The Alaskan Glacier Commemorative Project, Phase I

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Grant No. 456: In support of the first year of a continuing program to study changes in glaciers along the southern Alaskan coast since the NGS Tarr and Martin studies early this century; with special attention to effects of the spring 1964 earthquake in Alaska.

Supported by the National Geographic Society, a regional survey of coastal glaciers in southern Alaska between Dixon Entrance (lat. 55° N.) and Cook Inlet (lat. 61° 31′ N.) was conducted during the summer of 1964, with particular reference to effects of the 1964 Good Friday earthquake. This field season represented the first phase of a continuing 5-year project, the immediate purpose of which was to follow up and expand upon previous recent surveys (Miller, 1958, 1963, 1964a; Miller and Potter, 1965). A secondary aim was to record glaciomorphic effects of the March 1964 Alaskan earthquake in those areas of south coastal Alaska lying northwest of the Alexander Archipelago. The more basic objective, and that of observations in the succeeding four years, was to interpret changes in the glaciers of this region with respect to conditions reported on the National Geographic Society's expeditions of 1909-13. These expeditions too were interested in the possible effects of diastrophism, particularly the major earthquake of September 1899, which had its epicenter in Yakutat Bay (Tarr and Martin, 1914; also see discussion by Miller, 1957, 1958). Of further comparative interest in this study is the anomalous behavior of glaciers in other tectonically affected mountain ranges (Colqui, 1965; Miller and Prather, 1965; Miller, 1964b, 1966).

Without the benefit of aerial photography and with no observations at all in the upper reaches of these glaciers, the Society's 1914 Tarr and Martin monograph concluded that excessive advances of these glaciers, especially in Yakutat Bay, were the direct consequence of earthquake avalanching. Thus, during the summer of 1964 our approach was to look at the problem from the viewpoint of the total glacier system and in the context of a broader regional assessment. Emphasis was placed on the investigation of those glaciers believed to be dominantly controlled by climatic trends, as well as those most likely to have variations significantly altered by earthquake effects. A control locality was chosen where certain glaciers could be studied in detail well outside of the tectonically sensitive zone, or at least in sectors not obviously influenced by crustal displacement and/or related earthquake landslides.

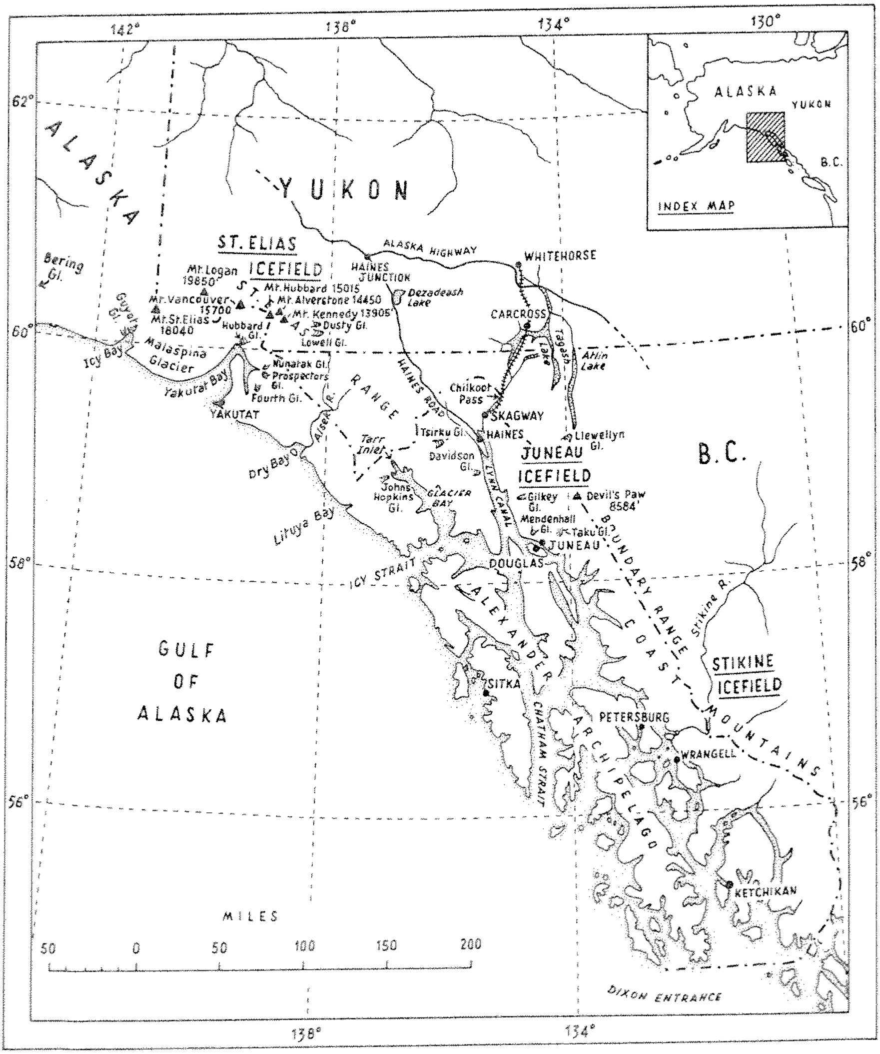

FIG. 1. Southeastern Alaska.

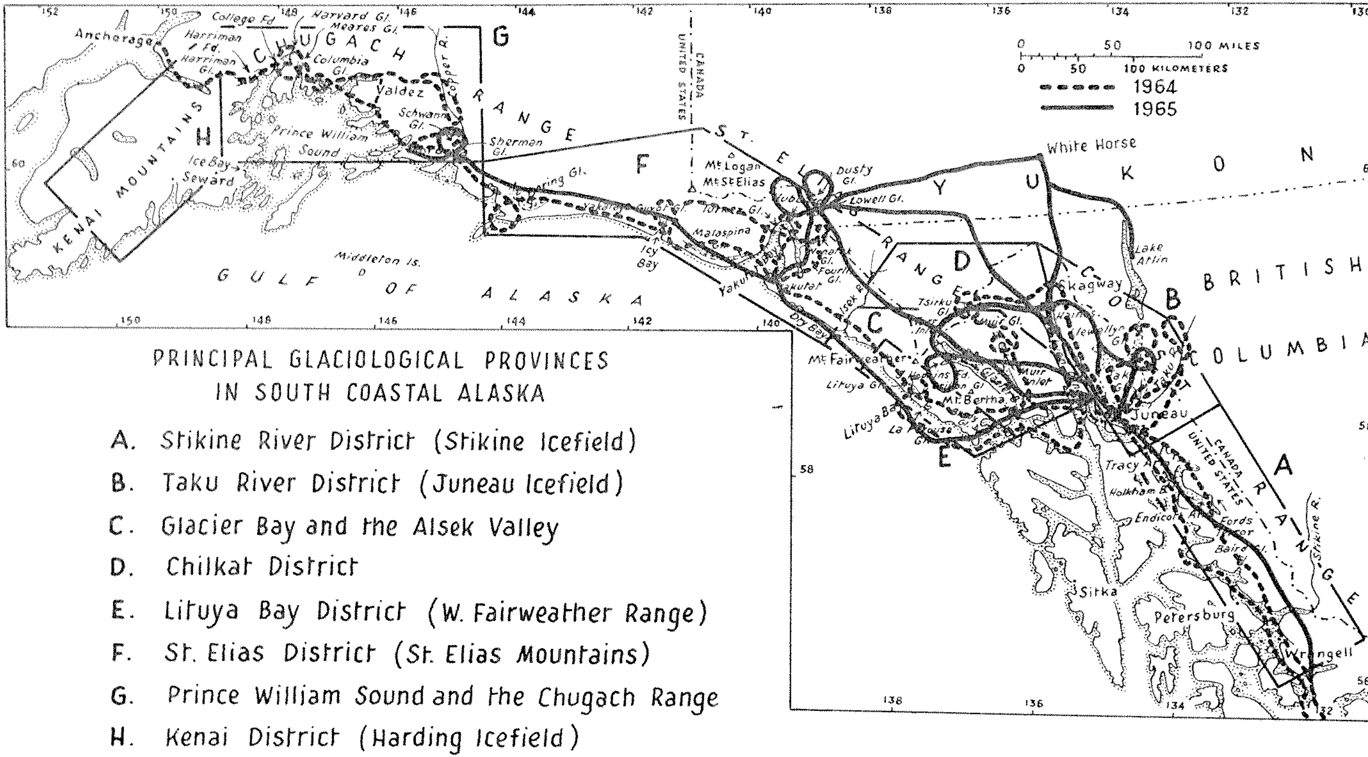

FIG. 2. Map showing route of National Geographic Society Alaskan coastal glacier regional survey during the summers of 1964 and 1965.

At the beginning of the 1964 field season, a reconnaissance was carried out in the Alaska-Canada Boundary Range, immediately east of the Alexander Archipelago (fig. 1). The observations were then continued north and westward from Ketchikan along the Alaskan coast as far as Anchorage at the head of Cook Inlet (fig. 2). The prototype control locality was on the Juneau Icefield in the Taku District of the Northern Boundary Range, lying east of Lynn Canal (fig. 3). Other prototype localities were studied within the tectonic zone, including Lituya Bay on the western flank of the Fairweather Range; Yakutat Bay in the St. Elias Mountains; the Copper River Basin in the eastern Chugach Range; and Prince William Sound, just north of the epicenter of the 1964 earthquake. Brief comments on the 1964 observations are here given with respect to a few of the representative glaciers observed and photographed in each of these sectors. Reference is also made to pertinent abstracts and papers produced to date by observers associated with the 1964 phase of this study. To these and all our other colleagues who have assisted in these researches special appreciation is accorded.

The 1964 field program involved ground studies, phototheodolite surveys, and aerial photography. An analysis of some 400 slides in the lower Panhandle region of the coast between Ketchikan and Juneau (fig. 1) revealed that these were predominantly of the debris-avalanche type, occurring at different times and apparently associated with maximum stages of weathering. The main causal factor in these instances is probably subaerial denudational stress, associated with the cyclic saturation of forest litter. The process is thus in the category of normal mass wastage (Swanston, 1968) and is quite distinct from the situation pertaining in the areas of earthquake-generated landslides observed farther north (figs. 4 and 5). In fact, no evidence of 1964 earthquake avalanching was found in any sector of the coast south and east of Glacier Bay.

The ground study team worked first in the control locale, emphasizing the 65-mile-long Taku-Llewellyn transection glacier on the Juneau Icefield (fig. 3). The Taku Glacier's terminus is a coastal outlet which is vigorously advancing, continuing a growth pattern initiated shortly before the turn of the century (fig. 6). In this season, also, detailed study was begun on the 22-mile-long Mendenhall Glacier, near Juneau, which is typical of a large, slowly downwasting and receding glacier terminus (fig. 7). Detailed investigations included a terrestrial photogrammetric map of the September 1964 position of each of these important valley glaciers for comparison with previous, and subsequent, positions (Gloss et al., 1965; Konecny, 1966). Results of the Mendenhall Glacier survey indicated a 1/4-mile retreat since 1948, with mean annual downwasting of 1.83 m/yr., and a volume loss of $3.4\times10^6 m^3$/yr. of ice in the terminal zone below the 1,200-foot contour (Al-Naqash, 1965).

This averages out at about 2 meters (6.5 feet) of net downwasting of ice annually over the total area up to 1,100 meters (3,600 feet) elevation. Because upward of 23 meters (75 feet) of ice ablation has been indicated for a single budget year, as observed by ablation measurements at the terminus, the glacier is interpreted as close to equilibrium in its frontal position though slightly negative in total mass exchange.

In the same 16-year interval (1948-64), the Taku Glacier's terminus advanced a full half mile and experienced a net increase in surface elevation of 137 meters (450 feet), at the 600-foot contour level. It has also changed morphologically from a tidal ice cliff to a convex snout rimmed by an upbulged push moraine protecting it from further attrition by tidal calving (see sequence of photos in figure 8). The Taku Glacier is considered proto-

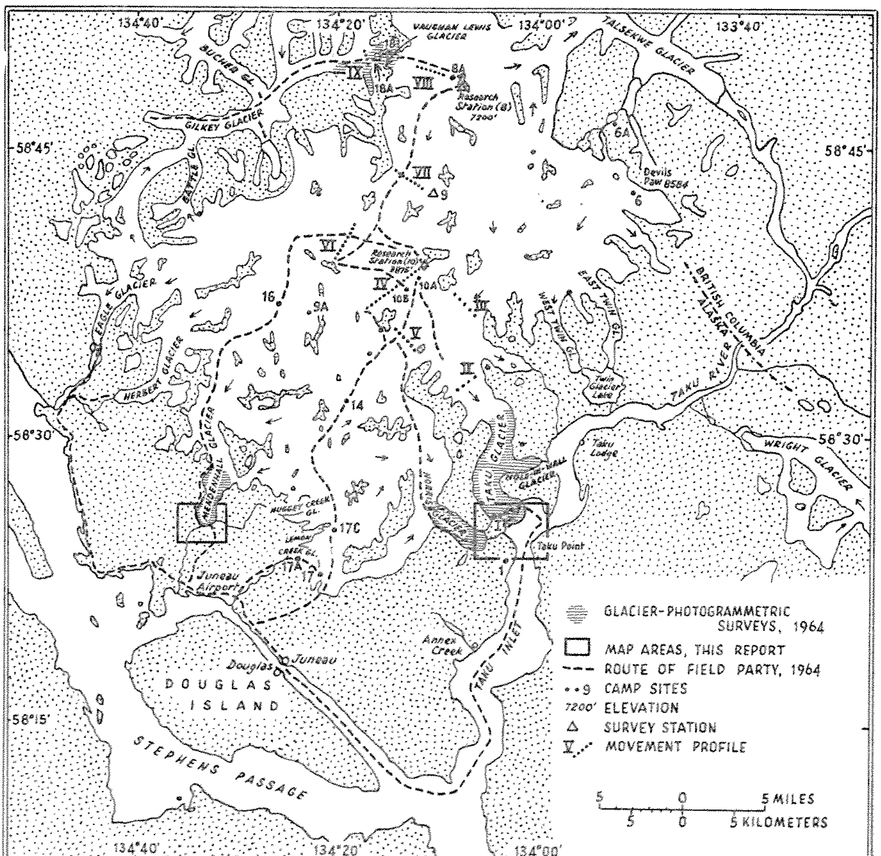

FIG. 3. Location map of the Juneau Icefield in southeastern Alaska.

typical of an advancing glacier with its regime climatologically controlled, and devoid of any earthquake avalanche effects.

Position changes were also noted through ground study of the adjoining Norris and Hole-in-Wall Glaciers. The retreat of the Norris Glacier is comparable to the Mendenhall Glacier, and typifies receding glaciers throughout this sector of the Boundary Range. The Hole-in-Wall Glacier is a distributary merely reflecting the advance of its parent Taku Glacier. Thus it has continued an advance which, since the early 1950's, has plowed up arcuate furrows in the muskeg flats of the Taku River Valley. Again it is noted that the Mendenhall-Norris Glacier pattern characterizes the present regime of about two dozen glaciers on the maritime flank of this range, each of which has been documented by aerial photography on the Juneau Icefield every summer since the early 1940's. (In this regard, figures 6 and 7 represent 1948 vertical photography of these key glaciers obtained by the U. S. Navy with our mapped 1964 terminal position indicated by dashed line.)

One unusual aspect of the recent downwasting of the Norris Glacier

FIG. 4. Debris slide covering 8 square miles of the Schwann Glacier, east of Valdez, Chugach Range. Photo by M. M. Miller, September 15, 1964.

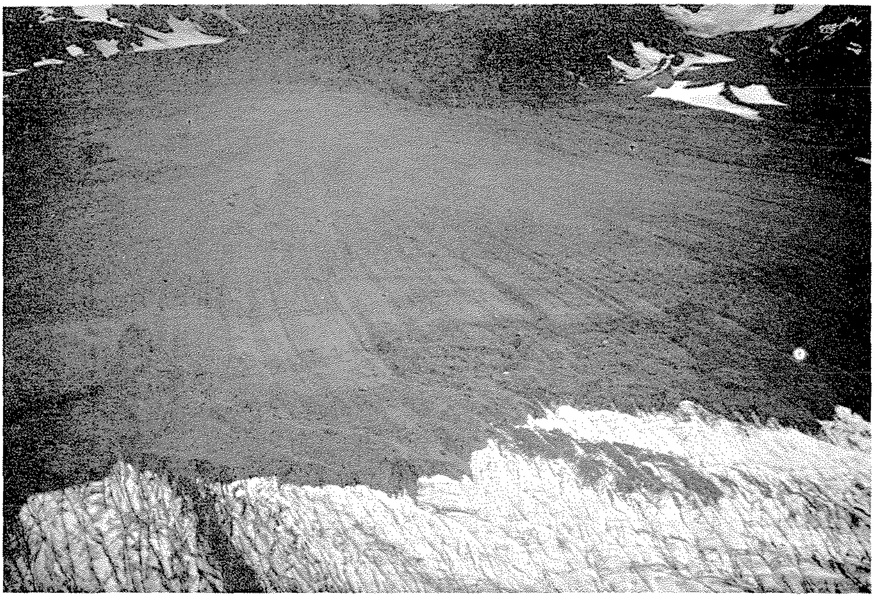

FIG. 5. Ten-square-mile area of Sherman Glacier covered by earthquake-avalanche debris, near Cordova, lower Copper River region. Photo by M. M. Miller, September 14, 1964.

was a proglacial feature exhumed by ablation at the center of the terminus. This feature is steep-sided and linear, with its axis parallel to the longitudinal direction of the ice tongue and hence in appearance much like an englacial esker formed beneath the Norris Glacier front (fig. 6). Study of the geometry, fabric orientation and existing terminal ice conditions revealed this instead to be a remnant of an overridden terminal moraine of the Taku Glacier itself, formed during or after its 18th-century maximum (Egan and Yates, 1965). Today, the ice of the Taku Glacier is again advancing toward this former position and, in fact, overriding a 200-year-old forest along its flanks. It has thus rapidly encroached on to the outwash fan formed by the simultaneously receding Norris Glacier (figs. 7 and 8). This ecological and geomorphological evidence suggests that the Taku Glacier's present position is almost as far advanced as in the 18th century and therefore close to the most forward position it has held since prior to the Thermal Maximum . . . i.e., possibly as much as 7,000 years ago. If current conditions prevail, this glacier will override even its former limit and coalesce with the slowly receding Norris Glacier before the end of the century. This means it may also bridge the waters of inner Taku Fiord and once again dam a huge lake in its lower Taku Valley as it did two centuries ago. As this could be a most significant development, the recent regime trends and stress conditions within the névé, or nourishment zone, of the Taku Glacier system are being continuously investigated in connection with the current long-term studies of the Juneau Icefield Research Program (Wu and Christensen, 1964; Miller, 1965a, 1965b, 1967).

Investigations were also carried out farther inland near the crestal névé of this glacier system and included the outflow of ice down the Berner's Trench, the main trunk glacier here being the Gilkey Glacier. This trench is a deeply eroded canyon trending westward from the high center of the Juneau Icefield (fig. 3). The precipitous configuration of its valley walls provided optimum possibilities for detection of any effects of the 1964 earthquake. It should be mentioned that in this region no direct earthquake influences have been reported, except for observation of a minor tsunami in Gastineau Channel at Juneau following the diastrophism of March 1964. Similarly no geologic evidence of recent earthquake avalanching was found in the Gilkey Glacier sector, although earlier (pre-1960) piles of avalanche detritus were seen on the tributary Battle and Bucher Glaciers. Studies were also continued on a spectacular series of wave-bulges which characterize the Vaughan Lewis Glacier and several others in this part of the Northern Boundary Range (Freers, 1965; Havas, 1965; Kittredge et al., 1965; Kittredge, 1967; Miller, 1968).

Geomorphic, pedological, and geobotanical studies of icefield nunataks and the Little Ice Age moraine patterns in the Taku District were also conducted (e.g., Lietzke and Whiteside, 1966). These included the collection of buried forest materials in Neoglacial outwash and till, for radiocarbon dating and palynological analysis (Cross, 1965; Warren et al., 1968). Also, a number of névé-zone measurements were carried out on adjacent névés of the highland (Egan, 1965a, 1965b). Among the unusual research efforts here was the measurement of nuclear detonation Beta activity in the Taku Glacier firn as a means for dating and differentiating older annual accumulation segments (Wu, 1968). By using a number of such techniques for delineating the firn stratigraphy and by relating the results to changes in névé-line position since 1946, a strongly positive regime trend has been demonstrated on this glacier system (fig. 9). As for our study of earlier regime conditions, the 1964 aerial reconnaissance revealed at least one notable pre-18th-century moraine system, not previously reported and which has subsequently been under close scrutiny by our ground crews.

A visit to Glacier Bay and supplemental aerial photography were made both at the beginning and the end of the 1964 summer. Aerial photography

FIG. 6. Vertical aerial photograph, Norris and Taku Glacier termini (U. S. Navy, August 14, 1948). Scale 1:60,000 at sea level.

was also accomplished in the Tsirku and Tahkin River Valleys and in the Jervis Glacier area of the Chilkat District west of Haines. Here a number of glaciers were found to be continuing slow retreat, but several were at equilibrium or in states of advance. This was in contrast to the generally accelerated diminishment and downwastage of ice which has characterized the Muir Inlet area since the 1930's. On the western side of Glacier Bay, however, glaciers in Tarr Inlet and Johns Hopkins Fiord were found to be at positions close to or somewhat forward of those held in the past decade. The Grand Pacific Glacier had crowded ahead substantially. Some thickening of ice was also observed at high level in the Fairweather Range, with downwastage being only the rule at lower levels. In the vicinity of Mount

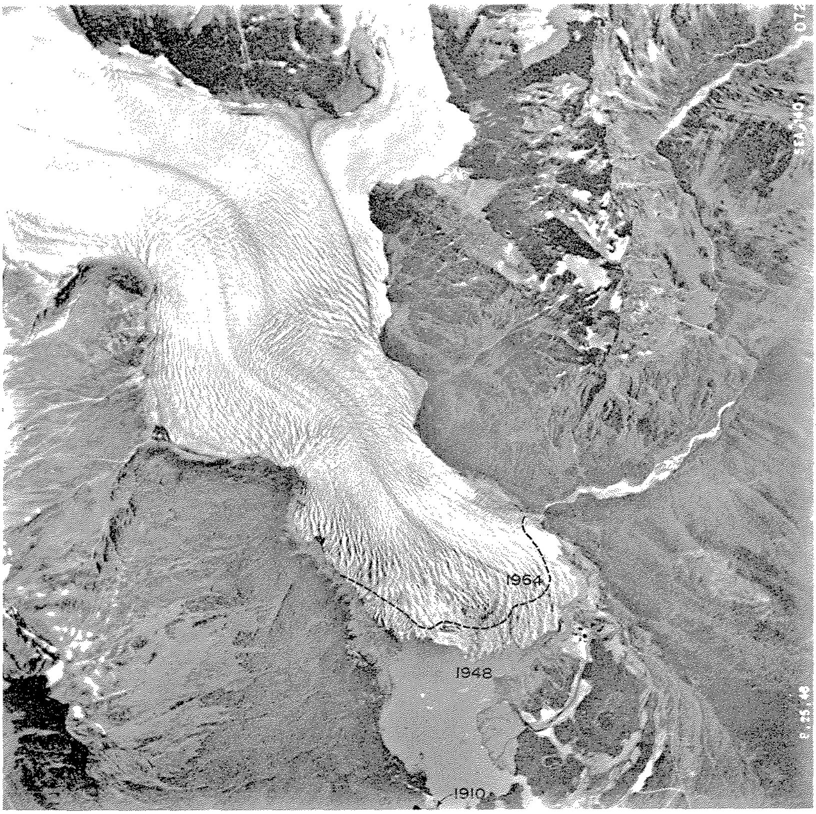

FIG. 7. Vertical aerial photograph, Mendenhall Glacier terminus (U. S. Navy, August 25, 1948). Scale approx. 1:60,000.

Fairweather, and southward along the heart of the Range, a surprisingly large number of substantial earthquake avalanche slides was observed. Some of these were presumably from the 1964 tremors, although other older ones were apparently a result of the strong quake of July 1958, which had it s epicenter in nearby Lituya Bay (fig. 1).

In Tidal Inlet of eastern Glacier Bay, a large fault scarp was observed, still as fresh in appearance as it was after the 1958 earthquake. It is planned to document this scarp in future aerial surveys in order to detail any future changes.

On a motor-vessel trip into Lituya Bay on the outer flank of the Fairweather Range, the North Crillon and Lituya Glaciers were surveyed by theodolite. A glaciobotanical assessment was also made in a key sector of the Fairweather Fault, with special attention paid to the area swept clean by the giant wave from the 1958 earthquake. The 1,800-foot-high scour zone produced by this wave at the head of the bay was found to be remarkably free of lichen growth. No direct evidence of 1964 earthquake avalanching could be detected through the close-in aerial photographs obtained on the glaciers and névés of the western flanks of the Fairweather Range.

Farther up the coast in the Yakutat Bay region (fig. 1) other situations pertained. Here both our ground and aerial observations revealed an anomalous trim zone, not previously reported. This was seen in the forest near the entrance to Disenchantment Bay. The trim-line appeared to be quite old. It may prove to be a double line related to a giant wave, possibly produced by the 1853 or 1899 earthquakes. No clear effects of the 1964 distrophism were found in Disenchantment Bay, although Turner and Hubbard Glaciers were somewhat forward of positions recorded during our ground observations in this fiord in 1962. In the last half-century, the Hubbard Glacier's terminus has been displaced forward a distance of several miles. Like the Taku Glacier, it is now threatening to close off its fiord by impinging against the valley wall near Osier Island, at the entrance to Russell and Nunatak Fiords. Considering the great amount of tidal calving which takes place on the Hubbard Glacier, this represents a vigorous advance, continuing that so well documented after the turn of the century by Tarr and Martin.

In the Nunatak Fiord area some distinct geomorphic evidence of 1964 earthquake effects came to light on Orange Glacier. The proglacial outwash here was riven by unhealed cracks, undoubtedly produced by the tremors of 1964. Variegated and Butler Glaciers also gave evidence of increased crevassing and marginal shearing, presumably relating to a current surge in the ice. The most distinct evidence was seen on Fourth Glacier. This is one of the ten glaciers reported by Tarr and Martin to have suffered catastrophic advance in the decade following the severe diastrophism of 1899. Fourth Glacier lies 75 miles east of the area perimeter at first believed to have been influenced by the 1964 tremors. Here we found a strong display of fresh fault scars on the western flank of the valley and directly above the glacier's terminal lake. Connected with these were a number of disconnected scarp fractures on the ridge flanks above the glacier, all attributable to the 1964 earthquake.

Other glaciers draining into Yakutat Bay were also photographed from the air, including Hidden, Nunatak, Cascade, and Turner Glaciers. On Turner Glacier, abnormal marginal shearing was observed, again suggesting pronounced surge effects, possibly earthquake related.

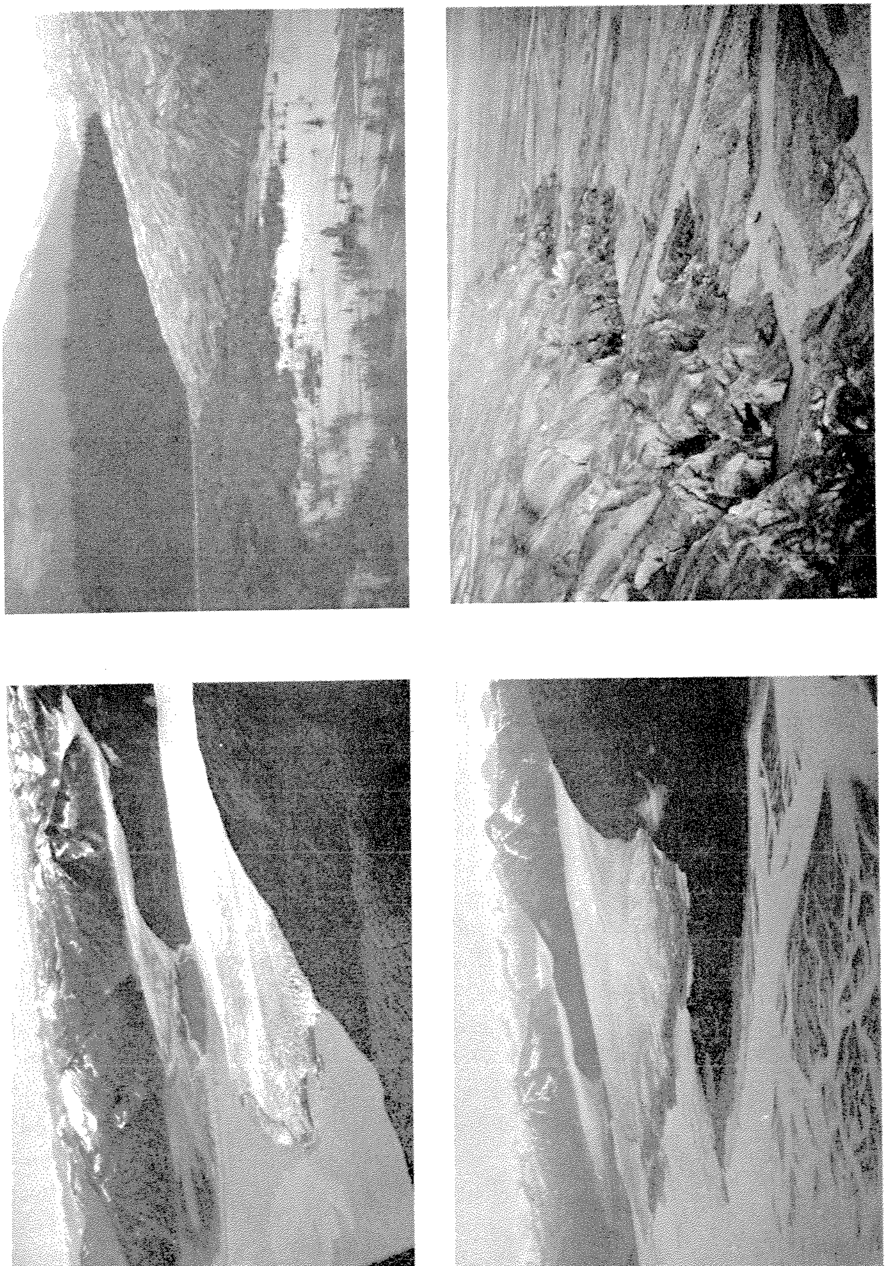

FIG. 8. See legend, top of next page. (Photos by M. M. Miller.)

FIG. 8. *Upper left:* Oblique view west over eastern side of Taku Glacier terminus. Norris Glacier visible in distance. August 12, 1948. Note eastern part of Taku terminus still tidal, with icebergs calving into fiord. *Upper right:* Closeup of western front Taku Glacier thrusting against Norris Glacier outwash. Note flooding of alder flats. September 25, 1964. *Lower left:* Same as upper left but 16 years later, showing pronounced development of terminus moraine. September 25, 1964. Swede Point and braided sand bars at mouth of Taku River in foreground. East part of terminus no longer tidal and no further attrition by calving. *Lower right:* Shattered frontal zone of Taku Glacier near western edge on September 25, 1964. Note steepened proglacial fan. Push moraine at center of glacier is partly visible in distant background.

Farther up the coast, beyond the Malaspina Glacier, it was found that Icy Bay has progressively enlarged since the Tarr and Martin surveys, again owing to excessive ice retreat. The main ice mass here is the Guyot Glacier, whose terminus is now 20 miles back from its turn of the century position, and is separated into five large and unnamed ice fronts. This probably represents the most phenomenal diminishment and lateral ice retreat in this century anywhere in the world.

Near the entrance of Icy Bay the 1964 diastrophism also caused diversion of the Yahtse River, an outwash of the Malaspina Glacier. Elsewhere in the St. Elias District we observed other glaciomorphic results of the earthquake, such as extensive fissures in proglacial valley train deposits and river channels and numerous cracks in the beach gravels and glacial forelands. Quite pronounced effects were found westward along the coast towards the Bering Glacier. The Bering Glacier, itself, along its western flank, was abnormally crevassed.

In all the areas visited during the 1964 summer, the most extensive effects of the 1964 earthquake were seen in the Copper River region. From the Martin River Glacier westward, several hundred significant earthquake avalanches were observed from the air. Areas of ground study included the Sheridan and Sherman Glaciers, near Cordova, and on the Valdez Glacier east of Valdez. A ground reconnaissance and phototheodolite survey were also carried out on the Sherman Glacier (fig. 5). All these glaciers had been experiencing slow retreat of their land termini in recent years. However, large sections of some were now covered with massive slides of avalanche debris, all fresh and all a consequence of the 1964 earthquake. Another very striking and massive slide was photographed on the Schwann Glacier (fig. 4), 40 miles east of Valdez. Here a huge landslide covered about 8 square miles of ice. The Sherman Glacier was covered with about 10 square miles of rock debris. This glacier was subsequently mapped in detail by an Ohio State University team in 1964-66 (C. Bull, personal communication). Other notably large slides were observed on major tributaries of the upper Allen and Childs Glaciers, west of the Copper River, and on the Martin River Glacier, well east of the Copper River. Since 1964 the latter has also been studied by a research team from the University of North Dakota (J. Reid, personal communication).

A number of earthquake-generated rock avalanches and landslides were also observed in the northern and western sectors of Prince William Sound.

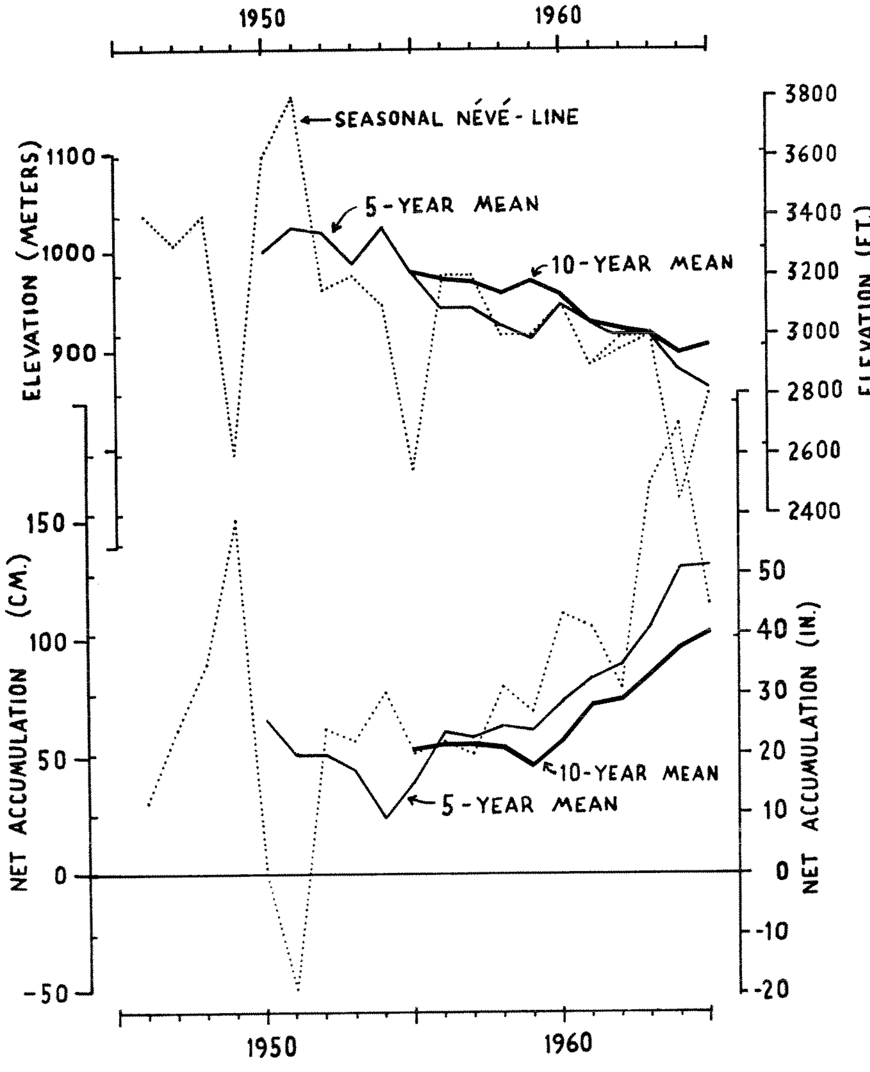

FIG. 9. Comparative névé line and net accumulation trends on the Taku Glacier, 1946-1965.

Since the terminal positions of glaciers in this magnificent region of fiords and waterways have been systematically documented in recent years by W. O. Field of the American Geographical Society, little need be added with respect to that area in our report at this time.

From our summer field work it would appear that three major zones of significant glaciomorphic effect pertain in relation to Alaska's 1964 distrophism. The key localities are: (1) the northern and western areas of Prince William Sound; (2) the Valdez Arm and adjoining Copper River regions, where the strongest effects have been found, some of which are under study by other groups; and (3) the inner Yakutat Bay-Russell Fiord area where unexpectedly pronounced effects were first reported by our surveys.

The recognition of subsidiary crustal displacements near Yakutat, and possibly related slides in the northern and eastern Fairweather Range, suggests a selective zone of seismic effect extending somewhat inland and, indeed, much farther down the coast than that so far reported in the Copper River Basin and northeastern shore areas of the Gulf of Alaska. There is a strong need for continuing close scrutiny of the eastern sector of this tectonic zone, especially in inner Yakutat Bay and from there southward towards Glacier Bay. The interpretations will be rendered more complete because of the availability of pertinent early photographs and maps of some of this area derived from the concentrated studies of Tarr and Martin in the Society's expeditions of a half-century ago.

Over the next few years, some glaciers, particularly in the Copper River region, may be expected to suffer abnormal terminal fluctuations in response to the 1964 earthquake-avalanching. As our 1965-68 continuing surveys have revealed, some have already initiated and even completed post-earthquake periods of strong marginal shearing and increased surface crevassing, with other associated manifestations of glacier surging. (The question of surging is still an open one which has created a great deal of interest and much speculation among glaciologists.)

These manifestations of surging are probably the result of one or more of the following: (1) long-term alterations in load, englacial stress, and volume discharge due to significant avalanching of rock and/or ice debris via earthquaking; (2) short-term kinematic wave dispersion, possibly the result of sudden abnormal loading by earthquake avalanches; (3) altered ablation regimes due to the insulation by millions of cubic yards of debris where landslides have inundated large areas, especially below the névé line; and (4) periodic changes in stress distribution within the glacier in consequence of significant shifts in the level and area of snowfall accumulation, presumably related to climatologically controlled variations in the magnitude of annual precipitation and in the mean position of regional storm paths.

The obvious surging effects described and documented in the Tarr and Martin report for several glaciers following the 1899 Yakutat Bay earthquake are seemingly similar to those which have been reported following the great 1964 Prince William Sound and Copper River region earthquake. Although it is tempting to conclude that these were primarily earthquake-influenced, our control studies already suggest the possibility of other factors leading to instability in glaciers. Although we hope to consider such details in reports on the subsequent seasons of this long-term project, at this stage we are obliged to remain cautious in our interpretations. Certainly, continuing study of this fascinating phenomenon is paramount to the full understanding of causal factors affecting the recent fluctuational history of Alaskan coastal glaciers in a situation which, as a whole, represents the largest aggregate of glacier ice outside of the Polar regions.

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