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DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Tony Knowles, *Governor*

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RECENT RETREAT OF LECONTE GLACIER AND ASSOCIATED CALVING AND ICEBERG HAZARDS

by
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RECENT RETREAT OF LECONTE GLACIER AND ASSOCIATED CALVING AND ICEBERG HAZARDS

by

Roman J. Motyka[1], James Begét[2], and Paul Bowen[3]

INTRODUCTION

LeConte Glacier is located 50 km east of Petersburg, Alaska (fig. 1). It is 35 km long and covers an area of 487 km^2, about half the size of Columbia Glacier, a large retreating, calving glacier near Valdez, Alaska (Meier, 1994). At a latitude of about 57°N, it is the southernmost tidewater calving glacier in the northern hemisphere. The glacier drains an accumulation basin that rises to 2,500 m in elevation, has an equilibrium line altitude (ELA) of about 920 m, and an extremely high (0.90) accumulation area ratio (AAR) (Post and Motyka, 1995). Ice flows from the accumulation area down through a narrow trough, and turns abruptly before descending steeply into LeConte Bay (figs. 2, 3). Icebergs are discharged into the bay, which is a deep and narrow steep-walled fjord in its upper reaches (figs. 2, 3). The upper part of the fjord consists of rocks that are part of the granodioritic Coast Mountains batholith, which forms the core of the Coast Mountains (Gehrels and Berg, 1992).

The last expansion of LeConte Glacier lasted from about 1300 AD to about 200 years ago, when it began to recede from a submarine moraine offshore from Thunder Point (fig. 3) (Post and Motyka, 1995). The glacier retreated 3.7 km between 1887, when it was first charted, and 1962, when it stabilized at a narrows near the head of the bay. The terminus was surveyed annually from 1983 to the present by one of the authors and students from Petersburg High School (PHS) (P. Bowen, unpub. data). These surveys, plus aerial photographs dating back to 1962, show that the terminus remained at its 1962 position until late 1994, and that the magnitude of seasonal fluctuations (up to 300 m) exceeded any annual changes (figs. 2, 3). These seasonal fluctuations are similar to those found on Columbia Glacier: retreat during the summer and fall followed by advance in the winter to late spring (e.g. Krimmel, 1992). LeConte Glacier and its activity have been and continue to be the subject of intense community interest because of its proximity and because of the hazards to navigation in Frederick Sound and Wrangell Narrows posed by icebergs from the glacier.

CALVING RETREAT

Surveys conducted by Petersburg High School (PHS) students documented a calving retreat of LeConte Glacier totaling about 1300 m that began in December 1994 and

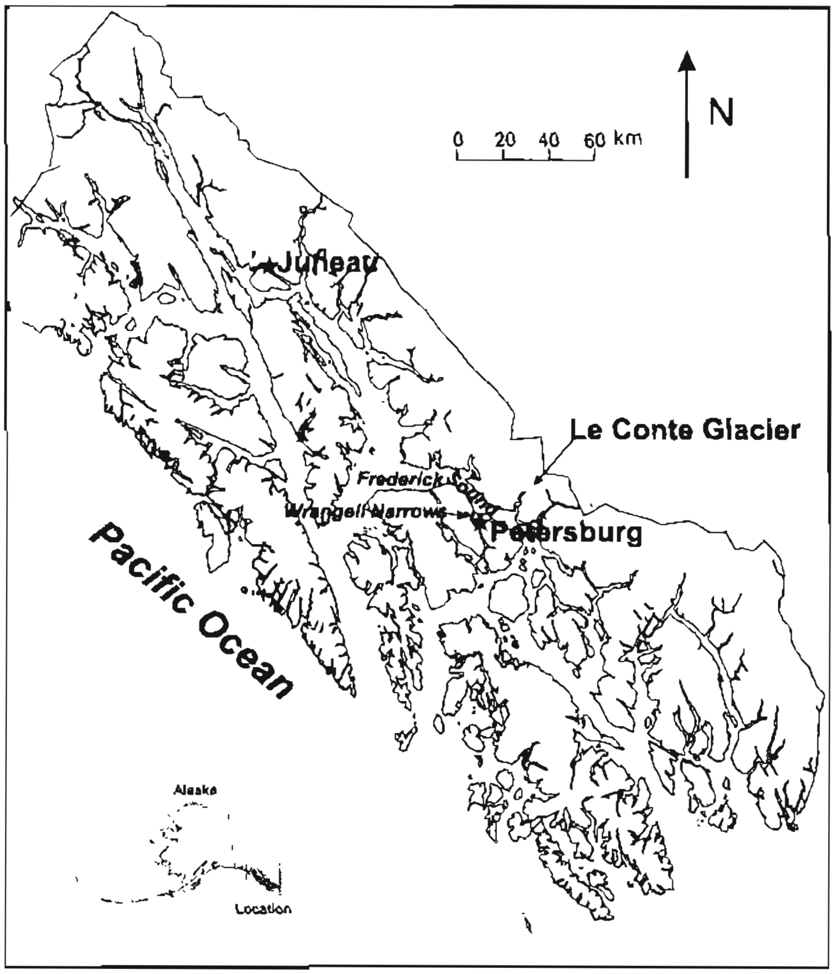

Figure 1. *Location of LeConte Glacier, Petersburg, Frederick Sound and Wrangell Narrows.*

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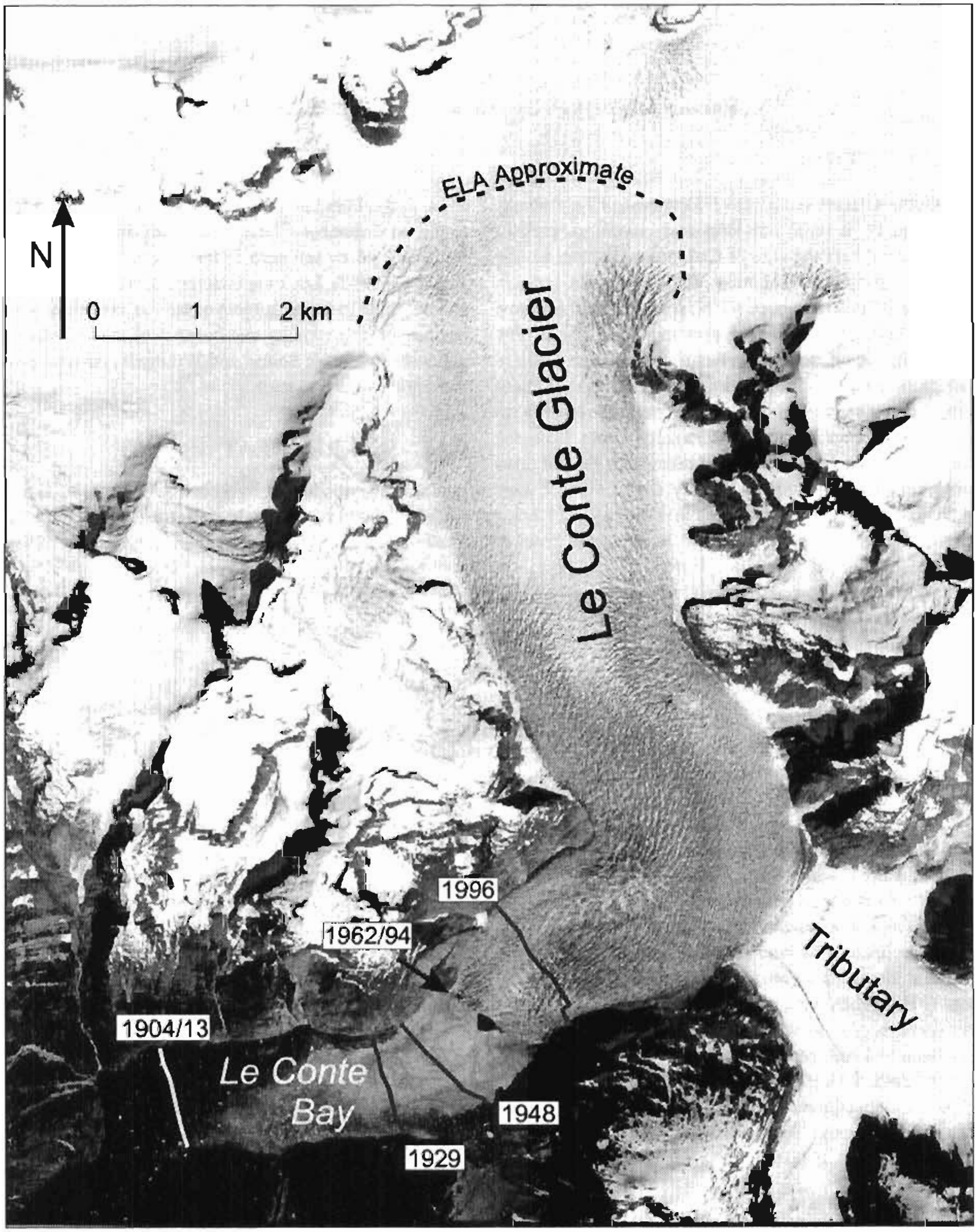

Figure 2. *Aerial photograph (U.S. Forest Service, July 30, 1985) of the lower LeConte Glacier showing historic terminus positions.*

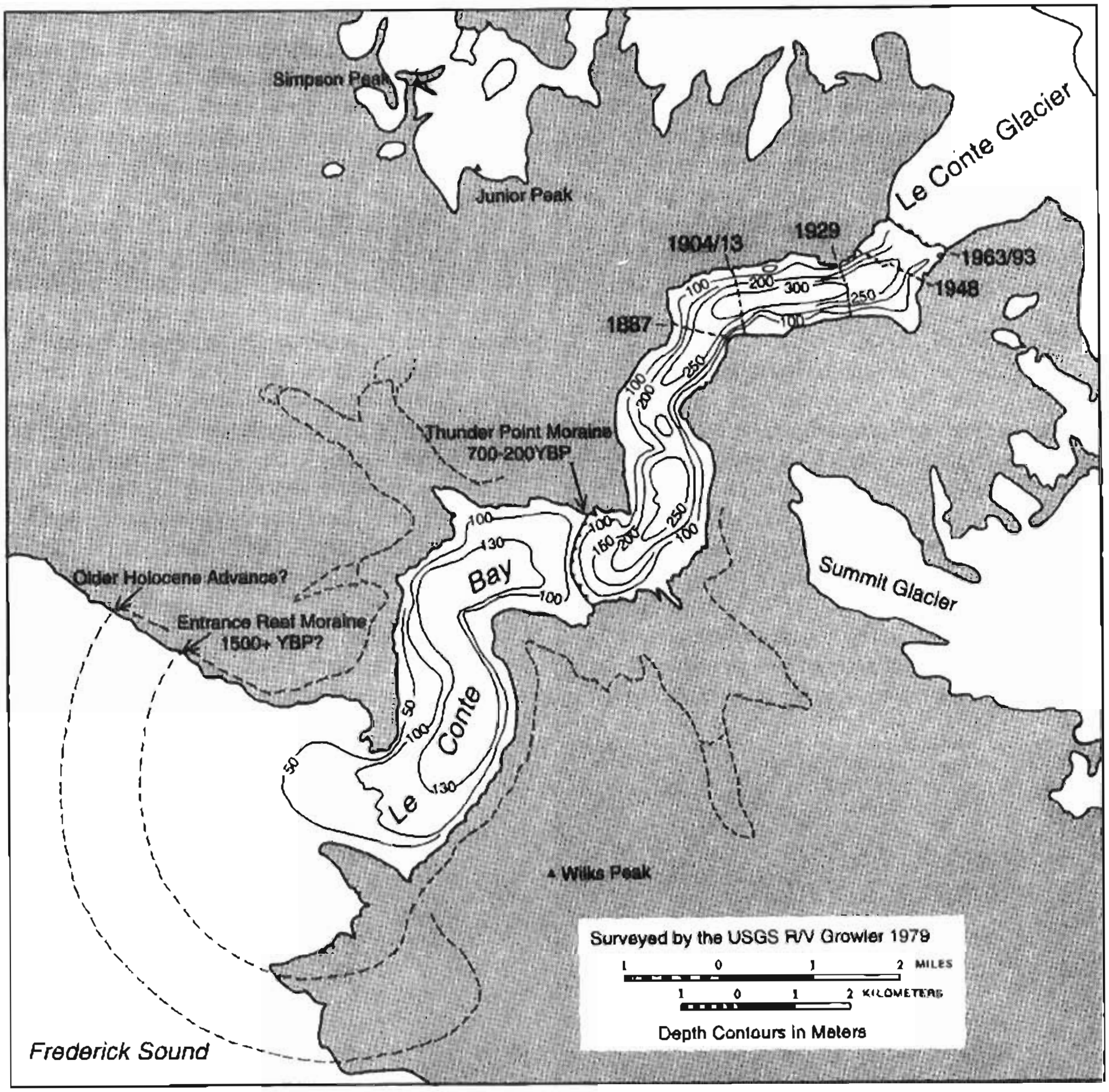

Figure 3. *Bathymetry and late-Holocene terminus positions in LeConte Bay.*

continued until August 1995 where it temporarily restabilized (fig. 2). The seasonally-corrected rate of retreat was about 1200 m per year, a rate equaling or exceeding other historic calving glacier retreats in Alaska (Meier and Post, 1987). The ice surface along the lower 2 or 3 km of the glacier dropped 50 to 80 m by September 1995, exposing a bedrock knob that protruded through the ice about 1.5 km from the calving front. Terminus positions were surveyed in late September 1995 and again during mid May, mid August, and mid October of 1996. A seasonal advance began in winter 1995-96, and by May 1996 the terminus had pushed forward 400 m from its September position. Thickening ice once again covered the bedrock knob that was exposed the previous September. A time-lapse camera installed to monitor daily changes shows that the seasonal maximum was attained by mid May and the glacier began receding shortly afterwards. The terminus retreated 360 m by August 8 and another 40 m by October 24, to its approximate fall 1995 position. Thinning ice re-exposed the bedrock knob.

Near-terminus glacier-surface velocities averaged 15 to 20 m per day, both in mid May and in mid August 1996; these rates are similar to those observed at Columbia Glacier, and at Glacier San Rafael in southern Chile (Krimmel, 1992; Harrison, 1992). Surveyed ice-cliff heights ranged from 40 to 60 m above water but occasionally were as high as 80 m.

The retreat significantly increased the iceberg flux into Frederick Sound. An abnormally large number of icebergs floated into Petersburg's harbors, lodged under wharves, and became general hazards to navigation throughout the area during the retreat. Icebergs from LeConte Glacier continue to pose a hazard to the Petersburg region. Strong tidal currents drove a 100-m-long iceberg into a fuel dock in late September 1996, destroying several pilings and nearly causing an oil spill (Petersburg Pilot, 1996) (fig. 4). The iceberg then continued up the narrows, barely missing a docked ferry.

CALVING EVENTS

We observed calving from a ridge near the terminus during May 1996. Deep water and a high mass flux combined to produce extremely active calving. The narrow channel (approximately 1 km) and our vantage point allowed excellent documentation of calving events. More than 400 individual events were catalogued during 25 hours of daylight observations in a three-day period. Magnitude of calving and frequency had no apparent correlation with tidal stage (fig. 5) or with subglacial freshwater discharge. The majority of events were subaerial; purely submarine events were observed on 44 occasions. These occurred mostly at or near the calving front. However, on several occasions we also witnessed emergence of isolated submarine icebergs (locally known as "shooters"), 50 m in length, at distances of up to 500 m from the calving face. These blocks appear to have risen vertically as no horizontal component of motion was noted after emergence. Although such events have been observed at other calving glaciers (Warren and others, 1995; A. Post, USGS, oral commun.; L. Hunter, CRREL, oral commun.), their genesis remains a mystery.

Only 16 of the events involved both subaerial and submarine calving, but they were by far the most voluminous. This finding is similar to that at Glacier San Rafael (Warren and others, 1995). Three particularly large events occurred on the final day of the May observations. The first occurred on the morning's falling tide, the second at morning low tide, and the third happened on the rising late-afternoon tide (fig. 5). The last two of these events were directly observed and documented on film (Motyka and Bégét, 1996). The events resulted in nearly wall-to-wall collapse of the calving front and release of massive submarine icebergs (fig. 6). The following sequence was observed for both events: massive subaerial collapse of the ice cliff near the center of the terminus; retrograde toppling of adjacent and

Figure 4. *Pilings snapped by tide-driven iceberg at Petersburg fuel dock.*

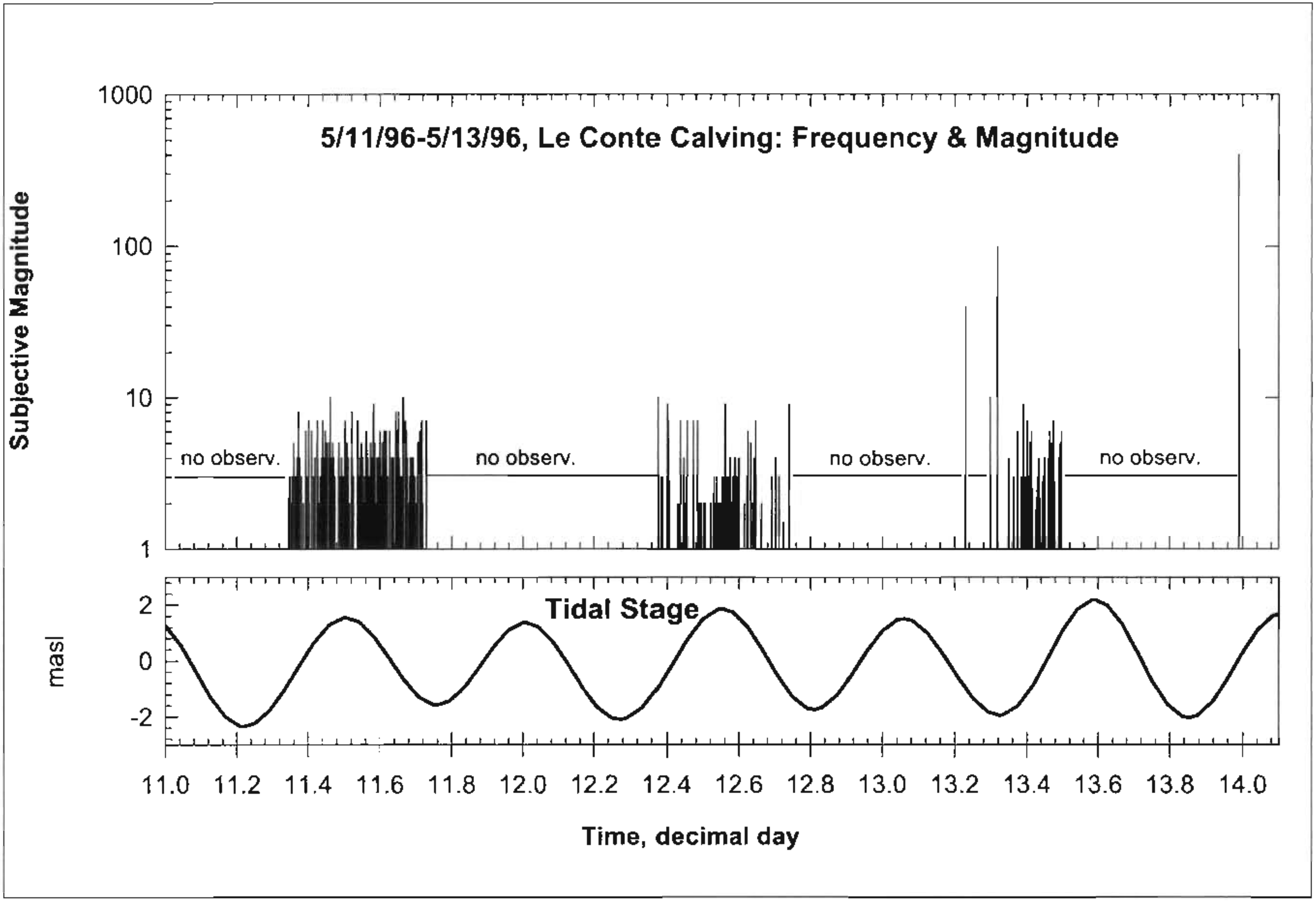

Figure 5. *Frequency and subjective magnitude of calving events compared to tidal stage (Petersburg correction).*

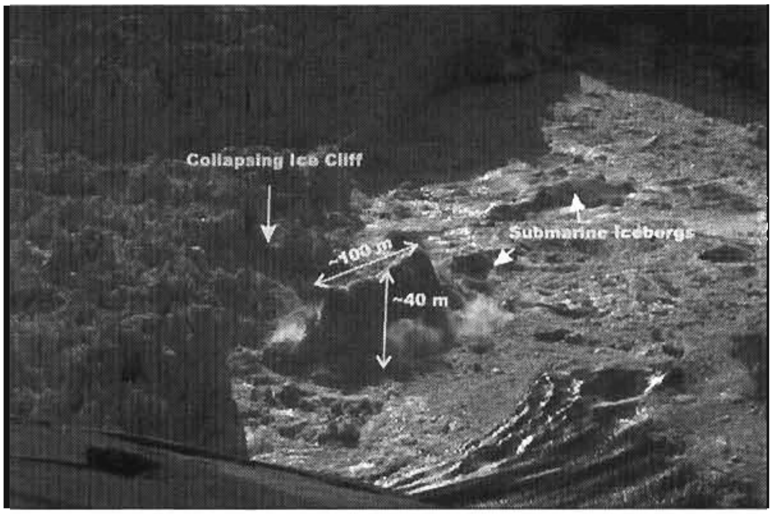

Figure 6a. *Tabular block of ice emerged along face following collapse of subaerial ice cliffs.*

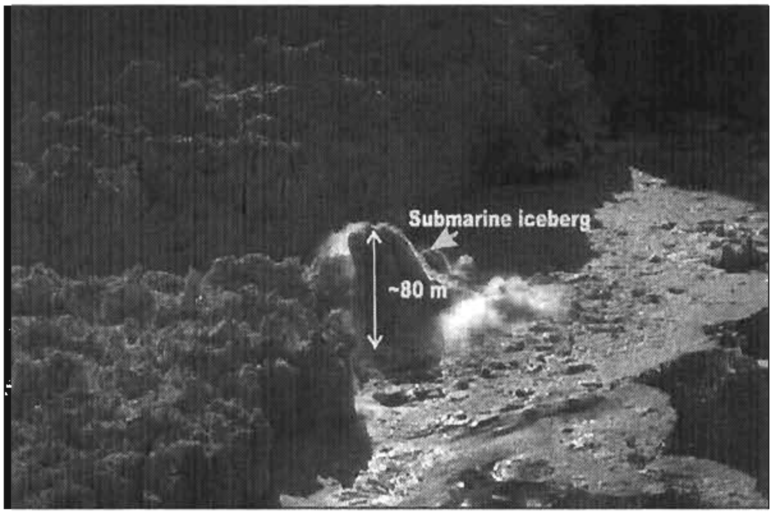

Figure 6b. *Oblong submarine iceberg was thrust upwards by buoyancy after a subaerial serac collapsed.*

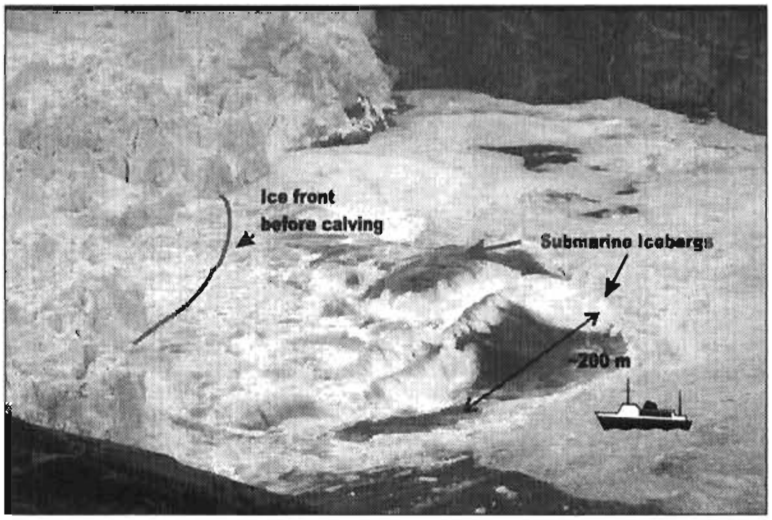

Figure 6c. *Deep-water submarine icebergs emerged 250 to 300 m from face following subaerial collapse of broad section of glacier terminus. The top of the iceberg in the foreground was driven 35 m above water.*

Figure 6. *Examples of calving at LeConte Glacier, Alaska.*

up-glacier ice columns and seracs; fracture and release of submarine ice; emergence of large submarine icebergs, tops rising 30 to 40 m above water; secondary collapse of adjacent ice cliffs and release of additional submarine icebergs. Both events transpired over a period of approximately 2 to 3 minutes and released submarine blocks of ice estimated at up to 150 m in length. An estimated 2.5 x 10^6 m^3 of ice were involved in the first event and 3.5 x 10^6 m^3 in the second. Massive up-welling of the affected water column preceded and continued well after the emergence of submarine icebergs.

These large-scale submarine events could be related to buoyancy and extensional flow. The extremely crevassed nature of the glacier, particularly where the ice descends and enters the fjord channel, is evidence of strong extensional flow. Reconnaissance soundings of proglacial water depths (September 1996, S. Barry, oral commun.) in the vicinity of the May terminus position ranged from 250 to 270 m parallel to the face, and averaged 270 m along the perpendicular. These water depths at the face are approximately 90 percent of the flotation value for ice. Following collapse of 50-m-high subaerial ice, the submarine section would be super-buoyant. The instantaneous increase in buoyancy-induced stresses following unloading of subaerial ice, combined with pre-existent horizontal stresses created by extensional flow, could have triggered the massive submarine calving events.

Detailed observations of calving events were not possible during our brief August and October visits. However, our subjective impression is that calving frequency and size, although still significant, were not as robust as during mid May. One large-scale calving event was witnessed during the three-day August visit. It followed a period of heavy precipitation and was initiated in a zone of constant and strong upwelling at the glacier front.

Assuming an average water depth of 250 m, the empirically-derived water-depth vs. calving-speed relationship of Brown and others (1982) gives a calving speed of 18.5 m per day; Reeh's (1994) ice-thickness versus calving-speed relationship, as modified by Meier (1994) for Alaska glaciers, gives 20 m per day. These calving speeds correspond closely to the May and August near-terminus ice velocities. The latter are probably good estimates of the calving speed because the terminus appeared to be only slightly advancing (approximately 1 m per day) in mid May and slightly retreating (approximately 1 m per day) in mid August. In contrast, applying the relationship derived by Pelto and Warren (1991) produces a value of 6 m per day. The difference may lie in using a summer velocity for the glacier rather than a mean annual value. Pelto and Warren (1991) suggested that the relationship described by Brown and others (1982) provides a better fit for maximum summer velocities while their equation is a better fit to annual average velocities. We do not yet know annual or winter velocity at LeConte Glacier.

DISCUSSION

Channel geometry is likely to have been the primary control on the temporary stabilization of LeConte Glacier between 1962 and 1994. The narrower channel would have reduced the area of icefront exposed to tidewater and thereby decreased calving velocity at a "pinning point" (Mercer, 1961; Wiles and others, 1995). The question remains whether a substantial moraine shoal developed during the 33-year period of relative stability. The limited bathymetric evidence available suggests not. Water depths near the 1994 face remained very deep, approximately 200 m (Post and Motyka, 1995; P. Bowen, Petersburg, unpublished data), despite 33 years of sedimentation. Compared to Glacier Bay, LeConte Glacier appears to have a very low sediment yield, as evidenced by the depth of the bay (fig. 3) and by the relatively clean discharge plume that emerges from the glacier's calving front. However, even in Glacier Bay, rapid sedimentation and build-up of moraine shoals have been insufficient to forestall renewed calving retreat following brief periods of stability at pinning points (Cai and Powell, 1995).

The causes of the recent calving retreat remain unclear. Retreat occurs when the calving speed exceeds ice velocity at the terminus. An increase in calving speed or decrease in terminus ice velocity, or some combination of both, would lead to the observed retreat. The loss of influx from a tributary entering at a low elevation (fig. 2) probably contributed to the glacier's general recession prior to 1962, but the tributary has contributed little since then. The equilibrium line altitude (ELA) of the main branch lies at a sensitive altitude where small rises in ELA will begin to seriously decrease the area of accumulation (fig. 2). The delicate balance between mass-balance driven flow and calving loss could have been disrupted either by a lowering of the ice surface relative to the ELA due to thinning and draw-down of ice induced by calving losses, or by a climate-induced change of the ELA, or a combination of both. A reduction in ice flux would cause thinning at the terminus, and renewed retreat (van der Veen, 1996). An alternative scenario could have been an increase in calving speed due to retreat into deeper water (e.g. Brown and others, 1982).

In order to investigate the relation between the calving front and the glacier as a whole, K. Echelmeyer (Geophysical Institute, University of Alaska Fairbanks, written and oral commun.) measured a series of elevation profiles along the glacier in June 1996. The profiles were made using the airborne laser altimetry system developed by Echelmeyer and others (1996). These profiles were compared with an existing map to determine elevation changes. (Note: The profile data were compared with 1948 USGS topographic maps. There is some uncertainty in the dates of the photography used in making these maps.) Echelmeyer (written and oral commun.) found that significant thinning has occurred along most of the glacier. Thinning averaged approximately 30 m over the large (AAR=0.9) accumulation area, 50 m at the present equilibrium line, and increased to a maximum of 200 m near the present terminus. This thinning must be related to the ongoing retreat or to a climate-induced reduction in mass balance, or both.

CALVING AND ICEBERG HAZARDS

Given the glacier's geometry, robust AAR (accumulation to area ratio), low sedimentation, and the deep proglacial bathymetry, the LeConte terminus is likely to experience strong seasonal fluctuations and continue to produce a high flux of icebergs for the foreseeable future. The greatest hazards occur, not surprisingly, within the immediate vicinity of the calving face. Vessels venturing within 0.5 km of the terminus are at extreme risk from both subaerial and submarine calving. Isolated submarine icebergs, as much as 50 m in length, were observed to emerge as far as 500 m from the terminus with little or no warning. Large calving events, which can produce submarine icebergs of considerable size (up to 150 m in maximum dimension), are particularly dangerous as they can affect the entire proglacial area (fig. 6). Calving can also generate waves up to 2 to 3 m in height, which are capable of capsizing smaller vessels.

Farther away from the terminus, the principal hazards are from floating icebergs and waves. Iceberg density is often so high that the bay is essentially unnavigable. Tides, winds, and fjord currents drive icebergs in different directions, posing hazards to unwary mariners. Large waves generated by calving events travel down-fjord and run up shorelines, potentially engulfing unsuspecting campers, kayakers, and other shoreline users.

Icebergs exit LeConte Bay across an entrance barrier moraine (fig. 3), which restricts maximum iceberg keel depths that can escape into Frederick Sound to about 12 to 15 m. Nevertheless, tabular dimensions of icebergs discharging into the sound are still large enough to constitute a general hazard to navigation. Icebergs entering Wrangell Narrows become additionally hazardous because they are driven by large tidal currents (up to several knots). Icebergs have hit moored vessels and shoreline structures. Icebergs also float under wharves and docks during low tides, and rise with the tide, causing damage to structures (Petersburg Harbormaster, oral commun.). Tabular icebergs of considerable size have entered Wrangell Narrows as demonstrated by the iceberg that battered the Petersburg fuel dock in October 1996 (Petersburg Pilot, 1996) (fig. 4).

For the near future, iceberg fluxes into LeConte Bay and Frederick Sound are likely to remain at levels substantially higher than existed prior to 1994, as the glacier continues to adjust to the recent calving retreat. Iceberg discharge is likely to be seasonal, in tandem with the seasonal fluctuations of terminus position—higher fluxes occurring in spring and summer, and lower fluxes during autumn and winter months.

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REFERENCES CITED

Brown, C.S., Meier, M.F., and Post, A., 1982, Calving speed of Alaska tidewater glaciers with application to Columbia Glacier: U.S. Geological Survey Professional Paper 1258-C, 13 p.

Cai, J. and Powell, R.D., 1995, Glacier fluctuations and sediment yields interpreted from seismic-reflection profiles in John Hopkins Inlet, Glacier Bay, Alaska: in Engstrom, D.R., ed., Proceedings of the Third Glacier Bay Science Symposium, September 14-18, 1993, National Park Service, Anchorage, p. 15-23.

Echelmeyer, K., Harrison, W., Larsen, C., Sapiano, J., Mitchell, J., DeMallie, J., Rabus, B., 1996, Airborne surface elevation profiling of glaciers: A case study in Alaska: Journal of Glaciology, v. 41, no. 141, p. 538-547.

Gehrels, G.E., and Berg, H.C., 1992, Geologic map of southeastern Alaska: U.S. Geological Survey Miscellaneous Investigations. Series Map I-1867, scale 1:600,000. 24 p.

Harrison, S., 1992, A large calving event of Ventisquero San Rafael, southern Chile, Journal of Glaciology, v. 38, no. 128, p. 208-209.

Krimmel, R.M., 1992, Photogrammetric determination of surface altitude, velocity, and calving rate of Columbia

Glacier, Alaska, 1983-1991: U.S. Geological Survey Open File Report 92-104, 71 p.

Meier, M.F. and Post A., 1987, Fast Tidewater Glaciers: Journal of Geophysical Research, v. 92, No. B9, p. 9051-9058.

Meier, M.F., 1994, Columbia Glacier during rapid retreat: interactions between glacier flow and iceberg calving dynamics: in Reeh, N., ed. Workshop on the calving rate of West Greenland glaciers in response to climate change, Sept. 13-15, 1993, Copenhagen Danish Polar Center, p. 63-84.

Mercer, J.H., 1961, The response of fjord glaciers to changes in the firn limit: Journal of Glaciology, v. 3, no. 29, p. 850-858.

Motyka, R.J. and Bégét, J.E., 1996, Large calving events at LeConte Glacier, southeast Alaska (abst.): EOS, Transactions of the American Geophysical Union, 1996 Fall Meeting, p. F177.

Pelto, M.S. and Warren, C.R., 1991, Relationship between tidewater glacier calving velocity and water depth at the calving front: Annual Glaciology, v. 15, p. 115-118.

Petersburg Pilot, 1996, "City OKs repair of iceberg-damaged dock," October 10, p. 11.

Post, A. and Motyka, R.J., 1995, Taku and LeConte Glaciers, Alaska: Calving speed control of late Holocene asynchronous advances and retreats: in Nelson, F.E., ed., Glaciers and Late Quaternary Environments of Alaska: I, Essays in Honor of William O. Field, Physical Geography, v. 16, no. 1, p. 59-82.

Reeh, N., 1994, Calving from Greenland glaciers: observations, balance estimates of calving rates, calving laws: in Reeh, N., ed., Workshop on the calving rate of West Greenland glaciers in response to climate change, Sept. 13-15, 1993, Copenhagen Danish Polar Center, p. 85-102.

van der Veen, C.J., 1996, Tidewater calving: Journal of Glaciology, v. 41, no. 141, p. 375-385.

Warren, C.R., Glasser, N.F., Harrison, S., Winchester, V., Kerr, A.R., and Rivera, A., 1995, Characteristics of tide-water calving at Glacier San Rafael, Chile: Journal of Glaciology, v. 41, no. 138, p. 273-289.

Wiles, G.C., Calkins, P.E., and Post, A., 1995, Glacier fluctuations in the Kenai Fjords, Alaska, U.S.A.: An evaluation of controls on iceberg-calving glaciers: Arctic and Alpine Research, v. 27, p. 234-245.