Holocene history of Hubbard Glacier in Yakutat Bay and Russell Fiord, southern Alaska

David J. Barclay*
Department of Geology, State University of New York College at Cortland, P.O. Box 2000, Cortland, New York 13045, USA
Parker E. Calkin
Institute of Arctic and Alpine Research, University of Colorado, 1560 30th Street, Campus Box 450, Boulder, Colorado 80309, USA
Gregory C. Wiles
Department of Geology, College of Wooster, Wooster, Ohio 44691, USA

ABSTRACT

Stratigraphic and geomorphic data defined by radiocarbon ages, tree-ring dates, and historical observations provide evidence of three major Holocene expansions of Hubbard Glacier. Early in each advance the Hubbard Glacier margin blocked Russell Fiord to create Russell lake, raising base level and causing stream beds and fan deltas throughout the Russell drainage basin to aggrade. Each Hubbard Glacier expansion continued with an ice lobe advancing through Disenchantment and Yakutat Bays in the west, and an eastern lobe advancing into Russell Fiord.

The earlier two Holocene expansions were, respectively, under way at 7690 and 5600 calibrated yr B.P., and each advance culminated more than 1 k.y. later. The late Holocene advance was under way by 3100 yr ago and reached ~13 km farther south in Russell Fiord than the preceding two expansions. Late Holocene deglaciation of Yakutat and Disenchantment Bays was complete before A.D. 1791; Nunatak Glacier flowing from névés east of Russell Fiord became the primary ice source to the Russell Fiord lobe at or before this date. Ice retreat from the southern end of Russell Fiord began in the late eighteenth century and the penultimate Russell lake drained ca. A.D. 1860.

The relatively slow advances and more rapid retreats of Hubbard Glacier are consistent with the model of the iceberg-calving glacier cycle. Hubbard Glacier is currently advancing and will likely reestablish Russell lake in the near future, affecting local fisheries. However, glacier lobes are unlikely to reach the area of the town of Yakutat, built on late Holocene glacial deposits, in the next 1 k.y.

Keywords: Fan deltas, glacial geology, glacial lakes, tidewater glaciers, Yakutat Bay.

INTRODUCTION

Hubbard Glacier at the head of Yakutat Bay, southern Alaska, is the longest iceberg-calving tidewater glacier in North America. Gradual advance during the twentieth century led to the terminus blocking the mouth of Russell Fiord in 1986, turning this tributary fjord arm into a 224 km² ice-dammed lake (Mayo, 1988a, 1988b, 1989). Although the ice and sediment dam failed after five months, Hubbard Glacier is predicted to continue its advance and establish a more permanent Russell lake in the near future (Trabant et al., 1991; Krimmel and Trabant, 1992). If this scenario is realized, lake drainage would pass through a 39-m-elevation spillway at the south end of the Russell basin, damaging a valuable salmon fishery and causing flooding around the Yakutat airport. Continued advance of Hubbard Glacier may eventually threaten the area of the town of Yakutat, built on late Holocene glacial moraines and outwash at the mouth of Yakutat Bay.

In this paper we document prior occurrences of Russell lake and fluctuations of Hubbard Glacier during Holocene time. This glacial history is based on stratigraphy and landforms within the Russell Fiord drainage basin, supplemented by data from the shores of Yakutat and Disenchantment Bays and adjacent areas of the Yakutat foreland. Temporal control is provided by 54 radiocarbon ages and tree-ring and historical records for most recent events.

Setting

Yakutat Bay and its tributary fjords extend almost 60 km inland from the northeastern Gulf of Alaska coast (Figs. 1 and 2). Yakutat Bay marks the western edge of the Yakutat foreland, a low relief area composed mostly of unconsolidated Quaternary sediments that in places are more than 100 m thick (Yehle, 1979). Russell and Nunatak fiords as well as Disenchantment Bay (Fig. 2) are cut through weakly metamorphosed sedimentary rocks of the Cretaceous Yakutat Group (Tarr and Butler, 1909; Miller, 1961; MacKevett and Plafker, 1970); the peaks of the main mountain massifs in this area are at elevations of 1000–1500 m. Farther north beyond the study area, the high peaks of the Saint Elias Mountains are higher than 4000 m and are formed of igneous and high-grade metamorphic rocks (MacKevett and Plafker, 1970).

Fjord segments and glacial valleys have preferentially formed along the strike-slip Fairweather and Boundary faults that strike north-northwest across the northern edge of the study area. These are major features of the Pacific–North American plate boundary and converge with the east-trending Chugach–Saint Elias thrust fault system just north of the terminus of Hubbard Glacier (Plafker et al., 1978, 1994). Seismic activity around Yakutat is high; five earthquakes of magnitude 7.0 or more shook the area between 1893 and

*E-mail: barclayd@cortland.edu.

GSA Bulletin; March 2001; v. 113; no. 3; p. 388–402; 11 figures; 1 table.

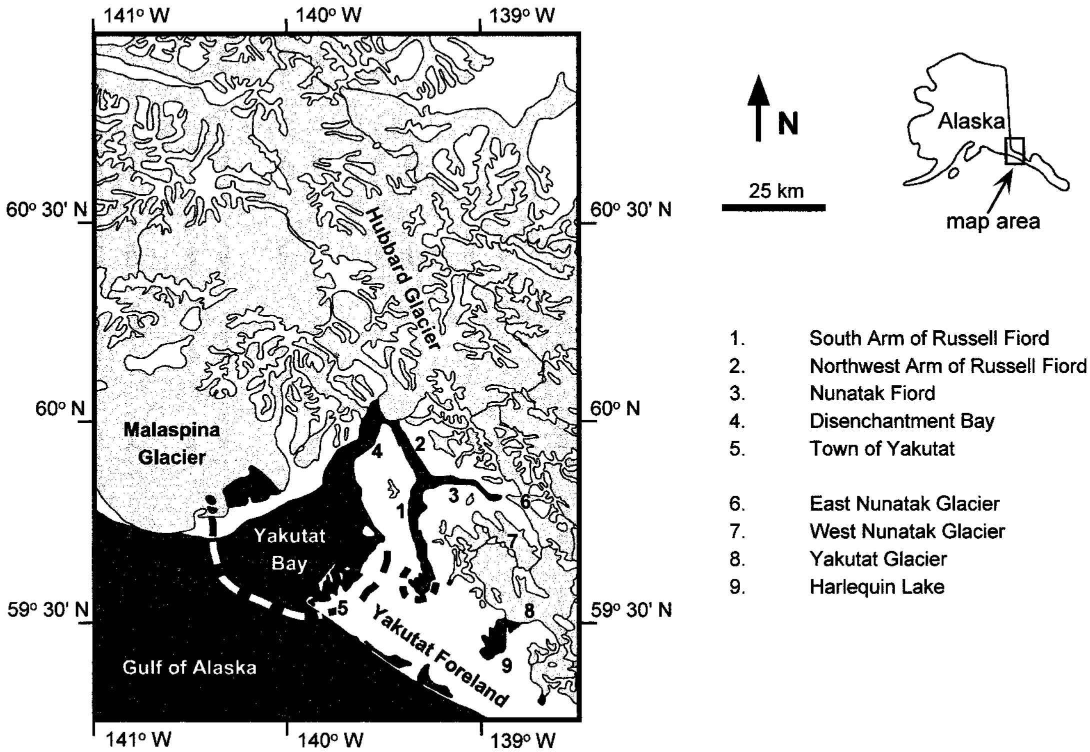

Figure 1. Location map of the Yakutat region, southern Alaska. Based on U.S. Geological Survey Yakutat and Mount St. Elias sheets, 1:250 000 series, 1959 (revisions in 1982 and 1983). Dashed lines indicate Holocene ice limits of Hubbard Glacier. Light shade is glacial ice, dark shade is water.

1975 (Yehle, 1979). Four of these earthquakes occurred in 1899 and 1900, causing several meters of coseismic uplift of the area between Yakutat Bay and Russell Fiord (Fig. 2). A local maximum of 14.4 m of uplift occurred in Disenchantment Bay, while coseismic settling of unconsolidated deposits resulted in several meters of subsidence in other areas (Tarr and Martin, 1912; Plafker and Thatcher, 1982). Earlier changes in relative sea level in the Yakutat area due to tectonic and glacioisostatic effects remain largely unresolved.

The climate of the area is maritime; the town of Yakutat (Fig. 1) records mean temperatures of −3.1 °C in January and 11.9 °C in July, and 3550 mm of precipitation annually (Alaska Climate Research Center, 1997, unpublished data). Heavy snowfall year-round in the surrounding mountains nourishes some of North America's most extensive and dynamic glacier complexes. Eight glaciers longer than 15 km together with 16 shorter named tongues drain to the shores of Yakutat Bay and its tributary fjords (Figs. 1 and 2).

The Yakutat area hosts dense coastal forests of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*). Mountain hemlock (*Tsuga mertensiana*) is also present, particularly at higher elevations and within muskeg tracts (Heusser, 1960; Peteet, 1991). Recently disturbed or deglaciated land is initially colonized by thickets of alder and willow, and the succession generally proceeds through a Sitka spruce subclimax to a western hemlock−dominated climax (Cooper, 1923; Heusser, 1960). However, within the inner fjords, dense thickets of alder occupy land that has been ice free for hundreds of years, suggesting that complete succession to climax Alaskan coastal forest is progressing very slowly in these areas.

Previous Studies

The first geologist to visit the Yakutat area was I.C. Russell, who in 1890 explored Yakutat and Disenchantment Bays and a year later entered the fjord that was subsequently named after him (Russell, 1891, 1893). Detailed studies of the region commenced with the visit of G.K. Gilbert in 1899 and were continued, primarily by R.S. Tarr and L. Martin, through to 1913. During this early period, investigations focused on bedrock geology (Tarr, 1906; Tarr and Butler, 1909), effects of the 1899 earthquakes (Tarr and Martin, 1906a, 1912), glacial surges (Tarr, 1907), and general glacial processes, histories, and regional physiography (Gilbert, 1904; Tarr and Martin, 1906b, 1907, 1914; Blackwelder, 1907, 1909; Tarr, 1909; von Engeln, 1911).

Pleistocene glacial features in the Yakutat area located beyond Holocene ice limits (Fig. 1) have been noted by a number of workers. Yehle (1979) suggested a glacial origin for topographic surfaces between 400 and 670 m elevation along the mountain front northeast and east of the town of Yakutat. Submarine features of possible glacial origin on the continental shelf seaward of Yakutat Bay were described by Molnia and Carlson (1978) and Carlson et al. (1982). Molnia (1986) synthesized these offshore data with onshore core, stratigraphic, and geomorphic evidence in a model of development of the Yakutat foreland from the late Wisconsinan through the Holocene. Peteet (1991) and Shephard (1995) suggested a glacial origin for the topography of the Pike Lakes area, 10 km southeast of Russell Fiord (Fig. 2). While these studies attest to extensive Pleistocene glacial action in the Yakutat area, the absence of radiometric ages older than about 10 ka leaves timing of Wisconsinan glacial events around Yakutat uncer-

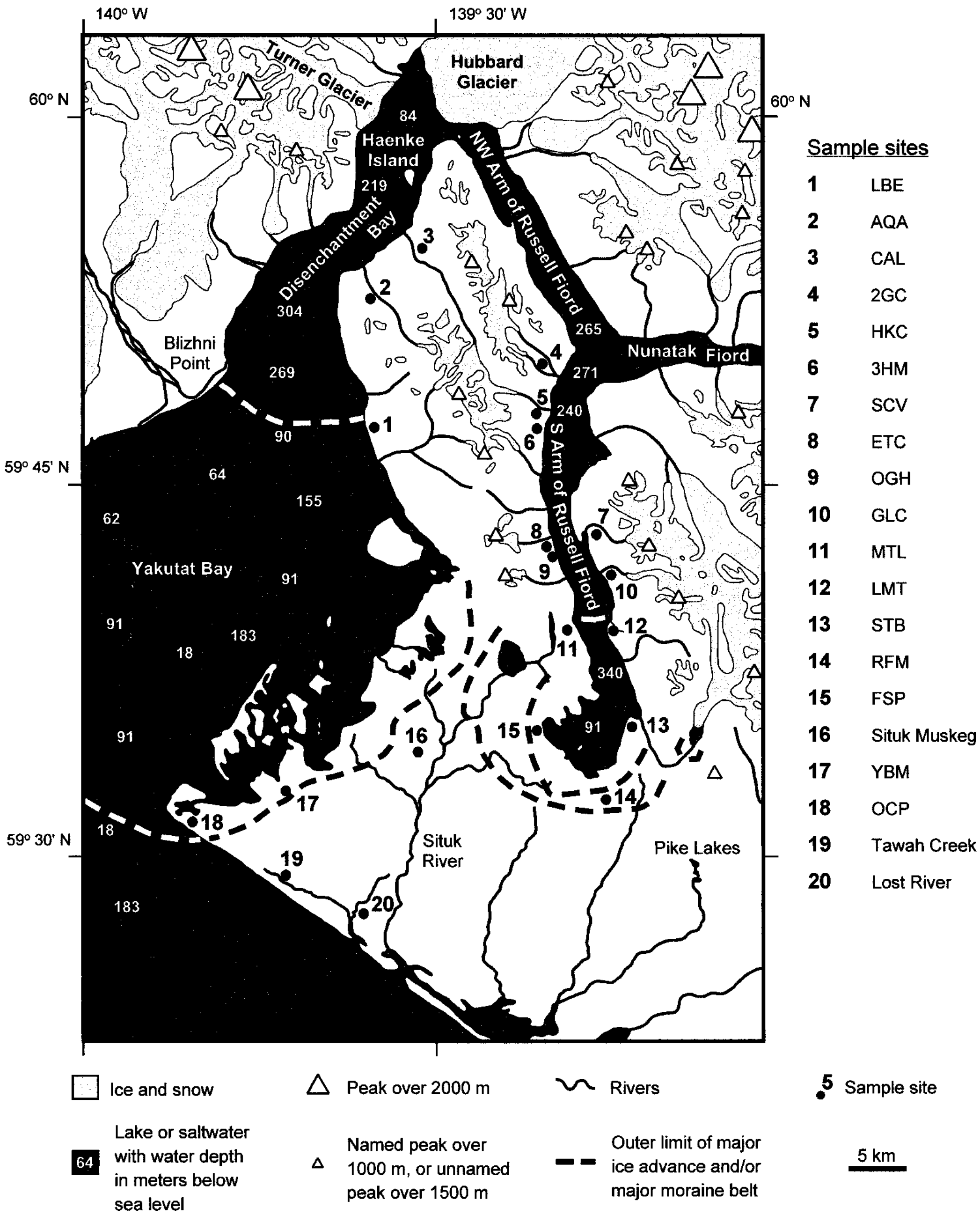

Figure 2. Location map of the study area. Based on U.S. Geological Survey Yakutat sheet 1:250 000 series, 1959 (revision in 1982), and NOAA 1:80 000, Yakutat Bay chart, 1990. LBE—Logan Beach; AQA—Aquadulce Creek; CAL—Calahonda Valley; 2GC—Two Gorge Creek; HKC—Hendrickson Creek; 3HM—Three Hummingbird; SCV—Shelter Cove; ETC—East Tebenkoff Creek; OGH—Organic High; GLC—Glacier Creek; MTL—Mountaintop Lake; LMT—Limit Bluffs; STB—Stump Bluffs; RFM—Russell Fiord Moraine; FSP—Forest Service Path; YBM—Yakutat Bay Moraine; OCP—Ocean Cape.

tain. However, a general estimate of retreat from late Wisconsinan ice stands may be made by consideration of other glaciers along the northeastern Gulf of Alaska coast, which had retreated to near modern positions by 13 500 yr B.P. (Mann and Hamilton, 1995).

Prior investigations of the Holocene glacial history of the Yakutat area have mostly been conducted at a reconnaissance level. Plafker and Miller (1958) suggested that Hubbard Glacier expanded to the mouth of Yakutat Bay between 970 and 1290 yr B.P., and a later readvance culminated at Blizhni Point (Fig. 2) between A.D. 1700 and 1791. Two terminal moraines enclosing the southern end of Russell Fiord were identified by Miller (1961) in a preliminary geologic map of the Yakutat area. Wright (1972) and Carlson (1989) detailed submarine glacial features in Yakutat and Disenchantment Bays. Evidence for Russell lake existing at 6310 and 4890 yr B.P.

were noted at the East Tebenkof Creek site (ETC in Fig. 2) in the South Arm of Russell Fiord (G. Plafker, 1987, written commun.; Mayo, 1988a; J. Clague, 1995, written commun.). Kaiser (1993) used tree-ring-width patterns from southern Russell Fiord to investigate possible occurrences of Russell lake prior to the 1986 damming. A preliminary glacial history and surficial geologic map of the Russell Fiord area was developed by King (1995).

Methods

The primary temporal control in this study (Table A1) was provided by 45 radiocarbon ages from our research together with 9 ages from other workers. Ages were converted to calendar years using the bidecadal dendrocalibration curve of Stuiver and Pearson (1993) in the CALIB 3.0.3 routine (Stuiver and Reimer, 1993). All radiocarbon ages used in this paper are expressed in calibrated years before present (cal yr B.P.), except for ages from the past millennium, which are in calibrated years A.D. (cal A.D.) to allow comparison with historical and tree-ring dates.

Ages of trees growing on moraines and glaciated surfaces were used to estimate minimum dates of ice retreat (Lawrence, 1950); problems and assumptions inherent in this technique were discussed in Wiles et al. (1996). Because trees were cored at various heights above the ground surface, depending on the ease of access and amount of basal flare of the trunk, all tree-ring ages in this paper have been adjusted to an age of the tree at the base using a growth-height relationship of 20 cm/yr. This relationship was determined for fast-growing Sitka spruce and so may underestimate the actual time taken by a tree to grow to the height of coring. Ecesis intervals, the elapsed time between availability of a surface and the germination of trees on that surface, are poorly understood in the Yakutat area and so have not been added to tree ages given in the text.

Historical observations by European explorers in the Yakutat area began in the late eighteenth century. We use these early records together with the detailed observations and photographs by Russell (1891, 1893), Tarr (1909), Tarr and Martin (1914), Field (1975), and A. Post (1994, unpublished data in personal commun.) to supplement our stratigraphic and geomorphic evidence of glacial fluctuations.

Our field studies were undertaken between 1994 and 1998. Absolute elevations were primarily determined by barometric altimeter and

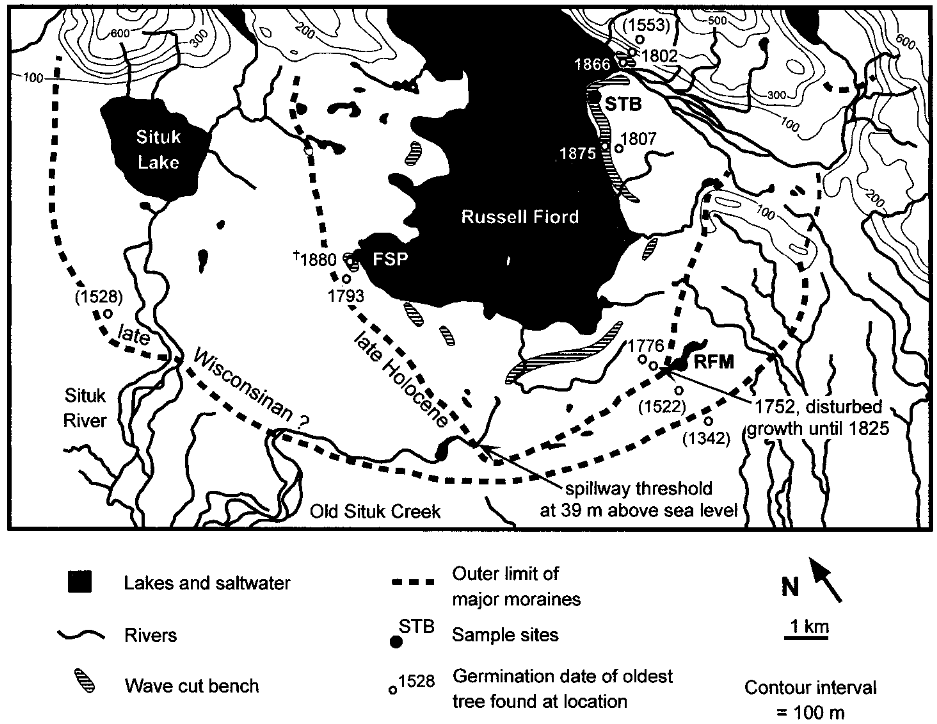

Figure 3. Southern end of Russell Fiord. Based on U.S. Geological Survey Yakutat (C-4) Quadrangle 1:63 360 series, 1959 (revision in 1973). Tree germination dates in parentheses are from trees on probable late Wisconsinan deposits and should not be interpreted as the true age of these substrates. Dagger indicates date from Kaiser (1993). For abbreviations, see Figure 2 caption.

may be considered accurate to within 5 m; reoccupation of sites on different days and in different years enabled detection of errors associated with changes in barometric pressure. A closed-loop survey with a Brunton pocket transit was used to constrain elevations at the East Tebenkof Creek site to within 1 m. All elevations are given relative to modern mean high water.

PRE-HOLOCENE EXPANSION OF HUBBARD GLACIER

The southern end of Russell Fiord is rimmed by two terminal moraines (Figs. 2 and 3). From the air, the outer of these morainal loops appears as a belt of interconnected muskeg, kettles, and low ridges encircling a zone of drumlinized and fluted ground moraine. These latter features indicate that ice flowing from Russell Fiord spread radially as it left the confines of the mountains. From ground inspection the moraine has low and subdued relief with slopes typically ~5°. In some areas of muskeg there is no moraine relief at all, but arcuate chains of meter-sized boulders outline the former ice boundary.

This subdued morphology contrasts markedly with the fresh character of the inner moraine loop at the southern end of Russell Fiord and the moraine ridges fringing the east shore of Yakutat Bay, all of which date to the late Holocene. Evidence from within the present Russell Fiord drainage basin suggests that expansions of Hubbard Glacier in the early and middle Holocene only reached partly down the South Arm. We suggest that the outer Russell Fiord moraine is late Wisconsinan age; this is when glaciers throughout southern Alaska last extended beyond Holocene ice limits (Mann and Hamilton, 1995). However, it is unclear whether this outer Russell Fiord moraine marks the late Wisconsinan maximum or a recessional stand following an advance seaward of the modern Gulf of Alaska shoreline.

HOLOCENE EVENTS IN RUSSELL FIORD

Early to Middle Holocene Russell Lake and Advance of Hubbard Glacier

Evidence for early to middle Holocene events in Russell Fiord are best exposed in the

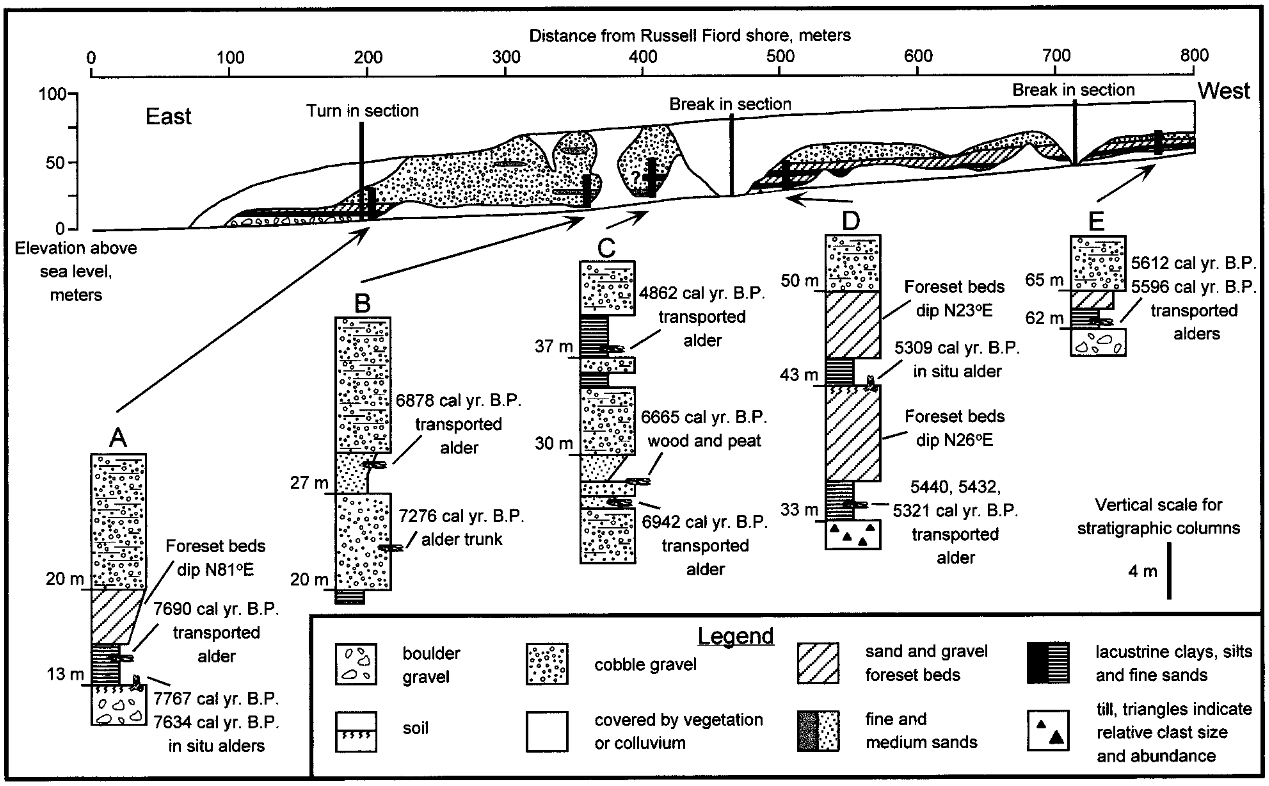

Figure 4. Stratigraphy and radiocarbon ages at the East Tebenkof Creek site (ETC). See Figure 2 for location. All elevations are above modern sea level.

East Tebenkof Creek stream cut (ETC in Figs. 2 and 4). Here, the lowest stratigraphic unit is a poorly sorted boulder gravel with subangular clasts derived from adjacent bedrock of the Yakutat Group (Fig. 4, section A). This unit is interpreted to be the deposit of an early Holocene fan delta that we presume was graded to tidewater.

The basal boulder gravel unit is overlain by 1.5 m of rhythmically bedded fine sand, silt, and clay (Fig. 4, sections A and B). Dropstones of crystalline lithologies from the Saint Elias Mountains within this lacustrine unit suggest that iceberg-rafted debris reached into the South Arm of Russell Fiord, an unusual occurrence today, and support interpretation of this flooding surface as the result of Hubbard Glacier damming the mouth of Russell Fiord. The lacustrine sediments grade vertically into steeply dipping sand and gravel foreset beds overlain by gravel topset beds (Fig. 4, section A), indicating progradation of the fan delta at the East Tebenkof Creek site out into the new, higher water level of Russell lake. The topset-foreset contact of this deltaic package is fairly constant along the exposure at 20 m above sea level; this contact marks the water level in this early to middle Holocene Russell lake and was probably controlled by a spillway cut through the late Wisconsinan moraine at the southern end of Russell Fiord (Fig. 3).

The date of this flooding event is provided by ages of alder stumps in growth position at the contact of the fan delta boulder gravel and the overlying lacustrine unit. Two such stumps at the East Tebenkof Creek site (Fig. 4, section A) have radiocarbon ages that intercept the calibration curve at 7767 and 7634 cal yr B.P., while a similar age of 7673 cal yr B.P. was obtained from wood in an identical setting at the Organic High site to the south (Fig. 2). Averaging these three samples gives an age of about 7690 cal yr B.P. for this first Holocene damming of Russell Fiord. Ages from wood incorporated into debris flow and fan delta deposits at, respectively, the Glacier Creek and Hendrickson Creek sites (Table A1; Figs. 2 and 5) indicate hillslope instability and aggradation of a second fan delta in response to the raising of base level in the Russell drainage basin at this time. Stratigraphy and ages of transported wood (Fig. 4) show that the fan delta at the East Tebenkof Creek site continued to aggrade for at least the next 1 k.y.

The advance of Hubbard Glacier southward into early to middle Holocene Russell lake is indicated by a silty basal till at the Hendrickson Creek site, stratigraphically constrained to have been deposited between 7787 and 5585 cal yr B.P. (Figs. 2 and 5). No terminal moraine preserved today marks the culmination of this advance. However, as described in the next section, topset-foreset contacts at the East Tebenkof Creek site indicate that the water level in the succeeding phase of Russell lake, during the middle Holocene, reached 45 m higher than water in the early to middle Holocene Russell lake (Fig. 4). This is consistent with the water level in middle Holocene Russell lake being controlled by a new, higher spillway cut through a terminal moraine constructed south of the East Tebenkof Creek site during culmination of the early to middle Holocene advance of Hubbard Glacier.

Further evidence indicating the maximum of the early to middle Holocene advance of Hubbard Glacier comes from stratigraphy at the Limit Creek site (Figs. 2 and 5). Here, early to middle Holocene Russell lake deposits are overlain by very poorly sorted stratified gravel beds containing faceted and striated

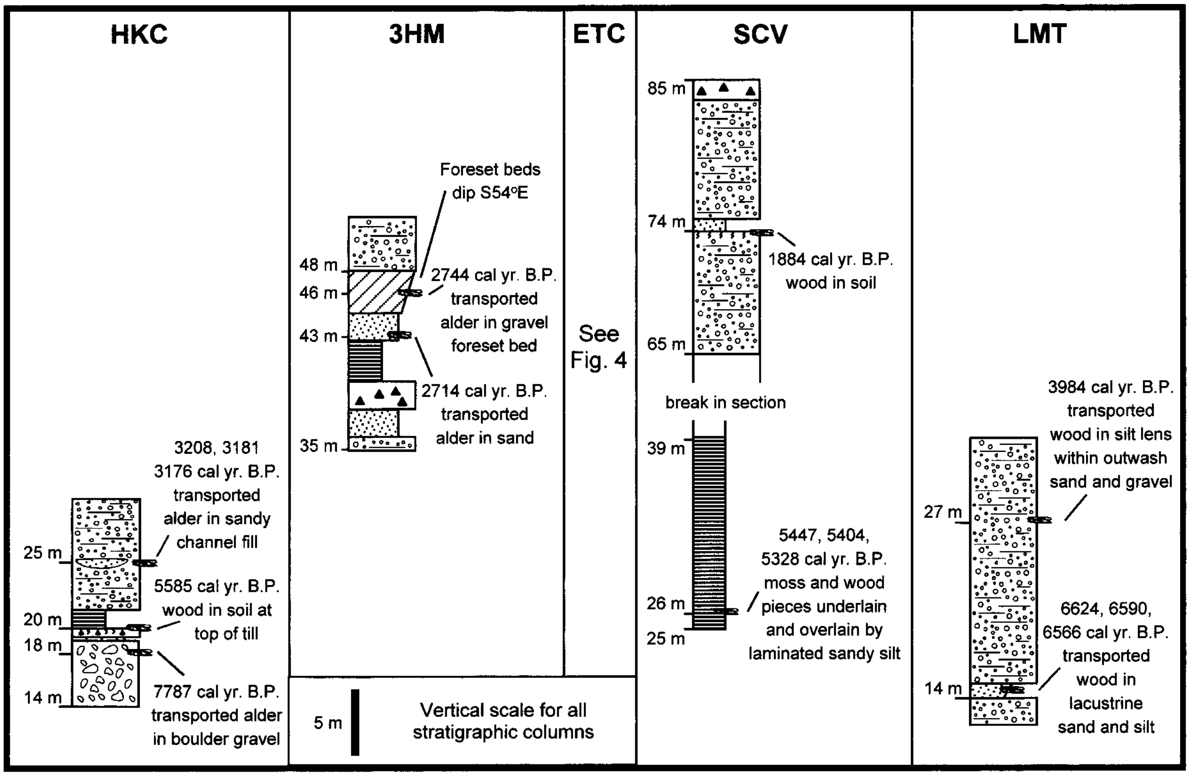

Figure 5. Stratigraphy and radiocarbon ages at the Hendrickson Creek (HKC), Three Hummingbird (3HM), Shelter Cove (SCV), and Limit Bluffs (LMT) sites. See Figure 2 for location and Figure 4 for legend. ETC—East Tebenkoff Creek.

stones. Granite and diorite clasts indicate that some of this sediment originated in the high Saint Elias Mountains, north of the study area. We interpret these gravel deposits to be ice-proximal outwash shed from Hubbard Glacier. Middle Holocene Russell lake deposits were not found around the Limit Creek site, despite examination of several kilometers of creek and shoreline bluffs. This suggests that the Limit Creek site was within the Russell drainage basin during the early to middle Holocene advance of Hubbard Glacier, but south of the drainage divide during the middle Holocene ice expansion. We conclude that the early to middle Holocene advance of Hubbard Glacier culminated just north of the Limit Creek site (Fig. 2), where a terminal moraine reaching at least 65 m above sea level was built.

Middle Holocene Glacial Damming of Russell Fiord

Buried soils exposed at the East Tebenkof Creek and Hendrickson Creek sites (Figs. 2, 4, and 5) attest to retreat of Hubbard Glacier and undamming of Russell lake following the early to middle Holocene glacial expansion. These soils are overlain by dropstone-bearing lacustrine sediments deposited during a second Holocene damming of Russell Fiord by Hubbard Glacier. At the Hendrickson Creek site, alder branches at the soil-lacustrine unit contact yielded a radiocarbon age of 5585 cal yr B.P. Similar ages of 5612 and 5596 cal yr B.P. were obtained from transported alder branches within a similar lacustrine unit at the East Tebenkof Creek site that stratigraphically overlies the fan delta built out into early to middle Holocene Russell lake (Fig. 4, section E; G. Plafker, 1987, written commun.; J. Clague, 1995, written commun.). Averaging these three ages yields an estimate of about 5600 cal yr B.P. for this second Holocene damming of Russell Fiord.

The aforementioned transported alders at the East Tebenkof Creek site were obtained from the upstream limit of the exposure at 62 m above sea level (Fig. 4, section E), and the lacustrine unit in which they were found forms the bottomset unit of a deltaic package deposited as a new fan delta began to prograde out into middle Holocene Russell lake (Fig. 4). This simple bottomset-foreset-topset deltaic sequence can be traced downstream toward the fjord, where it divides into two distinct packages, one set of deltaic units stacked above the other. In the downstream section (Fig. 4, section D), the lower deltaic package overlies a bouldery till and comprises sandy bottomset and gravelly foreset units. Transported wood near the top of this lower bottomset unit has an age that intercepts the radiocarbon calibration curve at 5440, 5432, and 5321 cal yr B.P., while an alder stem in growth position at the top of the lower foreset unit has an age of 5309 cal yr B.P. The presence of this in situ alder stem, together with a concentration of humus, wood and moss over an oxidized zone at the top of the lower gravel foreset unit (Fig. 4, section D), indicates that middle Holocene Russell lake drained for at least a few decades before deposition of the overlying, upper deltaic package.

The upper deltaic package comprises bottomset, foreset, and topset units, and is absent farther downstream toward Russell Fiord (Fig. 4, section C). Instead, 5 m of rhythmically bedded fine sand, silt, and clay with one gravel and coarse sand interbed occur at the same stratigraphic level, indicating that the delta front did not prograde this far out into the middle Holocene Russell lake. The radiocarbon age of transported wood from this lacustrine unit constrains arrival of the southward-

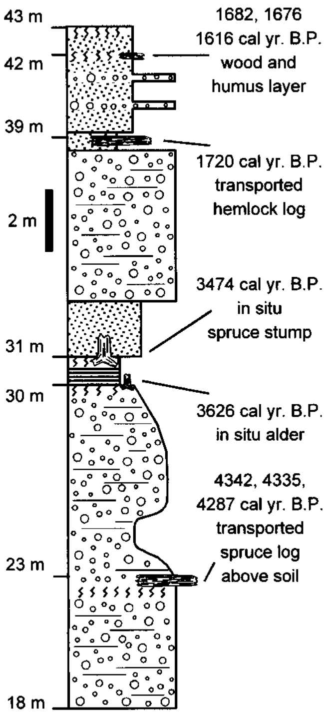

Figure 6. Composite stratigraphy and radiocarbon ages at the Stump Bluffs site. See Figure 2 for location and Figure 4 for legend.

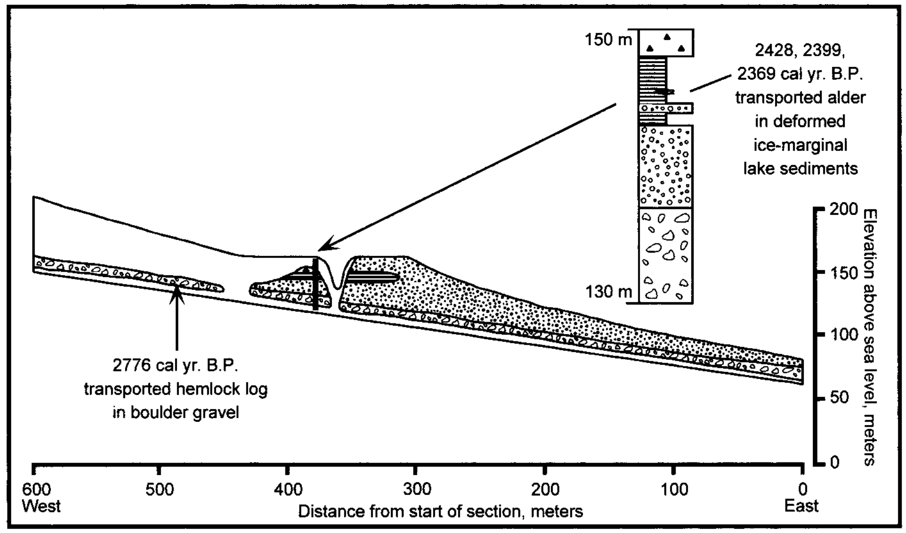

Figure 7. Stratigraphy and radiocarbon ages at the Two Gorge Creek site. See Figure 2 for location and Figure 4 for legend.

advancing Hubbard Glacier margin at the East Tebenkof Creek site to after 4862 cal yr B.P. (Fig. 4, section C). The topset-foreset contact of the middle Holocene fan delta at the East Tebenkof Creek site drops from 65 to 50 m above sea level when traced toward Russell Fiord (Fig. 4, sections E and D); this may reflect fluvial downcutting of the spillway through the early to middle Holocene terminal moraine during the 750 yr or more that the middle Holocene Russell lake existed.

Middle Holocene Maximum and Retreat of Hubbard Glacier in Russell Fiord

The Stump Bluffs site in southern Russell Fiord was south of the early to middle Holocene terminal moraine, and so outside of the area flooded by the middle Holocene Russell lake (Fig. 2). This bluff exposure (Fig. 6) displays several discrete episodes of meltwater ponding or sand and gravel aggradation, separated by intervals of landsurface stabilization and concomitant forest growth. Radiocarbon ages from the forest beds suggest that these sediments, which we interpret to be distal outwash from Hubbard Glacier, were being deposited here from at least ca. 4300 to 3474 cal yr B.P. (Table A1).

Distal outwash from Hubbard Glacier may also have been aggrading at the Forest Service Path site (Fig. 2) during the middle Holocene. Here, one of several tree stumps that protrude through the modern beach and intertidal zone has a radiocarbon age that intercepts the calibration curve at 3960, 3958, and 3926 cal yr B.P. Farther north, the upper ice-proximal outwash sediments at the Limit Creek site (Figs. 2 and 5) were also deposited at about this same time, based on an age of 3984 cal yr B.P. from transported wood incorporated into a thin silt lens within these poorly sorted gravel deposits.

The interval of outwash aggradation from at least ca. 4300 to 3474 cal yr B.P. at the widely spaced Stump Bluffs, Forest Service Path, and Limit Creek sites suggests that this is when Hubbard Glacier stood at the southern end of Russell lake and was delivering meltwater and sediment directly onto the forested lowland to the south. As with the preceding advance, no terminal moraine preserved today marks the maximum stand of Hubbard Glacier during middle Holocene time. However, the deposition of ice-proximal outwash at the Limit Creek site (Fig. 5) leads us to suggest that the middle Holocene advance culminated at or close to the terminal moraine built during the early to middle Holocene maximum of Hubbard Glacier, just north of the Limit Creek site (Fig. 2).

Retreat of the Hubbard Glacier terminus from its middle Holocene maximum and draining of Russell lake may be marked by deposition of a sandy fluvial channel fill 25 m above sea level at the Hendrickson Creek site (Figs. 2 and 5). Transported alder branches in this channel fill yielded a radiocarbon age that intercepted the calibration curve at 3208, 3181, and 3176 cal yr B.P. (Table A1).

Late Holocene Advance of Hubbard Glacier in Russell Fiord

A third major Holocene expansion of Hubbard Glacier occurred following retreat from the middle Holocene advance. Foreset beds of a fan delta at the Three Hummingbird site (Figs. 2 and 5) yielded two pieces of transported wood with respective ages of 2744 and 2714 cal yr B.P.; a late Holocene phase of Russell lake, into which this fan delta was prograding, had to have been initiated by this time. Topset-foreset contacts at the Three Hummingbird site and two other stream-cut exposures nearby to the south indicate that waters within this late Holocene Russell lake reached 45–50 m above sea level.

A similar age of 2776 cal yr B.P. was obtained from transported wood in a boulder gravel at 140 m above sea level at the Two Gorge Creek site (Figs. 2 and 7). This boulder gravel unit thickens toward Russell Fiord; we suggest that this deposit represents aggradation of a fjord-side stream channel in response to raised base level in the Russell drainage basin at this time.

Ice-contact deposits between 60 and 160 m elevation at the Two Gorge Creek site (Figs.

2 and 7) are evidence for arrival of the Hubbard Glacier margin in the South Arm of Russell Fiord. A kame gravel unit overlies the aforementioned boulder gravel at the base of the exposure and, in turn, is overlain by a severely deformed deposit of lacustrine clay and silt beds with occasional gravel interbeds and abundant dropstones. The exposure is capped by till and gravel that are part of a kame terrace that parallels the mountainside for ~1 km with a surface elevation of ~160 m above sea level. A late Holocene age for this sequence of ice-marginal deposits is suggested by transported wood within the deformed lake sediments that yielded a radiocarbon age that intercepts the calibration curve at 2428, 2399, and 2369 cal yr B.P.

Across Russell Fiord and 11 km south of the Two Gorge Creek site, 1 m of lacustrine sediment overlies a soil at 74 m above sea level at the Shelter Cove site (Figs. 2 and 5). Wood associated with the soil has a radiocarbon age of 1884 cal yr B.P. and provides an estimate of when continued advance of the Hubbard Glacier terminus dammed a small ice-marginal lake here. A similar age of 1820 cal yr B.P. was obtained from wood incorporated into an ice-marginal deposit of silt, sand, and gravel at 160 m above sea level on the mountain above the East Tebenkof Creek site.

Arrival of Hubbard Glacier at the south end of late Holocene Russell lake is recorded at the Mountaintop Lake site, directly across Russell Fiord from the Limit Creek site (Fig. 2). Outer growth rings from a large spruce trunk associated with till in a bedrock gully at 155 m elevation yielded an age of 1706 cal yr B.P., while a near-identical age was obtained from wood within a small ice-marginal lake deposit at 235 m above sea level (Table A1). Resumption of outwash aggradation to the south of the middle to late Holocene Russell basin drainage divide is recorded at the Stump Bluffs site (Figs. 2 and 6). Here, sandy outwash and silty pond deposits contain a number of transported logs, one of which yielded a radiocarbon age of 1720 cal yr B.P.

Late Holocene Maximum and Retreat of Hubbard Glacier in Russell Fiord

The late Holocene maximum stand of Hubbard Glacier at the southern end of Russell Fiord is marked by a large terminal moraine complex (Fig. 3). These morainal ridges locally rise to more than 100 m above sea level and encircle the fjord shore between 0.5 and 6 km inside of the outer, presumably late Wisconsinan moraine. A small lake at the Russell Fiord moraine site (Fig. 3) is dammed between these two terminal moraine loops. The outer rings of a tree stump submerged in this lake yielded a radiocarbon age that intercepts the calibration curve at 425, 392, and 319 cal yr B.P. (1525, 1558, and 1631 cal A.D.), and this provides a date for the Hubbard ice margin maximum at this site.

The oldest trees growing on the late Holocene moraine at the Russell Fiord moraine site germinated by A.D. 1752, and similar but slightly younger tree ages were obtained elsewhere around this terminal moraine loop (Fig. 3). Trees on the moraine at the Russell Fiord moraine site were observed to have tilted and arched trunks, indicative of substrate instability during the life of the tree, and cores revealed that erratic growth occurred until ca. A.D. 1825. These results suggest that active glacial ice began to back away from the southern end of Russell Fiord in the latter half of the eighteenth century and buried dead ice persisted locally into the early nineteenth century.

Erosion during the late Holocene expansion of the Russell Fiord lobe of Hubbard Glacier removed the early to middle and middle Holocene terminal moraine complex, and also excavated the basin that today forms the southern end of Russell Fiord. A new Russell lake developed as the ice front retreated northward, with water impounded between the glacier margin and the late Holocene terminal moraine. The spillway for this lake was 39 m above sea level and drainage passed into the Gulf of Alaska via Old Situk Creek (Fig. 3). Continued glacial retreat led to drainage of this penultimate Russell lake in about A.D. 1860. This date was estimated by Yakutat elders (Mayo, 1988a) and the draining event is described in a native tale recorded in 1952 by de Laguna (1972). Further support for this undamming date comes from trees growing on the wave-cut bench of this penultimate lake. The oldest tree we found germinated by A.D. 1866, and similar but slightly younger ages were obtained from trees on other areas of the bench and former lake floor around the southern end of Russell Fiord (Fig. 3).

HOLOCENE EVENTS IN DISENCHANTMENT AND YAKUTAT BAYS

Middle and Late Holocene Advances of the Disenchantment Bay−Yakutat Bay Lobe

Multiple tills at the Calahonda Valley site record middle and late Holocene expansions of Hubbard Glacier into Disenchantment Bay (Figs. 2 and 8). The lowest exposed unit is a clay-rich basal till that grades vertically into an ablation till dominated by angular boulders. A transported alder branch in the basal till has a radiocarbon age that intercepts the calibration curve at 4142, 4104, and 4097 cal yr B.P., suggesting deposition of this till at around the same time as the Russell Fiord lobe of Hubbard Glacier was expanded.

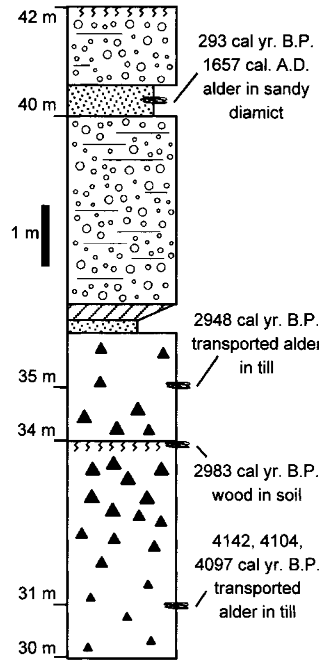

Figure 8. Stratigraphy and radiocarbon ages at the Calahonda Valley site. See Figure 2 for location and Figure 4 for legend.

In the top 40 cm of the ablation till a soil is developed that is overlain by a second till unit (Fig. 8). Pieces of alder on the upper contact of the soil yielded a calibrated radiocarbon age of 2983 cal yr B.P., and a similar age of 2948 cal yr B.P. was obtained from an alder branch incorporated into the upper till. The soil indicates retraction of the Hubbard Glacier margin into inner Disenchantment Bay following the middle Holocene expansion, deglaciating and undamming the northwest-facing Calahonda Valley (Fig. 2). The alders were probably killed when the late Holocene readvance of Hubbard Glacier dammed a small lake in this valley. Then, as the main Hubbard terminus in Disenchantment Bay expanded southward, a lobe of ice moved upvalley over the Calahonda Valley site and incorporated some of the alders during deposition of the upper till.

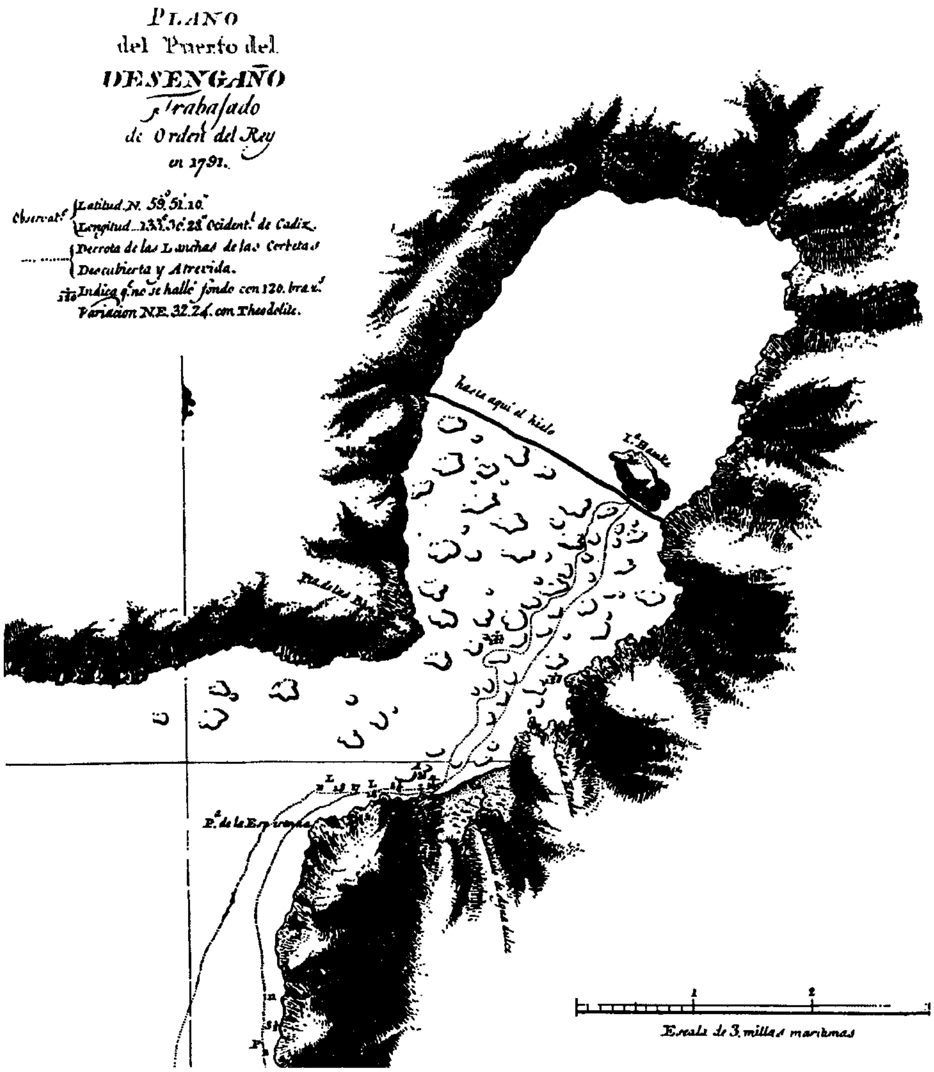

Figure 9. Chart of Disenchantment Bay from 1791 (Espinosa y Tello, 1802). "Hasta aqui el hielo" translates as "until here the ice" (B. Martinez-Batori, 1997, written commun.). The dotted line is the track of Malaspina's boats. Courtesy of the Bancroft Library, University of California, Berkeley, F851.5.E8.

Evidence of southward expansion of Hubbard Glacier into Yakutat Bay during the late Holocene occurs at the Logan Beach site (Fig. 2). Here, at least 90 spruce and hemlock tree stumps are intermittently exposed along 1 km of the beach. These stumps are still in growth position and are overlain by ~30 m of outwash capped with till. Radiocarbon ages that intercept the calibration curve at 1701 cal yr B.P. and at 1924, 1908, and 1897 cal yr B.P. (Table A1; G. Plafker, 1997, written commun.) were obtained from two of these tree stumps; the spread in ages may reflect multiple outwash aggradation events overwhelming this forest as Hubbard Glacier expanded during the late Holocene.

Late Holocene Maximum and Retreat of the Disenchantment Bay–Yakutat Bay Lobe

An extensive terminal moraine complex rims the southeastern shore of Yakutat Bay and marks the late Holocene maximum stand of the western lobe of Hubbard Glacier (Fig. 2). This moraine complex is composed of many parallel to subparallel, discontinuous ridges, and mounds that in places reach to more than 90 m above sea level. These ridges are interspersed with fluted ground moraine and many kettles (Yehle, 1979). The terminal moraine can be traced out across the mouth of Yakutat Bay where it forms a pronounced shoal (Wright, 1972; Carlson, 1989), and to the Malaspina foreland where the moraine curves back toward the north and disappears under Malaspina Glacier (Fig. 1; Plafker and Miller, 1958).

Logs, woody debris, and peat are incorporated into moraine ridges and kettle-fills at the Ocean Cape site near the mouth of Yakutat Bay (Fig. 2). Five samples have radiocarbon ages that intercept the calibration curve between 776 and 1405 cal A.D. (1174 to 545 cal yr B.P.; Table A1; Rubin and Alexander, 1960; Trautman and Willis, 1966), and give a general estimate of when Hubbard Glacier stood at its late Holocene maximum in Yakutat Bay. In addition, four ages between 999 and 1229 cal A.D. (951 and 721 cal yr B.P.) were obtained from the bottom of muskeg cores and from organic horizons in stream cutbanks at the Situk Muskeg, Lost River, and Tawah Creek sites (Table A1; Fig. 2; Peteet, 1991; Shephard, 1995). These latter four ages indicate vegetation recolonizing these sites following local cessation of outwash aggradation.

Retreat of the Disenchantment Bay-Yakutat Bay lobe of Hubbard Glacier from its late Holocene maximum is constrained by ring counts from recently logged Sitka spruce on the outermost terminal moraine ridge at the Yakutat Bay moraine site (Fig. 2). The oldest tree we found germinated by A.D. 1308; ring patterns on the stump were almost perfectly concentric, suggesting that growth did not begin until a stable substrate was available following ice removal. Further retraction of Hubbard Glacier northward into inner Yakutat Bay is constrained by living trees on a bluff at the Logan Beach site. Here, a western hemlock growing on a late Holocene fluted till substrate was cored to the pith and found to have germinated by A.D. 1466.

A prominent submarine moraine off Blizhni Point (Fig. 2) may record a major stillstand or readvance of the Disenchantment Bay–Yakutat Bay lobe of Hubbard Glacier (Gilbert, 1904; Plafker and Miller, 1958; Wright, 1972; Carlson, 1989). Trees north of the Logan Beach site within the area presumably covered by ice standing at this moraine were cored, and the oldest found germinated by A.D. 1465. However, no vegetative trimline marking this ice stand could be identified, and so this age may simply reflect the migration rate of trees into inner Yakutat Bay following late Holocene deglaciation.

Transported wood with an age of 1431 cal A.D. (519 cal yr B.P.) was found in a boulder layer between two tills or till-like diamicts at

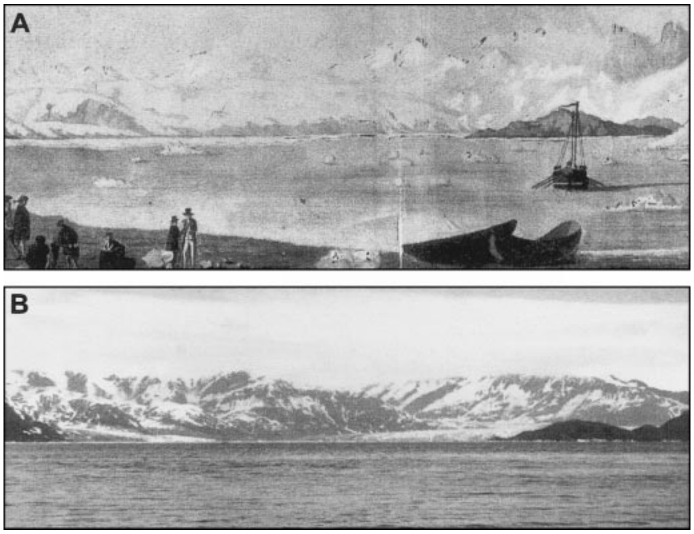

Figure 10. Views looking north into Disenchantment Bay in 1791 and 1996. The painting (A) was based on field sketches made by Malaspina's expedition in 1791; the photograph (B) was taken in 1996 from about the same vantage point near the Aquadulce Creek site (Fig. 2). The terminus of Turner Glacier appears at the left side of both views, and Haenke Island is directly above the boat in the bay in the 1791 painting. Hubbard Glacier is the white area above and west (left) of Haenke Island in the 1996 photograph, but is conspicuously absent from the 1791 painting. View A from Museo Naval MS 1726–73, Madrid, Spain.

the Aquadulce Creek site (Fig. 2; Table A1). While this deposit could be interpreted as showing a readvance of Hubbard Glacier in the fifteenth century, the stratigraphy at this site was not clear enough to be certain. The age and significance of the Blizhni moraine remain equivocal at this time.

DIRECT OBSERVATIONS OF GLACIER TERMINI SINCE A.D. 1791

The personnel of the expeditions of Malaspina in 1791 and Vancouver in 1794 were the first Europeans to enter Disenchantment Bay and make observations relating to glacier termini positions. However, interpretations of the descriptions and charts made by these expeditions have been contended for more than 100 yr. Russell (1891) and Davidson (1904) suggested that a solid line on a chart drawn by Bauzá, the geographer on Malaspina's expedition, depicts the terminus of Hubbard Glacier midway down Disenchantment Bay in 1791 (Fig. 9). In contrast, Tarr and Martin (1907) suggested this line denotes the limit of dense floating ice preventing passage of boats, and that the margin of Hubbard Glacier was positioned farther north at that time.

A landscape painting (Fig. 10A), based on field sketches most likely made by Bauzá in 1791 (Wagner, 1936; Cutter, 1991), captures most of the significant geography of Disenchantment Bay when compared with a photograph taken in 1996 from the same vantage point (Fig. 10B). The terminus of Hubbard Glacier can be seen in the 1996 photograph, but is barely if at all visible in the 1791 painting. This supports the stance of Tarr and Martin (1907), that Hubbard Glacier was withdrawn into inner Disenchantment Bay in 1791 and was less extensive than today. Verbal descriptions from members of Malaspina's expedition also support this interpretation (Russell, 1891; Wagner, 1936). The track of the expedition on Bauzá's chart (Fig. 9) shows the boats going up to the solid line labeled as ice, yet none of the verbal accounts mention or suggest that the exploring party saw an ice cliff or iceberg calving. It is unlikely that they could have gotten so close to the Hubbard margin and not witnessed a calving event from this, one of the most active iceberg-calving termini in Alaska.

Verbal descriptions from members of Vancouver's expedition in 1794 also failed to mention an ice cliff or iceberg calving (Vancouver, 1798). In addition, Vancouver's party noted open water in the approximate location of the mouth of Russell Fiord, beyond the ice that prevented their passage farther north. Because they were in a small boat this could not have been observed over the ice cliff of the Hubbard terminus. On the basis of these data, we conclude that the terminus of Hubbard Glacier in the late eighteenth century was in innermost Disenchantment Bay, to the north of its position in 1996.

The expeditions of Russell in 1890 and 1891 (Russell, 1891, 1893) provide the first detailed observations of the Hubbard ice margin. Maps and photographs since that time show that Hubbard Glacier has been advancing at an increasing rate through the twentieth century (Trabant et al., 1991). The outburst flood that terminated the 1986 damming of Russell lake carried away part of the Hubbard margin and its protective terminal moraine shoal (Mayo, 1988a, 1988b; Cowan et al., 1996). Although this probably slowed advance during the late 1980s, by the 1990s the Hubbard terminus was again threatening to block the mouth of Russell Fiord.

Russell (1893) described a large iceberg-calving tidewater glacier in Nunatak Fiord in 1891. Subsequent observations document that this ice tongue, Nunatak Glacier, has been retreating ever since (Gilbert, 1904; Tarr, 1909; Tarr and Martin, 1914; Field, 1975; King, 1995), and has now split into east and west branches that both terminate on land (Fig. 1). Most other glaciers in the Yakutat area that were tributary to the expanded Hubbard Glacier have been receding throughout the twentieth century.

ICE SUPPLY TO THE RUSSELL FIORD LOBE DURING THE LATE HOLOCENE

Tarr (1909) noted fresh grooves and striae at low elevation in the Northwest Arm of Russell Fiord that indicated that the most recent ice flow was toward the northwest. Tarr (1909) also cited an elderly Yakutat resident as having witnessed an iceberg-calving glacier terminus about midway along the Northwest Arm of Russell Fiord, facing toward Disenchantment Bay, during the nineteenth century. In addition, Tarr and Martin (1906b, 1907) observed that in the early twentieth century, vegetation thinned from mature, dense thickets of alder and willow in the northwestern and southern ends of Russell Fiord to immature, scattered thickets, and eventually almost no vegetation, at the mouth of and into Nunatak Fiord.

Tarr and Martin (1907) and Tarr (1909) suggested that Nunatak Glacier, flowing west out of Nunatak Fiord, dammed the penultimate Russell lake in the South Arm during the eighteenth and nineteenth centuries. We concur with this conclusion and infer that Nunatak Glacier became the primary source of ice to the Russell Fiord lobe when Hubbard Glacier in Disenchantment Bay retreated north of the entrance to Russell Fiord. This had occurred before Malaspina's visit in A.D. 1791, and possibly much earlier. Ice flow in the Northwest Arm of Russell Fiord would have reversed direction, and Nunatak Glacier would have been left with termini facing both northwest and south. We suggest that these two termini retreated back toward Nunatak Fiord during the nineteeth century and intersected in 1860, allowing the penultimate Russell lake to drain.

Support for a major expansion of ice from the névés east of Russell Fiord during the late Holocene comes from outlet glaciers that drain southward from this area to the Yakutat foreland. Trees close to the current terminus of Yakutat Glacier (Fig. 1) were drowned in an ice-dammed lake ca. 1100 cal yr B.P. (G. Wiles and G. Jacoby, 1996, unpublished data in personal commun.), indicating expansion of this major outlet tongue at that time. This advance of Yakutat Glacier culminated at the south end of Harlequin Lake (Fig. 1) before A.D. 1850 (A. Post, 1994, unpublished data in personal commun.). Furthermore, Shephard (1995) cored trees on the terminal moraines of several other glaciers farther east along the Yakutat foreland and inferred that these ice tongues had also reached maxima in the past 150 yr.

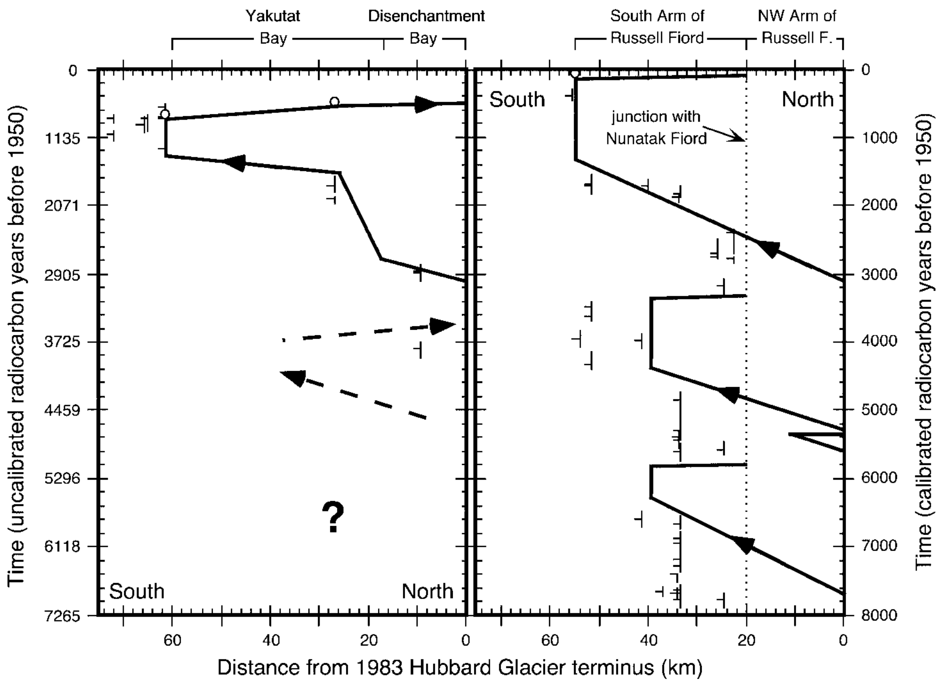

Figure 11. Time-distance diagram showing advances of Hubbard Glacier in Disenchantment and Yakutat Bays (left) and Russell Fiord (right). Control points are radiocarbon ages with one standard deviation range (T-bars) and tree-ring minimum dates (open circles). The dashed line indicates a middle Holocene advance of uncertain extent into Disenchantment and Yakutat Bays.

HUBBARD GLACIER AND THE ICEBERG-CALVING GLACIER CYCLE

A time-distance diagram (Fig. 11) that summarizes the Holocene history of Hubbard Glacier clearly shows the cyclic nature of the three major fluctuations. This strongly supports the notion of an iceberg-calving glacier cycle, wherein slow terminus advance is followed by rapid, often catastrophic breakup and retreat (Post, 1975; Trabant et al., 1991). The rate of advance is closely related to the rate at which a protective terminal moraine shoal can be reworked and moved down the fjord with the advancing terminus (Meier and Post, 1987; Alley, 1991; Powell, 1991); retreat from this shoal places the terminus in deeper water, where it is unstable and so prone to rapid calving and recession.

Reconstructed mean advance rates are best constrained for the Russell Fiord lobe and range from 28 to 42 m/yr; this compares favorably with observed advance rates of Hubbard Glacier during the twentieth century of 16–47 m/yr (Trabant et al., 1991), and similar advance rates documented at other Alaskan tidewater glaciers (Meier and Post, 1987). Advance of the western lobe was slowest through inner Yakutat Bay, where the bay widens while remaining deep (Figs. 2 and 11), requiring addition of sediment from upglacier to enable growth of the stabilizing terminal moraine shoal. In contrast, advance was faster through outer Yakutat Bay where water depths are generally much shallower.

Deglaciation during the late Holocene was initiated in the Disenchantment Bay–Yakutat Bay lobe. Presumably rapid calving retreat (Post, 1975; Post and Motyka, 1995) brought the margin of the western Hubbard Glacier lobe back into Disenchantment Bay; deglaciation then proceeded into Russell Fiord and eventually left the entire fjord system free of glacial ice. Given that the Disenchantment Bay–Yakutat Bay lobe is more exposed to the Gulf of Alaska and so potentially more unstable than the Russell Fiord lobe, this asynchronous retreat of the lobes of Hubbard Glacier probably also occurred following the early to middle and middle Holocene ice expansions.

Although Nunatak Glacier was blocking the South Arm of Russell Fiord during the late Holocene deglaciation, we have assumed in our reconstruction (Fig. 11) that it was Hubbard Glacier that dammed and then advanced southward along Russell Fiord during each of the major Holocene glacial expansions. This is reasonable given that iceberg-calving tongues such as Hubbard and Nunatak Glaciers usually only stabilize following rapid calving retreat once they reach shallow water at the heads of their fjords (Trabant et al., 1991). When readvance occurs, Hubbard Glacier has to advance only 10 km to block Russell Fiord, and this will happen long before Nunatak Glacier can extend 25 km to reach the junction of Nunatak and Russell Fiords. Also, Hubbard Glacier is much larger than Nunatak Glacier (Fig. 1), and so will dominate ice flow through Russell Fiord when both of these glaciers are expanded.

Hubbard Glacier today is early in the advancing stage of the iceberg-calving glacier cycle (Trabant et al., 1991) and this advance is driven by an accumulation area ratio (AAR) of 0.96, the highest of any Alaskan tidewater glacier (Meier et al., 1980; Viens, 1994). This high AAR reflects the loss by Hubbard Glacier of almost its entire ablation area during deglaciation of the fjord system following the late Holocene maximum. In order to attain a stable AAR of 0.65 (Meier and Post, 1962; Mann, 1986), Hubbard Glacier needs to gain ~2000 km^2 of ablation area (Barclay, 1998). This is approximately equal to the combined areas of Yakutat and Disenchantment Bays and Russell and Nunatak Fjords, suggesting that Hubbard Glacier will continue to expand in the future to restore its lost ablation area and reach equilibrium with current climate.

It is almost inevitable that Hubbard Glacier will redam Russell Fiord to create Russell lake in the near future, although exactly when this will occur is less certain. The Holocene history of Hubbard Glacier suggests that following this blockage the Hubbard terminus will divide into two lobes that will continue to advance southward through, respectively, Disenchantment Bay–Yakutat Bay in the west and Russell Fiord in the east. Although some temporary lake filling and draining episodes may occur such as happened in 1986 and in the middle Holocene, Russell lake will eventually become established as a stable feature of the Yakutat area.

Creation of a stable Russell lake with drainage into Old Situk Creek will initially have some negative local impacts, including death of saltwater organisms trapped in Russell lake, damage to the Situk River salmon fishery, and inundation of areas around Yakutat airport (Reeburgh et al., 1976; Mayo, 1988a). However, prior Holocene advances of Hubbard Glacier have taken 1 k.y. or more to reach maxima in outer Yakutat Bay or southern Russell Fiord following creation of Russell lake. This suggests that the area of the town of Yakutat, built on and adjacent to the terminal moraine of the late Holocene expansion, is unlikely to be threatened by Hubbard Glacier until late in the third millennium A.D., if at all.

SUMMARY AND CONCLUSIONS

The earliest recognized Holocene expansion of Hubbard Glacier blocked the mouth of Russell Fiord ca. 7690 cal yr B.P. Waters of this early to middle Holocene Russell lake rose to ~20 m above present sea level and drained across a late Wisconsinan moraine at the southern end of the Russell drainage basin. Hubbard Glacier advanced southward into Russell lake for ~1 k.y., to a maximum stand ~12 km north of the modern southern shore of Russell Fiord. A terminal moraine reaching at least 65 m above sea level was constructed at this maximum. The Disenchantment Bay–Yakutat Bay lobe of Hubbard Glacier presumably expanded at the same time; both lobes then retreated, restoring the tidewater connection to Russell Fiord.

The second Holocene expansion of Hubbard Glacier initially blocked Russell Fiord ca. 5600 cal yr B.P.; this lake drained for at least a few decades before being firmly established ca. 5309 cal yr B.P. This middle Holocene advance of the Hubbard Glacier margin into Russell Fiord culminated in the same area as the previous advance, and meltwater and outwash spread over a forested lowland in what is now the southern end of Russell Fiord for at least 800 yr during this maximum stand. The western lobe of Hubbard Glacier advanced into outer Disenchantment Bay and probably farther during this same middle Holocene interval. Retreat of both lobes restored the tidewater connection to Russell Fiord before ca. 3200 cal yr B.P.

A third advance of Hubbard Glacier was under way by ca. 3100 cal yr B.P. and brought the Russell Fiord ice margin to the terminal moraine complex of the previous advances by ca. 1710 cal yr B.P. Supplemented by ice flowing from Nunatak Fiord and névés to the east, the Russell Fiord lobe continued to advance, ultimately to construct the terminal loop moraine that forms the southern end of the Russell Fiord drainage basin today. During this late Holocene advance and maximum, the early through middle Holocene terminal moraine complex and the lowland area beyond were eroded into the current configuration of southern Russell Fiord.

The Disenchantment Bay–Yakutat Bay lobe of Hubbard Glacier reached a maximum at the Gulf of Alaska coast ca. A.D.1000. Retreat of this lobe was under way by A.D. 1308 and the terminus was behind its 1996 position before 1791. Following separation from Hubbard Glacier, ice flow in the Northwest Arm reversed direction as Nunatak Glacier became the primary source of ice to the Russell Fiord lobe. Ice began to retreat from the southern end of Russell Fiord in the late eighteenth century; simultaneous southeastward retreat of ice from the Northwest Arm led to the two termini backing into each other ca. 1860, allowing the penultimate Russell lake dammed in the South Arm of Russell Fiord to drain. Nunatak Glacier has continued to retreat through the twentieth century while Hubbard Glacier has been readvancing, certainly since 1891 and probably since before 1791.

The three major Holocene fluctuations of Hubbard Glacier are distinctly cyclic and strongly support the concept of an iceberg-calving glacier cycle (Post, 1975; Trabant et al., 1991). Slow advances taking 1–1.5 k.y. are followed by more rapid deglaciation, which for at least the late Holocene cycle was initiated in the Disenchantment Bay–Yakutat Bay lobe. Hubbard Glacier will likely block Russell Fiord in the near future and Old Situk Creek will become established as the outlet river from Russell lake. Although Hubbard Glacier will probably continue to advance southward, the terminus is unlikely to reach close to the area of the town of Yakutat for at least another 1 k.y.

APPENDIX

Table A1 provides further details of the radiocarbon samples and ages used to constrain the Holocene history of Yakutat Bay and Russell Fiord. All ages obtained for this study are included, together with selected ages of other workers that were used in this paper.

ACKNOWLEDGMENTS

We thank George Plafker and John Clague for sharing unpublished data and observations, and Jack McGeehin for providing details of U.S. Geological Survey radiocarbon data. Gordon Jacoby, Geoffrey King, Julie Gloss Barclay, David Frank, and Elowyn Yager assisted with field work and with laboratory analyses of tree-ring samples, and Bettina Martinez-Batori translated the text on Bauzá's chart. Logistical support from Meg Mitchell of the Tongass National Forest–Chatham area, and from staff of the Wrangell–Saint Elias National Park is gratefully acknowledged. Climate data were provided by the Alaska Climate Research Center (http://climate.gi.alaska.edu). This work was supported by the National Science Foundation under grant OPP-9321213.

TABLE A1. RADIOCARBON AGES FOR YAKUTAT REGION

Laboratory number*	Age (B.P.)†	Calibrated age (cal yr. B.P.)§	Sample site, description and interpretation	Ref.#
Russell Fiord lobe of Hubbard Glacier				
β-80,514	7000 ± 70	7920 (7787) 7640	HKC. Transported alder in alluvial gravel, fan delta aggrading due to damming of first Holocene Russell Lake.	1
β-122,431	6990 ± 70	7920 (7767) 7630	ETC. In situ alder stump under bottomset unit, killed by damming of first Holocene Russell Lake.	1
β-122,432	6930 ± 70	7900 (7690) 7580	ETC. Transported alder branch in Russell Lake fines.	1
β-122,440	6910 ± 70	7890 (7673) 7560	OGH. Wood in soil overlain by Russell Lake fines, interpretation as β-122,431.	1
β-85,671	6880 ± 60	7790 (7653) 7550	GLC. Transported alder branches in diamict, debris flow deposit.	1
β-76,876	6850 ± 70	7770 (7634) 7540	ETC. Alder branch underneath Russell Lake fines, interpretation as β-122,431.	1
β-85,672	6570 ± 70	7540 (7395) 7290	OGH. Wood with moss in Russell Lake fines.	1
β-122,433	6410 ± 70	7390 (7276) 7180	ETC. Large alder branch in gravel, interpretation as β-80,514.	1
I-14,735	6310 ± 110**	7390 (7190) 6880	ETC. Peat with wood within gravel, from same approximate area as β-122,433.	2
β-122,435	6100 ± 50	7160 (6942) 6810	ETC. Transported alder branch in sand and gravel, interpretation as β-80,514.	1
β-122,430	6030 ± 70	7150 (6878) 6720	ETC. Transported alder branch in sand, interpretation as β-80,514.	1
β-122,434	5830 ± 70	6850 (6665) 6460	ETC. Wood with peat under silty clay, deposited in small pond (?) on fan delta.	1
β-76,877	5780 ± 80	6760 (6624,6590,6566) 6410	LMT. Transported wood with alder leaves in sand, deposited in early to middle Holocene Russell Lake.	1
I-14,734	4890 ± 100††	5900 (5612) 5330	ETC. Transported wood in bottomset unit, dates initial middle Holocene formation of Russell Lake.	2
β-80,513	4860 ± 70	5730 (5596) 5340	ETC. Location and interpretation same as I-14,734.	1
β-85,681	4820 ± 70	5700 (5585) 5330	HKC. Wood in soil under bottomset unit, interpretation as I-14,734.	1
β-80,515	4680 ± 70	5590 (5447,5404,5328) 5100	SCV. Moss and wood fragments underlain and overlain by Russell Lake fines, same interpretation as β-85,677?	1
β-85,676	4650 ± 50	5570 (5440,5432,5321) 5290	ETC. Transported alder in bottomset unit, same lake phase as dated by I-14,734 and β-80,513.	1
β-85,677	4610 ± 70	5570 (5309) 5050	ETC. In situ alder stump above β-85,676 and buried by bottomset unit, constrains temporary draining and re-establishment of middle Holocene Russell Lake.	1
β-85,679	4320 ± 80	5210 (4862) 4650	ETC. Transported alder in lacustrine unit, deposited in second phase of middle Holocene Russell Lake.	1
β-76,879	3880 ± 70	4510 (4342,4335,4287) 4090	STB. Transported spruce log in gravel, dates middle Holocene outwash aggradation in southern Russell Fiord.	1
β-115,188	3680 ± 70	4230 (3984) 3780	LMT. Transported wood in gravel, dates aggregation of ice-proximal outwash.	1
β-85,673	3640 ± 70	4140 (3960,3958,3926) 3730	FSP. Hemlock(?) stump protruding through beach, dates distal outwash aggradation.	1
β-101,601	3380 ± 60	3820 (3626) 3470	STB. In situ alder, temporary landsurface stabilization during outwash aggradation.	1
β-80,516	3290 ± 60	3680 (3474) 3370	STB. In situ spruce(?) stump, interpretation as β-101,601.	1
β-85,680	3010 ± 70	3370 (3208,3181,3176) 2960	HKC. Transported alder in channel fill, dates undammed interval of Russell Fiord.	1
β-76,874	2700 ± 60	2930 (2776) 2740	2GC. Transported hemlock log in boulder gravel, gravel graded to water level of late Holocene Russell Lake.	1
β-76,875	2590 ± 50	2770 (2744) 2500	3HM. Transported wood in foreset unit, dates progradation of fan delta into late Holocene Russell Lake.	1
β-115,189	2520 ± 60	2760 (2714) 2360	3HM. Setting and interpretation same as β-76,875.	1
β-85,675	2430 ± 60	2730 (2428,2399,2369) 2340	2GC. Transported alder in deformed lake sediments, deposited in ice-marginal lake.	1
β-76,878	1960 ± 50	2000 (1884) 1810	SCV. Wood in soil overlain by lacustrine sand and silt, dates damming of this side valley by late Holocene advance of Hubbard Glacier.	1
β-85,678	1880 ± 70	1950 (1820) 1620	ETC. Transported alder in silt, sand and gravel at 160 m elevation, deposited adjacent to Hubbard Glacier.	1
β-98,987	1820 ± 60	1880 (1720) 1570	STB. Transported hemlock in silty sand, dates late Holocene resumption of outwash aggradation in southern end of Russell Fiord.	1
β-122,436	1790 ± 50	1830 (1706) 1560	MTL. Spruce trunk pushed into mountainside with till at 155 m elevation, dates advance of Hubbard Glacier over site.	1
β-122,437	1790 ± 60	1860 (1706) 1540	MTL. Transported spruce pieces in lacustrine fines at 235 m elevation, dates small ice marginal lake at site.	1
β-85,674	1730 ± 70	1820 (1682,1676,1616) 1500	STB. Woody debris layer in sand, temporary landsurface stabilization during outwash aggradation.	1
β-115,192	330 ± 50	500 (425,392,319) 290 1450 (1525,1558,1631) 1660 A.D.	RFM. Spruce(?) stump in lake dammed by late Holocene terminal moraine, dates advance of Russell Fiord lobe of Hubbard Glacier to maximum stand.	1
Disenchantment Bay–Yakutat Bay lobe of Hubbard Glacier				
β-98,979	3780 ± 70	4400 (4142,4104,4097) 3930	CAL. Transported alder in till, dates advance of western lobe of Hubbard Glacier up Calahonda Valley from Disenchantment Bay.	1
β-98,978	2890 ± 70	3220 (2983) 2810	CAL. Wood in soil, constrains retreat and readvance of western lobe of Hubbard Glacier in Disenchantment Bay.	1
β-115,190	2850 ± 60	3150 (2948) 2790	CAL. Transported alder in till over soil, wood presumably derived from landsurface associated with β-98,978.	1
β-98,988	2080 ± 70	2300 (2007) 1870	YBM. Transported wood in outwash 100 m beyond late Holocene moraine, contradicts β-98,983 and W-4486 at LBE and so is interpreted as reworked old wood.	1
β-98,983	1980 ± 50	2010 (1924,1908,1897) 1820	LBE. One of 90+ in situ trees protruding through modern beach, killed by outwash aggradation from advancing Disenchantment Bay-Yakutat Bay lobe.	1
W-4486	1780 ± 80††	1880 (1701) 1520	LBE. Location and interpretation same as β-98,983.	3
β-122,439	1260 ± 50	1290 (1174) 1060	OCP. Hemlock log in kettle fill within terminal moraine complex of Disenchantment Bay-Yakutat Bay lobe, same exposure as β-98,984, β-122,438 and I-439.	1
"Muskeg #1"	1090 ± 80**	1170 (951) 750 780 (999) 1200 A.D.	Lost River. Organic sediment from base of muskeg core, dates local cessation of outwash aggradation from Disenchantment Bay-Yakutat Bay lobe.	4
β-54,384	920 ± 110††	1060 (886,875,823,817,791) 660 890 (1064,1075,1127,1133,1159) 1300 A.D.	Tawah Creek. Wood in "basal peat", interpretation as "Muskeg #1".	5
USGS-923	880 ± 65**	930 (731) 650 1020 (1219) 1300 A.D.	Situk Muskeg. Basal peat from muskeg core, interpretation as "Muskeg #1".	6

TABLE A1. (*Continued*).

Laboratory number*	Age (B.P.)†	Calibrated age (cal yr. B.P.)§	Sample site, description and interpretation	Ref.#
W-559	830 ± 160††	1060 (725) 520 890 (1225) 1430 A.D.	OCP. Transported wood in silt lens in outermost ridge of Disenchantment Bay-Yakutat Bay lobe terminal moraine.	7
β-65,331	820 ± 80	920 (721) 650 1030 (1229) 1300 A.D.	Lost River. Organic sediment above gravel, interpretation as "Muskeg #1".	8
β-98,984	810 ± 50	790 (705) 660 1160 (1245) 1290 A.D.	OCP. Peat in same kettle fill as β-122,439, β-122,438 and I-439.	1
β-122,438	800 ± 50	790 (697) 650 1160 (1253) 1300 A.D.	OCP. Spruce log in same kettle fill as β-122,439, β-98,984 and I-439.	1
I-439	560 ± 75††	660 (545) 480 1290 (1405) 1480 A.D.	OCP. "In situ spruce stump under till" at same exposure as β-122,439, β-98,984 and β-122,438.	9
β-98,977	500 ± 40	550 (519) 490 1400 (1431) 1460 A.D.	AQA. Transported alder in boulder layer between till-like diamicts, either remobilized till deposits from valley walls or readvance of Hubbard Glacier to Blizhni moraine.	1
β-115,191	250 ± 50	440 (293) 0 1520 (1657) 1955 A.D.	CAL. Alders in sandy diamict, probably dates large landslide nearby.	1

Note: Sites: HKC—Hendrickson Creek; ETC—East Tebenkoff Creek; OGH—Organic High; GLC——Glacier Creek; LMT——Limit Bluffs; SCV—Shelter Cove; STB—Stump Bluffs; FSP—Forest Service Path; 2GC—Two Gorge Creek; 3HM—Three Hummingbird; MTL—Mountaintop Lake; RFM—Russell Fiord Moraine; CAL—Calahonda Valley; YBM—Yakutat Bay Moraine; LBE—Logan Beach; OCP—Ocean Cape; AQA—Aquadulce Creek.

*Laboratories: W-, U.S. Geological Survey; β-, Beta Analytic; I-, Teledyne Isotopes.

†Ages from this study are corrected for isotopic fractionation using measured $^{13}C/^{12}C$ ratios. Uncorrected ages from other workers are denoted by a superscript symbol.

§Determined using CALIB 3.0.3 (Stuiver and Reimer, 1993). All samples used bidecadal dendrocalibration curve (Stuiver and Pearson, 1993). Data are presented as calibration curve intercept(s) in calibrated years before present (cal yr. B.P.) with two standard deviation range. A.D. equivalents are given for samples from the last millennium.

#References: 1—this study; 2—G. Plafker (1987, written commun.) and J. Clague (1995, written commun.); 3—G. Plafker (1997, written commun.) and J. McGeehin (1997, written commun.); 4—Shephard (1995, collected by R.G. Holloway); 5—Shephard (1995); 6—Molnia (1986) and Peteet (1991); 7—Plafker and Miller (1958) and Rubin and Alexander (1960, collected by J.H. Hartshorn); 8—Davis (1996); 9—Trautman and Willis (1966, collected by D.J. Miller).

**The following isotopic fractionation values were assumed for humus or peat samples without measured $^{13}C/^{12}C$ ratios: -27 ± 3. Values are $\delta^{13}C$ per mil relative to Pee Dee belemnite standard (PDB).

††The following isotopic fractionation values were assumed for wood samples without measured $^{13}C/^{12}C$ ratios: -25 ± 2. Values are $\delta^{13}C$ per mil relative to PDB.

REFERENCES CITED

Alley, R.B., 1991, Sedimentary processes may cause fluctuations of tidewater glaciers: Annals of Glaciology, v. 15, p. 119–124.

Barclay, D.J., 1998, Tree-ring and glacial records of Holocene climate change, northern Gulf of Alaska region [Ph.D. dissert.]: Buffalo, State University of New York, 232 p.

Blackwelder, E., 1907, Glacial features of the Alaskan coast between Yakutat Bay and the Alsek River: Journal of Geology, v. 15, p. 415–433.

Blackwelder, E., 1909, The Yakutat coastal plain of Alaska: A combined terrestrial and marine formation: American Journal of Science, v. 27, p. 459–466.

Carlson, P.R., 1989, Seismic reflection characteristics of glacial and glacimarine sediment in the Gulf of Alaska and adjacent fjords: Marine Geology, v. 85, p. 391–416.

Carlson, P.R., Bruns, T.R., Molnia, B.F., and Schwab, W.C., 1982, Submarine valleys in the northeastern Gulf of Alaska: Characteristics and probable origin: Marine Geology, v. 47, p. 217–242.

Cooper, W.S., 1923, The recent ecological history of Glacier Bay, Alaska: II; the present vegetation cycle: Ecology, v. 4, p. 223–246.

Cowan, E.A., Carlson, P.R., and Powell, R.D., 1996, The marine record of the Russell Fiord outburst flood, Alaska, U.S.A.: Annals of Glaciology, v. 22, p. 194–199.

Cutter, D.C., 1991, Malaspina and Galiano; Spanish voyages to the northwest coast 1791 and 1792: Seattle, University of Washington Press, 160 p.

Davidson, G., 1904, The glaciers of Alaska that are shown on Russian charts or mentioned in older narratives: Geographical Society of the Pacific Transactions and Proceedings, v. 3, ser. 2, 93 p.

Davis, S.D., 1996, The archaeology of the Yakutat foreland: A socioecological view [Ph.D. dissert.]: College Station, Texas A&M University, 581 p.

de Laguna, F., 1972, Under Mount Saint Elias: The history and culture of the Yakutat Tlingit: Washington, DC., Smithsonian Institution Press, 3 volumes, 913 p.

Espinosa y Tello, J., 1802, Relacion del viage hecho por las goletas Sutil y Mexicana en al año de 1792 para reconocer el estrecho de Fuca: Madrid, Imprenta real, 185 p.

Field, W.O., 1975, Glaciers of the St. Elias Mountains, *in* Field, W.O., ed., Mountain glaciers of the Northern Hemisphere, Volume 2: Hanover, New Hampshire, U.S. Army Cold Regions Research and Engineering Laboratory, p. 143–297.

Gilbert, G.K., 1904, Glaciers and glaciation in Alaska, Volume 3: New York, Doubleday, Page and Company, 231 p.

Heusser, C.J., 1960, Late Pleistocene environments of north Pacific North America: American Geographical Society Special Publication 35, 307 p.

Kaiser, K.F., 1993, Growth rings as indicators of glacier advances, surges and floods: Dendrochronologia, v. 11, p. 101–122.

King, G.S., 1995, Surficial geology and preliminary chronology of Russell Fiord, Alaska [Master's thesis]: Buffalo, State University of New York, 103 p.

Krimmel, R.M., and Trabant, D.C., 1992, The terminus of Hubbard Glacier, Alaska: Annals of Glaciology, v. 16, p. 151–157.

Lawrence, D.B., 1950, Estimating dates of recent glacier advances and recession rates by studying tree growth layers: American Geophysical Union Transactions, v. 31, p. 243–248.

MacKevett, E.M., Jr., and Plafker, G., 1970, Geochemical and geophysical reconnaissance of parts of the Yakutat and Mount Saint Elias Quadrangles, Alaska: U.S. Geological Survey Bulletin 1312-L, p. 1–12.

Mann, D.H., 1986, Reliability of a fjord glaciers fluctuations for paleoclimatic reconstruction: Quaternary Research, v. 25, p. 10–24.

Mann, D.H., and Hamilton, T.D., 1995, Late Pleistocene and Holocene paleoenvironments of the North Pacific coast: Quaternary Science Reviews, v. 14, p. 449–471.

Mayo, L.R., 1988a, Advance of Hubbard Glacier and closure of Russell Fiord, Alaska—Environmental effects and hazards in the Yakutat area, *in* Galloway, J.P., and Hamilton, T.D., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 4–16.

Mayo, L.R., 1988b, Hubbard Glacier near Yakutat, Alaska—The ice damming and breakout of Russell Fiord/Lake, 1986: U.S. Geological Survey Water Supply Paper 2325, p. 42–49.

Mayo, L.R., 1989, Advance of Hubbard Glacier and 1986 outburst of Russell Fiord, Alaska, U.S.A.: Annals of Glaciology, v. 13, p. 189–194.

Meier, M.F., and Post, A., 1962, Recent variations in mass net budgets of glaciers in western North America: International Association of Scientific Hydrology, v. 58, p. 63–77.

Meier, M.F., and Post, A., 1987, Fast tidewater glaciers: Journal of Geophysical Research, v. 92, p. 9051–9058.

Meier, M.F., Rasmussen, L.A., Post, A., Brown, C.S., Bindschadler, R.A., Mayo, L.R., Trabant, D.C., and Sikonia, W.G., 1980, Predicted timing of the disintegration of the lower reach of Columbia Glacier, Alaska: U.S. Geological Survey Open-File Report 80–582, 34 p.

Miller, D.J., 1961, Geology of the Yakutat District, Gulf of Alaska Tertiary Province, Alaska: U.S. Geological Survey Open-File Map 61–103, scale 1:96 000.

Molnia, B.F., 1986, Glacial history of the northeastern Gulf of Alaska—A synthesis, *in* Hamilton, T.D., et al., eds., Glaciation in Alaska: Anchorage, Alaska Geological Society, p. 219–235.

Molnia, B.F., and Carlson, P.R., 1978, Surface sedimentary units of northern Gulf of Alaska continental shelf: American Association of Petroleum Geologists Bulletin, v. 62, p. 633–643.

Peteet, D.M., 1991, Postglacial migration history of lodgepole pine near Yakutat, Alaska: Canadian Journal of Botany, v. 69, p. 786–796.

Plafker, G., and Miller, D.J., 1958, Glacial features and surficial deposits of the Malaspina district, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-271, scale 1:250 000.

Plafker, G., and Thatcher, W., 1982, Geological and geophysical evaluation of the mechanisms of the great 1899–1900 Yakutat Bay, Alaska earthquakes [abs.], *in* American Geophysical Union Conference on Fault Behavior and the Earthquake Generation Process, Snowbird, Utah, October 1982: Programs and Abstracts, n.p.

Plafker, G., Hudson, T., Bruns, T., and Rubin, M., 1978, Late Quaternary offsets along the Fairweather fault and crustal plate interactions in southern Alaska: Canadian Journal of Earth Sciences, v. 15, p. 805–816.

Plafker, G., Gilpin, L.M., and Lahr, J.C., 1994, Neotectonic map of Alaska, *in* Plafker, G., and Berg, H.C., eds., The geology of Alaska: Boulder, Colorado, Geological Society of America, Geology of North America, v. G-1, plate 12, scale 1:2 500 000.

Post, A., 1975, Preliminary hydrography and historical terminal changes of Columbia Glacier, Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA-559, 3 sheets, scale 1:10 000.

Post, A., and Motyka, R.J., 1995, Taku and LeConte Glaciers, Alaska: Calving-speed control of late-Holocene asynchronous advances and retreats: Physical Geography, v. 16, p. 59–82.

Powell, R.D., 1991, Grounding-line systems as second-order controls on fluctuations of tidewater termini of temperate glaciers, *in* Anderson, J., and Ashley, G., eds., Glacial marine sedimentation; paleoclimatic significance: Geological Society of America Special Paper 261, p. 75–93.

Reeburgh, W.S., Muench, R.D., and Cooney, R.T., 1976, Oceanographic conditions during 1973 in Russell Fjord, Alaska: Estuarine and Coastal Marine Science, v. 4, p. 129–145.

Rubin, M., and Alexander, C., 1960, U.S. Geological Survey radiocarbon dates V: American Journal of Science Radiocarbon Supplement, v. 2, p. 129–185.

Russell, I.C., 1891, An expedition to Mount Saint Elias, Alaska: National Geographic Magazine, v. 3, p. 3–204.

Russell, I.C., 1893, Second expedition to Mount Saint Elias, in 1891: U.S. Geological Survey Thirteenth Annual Report, part 2, p. 1–91.

Shephard, M.E., 1995, Plant community ecology and classification of the Yakutat foreland, Alaska: Sitka, Alaska, U.S. Department of Agriculture, Forest Service, 214 p.

Stuiver, M., and Pearson, G.W., 1993, High-precision bidecadal calibration of the radiocarbon timescale, A.D. 1950–500 B.C. and 2500–6000 B.C.: Radiocarbon, v. 35, p. 1–23.

Stuiver, M., and Reimer, P.J., 1993, Extended ^{14}C database and revised CALIB radiocarbon calibration program: Radiocarbon, v. 35, p. 215–230.

Tarr, R.S., 1906, The Yakutat Bay region: U.S. Geological Survey Bulletin 284, p. 61–64.

Tarr, R.S., 1907, Recent advance of glaciers in the Yakutat Bay region, Alaska: Geological Society of America Bulletin, v. 18, p. 257–286.

Tarr, R.S., 1909, The Yakutat Bay region, Alaska; physiography and glacial geology: U.S. Geological Survey Professional Paper 64, p. 11–144.

Tarr, R.S., and Butler, B.S., 1909, The Yakutat Bay region, Alaska; aerial geology: U.S. Geological Survey Professional Paper 64, p. 145–178.

Tarr, R.S., and Martin, L., 1906a, Recent changes of level in the Yakutat Bay region, Alaska: Geological Society of America Bulletin, v. 17, p. 29–64.

Tarr, R.S., and Martin, L., 1906b, Glaciers and glaciation of Yakutat Bay, Alaska: American Geographical Society Bulletin, v. 38, p. 145–167.

Tarr, R.S., and Martin, L., 1907, Position of Hubbard Glacier front in 1792 and 1794: American Geographical Society Bulletin, v. 39, p. 129–136.

Tarr, R.S., and Martin, L., 1912, The earthquakes at Yakutat Bay, Alaska, in September, 1899: U.S. Geological Survey Professional Paper 69, 135 p.

Tarr, R.S., and Martin, L., 1914, Alaskan glacier studies: Washington, D.C., National Geographic Society, 498 p.

Trabant, D.C., Krimmel, R.M., and Post, A., 1991, A preliminary forecast of the advance of Hubbard Glacier and its influence on Russell Fiord, Alaska: U.S. Geological Survey Water-Resource Investigations Report 90-4172, 34 p.

Trautman, M.A., and Willis, E.H., 1966, Isotopes, Inc. radiocarbon measurements V: Radiocarbon, v. 8, p. 161–203.

Vancouver, G., 1798, A voyage of discovery to the North Pacific Ocean and around the world, 1791–1795: Edited and with appendices by Lamb, W.K., 1984: London, Hakluyt Society, 1665 p.

Viens, R.J., 1994, Dynamics and mass balance of temperate tidewater calving glaciers of southern Alaska [Master's thesis]: Seattle, University of Washington, 149 p.

von Engeln, O.D., 1911, Phenomena associated with glacier drainage and wastage: Zeitschrift für Gletscherkunde, v. 6, p. 104–150.

Wagner, H.R., 1936, Journal of Tomás de Suría of his voyage with Malaspina to the northwest coast of America in 1791: Pacific Historical Review, v. 5, p. 234–276.

Wiles, G.C., Calkin, P.E., and Jacoby, G.C., 1996, Tree-ring analysis and Quaternary geology: Principles and recent applications: Geomorphology, v. 16, p. 259–272.

Wright, F.F., 1972, Marine geology of Yakutat Bay, Alaska: U.S. Geological Survey Professional Paper 800-B, p. B9–B15.

Yehle, L.A., 1979, Reconnaissance engineering geology of the Yakutat area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards: U.S. Geological Survey Professional Paper 1074,44 p.

Manuscript Received by the Society September 22, 1999
Revised Manuscript Received April 20, 2000
Manuscript Accepted April 21, 2000

Printed in the USA