1946-1962 Survey of the Regional Pattern of Alaskan Glacier Variations

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Grant No. 303: In aid of the project to analyze and record the significant changes that have taken place in Alaskan glaciers in the half century since the Society-sponsored researches of Tarr and Martin.

Background and Objectives of Study

Between 1946 and 1953 I carried out a series of annual surveys of glacier termini and névé-line positions on a number of Alaskan ice masses (Miller, 1947, 1948, 1949, 1954). The purpose of the studies was to provide a teleconnectional framework for glacier regimen studies of the Juneau Icefield Research Program (Miller and Field, 1951). In 1960, with the support of the National Geographic Society, it was possible to repeat these surveys and to compare results with the record of glacier variations reported in 1914 by Tarr and Martin under Society sponsorship. Selective photography and mapping were also accomplished in 1954, 1955, 1958, and 1960 (Dudley and Miller, 1959; Miller, 1964), through support of the Foundation for Glacier and Field Research.

The National Geographic Society's reconnaissance survey was continued in 1961 and completed in 1962. This report summarizes the results of observations between 1946 and 1962.

The area concerned extends through the Alaskan Panhandle from Wrangell Narrows (lat. 56°N.) to Cook Inlet (lat. 61°31′N.). It is shown in figure 1, with survey routes indicated in figure 2. More than 2,700 ground and aerial photographs and observations on 174 major glaciers were obtained.

District Regime Patterns, Assessment and Comparisons

South coastal Alaska is divided into eight glaciological provinces, delineated in figure 3. The main icefield locations are shown in figure 1.

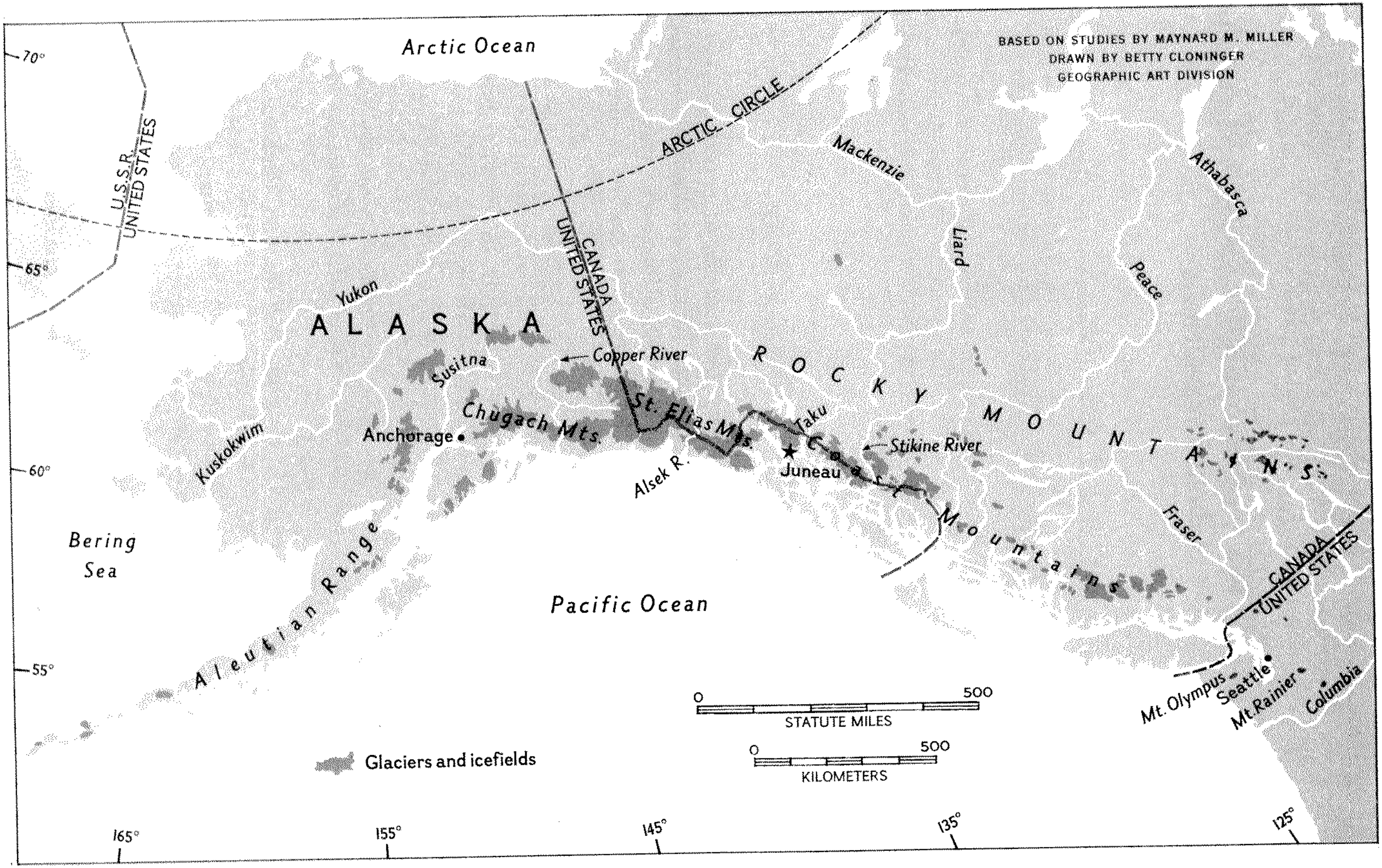

FIG. 1.—General map of Alaska and western Canada, showing principal locations and main centers of existing glaciers and icefields.

Only glaciers of the Kenai Peninsula (Harding Icefield) and the Aleutian Islands are omitted in the following discussions, as these were not observed by Tarr and Martin, with whose records current comparisons are being made. In geographical sequence from southeast to northwest the districts are: Stikine River (lat. 56°-58°N.); Taku River (lat. 58°-59°30′N.); Glacier Bay and Alsek Valley (lat. 58°-59°N.); Chilkat (lat. 59°-59°30′N.); Lituya Bay-Fairweather (lat. 58°-59°N.); St. Elias (lat. 59°-60°30′N.); Prince William Sound and the Chugach Mountains (lat. 60°-61°30′N.); and the Kenai or Harding Icefield (lat. 60°-61°N.).

In table 1, each district except the last is noted with subdivisions summarizing the principal facts from these surveys. The terms "shrinking glaciers" and "expanding glaciers" refer to changes in terminal volume as expressed by thinning or thickening rather than to changes of movement within the ice. An "advancing" or "retreating" (receding) glacier connotes one of volume increase or decrease, with emphasis on changes in lateral position of the termini. "Equilibrium glaciers" imply a static condition, with those factors controlling accumulation and wastage throughout the glacier system being more or less in balance.

A. Stikine River District

This district is delimited by rectangle A (fig. 3) and includes all glaciers between the Stikine River and Taku Valley. The area is extremely mountainous and in the long geological view is a characteristic coastline of submergence, with numerous inshore islands and deep fiords. Inland, the mountains average only 5,000 feet but are heavily glacierized at high elevation. The major present glaciation is the Stikine Icefield, 30 miles northeast of Petersburg, where the range culminates in high summits including Devil's Thumb (9,077 feet), Kates Needle (10,002 feet), and Mount Ratz (10,290 feet).

Observations have been made on few glaciers in this district; however, the summary in table 1 represents the general situation. Shrinkage dominates with only a few glaciers near equilibrium. One notable exception is *Baird Glacier,* which has held an advanced position over many years. It is a trunk glacier with six tributary arms, the central one 28 miles long and 2 miles wide. The gradient is about 3°, and the ice as a whole is nourished from a broad névé at 5,000 feet, extending in places to the summit of the Stikine Icefield, up to 9,000 feet.

In 1941, I photographed the *Baird Glacier* terminus on a gravel delta, with 1 mile of outwash separating it from the sea. The ice front was then a few feet from a mature forest trimline marking a position attained about 1935. From the absence of outer moraines and other geomorphic evidence,

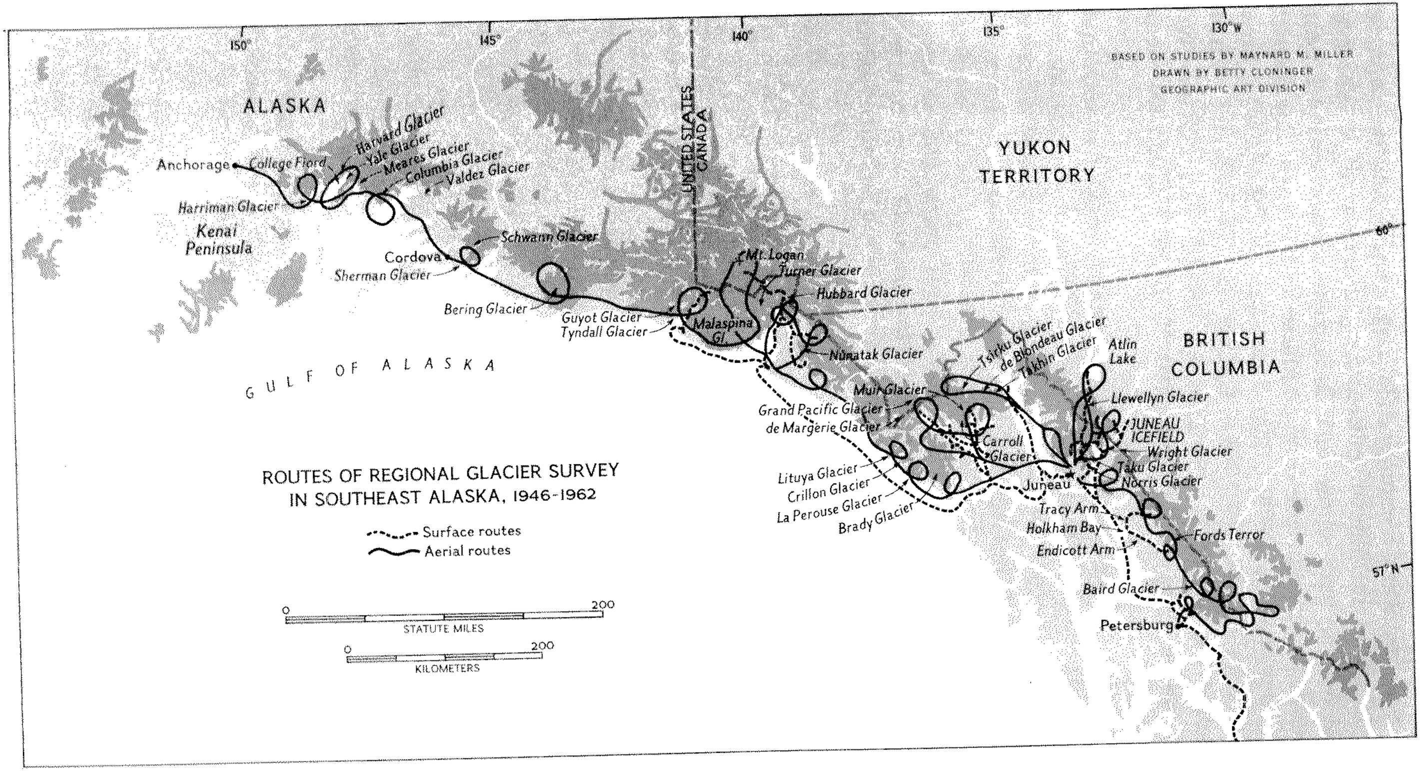

FIG. 2. Routes of the Alaska Glacier Commemorative surveys, 1946 to 1962.

this probably represents the post-Wisconsinan maximum. By 1946, a 300-foot recession had taken place on the southeast margin, but the main front was still well forward. Flights over the terminus in 1958, 1960, and 1961 showed it slightly farther back and thinner, but still within several hundred feet of its recent maximum.

B. Taku River District

At the northern end of the Alaska-Canada Boundary Range, this district is delimited on the south by the Taku River and on the north by Skagway River (frame B, fig. 3). Glaciers here comprise the extensive network of the Juneau Icefield, where our detailed ground studies were initiated in 1946. This icefield, covering 1,500 square miles, is the most heavily glacierized sector of the Alaska-Canada Coast Range. The highland is ice-flooded and has a much larger percentage of névé exposed than nunataks. The snowfields crest is at 7,500 feet. The highest peaks are Devil's Paw, 8,584 feet, and Mount Nesselrode, 8,100 feet. Included is the *Taku-Llewellyn Glacier* system, which stretches for 75 miles across the range.

Major ice tongues descend to low levels, with most termini diminishing in size over the past four decades. The exception is the main trunk glacier, the *Taku,* 40 miles long and extending southward to tide level from the high center of the icefield. Since 1894 this glacier has been continuously pushing forward in a spectacular advance. An account by Capt. George Vancouver (1801, vol. 3) reveals that another important advance occurred in historic time, with the upper end of Taku Inlet blocked by ice in 1794. Then there were "immense bodies of ice that reached perpendicularly to the surface of the water in the basin which admitted of no landing place for the boats" and so much floating ice, especially at the entrance of the inlet, that "a passage was with difficulty effected." Today the formation of icebergs is precluded by the presence of a wide push moraine at the front. Dendrochronological studies show that this glacier reached its most advanced position in 1755 (Lawrence, 1950). Its present position is approaching close to this mid-18th-century maximum.

Since Vancouver (1801, vol. 6), mentions that this "basin" was about 13 miles inland from the mouth of the inlet, the ice front at that time was evidently somewhere near the place where the fiord narrows and then widens again just southeast of *Norris Glacier.* This is corroborated by local Tlingit accounts of an ice "barrier" which at a time "before white man came" prevented travel to the interior. This barrier was removed by subsequent recession permitting Taku Inlet and its headward valley to be used regularly by natives to cross the Coast Range to the Atlin district. In the 1870's to

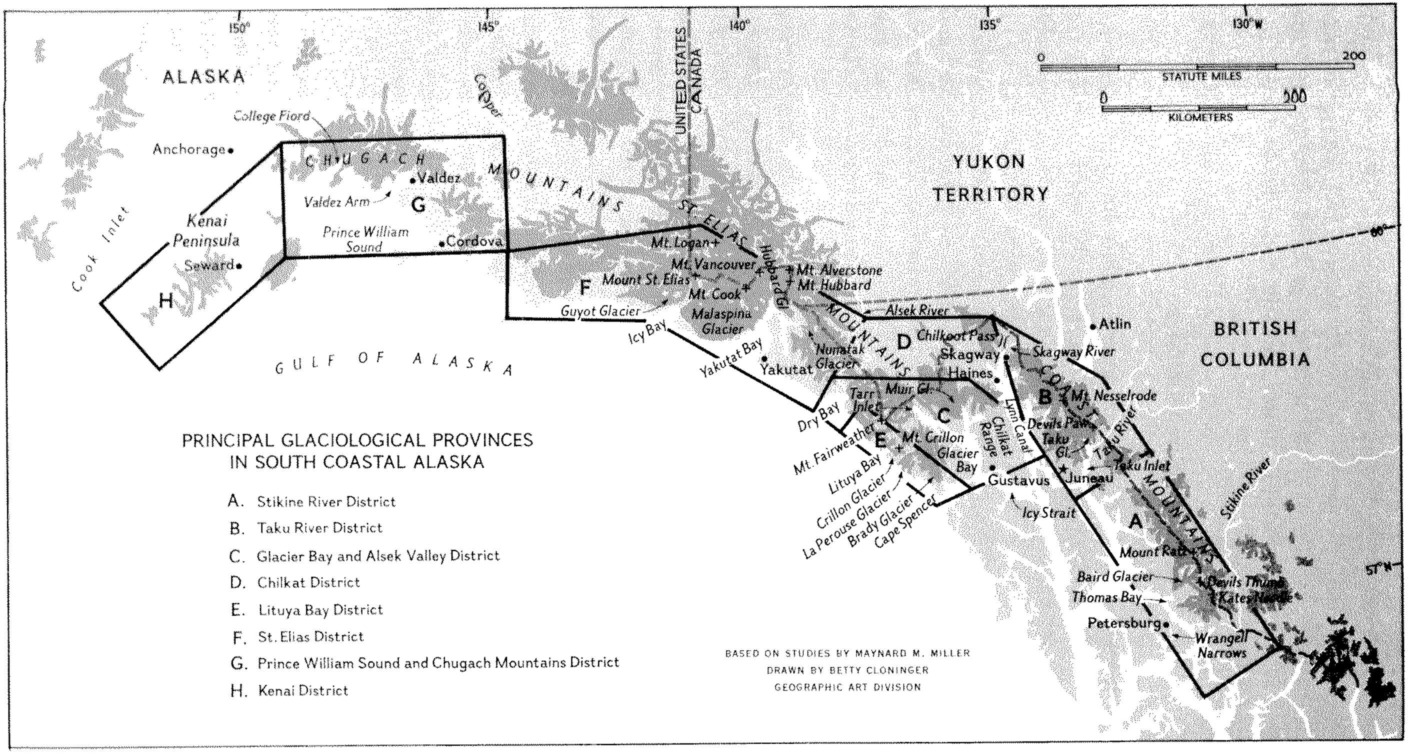

FIG. 3. Glaciological provinces in south coastal Alaska.

'90's this old trail was used also by prospectors until the discovery of Chilkoot and White Passes, near Skagway.

Variations of 10 of the most important glaciers in the Taku district are illustrated in figure 4. In this the present advance of the *Taku Glacier* is compared with the district pattern of retreat. Elsewhere in this region other ice bodies, such as *Wright* and *Sittakanay Glaciers,* and those occupying cirques along the sides of the Taku River Valley and Lynn Canal, have experienced shrinkage since the 1920's.

C. Glacier Bay District

This district is 100 miles west of the Juneau Icefield (frame C, fig. 3). Glacier Bay lies in a palmate valley with two main channels, one 60 and the other 90 miles in length. In 1794, Captain Vancouver (1801, vol. 5) observed that this great depression was filled with ice. The passageway to the south he named "Icy Strait" because of numerous bergs from the ice cliff which then blocked the entrance to the present bay. As in the case of Taku Inlet, only infrequent bergs can now be seen.

About 1,500 square miles of terrain has been opened by this remarkable recession. Fortunately, records and photographs are available since 1880, starting with those of Muir (1893), Wright (1887), and Reid (1892, 1896). I first visited the district in 1940 while on a survey expedition to the Brady Icefield at the southern end of the Fairweather Range (Miller, 1940). Then this fiord, which is more than 2,000 feet deep had experienced an unprecedented recession, losing 9 miles of ice since 1907. Details of such staggering diminution of the whole Glacier Bay ice-sheet in the 1920's and 30's, and description of the rapid encroachment of seed plants on the deglaciated terrain, were first reported by Cooper (1923; 1931). In a later paper (1937) he showed that the great Glacier Bay ice sheet reached its post-Glacial maximum near the mouth of Glacier Bay shortly after 1700 and that the major recessional trend set in sometime between 1735 and 1785. There was a slowing down in the retreat from 1880 to 1899, the rate becoming only half the average in effect since 1794. A readvance of one glacier, a short-lived one in the 1890's, was probably related to this "slowing down" period.

On another mapping survey in Glacier Bay in 1941, W. O. Field and I observed shrinkage still going on at a rapid rate on *Muir Glacier* in the eastern arm of the bay. We measured a recession of 12 miles from the 1899 frontal position (Miller, 1943). A detailed map of this survey, with an explanatory report, was subsequently published by the American Geographical Society (Field, 1947). Shrinkage continued in an accelerated fashion until 1946, as verified by my ground records in that year.

Our further aerial surveys in 1947, 1948, 1951, 1952, and 1961 show that over the past decade and a half a general slowing down of the retreat has again occurred, similar to that reported in the 1890's. This trend was further verified by ground observations while re-occupying our old photogrammetric stations in September 1962.

In spite of an over-all diminishment, there have been minor readvances, especially among a group of 11 hanging ice tongues clinging to the fiord wall of Johns Hopkins Inlet. All are sensitive to causal variations and each has a behavior out of phase with the others. This suggests relationship to the higher elevation positions of their névés and the fact that each is at a different level. Advances of some magnitude have also recently occurred on two large valley glaciers which reach tidewater in Tarr Inlet. These receive nourishment from tributaries at fair elevations on Mount Fairweather, the highest peak in the range. One is a lobe of *Grand Pacific Glacier* which came forward half a mile between 1941 and 1951 to a position from which it has fluctuated only to a small extent in the subsequent interval to 1962. The other is *de Margerie Glacier* which advanced a quarter of a mile in the period 1941-51 and has similarly maintained this position without significant change since. *Carroll Glacier,* in Queen Inlet, experienced thickening and advance in the decade 1941-51, with slow thinning and retreat up to the summer of 1962 (after which a spectacular readvance has occurred). The moraine pattern suggests that this glacier has previously suffered a number of strong oscillations.

The glaciers of the Alsek River Valley are in the northern part of this district. These too have been dominated by shrinkage. Several are transection glaciers connecting to the Muir and Grand Pacific Icefields. The Alsek River joins the ocean at Dry Bay just north of the Fairweather Range, splitting it off from the main St. Elias Mountains (fig. 1). This river valley permits maritime conditions to prevail far inland, an orographical situation which has helped to accelerate the ice retreat in both the Alsek and Glacier Bay sectors.

D. Chilkat District

This district lies northwest of Skagway in the Chilkat Mountains (frame D, fig. 3). Along its southern boundary, 40 miles to the southwest, are 10 or more glaciers with regimes close to equilibrium. Several ice tongues which drain northward from a serrated 7,000-foot range between Glacier Bay and Tsirku and Takhin River Valleys have expanded somewhat in the past 15 years. The *Tsirku Glacier* has advanced more than a quarter of a mile since 1910. This glacier shares a névé with *Carroll Glacier,* mentioned above as

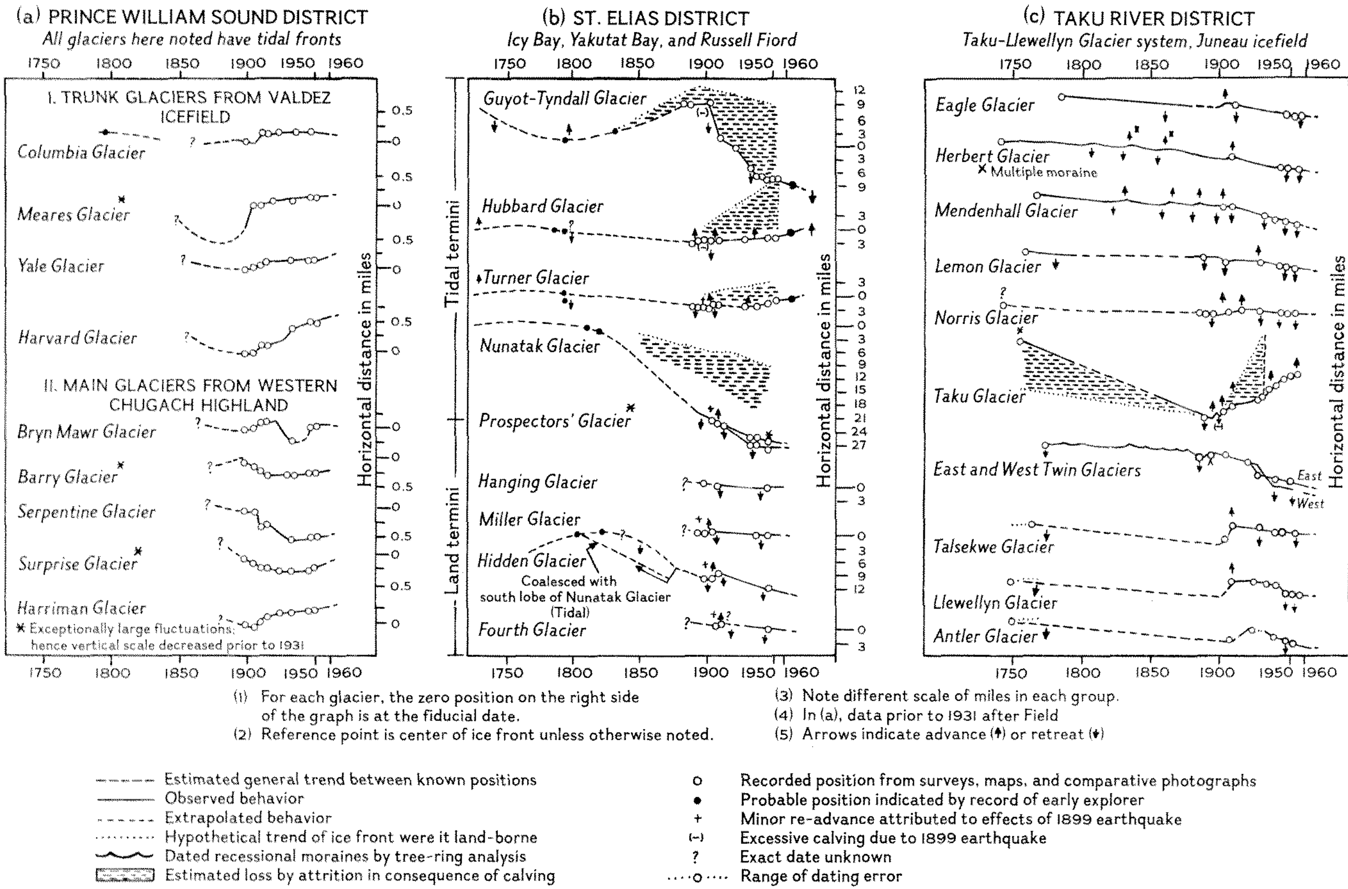

FIG. 4. Fluctuations in lateral position of representative glacier termini in south and southeastern Alaska, 1750-1962.

one of the periodically resurgent glaciers of the Glacier Bay complex. Three other large ice tongues in the Tsirku Valley have termini which were well forward up through the 1950's. Geological reports and photographs by the Boundary Commission (1905 and 1910) reveal that the *Takhin* and *de Blondeau Glaciers* experienced strong advances just prior to 1905, diverting the upper 10 miles of the Takhin River into a tributary of the Chilkat River (Spencer, 1906). Since then there has been little change.

The pattern is noteworthy in contrast to the general shrinkage of glaciers in the nearby Chilkat Mountains and to the situation in Muir Inlet 10 miles south of the Tsirku Valley.

E. Lituya Bay-Fairweather District

The Fairweather Range lies west of Glacier Bay on a peninsula 90 miles long and 30 miles wide. These ice-clad mountains average 10,000 feet in elevation and culminate in the great pyramid of Mount Fairweather (15,300 feet). On the western flank is the Lituya Bay district. As shown in rectangle E, figure 3, it includes the glaciers for 100 miles north of Taylor Bay east of Cape Spencer to Dry Bay at the delta of the Alsek River.

In Lituya Bay the glaciers were considerably receded at the end of the 18th century, while the Glacier Bay ice sheet was at its maximum. By the 1890's, these had expanded and advanced while the Glacier Bay ice was vigorously disappearing (Klotz, 1899). In 1946 and 1947 I observed them still well forward with minor readvances in some cases. This trend persisted up to the time of our 1952 and 1953 surveys. Our aerial photographic records in 1958 and 1961, reveal a slight reversal in trend on several major tongues.

The most southerly ice tongue is the *Brady Glacier,* at the southern tip of the Brady Icefield. This glacier was first sighted by Captain Vancouver in 1794 (Vancouver, 1801, vol. 5). He described its terminus as "an immense body of compact perpendicular ice extending from shore to shore" north of a deserted Indian village. An 1893 position on the Canadian Boundary Survey map (1895: sheet 15) shows that the glacier advanced 6 miles in the intervening century, the Indian village being covered by upward of 1,000 feet of ice (Klotz, 1899). A 1907 survey by the International Boundary Commission (1923: sheet 1) shows the position another mile forward. From then until 1947 it remained close to the 1907 line, indicating that for the previous 40 years it has been in equilibrium near its early 20th-century maximum. Between 1948 and 1961 downwasting characterized the terminal zone, with a static position being maintained close to the 1947 limit.

La Perouse Glacier, 30 miles up the coast, is the only Alaskan ice fronting on the open ocean and calving bergs directly into the surf. For 60 years this bulging lobe has oscillated within a few hundred feet of an 1895 forest trim-line. The same type of variation was found on a large *unnamed piedmont* reaching sea level 3 miles south of *La Perouse Glacier.* This attained its most advanced position in 1899, and now, after another six decades, it is still only a few hundred feet from the frontal moraine. At the time of the 1947 survey, noticeable thinning had occurred. In 1958 further retraction was observed but still within a few hundred feet of the 1899 position. Our 1961 survey revealed this condition to be continuing.

Crillon and *Lituya Glaciers,* at the head of Lituya Bay, are large tidal glaciers. From a map by the La Perouse expedition of 1786 (Klotz, 1899), the late 18th-century positions are known. Comparing these with the 1893 positions on the Canadian Boundary Survey map (1895: sheet 16), we see that each glacier came forward no less than 2.5 miles in the intervening century. Much of this occurred after 1874 (Dall, in Reid, 1899). Between 1895 and 1906 the *Lituya Glacier* advanced another half mile (Wright, F. E. and C. W., 1908). Our aerial photographs in 1947, 1948, 1958, and 1961 show that it continued to advance, the net gain being another one-third of a mile in the preceding half-century. *Crillon Glacier* also advanced but to a lesser extent. At the time of the Lituya Bay earthquake in July 1958 it was near equilibrium. By 1961 a slight resurgence was under way. As these glaciers are similar size, the differences in advance suggest relationship to areal and elevation differences affecting total accumulation on their névés. Superimposed effects by avalanche shaking from Mount Lituya (11,750 feet) and Mount Crillon (13,200 feet) during the 1958 diastrophism are not clear, but some effect is expected as the quake's epicenter was in Lituya Bay (Miller, D.J., 1960). As with the smaller glaciers in this bay, their terminal responses should continue to be documented by aerial photography.

F. St. Elias District

The St. Elias District embraces all glaciers in the area between Dry Bay and Copper River (frame F, fig. 3). This is a region covered by upward of 10,000 square miles of ice, representing the most extensive névés on the North American Continent. Here the coast is devoid of fiords and inlets, except for Yakutat Bay and Icy Bay (fig. 2). This also is the region of Tarr and Martin's most detailed studies reported in the National Geographic Society's monograph of 1914. Prior to our 1946 ground studies, no previous investigations had been made in Icy Bay, and none in Yakutat Bay, since Tarr and Martin's field work of 1909-1913 (Miller, 1948). In 1948 and 1951 and again in 1961 and 1962, we were able to add further ground and aerial observations. From this information the regime graph in figure 4 has been drawn.

In this figure the *Guyot Glacier,* comparable in the size and elevation of its catchment area to the former Muir Icefield of Glacier Bay, is shown to have experienced excessive retreat from a maximum position of about 1888. At that time there was no Icy Bay. Between 1904 and 1909 recession began which, continuing to 1951, caused 15 miles of bay to open up and more than 1,500 feet of thinning to take place at the combined terminus of the *Guyot* and *Tyndall Glaciers.* In the decade to 1961, continuing and vigorous retreat produced another 4 miles of open water at the Guyot terminus, with separation of the *Tyndall Glacier* taking place about 1953. By the summer of 1963, the *Guyot Glacier* had further separated into two tidal arms, the easternmost lying nearly one mile back from the late 1961 position (fig. 5). By the end of 1963 the western arm of the *Guyot Glacier* was about 6 miles farther back than the 1938 position shown in the photo. Thus, Icy Bay in 1961 was 20 miles long, with its inner reaches rimmed by three spectacular ice cliffs instead of the one composite tidal front it has had since the turn of the century. This represents the most catastrophic recent glacier retreat in Alaska. It compares to the phenomenal disappearance of Glacier Bay ice, except that the opening of Icy Bay was a century later and contemporaneous with the remarkable advance of the *Hubbard Glacier.* Information on the glacial changes in this bay since the 18th century can be gleaned from reports and maps of Tebenkof (1848, 1852) and Belcher (1843).

Up to 1962 practically all the other 28 glaciers observed in this district were found to have thrived notably over the previous 40 years. Only the *Hubbard Glacier* and *Turner Glacier* in Yakutat Bay are exceptions. *Turner Glacier* receives its main supply of ice from the heavily glacierized, avalanche-riven slopes of Mount Cook (13,760 feet). From the variations in position of this terminus known from 1909 to my 1946 and 1951 surveys, it appears to have been in equilibrium, but by allowing for the attrition effects of tidal action, it may be assumed to have undergone a slow but persistent advance. Such is corroborated by the expanded position shown through comparison of the 1946-1951 photos and those in 1961-1962. (See fig. 4b.)

The *Hubbard Glacier,* at the head of inner Yakutat Bay, exhibits the strongest departure from the district pattern (fig. 4b). This wide valley glacier has a spectacular frontal ice cliff and is one of the largest and most impressive in North America. Since 1890 it has been steadily advancing. As of 1961 it began to threaten closure of the entrance to Russell Fiord. In September 1962 the terminus was but a scant 500 yards from Osier Point in inner Disenchantment Bay (Miller, 1964). The net advance has been 1¼ miles between 1899 and 1958, both years in which severe earthquakes took place. The 1899 earthquake with its epicenter in Yakutat Bay

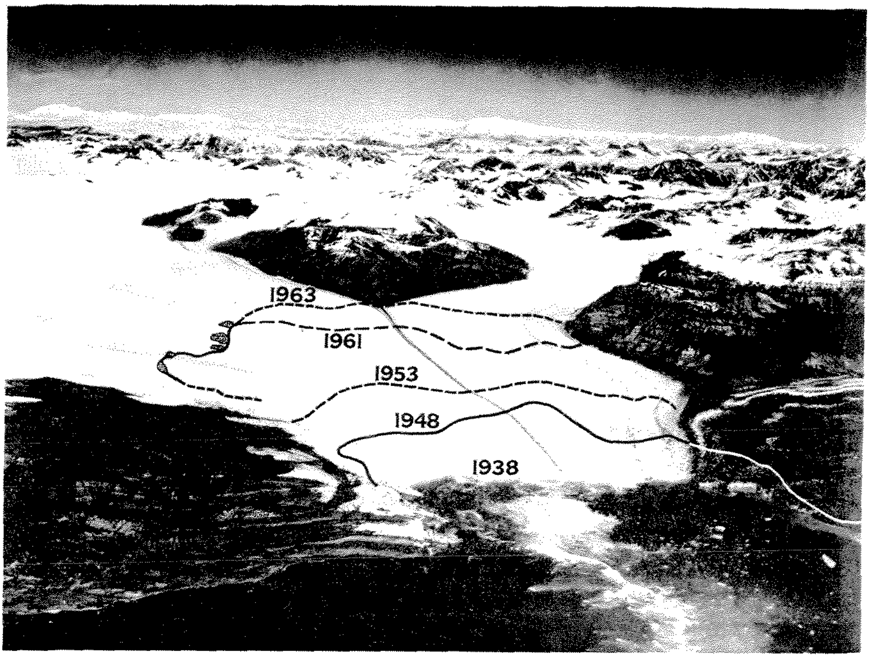

FIG. 5. Receding Guyot Glacier and Inner Icy Bay in the St. Elias District showing 6-mile retreat of tide-water terminus in the 25-year interval noted. Debris-filled ice on right is from Tyndall Glacier. (1938 photo by H. B. Washburn.)

caused massive terminal losses. This was concluded by Tarr and Martin (1914) to be the cause of the resurgence observed on most of the glaciers in Yakutat Bay between 1899 and 1910. It is my conviction that the Hubbard Glacier's persistent growth cannot be attributed to that diastrophism (Miller, 1958). The fact is that the nine glaciers described as having spectacular resurgences in the 11 years after the 1899 quake (Tarr and Martin, 1914) are all glaciers with the greatest part of their catchment zones at low or intermediate elevations (i.e., 2,500-4,000 feet). And all have suffered the most severe shrinkage since 1910. Of more importance is that the *Hubbard Glacier,* like the *Taku Glacier,* is the main outlet from the highest névés in the St. Elias Mountains (fig. 5). This is an exceedingly extensive source area embracing over 8,000 square miles between Mount Logan (19,850 feet), Mount Vancouver (15,820 feet), and Mounts Hubbard (15,015 feet) and Alverstone (14,565 feet).

Since the turn of the century an advance of only 1½ map miles can be documented for the *Hubbard Glacier.* However, a far more significant advance is represented when we consider what the pattern would be were this terminus land-borne. Special considerations, therefore, are necessary when attempting to interpret the regimen of a glacier on the basis of variations of termini which discharge into the sea. As previously seen, this is germane too in the case of the *Taku Glacier.* Of course, not only must advancing glaciers with tidal termini be so critically examined, but also those fiord-head glaciers with receding fronts. Examples of accelerated and catastrophic wastage on tidal glaciers compared with normal ablation losses of a land terminus are shown graphically for *Nunatak Glacier* and *Guyot Glacier* in the curves of figure 4b. In addition to accelerated ablation by warmer wind and rain at sea level, there is the combined effects of wave action, ocean currents, and diurnal fluctuations of tide. These processes are abetted by the natural buoyancy of a floating ice-foot which makes the rise and fall of the tide itself an effective calving agent.

Tidal influences thus increase the rate of shrinkage on retreating fronts and reduce the rate of advance on expanding glaciers. Although this makes it difficult to evaluate glacier fluctuations influenced by these factors, an estimate of relative lateral variation can be made from study of the average quantity of floating ice in the fiord and from comparisons with position changes of nearby land glaciers from comparable névés. For four main tidal glaciers in the St. Elias District, this kind of estimate is shown by dotted line in figure 4b. Note that the recessional rates of four typical west- and south-facing land termini are also compared. Stippled portions of the figure, shown between observed tidal rates and rates postulated for land-borne termini, represent the qualitative increments of attrition by calving.

G. Prince William Sound and Chugach Mountains

The Chugach Mountains comprise the final district considered. In the 1960-61 surveys reference is made only to the more heavily glacierized region to the west of the Copper River. This sector lies between Valdez and Seward and includes the extensive fiord system of Prince William Sound (frame G, fig. 3).

Early observations in this district were summarized by Martin (Tarr and Martin, 1914). Subsequent observations have been made by Field (1932 to present), to which a number of government photogrammetric surveys, my own obliques since 1949, and those of A. Post since 1964, can all be added.

The Chugach ranges rise in a great tectonic arc extending from the

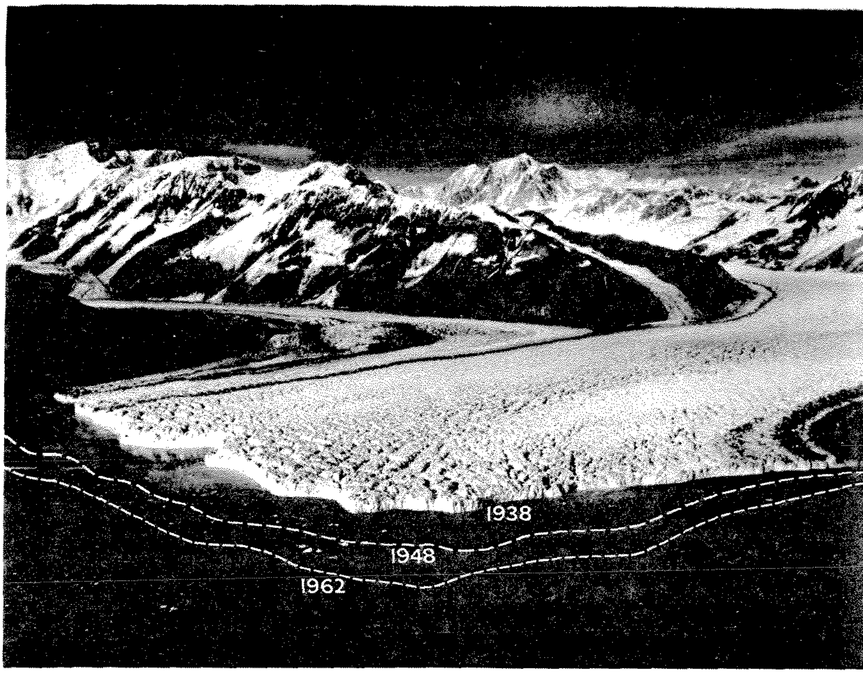

FIG. 6. Advancing Hubbard Glacier in Disenchantment Bay, St. Elias District, showing 3/4-mile net advance in the quarter century following 1938. Mount Vancouver (15,820 feet) on left skyline; Mount Hubbard (15,015 feet) and Mount Kennedy (13,905 feet) in center distance. (Photo by H. B. Washburn.)

St. Elias Mountains to the Kenai district. Glaciers here form in vast icefields with névés reaching great heights. The physiography of the region combines precipitousness of the mountains of the Fairweather Range with the broad and interconnected highland glacier character of the Boundary Ranges. Even the loftiest peaks are close to the sea and attain elevations of 9,000 to 13,000 feet. Precipitation is the heaviest in Alaska, with an annual mean snowfall of 266 inches at Valdez. As much as 671 inches of snow have been reported in one season (1902-03) at Fort Liscum, 5 miles southwest of Valdez (U. S. Weather Bureau, 1922). The regional snow-line and mean névé-line are lower here than elsewhere along the coast.

In this district many smaller glaciers are now in retreat, but significantly for 60 years a larger proportion have been advancing than in the other districts described. In fact, most of the trunk glaciers are now well forward. Each has a tidal terminus, and so the position records underestimate the magnitude of this general advance. The most persistently healthy glaciers come from the Valdez Icefield, situated on an inner peninsula of the Sound and framed between the largest fiords, Valdez Arm and College Fiord. This peninsula is subjected to strong maritime influences with constant cloudiness and frequent storms throughout the year. The fluctuation pattern of the four major glaciers with sources in this icefield is shown in figure 4a.

Since 1900 *Meares Glacier* and *Harvard Glacier* have been experiencing persistent advances, comparable to the similar advance of the *Taku Glacier.* Up to 1961, *Yale Glacier* and *Columbia Glacier* appeared to be near equilibrium. The main currents of these glaciers calve into the sea, however, and so their regime trends are interpreted as ones of gradual expansion. *Columbia Glacier* with a lobate terminus 7 miles wide is Alaska's largest tidal front. There have been many minor fluctuations within a quarter of a mile of the point reached by the center of the front in 1935, a position not greatly different from that on Captain Vancouver's 1794 map. Ring counts on tilted trees on the end moraine prove that the 1935 position was the maximum attained in at least 500 years (Cooper, 1942). This relationship may be extremely significant, because as in the case of *Baird Glacier* in the Stikine District the present glacial position probably represents the post-Wisconsinan maximum . . . i.e., over the past 9,000 years.

Variations of five major glaciers from the Chugach highland on the west side of College Fiord are also shown in figure 4a. These ice tongues show a different kind of pattern. Recession has been the rule since the 1890's. But in the last ten years a general resurgence has been indicated. Of this group, only the *Harriman Glacier* has experienced continuous advance (since 1910). This is a large glacier with a catchment area at the same elevation as the advancing ice streams of the Valdez sector.

Summary of Regional Pattern

Regime comparisons should be made between glaciers of similar size, form, and gradient and ones on which the respective névés and termini are at comparable elevations. The mountainous character of these Alaskan districts, however, provides such a diversity of morphological factors influencing glaciers that not many direct comparisons are possible. Yet, since the survey embraces about 90 percent of the main glaciers in south coastal Alaska, the regional pattern can be deduced. The general trend between the 1920's and the early 1960's is shown by the summary data in table 1.

In this tabulation the consistency of pattern in Districts A, B, and F is noteworthy, as is the similarity between Districts E and G. This appears to be due, in part, to the similar geographical position of the prime source névés of the Alaska-Canada Coast Mountains (the Boundary Ranges) and the inner St. Elias Mountains. Certainly, the most heavily glacierized highlands of these two areas lie 50 to 100 miles farther inland than the Fairweather and Chugach Ranges and are thus more continental than the icefields nourishing the Lituya Bay and Prince William Sound glaciers. (This important difference based on strongly maritime versus more continental climatic character is referenced in the right column of table 1.)

The Fairweather and Chugach Ranges lie astride a tectonically sensitive zone as previously noted for the maritime sector of the St. Elias district. This further begs the question of the occasional effects of diastrophism on the behavior of certain glaciers in these regions. Consideration of the probable role of earthquake effects as differentiated from those which are climatologically controlled has been previously published by Miller (1958, 1967, and 1970).

The significance of the climatological factor in explaining the larger proportion of advancing glaciers in these districts is underscored by the fact that the outer maritime provinces receive 80 to 100 percent more precipitation annually than the inner maritime and subcontinental areas, and as much as 800 percent more than the continental areas lying close behind the Coast Ranges. Likewise, the sea-level stations at Cordova and Yakutat often receive 200 to 300 percent more snowfall than the sea-level stations at Juneau or Petersburg. The rainfall patterns at the mouth of Glacier Bay (Gustavus) and in the Chilkat District (Haines) appear as gradational between the maritime and continental extremes.

Summing up the regional pattern: In spite of marked differences in the geographical factors affecting the nourishment of different ice masses, the dominant characteristic of most glacier termini in southeastern Alaska during the past 50 years has been shrinkage. The recessional rate on many glaciers, especially those having source névés at low elevation, became much accelerated in the 1920's. For many of those with high névés, a slower retreat took place in the 1920's and 30's, while a few experienced spasmodic readvances between 1938 and the present. The only persistently strong departures from the general trend have been on some of the largest trunk glaciers. For each such case of significant advance, however, there has been a marked and contemporaneous retreat of another valley glacier of comparable size. This opposite behavior has invariably taken place on glaciers derived from the same or adjoining névés.

The simultaneous advances and retreats of adjacent glaciers have been reported in parts of Iceland (Thorarinsson, 1940) and in Patagonia (Nichols

TABLE 1.—REGIME STATISTICS FROM 1946-62 RECONNAISSANCE SURVEYS

District	Number of glaciers observed	Termini dominantly shrinking	Near equilibrium but gradually shrinking	REGIM
				In equilibrium
A. STIKINE				
(a) Stikine Valley	10	5	3	2
(b) Forest Fiords to Speel River	18	15	1	
B. TAKU				
(a) Taku-Llewellyn Glacier System and vicinity	16	14	1	
(b) East side of Lynn Canal	15	12	3	
C. GLACIER BAY and the Alsek River	28	15	2	5
D. CHILKAT	22	7	5	6
E. LITUYA BAY-FAIRWEATHER	7	1	1	1
F. ST. ELIAS				
(a) Yakutat Bay and Brabazon Range	29	24	3	
(b) Icy Bay to Copper River Delta	12	10	2	
G. PRINCE WILLIAM SOUND				
(a) Valdez Icefield	4			
(b) West of College Fiord	13	3	2	4
TOTAL OBSERVED ON REGIONAL BASIS	174	106	23	18

*1, Baird Glacier. 2, Taku. 3, La Perouse. 4, Crillon. 5, Lituya. 6, Hubl

**As referred to in this column: Low elevation = 1-3,000 feet. Intermediate e

OF MAJOR GLACIERS IN SOUTH AND SOUTHEASTERN ALASKA

IEN PATTERN SINCE 1920's		Climatic character of névé area of glaciers observed**
Near equilibrium but gradually expanding	Strongly or recently advancing and near post-Glacial maximum	
		Coastal interior; intermediate and high elevation subcontinental
1	1*1	Intermediate elevation maritime to high elevation subcontinental
	1[2]	Intermediate and high elevation maritime; high elevation subcontinental; intermediate elevation continental
		Intermediate elevation maritime
6		Intermediate elevation maritime
4		Intermediate elevation subcontinental
1	3 3,4,5	Low, intermediate, and high elevation maritime
1	1[6]	Low, intermediate, and high elevation maritime; with interior as high elevation subcontinental and intermediate elevation continental
		Low and intermediate elevation maritime
1	3 7,8,9	Intermediate and high elevation maritime
3	1 10	Low, intermediate, and high elevation maritime
17	10	

oard. 7, Columbia. 8, Meares. 9, Harvard. 10, Harriman.

levation = 3-5,000 feet. High elevation = 5,000 feet and above.

TABLE 2.—SUMMARY OF REGIONAL GLACIER TRENDS BASED ON 1946-62 SURVEYS OF MAJOR SOUTH AND SOUTHEASTERN ALASKAN GLACIERS

District	Number of glaciers observed	Percentage of termini showing—		
		Dominant shrinkage	Near equilibrium*	Persistent advance**
A (Stikine River)	28	70	26	4
B (Taku River)	31	84	13	3
C (Glacier Bay and Alsek River)	28	54	46	0
D (Chilkat)	22	32	68	0
E (Lituya Bay-Fairweather)	7	14	57	29
F (St. Elias)	41	82	15	3
G (Prince William Sound and Chugach Mountains)	17	18	59	23
All districts	174	61	33	6

*Including *termini* close to equilibrium but still showing fluctuations either toward *shrinkage* or gradual expansion.
**Glaciers also near to their post-Glacial maximum.

and Miller, 1952). Periodic reports on French, Swiss, Italian, and Austrian glaciers (e.g., Mercanton, 1948, and Journal of Glaciology listings through 1960) also show that while 91 to 96 percent of the alpine glaciers have been retreating, over the previous 40 years, about 2 percent have remained stationary and 2 to 5 percent have advanced. The proportion of equilibrium and advancing glaciers in Alaska, however, is much higher than in any other glacier region in the world, and nowhere else has the contrast been so pronounced nor has it been seen on such a large scale. The pattern has also been so consistent over such a wide range of latitude (56° to 62°N.) that a causal factor must be involved which is of broad regional proportion and undoubtedly of global significance. Preliminary consideration of such a cause has been presented in Miller, 1967.

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