record this shift is evidenced by an increase in woody plant pollen from the early 1950's.

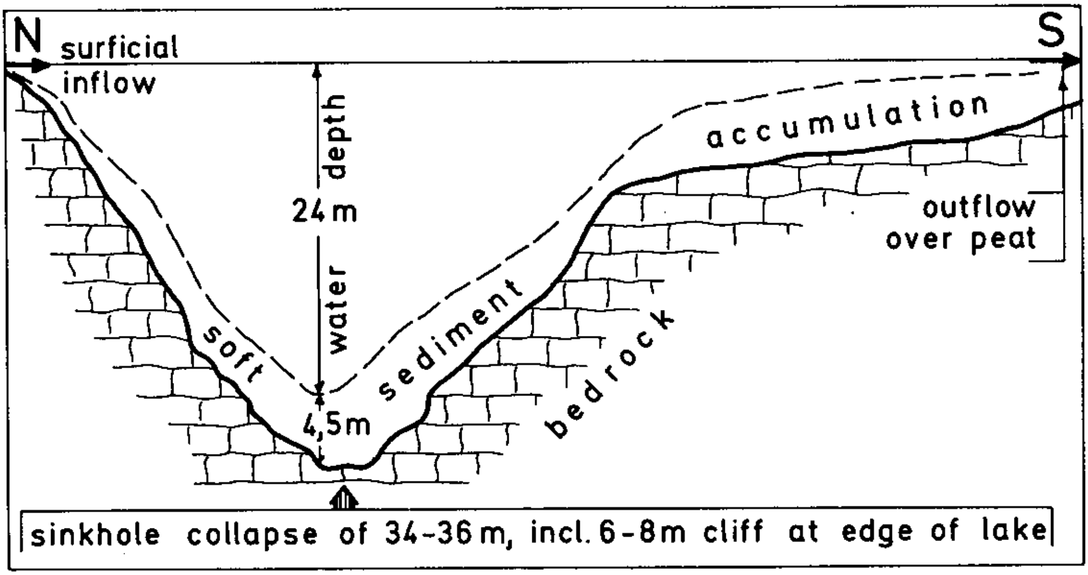

Figure 3. Crawford Lake - longitudinal section and bathymetry

The increase is caused by succession of shrubs and trees which replaced the herbs of the abandoned fields.

4. DISCUSSION AND CONCLUSIONS

The Crawford Lake sediments are laminated. Each couplet of a dark and underlying pale lamina appears to be an annual deposit similar to the varves of Fayetteville Green Lake. Since both these lakes are meromictic a brief search was made for potentially meromictic lakes. Three features were used to identify these lakes:

1. Great water depth compared to surface area.
2. Wind protection by steep slopes and forest cover of the slopes.
3. Oxygen concentration approaching zero with depth.

Two lakes, Found Lake and Greenleaf Lake, in Algonquin Park, Ontario, had these characteristics. Both had laminated sediments. Evidently there are more lakes with laminated sediments in Ontario than previously believed.

The varves of Crawford Lake were used to establish an absolute pollen chronology for the region extending 200 years into the past. Rumex acetosella pollen first appears in the early 1820's, about 30 years after settlement. A rise in native Ambrosia pollen began about 25 years later, between 1846 and 1851. Maximum forest clearance occurred after 1871 while the abandonment of farmland after World War II is clearly seen in a rise in woody plant pollen in the early 1950's.

Crawford Lake offers an excellent site for the study of deposition of varved lake sediments. The sediments offer an opportunity of paleoclimatological studies based on an absolute chronology.

5. ACKNOWLEDGEMENTS

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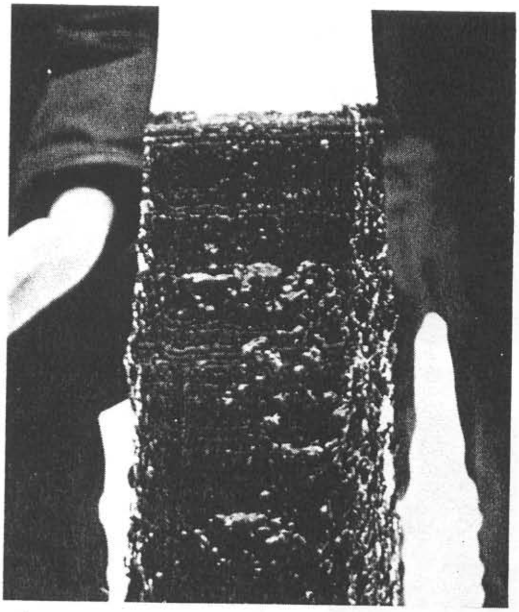

Figure 4. Frigid finger sampler illustrating water-sediment interface of Crawford Lake laminated sediments in March

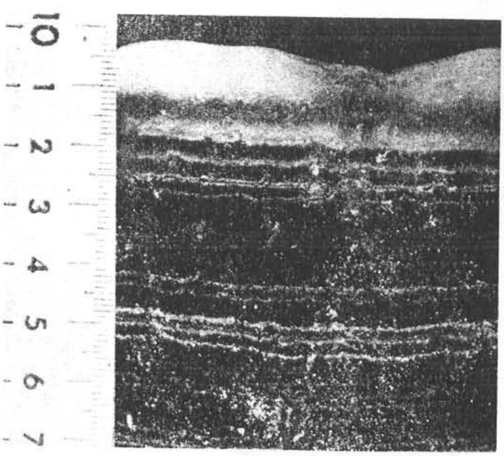

Figure 5. Crawford Lake laminated sediments, including water-sediment interface (dark winter lamina of 1971-72). Scale is in centimeters.

6. REFERENCES

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7. APPENDIX

The figures 1, 2 and 3 have been redrawn after handouts prepared by the author for ROM-members field-trip to Crawford Lake on May 3, 1972 (Ed.).