THE UNIVERSITY OF OTTAWA

CIRQUE MULTIPLE GLACIATION, GRIZZLY CREEK, YUKON TERRITORY, AND PALEOCLIMATIC IMPLICATIONS

A THESIS PRESENTED TO THE
UNIVERSITY OF OTTAWA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ARTS
IN GEOGRAPHY

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GEOGRAPHY 7999
MAY, 1980

ACKNOWLEDGEMENTS

It would have been difficult indeed to have carried out this thesis project without the advice, assistance, and time of the following people. I would like to express my thanks and appreciation to Dr. P.G. Johnson (Thesis Advisor), Dept. of Geography, University of Ottawa; Dr. D.A. St.-Onge, Dept. of Geography, University of Ottawa; and Dr. V.N. Rampton, Terrain Analysis and Mapping Services, Ltd. Field research at Grizzly Creek, Yukon Territory would not have been possible without the financial support of the Northern Research Group, Faculty of Graduate Studies and Research, University of Ottawa. I would like to thank the Northern Research Group for their support. Finally, a special note of thanks to Sally for her support and encouragement.

ABSTRACT

A morphostratigraphic investigation of the latest Pleistocene and Holocene deposits of Grizzly Creek, Yukon Territory, and environs was conducted. Basic objectives were (1) to describe the late Quaternary stratigraphy of Grizzly Creek, (2) to place any defined stratigraphic sequence within a precise chronologic framework, (3) to interpret the Grizzly Creek sequence with respect to any defined regional stratigraphy, and (4) to discuss the paleoclimatic implications. With regard to the last objective, gradual vs abrupt climatic change, and Denton and Karlen's model concerning Holocene climatic variability is discussed. Emphasis is placed on Denton and Karlen's research. The data derived during field research at Grizzly Creek provides support for Denton and Karlen's model concerning Holocene climatic variation. It was not possible, however, to derive a definitive statement in support of their model. In this regard, the difficulties involved in the establishment and association of a precise chronologic framework proved a major barrier.

RESUME

Cette étude porte sur la morphostratigraphie des dépôts du Wisconsin supérieur et Holocène dans la région de Grizzly Creek, Territoire du Yukon. Les objectifs étaient: (1) de décrire la stratigraphie du Quaternaire récent pour Grizzly Creek, (2) d'organiser les successions stratigraphiques dans un ordre chronologique bien défini, (3) d'interpréter la série Grizzly Creek en se basant sur la stratigraphie régionale déjà définie, (4) et de discuter des implications paléoclimatiques. En ce qui concerne le dernier objectif, les variations climatiques graduelles ou brusques, ainsi que le modèle de Denton et Karlen traitant des variations climatiques du Holocène sont discutées. L'emphase est mis surtout sur les recherches de Denton et Karlen. L'information recueillie sur le terrain à Grizzly Creek appuie le modèle de Denton et Karlen. Cependant, il ne fut pas possible d'aboutir à un appui inconditionnel de leur modèle. Et à cet égard, la principale difficulté rencontrée dans ce travail a trait à l'établissement d'une chronologie précise.

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INTRODUCTION

A General Framework

A characteristic feature of the Quaternary is the extreme complexity and discontinuity of derived deposits. This is so obvious, in fact, that many Pleistocene scientists have remarked that this period represents "an extremely anomalous time in earth history" (Matthews 1974: 321). This writer (as per Matthews 1974: 321), however, must adopt an opposing view. Such complexity and discontinuity in all probability is a function of time and the anomalous nature of the sedimentary record in question is merely a refection of its relatively recent age. In effect, the complex and discontinuous nature of these deposits too will become obscured with time. The Quaternary, given this rationale, may be conceived of as a model designed for projection into the past ("the Quaternary as the key to the past" Matthews 1974: 321).

That which can be applied to the Quaternary as a whole most certainly can be related, perhaps with even greater alacrity, to its most recent series...the Holocene. Deposits of this time interval exhibit not only complexity and discontinuity, a function of their very recent deposition, but in many instances are still actively in the process of accumulation and the implication with respect to the reconstruction of past environments is obvious. A wealth of paleoclimatic data remains to be discovered within these deposits, and, possibly, this expresses well the 'state of the art' as it stands today. Our understanding of Holocene climates and their variation has only just begun to gain momentum, and, perhaps significantly, glaciology and glacial geomorphology have provided much of the impetus (e.g., Matthes 1939, 1941, 1945; and more recently, Porter and Denton 1967, Denton and Porter 1970, Denton and Karlen 1973).

Glaciers, in this regard, respond to a broad continuum of climatic change of quite variable frequency and magnitude, whereas other mediums through which one could interpret records of past climatic variation (e.g., pollen sequences), frequently, are responsive only to a much narrower range of such a spectrum (i.e., the portion stressing low frequency/high magnitude variation...Denton and Karlen 1973: 156; Wright 1976: 581-596). Moreover, the sediments deposited by glaciers either directly or indirectly provide records of their behavioural response to changing climatic conditions, and it has been the reconstruction of such past glacier response patterns through stratigraphic investigation which has contributed so much to current notions concerning Holocene climatic variation.

Matthes' research (1939, 1941, 1945) represented a major contribution to general themes concerning the character and expression of glaciation since the Pleistocene. Prior to the publication of Matthes' investigations there existed the widespread belief that alpine glacier systems in general were merely "shrunken remnants of the large glaciers of the Pleistocene epoch" (Matthes 1941: 2030). Matthes (1939: 519 and 1941: 2030), on the basis of research undertaken in the Sierra Nevada, developed certain novel ideas concerning the 'rebirth' of these small glaciers. He felt this event was closely related to the onset "of the present relatively cool and moist conditions after the climatic optimum of the Post-Pleistocene had passed" and which began possibly 4000 yr ago (Matthes 1941: 2030). He designated this interval the Little Ice Age, and, after assuming a synchroneity with respect to climatic variation between the United States and Europe, felt its culmination occurred sometime during the last 500 years. Matthes (1945: 1181) eventually extended these ideas to a global level, and it has been only recently (Porter and Denton 1967; Denton and Porter 1970) that his research has undergone modification and further extension.

Denton and Porter (1970), synthesizing the results of numerous recent field studies of a quite varied nature (i.e., geochronology, paleobotany, paleopedology, glacial geology, etc.) have managed to develop and refine Matthes' original work. They propose to replace Matthes' 'Little Ice

Age' with 'neoglaciation', which they define as "the interval of rebirth or renewed growth, and all subsequent fluctuations, of glaciers after the time of maximum hypsithermal glacier shrinkage" (Denton and Porter 1970: 102). Furthermore, they indicate that whereas the "hypsithermal interval originally was conceived of as a period of rather uniformly mild climate" it has become apparent that various lower-order climatic variations "resulting in several early neoglacial episodes of glacier expansion" did occur during this interval of time (Denton and Porter 1970: 102). It would appear then that the hypsithermal and neoglacial, as conceived by Denton and Porter (1970: 102), overlapped to a degree. Their synthesis indicates that three intervals of glacier expansion have marked the last 6000 years of the Holocene (i.e., since the climatic optimum) with the culmination of each occurring sometime within the periods of time 5500-4500, 2800-2600, and 500-100 yr BP respectively.

Scientists have long suspected "that short-term atmospheric C^{14} variations may reflect changes in solar activity that in turn caused climatic change" (Denton and Karlen 1973: 157). The reader, in this regard, may refer to Stuiver (1965), Bray (1971), and especially Suess (1971)...as it is his "contention that past C^{14} variations represent a paleoclimatic curve" (Denton and Karlen 1973: 202). Denton and Karlen (1973), using this research as a basis, have managed to extend further general notions concerning neoglaciation.

They synthesize a vast amount of data and in the process provide for a model concerning climatic variability through the Holocene. They demonstrate an apparent relationship between "short-term C^{14} variations measured from tree rings" and "Holocene glacier and tree-line fluctuations during the last 7,000 yr." (Denton and Karlen 1973: 156). Such a relationship suggests that variation in solar output is causal with respect to Holocene climatic variation...as the "most prominent explanation of short term C^{14} variation involves modulation of the galactic cosmic-ray flux by varying solar corpuscular activity" (Denton and Karlen 1973: 156). Furthermore, such variation appears to have a recurrence interval of about 2500 years, and, effectively, Denton and Karlen predict glacier expansion, with intervals of contraction between, peaking at "200-330, 2800,...5300..., 7800, 10,300, 12,800, and 15,300 calendar yr BP" (Denton and Karlen 1973: 156) and so forth. They indicate in addition that such expansional/contractional intervals last approximately 600-900 and 1750 years respectively...thus roughly completing a 2500 year cycle. The model depicted may be described as high frequency fluctuation of a rather low-order magnitude which one can superimpose upon the longer term glacial/interglacial climatic trends.

It is important not to conceive of such intervals as smooth curves alternating between glacier advance and recession, and, in this regard, Denton and Karlen state that superimposed "on the broad intervals of glacier expansion were many smaller variations" (Denton and Karlen 1973: 203). The Little Ice Age (i.e., and following common usage, defined as the last broad interval of glacier expansion) illustrates this rather well with glacier oscillations of even higher frequency and lower magnitude peaking "about A.D. 1596-1620, 1640-1643, 1670-1680, 1720, 1740-1750, 1770-1780, 1816-1825, and 1840-1850" (dates refer to Little Ice Age oscillations from the Alps...Denton and Karlen 1973: 171).

Denton and Karlen encountered a variety of problems during the development of their model concerning climatic variation through the Holocene. The variation they allude to is considered synchronous within a global context and research undertaken in this direction must be comprehensive. Basic difficulties relate to sample size and representation, and, in this regard, "many of the pertinent data are derived not from comprehensive field studies but from widely scattered observations" (Denton and Karlen 1973: 159). This is certainly true of the documentation regarding the earlier Holocene expansional intervals. In addition, their study is a comparative one and until some measure of understanding is achieved at local and certainly regional levels must be viewed as tentative. Glaciers "within one region may experience divergent behaviour due to differences in meteorological conditions, dynamic-response characteristics, and net-budget distributions" (Denton and Karlen 1973: 157 and 159;...also, the reader may refer to Meier (1965) and Paterson (1969) for discussion of the extreme complexity of the many relationships involved). Thus, any future field study oriented toward 'filling in the gaps', so to speak, should contribute measurably to this field of endeavour. Denton and Karlen (1973: 171), in this regard, recently have conducted extensive field investigation of "Holocene moraines fronting glaciers along the northeastern flank of the St. Elias Mountains".

A Regional Setting

"The St. Elias Mountains, an extensively glacierized high-mountain system, trend from northwest to southeast through southern Alaska and southwestern Yukon Territory" (Denton and Karlen 1973: 171). A vast array of related features ranging from perennial snowbanks through cirque and independent valley glaciers to a "large intermontane icefield... drained on all sides by long valley glaciers" (Denton and Karlen 1973: 171) are characteristic of this region (Fig. 1). Thus, it becomes easy to understand that the St. Elias Mountains comprise an ideal setting within which a wide range of glacier-related studies can be undertaken, and even easier to comprehend Denton and Karlen's decision for choosing this area, that is, the northeast flank of these mountains, "to overcome

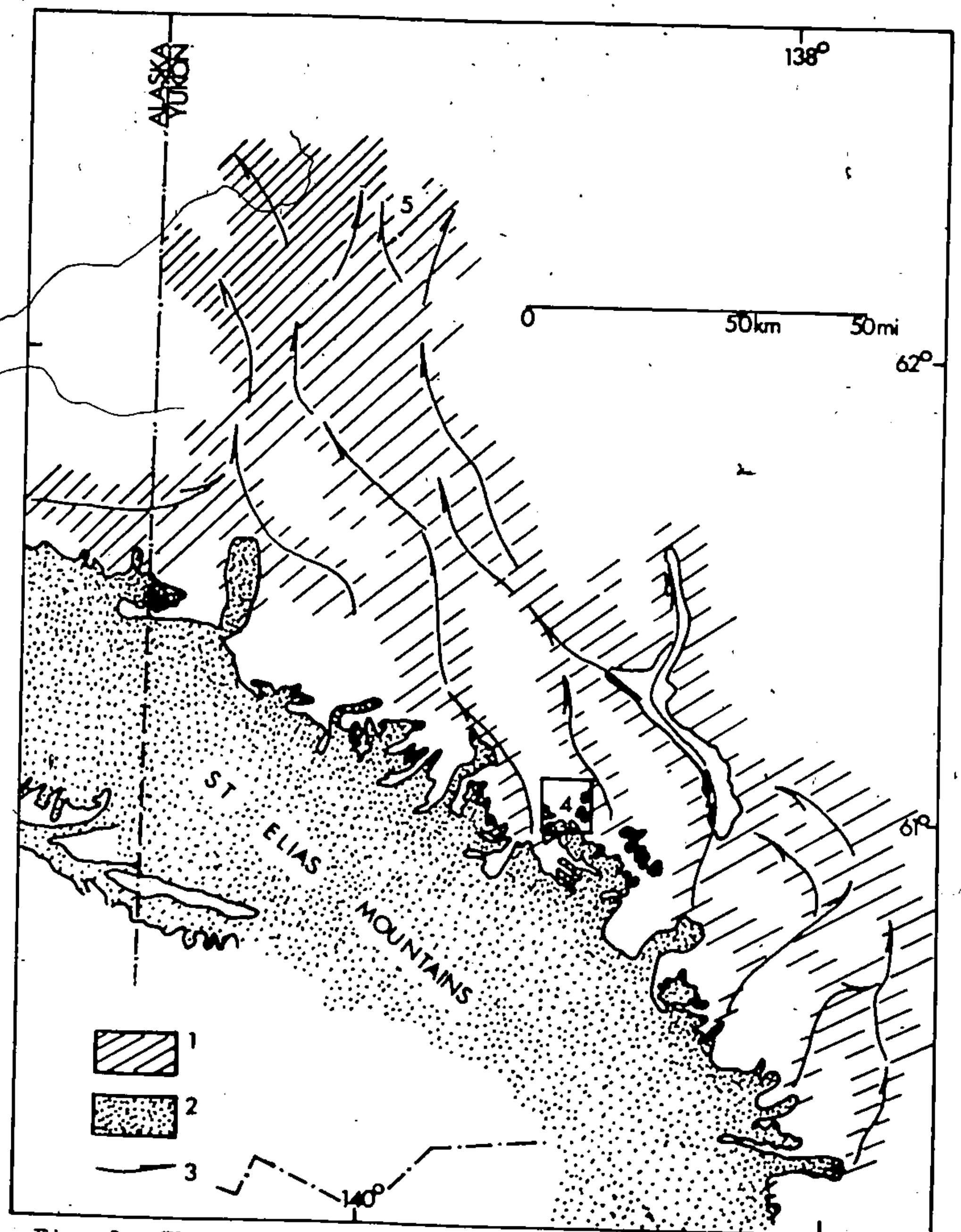

Fig. 1 THE NORTHEAST ST. ELIAS MOUNTAINS...

(1) "Configuration of Macauley-Kluane glaciers"; (2) Configuration of St. Elias glaciers today; (3) "Probable flow directions of Macauley-Kluane glaciers"; (4) Approximate location of Grizzly Creek study area; (5) Wellesley Basin area;...(Denton 1974: 884).

some of the data gaps associated with Holocene glacier events" (Denton and Karlen 1973: 171). The stratigraphy and chronology of late Wisconsin and Holocene events from the northeast St. Elias Mountains and environs generally is well documented, and, in this regard, discussion will turn to a consideration of the following events...the Kluane/Macauley glaciation, deglaciation, and neoglaciation.

During late Wisconsin time at the height of the Kluane/Macauley glaciation a vast and complex glacier-system comprised the predominant feature of the landscape of the northeast St. Elias Mountains and surrounding area (Fig. 1). Denton and Stuiver (1969a) and Rampton (1971), in this regard, have made major contributions toward understanding the development of this glacier-system. Denton and Stuiver investigated drift sequences from the Kluane Lake/Shakwak Trench area and defined the Kluane glaciation (i.e., "the climatic episode, characterized by glacial expansion, during which the Kluane tills were deposited"...Denton and Stuiver 1969a: 210). Rampton undertook stratigraphic investigation in the White River/Snag-Klutlan area, located adjacent to but north and somewhat west of Denton and Stuiver's study area, and there defined the Macauley glaciation (i.e., and following Denton and Stuiver's phraseology, 'the climatic episode, characterized by glacier expansion, during which the Macauley tills were deposited'). Glacier ice of Kluane provenance expanding and flowing in a generally northwest direction (i.e., glacier expansion "along the inner valley of the Duke Depression and the Shakwak Valley"...Rampton 1971: 292) eventually encountered ice of Macauley derivation moving very generally in a northeast direction (i.e., glacier flow "north out of the Icefield Ranges..., and...east from Alaska parallel to the upper reaches of the White River" Ibid.). Coalescence occurred, and, ultimately, upon further expansion towards the north a quite complex piedmont glacier developed in the Wellesley Basin area (Rampton 1971: 292-293). The culmination of the Kluane/Macauley glaciation, as inferred from a radiocarbon "date of 13,660±180 B.P....obtained on the basal part of lacustrine sediments directly overlying Macauley deposits near the Macauley glacial limit" (Rampton 1971: 295), occurred approximately 14,000 yr BP (Rampton 1971: 295, and Denton 1974: 871).

Deglaciation as evidence from the northeast St. Elias Mountains would indicate was a rapid event. Denton (1974: 871), in this regard, maintains that the "most striking late Wisconsin event in the St. Elias Mountains was the nearly complete disintegration of Macauley-Kluane ice within only 1,500 to 2,700 yr after attaining its maximum about 14,000 yr B.P.". Indeed, radiocarbon dates of 12,500±200 yr B.P. (Y-1386) and 11,270±200 yr BP (Y-2306) obtained, respectively, on "organic silt...from base of lacustrine silts that fill a kettle in Kluane ice-contact stratified drift" (Denton 1974: 877) and located in the vicinity of Kluane Lake, and "organic silt and muskeg... that rests on Macauley till" (Denton 1974: 877) and located in the upper reach of the White River Valley quite close to the present Russell Glacier terminus (Denton 1974: 884; and Rampton 1970: 1240) provide substantial support for such a contention. Also, and in keeping with notions concerning the rapidity or possibly abruptness of this event, only limited evidence of glacier readvance or stillstand during general recession has been discovered. In this regard, Denton and Stuiver (1969a: 211) hypothesize that a "cross-valley belt of ice-contact features bordering the southeast part of Kluane Lake...possibly record the outer position of a stillstand or readvance", and Rampton (1971: 296) maintains that a "rugged spatulate-shaped moraine near the Natazhat Glacier is the only evidence of a major stillstand or readvance" from the Snag-Klutlan area.

The amelioration of climate responsible for the rapid and abrupt pattern of late Wisconsin deglaciation as interpreted from the St. Elias Mountains obviously was a climatic change of great magnitude. Glacier systems withdrew "rapidly to...present positions before 11,000-12,500 C^{14} BP" (Denton and Karlen 1973: 173) and continued to recede thereafter. Indeed, the interval of time following the Kluane/Macauley deglaciation, referred to as the Slims nonglacial interval

(Denton and Stuiver 1969a: 212), was associated at least with respect to certain glaciers with recession considerable distances upvalley from current termini positions. Denton and Stuiver (1969a: 212), for example, have documented "a withdrawal of the Kaskawulsh glacier terminus more than 13.7 miles above its present position". Whether such an extended retraction reflected a regional pattern of glacier behaviour for the northeast St. Elias Mountains at that time has not yet been determined. The assumption that it did however does not seem unwarranted. At any rate, maximal glacier recession most probably occurred about the time of the climatic optimum, and available evidence would suggest this occurred about 6000 yr B.P. Denton and Porter (1970: 102), in this regard, maintain that very "likely maximum shrinkage coincided with the period of maximum warmth, which from various lines of evidence is thought to have occurred sometime between 8,000 and 5,000 years ago, probably close to 6,000 years ago".

The Slims nonglacial interval, defined as the interval separating "the Kluane glaciation from the Neoglaciation" (Denton and Stuiver 1969a: 212), was a time-transgressive interval. Radiocarbon dates of 12,500±200 (Y-1386) and 9780±80 yr BP (Y-1483) (Denton and Stuiver 1969a: 213) obtained from organic materials found in association with Kluane drift and related locally to deglaciation provide minimum limiting dates for its inception (Denton and Stuiver 1969a: 214). A radiocarbon determination of 2640±80 yr B.P. (Y-1435) obtained from "grass buried in place at the base of Neoglacial loess near the terminus of the Kaskawulsh Glacier" (Denton and Stuiver 1969a: 214) and related to the initiation of the Neoglaciation at this locality provides an approximate date for the termination of this nonglacial interval.

The stratigraphy and chronology of the Neoglaciation from the northeast St. Elias Mountains is well-documented especially when compared to Holocene glacier sequences defined elsewhere (e.g., the Colorado Front Range...Benedict 1973, or Baffin Island...Miller 1973). Benedict (1973: 597), in this regard, maintains the "St. Elias sequence, with 31 relevant radiocarbon dates, is the best controlled of any currently available". Effectively, the Neoglacial of the northeast St. Elias Mountains, as various radiocarbon determinations derived from organic materials and then related to the inception of such a regime would suggest (e.g., ^{14}C dates of 2780±90 (I-6490-C) and 3440±130 yr BP (GSC-1702) obtained respectively from wood "in organic silt layer located immediately below outermost Holocene moraine"...Denton and Karlen 1973: 166...of the Seven Sisters Glacier and "wood from mixed deposits of spruce wood and organic sediment buried beneath Holocene till"...Denton and Karlen 1973: 167...of the Natazhat Glacier), began approximately 3000-3500 yr BP and is still currently active (Denton and Stuiver 1969b: 175).

Detailed stratigraphic investigations of Holocene drift sequences (e.g., Denton and Stuiver 1969b; Rampton 1970; Denton and Karlen 1973, 1977) from the northeast St. Elias Mountains indicate that neoglaciation of this region was at least two-phased. Effectively, "C^{14}-dated fluctuations of 14 glacier termini show two major intervals of Holocene glacier expansion, the older dating from 3300-2400 calendar yr BP and the younger corresponding to the Little Ice Age" (Denton and Karlen 1973: 155). In addition, a minor interval of glacier expansion approximately 1250-1050 yr BP, and which represents divergence from the overall pattern of Holocene climatic variation as discussed by Denton and Karlen (1973, 1977), has been documented from this region. The significance of such divergent behaviour with relation to their model has not yet been determined. It may be that some measure of understanding will eventually be achieved within a strictly regional context.

Morainic complexes derivative in part of each such broad expansional interval do not necessarily front all glaciers of the St. Elias Mountains, and, in this regard, Denton and Karlen (1973: 173) remark that not "all advances are recorded by moraines fronting each glacier, probably because younger Holocene advances overran older moraines". Direct evidence of earlier Holocene glacier advances (i.e., of the broad expansional phases culminating ca. 5300 and 7800 yr BP) from the St. Elias Mountains is absent, and, possibly, a similar explanation may be involved. At any rate, and given such a preamble, it is interesting to note that Denton and Karlen's approach emphasized the examination of "moraines fronting numerous glaciers to discover situations where older moraines were preserved" (Denton and Karlen 1973: 173).

A Local Setting

During the summer of 1979 field research was conducted in Grizzly Creek, Yukon Territory, a locality represented by a long (ca. 15-16 km), narrow (ca. 1 km), and high alpine valley situated on the periphery of the St. Elias Ice Fields. A small valley glacier and several smaller cirque glaciers, each associated with massive ice-cored Neoglacial moraines, are features of this setting (Fig. 2). Such glaciers are very sensitive to the frequency and magnitude of the climatic variation discussed by Denton and Karlen, and consequently the question was raised as to whether an investigation of the late Quaternary stratigraphy of Grizzly Creek would lend additional support to their model. The probability that evidence relating to certain of the earlier intervals of Holocene glacier expansion is preserved in Grizzly Creek was considerable, and the key to understanding such a proposition relates to the many massive and ice-cored moraines so characteristic of this locale. Recent advances of these small glaciers (e.g., those of the Little Ice Age), very simply,

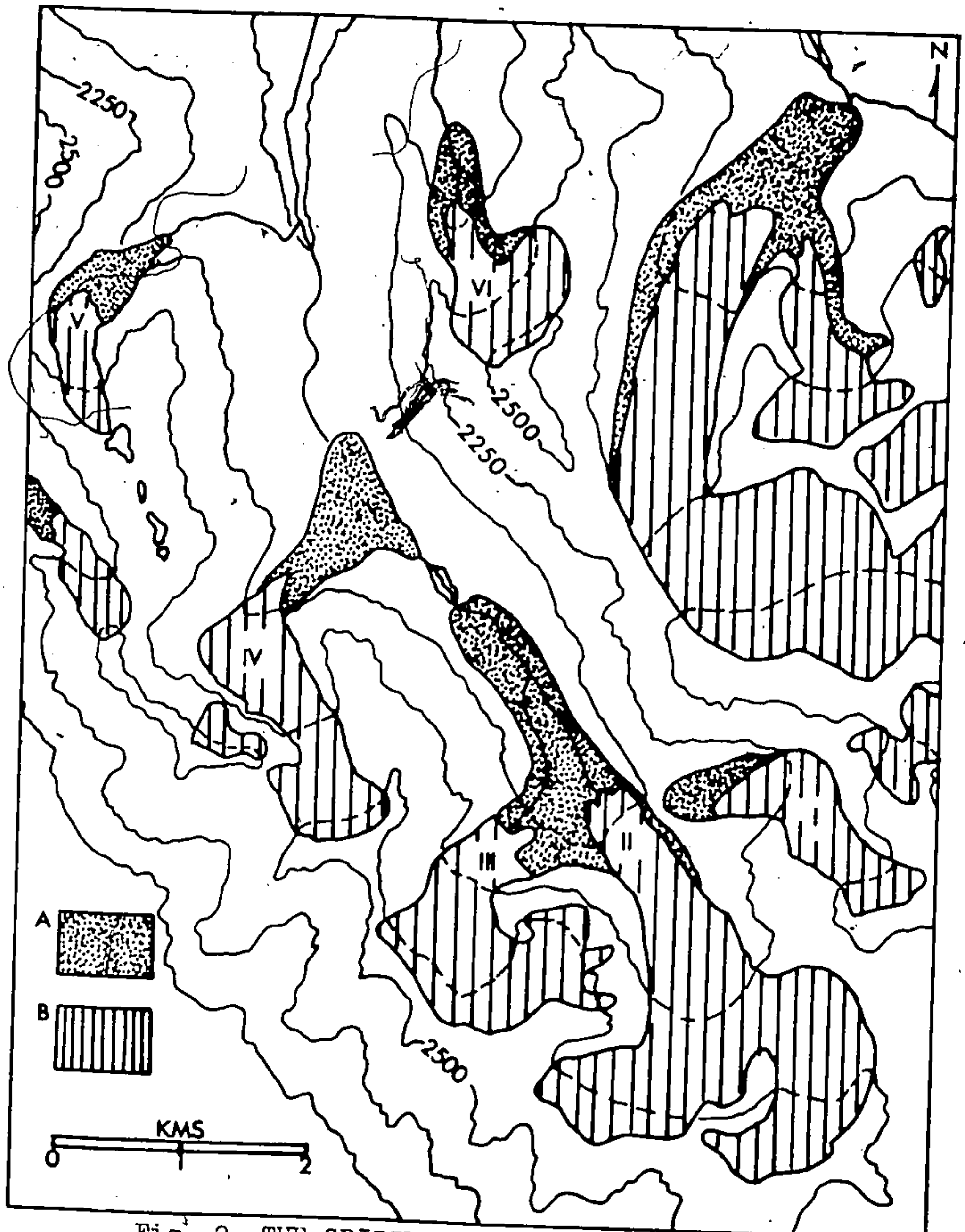

Fig. 2 THE GRIZZLY CREEK LOCALE...

(A) Neoglacial drift;
(B) Glaciers I to VI.

were unable to overrun at least not in every instance these very impressive morainic features (Denton and Karlen 1973, 1977). Thus, a record of Holocene glacier fluctuation rather more extensive than is usually the case was to be expected.

Research Objectives

(1) to describe the late Quaternary stratigraphy of Grizzly Creek, Yukon Territory, and environs.

(2) to place any defined stratigraphic sequence within a precise chronologic framework.

(3) to interpret the Grizzly Creek sequence with respect to any defined regional stratigraphy.

(4) to discuss the paleoclimatic implications of the Grizzly Creek data base. Denton and Karlen's model of Holocene climatic variability will be emphasized.

Methodology

It is the contention of this writer, following the writings of Willman and Frye (1970: 38), "that multiple hierarchies, or schemes of classification based on different sets of characteristics and criteria can and should exist side by side, entirely independent of one another". A comprehensive investigation of the late Quaternary stratigraphy of Grizzly Creek and environs was attempted and in keeping with the contention presented above a variety of classifications were utilized. The scheme ultimately proving of most use was based in morphostratigraphy with inputs from pedology and tephrochronology. Time stratigraphy provided the general framework.

Rock-stratigraphy, in many respects the mainstay of the Quaternary stratigrapher, proved untenable with regard to the investigation of the late Pleistocene and Holocene deposits of Grizzly Creek. The achievement of stated research objectives was largely dependent upon the recognition of former intervals of glacier expansion through the differentiation of units of till each representative of the advance of a particular glacier. "Rock-stratigraphic units are defined and recognized on the basis of observable lithology" (Willman and Frye 1970: 40) and the fact that no obvious lithologic differences characterized the units in question proved an obvious difficulty. In addition, the absence of substantial stratigraphic sections in the vicinity of key sites was to provide further difficulties. Another approach with an emphasis directed towards other criteria was required.

Whereas it proved extremely difficult if not impossible to delimit Grizzly Creek tills with regard to observable lithology, the accomplishment of such an objective was certainly feasible using morphology as a basis. Morphostratigraphic units are "defined as comprising a body of rock that is identified primarily from the surface form it displays" (Willman and Frye 1970: 43) and such an approach has particular utility with regard to the stratigraphic investigation of morainic systems (Willman and Frye 1970: 43-44). Indeed, much of the investigation involved the mapping of lateral moraine remnants with respect to their relative positions upon the valleyside, and the differentiation of terminal moraines comprising quite geographically restricted morainic complexes. Finally, while morphology obviously provides a very basic component of the overall classificatory scheme in question, soil and ash stratigraphy were to provide a specificity hitherto lacking. It is to a consideration of these aspects that discussion will now turn.

"A soil, as defined in stratigraphy, is a weathered zone formed in a surface or near-surface environment" (Willman and Frye 1970: 42) and with respect to the late Quaternary deposits of Grizzly Creek a consideration as to the degree of development of such zones was found to be of use. It would seem plausible that the comparison of such zones between landforms, tentatively, could lead to the establishment of time equivalence. Birkeland (1974: 258), in this regard, warns that "correlations based solely on soils do not come easily...because soils change laterally in their properties, because the factors responsible for soil morphology commonly change laterally" (i.e., a variety of environments or facies of soil formation are often characteristic of soil-stratigraphic units). Nevertheless, if the stratigrapher can achieve a measure of control over these factors, and the method is used in conjunction with other kinds of observation, a certain viability should be retained. Such would be the case if application were restricted to locales where a constancy with respect to environment could logically be assumed.

This emphasis upon degree of development of weathering profiles has utility within still another context. The "stratigraphic utility of a soil is to define an unconformable surface that can be identified and widely traced" (Willman and Frye 1970: 42) and through an emphasis upon the overall degree of development of weathering profiles one could speculate and, in association with other kinds of evidence, perhaps even obtain a crude estimate of the duration of the unconformity. This approach proved useful in relation to the tentative establishment of the limit of latest Pleistocene glaciation in Grizzly Creek, and a variety of other observations...the development of alluvial fans, the presence/absence of till, and the degree of glacial steepening of valley walls relative to position above or below such a projected limit... provided some confirmation. It would appear that a fairly substantial portion of the study area remained unglaciated during late Wisconsin time.

A prominent layer of volcanic ash deposited ca. 1460± 70 yr BP (Y-1363) (Stuiver, Borns and Denton 1969: 219; Denton and Stuiver 1969b: 175) is a characteristic of many southwest Yukon Holocene sequences, and was observed in many of the soil profiles investigated this summer. It provides a valuable time horizon because "it is everywhere synchronous" and as such, "affords a means of correlating and determining the relative age of Neoglacial drift" (Denton and Stuiver 1969b: 175). Moreover, and with regard to Grizzly Creek, its value could not be underemphasized because it represented the only means of time control available. Material both suitable for radiocarbon determination and associated with the stratigraphic sequences in question was difficult to find.

A serious difficulty then involved the placement of any defined stratigraphic sequence within a precise chronologic framework...a crucial point...as the correlation of drift sequences to the various phases of glacier expansion as outlined by Denton and Karlen was basic to the achievement of stated research objectives. Obviously, ash stratigraphy will not provide for a chronologic framework per se. The stratigrapher after all can only date deposits relative to such a time horizon and then only when intimately associated. The significance of the ash layer is best demonstrated when one realizes it effectively delimits the Little Ice Age. Stuiver, Borns, and Denton (1969: 219), in this regard, remark that a "reliable date for this ash layer will provide future workers with a limiting age for Little Ice Age deposits in this region". In effect, it provides the means to differentiate drift sequences of the Little Ice Age from those correlative to earlier intervals of Holocene glacier expansion.

FIELD RESULTS

Pre-Neoglacial Events

The Kluane glaciation defined as "the climatic episode characterized by glacial expansion, during which the Kluane tills were deposited" (Denton and Stuiver 1969a: 210) is believed to be represented in Grizzly Creek by an easily discerned and quite extensive hummocky moraine. The basis for this correlation is not derived from the exigencies of any particular absolute dating technique, but, rather, from a sequence of observation. (1) The extension of this morainic deposit downvalley from the position of the Neoglacial maximum of Grizzly Creek Glacier is considerable given the local context and as such must reflect a phase of major glaciation. (2) The rolling and hummocky character of this deposit is exceptionally well-preserved, and, in this regard, numerous high angle slopes were observed. Presumably, deposits of the earlier and more extensive phases of glaciation having been exposed to postdepositional modification for longer periods of time would not exhibit this degree of preservation. It is interesting to note that Rampton (1971: 298), in this regard, has determined quantitatively that the "average slopes on Macauley non-oriented moraines" are indeed more steeply inclined than those of the earlier and more extensive Mirror Creek glaciation. (3) Finally, the hummocky moraine in question represents the only obvious evidence for major glaciation in Grizzly Creek Valley.

The limit of the Kluane advance of Grizzly Creek Glacier, tentatively, is situated 6.75 and 7.75 km downvalley respectively from the positions of its Neoglacial maximum and present terminus. This proposed late Wisconsin limit is not marked by any easily discernible terminal moraine, and, consequently, its projection and determination were based on other kinds of observation (e.g., the general character and topographic expression of the valley, the degree of development of weathering profiles, the size of alluvial fans, and the degree of glacial steepening of valley walls relative to position above or below such a limit) and discussion will now turn to a consideration of these.

The character of the valley changes abruptly from a very discernible hummocky moraine above the projected limit to an open and obviously subdued landscape below. West (1977: 100), in this regard, maintains that gelifluction will result in a smoothed landscape, and, that such "a landscape, smoothed say, during the last glaciation in a periglacial region, contrasts greatly with the fresh landforms of the last glaciation deposits". Possibly, then, this lower reach of Grizzly Creek Valley comprised a harsh periglacial environment during the interval correlative to late Wisconsin time, and, this, in turn, might explain the apparent absence of till presumably of the earlier and more extensive phases of major glaciation below the glacial limit in question. The processes operative in such an environment effectively would have altered and masked the deposits and landforms resultant of these earlier glaciations. It is interesting to note given the immediate discussion that many of the periglacial features observed in this lower reach of the valley generally exhibited a more imposing development than those observed upvalley of the proposed glacial limit where one would expect harsher prevailing conditions.

The degree of weathering relative to position above or below the limit in question differs markedly. Soil profiles above typically exhibit shallow organic accumulations of 6-7 cm developed on till oxidized to depths of 20-25 cm, while below an extended weathering has resulted in the development of what might best be termed a thick regolith. The apparent absence of erratics in the profiles examined below the proposed glacial limit suggests primarily that such a regolith has developed in situ. This would appear a significant observation as the only obvious change in the bedrock geology in the entire valley occurs at a point situated just above and below the soil profiles under consideration and the projected late Wisconsin limit respectively. Possibly, it could be argued that such observed differences merely reflect the broad range of soil formational environments undoubtedly present within this locale rather than duration of weathering per se. However, it is difficult to envision such marked differences on this basis alone.

The development of alluvial fans with respect to position above or below the projected glacial limit is significantly different. Such features are small and constricted in appearance above, while they comprise large and imposing alluvial complexes below. It must be stressed that "many additional interrelated factors, among which are rock type, vegetation cover, steepness of slope, and climatic factors" (Vernon and Hughes 1966: 11) are related to the development of alluvial fans, and, possibly, could be invoked to explain such observed differences. Therefore, it might be stated that any consideration as to the position of this glacial limit based on relative size differences of alluvial fans necessarily is suspect. However, it becomes difficult indeed to discount the influence of a glaciation factor when consideration is given the other observations already developed. Observations concerning the size of alluvial fans relative to position above or below the limit in question then, when interpreted in this context tend only to provide additional positive support for the proposed demarcation.

Finally, glacial steepening of the valley walls was most obvious above the proposed limit. The conclusion that this lower reach of Grizzly Creek Valley remained unglaciated during late Wisconsin time would appear reasonable.

The easily discerned and quite extensive hummocky moraine apparently of the Kluane advance of Grizzly Creek Glacier for purposes of immediate discussion might better be termed an ablation complex. West (1977: 31), in this regard, indicates that a relationship exists between the sediment types comprising such complexes and effective deglaciation patterns. He states that a "downmelting in situ may produce a small amount of stratified drift, but a large amount of till, much of which may be flow till" (West 1977: 31). The ablation complex under consideration here is composed primarily of till, most of which appeared to be flow till (as per Boulton 1978, 1968). The quantity of stratified drift definitely is minimal. Also, evidence of stillstand or readvance during general deglaciation was not discovered. Therefore, one could interpret the ablation complex in question in terms of a major in situ down-melt, and, logically, it would follow that the regimen of the late Wisconsin glacier-system at this time must have been decidedly negative. Deglaciation must have proceeded rapidly.

Denton and Stuiver (1969a: 212) as discussed earlier documented at least with respect to certain glaciers in the St. Elias region recession considerable distances upvalley from current termini positions. Maximum glacier recession most probably occurred about the time of the climatic optimum and available evidence would suggest this occurred sometime within the interval 8000 to 5000 yr BP. Evidence indicative of a similar behavioural response for Grizzly Creek Glacier during the Hypsithermal was not discovered.

Neoglaciation

The Neoglacial stratigraphy of Grizzly Creek, Yukon Territory, as per stated objectives, will be (1) described, (2) placed within a chronologic framework (i.e., related to the eastern lobe of the White River ash), and (3) interpreted with respect to the regional stratigraphy. The drift stratigraphy of glaciers I, II, and III (Fig. 3) will be described and placed within a chronologic framework in sequence but interpreted in association. The relationships between these particular glaciers through the Neoglacial are quite complex... said glaciers having advanced and coalesced forming glacier complexes of varied combination on at least several occasions during the Neoglacial. Glaciers IV, V, and VI (Fig. 3) have existed as independent glacier-systems throughout Neoglacial time and their associated drift stratigraphies will be presented and interpreted accordingly.

Glacier I, II, and III

Neoglacial drift extends approximately 400 meters downvalley from the current terminus position of glacier 1. Three advances variously represented by a massive, ice-cored

Fig. 3 The Grizzly Creek Locale

moraine (Fig. 4 IA) devoid of lichen and vegetation, and two bench-like features (Fig. 4 IB and IC) composed of quite compacted till and characterized with extensive lichen and vegetation development were differentiated. Moraine IA on the basis of morphology (i.e., this morainic feature is massive and obviously ice-cored), an absence of lichen and vegetation, proximal position within the morainic sequence, and a similarity in these respects with moraine IIA (Fig. 4) which is associated with a radiocarbon date of 200±100 yr BP (Johnson 1979: personal communication) is believed to be of the Little Ice Age. The fact that lateral moraine IB and IC appear to have undergone similar degrees of down-wastage and exhibit approximately the same degree of lichen and vegetation development suggests a close age-relation between these morainic features. The fact that moraine IC is associated with the eastern lobe of the White River ash would indicate considerable antiquity, and, in this regard, moraine IC and possibly moraine IB are of a Holocene glacier expansional interval other than the Little Ice Age.

Neoglacial drift can be traced approximately 1000 meters downvalley from the present terminus position of glacier II. Tentatively, three advances represented by a sequence of lateral moraines (Fig. 4 IIA, IIB, and IIC) all of which are essentially devoid of lichen and vegetation have been recognized. Moraine IIA is massive and ice-cored and

Fig. 4 Neoglacial Drift Sequences Assoc. With Glaciers I, II, and III. Refer to text for discussion.

can be traced along both east and west sides of this upper reach of the valley. The association of this morainic feature with a radiocarbon date of 200±100 yr BP (Ibid.) obtained from organic material overrun by this moraine indicates a Little Ice Age derivation. Moraine IIB was almost completely overrun during the advance represented by moraine IIA, and, consequently, occurs only as isolated remnants of lateral moraine situated at a slightly higher elevation than moraine IIA and only on the east side of the valley. It was during the advance represented by moraine IIB that a talus-derived rock glacier (Fig. 5 a) the former position of which is indicated by its characteristic levee features (Fig. 5 b) was truncated. In this regard, note the levee features (Fig. 5 c) associated with the talus-derived rock glacier located further downvalley (Fig. 5 e). A deposit of talus situated immediately above moraine IIB is all that remains of this truncated rock glacier form. The angle of repose of this talus deposit could only be described as unstable, and the fact that moraine IIB has not been overrun as yet would indicate its relatively recent derivation. It is felt that moraine IIB represents an advance which occurred during the Little Ice Age. Moraine IIC is represented by an isolated terrace feature situated on the east side of the valley at a still higher elevation than moraine IIB. Moraine IIC has almost been completely overrun by talus but can be traced laterally as a slight perturbation

Fig. 5 Photograph Illustrating Relationships of Neoglacial Drift Sequences Assoc. with Glaciers I, II, and III to Rock Glaciers a and e. Refer to text for discussion.

within the talus fans flanking it. Assuming continuity with respect to the gradient of this small valley glacier through the Neoglacial this particular lateral moraine remnant was projected downvalley (Fig. 6 Projection 2) in an effort to determine the approximate terminus position of this glacier at the time of moraine emplacement. It is of interest to note that such a projection lies just the downvalley side of the talus-derived rock glacier (Fig. 5 e) which moraine IIA has so obviously cut into (Fig. 5 d). This suggests that the considerable volume of debris comprising this rock glacier form was originally deposited as a terminal moraine during the advance represented by moraine IIC. The talus-derived flow form derives its "material content from talus slopes on the valley side" (Johnson 1978: 1503), not, as is suggested in this particular case, through glacial process. The characteristic levee features of this rock glacier type (Fig. 5 c) indicate that a talus-derivation is indeed important, however, it would appear at least in this instance that a glacial-derived component is of importance too. The possibility that this particular flow form is of multiple origin, a composite, must not be discounted. At any rate, the intimate association of this debris landform with the eastern lobe of the White River ash would suggest considerable antiquity for this advance. It would appear that moraine IIC is derivative of a Holocene expansional interval other than the Little Ice Age.

Fig. 6 Projection 1...Little Ice Age Maximum (Glaciers II and III); Projection 2...Neoglacial Maximum (Glaciers I, II, and III); Projection 3...Representation of Downvalley Projection (Parallax Technique) of Small Terrace Feature (x) Composed of Till. (The significance and relationship of this feature to the Neoglacial drift sequences discussed has not yet been determined).

No obvious morainic complex fronts glacier III, and, consequently, it is much more difficult to achieve insight into its behaviour during the Neoglacial. Nevertheless, evidence does exist which suggests that this small cirque glacier has been behaving in accordance with the fluctuations of glacier II. In this regard, note the upward orientation of moraine IIA, IIB, and IIC (Fig. 4 b). The implication is that glacier III, during the intervals of time correlative with the advances represented by moraines IIA, IIB, and IIC, has advanced and merged with glacier II. The compressional forces set up during these advances were of sufficient magnitude to cause a local expansion of ice of glacier II at point b in Fig. 4, and which resulted in the upward orientation of these moraines.

The position of lateral moraine IC at the junction of its associated tributary valley and the main trunk valley occupied at this point by glacier II (Fig. 4) indicates the confluence of these glaciers during the advance represented by this moraine remnant. The elevation of moraine IC above lateral moraine IIA (Fig. 4) suggests that moraine IIC, which is elevated a similar distance above moraine IIA, is representative of the same glacial advance. The upward orientation of moraine IIC (Fig. 4 b) as discussed above indicates further that glacier III was coalescent at this time too. The down-valley projection of moraine IIC as discussed earlier suggests that this glacier-complex extended to just the downvalley side of the rock glacier outlined in Fig. 5 (Fig. 5 e), and, this, in turn, suggests that the bulk of this debris landform was originally emplaced as a terminal moraine during this particular advance. The relation to tephra of moraine IC and the rock glacier form just discussed indicates that this particular advance occurred during a Holocene glacier expansional interval other than the Little Ice Age. Also, it would appear the Neoglacial maximum was reached during this particular expansional interval. Moraine IB with respect to morphology and lichen/vegetation cover is felt to be approximately the same age as moraine IC, and, if so, may be interpreted as minor recession followed by readvance during this expansional interval.

Major recession to at least current terminus positions (refer to Fig. 4) and in all likelihood to positions located still further upvalley followed the Neoglacial advances just discussed. The formation of the talus-derived rock glacier outlined in Fig. 5 (Fig. 5 a) would suggest that considerable time elapsed before the intense advances of the Little Ice Age which it is felt were responsible for the truncation of this rock glacier form (Fig. 5 a) occurred. The continuity of the characteristic levee features of this particular rock glacier type (Fig. 5 b) obviously has not been disturbed until recently. Such features progress uninterrupted past the point where one would have expected truncation by the advance represented by moraine IIC, and although not readily apparent in either Fig. 4 or Fig. 5 moraine IIB and IIA of which both are believed to be of the Little Ice Age are clearly discernible at the truncation point. The rock glacier form in question very likely developed during the Holocene contractional phase immediately preceding the Little Ice Age.

The upward orientation of moraine IIB as indicated in Fig. 4 (Fig. 4 b) suggests as discussed earlier that glacier III was confluent during the advance represented by this moraine. It was not possible to determine whether glacier I was confluent at this time.

Moraine IA on the basis of its distinctively similar morphology and a complete absence of lichen and vegetation development as discussed earlier is considered correlative with moraine IIA. The association of moraine IIA with a radiocarbon date of 200±100 yr BP (Johnson 1979: pers. comm.) would indicate that this moraine at least is of the Little Ice Age. The Little Ice Age maximum of both glacier I and II then appears to have been attained during the advances represented by these moraines, and, obviously, these glaciers would not have been coalescent at this time. In effect, the possibility that moraine IA marks the Little Ice Age maximum of glacier I would indicate that coalescence of this glacier with glacier II never occurred during the Little Ice age. The upward orientation of moraine IIA at point b in Fig. 4 however indicates that glacier III very well may have been confluent at this time, and, effectively, the fact that the west lateral component of moraine IIA can be traced up to and almost alongside glacier III (Fig. 4) confirms such a contention.

Glacier IV

Neoglacial drift extends approximately 1000 meters downvalley from the present terminus position of this cirque glacier, and, with reference to stated research objectives, a massive and predominantly ice-cored morainic complex comprised the most interesting feature of this drift sequence. Five advances represented respectively by moraines IVA to IVE (Fig. 7) were recognized. Moraine IVA is massive and ice-cored, and merges with easily defined lateral moraines which extend back and up into the associated cirque. This particular moraine on the basis of the morphology just described, a complete absence of lichen and vegetation, its proximal position within the morainic complex, and a marked similarity in these respects with moraine IIA which is associated with radiocarbon control is also assigned to the Little Ice Age. The orientation of moraine IVA within the complex proper is of interest. It appears to have been deflected off to one side an indication of the formidable mass of this predominantly ice-cored morainic complex. Moraine IVb was almost entirely overrun during the emplacement of moraine IVA,

Fig. 7 Neoglacial Drift Sequence Assoc. With Glacier IV.

and, in this regard, is composed largely of extensively disturbed and overturned clumps of ground. This moraine as evidenced by its remaining lichen/vegetation cover must have been characterized with what might best be described as a moderate lichen and vegetation development. Moraine IVB was not associated with White River ash, and, consequently, is believed to be of the Little Ice Age. Moraines IVC, IVD, and IVE are all massive and ice-cored, and are all characterized with quite complex vegetation associations and extensive lichen cover. The fact these latter moraines were all associated with White River ash indicates they are part of a Holocene expansional interval (s) other than the Little Ice Age. Moraine IVE exhibits a greater degree of down-wastage than moraine IVD and for that matter moraine IVC, and the implication is that moraine IVE is considerably older. It is possible however that such down-wastage is related to differential ablation of respective ice-cores. Moraine IVE is located on the periphery of the complex proper and as such is not as well-insulated, and also subject to greater rates of basal erosion from Grizzly Creek which must have impinged upon the base of this particular moraine on various occasions during the past. The lateral moraine x_1 (Fig. 7) because of its similar lichen and vegetation development, its relation to tephra, and the fact it has been truncated during the advance when moraine IVC was emplaced is felt to be associated with moraine IVD. The lateral remnant x_2 because of a distinctive similarity with respect to degree of obvious down-wastage is felt to be associated with moraine IVE.

The relation to tephra of moraine IVE, IVD, and IVC indicates they are part of a Holocene expansional interval (s) other than the Little Ice Age. Whether these moraines are representative of the same or several expansional interval (s) could not be determined. However, evidence which will be elaborated upon shortly suggests these moraines are part of the same expansional interval. Treating this last statement as a postulate the following interpretation can be presented. The Neoglacial maximum of this cirque glacier was reached during the advance represented by moraine IVE. Minor recession followed by readvance on at least two occasions is represented respectively by moraine IVD and IVC. Considerable time as indicated by the relation to tephra of these particular moraines elapsed before the intense advances of the Little Ice Age believed to be represented by moraine IVB and IVA set in. This hiatus in time very likely is representative of a Holocene glacier contractional interval possibly the recessional phase immediately preceding the Little Ice Age. It was not possible to determine the actual extent of glacier retraction during this time interval.

Glacier V

Neoglacial drift extends approximately 500 meters downvalley of the present terminus position of this small cirque glacier. Four advances of this small cirque glacier represented respectively by moraines VA through to VD (Fig. 8) were discerned. Moraine VA comprises terminal and lateral components of which all are massive, ice-cored, and devoid of lichen and vegetation. Similarity in these respects with moraine IIA which undoubtedly is of the Little Ice Age suggests that moraine VA is of Little Ice Age origin too. Moraine VB comprises an obvious lateral moraine remnant which merges with what appears to be a terminal moraine. The somewhat greater antiquity of this moraine with relation to moraine VA is indicated by its more distal position within this sequence, and by what might best be termed an incipient <u>Rhizocarpon</u> growth. Moraine VB is felt to be of Little Ice Age origin also. Moraines VC and VD possibly could be described as 'plugs' of moraine the result no doubt of narrowing at these points within this tributary valley. The lichen and vegetation development of both moraine VC and VD could only be described as extensive with complex vegetation associations and considerable lichen cover being observed. White River ash was not observed in association with these moraines, and, as a result, a definite statement as to derivation was not possible. However, the marked similarity between this drift sequence and that of glacier IV, which has been related to the deposition of the eastern lobe of the White River ash (i.e., moraines IVC, IVD, and IVE are associated

Fig. 8 Neoglacial Drift Sequence Assoc. With Glacier V.

with tephra), suggests the possibility that moraine VC and VD too are of a Holocene expansional interval other than the Little Ice Age.

Glacier VI

Neoglacial drift extends approximately 500 meters downvalley from the present terminus position of this small cirque glacier. Two advances represented respectively by moraines VIA and VIB (Fig. 9) were recognized. Moraine VIA is massive, ice-cored, and devoid of lichen and vegetation. Its distinctive similarity in these respects with moraine IIA which undoubtedly is of the Little Ice Age suggests that moraine VIA also is a part of this most recent Holocene expansional interval. Moraine VIB is extensively vegetated and consideration of this in addition to its outermost position within this drift sequence indicates greater antiquity. Whether volcanic ash is or is not associated with this latter morainic feature was not determined, and, consequently, a definite statement as to derivation was not possible. However, the fact that all of the Neoglacial drift sequences examined this summer exhibited Little Ice Age moraines fronted by or nested within obviously much older Holocene moraines of which many were intimately associated with volcanic ash and as such obviously of a Holocene glacier expansional interval other than the Little Ice Age suggests the possibility that moraine VIB is as well.

Fig. 9 Neoglacial Drift Sequence Assoc. With Glacier VI.

PALEOCLIMATIC IMPLICATIONS AND DISCUSSION

Gradual vs Abrupt Climatic Change

Denton (1974: 890) points out that the Laurentide and Cordilleran ice sheets were "at or near late Wisconsin maximum positions as late as 14,000 yr B.P." and that both underwent major recession shortly thereafter. The Laurentide ice sheet needed approximately 8000 years to undergo complete deglaciation, whereas the Cordilleran which was approximately half the size required only 4000 years. The immense ice volume, and consequently the extended melt period of the Laurentide ice sheet, is obviously a factor to be considered. The inertia of this vast glacier-system which undoubtedly resulted in its preservation for some time despite the magnitude of any documented climatic amelioration must also be given consideration. The implication is that the smaller a glacier-system the more immediate its dynamic response, and, as such, the better its ability as a paleoclimatic medium to reflect the reality of a climatic event.

The St. Elias glacier-complex attained its late Wisconsin maximum about 14,000 yr BP, and underwent major recession very soon thereafter. This glacier-complex, smaller still than the Cordilleran ice sheet, required 1500-2700 years to dissipate. Deglaciation, then, as evidence from the northeast St. Elias Mountains would suggest, appears to have been a rapid event. The significance of this statement, although not immediately apparent, is perhaps best appreciated when one realizes it may have a direct bearing upon "the important question of whether major glacial-interglacial climatic changes can occur abruptly" (Denton 1974: 890). Denton, in this regard, maintains that such a concept at least "deserves serious consideration" (1974: 890).

Generally, traditional notions concerning late Wisconsin glaciation of the northeast St. Elias Mountains have embodied the idea that all valleys, especially those peripheral to the icefield today, were occupied in their entirety by glacier ice. Logically, such notions are derived from the concept of a vast and coalescent late Wisconsin glacier-complex, which is believed to have dominated the regional landscape at this time. Therefore, the discovery that the Grizzly Creek valley glacier during late Wisconsin time may never have merged with this regional glacier-complex, but, rather, functioned as an independent glacier-system was interesting. This is of interest from two points-of-view. First, such a determination challenges the traditional concept of glaciation for this region. Second, such a discovery may prove useful with respect to the question of abrupt climatic change.

The valley glacier-system occupying Grizzly Creek during late Wisconsin time was substantially smaller than the St.

Elias glacier-complex which underwent deglaciation over at most 2700 years and possibly in as little time as 1500 years. The most obvious question which emerges at this point relates to the time which would have been required for the Grizzly Creek valley glacier to have undergone deglaciation. Field evidence as discussed earlier suggests that locally deglaciation did indeed proceed rapidly. However, the determination of the actual time involved remained a problem. Shallow accumulations of peat, which very likely interface with till, occupy many of the depressions associated with the Grizzly Creek hummocky moraine. A sequence of radiocarbon dates obtained from such organic deposits immediately overlying till, and collected along a transect or series of transects extending upvalley from the proposed local late Wisconsin limit, may provide insight to this question. If the range between these dates proved to be narrow (speculatively from 500-1000 years) then it could be concluded that the concept of abrupt climatic change must be given serious consideration.

Holocene Climatic Variation

The stratigraphy and chronology of the Neoglacial drift sequences presented indicates minimally that two phases of Holocene glacier expansion are represented in Grizzly Creek Valley (i.e., the Little Ice Age and at least one earlier Holocene expansional interval). Perhaps the most obvious question which may be raised at this point questions which earlier Holocene glacier expansional interval (s) is (are) in fact represented. Denton and Karlen (1973: 155) predict glacier expansion, with intervals of contraction between, peaking at "200-330, 2800,...5300..., 7800, 10,300, 12,800 and 15,300 calendar yr BP" and so forth. Evidence exists, which, although inconclusive, suggests that the earlier expansional interval represented is that which culminated approximately 2800 yr BP. With regard to this latter point, further discussion is warranted.

Kluane/Macauley deglaciation "began about 13,660 C^{14} yr BP...and glaciers had receded rapidly to their present positions before 11,000-12,500 C^{14} BP" (Denton and Karlen 1973: 173). The expansional interval, which culminated 15,300 yr BP, then, occurred superimposed upon a late Wisconsin glacial maximum and therefore can be ruled out.

The glacier expansional intervals culminating 12,800 and 10,300 yr BP cannot be discounted with such ease. However, it could be stated that their representation in this locale is highly unlikely. The small valley and cirque glaciers of Grizzly Creek may have receded to approximately the positions they now occupy by 12,800 yr BP, and, certainly, to at least such positions by 10,300 yr BP. A glacier expansional interval occurring approximately concurrently then could have resulted in the emplacement of moraines in the very locations where such features were observed during the summer of 1979. However, the fact that most of the moraines in question are obviously ice-cored, and associated slopes are still relatively unstable, suggests a more recent derivation. Presumably, morainic deposits of the very early expansional intervals would not be so characterized. In this regard, one would expect a substantial, if not a complete, wastage of any associated ice core and a much greater degree of slope stability.

Denton and Stuiver (1969a) have documented, at least with respect to certain glaciers in this region, recession considerable distances upvalley from current termini positions. Maximum glacier recession most probably occurred at approximately the time of the climatic optimum, and available evidence suggests that this occurred sometime within the interval 8000 to 5000 yr BP. Evidence indicative of a similar behavioural response for the Grizzly Creek Glacier was not discovered. However, when consideration is given the magnitude of the climatic amelioration involved, the assumption that Grizzly Creek Glacier did in fact respond at this time with considerable recession upvalley from its current terminus position does not seem unwarranted. The expansional intervals culminating 7800 and 5300 yr BP then would have occurred as fluctuation superimposed upon extended glacier retraction. Moraines of these glacier expansional intervals would then logically have been deposited upvalley of, or at least in the vicinity of, current termini positions. They would then have been easily overrun subsequently by glacier advances derivative of the expansional intervals culminating 2800 and 200-330 yr BP. These two most recent expansional phases occurred superimposed upon the longer term trend of secular cooling which has characterized the latter Holocene and as a result were much more extensive.

The rationale presented above suggests that the earlier expansional phase in fact represented is that which culminated 2800 yr BP. In this regard, it may be highly significant that the oldest Holocene moraines discovered in this region date to this expansional interval. In addition, and with regard to St. Elias Neoglacial sequences, whenever it has been demonstrated that a particular moraine predates the deposition of the eastern lobe of the White River ash, and many of the moraines investigated this summer clearly did, radiocarbon dating when associated inevitably has bracketed such moraines within this expansional interval.

Conclusion

The data derived during field research at Grizzly Creek provide support for Denton and Karlen's model concerning Holocene climatic variability. However, it was not possible to derive a definitive statement in support of their model. There were severe difficulties involved in the establishment and association of a precise chronologic framework. This problem substantially precluded the complete fulfillment of research objectives. The Grizzly Creek moraines were only datable relative to the deposition of the eastern lobe of the White River ash an event which occurred approximately 1400 yr BP. Consequently, it could only be stated that two phases of Holocene glacier expansion minimally are represented in Grizzly Creek Valley. Moreover, and after having assumed continuity with the regional stratigraphy, it was suggested that the expansional intervals represented were those which culminated ca. 2800 and 200-330 yr BP respectively. Numerous other scenarios, however, are possible. For example, five moraines comprise the morainic complex associated with glacier IV. The possibility, however unlikely, that each is derivative of a major expansional interval effectively out-of-phase with the model under consideration must not be discounted. The difficulties involved in the establishment and association of a precise chronologic framework cannot be underemphasized. Denton and Karlen's approach emphasized the examination of "moraines fronting numerous glaciers to discover situations where older moraines were preserved" (Denton and Karlen 1973: 173). Their approach could be modified to restrict such examination to situations where the probability of establishing a precise chronologic framework is high.

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