Record of large, Late Pleistocene outburst floods preserved in Saanich Inlet sediments, Vancouver Island, Canada

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Abstract

Two anomalous, gray, silty clay beds are present in ODP cores collected from Saanich Inlet, Vancouver Island, British Columbia, Canada. The beds, which date to about 10,500 14C yr BP (11,000 calendar years BP), contain Tertiary pollen derived from sedimentary rocks found only in the Fraser Lowland, on the mainland of British Columbia and Washington just east of the Strait of Georgia. Abundant illite-muscovite in the sediments supports a Fraser Lowland provenance. The clay beds are probably distal deposits of huge floods that swept through the Fraser Lowland at the end of the Pleistocene. Muddy overflow plumes from these floods crossed the Strait of Georgia and entered Saanich Inlet, where the sediment settled from suspension and blanketed diatom-rich mud on the fiord floor. The likely source of the floods is Late Pleistocene, ice-dammed lakes in the Fraser and Thompson valleys, which are known to have drained at about the time the floods occurred.

1. Introduction

During Ocean Drilling Program (ODP) Leg 169S in 1996, a continuous sequence of sediments spanning the last 15,000 years was cored at two sites in Saanich Inlet, an anoxic fiord on southern Vancouver Island, British Columbia, Canada. The cores were collected using a hydraulic piston coring system to maximum depths of 105 and 118 m below the seafloor at the two sites. The uppermost part of the sediment sequence comprises varved, olive-gray, diatom-rich marine mud intercalated with beds of massive, olive-gray mud deposited by debris flows (Blais-Stevens et al., 1997; Blais-Stevens and Clague, 2001). The varved sediments are underlain by indistinctly laminated, olive-gray, diatom-rich marine mud of middle and early Holocene age, which in turn is underlain by gray glaciomarine sediments deposited at the end of the Last Glaciation (Blais-Stevens et al., 2001).

Three unusual beds occur within the indistinctly laminated mud unit: a thin layer of Mazama ash, about 7700 years old (Bacon, 1983); and two gray, silty clay beds of latest Pleistocene age. The origin of the gray silty clay beds is the subject of this paper. We argue that they are the distal deposits of huge outburst floods, probably caused by the sudden draining of Late Pleistocene, ice-dammed lakes in the Fraser and Thompson valleys, which are known to have drained at about the time the floods occurred.

2. Saanich Inlet

Saanich Inlet (Fig. 1) is 26 km long, up to 8 km wide, and has a maximum depth of 238 m. Its main source of freshwater and sediment is Cowichan River, which flows into Cowichan Bay north of the mouth of the inlet (Herlinveaux, 1962). A bedrock sill (Fig. 1) separates Saanich Inlet from Cowichan Bay and Satellite Channel and restricts deep-water circulation in the fiord, creating anoxic conditions below depths of 70–150 m (Gross et al., 1963). Satellite Channel extends eastward, via a
series of islands, into the southern Strait of Georgia, which is 200–300 m deep. The abundance of freshwater, the high primary productivity in Saanich Inlet during spring and summer, and the sluggish estuarine circulation contribute to anoxia of bottom waters (Herlinveaux, 1962), an absence of benthic fauna, and, consequently, excellent preservation of seasonally deposited laminae.

3. Gray silty clay beds

3.1. Description

Two gray silty clay beds are present within the lower part of the indistinctly laminated, diatomaceous mud unit about 3 m above its base (Figs. 2 and 3). The lower silty clay bed is about 30 cm thick and has an abrupt, non-erosional basal contact and a gradational upper contact (Fig. 3). This bed contains no macroscopic structures, but it is micro-laminated, and particle-size analyses reveal that it is normally graded (Fig. 4). A second, thinner (<10 cm) and less conspicuous bed of gray silty clay occurs several tens of centimetres above the first and is separated from it by indistinctly laminated, olive-gray mud (Figs. 2 and 3). The upper clay bed has gradational upper and lower contacts. The clay mineral fraction of the silty clay beds is dominated by illite-muscovite, which is abundant in modern Fraser River sediments (Mackintosh and Gardner, 1966).

3.2. Microfossils

The gray silty clay beds contain freshwater diatoms and silicoflagellates. The microfossil assemblage contrasts sharply with the typical marine assemblage in the bounding indistinctly laminated mud (McQuoid and Hobson, 2001).

Most palynomorphs in the Saanich Inlet cores are well-preserved Quaternary types such as pine pollen (Fig. 5a; Pellatt et al., 2001). Pre-Quaternary pollen and spores are present in only trace amounts throughout the cores, except in the gray silty clay beds. The silty clay beds contain diverse and abundant, pre-Quaternary pollen and spores. The pollen assemblage in these beds is similar to that reported from Tertiary sedimentary rocks in the Fraser Lowland (Hopkins, 1968, 1969; Mustard and Rouse, 1994). The Eocene to lower Oligocene Huntingdon Formation (Mustard and Rouse, 1994) is the most likely source for most of the reworked pollen. Examples of these pollen are shown in Fig. 5, including exotic ferns (Figs. 5c and d), Pterocarya (wingnut,
Figs. 5e and f), Liquidambar (sweetgum, Fig. 5g), Ulmus/Zelkova (elm family, Fig. 5h), Carya (hickory, Fig. 5i), and Tilia (basswood or linden, Fig. 5j). Not illustrated but also prominent are Fagus (beech) and Juglans (walnut). The presence of the extinct form genus Paraalnipollenites (Fig. 5k), a Paleocene taxon, suggests a source in the lower part of the Huntingdon Formation. Some of the pollen, however, may have come from the Miocene Boundary Bay Formation (Hopkins, 1968), including pollen of Cedrus (true cedar) (Fig. 5b), a middle and Late Tertiary taxon that is no longer native to North America.

Paleocene and Eocene rocks do not occur on southern Vancouver Island, which suggests that the pollen have a mainland source where such rocks are exposed at or near the surface. Some Upper Cretaceous pollen grains were recovered from the gray silty clay beds and are possibly derived from rocks of this age in the Cowichan River valley. However, they just as well could have come from Upper Cretaceous rocks at the northern edge of the Fraser Lowland in Vancouver (Rouse et al., 1975). Fig. 5l shows an Upper Cretaceous pollen grain of the form genus Nudopollis, a type recorded by Rouse et al. (1975) at Vancouver, but not in Cretaceous rocks on Vancouver Island.

3.3. Age

The ODP cores contain a record of the last 15,000 years of sedimentation in Saanich Inlet (Blais-Stevens et al., 1997, 2001). Among the 71 AMS radiocarbon ages
on the cores are 16 on shell and wood collected just above and below the gray silty clay beds (Fig. 2, Table 1). Reservoir-corrected ages on shells above the higher clay bed range from 10,190 ± 70 to 10,800 ± 70 ¹⁴C yr BP. A radiocarbon age of 10,480 ± 50 ¹⁴C yr BP was obtained on shell fragments recovered from indistinctly laminated mud between the two clay beds at site 1033. Two fragments of wood just below the lower clay bed at site 1034 yielded ages of 10,110 ± 50 and 10,410 ± 60 ¹⁴C yr BP. The age of the two silty clay beds thus is about 10,500 ¹⁴C years (10,900–11,110 cal yr). The silty clay correlates with a similar deposit of the same age, recently identified in three sediment cores from the central Strait of Georgia, about 100–120 km northwest of Vancouver (Conway et al., 2001).

4. Discussion

The abrupt, non-erosional, basal contact of the gray silty clay indicates that deposition began suddenly. The fine particle size and presence of micro-laminae suggest deposition from suspension, perhaps influenced by tidal ebb and flow. Two episodes of clay deposition were separated by a brief period during which indistinctly laminated olive-gray mud accumulated on the fiord floor. Based on an average varve thickness of 4 mm in the upper section of the core at site 1033 (Blais-Stevens et al., 1997), we estimate that approximately 110 years separated deposition of the two silty clay beds.

The microfossil content and mineralogy of the clay beds show that the sediment was carried into Saanich Inlet from a source external to southeastern Vancouver.

![Fig. 4. Silt abundance in the lower silty clay bed, core 1033. The bed is normally graded.](image)

![Fig. 5. Selected pollen and spores recovered from the lower silty clay bed in Saanich Inlet ODP core 1034B. Magnifications are 700 × unless stated otherwise. (a) Pleistocene *Pinus* (pine) pollen grain overlapping a spiny dinoflagellate cyst of the marine *Spiniferites* type (400 ×); both are common in the core. (b–k) Redeposited spores and pollen typical of Tertiary rocks in the Fraser Lowland: (b) *Cedrus* (true cedar) pollen grain (500 ×), a typical Miocene indicator; (c) *Osmunda* (fern) spore; (d) = *Gleichenia* (fern) spore; (e) *Pterocarya* (wingnut) pollen grain; (f) *Pterocarya* grain under phase contrast to highlight the six pores; (g) *Liquidambar* (sweet-gum) pollen grain; (h) *Ulmus/Zelkova* (elm family) pollen in phase contrast; (i) *Carya* (hickory) pollen; (j) *Tilia* (linden or basswood) pollen; (k) extinct form-genus pollen of *Paraalnipollenites*, a Paleocene guide fossil; and (l) *Nudopolis*, an Upper Cretaceous indicator pollen.](image)
Island, probably the Fraser Lowland. The sediment must have been transported in suspension because underflows from the British Columbia mainland coast cannot cross the Strait of Georgia, at depths of 200 m or more, and overtop the sill at 70 m depth at the north end of the inlet. Because very little Fraser River sediment reaches Saanich Inlet today (Thomson, 1994), we argue that the beds are products of very large flows, probably floods that swept through the Fraser Lowland where they eroded Pleistocene sediments and Tertiary sedimentary rocks.

When the gray clay beds were deposited, about 11,000 years ago, Vancouver Island, much or all of the Fraser Lowland, and the Strait of Georgia were ice-free (Clague, 1981; Huntley et al., 2001). The Cordilleran ice sheet had retreated from these areas between a few hundred years to as much as 3000 years earlier. Active glaciers, however, may have persisted until 11,000 cal yr BP in some mountain valleys and possibly in the eastern Fraser Lowland (Kovenan and Easterbrook, 2001, 2002; Friele and Clague, 2002a, 2002b; Kovenan, 2002). Large masses of dead ice were probably present in the British Columbia interior at this time (Fulton, 1969, 1971). For example, the Fraser River valley north of Lillooet was blocked by ice until near the end of the Pleistocene (Ryder, 1976; Huntley and Broster, 1997). This ice impounded a large lake in central British Columbia, termed Glacial Lake Fraser (Clague, 1987; Huntley and Broster, 1997). An ice dam near Spences Bridge in the Thompson River valley likewise impounded Glacial Lake Deadman, which extended north and east to Kamloops (Fig. 1; Fulton, 1969). Smaller glacier-dammed lakes existed in some valleys in the Coast and Cascade Mountains bordering the Fraser Lowland.

<table>
<thead>
<tr>
<th>Core, section, interval (cm)</th>
<th>Depth below seafloor (m)</th>
<th>Position relative to clay beds (m)</th>
<th>$^{14}$C age (yr BP)</th>
<th>Calibrated $^{14}$C age range (yr ago)</th>
<th>CAMS#</th>
<th>Sample material</th>
<th>Taxon</th>
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<tr>
<td>1033B-103D-</td>
<td>6H4, 110</td>
<td>55.5</td>
<td>0.51 aub</td>
<td>10,190±70</td>
<td>10,354–10,929</td>
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<td>0.17 blb</td>
<td>10,700±50</td>
<td>11,053–11,693</td>
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<td></td>
<td>6H6, 13</td>
<td>57.5</td>
<td>0.4 blb</td>
<td>10,710±60</td>
<td>11,050–11,737</td>
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<td>6H6, 88</td>
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**Table 1**

Accelerator mass spectrometer (AMS) radiocarbon ages

<table>
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<tr>
<th>Core, section, interval (cm)</th>
<th>Depth below seafloor (m)</th>
<th>Position relative to clay beds (m)</th>
<th>$^{14}$C age (yr BP)</th>
<th>Calibrated $^{14}$C age range (yr ago)</th>
<th>CAMS#</th>
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<td>11,752–12,411</td>
<td>30,696</td>
<td>Shell</td>
<td>Nuculana fossa</td>
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</table>

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Accelerator mass spectrometer (AMS) radiocarbon ages
These lakes may have drained catastrophically, either individually or in tandem, when their ice dams weakened during deglaciation to the point that they could no longer retain the impounded waters. Jökulhlaups from Glacial Lake Fraser and Glacial Lake Deadman may have discharged many cubic kilometres of water down the Thompson and Fraser River valleys, through the Fraser Lowland, and into the Strait of Georgia. The huge overflow plumes from any such floods would have extended widely over the Strait of Georgia and could have reached into Saanich Inlet, depositing silty clay on the fiord floor.

Definitive evidence of these floods has not yet been found in the Fraser Lowland or Fraser River valley. Much of the flood path across the Fraser Lowland was an arm of the sea at the end of the Last Glaciation (Clague et al., 1982). This seaway later became filled with marine, deltaic, and fluvial sediments (Clague et al., 1982, 1983), consequently the flood deposits would be deeply buried. However, landforms that may have been created by the floods occur on Pleistocene surfaces bordering the Fraser River. Flutes up to 9 m high, 200 m wide, and 2 km long, oriented in a west-northwest direction and eroded into Late Pleistocene glaciomarine sediments, occur at Fort Langley (Figs. 1 and 6; Armstrong and Hicock, 1980). Clague and Luternauer (1982) suggested that a large flood might have produced the flutes, although they did not specify a possible source for the floodwaters.

Jökulhlaup deposits possibly associated with a catastrophic drainage of Glacial Lake Fraser occur in the Fraser River valley north of Lillooet (Fig. 1). The deposits extend over a large area beneath a terrace about 250 m above the Fraser River. They comprise blocks of reddish-brown till up to 10 m across, floating in a chaotic gravel matrix (Fig. 7). The reddish-brown till blocks are derived from outcrops in the Pavilion area in the Fraser River valley about 20 km north of Lillooet.

Any outburst floods must have had a large impact on the lower Fraser valley and Strait of Georgia. Large volumes of sand and gravel probably were deposited along the seaway that extended eastward from the Strait of Georgia across the western Fraser Lowland at the end of the Pleistocene. The flood deposits may form the core of the postglacial fill in this area. Finer flood sediment, perhaps of considerable thickness, also underlies Holocene sediments in the southern and central Strait of Georgia (Conway et al., 2001), and thinner, distal sediments like those in Saanich Inlet could possibly extend farther south and west into Puget Sound and Juan de Fuca Strait. These catastrophic floods were
unique events in the 15,000-year postglacial history of southwestern British Columbia.

5. Conclusion

Two beds of silty clay occur within the dominantly diatomaceous sediments in ODP cores collected from Saanich Inlet in 1996. The silty clay beds are unique in the continuous, 15,000-year sediment sequence. They abruptly overlie, and are gradationally overlain by, indistinctly laminated, diatomaceous mud, and they contain Tertiary pollen, which are exotic to eastern Vancouver Island, and abundant illite-muscovite, which are common minerals in Fraser River sediments. Radiocarbon ages on shells and wood from just above and below the silty clay beds show that they are about 11,000 cal yr old.

We hypothesize that the silty clay beds were deposited during large, sediment-charged floods that swept across the Fraser Lowland just before the end of the Pleistocene. The floods eroded Tertiary rocks and Pleistocene sediments in the Fraser Valley. Some of the entrained sediment was carried in overflow plumes across the Strait of Georgia into Saanich Inlet, where it rained out onto the fiord floor. We attribute the floods to the sudden draining of ice-dammed lakes in the lower Fraser River basin, possibly Glacial Lake Deadman and/or Glacial Lake Fraser.

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References


