NEOTECTONIC INVESTIGATIONS ON WESTERN VANCOUVER ISLAND, BRITISH COLUMBIA (92F/4)

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INTRODUCTION

Interest in the contemporary geodynamic setting of southwestern British Columbia stems from a concern that a large earthquake may impact the major urban centres of the province. Indeed, monitoring of seismic activity in western Canada indicates that numerous smaller magnitude (<M4) intraplate earthquakes affect the southern coastal region annually, and that very small tremors occur daily. Large (M6 to 7+) intraplate earthquakes are frequent, the most recent being the M7.2 event of 1946 near Comox on Vancouver Island. Recently, concern has been expressed that an unprecedented, great (>M8) earthquake could also occur in the eastern North Pacific Ocean near populated areas of British Columbia (Rogers, 1988).

The dire consequences of a great earthquake, as perceived by the public through popular articles (*cf.* Koppel, 1989), are warranted insofar as previous M8+ events elsewhere (*e.g.* M9.5 in Chile, 1960, and M8.6 in Alaska, 1964) have caused considerable property damage and loss of human life. Our understanding of these rare but devastating events has improved considerably during the last few decades. For example, they are now known to occur along zones of interaction between converging lithospheric plates. Commonly referred to as "megathrust" earthquakes, they result from the sudden release of large amounts of strain stored between two locked lithospheric plates (Rogers, 1988). In the case of western Canada, the Cascadia subduction zone west of Vancouver Island marks the interface between the eastward subducting Juan de Fuca plate and the over-riding North American plate. The Cascadia subduction zone shares many of the same attributes as other subduction zones bordering the Pacific Ocean that have experienced megathrust earthquakes in recorded history (Rogers, 1988).

Responding to concern that a megathrust event could effect southwestern British Columbia, the Geological Survey of Canada and the provincial Geological Survey Branch have undertaken integrated geological investigations as part of a neotectonics program. The primary purpose of this research is to locate and interpret the geologic evidence for past earthquakes, and if possible determine the frequency and magnitude of these events. Such information could prove invaluable in formulating and implementing proactive policy and actions for safer building codes, emergency response procedures, as well as general land-use planning.

SETTING

During the summer of 1990, geological investigations were undertaken in coastal areas of southern and western Vancouver Island. The primary objective of this work was to add to, and improve upon, the existing intertidal record of paleoseismicity and sea-level changes documented previously (Clague, 1989; Clague and Bobrowsky, 1990). This report provides details of field activities conducted in the area of Tofino, British Columbia.

Surficial geologic reconnaissance was restricted to the peninsula extending east from the town of Tofino to Grice Bay (Figure 4-3-1, Plate 4-3-1, Table 4-3-1). Marine and glaciomarine sand, silt and clay underlie low-lying areas of the peninsula, and veneers of colluviated till and marine sediments drape bedrock-cored hills. The West Coast fault, which extends in a northwest direction along the peninsula, separates the Pacific Rim Complex to the west from rocks of Wrangellia to the east. The Pacific Rim Complex consists mainly of Jura-Cretaceous mudstone, sandstone and chert, which overlie Triassic volcanics. The Wrangell Terrane comprises a diverse assemblage of Paleozoic and Mesozoic rocks which were metamorphosed during the Late Jurassic (Brandon, 1985).

TABLE 4-3-1
LOCATION OF SAMPLE SITES

Locality	Latitude	Longitude	UTM
90-90	49°04.5′	125°45.0′	BK992393
90-91	49°05.1′	125°50.4′	BK927405
90-92	49°05.7′	125°50.8′	BK922412
90-93	49°05.8′	125°50.9′	BK921420
90-94	49°06.0′	125°51.0′	BK920423
90-95	49°06.5′	125°52.3′	BK905436

RESULTS

Six sites were examined in detail (Figure 4-3-1). Three of these provide good evidence for glaciation of the area. Site PTB90-91 (Plate 4-3-1), located on a prominent topographic high called Radar Hill, consists of well-developed striae etched into glacially polished bedrock. Micro crag-and-tail features associated with the striae suggest ice flow toward 220°.

Section PTB90-92 (Tofino dump), northwest of Radar Hill (Plate 4-3-1), provides a good stratigraphic and sedimentologic record of the last glacial maximum (Figure 4-3-2; Plates 4-3-1 and 2). Basal, crossbedded coarse sand

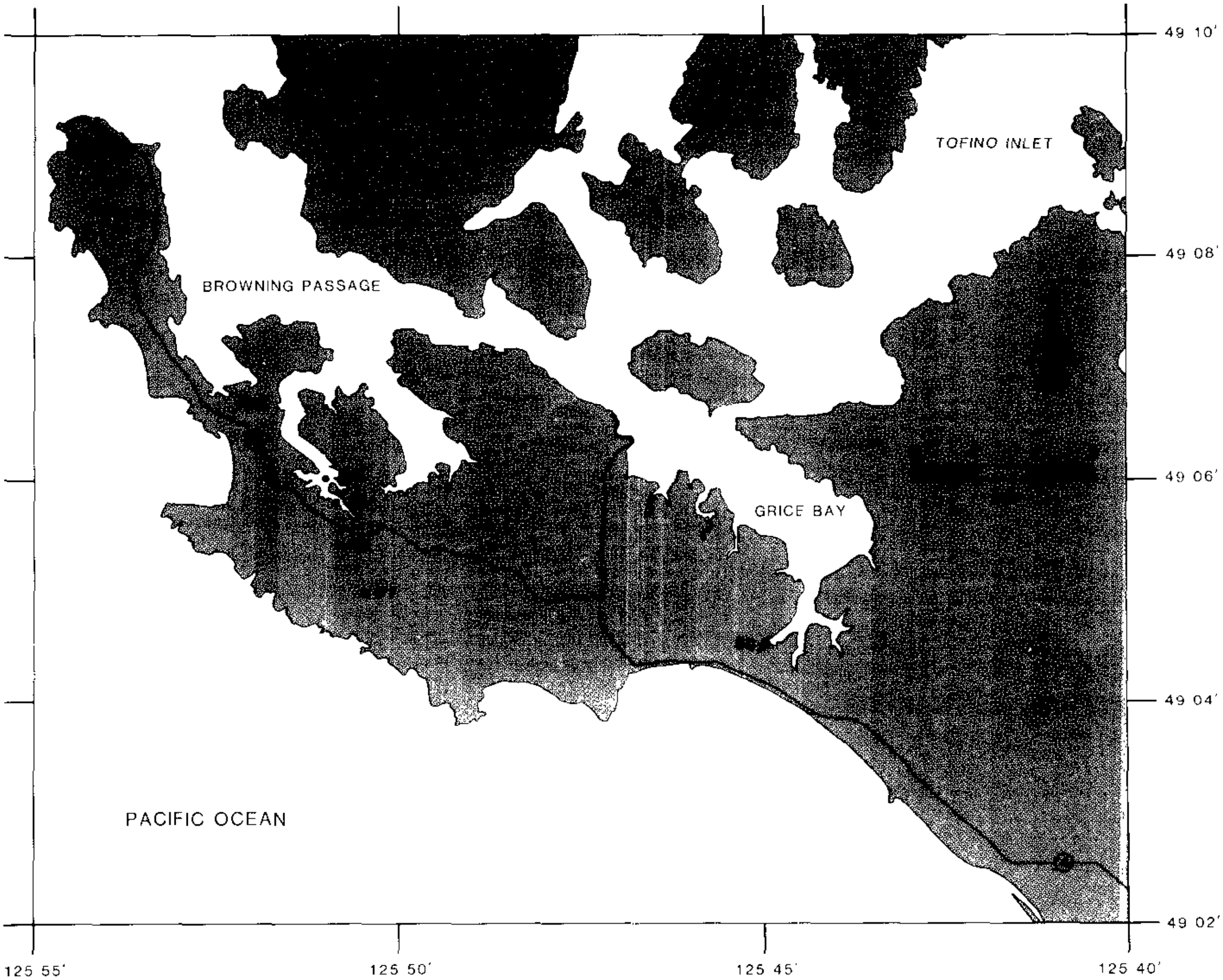

Figure 4-3-1. Location map showing sites in the Tofino area investigated in 1990 as part of the GSB/GSC neotectonics program. Numbers refer to sites discussed in the text. Coordinates for all sites are given in Table 4-3-1.

over 3 metres thick contains minor pebble lenses and ripple-laminated silty clay lenses indicating flow to the west (Unit 1). The sand grades upwards into 3 metres of chaotic, clast-supported, pebble-cobble gravel, supporting boulders up to 40 centimetres in diameter (Unit 2; Plate 4-3-2). Approximately 2 metres of poorly sorted, matrix-supported, crossbedded, sandy granules overlie the gravel (Unit 3). This unit, in turn, is overlain sharply by approximately 2 metres of clast-supported, bouldery cobble gravel (Unit 4). Finally, the gravel is overlain gradationally by approximately 10 metres of stratified, matrix-supported diamicton (Unit 5; Plate 4-3-3). Boulders up to 1.5 metres in diameter are present in the diamicton, and well-rounded pebbles (up to approximately 10 per cent of the sediment) accentuate a well-developed planar fabric. A radiocarbon age of 16 700±150 years B.P. (GSC-2768) on wood (*Pinus contorta*) from the top of Unit 4 at 37 metres elevation indicates the overlying diamicton was deposited during the Fraser Glaciation (Clague *et al.*, 1980). Units 1 to 4 are interpreted to be different facies of advance outwash and ice-contact deposits.

Section PTB90-95 is a 2-metre-high road exposure of banded and locally deformed rhythmites consisting of silty sand and sandy silt. These sediments are interpreted to be glaciolacustrine or glaciomarine in origin, and were deposited during the Fraser Glaciation.

Several upright stumps with laterally extensive root systems up to several metres across are present in Maltby Bay (PTB90-93, 94; Plates 4-3-1 and 4). The stumps appear to be rooted in dense marine or glaciomarine clay and are overlain by up to 2 metres of mud. Level surveying indicated the root boles of the stumps are approximately 0.5 to 1.5 metres below Highest High Water.

Intertidal accumulations were examined in detail in a small inlet of Grice Bay (PTB90-90; Figure 4-3-3). Shovel

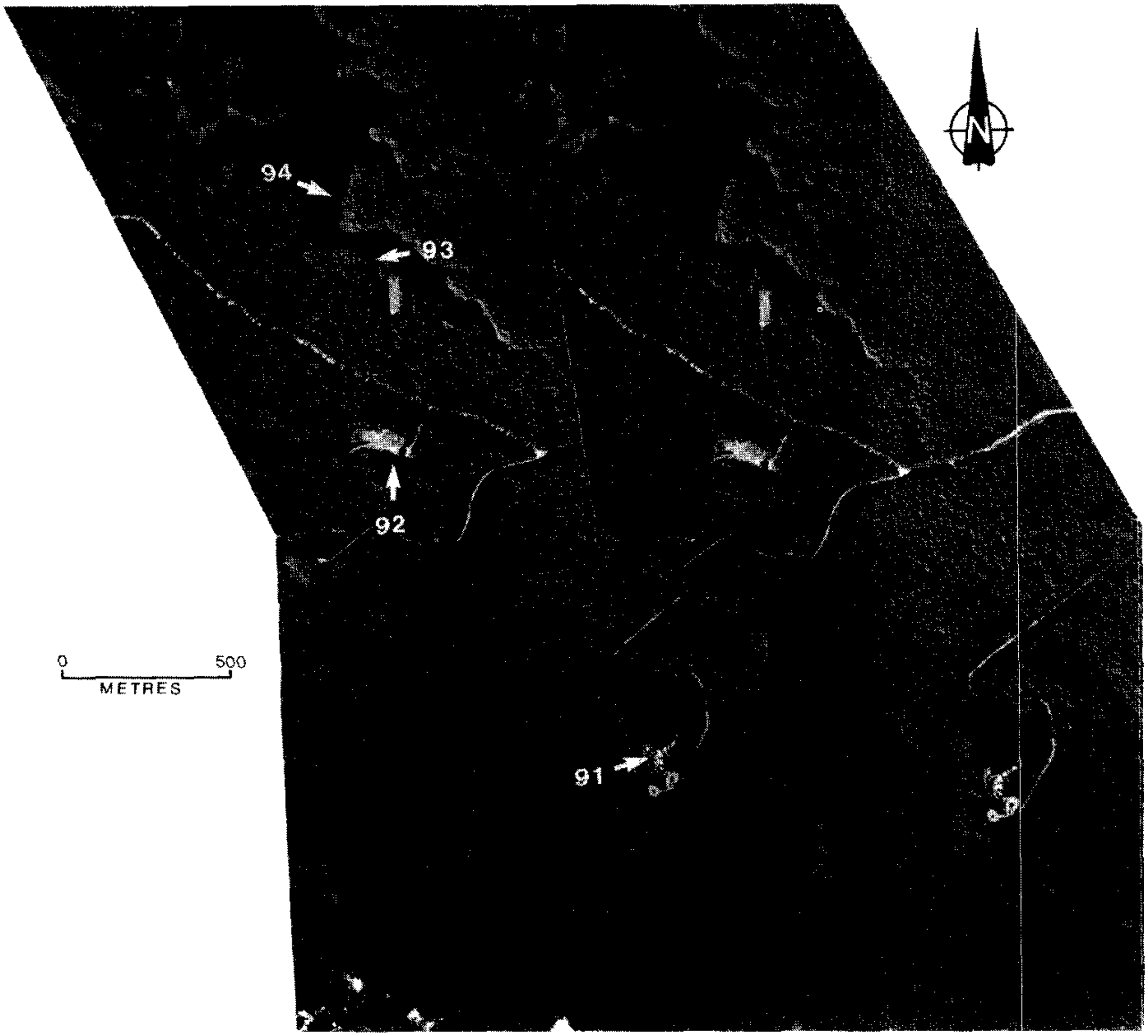

Plate 4-3-1. Photostereogram of Maltby Bay and surrounding area, southeast of Tofino, B.C. Numbered localities correspond to those discussed in text and shown on Figure 4-3-1. (Photographs BC84084-174 and 175).

holes and trenches, tidal-channel sections and cores along two transects provided stratigraphic and sedimentologic information. Cores were obtained using an Oakfield soil corer with a 2.54-centimetre (1″) diameter sampling tube and extension rods capable of reaching over 2 metres in depth. Transect A-A′ consisted of six holes spaced 10 metres apart along a line trending 161° (Figure 4-3-4). Holes were dug to depths of about 25 centimetres and cores were then taken from the base of each hole. Except for some differences in facies thickness, the observed stratigraphy is essentially similar at all six sites. Briefly, the lowest unit in each hole is compact grey mud and silty mud, which in some cases contains marine gastropods and bivalves. Some sand and silt stringers are present in the mud. This unit is overlain by a prominent deposit of massive sand and silty sand, with minor shells, pebbles and cobbles. Organic detritus and silt increase in abundance in the upper part of the unit. The sand unit is gradationally overlain by interbedded muddy peat, silt and organic mud. The upper few centimetres of each hole are exclusively muddy peat. Of particular note is a massive, fine sand bed, 6 to 12 centimetres thick, with sharp contacts, in the upper peaty sediments of Holes 2 and 6 (Plate 4-3-5).

A second, nonlinear transect (B-B′) of holes, cores and tidal-channel sections was established almost perpendicular to the first transect (Figure 4-3-5). Adjoining sites along this transect were 20 to 125 metres apart. The stratigraphy along Transect B-B′, although more complex and variable than that of Transect A-A′, shows several similarities. The basal mud unit was not encountered at all sites, but its local

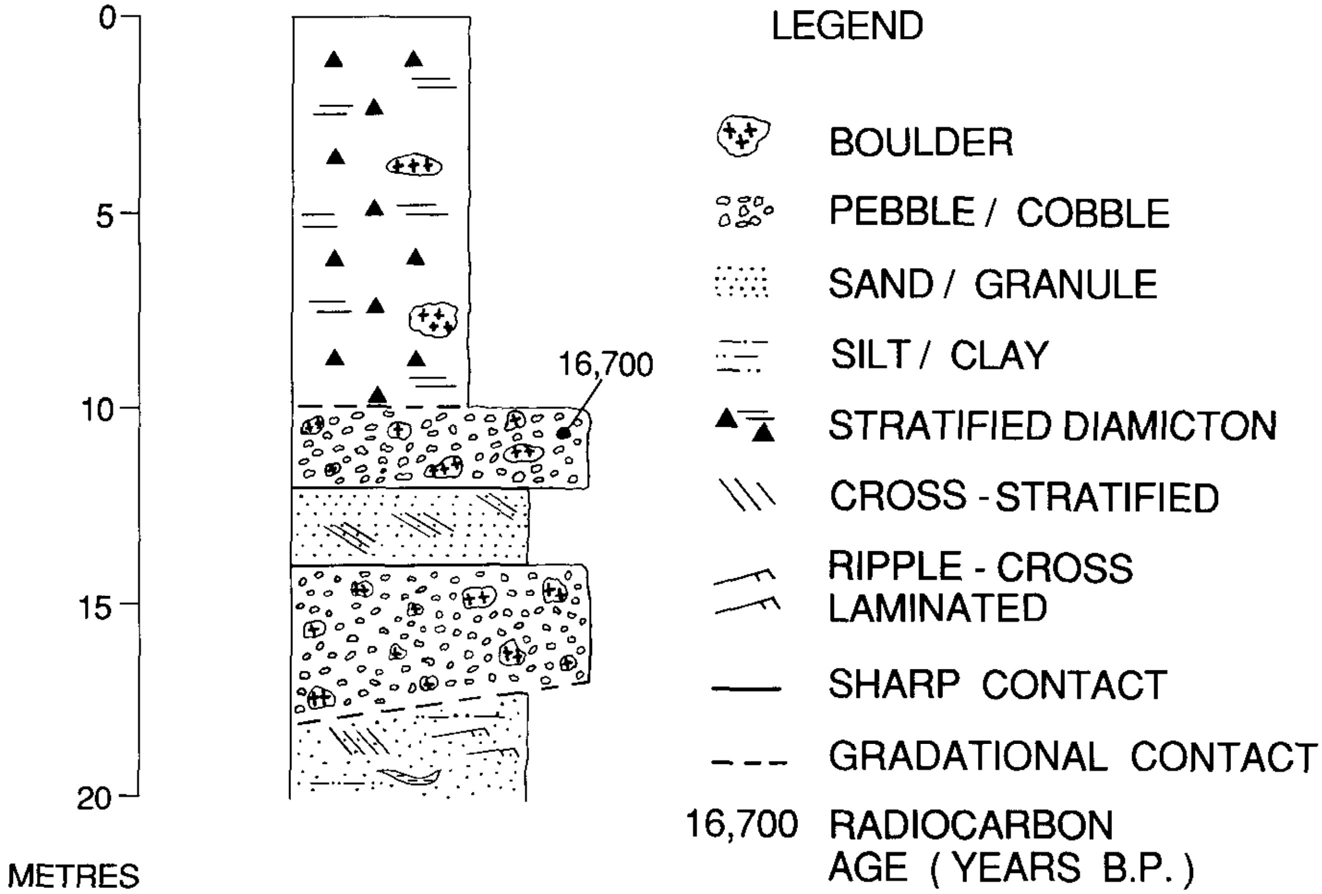

Figure 4-3-2. Composite stratigraphic section of site PTB90-92 (Tofino dump).

Plate 4-3-2. Section PTB90-92 (Tofino dump) showing Units 1, 2, 3 and 4 (*see* text for details). (GSB photograph PTB 90-16-14).

Plate 4-3-3. Stratified diamicton at section PTB90-92 (Tofino dump). Diamicton is >10 metres thick and overlies a sequence of poorly sorted sand and gravel deposits. Boulders up to 1.5 metres in diameter occur in the diamicton. Arrow points to knife. (GSB photograph PTB 90-16-99).

Plate 4-3-4. Stump at site PTB90-94 (Maltby Bay). (GSB photograph PTB 90-15-35).

Plate 4-3-5. View of upper part of Hole 2 of Transect A-A', locality PTB90-90 (Grice Bay), showing clean sand bed (arrow) within muddy organic sediments. White card is 9 centimetres long. (GSB photograph PTB 90-16-17).

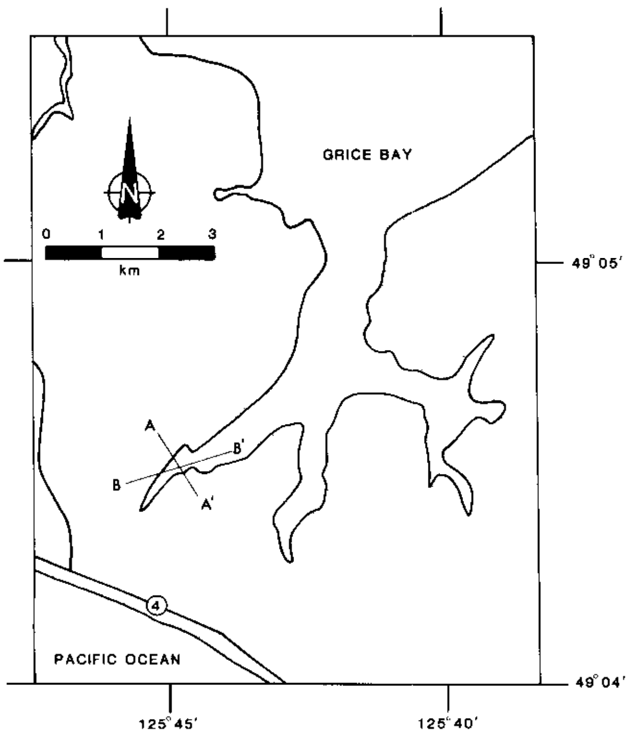

Figure 4-3-3. Locality PTB90-90 (Grice Bay). Locality is centred at the intersection of two transect lines. Lengths of transect lines exaggerated for clarity. Transect A-A' corresponds to Holes 1 to 6 (Figure 4-3-4), and Transect B-B' corresponds to various core and bank sections (Figure 4-3-5).

absence is most likely a function of shallow probing and increasing thickness of the overlying sand unit seaward. The mud commonly contains molluscs and wood fragments. Where observed in its entirety, the overlying sand unit was generally thick, attaining a maximum thickness of 1.6 metres in core 90-117. At some sites, significant amounts of shell occur in the lower part of the sand unit. The sand unit is overlain by alternating beds and lenses of mud, organic silt and muddy peat. Samples for radiocarbon dating and foraminiferal analysis were collected from the bank section at station 90-115. A series of samples for both foraminiferal and diatom study were also recovered from core 90-120.

DISCUSSION

The Pleistocene exposure at the Tofino dump indicates that there was at least one Late Wisconsinan ice advance over the study area sometime after 16 700 years B.P. Ice probably flowed from highlands northeast of the study area, across the peninsula southeast of Tofino, and out into the Pacific Ocean for an indeterminate distance, as interpreted from striations (PTB90-91) and deposits of stratified diamicton (Section PTB90-92). As ice retreated from the area, glaciomarine and marine muds probably accumulated over much of the isostatically depressed area. Subsequent uplift, resulting from isostatic and/or tectonic processes, may have caused the deposition of sandy, nearshore facies in Grice Bay (PTB90-90). Continued uplift during the late Holocene may have isolated Grice Bay from the open Pacific Ocean, causing silt, mud and peat to be deposited on the sand. Accretion of these fine sediments and organics has continued to the present day, essentially uninterrupted, except for deposition of the prominent, thin sand bed observed in several holes along the two transects at PTB90-90.

A genetic interpretation for the thin sand bed at PTB90-90 points to three possible influences: flood, storm, or tectonic. This bed is patchily distributed, massive, lacks grading, displays sharp contacts and appears to thicken seaward. Internal crossbedding, which might reflect oscillatory flow or traction-current transport, is absent. There is no

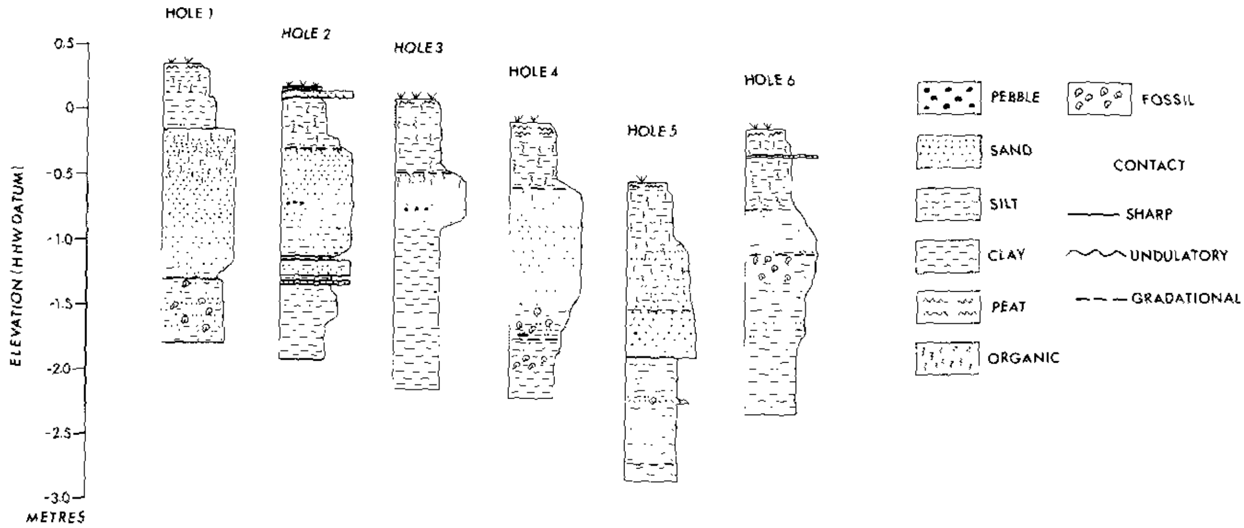

Figure 4-3-4. Stratigraphic sections along Transect A-A', PTB90-90.

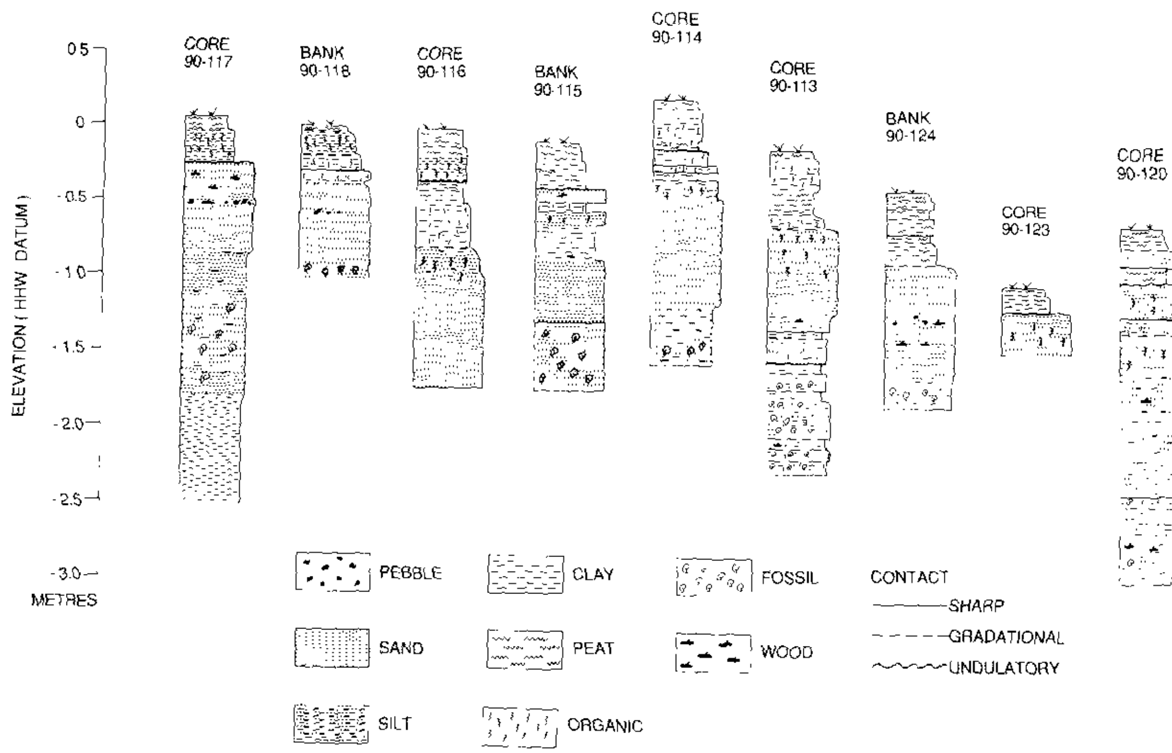

Figure 4-3-5. Stratigraphic sections along Transect B-B', PTB90-90.

significant source of riverine water entering the tidal inlet, ruling out a flood origin. On a geologic scale, severe storm surges are considered frequent events, suggesting that resulting depositional products should be common, where preservation permits; this seems to argue against a storm origin for the sand bed. In a similar setting in northern Oregon, the absence of stratification in sand beds has been cited as evidence against them being flood or storm-generated features (Peterson and Darienzo, 1988). A similar, laterally continuous, ungraded sand bed described from Scotland has been interpreted to be a tsunami deposit (Long *et al.*, 1989). We suggest that the thin sand bed near the top of the Grice Bay sequence may also have been deposited by a tsunami.

Attention focused on large-magnitude earthquakes during the last several years has led to a better understanding of the geologic effects of seismogenic phenomena such as coseismic subsidence, coseismic uplift and tsunamis (*e.g.* Atwater, 1987). For example, sandy units sharply overlying down-dropped peats in tidal sequences in Washington State have been interpreted as products of tsunami-genic earthquakes (Reinhart and Bourgeois, 1988).

To date there is no geologic evidence to support the contention that one or more megathrust earthquakes have occurred during the Holocene near Vancouver Island. However, tsunamis from earthquakes occurring elsewhere in the Pacific Ocean have impacted the British Columbia coast in historic times (Murty, 1977). The March 27, 1964, earthquake centred under Prince William Sound, Alaska (M8.6), generated a tsunami that caused millions of dollars damage to communities on Vancouver Island. (Wigen and White, 1964; White, 1966). Although no tidal records are available for Grice Bay, the tidal station at Tofino, recorded a maximum rise of 2.5 metres during this event (Murty, 1977). It is thus reasonable to conclude that a tsunami may have deposited the thin sand bed near the top of the Holocene sequence at Grice Bay.

The stumps in Maltby Bay are presently undecipherable. Although unquestionably Holocene in age, they could represent relict, submerged soil surfaces (gradual sea level rise or rapid subsidence), organic lag deposits, or could be a product of some recent cultural activity. These stumps and the thin sand bed are the focus of continuing research in this area. In particular, attempts are being made to date these features.

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