Reports

Ice-Free Conditions on the Queen Charlotte Islands, British Columbia, at the Height of Late Wisconsin Glaciation

Abstract. *New radiocarbon dates and plant macrofossil data establish that parts of the Queen Charlotte Islands, British Columbia, were ice-free during and subsequent to the late Wisconsin glacial maximum on the Pacific coast of Canada. A paleoecological investigation of dated sediments at Cape Ball has indicated that a varied flora consisting of terrestrial and aquatic plants was present there about 16,000 years ago. This finding provides support for the existence of a heretofore questioned biotic refugium on the Queen Charlotte Islands during the last glaciation. These results shed new light on problems of glacial chronology, climatic change, biogeography, and archeology along the western margin of North America.*

Many organisms on the Pacific coast of Canada, including some bryophytes, beetles, marine amphipods, birds, mammals, and flowering plants, are characterized by endemism and disjunct distributions (*1–3*). Biologists have long argued that the peculiar distributions of these taxa are the result of long-term survival in glacial refugia, a concept that is incompatible with suggestions by geologists that the entire British Columbia coast was buried under glacial ice at the climax of the last (late Wisconsin) glaciation (*4*). Relatively restricted late Wisconsin glaciation of parts of the British Columbia coast also has been suggested by archeologists in support of their hypothesis that a chain of sea level refugia may have served as a migration corridor for the entry of man into North America (*5, 6*).

The controversy concerning glacial refugia on the Pacific coast has focused in recent years on the Queen Charlotte Islands, a rugged archipelago about 80 km off the north-central coast of British Columbia (Fig. 1). Several endemic taxa are present on the islands (*1, 2*), yet geologists who have worked there concluded that late Wisconsin ice covered the entire landmass, with the possible exception of a few small mountain nunataks that probably were incapable of supporting higher forms of life (*7*). Man may have used these islands as an important link in early coastal travels (*6*). We report here new data relevant to the controversy concerning both the extent of late Wisconsin glaciers and the existence of a biotic refugium on the Queen Charlotte Islands. These data have been obtained through geological and paleoecological studies of late Quaternary sediments exposed in a sea cliff at Cape Ball on eastern Graham Island.

The critical Cape Ball sections (Fig. 2), although only 4.5 m high, provide a nearly continuous sedimentary record extending from the last glaciation to the present. At the base of the sections, glaciomarine stony clayey silt is overlain successively by lodgment till and outwash gravel and sand. The till and outwash are of local, rather than mainland, provenance and probably were deposited by glaciers and meltwater streams issuing from the mountains west and southwest of Cape Ball. These sediments have not been dated directly but possibly are of late Wisconsin age (*8*). If so, at least parts of the lowlands of the Queen Charlotte Islands were covered by mountain glaciers during the last glaciation. Alternatively, if the till and outwash predate the last glaciation, lowland areas on the islands probably were continuously ice-free throughout the middle and late Wisconsin time (*9*).

The upper surface of this drift complex is irregular; troughs or basins up to a few

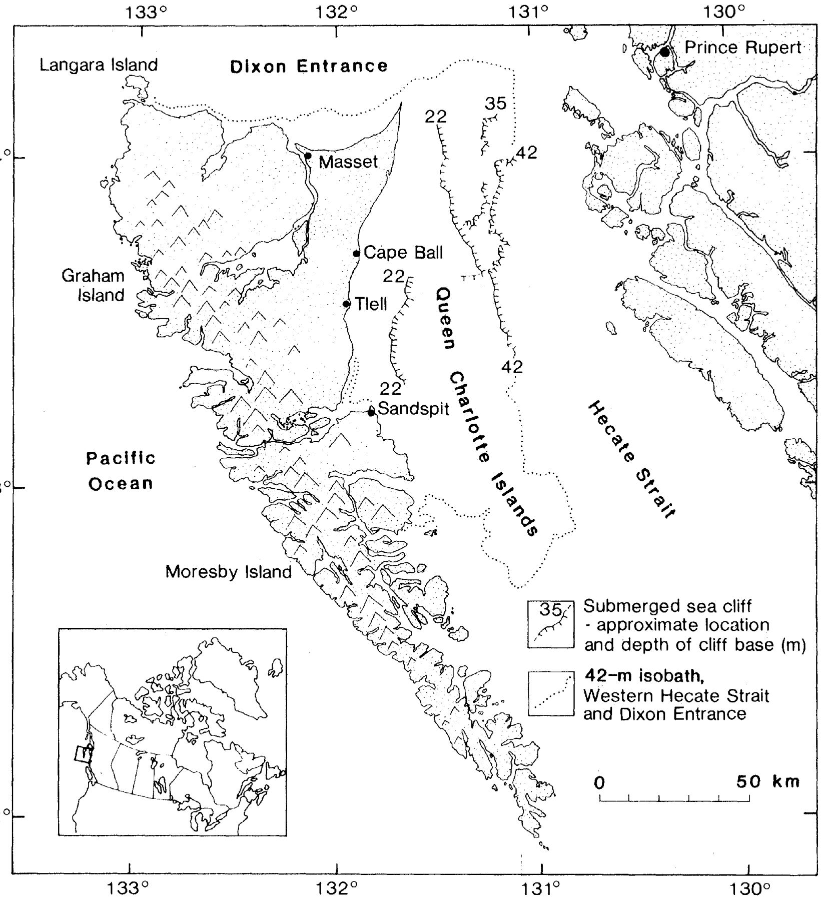

Fig. 1. Index map of the Queen Charlotte Islands and adjacent mainland British Columbia. Also shown are the locations of submerged sea cliffs in Hecate Strait. The 42-m isobath delineates the main areas of Hecate Strait and Dixon Entrance that are shallower than the lowest wave-cut cliff. This shallow submerged platform probably was subaerially exposed during part of the last glaciation (*6, 14*).

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tens of meters wide and 2 m deep occur on the outwash and till. These depressions are filled with laminated sand and clay and massive sandy silt. Radiocarbon dates of 15,400 ± 190 and 16,000 ± 570 years before present (B.P.) (GSC-3319 and GSC-3370, respectively) have been obtained on plant material from the laminated sediments (*10*). These dates provide a minimum age for the underlying drift and for deglaciation of the Cape Ball area. Macroscopic plant remains (Fig. 3) washed from the laminated sand and clay include abundant seeds of *Juncus*, Caryophyllaceae, and *Rumex*. *Potamogeton filiformis* seeds and *Chara* oospores are also present. In contrast, the overlying massive sandy silt contains abundant *Chara* and less abundant *Nitella* oospores, *Callitriche*, and *Ranunculus aquatilis* seeds. *Salix reticulata* leaf remains and one complete *Picea* needle were recovered from the middle of the sandy silt unit. *Juncus*, Caryo-

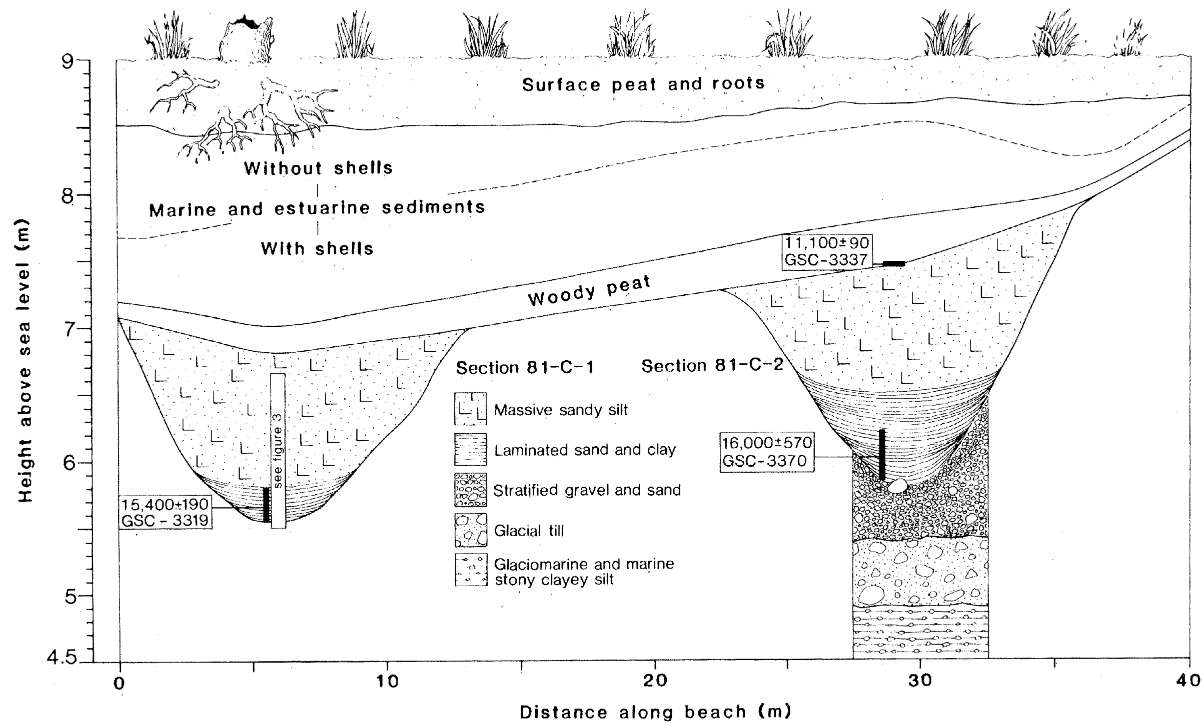

Fig. 2. Quaternary stratigraphy of the studied sea cliff sections at Cape Ball. Elevation datum is mean sea level; the base of the cliff is 0.5 to 1 m above high tide level.

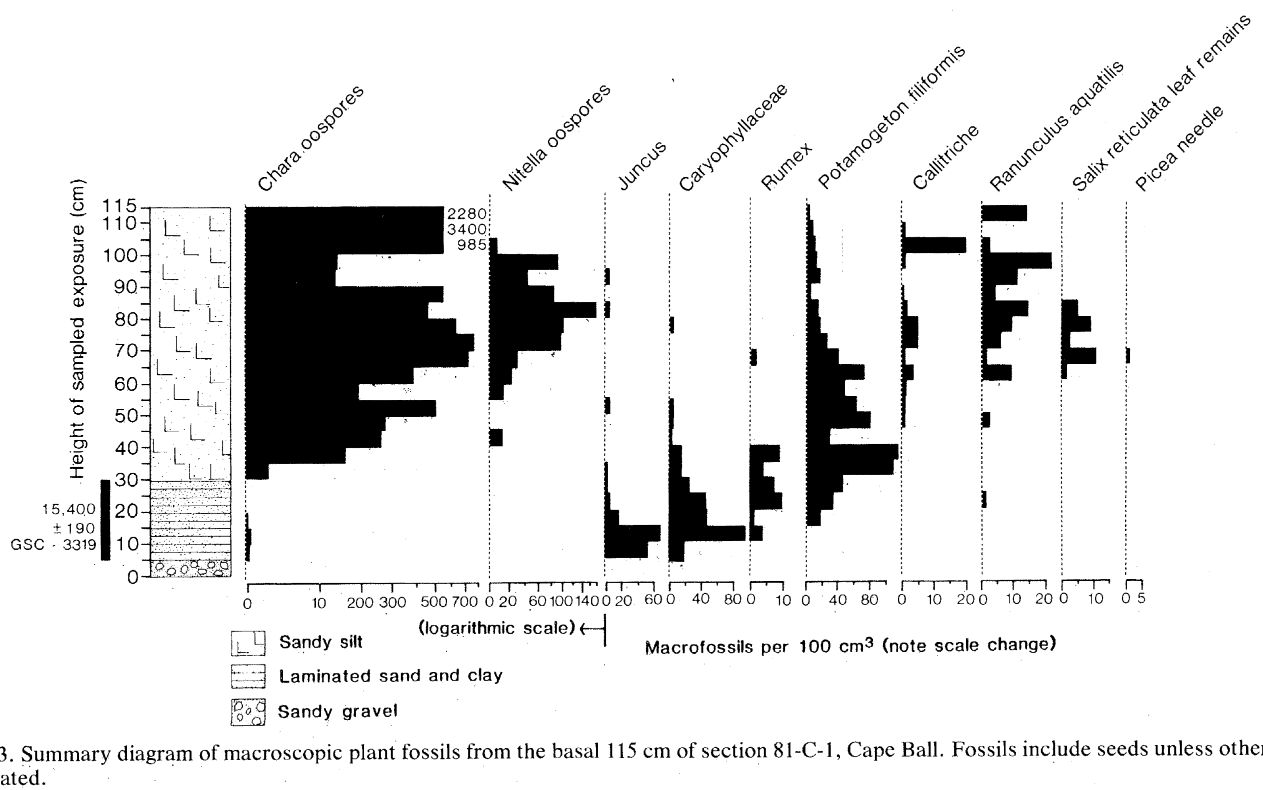

Fig. 3. Summary diagram of macroscopic plant fossils from the basal 115 cm of section 81-C-1, Cape Ball. Fossils include seeds unless otherwise indicated.

phyllaceae, and *Rumex*, major constituents of the laminated clay and sand, are rare in the massive sandy silt, except near the base of the unit. *Potamogeton filiformis* seeds are abundant in the massive sediments but decrease upward. The fact that there are no foraminifera in either the laminated or massive sediments suggests that shorelines on eastern Graham Island 15,000 to 16,000 years ago probably were no higher than at present.

A woody terrestrial peat bed overlies the drift complex and the organic-rich mineral sediments described above. At the study site, the base of this peat is 11,100 ± 90 years old (GSC-3337), but radiocarbon dates as old as 12,400 ± 100 years B.P. (GSC-3112) have been obtained from the peat at other localities on eastern Graham Island (*8, 11*). Logs, tree stumps in life position, and *Picea sitchensis* cones indicate forested conditions at Cape Ball during the later phase of peat deposition. The peat bed locally extends across the present intertidal platform below sea level, an indication that the level of the sea relative to the land was lower at the close of the Pleistocene than at present. In contrast, at the same time, shorelines on the British Columbia mainland coast east of the Queen Charlotte Islands were as much as 200 m above present sea level (*12*). This difference is the result of variable isostatic depression of the crust by late Wisconsin glaciers. On the mainland coast, glacier ice was sufficiently thick (up to about 2000 m) that isostatic depression more than compensated for lower eustatic water levels, and consequently lowland areas were inundated. In contrast, in the vicinity of Graham Island, eustatic lowering dominated over glacio-isostatic depression, indicating a thin localized ice cover. A large part of western Hecate Strait probably was subaerially exposed during latest Pleistocene time, as shown by the presence of what are thought to be submerged sea cliffs and drowned stream valleys to about 42 m below sea level east of Graham Island (Fig. 1).

The peat bed at the study site is overlain by marine and estuarine sediments deposited during a transgression which culminated about 7500 to 8000 years ago when the sea was about 15 m higher relative to the land than at present (*12*). Subsequent marine regression during middle and late Holocene time permitted recolonization of formerly submerged lowland areas and led to the accumulation of the surface peat at Cape Ball.

Several important implications emerge from these studies. The Cape Ball area was ice-free 15,000 to 16,000 years ago at the time of maximum late Wisconsin glaciation in southern British Columbia (*9, 13*) and the area remained unglaciated continuously thereafter. The variety and abundance of plant macrofossils in the laminated clay and sand unit at Cape Ball argue that there was a well-established flora there at 16,000 years B.P. Because present land areas bordering the Queen Charlotte Islands probably were covered by glaciers at this time, the flora recorded at Cape Ball most likely persisted somewhere on the islands throughout the last glaciation, perhaps on a presently submerged platform in western Hecate Strait or on mountain nunataks. The low sea levels necessary to form such a subaerial surface imply only minor glacio-isostatic depression of the crust, which supports our contention that late Wisconsin ice on the Queen Charlotte Islands was thin and localized.

The climatic regime on the Queen Charlotte Islands during late Pleistocene time probably was moderately oceanic and cooler than the present but was not so severe as to preclude the survival of biota. The former coexistence near sea level of *Salix reticulata*, which is now restricted to high elevations on the Queen Charlotte Islands, and *Callitriche*, a low-elevation aquatic taxon (*1*), supports this conclusion and raises the possibility that late glacial landscapes at the edges of the Cordilleran ice sheets were able to accommodate a more diverse biota than modern environments.

The presence of a refugium on northeastern Graham Island indicates that land areas on the islands were available for possible occupation by early man. Only after more studies of this kind have been carried out in other parts of the Pacific coast of northwestern North America can we assess the importance of past ice margin positions in shaping both modern biotic and cultural patterns.

BARRY G. WARNER
ROLF W. MATHEWES
Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada
JOHN J. CLAGUE
Geological Survey of Canada, 100 West Pender Street, Vancouver, British Columbia V6B 1R8, Canada

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15. Radiocarbon dates were provided by W. Blake, Jr. (Geological Survey of Canada). R. G. Long assisted in the field. We thank the Province of British Columbia, Ministry of Parks and Housing, for giving us permission to collect samples in Naikoon Provincial Park, and in particular we appreciate the cooperation of R. Roos. We thank W. B. Schofield and J. M. White who read a draft of the manuscript. This study was supported in part by grant A3835 from the Natural Sciences and Engineering Research Council of Canada.

24 May 1982; revised 22 July 1982

Chemical Composition of Acid Fog

Abstract. *Fog water collected at three sites in Los Angeles and Bakersfield, California, was found to have higher acidity and higher concentrations of sulfate, nitrate, and ammonium than previously observed in atmospheric water droplets. The pH of the fog water was in the range of 2.2 to 4.0. The dominant processes controlling the fog water chemistry appear to be the condensation and evaporation of water vapor on preexisting aerosol and the scavenging of gas-phase nitric acid.*

In the fall of 1981, a field study was initiated to determine the chemical composition of fog water in the Los Angeles basin. Results show that the fog water is significantly more acidic and concentrated with respect to chemical composition than cloud and rain water collected in southern California. Liljestrand and Morgan (*1*) determined the chemical composition of rain in Los Angeles and reported that light, misting rainfalls had the highest acidity (*2*). Earlier fog water studies (*3–5*) in nonurban environments have reported concentrations of major

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