Palynology of Indian and European forest clearance and farming in lake sediment cores from Awenda Provincial Park, Ontario

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Palynologic analyses of four short cores collected along shallow- to deep-water transects in Second and Gignac lakes indicate two periods of forest clearance for farming. The first deforestation was by Huron Indians between A.D. 1450 and 1650, when a maple (*Acer*), beech (*Fagus*), and oak (*Quercus*) forest was cleared and corn (*Zea*) planted. This disturbance is identified by decreased tree pollen and increased *Pteridium*, *Artemisia*, and other herbs and is confirmed by *Zea* pollen in Gignac Lake. From 1650 to 1875 there was a forest succession to oak, birch (*Betula*), and pine (*Pinus*). Following this recovery European loggers and farmers cleared this forest and attempted farming. Besides a reduction in tree pollen, a product of this deforestation includes the pollen of weedy *Ambrosia*, *Gramineae*, and introduced European *Rumex* and *Plantago*. During the last 25 years an increase in tree pollen indicates local forest recovery consistent with present land use.

By relating upland vegetation successions to lacustrine algal assemblage changes, probable ecological controls on algae during the last 600 years are identified. *Peridinium willei* Huitfeldt-Kaas and *Pediastrum* respond to changes induced by forest clearance and agriculture. ***Aquadulcum awendae*** n. sp. and *Peridinium wisconsinense* Eddy prefer less alkaline water.

Variations in palynomorph influx are related to basin morphology and water circulation. Gignac Lake, a steep sided and relatively deep lake, directs palynomorphs from shallow marginal banks to the deeper basin, whereas Second Lake, with a gently sloping shallow lake bottom, preferentially accumulates palynomorphs close to shore.

Les analyses palynologiques de quatre carottes courtes prélevées le long de sections transversales de profondeur d'eau croissante dans les lacs Second et Gignac révèlent deux périodes de défrichement de la forêt en terres cultivalbles. Ce sont les Indiens de la tribu des Hurons qui furent les premiers à défricher la forêt entre A.D. 1450 et 1650, les érables (*Acer*), les hêtres (*Fagus*) et les chênes (*Quercus*) furent abattus pour faire place à la plantation du maïs (*Zea*). Ce changement est exprimé au lac Gignac par une diminution du pollen des arbres et une augmentation du pollen de *Pteridium*, *Artemisia* ainsi que de d'autres herbes, et et il est corroboré par le pollen de *Zea*. De 1650 à 1875 la forêt est réapparue selon une succession passant du chêne au bouleau (*Betula*) au pin (*Pinus*). Après cet épisode de reforestation, les bûcherons et les fermiers européens ont clairé la forêt et y ont instauré la culture. En plus d'une diminution du pollen des arbres, on observe les pollens caractéristiques de cette déforestation incluant la mauvaise herbe *Ambrosia*, les graminées et le *Rumex* et le *Plantago* introduits d'Europe. Durant les 25 dernières années il y a eu augmentation du pollen des arbres indiquant une reforestation locale reflétant l'utilisation actuelle des terres.

Une comparaison des successions végétales des terres élevées avec les changements des algues lacustres permet d'identifier les facteurs écologiques possibles qui ont affecté les algues durant les 600 dernières années. Le *Peridinium willei* Huitfeldt-Kaas et le *Pediastrum* répondent aux chagements imposés par la déforestation et l'agriculture. ***Aquadulcum awendae*** n. sp. et *Peridinium wisconsinense* Eddy préfèrent l'eau moins alcaline.

Les variations dans l'affluence des palynomorphes dépendent de la morphologie du bassin et de la circulation des eaux. Le lac Gignac est un lac à pentes abruptes et très profond, où les palynomorphes sont dirigés des bancs peu profonds de la marge vers le bassin plus profond, tandis que dans le lac Second, à pentes douces et peu profond, les palynomorphes sont accumulés préférentiellement près de la rive.

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Introduction

Awenda Provincial Park (Fig. 1) is a recently opened heritage park with a human history covering the last 10 000 years (O'Brien 1976). During most of this time Indians used the area for hunting and fishing, which had little impact on the natural environment. However, beginning about A.D. 1450 and ending in 1650, Huron farmers cleared the forest for villages and fields. Reforestation after 1650 preceded deforestation, farming, and industrialization by Europeans in southern Ontario during the last century. The impact of Europeans on lake sediments has been well documented (Kemp *et al.* 1972; Bormann *et al.* 1974; Davis 1976; Kemp and Thomas 1976; McAndrews 1976; Brugham 1978; Mathewes and D'Auria 1982). In contrast, there is little known of the impact of Indian farmers.

To obtain a detailed record of the environmental changes wrought by Indians and Europeans clearing and farming the same area, multiple cores from both Second and Gignac lakes (Fig. 1) were collected for sedimentology, geochemistry, and palynology analyses. In our study, historic and archeologic records of land use for more than 500 years are compared with the palynology of the upland and lacustrine environment.

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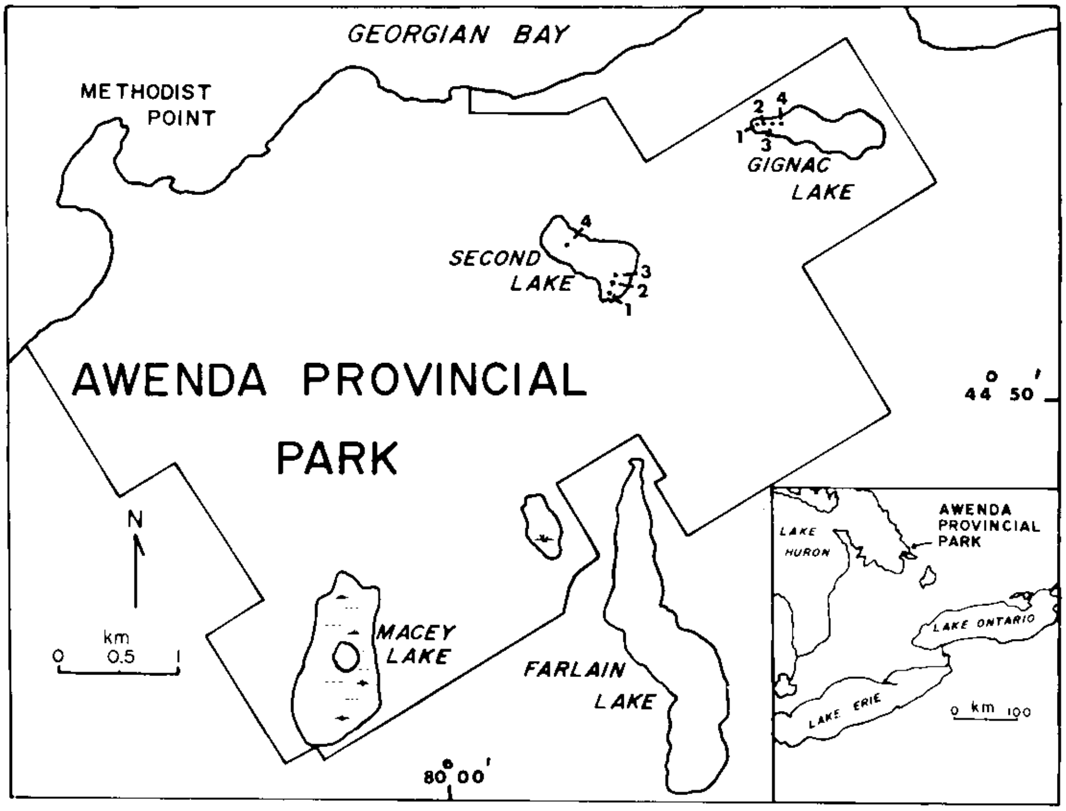

FIG. 1. Location map of Awenda Provincial Park showing coring sites in Second and Gignac lakes.

Historical background

Much of what is known about the Huron Indian culture comes from reports of the early explorers and missionaries who visited Huronia (Simcoe County) between 1615 and 1650. Archaeologists have shown that prior to European contact, Indian farmers first moved into the park area about 1450 (O'Brien 1976). These village people cleared forest and grew crops, but once soil nutrients were depleted and firewood became scarce, they moved to a new village site. Villages were occupied for 15–25 years (Heidenreich 1971). Three Indian villages lie within 1 km of Second Lake, and one village has been located at the western end of Gignac Lake.

Champlain in 1615 and Sagard in 1623 were the first Europeans to record observations of the Huron and their country. Both men described the landscape as cleared, with many open fields and meadows (Champlain, *in* Heidenreich 1971; Wrong 1939). Corn, the staple of the Huron diet, was planted along with beans and squash. After French contact, European diseases and intra-Indian warfare reduced the Huron population until 1650, when the New York Iroquois drove the Huron from their land.

After the Huron dispersal, formerly cultivated fields succeeded to forest. In 1820 the first British land surveys showed forest covering the area; during the intervening 170 years no clearings remained.

From 1866 to 1878 the land surrounding Second and Gignac lakes was patented by settlers or timber speculators (Anonymous). Selected logging of white pine and clearing for farms probably occurred, although such activity is not specifically documented. Farming seems to have been restricted to the level, dry land around Second Lake. A cabin on the northwest shore of the lake was burned sometime after 1903; on the northeast shore a second small farm was probably abandoned after 1953. The open fields have since been planted with pine trees.

Methods

Field methods

Four short cores were collected from each lake where the offshore slope was steep and where environmental changes related to agriculture should have been detectable, that is, near Indian villages and European farms.

At the south end of Second Lake (Fig. 1) three cores less than 1 m long were collected in a transect near an Indian village site. The core nearest the shore was taken away from visible surface disturbances caused by the nearby stream, small boats, and ice gouging. Core 4 was taken from a basin near the abandoned farms at the northern end of the lake. It provides a test of the continuity of facies and biostratigraphic zones across the lake.

The four short cores from Gignac Lake were collected along a transect beginning about 75 m from the western shore (Fig. 1). Core spacing was about 40 m. Core 4 came from a small, relatively deep basin; a steep slope separated cores 3 and 4. About 200 m west of the lake lies the site of a Huron village.

Two methods were used to collect cores. The first method used the freezing tube sampler (Swain 1973), a metal pipe filled with dry ice. Three cores, Gignac 1, 2, and 3, were collected with this device. The advantage of this method lies in the potential for recovering undisturbed stratigraphic sections. However, we found that the important surface sediments could not be adequately sampled because heat exchange between the lake water and core tube at the sediment–water interface prevented formation of a thick frozen rind. Furthermore, once removed from the pipe, the brittle and friable core rind fragmented with handling, and subsampling was more difficult than for soft-sediment cores.

A 7.6 cm diameter, stationary piston sampler with a clear plastic barrel was used to collect Gignac Lake core 4 and all Second Lake cores. The cores were either sampled in the field or in the laboratory.

The top 15–20 cm of cores from Second Lake was sampled in the field at 1 cm intervals. After each core was described (see Burden *et al.* 1986), the piston at the top of the core was removed and the core extruded from the top of the tube. Each centimetre of the upper loose sediment was collected in a plastic bag. Below 20 cm the sediments were firm enough to extrude as a unit. Gignac Lake core 4 sediment was fluid and was sampled in the laboratory at 1 cm intervals.

Laboratory methods

Unsampled core sections from Second Lake were scraped to remove surface contaminants, cut into 1 cm thick slices, and placed in plastic bags for storage at −30°C. Each frozen core from Gignac Lake was cut in half longitudinally; half the core was stored in a freezer and the other half was scraped and described. Samples were taken at 1 cm intervals by cutting slices from the core. After each slice was removed, the inner side of the core rind was scraped to remove distorted sediments produced when the pipe entered the mud. Clean samples were frozen until analysis.

For palynomorph analysis 1 mL samples of sediment were processed. Prior to chemical treatment, tablets containing a known number of *Lycopodium clavatum* spores were added to each sample so that fossil concentration could be calculated (Stockmarr 1971). Pollen, spores, and other palynomorphs were concentrated by digesting mineral and organic matter with successive washes in 10% HCl, hot 10% KOH, and hot acetolysis solution. Silicate minerals and diatom frustules were not abundant, and thus HF treatment was omitted. Palynomorph concentrates were mounted in silicone oil.

Pollen, spores, dinoflagellate cysts, *Pediastrum* coenobia, and introduced *Lycopodium* spores were identified and counted until a minimum of 300 tree and shrub pollen grains was recorded. Taxonomic procedure is described in Burden (1978).

Influx calculations are based on sedimentation rates that, in turn, are based on palynological–historical chronostratigraphic horizons (Fig. 2). Palynomorph influx was calculated from the number of *Lycopodium* spores added to volumetric samples.

Palynology

The palynomorph diagrams are grouped into sections containing woody plant pollen (mostly tree pollen), herb pollen and spores, algae, and total pollen and spores. Sediment lithology and stratigraphy are discussed in Burden *et al.* (1986).

Three regionally correlative pollen zones are present. For these short cores a chronology is established by correlating pollen zone boundaries with those of Crawford Lake 150 km to the south. There pollen zones are accurately dated with organic varves (Boyko 1973; McAndrews 1976; McAndrews and Boyko-Diakonow, in press). Local refinement of the sediment chronology in Second Lake and Gignac Lake is by correlation of local historic events and palynological horizons. Thus, sediment and palynomorph changes immediately above the base of zone 4 represent deforestation by Europeans about 1875. The decline of *Pteridium* spores and herb pollen associated with *Zea* in the lower part of pollen zone 3d corresponds to the early forest succession following the dispersal of the Hurons in 1650. Varve dates from Crawford Lake suggest that the zone 3c–3d boundary is about 1360, but this boundary cannot be as accurately dated in the park. From archaeological evidence the 3c–3d boundary probably represents a somewhat younger date, perhaps 1450, the probable date for the first village in the park (O'Brien 1976).

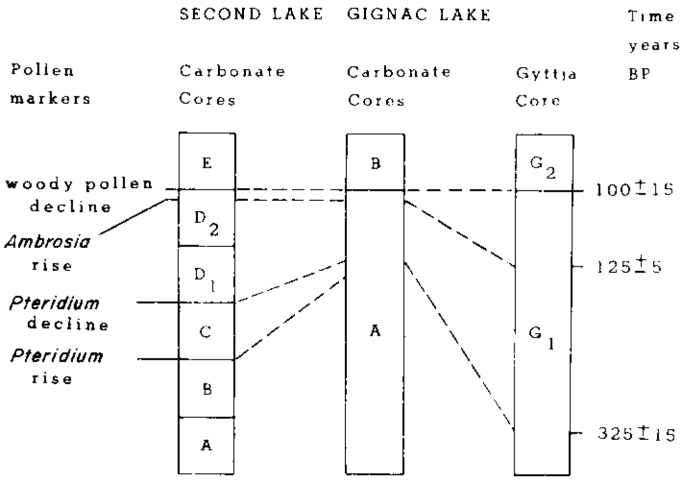

FIG. 2. Palynological horizons of historical events in Second Lake and Gignac Lake cores and their approximate age. Letters identify strata in each lake.

Second Lake

There are three pollen zones in the deeper water cores from Second Lake but only two pollen zones in the more rapidly deposited shallow-water cores (Fig. 3).

Zone 3c is best displayed in core 4; it is only represented in one level in core 3. This zone is dominated by *Fagus* (20–25%) and *Betula* (12–25%). *Tsuga*, *Acer*, and Cupressineae (probably *Thuja*) are each 8–12%. *Quercus* and *Pinus* contribute 5–10% each. *Pinus* is almost entirely that of *P. strobus*; a few grains of *P. banksiana* or *resinosa* were found. Pollen from other woody and herbaceous plants are present at less than 5% of the total. *Peridinium wisconsinense* represents 5–10%, whereas *P. willei* and *Pediastrum* sp. represent 1–5%. ***Aquadulcum awendae*** n. sp. (see Appendix) is absent from the calcareous muds at the top of pollen zone 3c, but below the calcareous muds it contributes less than 3%. Tree pollen constitutes more than 90% of the total pollen and spores in zone 3c; herb pollen constitutes less than 10%. Algae is 9–18% of the pollen sum but falls to less than 5% at the top of zone 3c.

Zone 3d is present in all four cores; however, only the deep-water cores 3 and 4 contain the entire zone. *Betula* (15–32%), *Quercus* (7–30%), and *Pinus* (10–25%) are higher in zone 3c. Cupressioneae, *Tsuga*, *Acer*, and *Fagus* represent 3–10%, a sharp decrease from zone 3c. *Ulmus* declines slightly, and *Populus* appears in low but consistent amounts.

In zone 3d there is a systematic trend in tree pollen abundances. *Quercus* increases first, followed by *Betula* and later *Pinus*. Peak abundances for *Pinus* extend into zone 4 in cores 1 and 2, but resolution in the more slowly sedimenting cores 3 and 4 is not sharp enough to enable the exact level of the *Pinus* peak to be determined.

Near the base of zone 3d, herb and spore taxa increase to more than 10%. Most of the herbaceous pollen is *Pteridium* (5–7%), although *Artemisia* and Gramineae are also important. *Salix* increases slightly in core 4, but this change is not obvious in all cores. At the C–D sediment boundary the weed

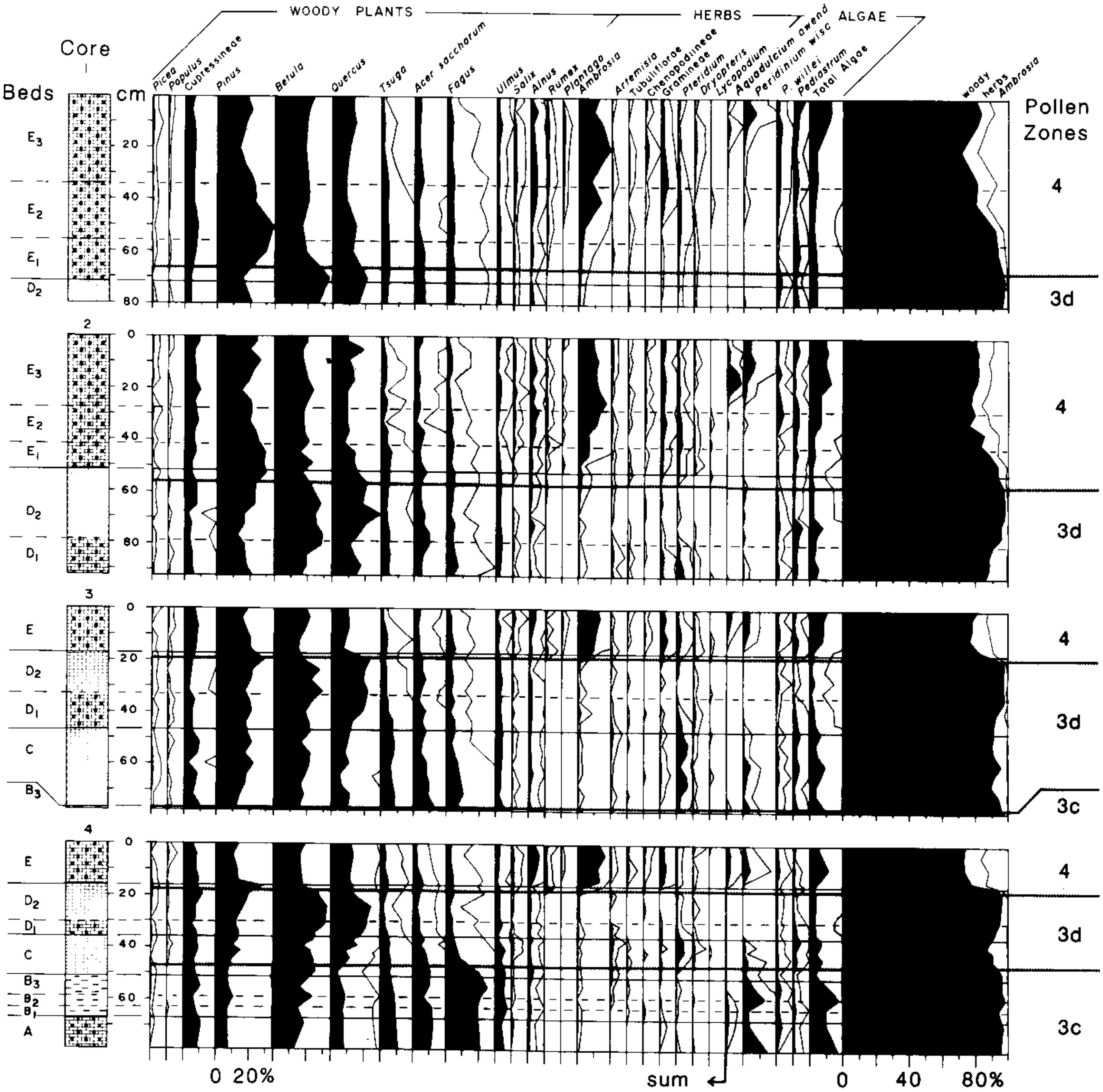

FIG. 3. Percent pollen diagrams of Second Lake cores. Core 1 is from shallow water nearshore, whereas cores 3 and 4 are from deeper water offshore.

pollen and spores decline, whereas the three dominant tree taxa increase rapidly.

Algae are less abundant in zone 3d than in zone 3c. *Peridinium wisconsinense* only occurs in the lower part of zone 3d in cores 3 and 4. In cores 1 and 2 this cyst is present in small amounts throughout zone 3d. The abundance of *Peridinium willei* is unchanged throughout this zone. *Pediastrum* increases slightly in the lower part of zone 3d.

Zone 4, present in all four cores, has decreased tree pollen and increased herb pollen, particularly *Ambrosia*. Near the top of this zone tree pollen constitutes 70–80%; *Ambrosia* represents 10–15%, with other herbaceous taxa 5–10%.

Continuous *Ambrosia* defines the zone 4 boundary. Where sedimentation is slow, the lower boundary is sharp, but in the shallow-water cores, where sedimentation is rapid, *Ambrosia* first appears in relatively small amounts.

As in zone 3d, *Pinus*, *Betula*, and *Quercus* form most of the tree pollen assemblage, each contributing 8–32%, with *Betula* and *Pinus* generally more abundant than *Quercus*. Cupressineae, *Tsuga*, *Acer*, *Fagus*, and *Ulmus* contribute 3–10% each. *Populus* may increase slightly, but the abundances are not significant. *Salix* (1–3%) and *Alnus* (3–8%) exceed background levels.

Besides *Ambrosia*, other herb taxa increase in abundance. *Rumex* and *Plantago* pollen are probably from European species introduced during the last century and together constitute

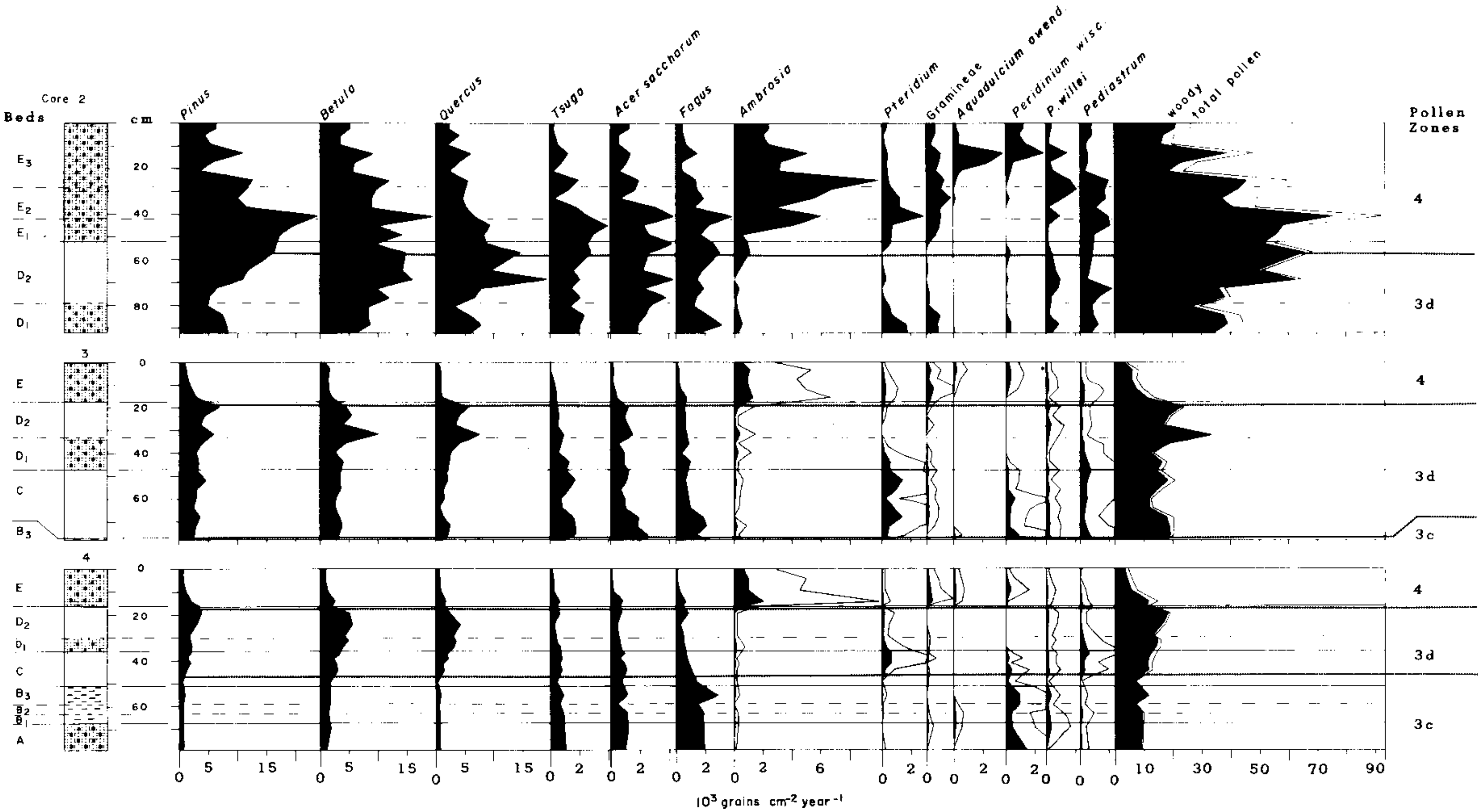

FIG. 4. Influx diagram for Second Lake cores 2, 3, and 4.

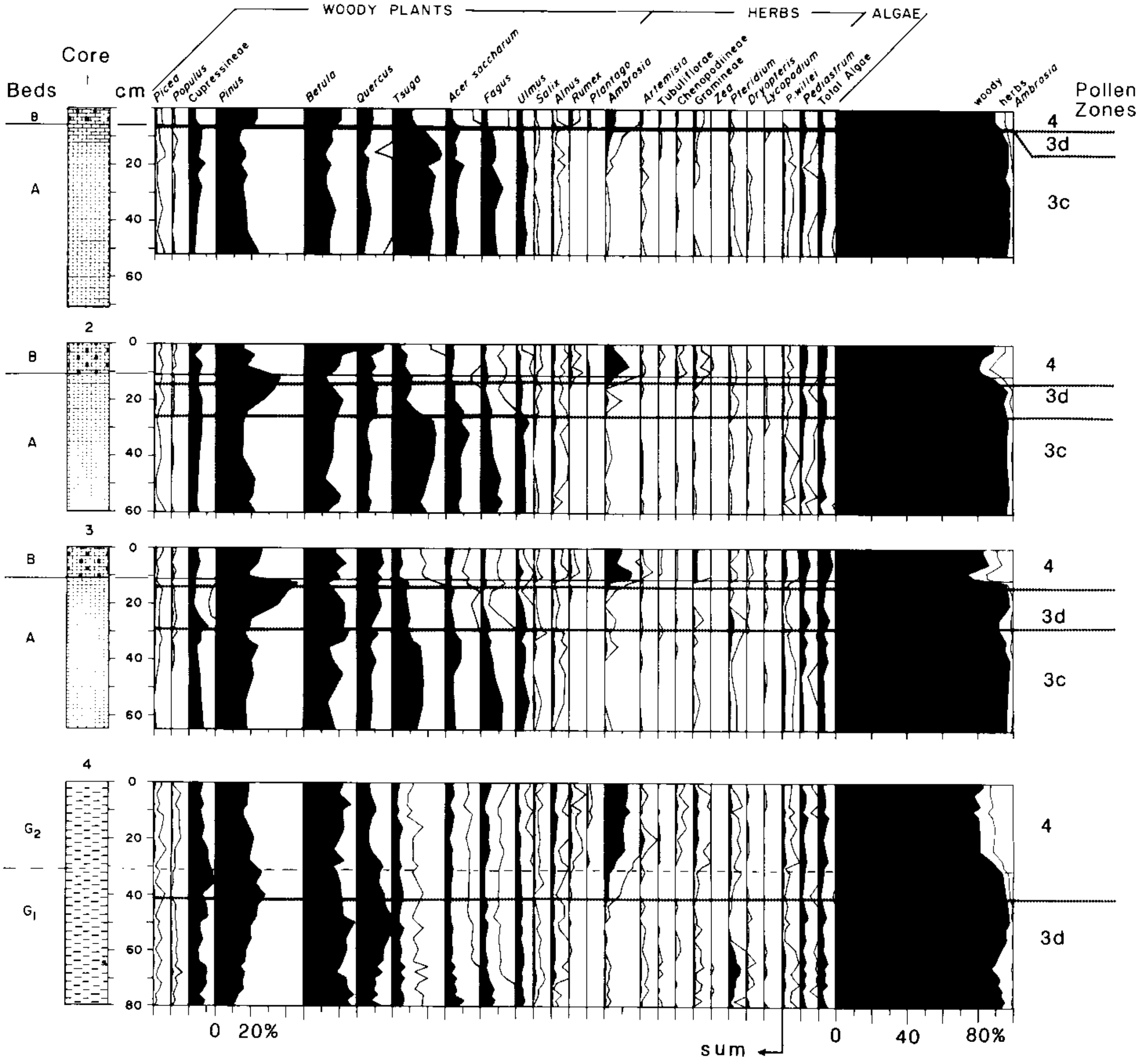

FIG. 5. Percent pollen diagrams of Gignac Lake cores. Cores 1, 2, and 3 are from a shallow carbonate mud bank, whereas core 4 is from a basin farther offshore.

about 2%. *Artemisia*, Tubuliflorae, Chenopodiineae, Gramineae, *Pteridium*, and *Dryopteris* form the bulk of the herbs.

Algae increases in zone 4. Here *Aquadulcum awendae* reappears at 1–8%. *Peridinium wisconsinense* increases in cores 1 and 2 and reappears in cores 3 and 4 with values of 1–6%. *Peridinium willei* and *Pediastrum* remain at 1–5%, with the greater abundances in the shallow-water cores.

Although palynomorph zones can be correlated across Second Lake, larger pollen grains such as *Pinus* are slightly more abundant in shallow-water cores, whereas the smaller pollen grains are more abundant in the deep-water cores. This is much more apparent in Gignac Lake, where a steep slope from the shallow to deep water exists.

The Second Lake influx diagram (Fig. 4) complements the percentage diagram. The most striking feature of this diagram is that influx ranges from 5000 – 19 000 grains cm^{-2} year^{-1} in core 4 to 25 000 – 93 000 grains cm^{-2} year^{-1} in core 2. The highest pollen influx occurs at the top of zone 3d and at the base of zone 4; thereafter, influx decreases by about 50%. As in the percentage diagram, *Pinus*, *Betula*, and *Quercus* are the dominant taxa, followed by *Tsuga*, *Acer*, and *Fagus*. *Ambrosia* is an important addition to the total influx in pollen zone 4; elsewhere it is insignificant. In core 2, where rapid sedimentation allows greater resolution of zone 4, *Pteridium* and Gramineae are more abundant than *Ambrosia* in the lower part of the zone. In zone 3d *Pteridium* represents the highest influx of the herbs, exceeding that in zone 4.

In core 2 the sedimentation rate is rapid enough to distinguish sequential changes in the influx of algae. In zone 4 *Pediastrum* is the first taxon to increase; it is followed by *Peridinium willei* and later by *P. wisconsinense* and *Aquadulcum awendae*. *Peridinium wisconsinense* and *A. awendae* only increase after *Pediastrum* declines. Similar changes are suggested from cores 3 and 4, but the resolution is unclear. In zones 3c and 3d the inverse relationship of *Pediastrum* and dinoflagellates *P. wisconsinense* and *A. awendae* is repeated. Furthermore, the increases in *Pediastrum* parallel increases *Pteridium* and Gramineae.

Gignac Lake

Three pollen zones were also found in Gignac Lake (Fig. 5), but only cores 2 and 3 have all three zones. In core 4 the sedimentation rate is rapid, and zone 3c was not penetrated. In core 1 the sedimentation rate is very slow, and pollen zone 3d is absent or, more likely, mixed with zone 4.

The shallow-water cores 1, 2, and 3 contain zone 3c. *Tsuga*, *Pinus*, and *Betula* are dominant; each contributes between 12 and 27%. *Tsuga* slightly exceeds *Betula* and *Pinus* in cores 1 and 2, but in core 3 they are equal. *Acer* and *Fagus* represent 5–12%. Cupressineae and *Ulmus* (3–8%) are nearly constant throughout 3c. In zone 3c tree pollen (over 90%) and herbs (less than 10%) are relatively constant.

Peridinium willei and *Pediastrum* are the only algal palynomorphs recognized in the Gignac Lake cores. In zone 3c *P. willei* and *Pediastrum* sp. contribute 1–5%.

Zone 3d is dominated by *Pinus*, *Betula*, and *Quercus* pollen. *Pinus* dominates the shallow-water cores with 17–45%; *Betula* and *Quercus* contribute 8–21%. In core 4 *Betula* and *Quercus* (8–29%) dominate the assemblage, whereas *Pinus* constitutes only 10–20%. *Tsuga* (5–10%) is diminished from zone 3c. *Acer* and *Fagus* (1–10%) also decline in zone 3d. Cupressineae increases slightly from zone 3c, though it never exceeds 10% in any of the cores. *Ulmus* (2–7%) is unchanged from zone 3c.

Among the herbs, *Pteridium* contributes up to 7% at the base of zone 3d in core 4. In cores 2 and 3 this peak is less pronounced; in core 3 *Pteridium* contributes about 4%, whereas in core 2 it represents about 2%. Gramineae and *Artemisia*, the next most abundant herbs, contribute 1–3% in the lower part of 3d. Other herbs are infrequent, but among these, *Zea* pollen at 66 and 72 cm in core 4 is direct evidence for Indian farming. Toward the top of zone 3d all herb taxa decline.

Peridinium willei represents 2–3% in the lower part of zone 3d in core 4, decreasing to about 1% at the top of this zone. In cores 2 and 3 *P. willei* represents only about 1%. *Pediastrum* contributes 3–6% in these cores; it is slightly more abundant in the lower part of zone 3d in cores 2 and 3.

The total pollen and spore curves for zone 3d closely resemble those from Second Lake, with tree pollen decreasing to 80–90% in the lower half of this zone. The greatest decrease in tree pollen occurs in core 4, where the herbs reach 15%.

Zone 4 occurs in all Gignac Lake cores, but in core 1 it may be mixed with zone 3d. The peaks of *Tsuga*, *Acer*, and *Fagus* of zone 3c are immediately below sediments containing abundant *Pinus* and *Ambrosia* pollen.

At the base of zone 4 *Pinus* represents 30–45% but declines to 15–20%. Betula (18–22%) is the second most abundant pollen type in zone 4. Cupressineae (5–7%) and Quercus (7–10%) are unchanged in cores 1, 2, and 3; in core 4, where faster sedimentation allows greater resolution, both taxa decrease. *Quercus* drops from 15 to 8%, and Cupressineae drops from 15 to 7%. *Tsuga*, *Acer*, *Fagus*, and *Ulmus* represent less than 5%.

Ambrosia (2–15%) is the most abundant herb in zone 4, followed by *Pteridium* and Gramineae (1–3% each). With the large increase in herb pollen, tree pollen falls to between 90 and 75%. More than half the herb pollen is *Ambrosia*.

In core 4 *Peridinium willei* contributes about 1% in the lower part of zone 4. At 31 cm, the horizon where *Ambrosia* begins to increase rapidly, *P. willei* increases to 2%. *Pediastrum* varies from 0 to 5% in zone 4 of the Gignac Lake cores. There is a slight increase in abundance from zone 3d and an increase in abundance from the nearshore core 1 to the offshore core 3.

In Gignac Lake the greatest influx is in the deep water, where 12 000 – 29 000 grains cm^{-2} $year^{-1}$ are accumulating (Fig. 6). In the shallow water the influx is much less, 2000–5000 grains cm^{-2} $year^{-1}$. Most of the palynomorphs are probably carried off the shallow carbonate bank into the deeper basin.

Pinus, *Betula*, and *Quercus* dominate, with *Tsuga*, *Acer*, and *Fagus* following in abundance. In the shallow-water cores, *Tsuga* influx is as great as that of *Pinus* and *Betula*. *Ambrosia* dominates the herb assemblage of zone 4, followed by Gramineae and *Pteridium*. In the lower part of zone 3d, where *Zea* pollen has been identified, *Pteridium* and Gramineae are dominant herb taxa, whereas *Ambrosia* is insignificant. In core 4 *Peridinium willei* and *Pediastrum* influx changes compare with changes to the herbs. For the other cores, variations in the influx of algae are small, and any relationship with the herb pollen is unclear.

Discussion

Upland vegetation during the last 600 years

Before the movement of Indian farmers to the lands surrounding Second and Gignac Lakes (ca. 1450), the forest was dominated by maple, beech, and hemlock, with subordinate birch, oak, and pine. After 1450 forest was cleared for villages and corn fields.

In southern Ontario the pollen record from lakes with Indian villages nearby (Crawford Lake, Second Lake, and Gignac Lake) indicates a period of forest clearance and agriculture. *Fagus*, *Acer*, and *Tsuga* pollen decline in abundance as herbs, *Quercus*, *Betula*, and *Pinus* pollen increase.

Zea pollen in zone 3d is the best indicator of Indian farming but is an uncommon fossil, and more abundant herb species must be used to identify farming. In Gignac and Second lakes the lower part of zone 3d contains abundant *Pteridium* and Gramineae pollen. Bracken and grass probably grew on abandoned fields, where their palynomorphs were easily blown into lakes. As forest was cleared, farmed, and abandoned, the number of fields in this early stage of succession was large.

It is unlikely that forest fires create similar pollen assemblages. Swain (1973) and Cwynar (1978) have shown that forest succession on burned areas is rapid and shade-intolerant plants are quickly replaced by trees. The persistence of abundant *Pteridium*, Gramineae, and other herb pollen through two hundred years of lake sedimentation is due to continuous agriculture. Archaeological evidence (O'Brien 1976) indicates that the land around these lakes was cleared, farmed, and abandoned several times before the Huron were forced from their homeland in 1650.

After 1650 all abandoned farm fields were soon reforested. The abandoned fields are indicated by the decline of *Pteridium*. In addition, oak and pine are pioneer trees in an old field succession, and increases in *Quercus* and *Pinus* pollen are expected.

Through the latter half of pollen zone 3d the influx of herb pollen is low, and tree species dominate pollen assemblages.

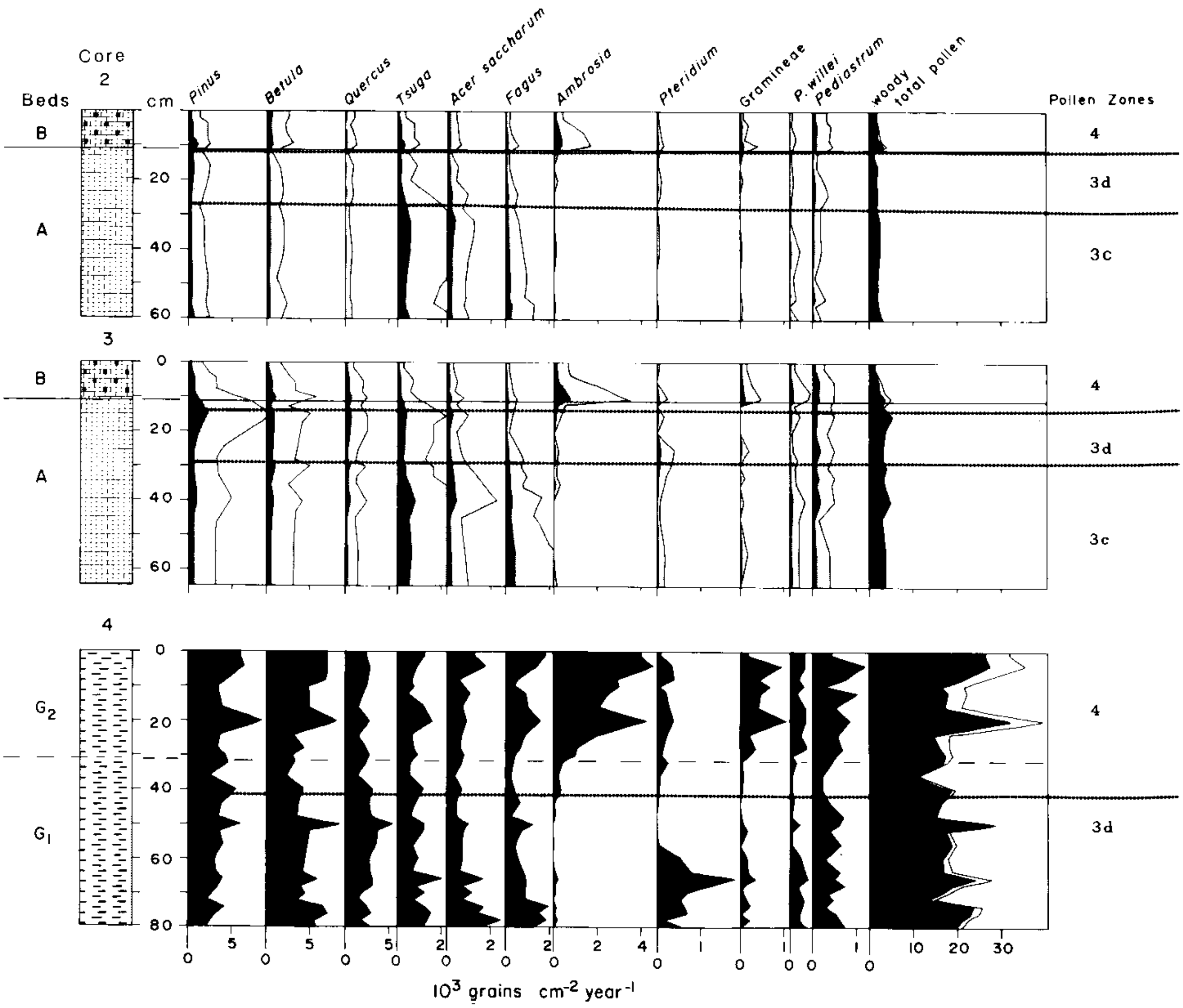

FIG. 6. Influx diagram for Gignac Lake cores 2, 3, and 4.

Near the top of zone 3d small amounts of *Rumex* and *Plantago* are present. These taxa and later *Ambrosia* indicate Europeans were clearing forest.

Zone 4 starts with a rapid rise in *Ambrosia* pollen, usually just before other herbs increase and tree pollen declines. In cores with slow sedimentation rates this transition is absent. However, in cores exhibiting a faster sedimentation rate (i.e., Gignac Lake 4 and Second Lake 2), there is several centimetres of sediment between the appearance of *Ambrosia* and the decline of tree pollen. Boyko (1973) observed and dated this change in Crawford Lake, where *Ambrosia* rises between 1846 and 1851 and *Pinus* did not decline until 1871. Around Second Lake and Gignac Lake, logging companies acquired the timber rights around 1870, and clearing likely occurred soon thereafter.

With deforestation and agriculture by Europeans the tree pollen declines, whereas the herb pollen increases. The introduced European *Plantago* and *Rumex* with the abundant *Ambrosia* confirm that these are European farms. Furthermore, *Pteridium* and Gramineae in zone 4 do not respond in the same manner as those for Indian farms. European farms in southern Ontario are plowed annually, and this inhibits bracken. With larger tilled fields and more grain crops, grasses were more prevalent than bracken.

In the most recent sediments, tree pollen is more abundant. This is consistent with local farmers abandoning their land and allowing forest recovery.

Ecological controls on algal assemblages during the last 600 years

Trends in algal assemblages during the last 600 years reflect the two cycles of forest clearance, farming, and reforestation. Prior to deforestation by Indians more than 500 years ago, the algal assemblages in Second Lake were dominated by *Peridinium wisconsinense*, with lesser amounts of *P. willei*, *Aquadulcum awendae*, and *Pediastrum*. In Gignac Lake the composition of the predisturbance algal assemblages is not so clear; core 4 did not penetrate the older sediments, and in the shallow-water cores the slow sedimentation resulted in poor resolution.

Increased *Pediastrum* in Second Lake and both *Pediastrum* and *Peridinium willei* in Gignac Lake parallel the pollen record for forest clearance and farming. Deforestation and farming probably had an indirect effect on algal assemblages through soil erosion. Burden *et al.* (1986) show detrital minerals and elements entering these lakes when the forest is cleared.

Although the influx of detrital minerals correlates with, and possibly controls production of, *Pediastrum* and *Peridinium willei*, the important limiting nutrients are probably phosphorus, nitrogen, and carbon (Sakamoto 1971; Schindler 1977). Deforestation and farming increase sediment erosion and nutrient loss from exposed upland soils (Baker and Krumer 1973; Golterman 1975; Likens *et al.* 1978). Thus, with forest clearance by both Indian and European farmers the nutrient budget for each lake was altered, and populations of *Pediastrum* and *Peridinium willei* increased.

Other factors such as temperature and salinity affect modern marine dinoflagellates (Wall *et al.* 1977; Reid and Harland 1977). Salinity is not important in these freshwater lakes, as neither lake is prone to drying. Temperature controls are difficult to determine from these short cores: *Peridinium wisconsinense* may prefer warmer water than that found in Second Lake during the last 600 years (E. T. Burden, unpublished data).

Holl (*in* Hutchinson 1957) indicated that some species of freshwater dinoflagellates are adapted to acid and calcium-deficient waters, whereas others prefer alkaline and calcium-rich water. *Aquadulcum awendae* and probably *Peridinium wisconsinense* are two species that occur in the less alkaline, organic sediments of Second Lake. There is no relationship of these species to the deforestation by Indians and Europeans.

Intralake variations in palynomorph assemblages

Although zones 3c, 3d, and 4 occur in cores from these lakes, variations in the abundances of taxa between cores is large, and physical controls on the distribution of palynomorphs is suspected. Davis (1967, 1968, 1973) and Davis and Ford (1982) found that the pollen rain into lakes was 8000 - 21 000 grains cm^{-2} year^{-1}, but sediment focusing and recirculation can cause large variations in the influx of pollen to the sediment. Both Lehman (1975) and Davis (1976) believed that with sediment focusing, palynomorph movement is from the littoral areas to the deeper water. In Gignac Lake this is the most likely dispersal mechanism, because palynomorphs deposited on the shallow-water carbonate bank are not abundant and size sorting is apparent. The larger grains, *Pinus* and *Tsuga*, are more numerous than those of *Quercus* and *Ambrosia*.

In Second Lake the pattern of sedimentation is not consistent with the models proposed by Lehman (1975) and Davis (1976). Here the most rapid sedimentation and the greatest palynomorph influx are in shallow water. Sediments are not being swept towards the centre of the basin. Sorting of taxa by size is not pronounced, and there is a subtle increase in *Pinus* in the shallow-water cores.

The differences in the sedimentation patterns in these lakes may be related to basin morphology and, by inference, to the development of a hypolimnion in Gignac Lake. Second Lake is relatively shallow, with gentle slopes into the basin. A hypolimnion, if present, may be only weakly developed. After spring breakup, the water in small, shallow lakes heats quickly, and convection cells prevent thermal stratification (Gorham 1964; Schindler 1971). Palynomorphs and other sedimentary particles are kept in suspension until freeze-up. In Gignac Lake the water is deep, and a hypolimnion may act to trap fine sediment and palynomorphs moving from the shallow water to the basin.

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ANONYMOUS. Abstract index to deeds for Tiny Twp., Simcoe Co., Ontario. Vol. 2. 1831–1957. Ontario Archives, Microfilm No. LML 1154.

BAKER, D. B., and KRUMER, J. W. 1973. Phosphorous sources and transport in agricultural river basin of Lake Erie. Proceedings, 16th Conference on Great Lakes Research, International Association of Great Lakes Research, pp. 858–871.

BORMANN, F. H., LIKENS, G. E., SICCAMA, T. G., PIERCE, R. S., and EATON, J. S. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecological Monographs, **44**, pp. 255–277.

BOYKO, M. 1973. European impact on the vegetation around Crawford Lake in southern Ontario. M.Sc. thesis, Department of Botany, The University of Toronto, Toronto, Ont.

BRUGHAM, R. B. 1978. Pollen indicators of land-use change in southern Connecticut. Quarternary Research, **9**, pp. 349–362.

BURDEN, E. T. 1978. Pollen and algal assemblages in cored sediments from Gignac Lake and Second Lake (Simcoe Co., Ontario): relationships with lacustrine facies, geochemistry and vegetation. M.Sc. thesis, Department of Geology, The University of Toronto, Toronto, Ont.

BURDEN, E. T., NORRIS, G., and MCANDREWS, J. H. 1986. Geochemical indicators in lake sediment of upland erosion caused by Indian and European farming, Awenda Provincial Park, Ontario. Canadian Journal of Earth Sciences, **23**, pp. 55–65.

CWYNAR, L. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Canadian Journal of Botany, **56**, pp. 10–21.

DAVIS, M. B. 1967. Pollen accumulation rates at Rogers Lake Connecticut, during late- and postglacial time. Review of Palaeobotany and Palynology, **2**, pp. 219–230.

——— 1968. Pollen grains in lake sediments: redeposition caused by seasonal water circulation. Science, **162**, pp. 796–799.

——— 1973. Redeposition of pollen grains in lake sediment. Limnology and Oceanography, **18**, pp. 44–52.

——— 1976 Erosion rates and land use history in southern Michigan. Environmental Conservation, **3**, pp. 139–148.

DAVIS, M. B., and FORD, M. S. 1982. Sediment focusing in Mirror Lake, New Hampshire. Limnology and Oceanography, **27**, pp. 137–150.

EDDY, S. 1930. The fresh-water armoured or thecate dinoflagellates. Transactions of the American Microscopical Society, **49**, Part 4, pp. 277–321.

GOLTERMAN, H. L. 1975. Developments in water science: physical limnology. Elsevier Scientific Publishing Co., New York, NY., 489 p.

GORHAM, E. 1964. Morphometric control of annual heat budgets in temperate lakes. Limnology and Oceanography, **9**, pp. 525–529.

HARLAND, R., and SARJEANT, W. A. S. 1970. Fossil freshwater microplankton (dinoflagellates and acritarchs) from Flandrian (Holocene) sediments of Victoria and Western Australia. Proceedings of the Royal Society of Victoria, **83**, Part 2, pp. 211–234.

HEIDENREICH, C. 1971. Huronia: a history and geography of the Huron Indians, 1600–1650. McClelland and Stewart, Toronto, Ont. 337 p.

HUBER-PESTALOZZI, G. 1950. Pyrrophyta. *In* Die Binnengewasser. Das phytoplankton des susswassers, 16(3), Cryptophyceen, Chloromonadinen, Peridineen. *Compiled by* A. Thieremann. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, West Germany, pp. 1–310.

HUTCHINSON, G. E. 1957. A treatise on limnology. Vol. 2. Introduction to lake biology. John Wiley & Sons, Toronto, Ont., 1115 p.

KEMP, A. L., and THOMAS, R. L. 1976. Cultural impact on the geochemistry of the sediments of Lake Ontario, Erie and Huron. Geoscience Canada, **3**, pp. 191–207.

KEMP, A. L., GRAY, C. B., and MUDROCHOVA, A. 1972. Changes in C, N, P and S in the last 140 years in three cores from Lake Ontario, Erie, and Huron. *In* Nutrients in natural waters. *Edited by* H. E. Allen and J. R. Kramer. John Wiley & Sons, Toronto, Ont., pp. 251–279.

LEHMAN, J. T. 1975. Reconstructing the rate of accumulation of lake sediment: the effect of sediment focusing. Quaternary Research, **5**, pp. 541–550.

LIKENS, G. E., BORMANN, F. H., PIERCE, R. S., and REINERS, W. A. 1978. Recovery of a deforested ecosystem. Science, **199**, pp. 492–496.

MATHEWES, R. W., and D'AURIA, J. M. 1982. Historic changes in an urban watershed determined by pollen and geochemical analyses of lake sediment. Canadian Journal of Earth Sciences, **19**, pp. 2114–2125.

MCANDREWS, J. H. 1976. Fossil history of man's impact on the Canadian flora: an example from southern Ontario. Canadian Botanical Association Bulletin, **9**, pp. 1–6.

MCANDREWS, J. H., and BOYKO-DIAKONOW, M. In press. Pollen analysis of varved sediment at Crawford Lake, Ontario: evidence of Indian and European farming. *In* Quaternary geology of Canada and Greenland. *Edited by* R. J. Fulton and J. A. Hegenbottom. Geological Survey of Canada.

NORRIS, G., and MCANDREWS, J. H. 1970. Dinoflagellate cysts from post-glacial lake muds, Minnesota (U.S.A.). Review of Palaeobotany and Palynology, **10**, pp. 131–156.

O'BRIEN, R. M. 1976. An archaeological survey of Methodist Point Park Reserve. Ontario Ministry of Culture and Recreation, Historical Planning and Research Branch, Research Report No. 9, p. 102.

REID, P. C., and HARLAND, R. 1977. Studies of Quaternary dinoflagellate cysts from the North Atlantic. *In* Contributions of stratigraphic palynology. Vol. 1. Cenozoic palynology. *Edited by* W. C. Elsik. American Association of Stratigraphic Palynologists, Contribution Series 5A, pp. 147–165.

SAKAMOTO, M. 1971. Chemical factors involved in the control of phytoplankton production in Experimental Lakes area, northwestern Ontario. Journal of the Fisheries Research Board of Canada, **28**, pp. 203–213.

SCHINDLER, D. W. 1971. Light, temperature and oxygen regimes of selected lakes in the Experimental Lake area, northwestern Ontario. Journal of the Fisheries Research Board of Canada, **28**, pp. 157–169.

——— 1977. Evolution of phosphorus limitation in lakes. Science, **195**, pp. 260–262.

STOCKMARR, J. 1971. Tablets with spores used in absolute pollen analysis. Pollen et spores, **XIII**, pp. 615–621.

SWAIN, A. M. 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quaternary Research, **3**, pp. 383–396.

WALL, D., DALE, B., LOHMANN, G. P., and SMITH, W. G. 1977. The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic oceans and adjacent seas. Marine Micropaleontology, **2**, pp. 121–200.

WRONG, G. M., *editor*. 1939. The long journey to the country of the Hurons. *By* Fr. G. Sagard. *Translated by* H. H. Langton. The Champlain Society, Toronto, Ont., 411 p.

Appendix: Systematic description

CLASS Dinophyceae Fritsch
ORDER Peridiniales Haeckel
GENUS *Aquadulcum* Harland and Sarjeant, 1970
TYPE SPECIES ***Aquadulcum serpens*** Harland and Sarjeant, 1970
Aquadulcum awendae sp. nov.
(Pl. 1, figs. 1–15)

HOLOTYPE: Second Lake 2, 10 cm, slide 1 (Pl. 1, figs. 1–3). Slides and residues are housed in the Royal Ontario Museum, Toronto, Ontario.

DIAGNOSIS: Vesicae sphaeraticae atque spiniferae, quae multas prolationes ramosas habent. Haec non tabulares sunt. Cingulum angustisque pandasutilibusque regionibus vesicam impariter secat. Inde illud minorem epitractum definit. Autophragma scabera. Foramen archeopylanum (AIP?).

DIAGNOSIS: Cysts spheroidal, spiniferate, with numerous, nontabular branching processes. Cingulum with narrow pandasutural zones divides cyst unequally, delimiting smaller epitract. Autophragm scabrate. Archeopyle (AIP?).

DERIVATION OF NAME: Awenda (8endat, Ouendat, or Wendat) is what the Huron called themselves collectively. The name could mean "The Islanders," "Dwellers of the Peninsula," or simply "Villagers" (Heidenreich 1971).

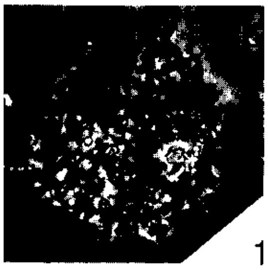
DIMENSIONS: 35–60 μm long (mean 46 μm, standard deviation 5.8 μm); 24–50 μm wide (mean 35 μm, standard deviation 7.6 μm); 15 specimens measured.

DISTRIBUTION: This cyst forms a small part of the Holocene palynomorph record from Second Lake, Awenda Provincial Park, Ontario.

DESCRIPTION: Spheroidal prolate–peridinoid (polar to equatorial axis ratio 1.35, standard deviation 0.28, range 1.04–2.00; 15 specimens) scabrate autophragm, less than 1.0 μm thick, covered with numerous (40–60?) spiny processes. Two distinct sizes of processes are evident. Longer processes (mean length 9.6 μm, standard deviation 2.6 μm, range 5–15 μm; 15 specimens) are branched bifid, bifid, and digitate, whereas shorter acicular processes (rarely bifid type) are less than 2 μm high. Larger processes may sometimes appear striated in their basal expanded parts. The largest and most complex processes tend to occur in the apical and antapical areas. Large processes seldom occur alone; more often, large processes occur in clusters linked by linear arrangements

PLATE 1

FIGS. 1–15. *Aquadulcum awendae* n. sp. Second Lake 2, 10 cm, slide 1 (Royal Ontario Museum catalogue No. 44056). (1) Holotype; phase contrast; 106.0 12.3; ×750. (2, 3) Holotype; interference contrast; high and low focus; ×1000. (4) Incomplete penetabular paratabulation; phase contrast; 101.6 18.8; ×750. (5, 6) Details of paratabulation at low and high focus (t) and striations on large processes (s); interference contrast; ×1000. (7) Archeopyle; phase contrast; 78.1 10.8; ×750. (8) Details of archeopyle suture and cingulum(?) (c); interference contrast; ×1000. (9) Specimen with bifid and branched bifid processes and an equatorial (?) split; phase contrast; 100.2 12.8; ×750 (10) Details of process morphology at high focus; interference contrast; ×1000. (11) small hexagonal plate (p) at low focus; interference contrast; ×1000. (12) Prolate cyst; phase contrast; 83.8 12.4; ×750. (13) High focus on processes and sulcus(?) (s); interference contrast; 94.7 11.2; ×1000. (14) Low focus on archeopyle (a); interference contrast; ×1000. (15) Spheroidal cyst; phase contrast; 101.6 11.9; ×750.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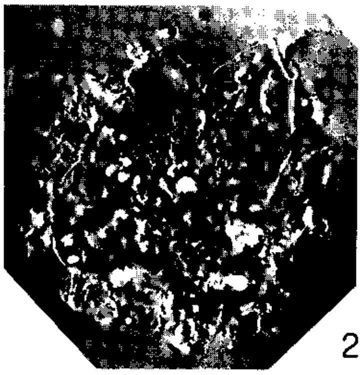
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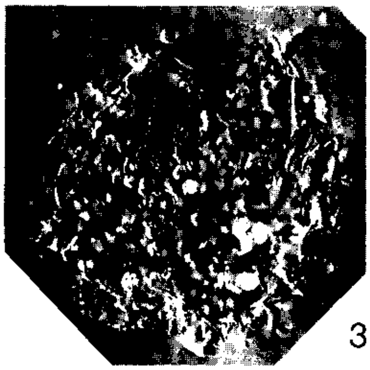
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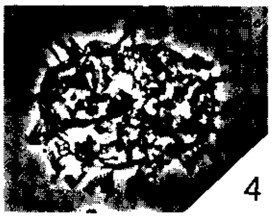
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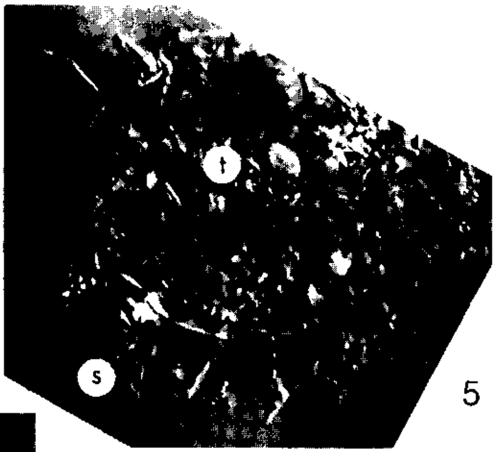

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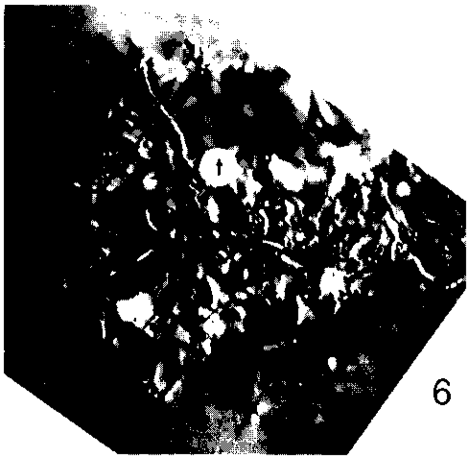

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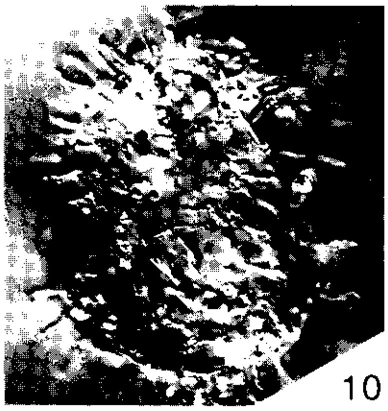
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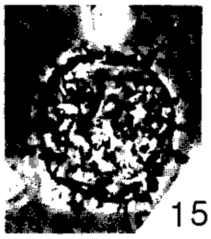
15

of low ridges, short acicular processes, and scabrae. The tabulation is not clear. On some specimens a cingulum about 8 μm wide is delineated by a linear arrangement of short discontinuous ridges and processes. The cingulum divides the cyst into two unequal halves: the epitract tends to be slightly smaller than the hypotract. Elsewhere on the cyst, short discontinuous ridges and processes may represent incomplete penetabular paratabulation. Plate boundaries are only clear along the polygonal edge of the archeopyle. In some specimens the archeopyle opens by means of a transapical suture and a suture along the anterior edge of the cingulum; in other specimens a split along what is probably the sulcus divides the cyst into left and right halves.

COMPARISON: Cysts of *Peridinium limbatum* (Stokes) Lemm., *P. willei* Huitf.-Kass, *P. bipes* Stein, and *P. wisconsinense* Eddy lack long processes (see Norris and McAndrews 1970) and are clearly distinguished from the spiniferate cyst *Aquadulcum awendae*. *Aquadulcum serpens* Harland and Sarjeant, 1970 has dense ornamentation of very short spines and vermiculae, whereas *A. awendae* has long bifid, branched bifid, and digitate processes. Cysts of ?*Aquadulcum yanchepense* Harland and Sarjeant, 1970 have a granular wall of "moderate thickness" and "some sixty short, rather stubby processes"; *Aquadulcum awendae* has a thin wall and 40–60(?) long, delicate processes. Cysts of ?*Aquadulcum* cf. *yanchepense* Harland and Sarjeant, 1970 are broadly similar to *Aquadulcum awendae*; however, ?*A.* cf. *yanchepense* has a granular surface with more numerous (70–80), shorter (3–8 μm) processes. Species of *Cobricosphaeridium* Harland and Sarjeant, 1970 are broadly similar in size, shape, and morphology to *Aquadulcum awendae*; *Cobricosphaeridium* has an apical (A) archeopyle that differs from the transapical slit characteristic of *Aquadulcum* (Harland and Sarjeant 1970).

AFFINITY: None of the small number of lacustrine *Peridinium* cysts described to date are spiniferate. At this time we believe it unlikely that *Aquadulcum awendae* sp. nov. is a cyst of a *Peridinium* species. In addition, the displacement of the cingulum towards the apical pole is not characteristic of thecate *Peridinium* in lacustrine environments (Eddy 1930; Huber-Pestalozzi 1950). *Gonyaulax apiculata* (Penard) Entz is one of a small number of lacustrine Gonyaulacaceae (Eddy 1930). It has an apically displaced cingulum, and its size is comparable to that of the cyst observed here. However, cysts of *G. apiculata* have never been reported.