MORPHOGENETIC CLASSIFICATION OF PLEISTOCENE GLACIATIONS IN THE ALASKA-CANADA BOUNDARY RANGE

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INTRODUCTION

THE fundamental relationship between Arctic terrain in different areas and the common genetic denominator, climate, has been elaborated by Büdel (1944; 1948). In a broader geomorphic sense, comparable landscapes resulting from similar sets of climatic conditions have been termed morphogenetic regions (Thornbury, 1954). The form, dimension, and geophysical character of glaciations likewise can be genetically related to climate. Therefore, although a shorter time scale is involved, it is appropriate to apply this concept to the classification of ice sheets, both existent and ancient. With respect to Cordilleran regions, a morphogenetic classification is especially helpful in delineating the repeated effects of Pleistocene glaciations, and the consequent accentuation of features, without pinpointing cycles or attempting a chronology. Such a classification paves the way for the fullest interpretation of sequential land forms which, of course, is fundamental to the establishment of either relative or absolute chronologies. In this paper, the phases of Pleistocene glaciation in the coastal Cordillera of the Alaska-Canada Boundary region are classified in accordance with this concept.

CHARACTER OF THE CORDILLERAN GLACIER COMPLEX

In the culminating stage of the Pleistocene Epoch, the Cordilleran Glacier Complex reached its most extensive development at the latitude of the Taku District of the Alaskan Panhandle. The whole confluent mass was some 500 miles wide on a line extending inland normal to the present coast in the vicinity of Sitka, Alaska. Thermodynamically, the ice sheet was probably of the Polar type, completely filling the elevated subcontinental platform between the Northern Rocky Mountains and the Coast Range and extending as far south as the Columbia River in Washington State. As such, it was similar in nature, form, and dimension to the present-day Greenland Icecap.[1] By comparison, today's Cordilleran glacier cover (fig. 1) is greatly reduced, embracing less than three per cent of the formerly glaciated landscape. Of this, the area of existing glaciers in the Juneau Icefield and the Stikine Icefield of the Alaska-British Columbia Boundary Ranges encompasses less than one-fifth of one per cent of the former total. There are certain features of the present glacier system, however, which were characteristic of the coastal area in the periods of maximum glaciation. For example, it is still an ice-flooded landscape (figs. 2 and 3). Here some of the western glacial tongues descend to sea-level as they formerly did, although they are indeed far inland from the ice shelf which it is believed once rimmed much of the Pacific shore along the outer edge of the Cordilleran islands as far south as the Olympic Mountains (fig. 1, and Flint *et al.*, 1945, map).

In Alaska and northern British Columbia, the prime center of the continental "icecap" lay 200 miles east of the present axis of the range and was situated in the interior plateau region, probably near the northern end of the Cassiar Mountains. This places it between the present watersheds of the upper Stikine, Taku, Yukon, and Liard rivers (fig. 1). From this center, ice moved outward in all directions. In its westward passage, it buried and overrode sections of the Coast Range in order to reach the sea. Johnston (1926: p. 137), from studies in the central plateau mountains, concluded that at one maximum as much as 3,000 feet of Pleistocene ice buried even the highest ridges, although he found no direct evidence by erratics and striae above 6,500 feet.

In the Cassiar District, 250 miles east of Wrangell, Lord (1943: p. 4) observed the maximum

[1] Flint (1957) estimates its area at the Pleistocene maximum to have been 2,160,000 square kilometers. The present area of the Greenland Icecap is 1,726,400 square kilometers.

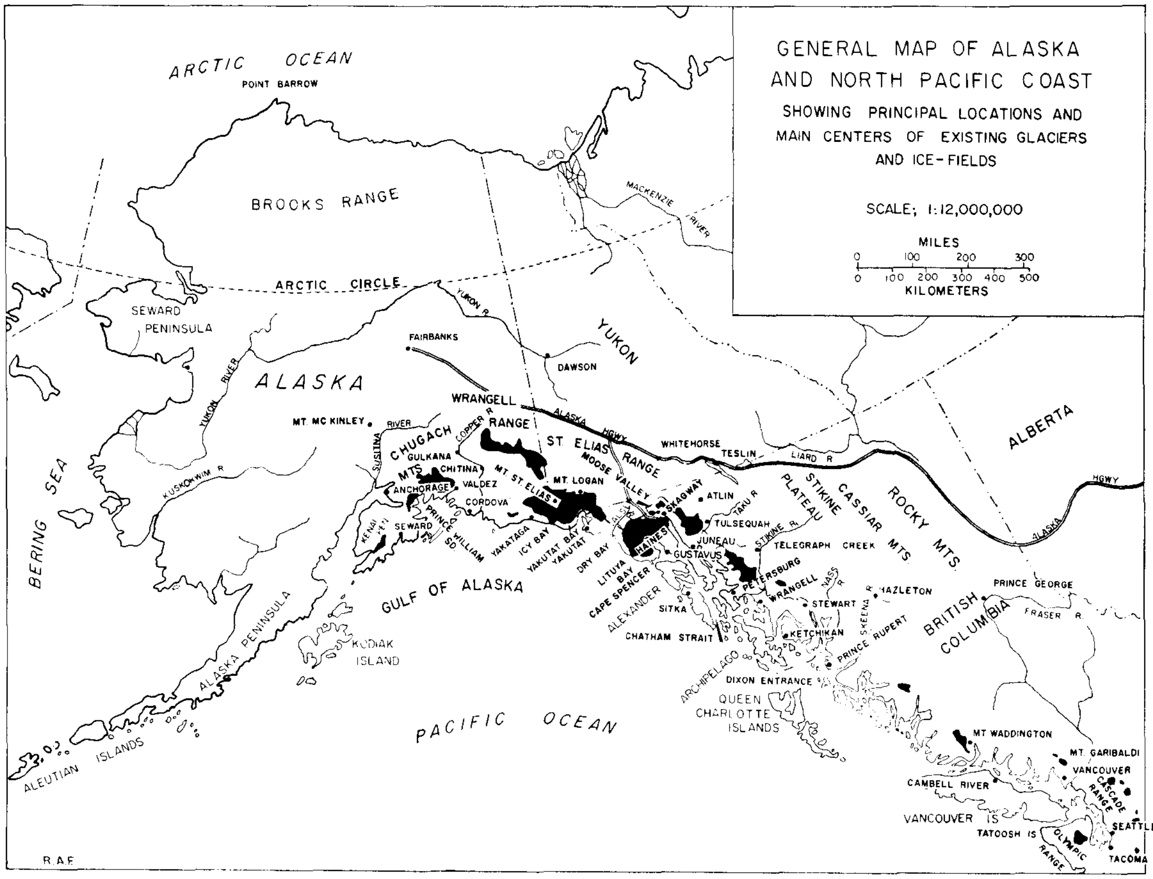

FIG. 1. General Map of Alaska and North Pacific Coast.

elevation of striae and erratics to be 7,250 feet.[2] As will be shown later, these striae may be from a lesser phase, with the evidence for a greater glaciation having been eradicated. Nevertheless, allowing for sufficient thickness of ice to produce the striae, it may be assumed that in at least one stage the glacier surface in the interior was at or probably above 8,000 feet. Observations of the summit forms and related features along the crestline of the Boundary Range have led the author to conclude that the corresponding ice level of this maximum was of the same order. The highest axial peaks in the Taku and Stikine Districts may, however, not have been overridden by glaciers from the east. Regardless of the extent of glaciation, many of these axial ridges served as deflection agents. This is borne out by the regional morphology, which shows that the alignment of the Coast Mountains channelled much interior ice from an extensive early glaciation northward through the Atlin lowland into the drainage system of the Yukon Valley and southward through the Nass Basin and the Skeena River channel to Dixon Entrance and the open ocean at Queen Charlotte Sound (fig. 1).

At least during the reduced ice-sheet phases of the Pleistocene, the Juneau and Stikine Icefields acted as "local" centers with their own "icecaps" standing higher than the surface of the more continental glaciation to the east. That there was east–west transfer of ice cannot be denied; but the movement was mainly over the lower mountains and cols between the high centers, with the most concentrated flow in the over-deepened trans-range valleys of the Taku, Whiting, and Stikine rivers.

Another important drainage outlet was north of the Taku District through the broad saddle of the

[2] The summits of the higher Cassiar Mountains lie between 7,000 and 8,100 feet, which approximates the height of those in the Northern Boundary Range in the region of the Juneau Icefield.

White and Chilkoot Passes where a large tongue of continental ice penetrated the range to pass southward into the Coastal Trough. The result was much erosion in the main fiord system west of the present Cordilleran glaciation. This partially explains the great length and depth of Lynn Canal and Chatham Strait which, if considered as a single fiord, is over 200 miles long, and 1,000 to 2,000 feet deep (Flint *et al.,* 1945). Deep grooving, with a longitudinal trend on the valley walls, and broadly convex hogback ridges bordering the Taku River and Fiord prove that great quantities of ice also scoured this depression, some of it from the local center, but probably much as spill-over from the continental glacier sheet which inundated the Taku Plateau.

THE PRE-WISCONSINAN INTERMONTANE ICECAP GLACIATION

In the Taku District, at the maximum stage, the regional ice center was well east of the present water divide and probably existed as an elongated zone or broad glacial ridge connecting the highest bedrock massifs. Its axial line may be assumed to have extended ten to twenty miles east of the present International Boundary and to have run parallel to the structural axis of the range between Mount Nesselrode, Mount Nelles, and Mount Lester Jones east of Tulsequah (figs. 2 and 4). These peaks rise to about 8,000 feet and all have been subjected to extreme frost shattering and severe subaerial denudation in late-Pleistocene time.

It is probable, therefore, that at these summit levels any direct sign of glaciation earlier than the Wisconsinan has been removed. If not actually inundated by the regional glaciation, these peaks were certainly obscured by a deep mantle of local ice. On isolated, somewhat lower summits of 7 to 8,000 feet elevation, unquestionable remnants of a former extensive erosion surface provide geomorphic evidence that this ice was significantly thick. Although the details are difficult to reconstruct, it is clear that the glacial cover in this maximum phase was confluent with the interior "Icecap" of sub-continental dimension. Therefore, it is appropriate to refer to this greatest high-stand as the Intermontane Icecap Glaciation. It is considered to be pre-Wisconsinan in age and, as a regional reference, to correspond to the Continental Ice-sheet Stage of Kerr (1936: p. 682).

FIG. 2. Oblique view northeast across southern portion of Juneau Icefield, Alaska-Canada Boundary Range. In foreground is the 4,000-foot névé of Taku Glacier. Mean elevation of closest nunataks is 6,000 feet. Crestal névé in left distance at 6,200 feet. Mount Nelles (8,000 ft.) is cloud-topped summit in right distance. (Aerial photo by M. M. Miller, Sept. 8, 1962.)

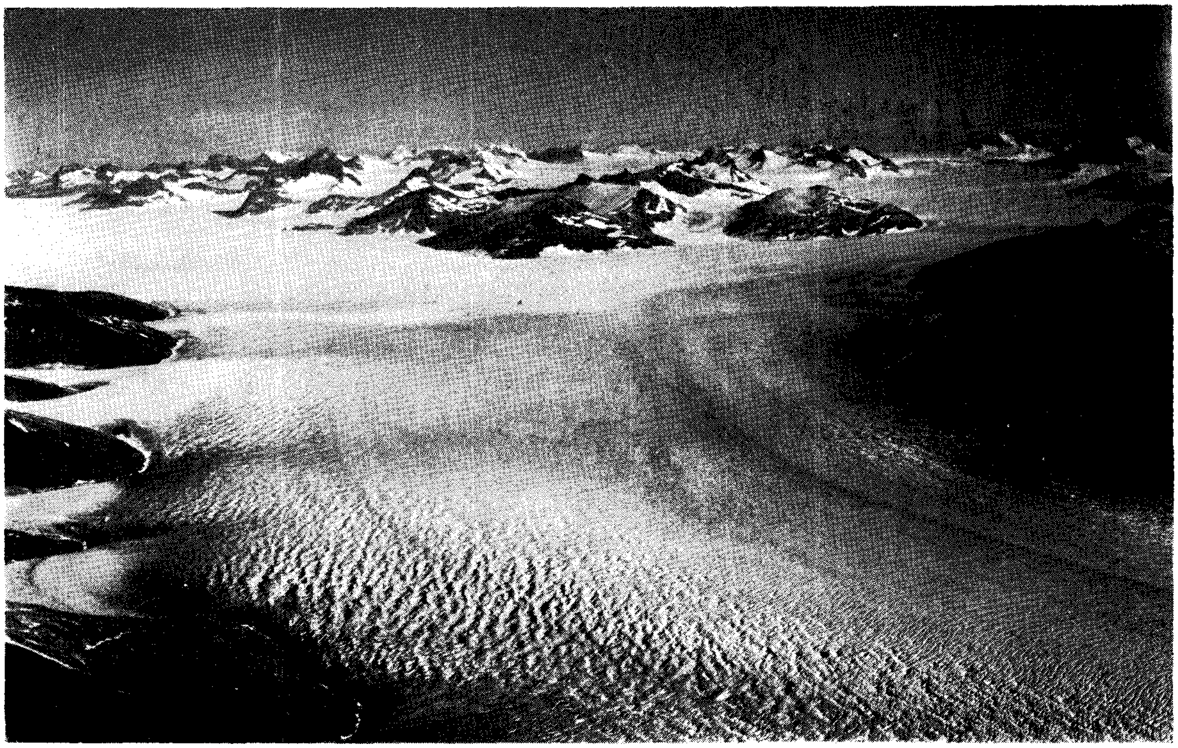

FIG. 3. View north up main branch Taku Glacier, Juneau Icefield. In middle foreground is the 1962 seasanal névé-line at 3,000 feet and the semi-permanent névé-line at 2,900 feet. This glacier is a prototype of a thickening ice mass in the current regime cycle of the Retracted Icefield glaciation. Ice reentrant in lower left corner is same as in upper right hand corner of Fig. 6. (Aerial photo by M. M. Miller, Sept. 8, 1962.)

GREATER, INTERMEDIATE, AND LESSER MOUNTAIN ICE-SHEET PHASES OF WISCONSINAN GLACIATION

In the next lesser stage which is the one most clearly recognized from local evidence in the Boundary Range, some of the nunataks between 6,000 and 8,000 feet protruded through the ice surface. The glaciation may correlate with that forming striae at 6,500 to 7,250 feet in the Cassiar Range. Again it was of regional proportion, with the Taku area in general deeply inundated; but in this period ice moved north and east from the Coast Range as well as west and south (fig. 7, *A*). The outlet glaciers, however, were restricted more to the mountain area and only formed piedmonts in the immediately adjacent lowland, thus leaving large ice-free zones between the Coast Ranges and the Rocky Mountains. The flow came from several local mountain centers. It is convenient, therefore, to use the term devised by Kerr (1936) and to refer to this as the Mountain Ice-sheet Phase. The most important center in the Juneau Icefield sector was still somewhat east of the present crestal névé between Mount Ogilvie and Mount Nelles, as evidenced by the direction of striae on neighboring summits at 7 to 8,000 feet elevation; and the fact that there are very deeply incised valleys radiating out in four directions from this sector.

In the earliest phases of this glaciation, the great fingerlike channels of the lakes in the Atlin District were formed behind an immense terminal moraine complex, 60 or more miles north of the present Juneau Icefield. The farthest limit of this phase corresponds to the Wisconsinan maximum. That the retreat of ice from this position was rapid is suggested by the reverse slope of these channels and the lack of prominent recessional moraines and other glacial products on the lake beds (Cairnes, 1913: p. 28). Towards the east, the glaciers deeply filled the lowland valleys and one of them extended for 40 or more miles up the Taku Valley into the Nakina depression, probably as far as the Sloko River (fig. 4). The ice-eroded topography near the abandoned native settlement of Inklin shows that the eastern limit of one ice tongue in this stage reached a point several miles above the junction of the Taku and Inklin rivers.

To the west, the ice pushed well out into the Alaskan archipelago and, although it did not extend as far as in the preceding continental stage, it continued to erode fiords well below sea level (fig. 5). At Juneau, there is a drift sequence believed to correlate with this phase. Although few details of these limits are known at present, it is certain that the last great Mountain Ice-sheet was a major one and that it had several important phases . . . i.e., a Greater, Intermediate and Lesser Mountain Ice-sheet phase . . . none of which, however, was as extensive as the Intermontane Icecap Glaciation. Each of these phases probably corresponds to several of the distinct stages of Wisconsinan glaciations in the Laurentide Ice-sheet chronology. It is difficult to distinguish between the erosive effect of this later ice-sheet type of glaciation and that of earlier ages; but there is evidence of an upper glacial limit on some of the high granitic summits and also of a lower limit according to the elevation of old cirques (Miller, 1961).

THE EXTENDED ICEFIELD PHASES

The latest separate glaciation which has left measurable traces in the Taku District was much smaller than the earlier Wisconsinan maxima. It was likewise characterized by substages. There were local centers of outflowing ice, several of which lay within the confines of the present icefield. The one near Mount Ogilvie (fig. 4) was shifted farther west and is still in effect. Another centered on the present Mendenhall and Berner's Bay highland west of the Taku Range and a third on the upper Twin Glacier névé near Devils Paw (fig. 7, *B*). An additional center lay east of the present icefield beyond the Talsekwe Trench and, as suggested by Kerr (1948), was situated about seven miles east of Tulsequah. In view of this separation between areas of disbursement, reference cannot be made to a single icecap or over-all ice-sheet. This condition is therefore generally referred to as the Extended Icefield Phase.

In this glaciation, ice filled the bottom part of the Taku Valley and close to the area of present glaciation coalesced with tongues from the tributary valleys. In successive phases, the main terminus rested at different positions, resulting in the building of extensive valley trains and the

THE NORTHERN BOUNDARY RANGE

ALASKA - CANADA

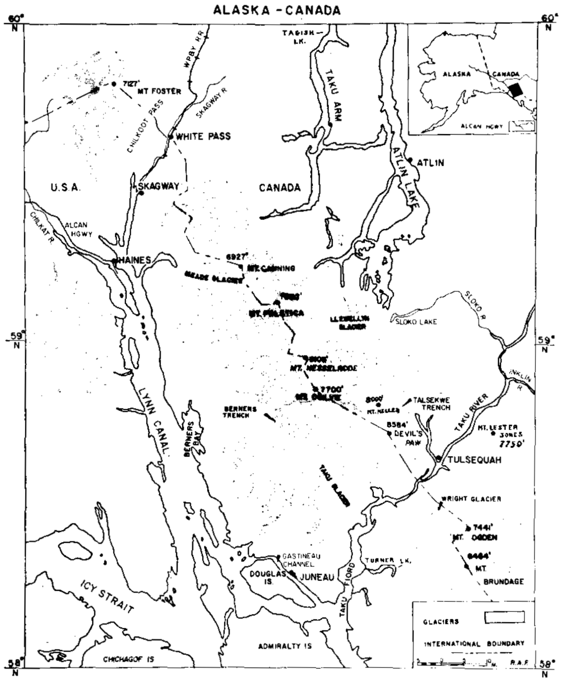

FIG. 4. Northern Boundary Range showing limits of present Retracted Ice Field position. Designated river valleys, elongated lakes and fiords served as main channels of outflowing ice during the Mountain Ice-sheet glaciations.

impounding of large glacial lakes. This is shown by the terraced remnants of outwash plains and fine material representing old lacustrine levels. A number of paired terraces occurring at the upper end of the Taku River valley east of the International Boundary indicate that the fluctuations were manifold. The highest of these is probably from the very latest Mountain Ice-sheet glaciation, with the younger terraces being from an Extended Icefield Stage.

In the mouths of valleys tributary to Lake Tagish (Taku Arm) and Lake Atlin (fig. 4), far back from the main Wisconsinan terminal complex yet 20 to 30 miles north of the present glacial limit, is a similar series of terrace accumulations.[3] These are composed predominantly of water-sorted material which may correlate with Late Wisconsinan remnants in the upper Taku Valley. Cairnes (1913: p. 32) believes that they largely represent glacier-dammed lake deposits, although his de-

[3] The complex distribution of Pleistocene drift in the Atlin District is illustrated on a reconnaissance map by Aitken (1959).

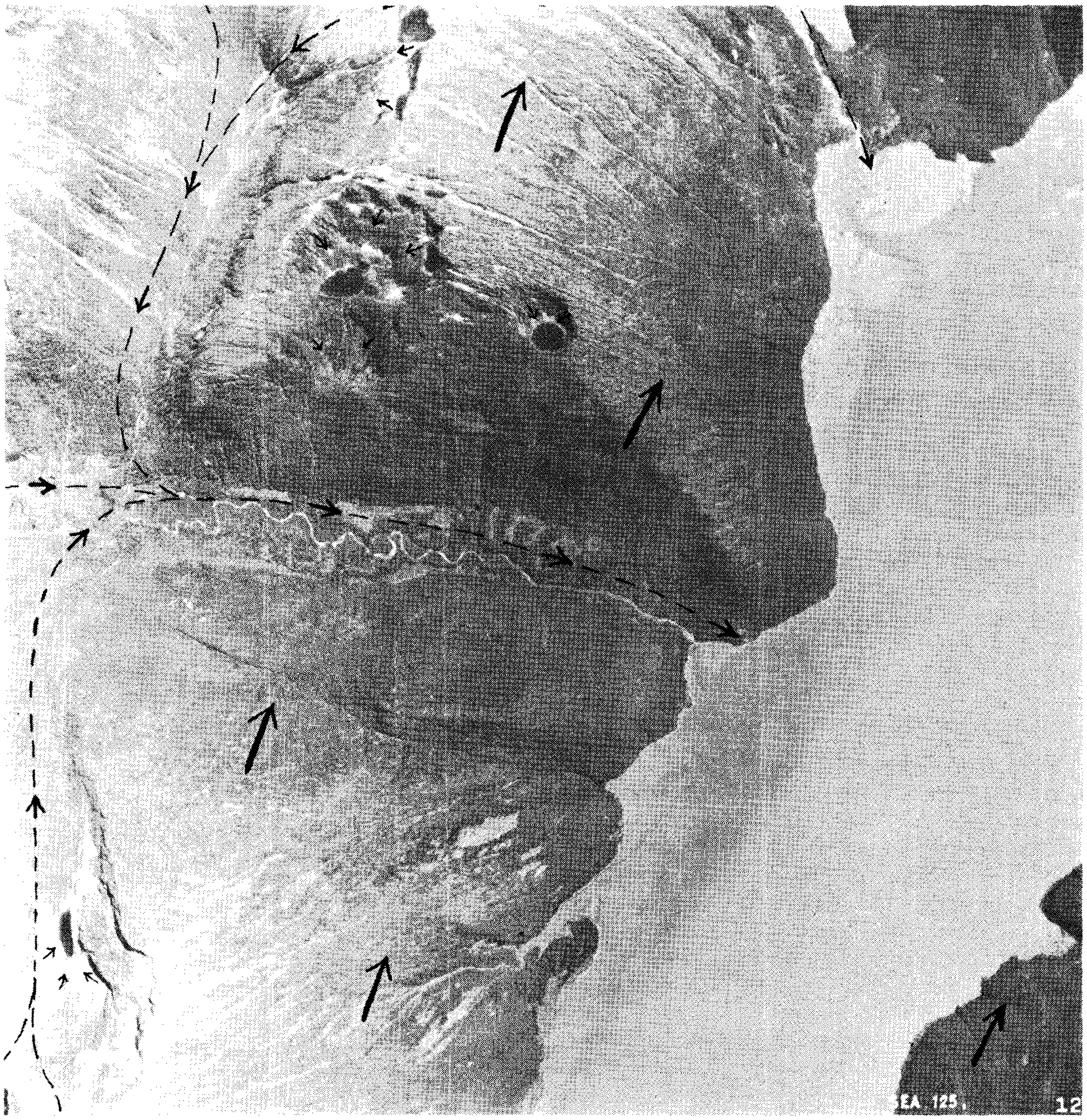

FIG. 5. Vertical view (flight altitude 20,000 feet). Deglaciated granitic surface east of Taku Fiord, near Turner Lake (outlet visible in upper right). Fiord trend due south. This terrain affected by Mountain Ice-sheet glaciation. Large arrows indicate southerly direction of overriding by Greater Mountain Ice-sheet. Dashed lines follow longitudinal axes of a tributary valley glacier system of the Intermediate and Lesser Mountain Ice-sheet glaciations. Contemporaneous with, and subsequent to, the valley glaciation was a local glacier condition, indicated by small arrows. Tarn lakes produced in final phase of deglaciation. (U. S. Navy photo, 1948.)

scription implies that some of them may also be marginal drainage terraces. The composite development of some of the upper level cirques on the icefield may also relate to this phase. It suffices to mention here that an Extended Icefield condition characterized the last significant fluctuation before the close of Wisconsinan time.

THE RETRACTED ICEFIELD AND LOCAL GLACIER CONDITIONS

The next phase to be considered is typified in the Taku District by the Alaskan Little Ice Age. Although an icefield-type of glaciation (figs. 3 and 6) it is much more retracted than those of the Wisconsinan and is characterized by only one

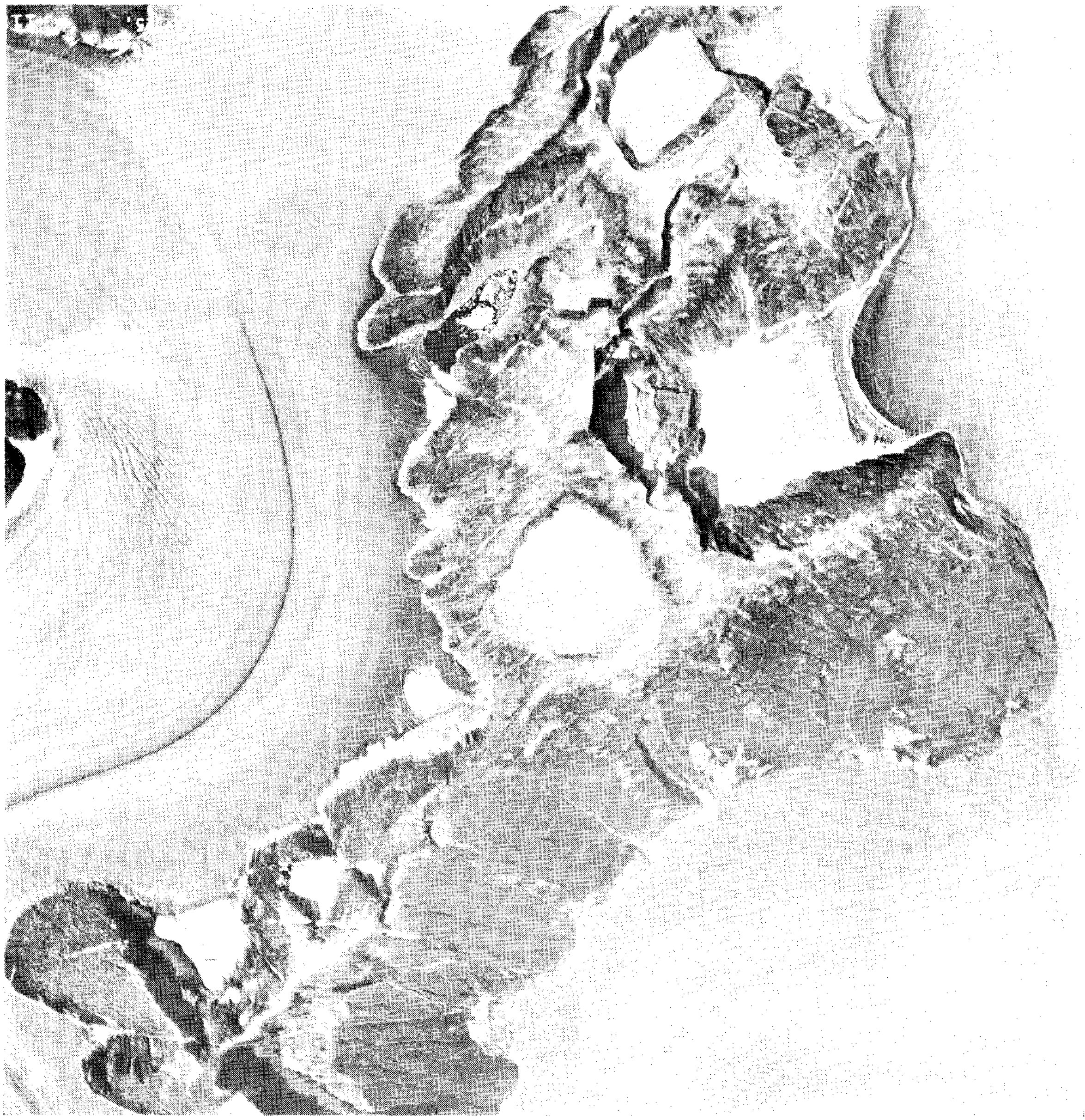

FIG. 6. Vertical view (indicated flight altitude 20,000 feet) illustrating two contemporaneous phases of glaciation. Norris Glacier on left, and Taku Glacier on right . . . segments of the Retracted Icefield phase. On the intervening ridge small cirque glaciers represent Local Glacier conditions at elevations of 2,500 to 4,500 feet. The surrounding surface of granodiorite modified by the Greater, Intermediate and Lesser Mountain Ice-sheets, the upper limits of which are shown by successive berm levels along the flanks of these ridges. (U. S. Navy photo, Aug. 14, 1948.)

important disbursing center in the Mount Ogilvie crestal névé (fig. 7, *C*). I, therefore, refer to this modern condition, representing essentially the last two and one-half millenia, as a Retracted Icefield Stage.

One final phase is mentioned. This corresponds to the even more contracted condition of the Thermal Maximum. In the morphogenetic classification, this is the Local Glacier Phase. This condition is illustrated by small glacierets today, particularly in the coastal islands to the west, well outside of present icefield positions in the Boundary Range. Recognition of this phase is of importance in geomorphological considerations

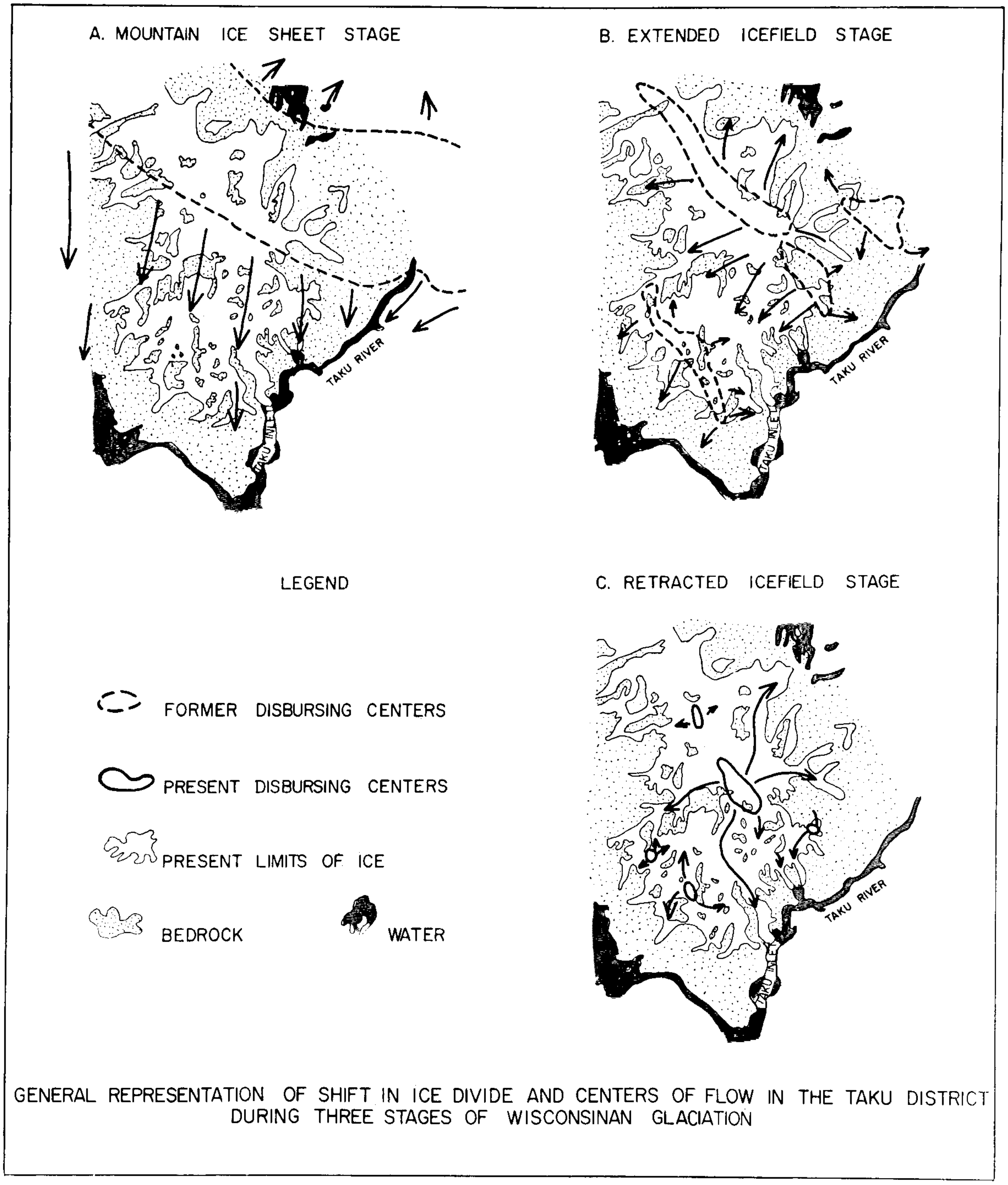

FIG. 7. General representation of shift in ice divide and centers of disbursement in the Taku District, Northern Boundary Range, during three stages of Wisconsinan Glaciation.

because it focuses on selective glacial erosion during interstadial time. Traces of its effect are found close to the present icefield and also in isolated areas of the deglaciated highland. The resultant terrain features are usually allied with those of each of the final icefield phases. It is particularly related to the modification of the crestal flanks of ridges and the floors of cirques (figs. 5 and 6). Most of the evidence of local glaciation during the post-Glacial Thermal Maximum stage has been covered by renewed development of the present Retracted Icefield stage.

With respect to the morphogenetic phases involved, discussion of the actual time relationships of each glacial stage is not within the scope of this paper. An attempt at chronology, therefore, has not been detailed, other than to facilitate the distinction in terms. It is reiterated that each of the glacial phases discussed has recurred repeatedly in the Pleistocene, and in these districts several of the lesser ones have occurred simultaneously (as illustrated in fig. 6). For these reasons, an unqualified reference to any one morphogenetic phase does not imply a selective event or stage in Pleistocene chronology. This is why the term "phase" is used for general reference to a type glacial condition, while the term "stage" is reserved for reference to a specific time interval in which a known condition of glaciation has pertained.

Field evidence reveals that the passage from one distinct stage to another in both the northern and southern sectors of the Boundary Range has changed the east–west balance of glaciation. This has been through a series of successive shifts of the ice divide to the present position which is coincident with the water divide. For the Taku District such is represented in the stage evolution sequence of figure 7. From this figure one can visualize that in the progressive and retrogressive stages, the disbursing centers were farther west than in the maximum stages. In the waning hemi-cycle of each glacial maximum, the shift has, therefore, occurred from east to west. Thereafter, during further deglaciation, there has been gradual shrinkage and splitting up of the icefields into several local centers at separate points along the crestline. In the waxing hemicycle, the reverse sequence has applied.

In table 1, the five recognized morphogenetic types of glaciation are summarized. Some evidence of intermediate phases has been detected but the detail and extent of these will only be clarified through systematic study of selected stages and sub-stages via the glacial stratigraphy on the fringes of these districts. The Mountain Ice-sheet Glaciations of the Wisconsinan, however, were of such intensity that they destroyed most of the distinct evidence of previous major fluctuations in the immediate vicinity of the Juneau Icefield and the Stikine Icefield. As a result, morphological studies in these areas

TABLE 1

MORPHOGENETIC PHASES OF GLACIATION WHICH HAVE OCCURRED IN THE BOUNDARY RANGE, ALASKA–CANADA

A. *Intermontane "Icecap" Glaciation* (Kerr's Continental Ice-sheet Stage; Davis and Mathews' Phase IV)	The maximum phase, attained only in pre-Wisconsinan time; of *sub*- continental proportion. Generally covering all summits and overriding most of them but with some radial flow from local centers. Confluent with main continental ice-sheet to the east, which was deflected north and south, but with westward spill-over through low passes and major trans-range river gorges.
B. *Mountain Ice-sheet Glaciation,* with stages. (Kerr's Mountain Ice-sheet Stage; Davis and Mathews' Phase III)	Corresponds to Wisconsinan maxima; of *regional* proportion; with localized crestal centers and nunataks of higher peaks protruding through the surface. A confluent mass of mountain and low-land piedmont and valley-filling glaciers, extending only slightly beyond the topographic borders of the range; distinct stages designated as the Greater, Intermediate and Lesser Mountain Ice Sheets.
C. *Extended Icefield Glaciation* (Kerr's "Intense Alpine" Stage; Davis and Mathews' Phase II)	A stage of *district* proportion; several local centers. Essentially a mountain glaciation, confined entirely within the fiords and valleys of the range. Corresponds to pulsation limits of the latest Wisconsinan.
D. *Retracted Icefield Glaciation* (Kerr's "Alpine" Stage; Davis and Mathews' Phase I)	A sub-stage of *local* proportion with névé areas restricted to intermediate and high elevations. Corresponds to present situation; within limits of maximum Little Ice Age pulsations.
E. *Local Glacier Condition*	End phase (or initial phase) just before complete disappearance; disconnected glaciers or small icefield systems only at the highest level. Characterized interstage periods including the Thermal Maximum. Also an adjunct phase, typified by minor glacierets and high-level cirque glaciers above or outside of the main icefields during each of the other stages noted.

must almost wholly be concerned with landforms, the surfaces of which have been severely altered in Wisconsinan and Recent time.

Kerr (1936) and Davis and Mathews (1944) have recognized four general stages in the central and southern parts of the British Columbia Coast Range. These seem to correspond with the major phases observed by the writer in this northern sector of the Coast Range. A notation of their terminology is given in parentheses in the table. The writer's references, however, are specifically to the Alaska-Canada Boundary Range and are therefore made on a slightly different basis.[4] Although Kerr's use of the term "Mountain Icesheet" is retained in the present usage for reference to the lesser phases, it seems advisable to use other than his "alpine" nomenclature so that the connotations will be consistent with the field facts as we now know them. In the first place, we are dealing with glacier systems which are Subtemperate "icefields" of far greater extent than any ice masses found today in the Alps. The word "alpine" also connotes a chronological development or stage sequence corresponding to the highland glaciation in Europe which may not be warranted in the present comparison. It is a term probably more indicative of the Local Glacier condition during the final disappearance of ice in the warmest interglacial and intraglacial intervals. Furthermore, it is one which is more appropriate for a description of local conditions which have continued in effect outside of the main glacial area during each of the larger stages.

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[4] For example, the term "icefield" is used to connote a smaller and less contiguous type of glacial cover than in the continental "icecap" or mountain "ice-sheet" phases; and to signify the true "icefield" character of present glaciation in the Taku and Stikine districts.

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