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ABSTRACT

Glaciation is schematically considered as a perturbation of "normal" fluvial conditions. Drift is unstable in a proglacial or postglacial fluvial environment, resulting in heightened sediment movement that continues as long as drift material remains easily accessible for fluvial erosion and transportation. Sediment yield bears no relation to concurrent primary production of weathered debris.

Examples of such "paraglacial" denudation and sedimentation are reported from two contrasting areas. Postglacial valley alluvial deposits are widespread in central Baffin Island where rapid sedimentation continues today; estimated denudation rates are an order of magnitude higher than in comparable unperturbed areas. In south-central British Columbia, rapid sedimentation during the paraglacial period contrasts sharply with present-day conditions.

DEFINITION

The term "paraglacial" is introduced to define nonglacial processes that are directly conditioned by glaciation. It refers both to proglacial processes, and to those occurring around and within the margins of a former glacier that are the direct result of the earlier presence of the ice.

It is specifically contrasted with the term "periglacial," which does not imply the necessity of glacial events occurring (*see* the discussion by Tricart *in* Fairbridge, 1968, p. 829). The term "paraglacial" has previously been introduced by Ryder (1971a, 1971b), but was not critically defined there.

In this paper the term is used, additionally, as an adjective of time; such as, "paraglacial period," to define the time during which paraglacial processes occur.

INTRODUCTION

Glaciation introduces an abrupt and radical change in a terrestrial erosional environment. The magnitude, duration, and extent of erosional forces beneath a glacier are altogether different from those that occur in the more usual, subaerial environment, and the resulting patterns of sediment production and movement are highly disparate. Glaciation produces a large amount of detrital material that is left in the form of glacial drift. While this material may have reached a position of stability with respect to the glacial environment (that is, deposition at the ice margin), it usually is not stable with respect to the succeeding fluvial environment.

Large volumes of drift may be appropriated by proglacial rivers and transported away at rates far in excess of "normal" material supply by subaerial weathering processes. This condition is not restricted to proglacial situations: heightened sediment movement will continue as long as drift remains easily accessible to fluvial activity. The extraordinary sediment transfer during this time results in many fluvial deposits that represent temporary storage areas for material. The occurrence of many alluvial cones and fans, in particular, indicates the lack of complete integration of the fluvial sediment transporting system. Sediment yield during periods as long as several thousand years bears no relation to contemporary production of weathered material. Little direct emphasis has been given to these special, "paraglacial" effects, directly conditioned by glaciation and occurring in the transition from one environment to the other.

The broad relation between glaciation and fluvial sediment movement has been considered by many writers. Broecker and others (1958) have shown that gross sedimentation rates are generally much higher during glacial periods

than during interglacial times. Tricart (1952), Frye (1961), and Embleton and King (1968) have discussed various relations between glacier activity and outwash sedimentation. The distinction among several possible schemes probably depends on climate and glacier regimen. Zeuner (1959) has examined the nature of fluvial activity in periglacial environments, while other studies (*notably* Frye, 1961; Tricart and Lilliès-Lacroix, 1962) have discussed the development of alluvial fills in nonglacial regions during Pleistocene times. Schumm (1965) and Tricart (1966) have provided systematic summaries of the development of such "climatic terraces."

Paraglacial sediment movement has been investigated in two areas: a region of east-central Baffin Island, N.W.T., where glaciers are still present and where paraglacial sedimentation is still highly active (Fig. 1); and a region in south-central British Columbia (Fig. 6) where deglaciation occurred some 10,000 yrs ago, and the process of relaxation after the glacial event should be nearing completion or should have passed it. Following the presentation of the field data, some comparisons are made with other relevant data from the literature.

Gage (1970) has noted that data derived from short-term observations—as was the case with most of the data given in the paper—may be very misleading when applied to changes over geological spans of time. Average rates may also mask a complex structure of real events. This will be particularly so when the actual generating events involve "thresholds" of significant activity (as of sediment motion in a stream), and when the true structure of the duration-frequency series of events is unknown (*compare* with Tricart, 1962). With these restrictions in mind, the paper concludes with some speculations concerning the general nature of paraglacial processes.

PARAGLACIAL SEDIMENTATION IN EAST-CENTRAL BAFFIN ISLAND

Valley alluvium is a prominent post-glacial feature of the Canadian Arctic. It is composed of coarse sands and gravels, with frequent cobble beds. Braided streams characterize
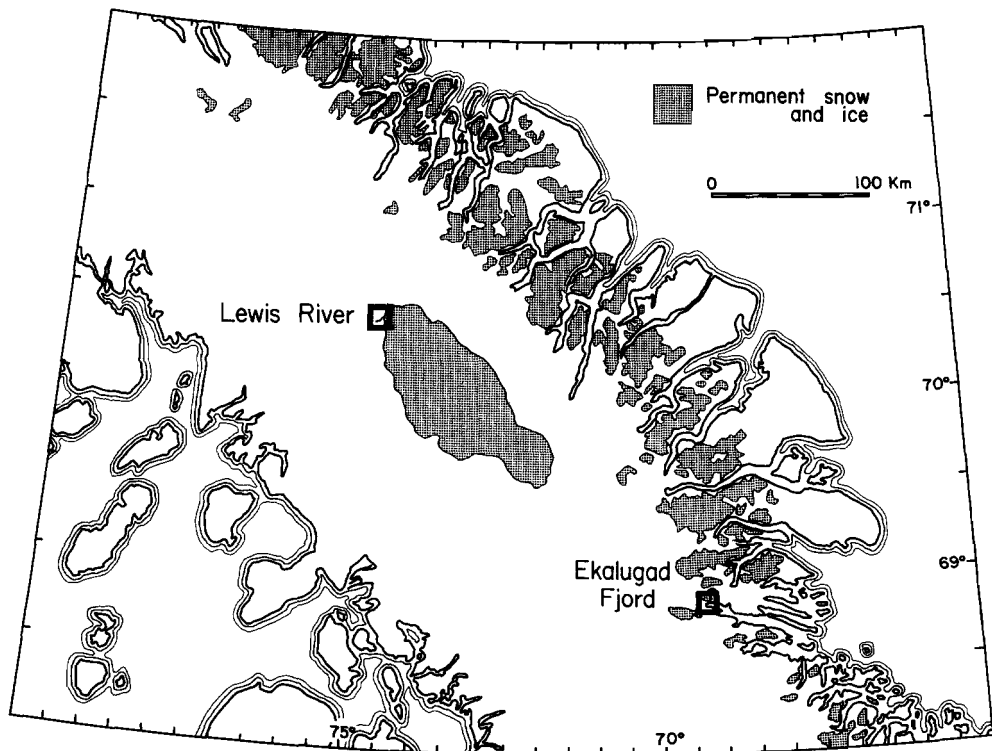

Figure 1. Location of field sites in central Baffin Island.

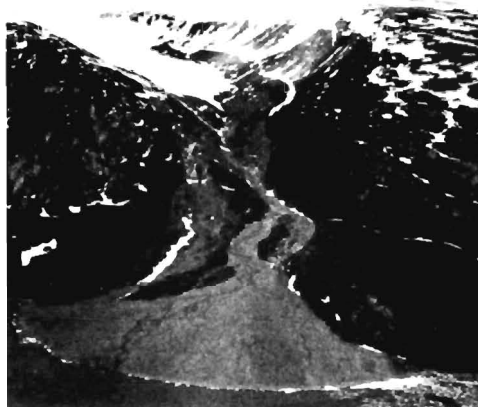Figure 2. Alluvial cone at Nudlung Fjord, Baffin Island.

Figure 3. Alluvial fan at Ekalugad Fjord, Baffin Island.

Figure 4. Alluvial plain at Ekalugad Fjord; the dark surface is an earlier alluvial plain dating from about 5,700 yrs B.P.

presently active surfaces. The deposits range from alluvial cones, which exhibit surface gradients in excess of 20°, and upon which mass movements may also be important (Fig. 2), through alluvial fans (Fig. 3), to large alluvial plains (Fig. 4) and deltaic deposits in lakes or the sea.

Many of the older deposits appear to be of greater extent than the recent ones. Such deposits probably date from the period of most rapid reduction of late-glacial ice, commencing sometime after 9,000 yrs B.P. (*compare* date and discussions in Falconer and others, 1965, and Blake, 1966) and extending through the hypsithermal interval. Nevertheless, considerable activity still occurs, particularly in watersheds where glaciers still exist. Measurements of present sediment transport in the rivers, and of the total volume of sediments have been made at two sites in east-central Baffin Island (Fig. 1). One site, at Lewis River, at the northwest corner of the Barnes Ice Cap (70°24′ N., 74°53′ W.), is in direct proglacial position. The other, at Ekalugad Fjord on the Home Bay coast (68°50′ N., 69°20′ W.), is at the confluence of three watersheds with contemporary ice cover occupying between 11 and 49 percent of the total area (Table 1). The rocks at Lewis River are Precambrian granite gneiss, whereas at Ekalugad Fjord, metamorphosed Precambrian sediments occur.

Summary data of sediment transport are given in Table 1. Of course, not all of the sediment moved within the watershed passed the gauging points on the valley alluvial plain; and in any event, the results of one or a few seasons' observations are not likely to be representative of long-term yields. Yet the results indicate the order of magnitude of sediment movement.

Another measure of sediment movement is the total volume of sediment contained in the recent alluvial deposit at Ekalugad Fjord. Radiocarbon evidence (Andrews, 1969) indicates that deposition commenced not more than 4,000 yrs ago, while regional evidence suggests that most activity has occurred during the last 2,000 yrs since an early neoglacial period. The plain has advanced 1,300 m into the fjord, indicating progression at a rate of less than 0.65 m/yr on a 1.5-km front. Total volume of sediment, as determined from electrical resistivity profiling for depths of unconsolidated materials, soundings in the fjord to estimate the thickness of the outwash wedge,

TABLE 1. CHARACTERISTICS OF AND SEDIMENT YIELD FROM BAFFIN ISLAND WATERSHEDS

Basin	Total area of watershed (km²)	Proportional ice-cover (percent)	Basin relief (m)	Annual runoff (cm depth)	Annual specific sediment yield* (metric tons/km²)	Equivalent denudation rate (mm/1,000 yr)
Lewis River	205	89	735	59	735[†]	280
Ekalugad Fjord:						
North Valley	189	11	1,060	62	720[§]	270
Middle Valley	106	15	865	54	610[§]	230
South Valley	90	49	1,025	62	1,170[§]	440
Total watershed	385	21	1,060	60	790[§]	300

*Dissolved and suspended sediment load were sampled directly (several times weekly for the former; several times daily for the latter) throughout the runoff season between late June and late August. Sediment concentration was determined by usual laboratory procedures. Bed load was computed using the Meyer-Peter and Müller (1948) formula, modified for actual threshold conditions in the sections for which computations were made. Threshold conditions were determined from direct bedload sediment transport measurements using a basket-type sampler at low and moderate flow levels. Continuous discharge records, derived via stage recordings and discharge rating curves, were used to estimate total sediment discharge from the sample measurements. See Church (1972) for further details.

[†]Mean of three years' data, 1963–1965; in 1964, measurements ended 2 weeks before the end of the runoff season and the results were not adjusted.

[§]One season's data only: 1967. North Valley results include estimated bedload sediment transport.

and projection of valley side morphology to determine the shape of the wedge, is about 1×10^8 m³. This represents an annual sediment delivery of between 2.5 and 5×10^4 m³, or 150 to 300 metric tons/km² of the total contributing watershed (assuming a bulk density of 2.25 for the sediment) (Church, 1972). This probably accounts for about 75 percent of total delivery (suspended sediment load would not come to rest on the delta, while some material will have remained on the alluvial plain), so that 200 to 400 metric tons per annum, or about one-half of the amount indicated from the 1967 observations presented in Table 1, appears to represent an upper limit for average delivery. The apparent disparity of the two estimates may be somewhat reconciled if it is recalled that much of the past 2,000 yrs has been cooler than the present, so that fluvial activity during this period would have been somewhat less than that of today (Ives, 1962).

An interesting comparative measure of sediment movement and deposition in Ekalugad Valley in earlier postglacial time is obtained from consideration of an old alluvial plain (Fig. 4), deposited during the final retreat of late Wisconsinan ice from the valley (Church, 1972). J. T. Andrews (1969) has provided a radiocarbon chronology for the development of this outwash plain. Construction commenced about 5,700 yrs B.P., when the ice began to retreat from valley-head moraines, and was essentially complete by 4,300 yrs B.P. During this 1,400-yr span, between 4 and 5×10^8 m³ of sediment was delivered to

the plain, for an average annual delivery of about 3.0 to 3.5 × 10⁵ m³ of sediment. While comparison with recent events cannot be made complete, as it is uncertain what the contributing drainage area (largely glacier surface) or the magnitude of discharges were at that time, it is nevertheless evident that sediment yields were much higher than in recent times (*compare* the rate of 2.5 to 5 × 10⁴ m³/yr for the last 2,000 to 4,000 yrs, quoted above).

A further aspect of the relation between the older surface and the contemporary alluvial plain illuminates the role of base-level changes in paraglacial sedimentation. The usual isostatic uplift following removal of the glacial load, adjusted for eustatic effects, produced 23 m of emergence during the active life of the old alluvial plain. Another 20 m of emergence has subsequently occurred (Andrews, 1969). The old surface appears to have continuously regraded itself during its life, so that redistribution of sediment on the surface must have occurred. During the last 4,000 yrs at least 0.5 × 10⁸ m³ of material has been eroded from the old deposit: this represents just one-half of the total amount of material incorporated in the contemporary alluvial plain. Much material moved during later phases of the paraglacial period therefore may not be derived directly from glacial deposits at all.

In the Ekalugad area, there is an apparent relation between the fraction of a watershed presently covered by glaciers and sediment yield (Fig. 5). Such a relation might be affected by variations in total runoff among the different
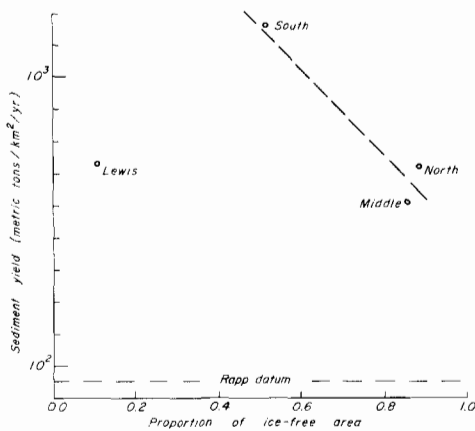
Figure 5. Relation between proportional ice cover and sediment-removal rate.

Figure 6. Location of study areas in south-central British Columbia.

watersheds, but this does not appear to be a factor in the present case (*see* runoff data in Table 1).

PARAGLACIAL SEDIMENTATION IN SOUTH-CENTRAL BRITISH COLUMBIA

Since the final recession of Pleistocene glaciers 10,000 yrs ago (Fulton, 1971), the trunk valleys of the region have been the site of as much as 175 m of deposition under paraglacial conditions. Although some beds of till are present within the sequence, they constitute only a small proportion of the total volume of material and present minor glacial fluctuations. Within the areas of detailed study (Fig. 6), recent degradation by the Fraser and Thompson Rivers has led to the dissection of the valley-fill sediments and the formation of extensive sections where detailed observations were carried out. Where natural sections are scarce, data from well logs were utilized.

Three major types of nonglacial sediments occur: (1) alluvial fan sediments deposited as debris flows or fluvial gravels derived from tributary valleys (Fig. 7) are common in all five of the areas investigated; (2) fluvial sediments deposited by trunk rivers (Fig. 8) predominate in Fraser, Bonaparte, and Similkameen Valleys and the lower 25 km of Thompson Valleys; and (3) lacustrine sediments of proglacial lakes are extensive in the remainder of Thompson Valley and along a 20-km stretch of Fraser Valley near Lillooet.

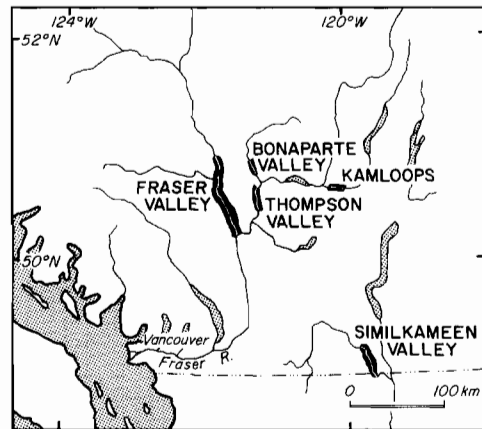Paraglacial alluvial fans were constructed from reworked drift concurrently with the general aggradation of valley floors by trunk streams. In general, the proportion of mud-flow gravel is higher in fans that originated from small, steep basins, while fluvial gravels predominate in fans from larger basins with perennial streams. However, in places, the character of available drift strongly influenced the mode of deposition. For example, mud-flow and debris-flow deposition were most common where suitably fine-textured "mud" matrix was present as glacio-lacustrine silt or as silty or clayey till. The thickest debris-flow beds (as much as 3 m in thickness) occur in the lower part of the fan sequences. They indicate the relatively greater magnitude of mud-flow events during the early part of the paraglacial period.

There is little evidence of fan deposition today and degradation is occurring along many of the major valleys rather than aggradation. The Fraser and Thompson Rivers have eroded down through the valley sediments as much as 225 m. Minor degradation and fan-head trenching have occurred in the other valleys. The dissection may be chiefly attributed to reduction of sediment supply toward and after the end of the paraglacial period.

The Mazama ash bed of 6,600 yrs B.P. (Wilcox and Powers, 1964) was found (and identified mineralogically) in fans throughout the region (except in Fraser Valley), providing an excellent time-stratigraphic marker and a useful reference horizon for studies of sedimentation rates. It occurs at an average depth of 2 m, with a range of 1 to 6.5 m. This indicates that most fan deposition took place prior to 6,000

yrs ago, and that this date, in fact, approximately marks the end of paraglacial sedimentation.

Within Thompson Valley, up to 175 m of early postglacial gravels and sands were deposited by a large braided stream (Anderton, 1970). Fan material was not observed within these sediments, indicating that the early postglacial Thompson River was sufficiently competent to rework tributary sediment into its own deposits. Stratigraphic evidence and radiocarbon dates from terraces in adjacent areas suggest extremely rapid accumulation of this valley fill, possibly entirely within 1,000 yrs (Anderton, 1970). Similar gravels occur in Fraser Valley; but elsewhere, equivalent river sediments are thinner, comprising 45 m of sandy gravel in Similkameen Valley and 20 m of sand and gravel in Bonaparte Valley.

Rates of sedimentation during the paraglacial period have been estimated by determining volumes of sediment laid down within approximately known time periods. The bases of computations and results are given in Table 2. These are minimum values because, if fan deposits are interbedded with river sediments at elevations below that of the river flood plain, the total volume of sediment in the fans will have been considerably underestimated. Fur-

Figure 7. Alluvial fans in Similkameen Valley; the fans are not generally active at present.

thermore, no account has been taken of material transported entirely across fans to trunk rivers.

Silt was the chief component of sedimentation in the proglacial lakes. In Thompson Valley between Ashcroft and Spences Bridge, lacustrine sediments are at least 150 m thick, while Fraser Valley silt at Lillooet has a minimum thickness of 170 m. Near Kamloops, the silt totals 200 m in thickness, although it is possible that the lower part may belong to an earlier, interglacial lake. This unit contains a rhythmite sequence with basal members more than 6 m in thickness. Fulton (1965) suggested

TABLE 2. PARAGLACIAL SEDIMENT YIELD DATA FROM SOUTH-CENTRAL BRITISH COLUMBIA

Area	Landform	Volume of sediment* (10^{-3} km³)	Watershed area (km²)
Lower Thompson Valley	riverine fill[#]	2,040 to 4,080	372
Thompson Valley	fan TF13	2.35	0.73
	fan TF15	9.1	18.2
S. Thompson	fan KF 1	2.35	0.19
	fan KF5	0.59	0.20
Similkameen	fan SF1	16.7	2.4
	fan SF9	8.0	7.8
	fan SF10	8.1	79.9
	fan SF11	29.0	4.2
Fraser Valley	fan S21	98.7	2.0
	Laluwissen fan	78.1	67.7
	McGillivray fan	50.2	48.9

*The volume of sediment within some of the fans was calculated by assuming fan base to be horizontal at the lowest exposed fan deposit, and fan shape to be a segment of a cone. In the case of the Thompson Valley fans, the resulting volume was reduced to 1/3, because these fans overlie a series of broad terraces rather than a horizontal base.

[†]Computed as the mean value $\dfrac{\text{volume of sediment} \times 2.65}{\text{watershed area} \times \text{period of sedimentation}}$.

[§]It is difficult to estimate the time when fan deposition commenced because of the scarcity of absolute dates in south-central British Columbia. There is a general correspondence of bog-bottom dates, suggesting that the modern drainage pattern of Thompson River was established by 9,000 yrs B.P. (Fulton, 1969, 1971) and that Fraser Valley may have been open some 1,000 yrs earlier (W. H. Mathews, 1969, personal commun.). In the absence of any more specific information, these dates can be used as estimates for the time of initial fan deposition.

[#]Sediment entered the Thompson Valley from tributary valleys in the Lytton-Seddall sector only since Thompson Valley upstream was blocked by an ice dam and a proglacial lake. Total volume depends on the bedrock valley cross section assumed.

Figure 8. Valley fill in Fraser Valley; the terracing is the result of recent degradation by the river.

that the rhythmites are varves: if this is correct, sedimentation must have proceeded very rapidly indeed, at least for short intervals of time.

It is apparent that denudation rates between 10,000 and 6,000 yrs ago in south-central British Columbia were very high. This remains true even if the time span of sedimentation has been underestimated by two or three times.

The variation in basin denudation that is apparent within single regions (for example, Similkameen Valley), with the larger basins apparently having undergone less denudation than the smaller ones, may be partially due to the relatively greater loss of sediment from larger fans via their more competent streams, or may simply reflect the normal decrease in sediment yield per unit area with increasing basin size.

COMPARISONS WITH DATA FROM OTHER AREAS

In view of the comparative rarity of glacial events, one might define as the geological "norm" of denudational processes (Lowdermilk, 1934) that condition in which a fluvial transport system operates in equilibrium with its weathering environment. That is, it transports and disposes of just the amount of material that is made available for movement by weathering processes in the ambient environment. Tectonic and climatic instability may render this a completely hypothetical concept for large areas—this need not prevent its consideration. It almost certainly can be realistically considered in relation to low-order watersheds; and in any case, it provides a theoretical reference with which to compare

TABLE 2 (continued)

Assumed limits of sedimentation§ (yrs B.P.)	Total degradation (mm)	Equivalent denudation rate (mm/1,000 yrs)	Annual specific sediment yield[†] (M.T./km²)
9,000 to 7,500	5,500 to 11,000	3,700 to 7,300	9,700 to 19,400
9,000 to 7,500[**] 6,000[††]	3,200	1,050 to 2,100	2,850 to 5,700
Do.	500	170 to 335	440 to 880
9,000[7] to 1,000[§##]	12,400	1,550	4,100
Do.	2,950	370	975
10,000[9**] to 6,000[††]	7,000	1,750	4,610
Do.	1,000	250	680
Do.	100	25	67
Do.	6,900	1,725	4,575
9,000 to present[†††]	49,000	5,440	14,500
9,000 to 6,000 or present	1,150	125 to 380	340 to 1,020
9,000 to 6,000	1,030	340	900

[**]*Time limit is radiocarbon dated as 7,530 ± 270 yrs B.P. (G.S.C.-530; Lowden and others, 1969) from charcoal in aeolian sand on the post-aggradational river terrace.*

[††]*Minor sedimentation only since the deposition of the Mazama ash, 6,600 yrs B.P.*

[§§]*Minimum date. Fans are located on a terrace which postdates the establishment of modern drainage.*

[##]*By extrapolation of absolute sedimentation rate obtained from the zone between the Mazama and St. Helens "Y" (3,200 yrs B.P.; Crandell and others, 1962) ash bands.*

[***]*Estimated date for regional deglaciation.*

[†††]*Fan S21 is not dissected, and there is some evidence of recent deposition. McGillivray was dissected as Fraser River degraded: it had achieved considerable dissection of the valley fill by 6,000 yrs B.P. (Sanger, 1970). The situation on Laluwissen fan is intermediate between the above two cases.*

conditions in real landscapes. Glacial events may be looked upon as perturbations of the fluvial evolution of the landscape.

Table 3 presents summary data of sediment yield rates from various environments which can be compared with the present field areas. Some are, similarly, under paraglacial in fluences, whereas others have been deglaciated for a sufficiently long period that the quoted rates are assumed to approximate "normal" conditions.

It is difficult to determine what is "normal" sediment yield in east-central Baffin Island.

Although the measured rates of several hundred tons per square kilometer per year are in good agreement with results from other glacial watersheds (Table 3C), they are considerably higher than results from most ice-free mountains and from most arctic and subarctic watersheds (Table 3A: especially the data of Dahl, 1967, at Narvik, Norway, and Rapp, 1960, at Kärkevagge, Sweden). These data, together with consideration of the present rates of primary bedrock weathering (Church, 1972) in the Baffin watersheds, make it clear that "normal" sediment production is at least one

TABLE 3.   INDICATED POST-GLACIAL AND RECENT SEDIMENT YIELD (DENUDATION) RATES IN VARIOUS ENVIRONMENTS*

Area	(as M.T./km²/yr)	Datum (as mm/1,000 yrs)	Remarks
A. *Arctic*			
Paraglacial			
Lewis River, Baffin Island	735	280	3 yrs record of sediment transport.
Ekalugad Fjord, Baffin Island	400 to 790	150 to 300	High estimate: one year's record of sediment transport; low estimate: gross sedimentation over 2,000 yrs.
Rapaalven, Sweden	265	100	684 km²: 12 percent ice-covered. Igneous and metamorphic terrane. Subarctic (Axelsson, 1967).
Colville River, Brooks Range, Alaska	140	52	50,000 Km². One season's record (Arnborg and others, 1967).
Normal (nonglacial)			
Narvik, Norway	2.8 to 3.4	1.05 to 1.28	Rock lowering on granite over 10,000 yrs (Dahl, 1967).
Kärkevagge, Sweden	53	20	Slope denudation from 9-yrs record on schists. Slopewash not considered (Rapp, 1960).
Spitsbergen	<19	<7	Runoff plots (slopewash). Weathered material disintegrated *in situ*. Short record. A. John (1970, personal commun.).
B. *Western Cordillera*			
South-central British Columbia (proglacial period)	3,075	1,160	Unweighted mean of data in Table 2, Thompson Valley datum.
Thompson Valley Lytton-Seddall (proglacial period)	9,400 to 19,400	3,700 to 7,300	Sedimentation time uncertain.
Rocky Mountain region, U.S.A.	130	50	5 records of reservoir sedimentation (Geiger, 1958).
Sierra Nevada, California	630	238	37 records of reservoir sedimentation (Geiger, 1958).
Pacific Slopes, California	250	91	Normal sediment transport data (Judson and Ritter, 1964).
Coast Range, Pacific Northwest, U.S.A.	58	22	6 records of reservoir sedimentation (Geiger, 1958).
Coast Range watershed in Oregon	500	190	Estimated by writers from 9,500-yr gross estimate of erosion (poor date). (Balster and Parsons, 1968).
Columbia River Basin	102	38	6.75 x 10⁵ km²; Normal sediment transport data. (Judson and Ritter, 1964).

order of magnitude lower than the present total yield rate. The indication of Figure 5 is that there will still be a considerably higher sediment yield after complete deglaciation than long-term "normal" considerations might indicate. This would represent paraglacial sedimentation continuing for some time after the close of the glacial period. The generally greater extent of earlier fluvial deposits suggests that rates of sediment yield and apparent denudation may have been even more extreme some 5,000 to 9,000 yrs ago when the late Wisconsinan ice sheet was breaking up. Data

from other glacial mountain regions (Table 3C), along with Baffin data, indicate that yield values of more than 500 M.T./km^2/yr (200 mm/1,000 yrs of denudation) may be quite typical of granitic and gneissic terranes under paraglacial conditions.

Similarly, morphological evidence indicates that very high rates of sediment yield occurred in south-central British Columbia during the first three of four millennia following the disappearance of the ice. Unfortunately, almost no information is available on current rates of sediment movement here: useful sediment

TABLE 3 (continued)

Area	Datum (as M.T./km^2/yr)	(as mm/1,000 yrs)	Remarks
Fraser River Basin, British Columbia	115	43	See Table 4.
C. Glacial Mountains			
Erdalsbreen, Norway	1,300	490	16 km^2: 70 percent ice-covered. 1967-1969 mean. No bedload data (Østrem and others 1970).[†]
Vesledalsbreen, Norway	140	54	As above. 7.2 km^2: 56 percent ice-covered. (Østrem and others, 1970).
Austre Memurubre, Norway	330	125	As above. 15.9 km^2: 57 percent ice-covered. (Østrem and others, 1970).
Nigardsbreen, Norway	330	126	57 km^2: 75 percent ice-covered. 1968-1969 mean. Total sediment transport (Østrem and others, 1970).
Rhine River at Lake Constance	744	281	11,800 km^2 (Corbel, 1959).
Austrian watershed	1,500	571	165 km^2: 47 percent ice-covered (Lanser, 1958).
Austrian watershed	34	13	250 km^2. Ice-free (Lanser, 1958).
Venter-Ache, Vent, Austria	1,150 to 1,520	434 to 574	165 km^2. Ice-free, but high rate of moraine erosion (Moosbrugger, 1958).
D. Some Extreme Rates			
Hoffellsjökull, Iceland	4,290 to 8,220	1,620 to 3,100	313 km^2: recent volcanic terrane. Data recomputed from Thorarinsson (1939).
Upper Indus, Karakoram Ra.	2,900	1,100	190,000 km^2 (Hewitt, 1968).
Nebraska	19,350	7,300	<1 km^2: small basin in White River sediments (Schumm and Hadley, 1961).
Iowa	33,900	12,800	0.36 km^2: in loess (Schumm, 1963).
Iowa	2,680	1,010	2,975 km^2: Little Sioux River, in central lowland till plain (A.S.C.E. Task Comm., 1970).
Eel River, above Scotia, California	2,076	783	8,000 km^2 (Judson and Ritter, 1964).
Minnesota	1,330	501	589 km^2; Whitewater River, Driftless area (A.S.C.E. Task Comm., 1970).

*Some of the data have been adjusted to be in conformity with the representation of results as mm lowering/1,000 yrs, with bedrock density assumed at 2.65.

[†]Data of Østrem and others, 1970, has been adjusted to distribute eroded material over the entire contributing watershed. Their report assigns it all to the ice-covered area.

TABLE 4. CONTEMPORARY SEDIMENT YIELD FROM FRASER RIVER WATERSHED
(AS MEASURED AT HOPE)*

Year	Annual total sediment yield (metric tons)	Annual specific sediment yield (M.T./km²)	Equivalent denudation (mm/1,000 yrs)
1950 through 1952[†]	17×10^6 (mean)	85	31
1966[§]	20×10^6	100	37
1967[§]	23×10^6	115	43
1929 through 1959[#]	23×10^6 (mean)	115	43

*Contributing area, 200,450 km²: observed results based on suspended sediment only, which probably accounts for more than 80 percent of the sediment transport at Hope.

[†]Kidd (1953).

[§]Inland Waters Branch: Sediment Data for Canadian Rivers, 1966 and 1967 Reports.

[#]Mathews and Shepard (1962). Indirect estimate of sediment transport at Hope, based on observed sediment deposition at Fraser River mouth, adjusted for changes in transport below Hope.

transport data are available only for the Fraser River at Hope; this river drains a large area of diverse characteristics, only part of which is typified by the montane forest and semiarid valleys of the study area. Table 4 summarizes the data and shows that watershed sediment yield is very much lower than most values reported in Table 2. Nowhere in western North America (except perhaps in some high mountain proglacial situations) are rates in excess of 2,500 M.T./km²/yr (1,000 mm/1,000 yrs) approached today over considerable areas. In fact the deduced paraglacial rates approach the magnitude of some of the most extreme recorded sediment-movement data (Table 3D).

The degree to which depositional landforms, essentially completed 6,000 yrs ago, are still preserved in south-central British Columbia does indicate that rates of erosion and deposition have since been very small. The alluvial fans and valley-fill deposits of the region may comprise only temporary storage for sediment that will ultimately be moved farther through the fluvial transport system, but they are certainly more stable in the ambient environment than was the glacial drift from which the material has been derived.

DISCUSSION

It is difficult to make generalizations about the nature of the paraglacial period from the sparse existing data. In attempting to compare the data on paraglacial sediment yields with appropriate geological norms, it has been necessary to make comparisons with other basins. This involves several difficulties. The basin denudation rate may ordinarily be expected to decline as the basin becomes larger (Brune, 1948; Schumm, 1963), because of the increase in proportion of eroded material

that may again be deposited within the confines of larger basins. Schumm's relation, giving specific yield ∝ (area) $^{-0.15}$, is relatively insensitive and has *not* been considered in this paper in virtue of the low precision attained from the data. Relief (Schumm and Hadley, 1961; Schumm, 1963; Ahnert, 1970) is also important in determining sediment yield. As this factor does not vary greatly among the study areas, no data pertaining to it can be presented here. It seems reasonable to speculate that, other things being equal, paraglacial redistribution of sediment will be more severe in areas of high relief then in ones of low relief.

The effects of geology and climate must also be considered. In the two regions studied here, the geology is an important point of contrast: the granite-gneiss terrane of Baffin Island and its predominantly coarse-grained weathered material are relatively resistant to glacial and fluvial erosion; thus, maximum paraglacial denudation rates remain modest. The varied intrusive and extrusive, metamorphic and sedimentary terrains of southern British Columbia have produced a wide range of rates.

Climate undoubtedly has significant influences as well. The relative length of the runoff season during the paraglacial period and the magnitude, duration, and frequency of periods of rapid snow and ice melt, and of major summer (rain) storms, all probably favored more rapid erosion and sedimentation in the southern region during the paraglacial period than in the Arctic today.

The period of major sedimentation in southwestern British Columbia appears to have drawn to a close by the time of the warm, dry hypsithermal period (Heusser, 1960) ~ 6,500 yrs ago. Whether the increasing dryness of the period contributed to a significant reduction in

the efficiency of fluvial processes is unknown. Precipitation in the valleys today (125 mm to 375 mm) lies within the range of effective precipitation totals for which Langbein and Schumm (1958) found the greatest characteristic sediment yields. The higher precipitation in the mountains, and the concentration of runoff during spring snowmelt, should also provide relatively efficient conditions for moving sediment. Nevertheless, sediment yields remain relatively low today.

Simple proximity to the extraordinary supply of water represented by melting ice sheets is important. The largest proportion of material is probably moved during the proglacial phase when frequent floods may occur as a result of melt. As glaciers have maintained a long, lingering existence in east Baffin Island, marked by several post-Wisconsinan advances, the paraglacial period has been extended greatly over that apparently experienced in the south.

Vegetation (in part a climatically controlled factor) also influences the duration of paraglacial conditions. Immediately after deglaciation, bare slopes are very vulnerable to erosive forces. The rapid influx of a relatively rich flora, including tree species, such as occurred in southwestern British Columbia, removes many deposits from the category of "unstable in the fluvial environment," hence making them unavailable for erosion and redeposition elsewhere. This has not occurred in the severe environment of the Arctic.

Finally, regional uplift, as has been noted above, has undoubtedly been significant in the timing of shifts in the balance from deposition to erosion, in trunk valleys, and then in side valleys. When sediment supply is no longer sufficient to maintain the rate of progradation of sediment deposits ahead of the effect of falling base level, then dissection of the deposits must occur. This in itself has the effect of providing material for transport and redeposition farther downstream. Such multi-generation activity has demonstrably occurred in eastern Baffin Island. It prolongs the total period of paraglacial effects.

With reservations concerning the crudeness of the data still in mind, the sequence sketched in Figure 9 is tentatively suggested as representing the progress of paraglacial sediment movement in the two study areas during the late glacial and postglacial periods. Little is
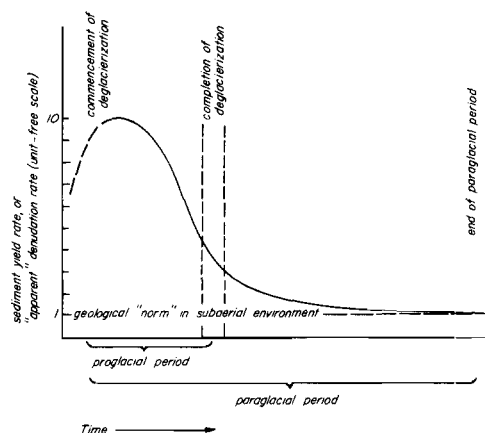

Figure 9. Schematic diagram of the pattern of sedimentation during the paraglacial period.

known of conditions during the full-glacial period. Andrews (1971) estimates denudation rates of 25 to 90 mm/1,000 yrs (corresponding to sediment yields of 65 to 240 M.T./km²/yr) in Baffin Island from cirque and moraine volumes. While well above subaerial "norms," this remains below indications for the early paraglacial period. Maximum sediment movement probably occurs very soon after deglaciation, with rates declining rapidly as the ice disappears. After that, the rate of paraglacial sediment yield probably follows an asymptotic decline toward the regional "norm."

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