Some Observations on the Hydrochemistry and Sedimentation of the Chamberlin Glacier Area Alaska

By FRANK H. RAINWATER *and* HAROLD P. GUY

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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Analysis of a program of sampling and measuring precipitation and melt water to determine water quality and suspended-sediment concentration, July-August 1958, and interpretation and summary of available data

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

CONTENTS

ILLUSTRATIONS

TABLES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

SOME OBSERVATIONS ON THE HYDROCHEMISTRY AND SEDIMENTATION OF THE CHAMBERLIN GLACIER AREA, ALASKA

By FRANK H. RAINWATER and HAROLD P. GUY

ABSTRACT

This report describes a reconnaissance of the hydrochemical and sediment characteristics of Chamberlin Glacier near Barter Island Alaska. Twenty-eight observations of the streamflow and one of the precipitation were made to define the important aspects of hydrochemistry and sedimentation during the 2-month period of record July to August 1958. The sampling program had to be planned without prior knowledge of the conditions in the vicinity of the glacier. The adequacy of this program is evaluated in the last section of the report and suggestions are offered that may be useful in designing future studies of this kind.

These limited observations are sufficient to define the important dissolved constituents in the glacial melt waters and nearby streams. The dissolved solids range from 7 ppm (parts per million) in a composite sample of precipitation, to 55 ppm in a nearby nonglacial stream. The inverse relation of water hardness to quantity of streamflow is defined with sufficient accuracy to empirically subdivide total flow into components of water from ground environment and water from glacial melt water and precipitation.

The streambed contains fragments of well-foliated schist from the Neruokpuk formation, that range in size from boulders to sand—a sample contained 1 percent sand, 49 percent gravel, and 50 percent cobbles. Diurnal and day-to-day variation in suspended-sediment concentration, load, and particle size are appreciable. Excellent correlations are demonstrated between (a) the concentration of sand and water discharge and (b) the concentration of clay, or clay plus silt, and turbidity.

INTRODUCTION

Glacial hydrochemistry and sedimentation can be very intriguing because the environmental factors molding the flow and composition of streams behave differently around glaciers than at lower altitudes or latitudes. This paper is a study both of (a) the hydrochemistry and sedimentation of Chamberlin Glacier as determined by limited observations, and (b) sampling and interpretive techniques perhaps applicable to glaciers in general. Experience in making relevant measurements and in interpreting the data from such environments is meager. Subsequent glacial research may benefit from the successes and shortcomings of this investigation.

Chamberlin Glacier is in the eastern Brooks Range about 60 miles south of the Arctic Coast and 100 miles west of the Canadian border. The immediate area is shown in figure 1. The drainage area of Chamberlin Creek at the gage is 1.46 square miles, of which 0.93 square mile is covered by the glacier. During the summer of 1958 a team of scientists supported by the Air Force Cambridge Research Center studied the glacier and surrounding terrane in detail. D. G. Anderson was the U.S. Geological Survey's representative. As a part of his hydrologic studies, he collected water samples for the chemical and sediment phases of the investigation. For the interpretations in this report the authors drew also from data and preliminary reports compiled by members of the team.

MEASUREMENT PROGRAM

The sampling program was carefully planned because all equipment and samples must be transported by plane into and out of a base camp and carried several miles over steep terrane on a packboard. Samples must be returned the same way. Except for turbidity, field measurements were ruled out because it was easier to bring the water to the laboratory than to take the laboratory to the water. In arranging the sampling program, experience gained from hydrochemical and sediment studies of other locations was drawn upon to anticipate what chemical and sediment measurements would be useful, what concentration ranges would be found, and what volumes of sample would be required. In most instances a single sample served for both chemical and sediment analysis.
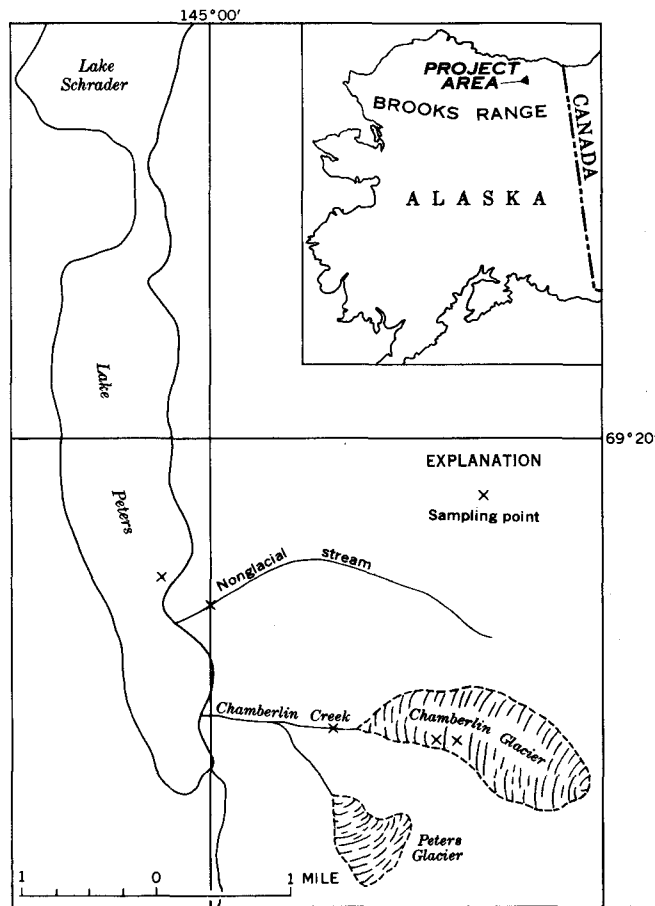
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FIGURE 1.—Map of Chamberlin Glacier area, Alaska, showing location of sampling points.

events. Analyses of the large-volume samples would show which ions were the most useful in hydrochemical interpretation. The small-volume samples would then be analyzed for these ions only. Analyses representing the major hydrologic environments are shown in table 1. The composites reported in this table were prepared at the glacier by pouring equal volumes of sample collected each day into a large polyethylene bottle.

One of the specific hydrologic events is the diurnal variation in flow from the glacier. Small-volume samples were to be collected every 2 hours for a 24-hour period to evaluate the important water-quality factors, including suspended sediment. The results of analyses of these sequential samples are given in table 2.

A third set of samples (small-volume) were to be collected periodically about once every 2 weeks to define the change of chemical quality and suspended sediment with time. Analyses of these samples are given in table 3.

The samples of suspended sediment were collected in plastic bottles by hand-lowering the bottle vertically at a uniform rate from the water surface to the streambed and return, at one or more representative verticals in the channel cross section.

Turbidity measurements were planned because of possible correlation with the concentration of silt and clay in suspension. Turbidity was measured in the field with the U.S. Geological Survey turbidity rod (Newell, 1902). Numerical results obtained with this instrument are not strictly comparable to results with other instruments but are believed to be more realistic than measurements made in the laboratory several weeks after the sample is collected.

Three half-shovels of bed material were collected to give an idea of the size distribution and of the physical

The plan, in general, was to collect a few large-volume samples that were representative of the major chemical or hydrologic environments for comprehensive analysis, and to supplement these with a larger number of small-volume samples collected to define the chemical and sediment characteristics of specific hydrologic

TABLE 1.—*Water-quality observations of major hydrologic environments, Chamberlin Glacier area, Alaska*

[Analyses in parts per million except as indicated]

Environment and date of collection (1958)	Altitude (feet above mean sea level)	Relative deuterium [1]	Water discharge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Silica (SiO₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO₃)	Sulfate (SO₄)	Chloride (Cl)	Ammonia nitrogen (as N)	Nitrate (NO₃)	Dissolved solids	Hardness as CaCO₃ Total	Hardness as CaCO₃ Noncarbonate	Specific conductance (micromhos at 25°)	pH
Composite of precipitation: July and August	6,100	−14.4				0.0	0.7	0.1	0.3	0.1	5	0.4	0.0	0.17	0.0	7	2	0	8	5.7
Surface ice from glacier: Aug. 20	6,200	−16.5				.0	.4	.0	.8	.7	7	.6	.1	.29	.0	9	1	0	9	6.0
Subsurface ice from glacier: Aug. 14	6,000	−14.5				.0	.8	.0	.7	1.9	9	.4	.0	.32	.0	11	2	0	16	6.2
Unnamed nonglacial tributary to Lake Peters: July 30			8	51	43	1.3	12	3.3	.2	.1	35	19	.2	.32	.0	54	43	14	97	7.0
Lake Peters: Sept. 2		−14.3				.8	8.2	1.9	.2	.3	25	9.4	.3	.00	.0	35	26	6	60	7.0
Composite (time-weighted) of Chamberlin Creek at gaging station, 800 ft downstream from glacier snout: July 7–14		−16.7				.3	1.5	.1	.1	.0	9	1.4	.2	.18	.0	11	4	0	11	6.5
Aug. 17–31		−15.7				.4	6.1	1.5	.2	.2	12	15	.7	.02	.0	32	20	10	52	6.6

[1] Expressed as percent depletion of that found in Lake Michigan.

TABLE 2.—*Sequential observations of water quality, August 5 and 6, 1958, 800 feet downstream from Chamberlin Glacier, Alaska*

Time	Water dis-charge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Sulfate, SO$_4$ (ppm)	Hardness as CaCO$_3$ (ppm)	Specific conduct-ance (microm-hos at 25°C)	Suspended sediment Concen-tration of sample (ppm)	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	4.000
2:00 p.m.	30.3	52	34	0.6	4	10	971		18	26	34	40	45	50	67	71	80	89	100
4:00	38.0	54	34	2.0	5	14	2,820		11	19	27	32	38	43	49	65	76	86	96
6:10	40.9	52	34	3.0	5	12	1,780		12	18	27	32	39	46	57	78	94	100	
8:00	27.8	45	34	1.6	3	9	408	13	19	29	42	49	54	58	64	74	86	95	100
10:00	18.2	45	34	2.4	4	10	110		42	54	78	89	92	92	92	96	100		
12:00	12.4	44	34	1.6	5	12	71		62	80	88	93	99	100					
2:00 a.m.	9.2	42	34	.8	6	14	} 30		46	61	68	80	84	89	95	98	100		
4:00	8.5	43	34	1.2	7	16													
6:00	7.8	46	34	1.0	7	16													
8:00	7.8	45	34	1.2	6	16													
10:00	17.7	52	34	1.2	5	13	161	18	29	42	56	68	72	78	86	94	100		
12:00	33.8	53	35	1.0	4	10	440	10	16	25	35	44	50	63	74	88	98	100	

Time (weighted mean)_____ 574
Discharge (weighted mean)_____ 965

TABLE 3.—*Periodic observations of water quality, 800 feet downstream from Chamberlin Glacier, Alaska*

Date (1958)	Time	Water discharge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Sulfate, SO$_4$ (ppm)	Hardness as CaCO$_3$ (ppm)	Specific conduct-ance (mi-cromhos at 25°C)	Suspended-sediment concentra-tion (ppm)	Turbidity
July 7	11:50 a.m.	33.8			1.0	4	12	265	
14	3:12 p.m.	29.0			1.2	4	11	616	
28	3:00	37.3			1.0	5	12	758	
Aug. 3	1:55	12.4			1.2	6	15	84	
5 [1]	6:30	41.7			.8	4	10	1,090	
10	5:30	14.2	48	34	1.6	6	14	85	80
17	11:40 a.m.	14.7	41	34	2.4	8	20	131	150
26	5:15 p.m.	8.5	42	34	2.6	9	24	60	70
28	11:45 a.m.	1.6			17	25	60	2	20

[1] Sample collected at glacier snout.

and chemical properties of the particles. This sample is described in the section, "Bed material."

HYDROCHEMISTRY

CHEMISTRY OF THE WATER

The concentrations of dissolved solids shown on figure 2, for the major hydrologic units are in logical sequence, beginning with precipitation. This speaks well for the care in collecting, handling, and analyzing the samples because contamination is a serious problem when dealing with such dilute waters. The difference in the two composites from Chamberlin Creek indicates that some seasonal variation exists. The relatively high concentration of the nonglacial tributary, even when the sample was collected soon after a rain, suggests that, in its brief contact with weathered and unweathered soil and rocks, the water may pick up considerable soluble material.

All of Chamberlin Creek above the gage drains the Neruokpuk formation or glacial till derived from it. Although the dominant rocks are crystalline there are sufficient corrodible minerals to influence the chemistry of the water that comes in contact with the ground.

The saturation index is an indication of instability with respect to calcium carbonate deposition and solu-tion and is defined as the algebraic difference between the actual pH of a sample and its computed pH$_s$. The term pH$_s$ designates the pH at which water of given calcium content and alkalinity is in equilibrium at the temperature of the water. Waters of the Chamberlin region are highly corrosive, as indicated by the negative calcium carbonate saturation indexes shown in table 4. Such waters, for example, will readily dissolve limestone and other minerals weathered by carbonic acid, and they will also corrode iron pipes. These indexes are not exact because the temperatures used in the computations were estimates and the pH values used were not measured at the time of collection. However, the error probably does not exceed a few tenths of a pH unit. The magnitudes of the indexes are inversely proportional to the waters' contact with rocks and soils. Not only can the waters dissolve minerals, but evidently do so rapidly when given the opportunity for contact.

TABLE 4.—*Saturation indexes of water samples of the Chamberlin Glacier area, Alaska, 1958*

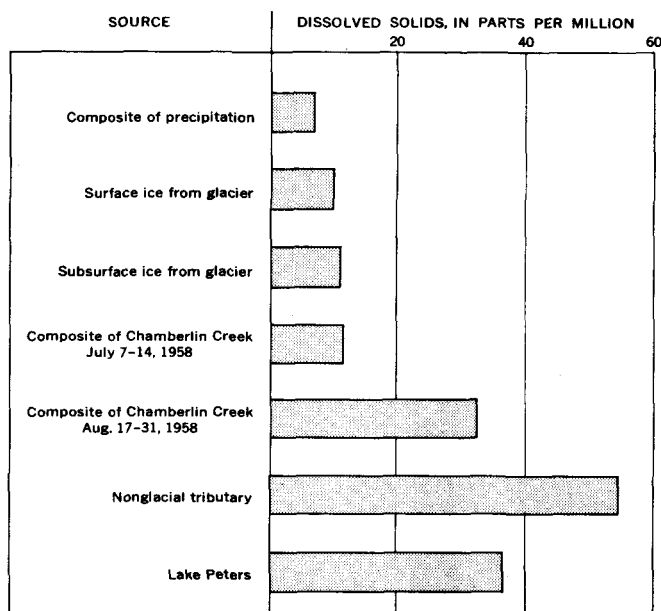| Source	Index
Composite of precipitation	−5.5
Surface ice from glacier	−5.2
Subsurface ice from glacier	−4.7
Composite of Chamberlin Creek (July 7–14)	−4.3
Composite of Chamberlin Creek (August 17–31)	−3.4
Nonglacial tributary	−3.1
Lake Peters	−2.6

FIGURE 2.—Dissolved solids of major hydrologic units of the Chamberlin Glacier area, Alaska.

Nitrate is completely absent, but ammonia nitrogen is present in large amounts in all but one of the samples tested. The significance of this condition is not known. It may be related to the oxidation-reduction system of the waters, or more simply, to a deficiency of the glacial till in certain types of oxidizing bacteria that are commonly active in soils. Measurements of oxidation-reduction potential of the waters were not made at the glacier, and could not be made in the laboratory several weeks after the samples had been collected.

The low percentage of sodium and chloride in the precipitation suggests that the ocean is not the dominant source of chemical salts in the rains of this region. The deuterium measurements (table 1) further substantiate this hypothesis. The samples of rain, glacial ice, and streamflow are low in deuterium content for water originally derived from the sea and precipitated at summer temperatures. The precipitation in the study area would have to be derived from a source that is about 10 to 15 percent lighter than sea water. Irving Friedman (written communication, 1959) postulates that snow on the Arctic Ocean ice and continental water at altitudes lower than the glacier satisfy this condition, and concludes that the waters of the Chamberlin area probably have such origins.

The ions that account for the differences in concentrations of dissolved solids are shown by figure 3. This illustration is a plot of the concentration of the individual ions against total ionic concentration expressed in terms of specific conductance. The ordinates are scaled in proportion to the precision of the individual laboratory measurements. This type of treatment is impera-

tive lest hydrological, chemical or geological significance be falsely attributed to reported concentration differences arising from the laboratory methods themselves.

The ions that contribute the most to the differences in dissolved-solids content of the streamflow are those which are related to the nature of the rocks of the area—in this area calcium and magnesium (hardness), bicarbonate (alkalinity), and sulfate. Consequently, the concentrations of these ions are indexes of the amount of contact between water and local rocks and soils. Hardness is the best index because the slope of its line (fig. 3) is maximum, and the scatter of the points about its line is minimum. Alkalinity and sulfate follow as the second and third choices as indexes.

One might normally expect all intercepts on figure 3 to be zero. This expectation is more often false than true, particularly when dissolved carbon dioxide (carbonic acid) or other gases that ionize in solution are present. The low pH of the precipitation and glacial melt water suggests the presence of ionized carbonic acid. The negative intercept of the alkalinity line with the abscissa is comparable in magnitude to the positive intercept of the hardness and silica lines. Apparently about 3 to 5 micromhos of conductance is attributable to carbonic acid.

The slight negative slope of the sodium line may indicate that sodium in the rainfall and glacial melt is exchanged for calcium when the water contacts the rocks and soil. However, this slope may be due only to chance or limitations of the data.

HYDROLOGIC INFERENCES FROM CHEMICAL DATA

The chemical indexes of a water's environment provide a basis for hydrologic deductions not available from streamflow measurements. A current meter does
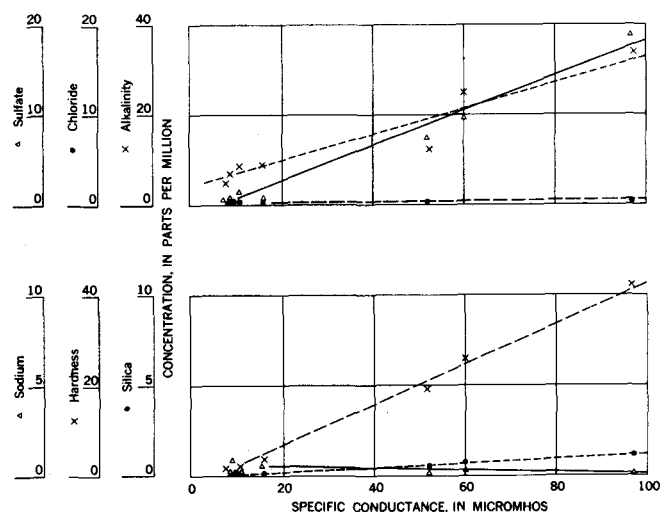

FIGURE 3.—Relations of ions to total concentration, Chamberlin Glacier area, Alaska.
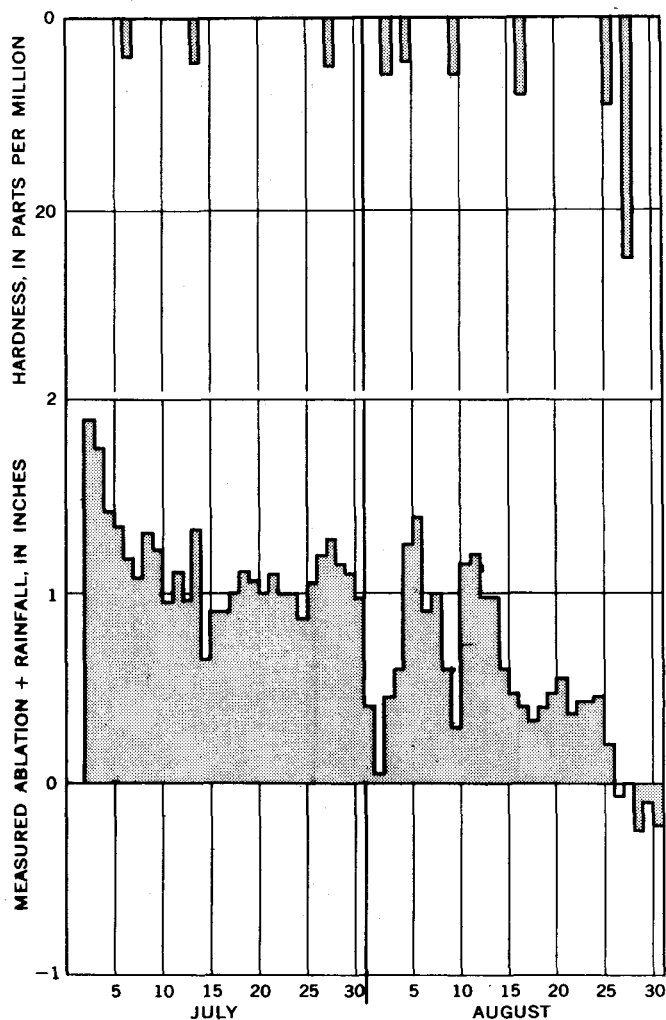
FIGURE 4.—Response in concentration of Chamberlin Creek to dilution, Chamberlin Glacier area, Alaska.

not differentiate the complex past environments of the water that spins its cups.

It has been shown in the preceding section that the water readily dissolves material from the ground. In the Chamberlin drainage basin above the gage, water comes in contact with the soil and rock in two principal ways. First, and probably the most important chemically, is the seepage through the silty till of melt water from the glacier or ice-cored moraines, frozen soil, and ice lenses. Second, and of less importance, is the water-ground contact of underflow beneath the glacier. Consequently, the flow that has chiefly a ground environment can be separated, on the basis of chemical composition, from precipitation and glacial melt water that flow over thoroughly leached outwash gravel and cobbles.

The relation of water hardness at the gaging station to measurements of ablation plus rainfall is shown on figure 4. The ablation data are not quantitative for the

entire glacier. During periods of appreciable ablation, the water passing the gage on Chamberlin Creek showed little evidence of ground influences. These influences, though, increased a little during August as ablation decreased; and then on August 28, 2 days after ablation ceased, the sample concentration reached the maximum for the period. Hence, the chemical makeup of water passing the gage must respond rapidly to variations in percentages of water from the two environments.

Correlations of (a) factors effecting ablation with (b) diurnal fluctuations in the concentrations of samples collected every 2 hours for a 24-hour period (Aug. 5 and 6, 1958) at the gage, demonstrate that the variation in the relative contributions of glacial melt water to Chamberlin Creek lag behind the actual increase and decrease in air temperature and radiation. However, quantitative deductions cannot be made from the sparse data available. To understand this phenomenon completely would require a rather comprehensive and continuous heat budget for the glacier. These chemical fluctuations do, nevertheless, add evidence substantiating the hypothesis of a 2-component system of flow. The system consists essentially of a rather stable discharge from the ground environment that is diluted to varying degrees with relatively pure precipitation and glacial melt water.

A general equation can be developed to approximate proportions of flow from each environment for any given flow at the gage. Figure 5 shows the relation of hardness to water discharge in the channel.

$$C_3 = aQ_3^{-0.6}$$

where

C_3 is hardness at the gage, in parts per million,

Q_3 is discharge at the gage, in cubic feet per second, and a is a constant $= 34$ ppm.

From the foregoing discussion of the chemistry of the water from the two sources, we know that

$$Q_2/Q_1 \propto C_3$$

where

Q_1 is uncontaminated runoff, in cubic feet per second,

Q_2 is flow from the ground environment, in cubic feet per second, and

C_3 is hardness concentration at the gage, in parts per million.

Note that none of the samples plotted on figure 5 represent all Q_1 or all Q_2. Without data representing the chemical concentration of flow from the ground environment, one cannot mathematically relate the flow ratio to total channel flow. Nevertheless, the slope of the regression line on figure 5 can be used empirically to separate the two types of flow. With water discharge expressed in cubic feet per second,

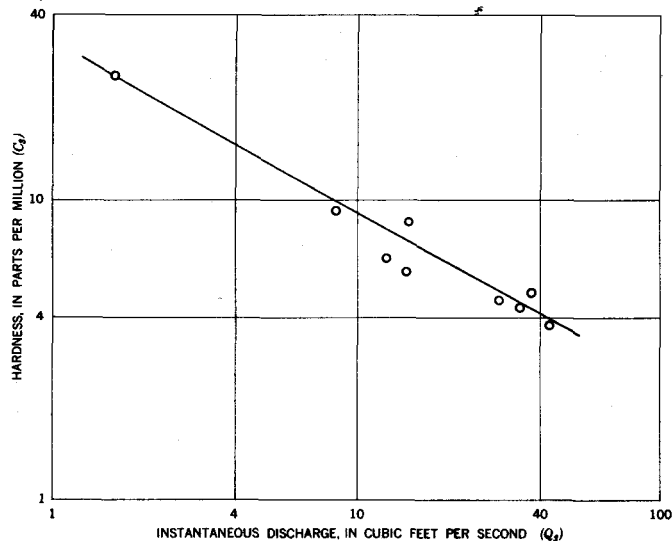$$Q_2/Q_1 \approx Q_3^{-0.6} \text{ or } Q_1/Q_2 \approx Q_3^{0.6}$$

FIGURE 5.—Relation of water hardness to stream discharge, Chamberlin Creek, Alaska.

The approximate ratios and the values of Q_1 and Q_2 for selected channel flows, given in table 5, look realistic and they can be checked roughly by computing the hardness of Q_2 for different channel flows. This computation uses the basic addition-of-loads equation, $Q_1C_1+Q_2C_2=Q_3C_3$. The hardness of precipitation and glacial melt water is nearly zero. Hence, the equation becomes,
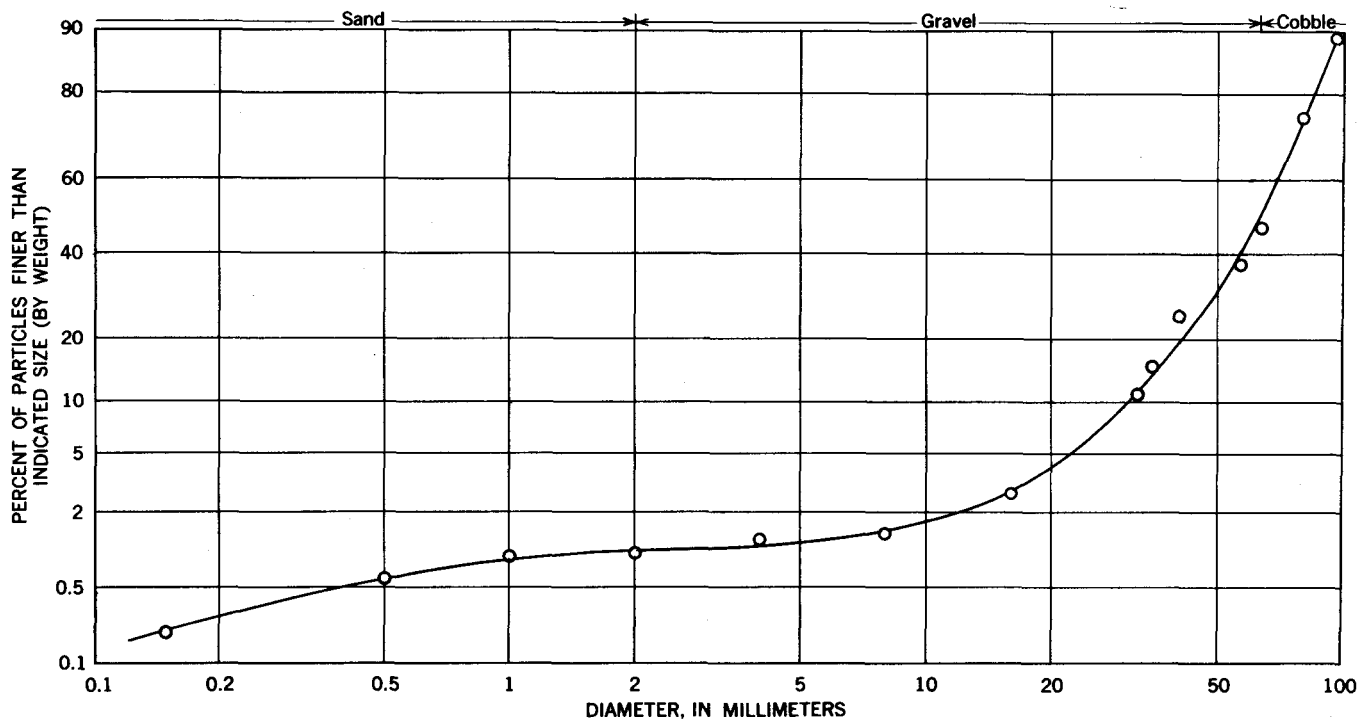
$$C_2=\frac{Q_3C_3}{Q_2}.$$

The concentration of water from ground environment, C_2, computed from values of C_3 and Q_3 on figure 5 and of Q_2 in table 5, range from 40 to 55 ppm at channel flows ranging from 40 to 2 cfs, respectively. These are of the logical magnitude. That the concentration of the "ground-water" contribution decreases with the increasing discharge is to be expected and is consistent with observations elsewhere. Furthermore, the hardness of the one sample from the nonglacial tributary was 43 ppm, which is of the same magnitude as these computed concentrations.

TABLE 5.—*Approximate percentage makeup of channel flow 800 feet downstream from Chamberlin Glacier, Alaska*

Channel flow, Q_3 (cfs)	Q_1/Q_2	Precipitation and glacial melt water, Q_1 (cfs)	Water from ground environment, Q_2 (cfs)
2	1. 5	1. 2	0. 8
4	2. 3	2. 8	1. 2
7	3. 2	5. 3	1. 7
10	4. 0	8. 0	2. 0
20	6. 0	17	3
40	9. 2	36	4

SEDIMENTATION

BED MATERIAL

On August 25, three half-shovels of typical bed material were collected from the channel near the gaging station (800 ft downstream from the glacier snout) where water no longer flowed. Figure 6 illustrates the

FIGURE 6.—Particle-size graduation of bed material, Chamberlin Creek, Alaska.

size gradation of this material—about 1 percent sand, 49 percent gravel, and 50 percent cobbles. The particles are subangular, showing some evidence of wear, and the sphericity of most particles ranges from 0.50 to 0.80.

While digging the stilling wells for the stage recorders Mr. Anderson noted that the valley fill immediately adjacent to and under the stream is somewhat consolidated and contains considerably more sand and fines than indicated by the bed-material sample. He noted also that ground water did not readily flow into his excavation except for some small "pipes" of flow, which generally could be plugged with small rocks and clay.

Estimates of permeability, based on size distribution, visual observation, angularity of the rocks, and slope in the stream valley (about 25 percent), suggest that the valley deposit may transmit a water discharge ranging from 0.05 to 1.0 cfs per 100 square feet of cross-sectional area. The total cross-sectional area of the till in the valley at the gaging station is unknown.

The rocks in the channel, derived from the Neruokpuk formation, are largely metamorphosed graywacke that has good remnant clastic texture. The major part of the sample consists of fragments of well-foliated quartz schist containing numerous veins of massive quartz. The rocks are about 65 percent quartz; the remaining fraction includes feldspar, chlorite, biotite, epidote, amphibole, pyrite, and smaller quantities of other minerals.

COMPOSITION OF FINE SEDIMENT

Spectrographic analysis of fine suspended sediment in streamflow from Chamberlin Glacier indicates that the minor constituents are similar to shales as given by Krauskopf (1955). Quantitative values are compared in table 6. Tin and strontium are below the range reported for average shales. Elements ordinarily present in shales but not found by this analysis are cesium and zinc. These characteristics indicate a trend toward an arenaceous type of material. In summary, the composition is similar to what might be expected from the finer grained portions of the quartzose schist in the bed material.

DIURNAL VARIATION OF SUSPENDED SEDIMENT

One of the most important consequences of snow and ice melt is the diurnal fluctuation in concentrations of suspended sediment carried in transport by the stream. Thus, beginning at 2:00 p.m. on August 5, 1958, and ending at noon the next day, suspended-sediment samples of a 1-liter volume were collected every 2 hours at the gaging station, which is located about 800 feet downstream from the glacier snout.

TABLE 6.—*Comparison of the composition of sediment from Chamberlin Glacier with that of shales given by Krauskopf*

Element	Concentration, in parts per million	
	Chamberlin Glacier	Krauskopf (1955)
Fe	30,000	----------
Mg	7,000	----------
Ca	700	----------
Na	3,000	----------
K	15,000	----------
Ti	7,000	----------
Mn	300	----------
Ba	300	300–600
Be	3	1–6
Co	15	10–50
Cr	70	50–190
Cs	0	10
Cu	70	0–55
Ni	30	20–100
Pb	30	20
Sc	15	0–30
Sn	15	40
Sr	30	100–1,300
V	70	50–300
Y	30	----------
Yb	3	----------
Zn	0	50–300
Zr	300	60–360

In addition to the water discharge, turbidity and air and water temperatures were recorded.

The particle-size gradation and the sediment concentration were measured in each of the 12 samples. The particle-size analyses were made by the bottom-withdrawal-tube method; the settling medium used was a mild chemical dispersant in distilled water. The concentration for each sample was determined from the sum of the residue of each withdrawal. The samples from the period of low-water discharge, at 2, 4, 6, and 8 a.m. on August 6, were combined to obtain enough sediment for a reliable analysis.

The results of the particle-size analyses and concentration determinations are summarized in table 2. Clay is defined as material finer than 0.004 mm, sand as coarser than 0.062 mm, and silt as the fraction between these limits. The percentages in the table can then be used together with the sample concentration to define the concentration of the clay, silt, and sand fractions in transport. These concentrations and the associated water discharge and turbidity for each sample are given in table 7. The instantaneous load of each fraction transported at the time each sample was collected is also shown in table 7.

The patterns of diurnal fluctuation in water discharge, turbidity, and concentration of suspended clay, silt, and sand are shown in figure 7. The peak concentrations precede the peak water discharge about 1 or 2 hours. The three right-hand columns of table 7 show the ratios of the instantaneous water discharge, concentration, and load to their respective means for each of the observations. These ratios represent the general expression of variation for this

TABLE 7.—*Suspended-sediment concentration and discharge data for sequential observations, August 5 and 6, 1958, Chamberlin Creek, Alaska*

Time	Water discharge (cfs)	Turbidity	Concentration (ppm)			Instantaneous discharge (tons per day)				Ratio to mean		
			Clay	Silt	Sand	Clay	Silt	Sand	Sum	Water discharge	Concentration	Sediment discharge
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
2:00 p.m	30.3	300	175	262	534	14.3	21.4	43.8	79.5	1.44	1.69	1.46
4:00	38.0	600	305	765	1,750	31.3	78.5	180	290	1.81	4.92	5.32
6:10	40.9	500	214	486	1,080	23.7	53.7	119	196	1.95	3.11	3.59
8:00	27.8	200	78	142	188	5.9	10.7	14.1	30.6	1.32	.71	.56
10:00	18.2	110	46	55	9	2.3	2.7	.44	5.4	.87	.192	.099
12:00 p.m	12.4	100	44	26	1	1.5	.87	.03	2.4	.59	.124	.044
2:00 a.m	9.2	75								.44	.052	.012
4:00	8.5	75	14	11	5	.32	.25	.11	.68	.40	.052	.012
6:00	7.8	70								.37	.052	.012
8:00	7.8	65								.37	.052	.012
10:00 a.m	17.7	85	47	69	45	2.2	3.3	2.2	7.7	.84	.281	.141
12:00 m	33.8	140	70	220	150	6.4	20.1	13.7	40.2	1.61	.77	.74
Time (weighted mean)	21.0	193	86	167	321	--------	--------	--------	32.5			
Water discharge (weighted mean)	--------	276	130	282	548	7.4	16.1	31.1	54.6			

24-hour period and are useful for determining the variation for other days.

CORRELATIONS WITH TURBIDITY AND WATER DISCHARGE

Turbidity is sometimes considered an indirect indicator of the concentration of the fine sediment in transport. As a check on this hypothesis, the instantaneous concentrations of both clay and the sum of those of clay and silt were plotted against turbidity in figure 8. Statistics for these regressions are shown in table 8. The high correlation coefficient and the relatively low standard error of estimate indicate that concentration of fines can be computed from turbidity readings with reasonable accuracy.

The sand fraction's contribution to turbidity is slight and correlation cannot be expected. However, the suspended transport of sand varies with mean velocity and hence water discharge (Colby, 1959) at a given stream cross section. Figure 9 shows the plot of sand concentration with the rate of water discharge for Chamberlin Creek. The statistics (table 8) for this regression indicate that the relation is less reliable than that of the concentration of fines to turbidity. Total suspended-sediment concentration, however, can be determined with reasonable accuracy by substituting values of turbidity and water discharge into the equations defined by these regressions.

DAILY SUSPENDED-SEDIMENT DISCHARGE

The overall transport of the glacial debris by streams in relation to their supply by the glacier is an important factor influencing the geometry of the stream channel and even of the valley floor. Bed material in transport was not measured. However, in order that some measure be obtained of the suspended load being transported throughout the season by the stream, several small 8-ounce samples were collected on different days during

TABLE 8.—*Relation of the concentration of suspended-sediment fractions to turbidity and water discharge, Chamberlin Glacier area, Alaska*

Relation	Regression equation [1]	Correlation Coefficient	Standard error of estimate
Clay to turbidity	$Y_1 = 0.50X_1 - 6$	0.98	15 ppm
Clay and silt to turbidity	$Y_2 = 1.75X_1 - 75$	.98	79 ppm
Sand to water discharge	$Y_3 = \dfrac{X_2^{4.275}}{8,420}$	.90	0.52 $\log_{10}$ units

[1] Where: Y_1 = concentration of clay; Y_2 = concentration of clay and silt; Y_3 = concentration of sand; X_1 = turbidity; X_2 = water discharge.

the 2-month investigation. Because of the wide variation in sediment concentration during the course of a single day, as well as the day-to-day variation, these samples represent only a rough measure of the load for the period.

These instantaneous-concentration determinations, together with the information concerning the diurnal fluctuations shown by figure 7 and table 7, can be used to compute, by two methods, the suspended-sediment transported on the sampled days. Following are steps used for the first method:

1. Compute an instantaneous sediment discharge on the basis of the sampled instantaneous concentration and the instantaneous water discharge.
2. Adjust this by the ratio shown by column 13, table 7. Following are steps used for the second method:

1. Compute a daily mean concentration from the product of the sampled instantaneous concentration and the ratio shown by column 12 of table 7.
2. Use this together with the daily mean water discharge to compute a time-weighted sediment discharge; and
3. Adjust this by a factor of 1.68 to obtain a water discharge-weighted sediment discharge.
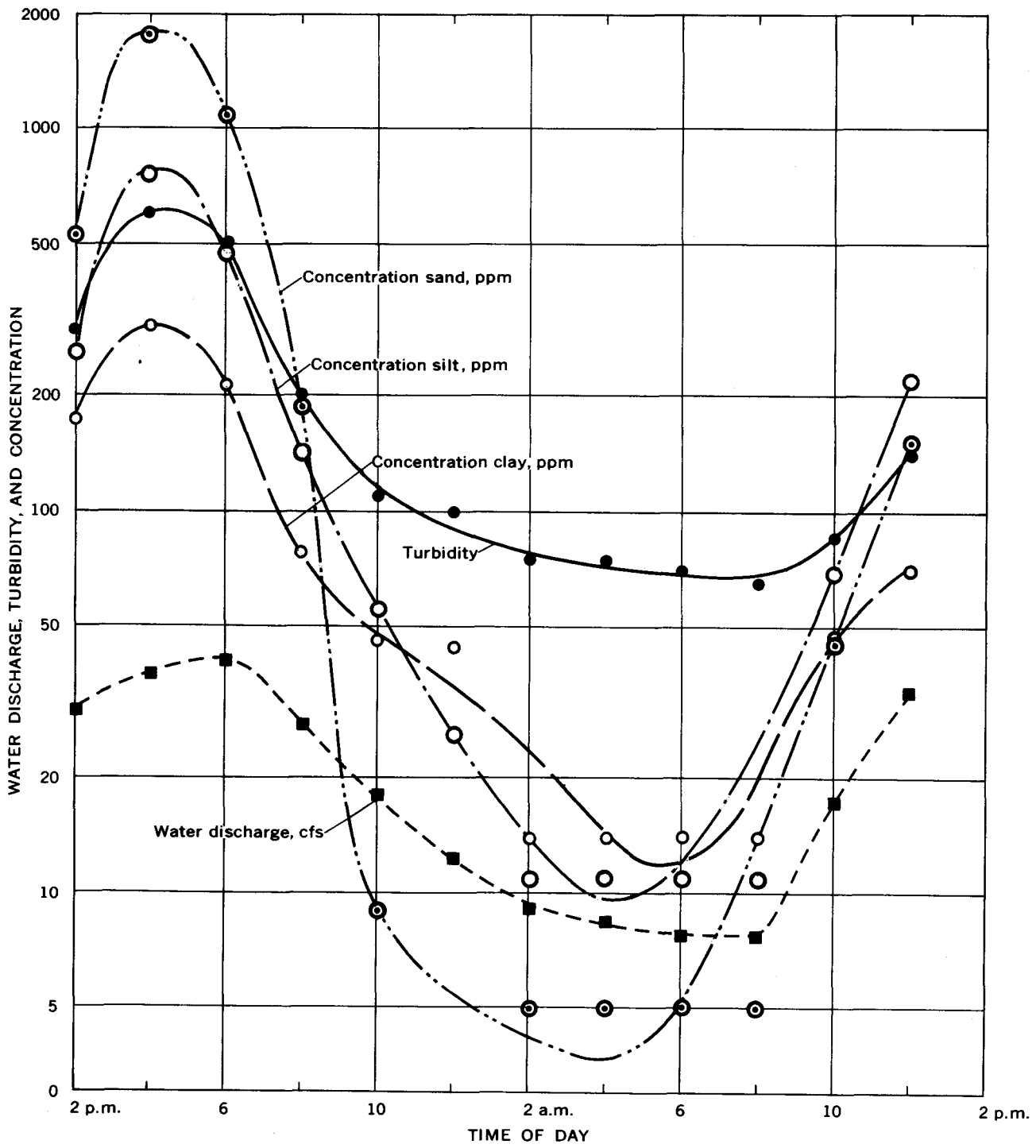
FIGURE 7.—Diurnal variation of water discharge, turbidity, and suspended-sediment concentration, Chamberlin Creek, Alaska.
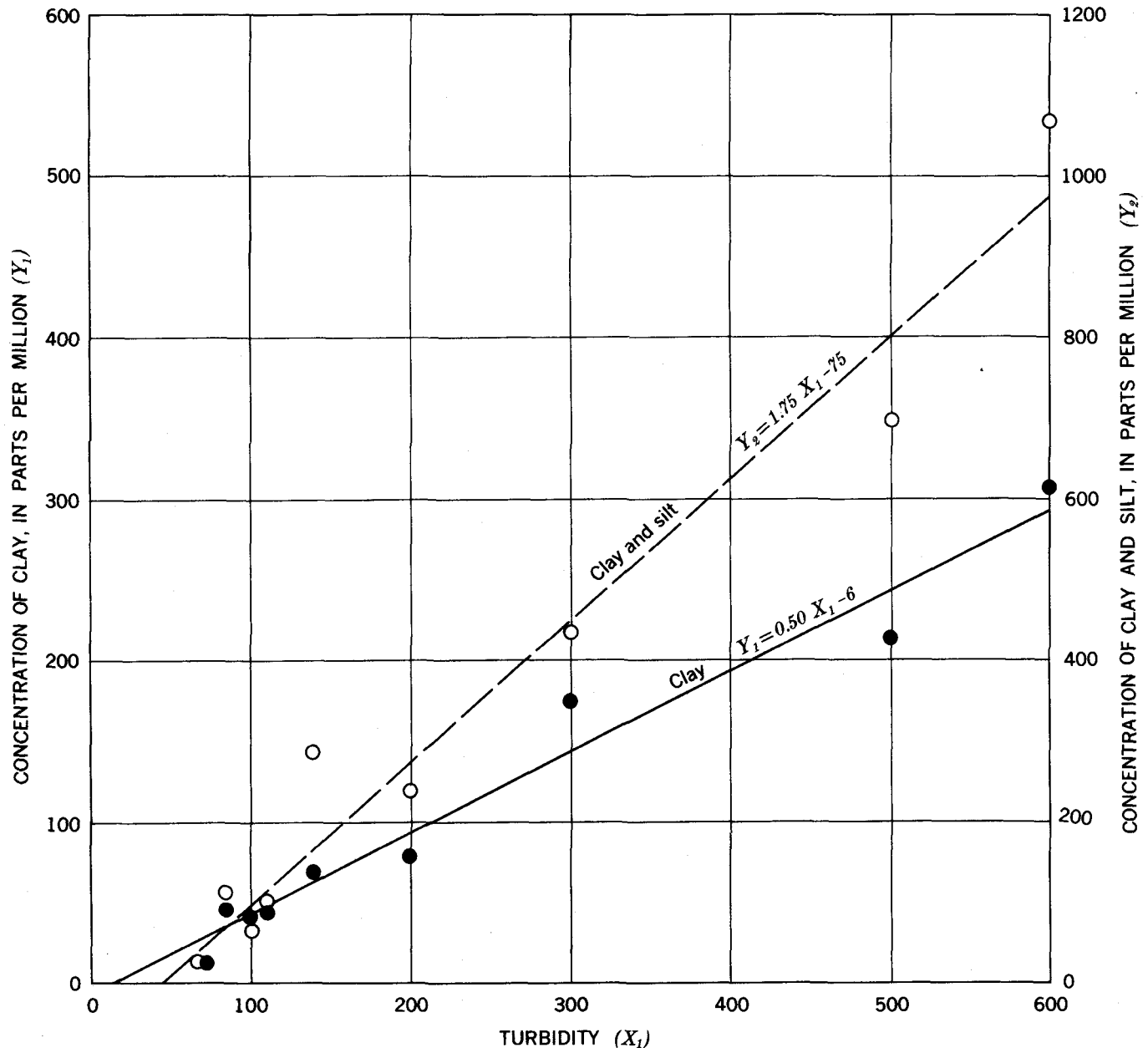
FIGURE 8.—Relation of clay and of silt and clay concentration to turbidity, Chamberlin Creek, Alaska.

The last adjustment in the second method is obtained by contrasting the time-weighted mean sediment discharge with the water discharge-weighted mean sediment discharge as shown at the bottom of column 10 in table 7.

The suspended-sediment discharge computed by these two methods for specific days is plotted with the daily mean water discharges on figure 10. The daily suspended-sediment discharge, estimated on the basis of the hydrograph of the mean daily water discharge, and the mean of the computed values of sediment discharge are given in table 9. The total for both months is nearly 1,200 tons for about 890 cfs-days of water discharge.

This is 820 tons of sediment per square mile of drainage area. The water discharge-weighted mean suspended-sediment concentration is then about 500 ppm for this period of record. The wide fluctuation in suspended-sediment discharge is largely explained by the fact that the concentration and water discharge change rapidly and in the same direction.

The relation of the suspended-sediment discharge at the gaging station 800 feet downstream from the glacier to that released by the glacier cannot be studied for lack of information concerning the quantity and character of sediment yielded by ablation. This information might indicate how a glacier forms moraines and chan-
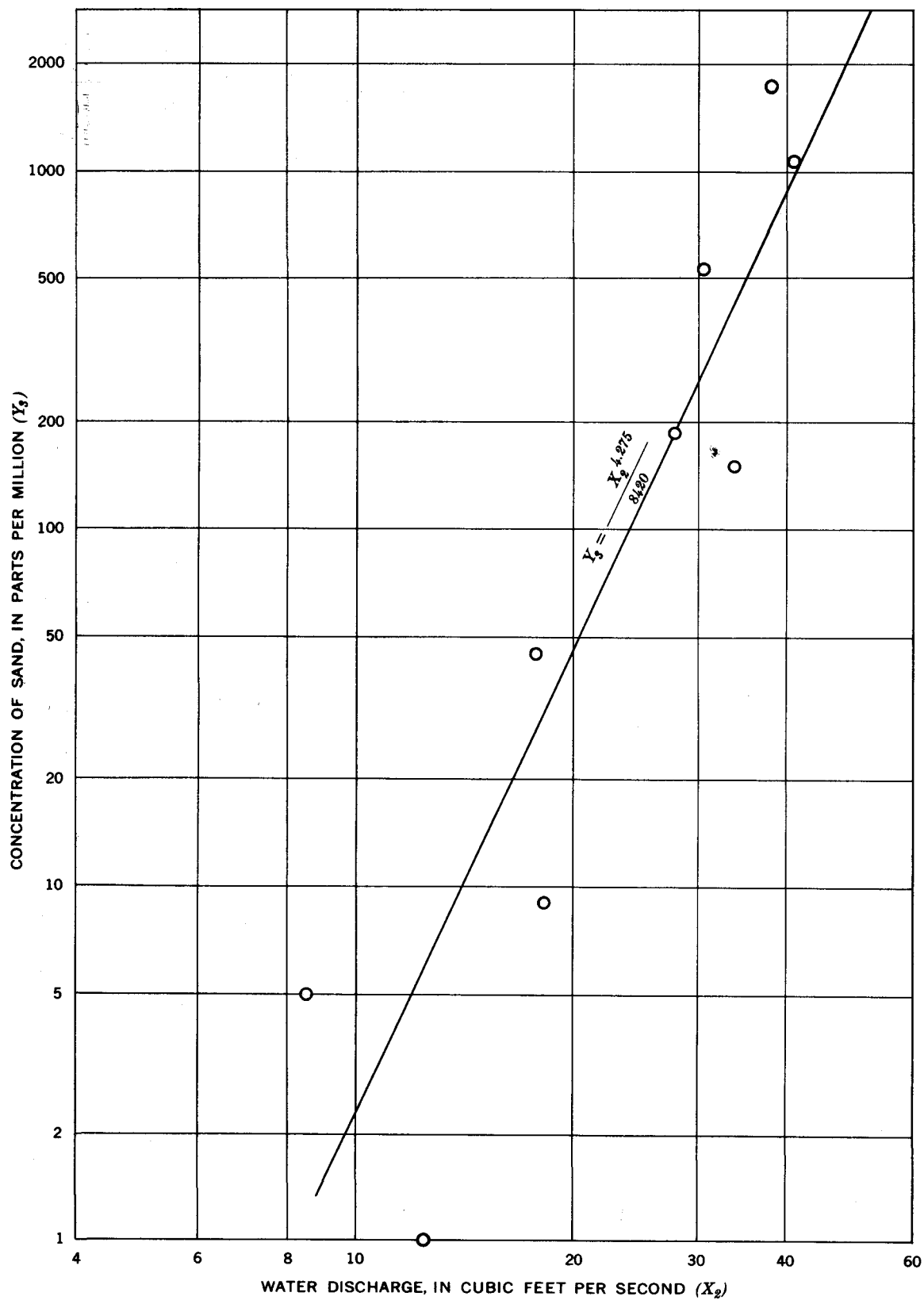
FIGURE 9.—Concentration of suspended sand in relation to water discharge, Chamberlin Creek, Alaska.
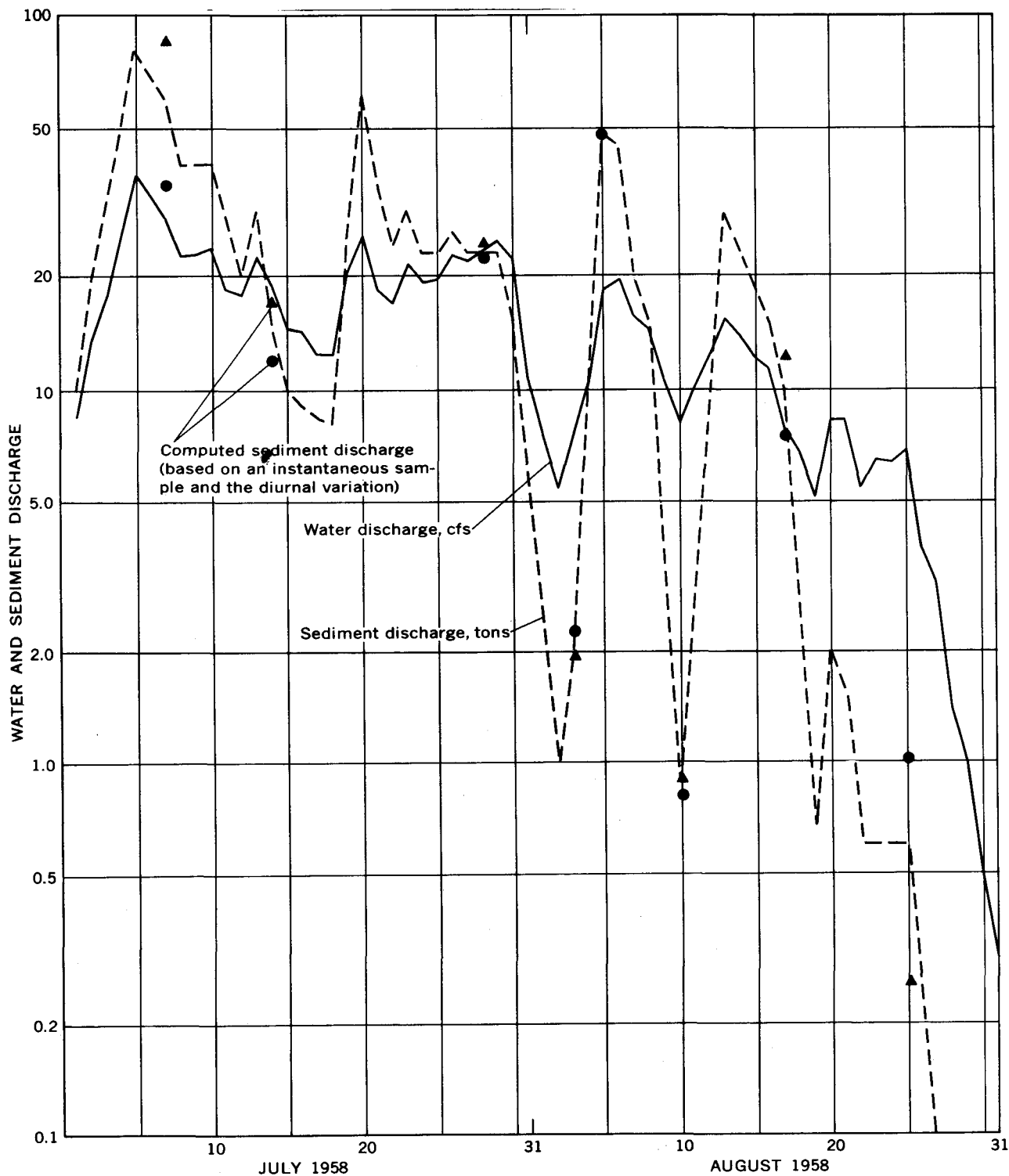
FIGURE 10.—Daily water and sediment discharge, Chamberlin Creek, Alaska.

nels to carry its runoff. Mr. Anderson noted that a large percentage of the sediment in transport this season appeared to be derived from erosion of the moraines downstream from the snout of the glacier.

EVALUATION OF THE STUDY

The most critical evaluation of the conduct of any study is the answer to the question, "What should be

TABLE 9.—*Daily mean water and suspended-sediment discharge, Chamberlin Creek, Alaska*

Date (1958)	Water (cfs)	Suspended sediment (tons)	Date (1958)	Water (cfs)	Suspended sediment (tons)
July 1	8.5	10	Aug. 1	7.5	2
2	13.6	20	2	5.4	1
3	17.3	30	3	7.5	2
4	25.9	50	4	10.3	10
5	37.4	80	5	18.4	48
6	32.7	70	6	19.6	45
7	28.2	59	7	15.7	20
8	22.6	40	8	14.3	15
9	22.9	40	9	10.5	4
10	23.5	40	10	8.1	.9
11	18.4	27	11	10.1	3
12	17.9	20	12	12.2	9
13	22.4	30	13	15.4	29
14	18.9	15	14	13.9	24
15	14.7	10	15	12.1	19
16	14.2	9	16	11.3	15
17	12.5	8	17	7.8	10
18	12.4	8	18	6.8	3
19	20.3	28	19	5.1	.7
20	25.3	60	20	8.2	2
21	18.4	35	21	5.8	2
22	17.0	24	22	6.4	.6
23	21.3	30	23	6.3	.6
24	19.2	23	24	6.8	.6
25	19.6	23	25	3.7	.6
26	22.7	26	26	3.0	.2
27	21.8	23	27	1.4	----
28	23.1	23	28	1.0	----
29	29.5	23	29	.5	----
30	22.2	15	30	.3	----
31	10.7	6	31	----	----
Total, July and August				890.5	1,172.2

done differently if the study were repeated?" In spite of the fact that the sampling program was formulated without prior knowledge of chemical, sediment, or hydrologic conditions that would be encountered, much useful information was obtained, and without excessive costs in time or money.

HYDROCHEMICAL

Analyses of most of the samples provided useful information. The analysis of the sample from Lake Peters contributed little to the investigation, other than to indicate that the total drainage to the lake probably is similar chemically to the drainage in the area of study. An analysis of an isolated segment of a complex hydrologic system is not very useful for hydrochemical interpretations. One cannot add to it, subtract from it, compare it with anything else, or manipulate it in any way to learn something about the system.

Probably the weakest points in the project were the absence of chemical data on seepage from the ground environment, the lack of quantitative measurements of ablation, and the failure to get some approximation of the volume of underflow at the gage.

The importance of the chemistry of the water from the ground environment would not have been missed if the field party had had with them a portable conductivity apparatus to measure differences in concentration

of water comprising the various parts of the hydrologic system. The application of chemical measurements to hydrologic problems usually is a study of chemical differences. One samples these chemical differences whenever and wherever they occur, and combines the field and laboratory results with the available hydrologic data for the solution of problems—each supplements the other.

Quantitative measurements of ablation should be given higher priority in future studies because of its multiple importance in defining the hydrology and cross checking hypotheses of origin and movement of solutes and water.

Without a measure or reasonable approximation or underflow at the gage, an estimate of the chemical degradation of the drainage area is impossible. Although the volume of underflow may not have been an appreciable fraction of the total flow, the quantity of dissolved material transported by underflow may have been an appreciable fraction of the total, because its concentration could easily be five times that of channel flow. Collection of core samples and measurements of slope and cross-sectional area of the saturated channel fill are strongly recommended in future studies.

Spectrographic analysis for the minor (trace) dissolved elements was attempted, but the weight of residue from the water left after the major constituents had been determined was insufficient for reliable results. These waters were so dilute that the residue from several liters would have been required for most samples. In future studies, larger volumes of sample could be collected or, more simply, water could be evaporated at the glacier and the residue returned to the laboratory for spectrographic analysis.

SEDIMENT

The diurnal variation of suspended sediment, as defined by the one set of 1-liter samples collected about every 2 hours in a 24-hour period, has limitations because the set must be considered as a single sample of this phenomenon. Fortunately, the timing of the observation was such that it probably represents most of the flow conditions. For good definition, additional samples depicting diurnal variation should have been obtained in the first and third weeks of July. Two of the three sets of samples could be collected at 3- or 4-hour intervals instead of the 2-hour intervals used for this study.

Single samples to define the day-to-day change of suspended sediment should be collected from 2 to 5 times a week instead of only 6 times during the 2-month period, for this type of stream. Better definition of the diurnal and day-to-day changes in sediment concentration could have been obtained with more turbidity

readings, which together with the water discharge, define indirectly the suspended solids (figs. 8, 9). Because of the deficiency in the sampling program, the computed suspended load for the period is rather crude but is probably not in error by more than 20 or 30 percent.

The steep gradient of the stream and the wide range in sizes of sediment in the supply undoubtedly result in a very high bedload. Bedload is defined here as the rock and sand in transport which was not sampled as suspended load. The bedload could have been estimated by observing the rate of filling of a small pool excavated in the streambed for at least three different rates of water discharge. If it is assumed that the channel was not scoured to the compacted till, the rate of bed-material transport should be approximately related to water discharge. Mr. Anderson noted difficulty in operating the current meter because of the gravel and rocks in transport.

The relation between sediment yield at the gaging station and that supplied by the glacier during the 2-month period is probably poor because of the erosion of moraines in part of the 800-foot reach downstream from the snout of the glacier. An evaluation of the sediment discharge at or near the glacier snout would logically prove worthwhile. Information concerning the amount of sediment contained in the glacier at the ablation faces would be useful for determining the yield of the glacier and consequently help evaluate the formation of moraines and channel degradation or aggradation downstream from the glacier snout.

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Some Observations on the

Hydrochemistry and

Sedimentation of the

Chamberlin Glacier Area

Alaska

By FRANK H. RAINWATER *and* HAROLD P. GUY

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 414-C

Analysis of a program of sampling and measuring precipitation and melt water to determine water quality and suspended-sediment concentration, July-August 1958, and interpretation and summary of available data

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

CONTENTS

ILLUSTRATIONS

TABLES

III

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

SOME OBSERVATIONS ON THE HYDROCHEMISTRY AND SEDIMENTATION OF THE CHAMBERLIN GLACIER AREA, ALASKA

By Frank H. Rainwater and Harold P. Guy

ABSTRACT

This report describes a reconnaissance of the hydrochemical and sediment characteristics of Chamberlin Glacier near Barter Island Alaska. Twenty-eight observations of the streamflow and one of the precipitation were made to define the important aspects of hydrochemistry and sedimentation during the 2-month period of record July to August 1958. The sampling program had to be planned without prior knowledge of the conditions in the vicinity of the glacier. The adequacy of this program is evaluated in the last section of the report and suggestions are offered that may be useful in designing future studies of this kind.

These limited observations are sufficient to define the important dissolved constituents in the glacial melt waters and nearby streams. The dissolved solids range from 7 ppm (parts per million) in a composite sample of precipitation, to 55 ppm in a nearby nonglacial stream. The inverse relation of water hardness to quantity of streamflow is defined with sufficient accuracy to empirically subdivide total flow into components of water from ground environment and water from glacial melt water and precipitation.

The streambed contains fragments of well-foliated schist from the Neruokpuk formation, that range in size from boulders to sand—a sample contained 1 percent sand, 49 percent gravel, and 50 percent cobbles. Diurnal and day-to-day variation in suspended-sediment concentration, load, and particle size are appreciable. Excellent correlations are demonstrated between (a) the concentration of sand and water discharge and (b) the concentration of clay, or clay plus silt, and turbidity.

INTRODUCTION

Glacial hydrochemistry and sedimentation can be very intriguing because the environmental factors molding the flow and composition of streams behave differently around glaciers than at lower altitudes or latitudes. This paper is a study both of (a) the hydrochemistry and sedimentation of Chamberlin Glacier as determined by limited observations, and (b) sampling and interpretive techniques perhaps applicable to glaciers in general. Experience in making relevant measurements and in interpreting the data from such environments is meager. Subsequent glacial research may benefit from the successes and shortcomings of this investigation.

Chamberlin Glacier is in the eastern Brooks Range about 60 miles south of the Arctic Coast and 100 miles west of the Canadian border. The immediate area is shown in figure 1. The drainage area of Chamberlin Creek at the gage is 1.46 square miles, of which 0.93 square mile is covered by the glacier. During the summer of 1958 a team of scientists supported by the Air Force Cambridge Research Center studied the glacier and surrounding terrane in detail. D. G. Anderson was the U.S. Geological Survey's representative. As a part of his hydrologic studies, he collected water samples for the chemical and sediment phases of the investigation. For the interpretations in this report the authors drew also from data and preliminary reports compiled by members of the team.

MEASUREMENT PROGRAM

The sampling program was carefully planned because all equipment and samples must be transported by plane into and out of a base camp and carried several miles over steep terrane on a packboard. Samples must be returned the same way. Except for turbidity, field measurements were ruled out because it was easier to bring the water to the laboratory than to take the laboratory to the water. In arranging the sampling program, experience gained from hydrochemical and sediment studies of other locations was drawn upon to anticipate what chemical and sediment measurements would be useful, what concentration ranges would be found, and what volumes of sample would be required. In most instances a single sample served for both chemical and sediment analysis.
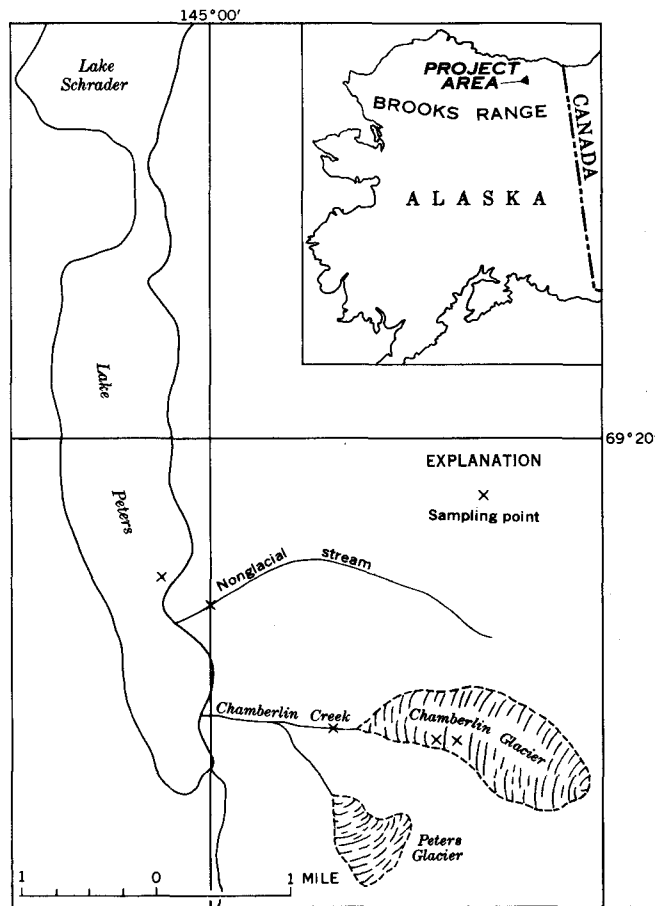
FIGURE 1.—Map of Chamberlin Glacier area, Alaska, showing location of sampling points.

The plan, in general, was to collect a few large-volume samples that were representative of the major chemical or hydrologic environments for comprehensive analysis, and to supplement these with a larger number of small-volume samples collected to define the chemical and sediment characteristics of specific hydrologic events. Analyses of the large-volume samples would show which ions were the most useful in hydrochemical interpretation. The small-volume samples would then be analyzed for these ions only. Analyses representing the major hydrologic environments are shown in table 1. The composites reported in this table were prepared at the glacier by pouring equal volumes of sample collected each day into a large polyethylene bottle.

One of the specific hydrologic events is the diurnal variation in flow from the glacier. Small-volume samples were to be collected every 2 hours for a 24-hour period to evaluate the important water-quality factors, including suspended sediment. The results of analyses of these sequential samples are given in table 2.

A third set of samples (small-volume) were to be collected periodically about once every 2 weeks to define the change of chemical quality and suspended sediment with time. Analyses of these samples are given in table 3.

The samples of suspended sediment were collected in plastic bottles by hand-lowering the bottle vertically at a uniform rate from the water surface to the streambed and return, at one or more representative verticals in the channel cross section.

Turbidity measurements were planned because of possible correlation with the concentration of silt and clay in suspension. Turbidity was measured in the field with the U.S. Geological Survey turbidity rod (Newell, 1902). Numerical results obtained with this instrument are not strictly comparable to results with other instruments but are believed to be more realistic than measurements made in the laboratory several weeks after the sample is collected.

Three half-shovels of bed material were collected to give an idea of the size distribution and of the physical

TABLE 1.—*Water-quality observations of major hydrologic environments, Chamberlin Glacier area, Alaska*

[Analyses in parts per million except as indicated]

Environment and date of collection (1958)	Altitude (feet above mean sea level)	Relative deuterium [1]	Water discharge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Silica (SiO₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO₃)	Sulfate (SO₄)	Chloride (Cl)	Ammonia nitrogen (as N)	Nitrate (NO₃)	Dissolved solids	Hardness as CaCO₃ Total	Hardness as CaCO₃ Noncarbonate	Specific conductance (micromhos at 25°)	pH
Composite of precipitation: July and August	6,100	−14.4				0.0	0.7	0.1	0.3	0.1	5	0.4	0.0	0.17	0.0	7	2	0	8	5.7
Surface ice from glacier: Aug. 20	6,200	−16.5				.0	.4	.0	.8	.7	7	.6	.1	.29	.0	9	1	0	9	6.0
Subsurface ice from glacier: Aug. 14	6,000	−14.5				.0	.8	.0	.7	1.9	9	.4	.0	.32	.0	11	2	0	16	6.2
Unnamed nonglacial tributary to Lake Peters: July 30			8	51	43	1.3	12	3.3	.2	.1	35	19	.2	.32	.0	54	43	14	97	7.0
Lake Peters: Sept. 2		−14.3				.8	8.2	1.9	.2	.3	25	9.4	.3	.00	.0	35	26	6	60	7.0
Composite (time-weighted) of Chamberlin Creek at gaging station, 800 ft downstream from glacier snout:																				
July 7–14		−16.7				.3	1.5	.1	.1	.0	9	1.4	.2	.18	.0	11	4	0	11	6.5
Aug. 17–31		−15.7				.4	6.1	1.5	.2	.2	12	15	.7	.02	.0	32	20	10	52	6.6

[1] Expressed as percent depletion of that found in Lake Michigan.

TABLE 2.—*Sequential observations of water quality, August 5 and 6, 1958, 800 feet downstream from Chamberlin Glacier, Alaska*

Time	Water dis-charge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Sulfate, SO₄ (ppm)	Hardness as CaCO₃ (ppm)	Specific conduct-ance (microm-hos at 25°C)	Suspended sediment Concen-tration of sample (ppm)	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	4.000
2:00 p.m.	30.3	52	34	0.6	4	10	971	---	18	26	34	40	45	50	67	71	80	89	100
4:00	38.0	54	34	2.0	5	14	2,820	---	11	19	27	32	38	43	49	65	76	86	96
6:10	40.9	52	34	3.0	5	12	1,780	---	12	18	27	32	39	46	57	78	94	100	---
8:00	27.8	45	34	1.6	3	9	408	13	19	29	42	49	54	58	64	74	86	95	100
10:00	18.2	45	34	2.4	4	10	110	---	42	54	78	89	92	92	92	96	100	---	---
12:00	12.4	44	34	1.6	5	12	71	---	62	80	88	93	99	100	---	---	---	---	---
2:00 a.m.	9.2	42	34	.8	6	14	} 30	---	46	61	68	80	84	89	95	98	100	---	---
4:00	8.5	43	34	1.2	7	16													
6:00	7.8	46	34	1.0	7	16													
8:00	7.8	45	34	1.2	6	16													
10:00	17.7	52	34	1.2	5	13	161	18	29	42	56	68	72	78	86	94	100	---	---
12:00	33.8	53	35	1.0	4	10	440	10	16	25	35	44	50	63	74	88	98	100	---

Time (weighted mean)_____ 574
Discharge (weighted mean)_____ 965

TABLE 3.—*Periodic observations of water quality, 800 feet downstream from Chamberlin Glacier, Alaska*

Date (1958)	Time	Water discharge (cfs)	Temperature (°F) Air	Temperature (°F) Water	Sulfate, SO₄ (ppm)	Hardness as CaCO₃ (ppm)	Specific conduct-ance (mi-cromhos at 25°C)	Suspended-sediment concentra-tion (ppm)	Turbidity
July 7	11:50 a.m.	33.8	---	---	1.0	4	12	265	---
14	3:12 p.m.	29.0	---	---	1.2	4	11	616	---
28	3:00	37.3	---	---	1.0	5	12	758	---
Aug. 3	1:55	12.4	---	---	1.2	6	15	84	---
5 [1]	6:30	41.7	---	---	.8	4	10	1,090	---
10	5:30	14.2	48	34	1.6	6	14	85	80
17	11:40 a.m.	14.7	41	34	2.4	8	20	131	150
26	5:15 p.m.	8.5	42	34	2.6	9	24	60	70
28	11:45 a.m.	1.6	---	---	17	25	60	2	20

[1] Sample collected at glacier snout.

and chemical properties of the particles. This sample is described in the section, "Bed material."

HYDROCHEMISTRY

CHEMISTRY OF THE WATER

The concentrations of dissolved solids shown on figure 2, for the major hydrologic units are in logical sequence, beginning with precipitation. This speaks well for the care in collecting, handling, and analyzing the samples because contamination is a serious problem when dealing with such dilute waters. The difference in the two composites from Chamberlin Creek indicates that some seasonal variation exists. The relatively high concentration of the nonglacial tributary, even when the sample was collected soon after a rain, suggests that, in its brief contact with weathered and unweathered soil and rocks, the water may pick up considerable soluble material.

All of Chamberlin Creek above the gage drains the Neruokpuk formation or glacial till derived from it. Although the dominant rocks are crystalline there are sufficient corrodible minerals to influence the chemistry of the water that comes in contact with the ground.

The saturation index is an indication of instability with respect to calcium carbonate deposition and solu-tion and is defined as the algebraic difference between the actual pH of a sample and its computed pH$_s$. The term pH$_s$ designates the pH at which water of given calcium content and alkalinity is in equilibrium at the temperature of the water. Waters of the Chamberlin region are highly corrosive, as indicated by the negative calcium carbonate saturation indexes shown in table 4. Such waters, for example, will readily dissolve limestone and other minerals weathered by carbonic acid, and they will also corrode iron pipes. These indexes are not exact because the temperatures used in the computations were estimates and the pH values used were not measured at the time of collection. However, the error probably does not exceed a few tenths of a pH unit. The magnitudes of the indexes are inversely proportional to the waters' contact with rocks and soils. Not only can the waters dissolve minerals, but evidently do so rapidly when given the opportunity for contact.

TABLE 4.—*Saturation indexes of water samples of the Chamberlin Glacier area, Alaska, 1958*

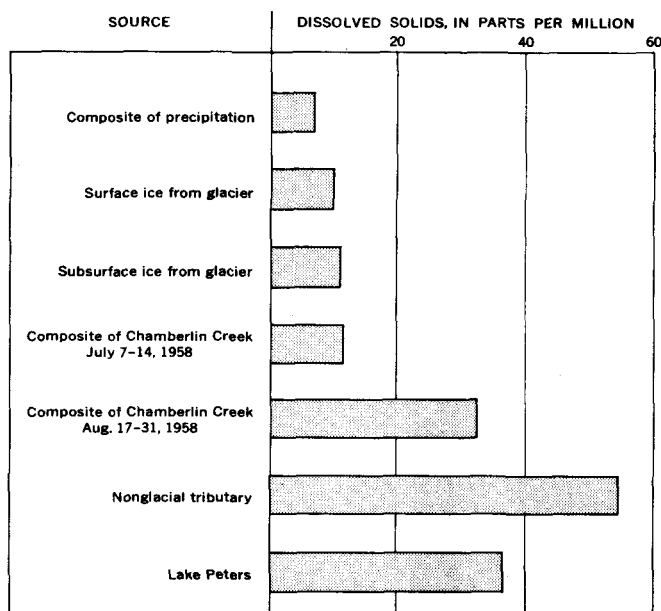| Source	Index
Composite of precipitation	−5.5
Surface ice from glacier	−5.2
Subsurface ice from glacier	−4.7
Composite of Chamberlin Creek (July 7–14)	−4.3
Composite of Chamberlin Creek (August 17–31)	−3.4
Nonglacial tributary	−3.1
Lake Peters	−2.6

FIGURE 2.—Dissolved solids of major hydrologic units of the Chamberlin Glacier area, Alaska.

Nitrate is completely absent, but ammonia nitrogen is present in large amounts in all but one of the samples tested. The significance of this condition is not known. It may be related to the oxidation-reduction system of the waters, or more simply, to a deficiency of the glacial till in certain types of oxidizing bacteria that are commonly active in soils. Measurements of oxidation-reduction potential of the waters were not made at the glacier, and could not be made in the laboratory several weeks after the samples had been collected.

The low percentage of sodium and chloride in the precipitation suggests that the ocean is not the dominant source of chemical salts in the rains of this region. The deuterium measurements (table 1) further substantiate this hypothesis. The samples of rain, glacial ice, and streamflow are low in deuterium content for water originally derived from the sea and precipitated at summer temperatures. The precipitation in the study area would have to be derived from a source that is about 10 to 15 percent lighter than sea water. Irving Friedman (written communication, 1959) postulates that snow on the Arctic Ocean ice and continental water at altitudes lower than the glacier satisfy this condition, and concludes that the waters of the Chamberlin area probably have such origins.

The ions that account for the differences in concentrations of dissolved solids are shown by figure 3. This illustration is a plot of the concentration of the individual ions against total ionic concentration expressed in terms of specific conductance. The ordinates are scaled in proportion to the precision of the individual laboratory measurements. This type of treatment is impera-

tive lest hydrological, chemical or geological significance be falsely attributed to reported concentration differences arising from the laboratory methods themselves.

The ions that contribute the most to the differences in dissolved-solids content of the streamflow are those which are related to the nature of the rocks of the area—in this area calcium and magnesium (hardness), bicarbonate (alkalinity), and sulfate. Consequently, the concentrations of these ions are indexes of the amount of contact between water and local rocks and soils. Hardness is the best index because the slope of its line (fig. 3) is maximum, and the scatter of the points about its line is minimum. Alkalinity and sulfate follow as the second and third choices as indexes.

One might normally expect all intercepts on figure 3 to be zero. This expectation is more often false than true, particularly when dissolved carbon dioxide (carbonic acid) or other gases that ionize in solution are present. The low pH of the precipitation and glacial melt water suggests the presence of ionized carbonic acid. The negative intercept of the alkalinity line with the abscissa is comparable in magnitude to the positive intercept of the hardness and silica lines. Apparently about 3 to 5 micromhos of conductance is attributable to carbonic acid.

The slight negative slope of the sodium line may indicate that sodium in the rainfall and glacial melt is exchanged for calcium when the water contacts the rocks and soil. However, this slope may be due only to chance or limitations of the data.

HYDROLOGIC INFERENCES FROM CHEMICAL DATA

The chemical indexes of a water's environment provide a basis for hydrologic deductions not available from streamflow measurements. A current meter does
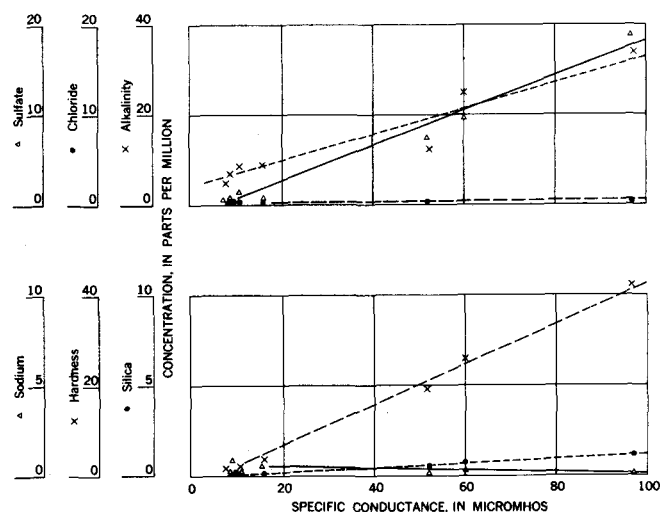

FIGURE 3.—Relations of ions to total concentration, Chamberlin Glacier area, Alaska.
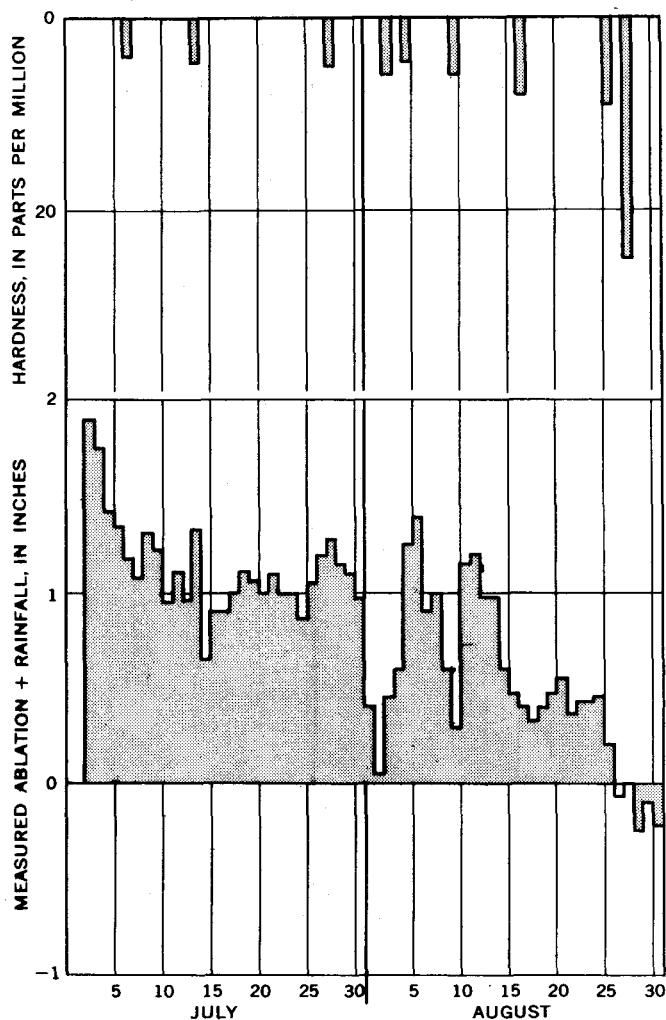
FIGURE 4.—Response in concentration of Chamberlin Creek to dilution, Chamberlin Glacier area, Alaska.

not differentiate the complex past environments of the water that spins its cups.

It has been shown in the preceding section that the water readily dissolves material from the ground. In the Chamberlin drainage basin above the gage, water comes in contact with the soil and rock in two principal ways. First, and probably the most important chemically, is the seepage through the silty till of melt water from the glacier or ice-cored moraines, frozen soil, and ice lenses. Second, and of less importance, is the water-ground contact of underflow beneath the glacier. Consequently, the flow that has chiefly a ground environment can be separated, on the basis of chemical composition, from precipitation and glacial melt water that flow over thoroughly leached outwash gravel and cobbles.

The relation of water hardness at the gaging station to measurements of ablation plus rainfall is shown on figure 4. The ablation data are not quantitative for the

entire glacier. During periods of appreciable ablation, the water passing the gage on Chamberlin Creek showed little evidence of ground influences. These influences, though, increased a little during August as ablation decreased; and then on August 28, 2 days after ablation ceased, the sample concentration reached the maximum for the period. Hence, the chemical makeup of water passing the gage must respond rapidly to variations in percentages of water from the two environments.

Correlations of (a) factors effecting ablation with (b) diurnal fluctuations in the concentrations of samples collected every 2 hours for a 24-hour period (Aug. 5 and 6, 1958) at the gage, demonstrate that the variation in the relative contributions of glacial melt water to Chamberlin Creek lag behind the actual increase and decrease in air temperature and radiation. However, quantitative deductions cannot be made from the sparse data available. To understand this phenomenon completely would require a rather comprehensive and continuous heat budget for the glacier. These chemical fluctuations do, nevertheless, add evidence substantiating the hypothesis of a 2-component system of flow. The system consists essentially of a rather stable discharge from the ground environment that is diluted to varying degrees with relatively pure precipitation and glacial melt water.

A general equation can be developed to approximate proportions of flow from each environment for any given flow at the gage. Figure 5 shows the relation of hardness to water discharge in the channel.

$$C_3 = aQ_3^{-0.6}$$

where

C_3 is hardness at the gage, in parts per million,
Q_3 is discharge at the gage, in cubic feet per second, and a is a constant$=34$ ppm.

From the foregoing discussion of the chemistry of the water from the two sources, we know that

$$Q_2/Q_1 \propto C_3$$

where

Q_1 is uncontaminated runoff, in cubic feet per second,
Q_2 is flow from the ground environment, in cubic feet per second, and
C_3 is hardness concentration at the gage, in parts per million.

Note that none of the samples plotted on figure 5 represent all Q_1 or all Q_2. Without data representing the chemical concentration of flow from the ground environment, one cannot mathematically relate the flow ratio to total channel flow. Nevertheless, the slope of the regression line on figure 5 can be used empirically to separate the two types of flow. With water discharge expressed in cubic feet per second,

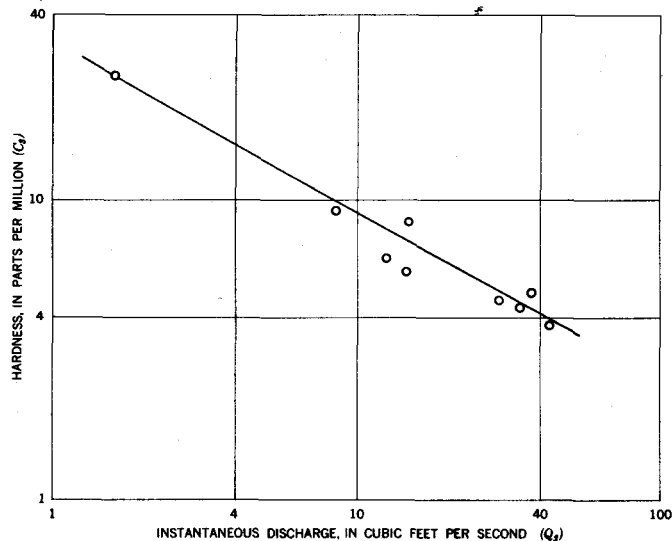$$Q_2/Q_1 \approx Q_3^{-0.6} \text{ or } Q_1/Q_2 \approx Q_3^{0.6}$$

FIGURE 5.—Relation of water hardness to stream discharge, Chamberlin Creek, Alaska.

The concentration of water from ground environment, C_2, computed from values of C_3 and Q_3 on figure 5 and of Q_2 in table 5, range from 40 to 55 ppm at channel flows ranging from 40 to 2 cfs, respectively. These are of the logical magnitude. That the concentration of the "ground-water" contribution decreases with the increasing discharge is to be expected and is consistent with observations elsewhere. Furthermore, the hardness of the one sample from the nonglacial tributary was 43 ppm, which is of the same magnitude as these computed concentrations.

TABLE 5.—*Approximate percentage makeup of channel flow 800 feet downstream from Chamberlin Glacier, Alaska*

Channel flow, Q_3 (cfs)	Q_1/Q_2	Precipitation and glacial melt water, Q_1 (cfs)	Water from ground environment, Q_2 (cfs)
2	1. 5	1. 2	0. 8
4	2. 3	2. 8	1. 2
7	3. 2	5. 3	1. 7
10	4. 0	8. 0	2. 0
20	6. 0	17	3
40	9. 2	36	4

The approximate ratios and the values of Q_1 and Q_2 for selected channel flows, given in table 5, look realistic and they can be checked roughly by computing the hardness of Q_2 for different channel flows. This computation uses the basic addition-of-loads equation, $Q_1 C_1 + Q_2 C_2 = Q_3 C_3$. The hardness of precipitation and glacial melt water is nearly zero. Hence, the equation becomes,
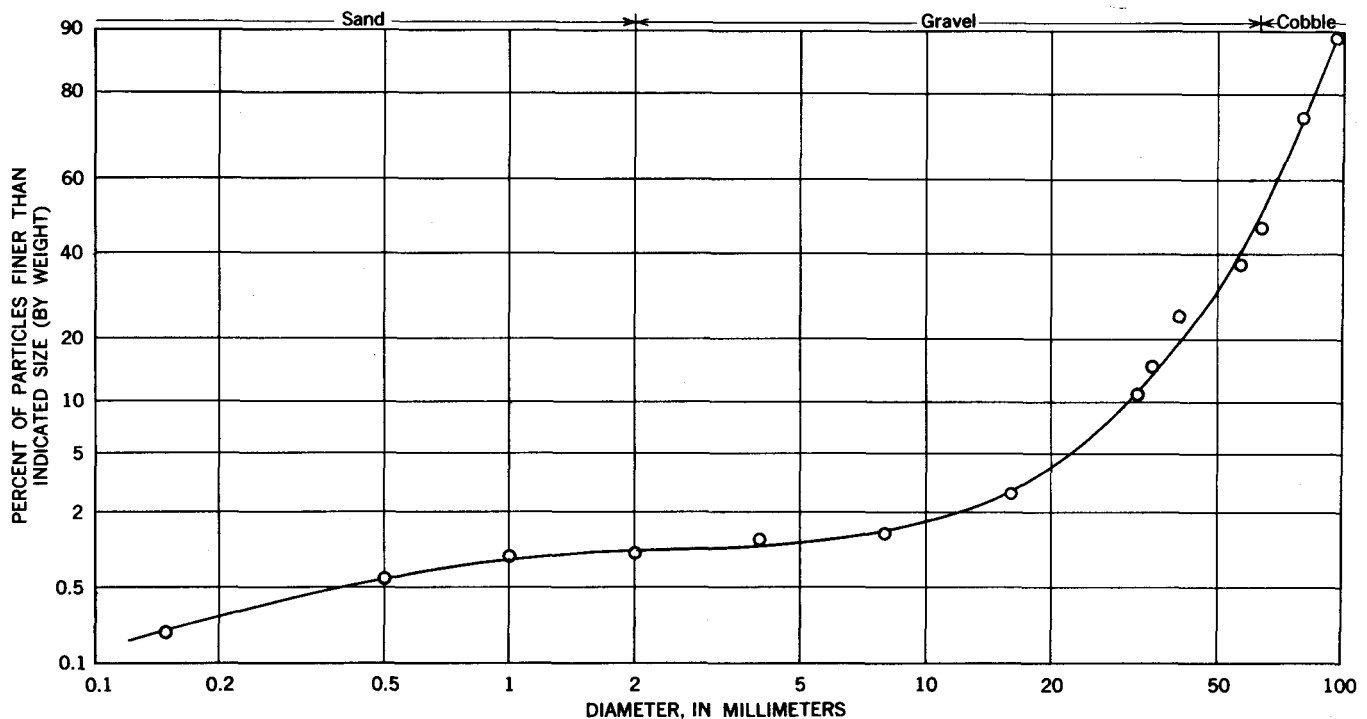
$$C_2 = \frac{Q_3 C_3}{Q_2}.$$

SEDIMENTATION

BED MATERIAL

On August 25, three half-shovels of typical bed material were collected from the channel near the gaging station (800 ft downstream from the glacier snout) where water no longer flowed. Figure 6 illustrates the

FIGURE 6.—Particle-size graduation of bed material, Chamberlin Creek, Alaska.

size gradation of this material—about 1 percent sand, 49 percent gravel, and 50 percent cobbles. The particles are subangular, showing some evidence of wear, and the sphericity of most particles ranges from 0.50 to 0.80.

While digging the stilling wells for the stage recorders Mr. Anderson noted that the valley fill immediately adjacent to and under the stream is somewhat consolidated and contains considerably more sand and fines than indicated by the bed-material sample. He noted also that ground water did not readily flow into his excavation except for some small "pipes" of flow, which generally could be plugged with small rocks and clay.

Estimates of permeability, based on size distribution, visual observation, angularity of the rocks, and slope in the stream valley (about 25 percent), suggest that the valley deposit may transmit a water discharge ranging from 0.05 to 1.0 cfs per 100 square feet of cross-sectional area. The total cross-sectional area of the till in the valley at the gaging station is unknown.

The rocks in the channel, derived from the Neruokpuk formation, are largely metamorphosed graywacke that has good remnant clastic texture. The major part of the sample consists of fragments of well-foliated quartz schist containing numerous veins of massive quartz. The rocks are about 65 percent quartz; the remaining fraction includes feldspar, chlorite, biotite, epidote, amphibole, pyrite, and smaller quantities of other minerals.

COMPOSITION OF FINE SEDIMENT

Spectrographic analysis of fine suspended sediment in streamflow from Chamberlin Glacier indicates that the minor constituents are similar to shales as given by Krauskopf (1955). Quantitative values are compared in table 6. Tin and strontium are below the range reported for average shales. Elements ordinarily present in shales but not found by this analysis are cesium and zinc. These characteristics indicate a trend toward an arenaceous type of material. In summary, the composition is similar to what might be expected from the finer grained portions of the quartzose schist in the bed material.

DIURNAL VARIATION OF SUSPENDED SEDIMENT

One of the most important consequences of snow and ice melt is the diurnal fluctuation in concentrations of suspended sediment carried in transport by the stream. Thus, beginning at 2:00 p.m. on August 5, 1958, and ending at noon the next day, suspended-sediment samples of a 1-liter volume were collected every 2 hours at the gaging station, which is located about 800 feet downstream from the glacier snout.

TABLE 6.—*Comparison of the composition of sediment from Chamberlin Glacier with that of shales given by Krauskopf*

Element	Concentration, in parts per million	
	Chamberlin Glacier	Krauskopf (1955)
Fe	30,000	
Mg	7,000	
Ca	700	
Na	3,000	
K	15,000	
Ti	7,000	
Mn	300	
Ba	300	300–600
Be	3	1–6
Co	15	10–50
Cr	70	50–190
Cs	0	10
Cu	70	0–55
Ni	30	20–100
Pb	30	20
Sc	15	0–30
Sn	15	40
Sr	30	100–1,300
V	70	50–300
Y	30	
Yb	3	
Zn	0	50–300
Zr	300	60–360

In addition to the water discharge, turbidity and air and water temperatures were recorded.

The particle-size gradation and the sediment concentration were measured in each of the 12 samples. The particle-size analyses were made by the bottom-withdrawal-tube method; the settling medium used was a mild chemical dispersant in distilled water. The concentration for each sample was determined from the sum of the residue of each withdrawal. The samples from the period of low-water discharge, at 2, 4, 6, and 8 a.m. on August 6, were combined to obtain enough sediment for a reliable analysis.

The results of the particle-size analyses and concentration determinations are summarized in table 2. Clay is defined as material finer than 0.004 mm, sand as coarser than 0.062 mm, and silt as the fraction between these limits. The percentages in the table can then be used together with the sample concentration to define the concentration of the clay, silt, and sand fractions in transport. These concentrations and the associated water discharge and turbidity for each sample are given in table 7. The instantaneous load of each fraction transported at the time each sample was collected is also shown in table 7.

The patterns of diurnal fluctuation in water discharge, turbidity, and concentration of suspended clay, silt, and sand are shown in figure 7. The peak concentrations precede the peak water discharge about 1 or 2 hours. The three right-hand columns of table 7 show the ratios of the instantaneous water discharge, concentration, and load to their respective means for each of the observations. These ratios represent the general expression of variation for this

TABLE 7.—*Suspended-sediment concentration and discharge data for sequential observations, August 5 and 6, 1958, Chamberlin Creek, Alaska*

Time	Water discharge (cfs)	Turbidity	Concentration (ppm)			Instantaneous discharge (tons per day)				Ratio to mean		
			Clay	Silt	Sand	Clay	Silt	Sand	Sum	Water discharge	Concentration	Sediment discharge
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
2:00 p.m	30.3	300	175	262	534	14.3	21.4	43.8	79.5	1.44	1.69	1.46
4:00	38.0	600	305	765	1,750	31.3	78.5	180	290	1.81	4.92	5.32
6:10	40.9	500	214	486	1,080	23.7	53.7	119	196	1.95	3.11	3.59
8:00	27.8	200	78	142	188	5.9	10.7	14.1	30.6	1.32	.71	.56
10:00	18.2	110	46	55	9	2.3	2.7	.44	5.4	.87	.192	.099
12:00 p.m	12.4	100	44	26	1	1.5	.87	.03	2.4	.59	.124	.044
2:00 a.m	9.2	75								.44	.052	.012
4:00	8.5	75	14	11	5	.32	.25	.11	.68	.40	.052	.012
6:00	7.8	70								.37	.052	.012
8:00	7.8	65								.37	.052	.012
10:00 a.m	17.7	85	47	69	45	2.2	3.3	2.2	7.7	.84	.281	.141
12:00 m	33.8	140	70	220	150	6.4	20.1	13.7	40.2	1.61	.77	.74
Time (weighted mean)	21.0	193	86	167	321				32.5			
Water discharge (weighted mean)		276	130	282	548	7.4	16.1	31.1	54.6			

24-hour period and are useful for determining the variation for other days.

CORRELATIONS WITH TURBIDITY AND WATER DISCHARGE

Turbidity is sometimes considered an indirect indicator of the concentration of the fine sediment in transport. As a check on this hypothesis, the instantaneous concentrations of both clay and the sum of those of clay and silt were plotted against turbidity in figure 8. Statistics for these regressions are shown in table 8. The high correlation coefficient and the relatively low standard error of estimate indicate that concentration of fines can be computed from turbidity readings with reasonable accuracy.

The sand fraction's contribution to turbidity is slight and correlation cannot be expected. However, the suspended transport of sand varies with mean velocity and hence water discharge (Colby, 1959) at a given stream cross section. Figure 9 shows the plot of sand concentration with the rate of water discharge for Chamberlin Creek. The statistics (table 8) for this regression indicate that the relation is less reliable than that of the concentration of fines to turbidity. Total suspended-sediment concentration, however, can be determined with reasonable accuracy by substituting values of turbidity and water discharge into the equations defined by these regressions.

DAILY SUSPENDED-SEDIMENT DISCHARGE

The overall transport of the glacial debris by streams in relation to their supply by the glacier is an important factor influencing the geometry of the stream channel and even of the valley floor. Bed material in transport was not measured. However, in order that some measure be obtained of the suspended load being transported throughout the season by the stream, several small 8-ounce samples were collected on different days during

TABLE 8.—*Relation of the concentration of suspended-sediment fractions to turbidity and water discharge, Chamberlin Glacier area, Alaska*

Relation	Regression equation [1]	Correlation Coefficient	Standard error of estimate
Clay to turbidity	$Y_1 = 0.50X_1 - 6$	0.98	15 ppm
Clay and silt to turbidity	$Y_2 = 1.75X_1 - 75$	.98	79 ppm
Sand to water discharge	$Y_3 = \dfrac{X_2^{4.275}}{8,420}$	.90	0.52 log₁₀ units

[1] Where: Y_1 = concentration of clay; Y_2 = concentration of clay and silt; Y_3 = concentration of sand; X_1 = turbidity; X_2 = water discharge.

the 2-month investigation. Because of the wide variation in sediment concentration during the course of a single day, as well as the day-to-day variation, these samples represent only a rough measure of the load for the period.

These instantaneous-concentration determinations, together with the information concerning the diurnal fluctuations shown by figure 7 and table 7, can be used to compute, by two methods, the suspended-sediment transported on the sampled days. Following are steps used for the first method:

1. Compute an instantaneous sediment discharge on the basis of the sampled instantaneous concentration and the instantaneous water discharge.
2. Adjust this by the ratio shown by column 13, table 7.

Following are steps used for the second method:

1. Compute a daily mean concentration from the product of the sampled instantaneous concentration and the ratio shown by column 12 of table 7.
2. Use this together with the daily mean water discharge to compute a time-weighted sediment discharge; and
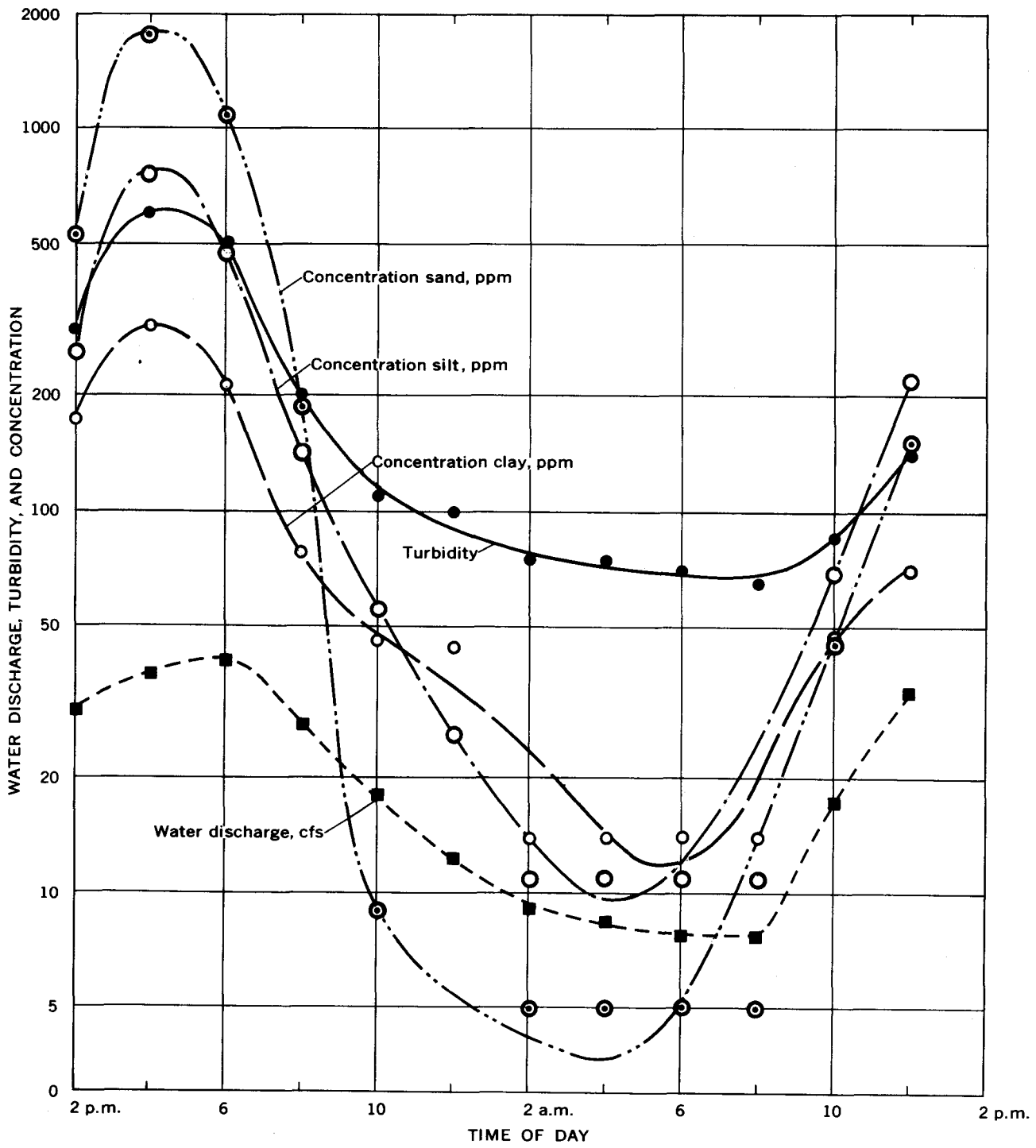3. Adjust this by a factor of 1.68 to obtain a water discharge-weighted sediment discharge.

FIGURE 7.—Diurnal variation of water discharge, turbidity, and suspended-sediment concentration, Chamberlin Creek, Alaska.
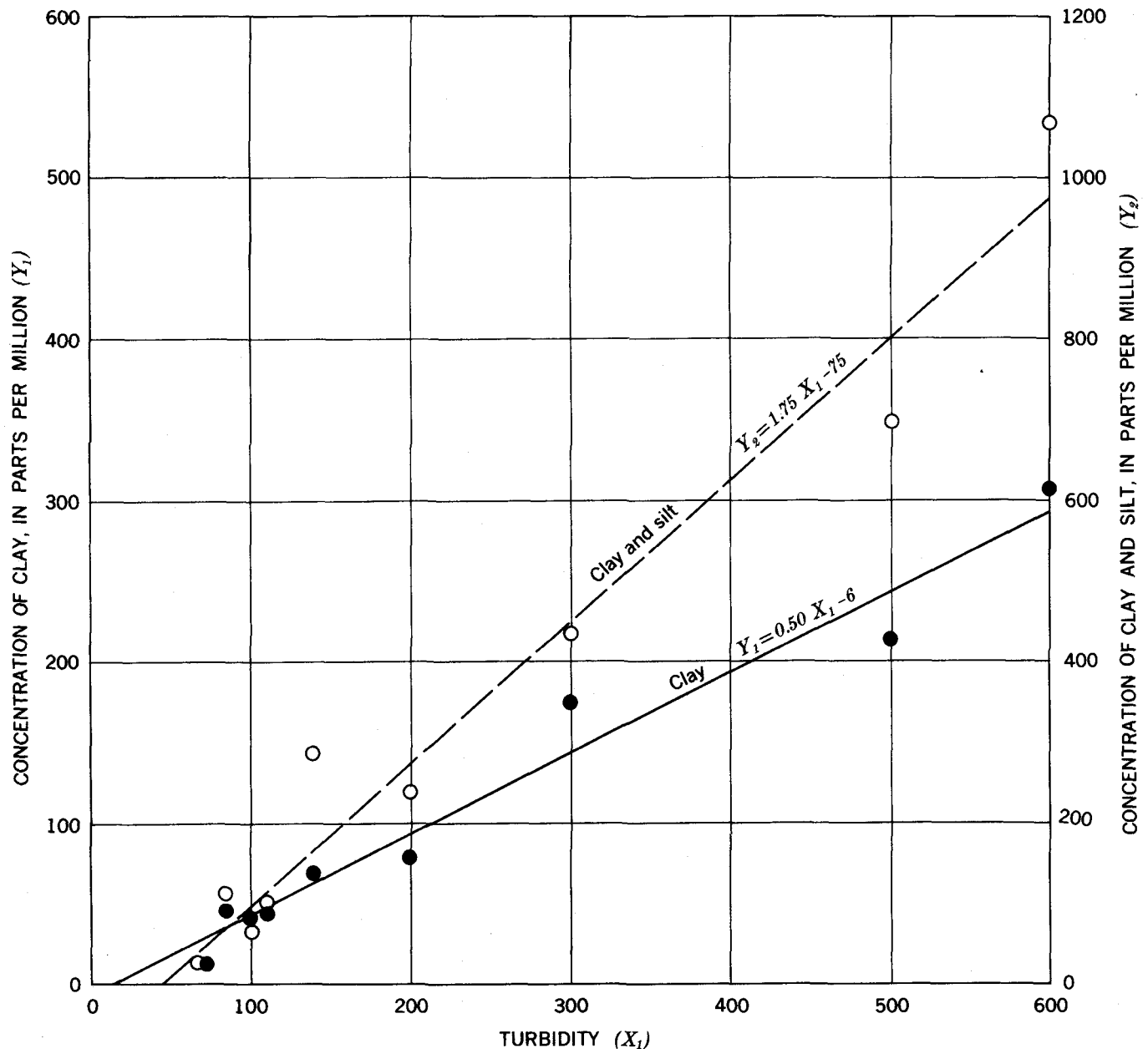
FIGURE 8.—Relation of clay and of silt and clay concentration to turbidity, Chamberlin Creek, Alaska.

The last adjustment in the second method is obtained by contrasting the time-weighted mean sediment discharge with the water discharge-weighted mean sediment discharge as shown at the bottom of column 10 in table 7.

The suspended-sediment discharge computed by these two methods for specific days is plotted with the daily mean water discharges on figure 10. The daily suspended-sediment discharge, estimated on the basis of the hydrograph of the mean daily water discharge, and the mean of the computed values of sediment discharge are given in table 9. The total for both months is nearly 1,200 tons for about 890 cfs-days of water discharge.

This is 820 tons of sediment per square mile of drainage area. The water discharge-weighted mean suspended-sediment concentration is then about 500 ppm for this period of record. The wide fluctuation in suspended-sediment discharge is largely explained by the fact that the concentration and water discharge change rapidly and in the same direction.

The relation of the suspended-sediment discharge at the gaging station 800 feet downstream from the glacier to that released by the glacier cannot be studied for lack of information concerning the quantity and character of sediment yielded by ablation. This information might indicate how a glacier forms moraines and chan-
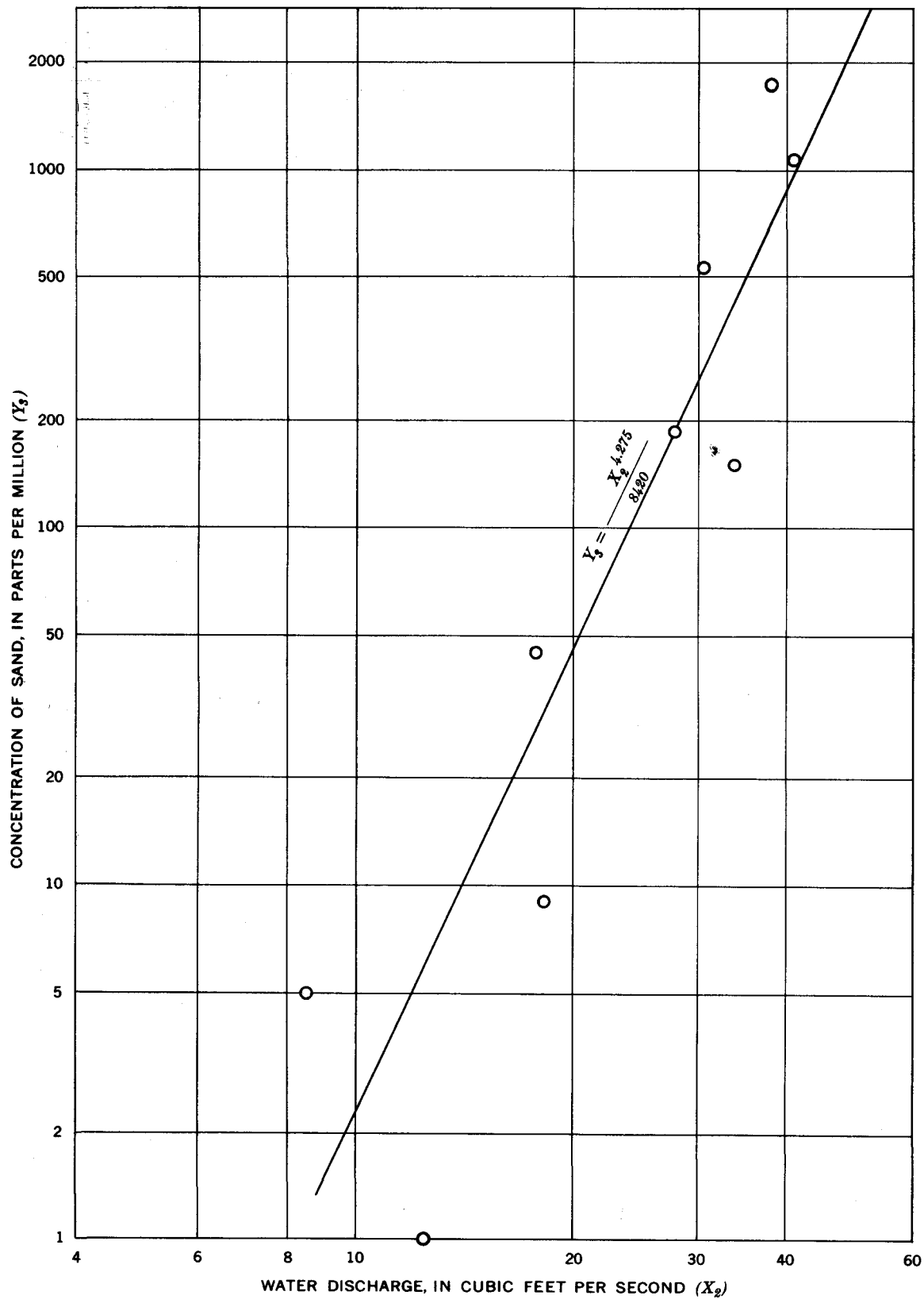
FIGURE 9.—Concentration of suspended sand in relation to water discharge, Chamberlin Creek, Alaska.
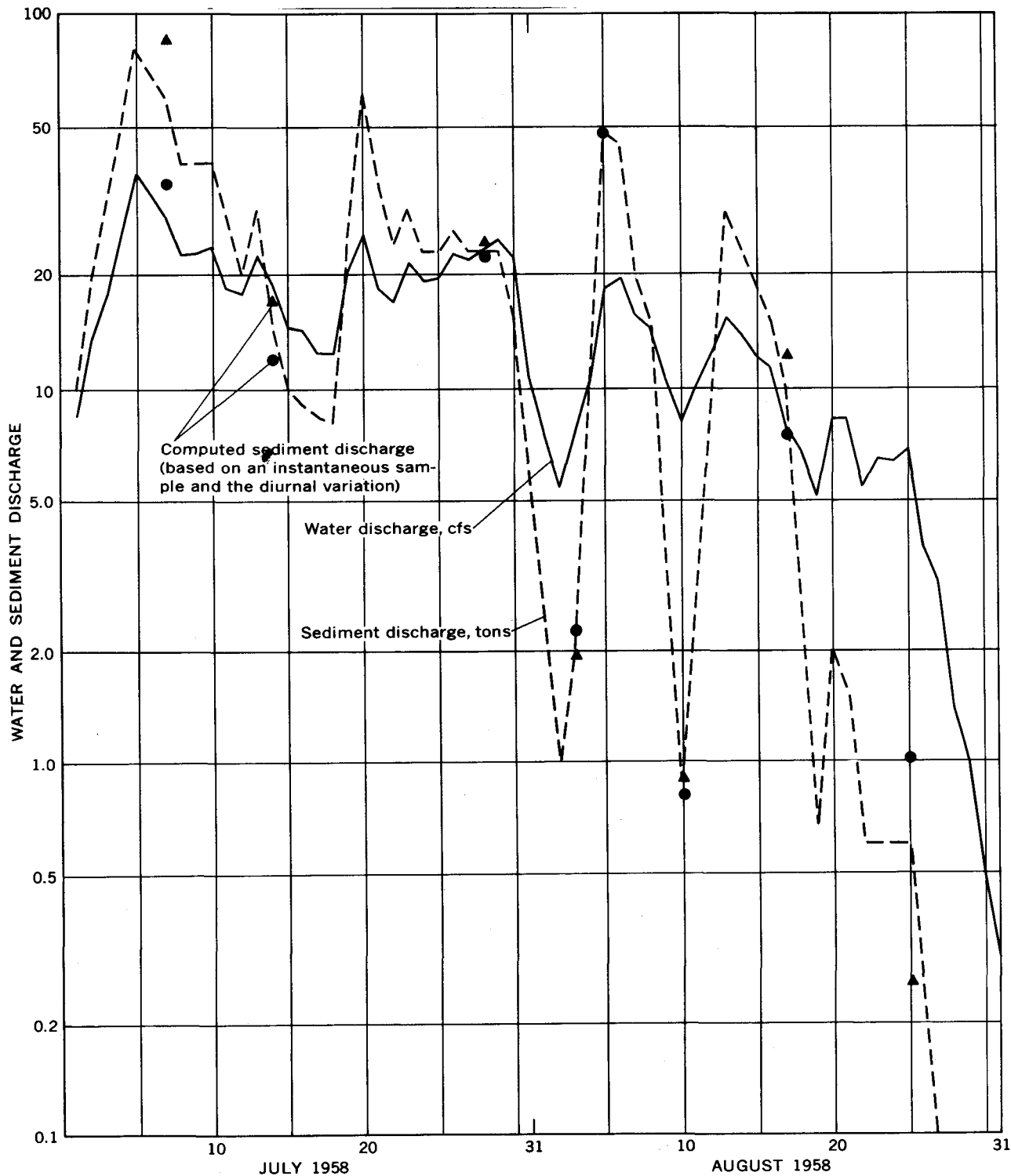
FIGURE 10.—Daily water and sediment discharge, Chamberlin Creek, Alaska.

nels to carry its runoff. Mr. Anderson noted that a large percentage of the sediment in transport this season appeared to be derived from erosion of the moraines downstream from the snout of the glacier.

EVALUATION OF THE STUDY

The most critical evaluation of the conduct of any study is the answer to the question, "What should be

Table 9.—*Daily mean water and suspended-sediment discharge, Chamberlin Creek, Alaska*

Date (1958)	Water (cfs)	Suspended sediment (tons)	Date (1958)	Water (cfs)	Suspended sediment (tons)
July 1	8.5	10	Aug. 1	7.5	2
2	13.6	20	2	5.4	1
3	17.3	30	3	7.5	2
4	25.9	50	4	10.3	10
5	37.4	80	5	18.4	48
6	32.7	70	6	19.6	45
7	28.2	59	7	15.7	20
8	22.6	40	8	14.3	15
9	22.9	40	9	10.5	4
10	23.5	40	10	8.1	.9
11	18.4	27	11	10.1	3
12	17.9	20	12	12.2	9
13	22.4	30	13	15.4	29
14	18.9	15	14	13.9	24
15	14.7	10	15	12.1	19
16	14.2	9	16	11.3	15
17	12.5	8	17	7.8	10
18	12.4	8	18	6.8	3
19	20.3	28	19	5.1	.7
20	25.3	60	20	8.2	2
21	18.4	35	21	5.8	2
22	17.0	24	22	6.4	.6
23	21.3	30	23	6.3	.6
24	19.2	23	24	6.8	.6
25	19.6	23	25	3.7	.6
26	22.7	26	26	3.0	.2
27	21.8	23	27	1.4	----
28	23.1	23	28	1.0	----
29	29.5	23	29	.5	----
30	22.2	15	30	.3	----
31	10.7	6	31	----	----
Total, July and August				890.5	1,172.2

done differently if the study were repeated?" In spite of the fact that the sampling program was formulated without prior knowledge of chemical, sediment, or hydrologic conditions that would be encountered, much useful information was obtained, and without excessive costs in time or money.

HYDROCHEMICAL

Analyses of most of the samples provided useful information. The analysis of the sample from Lake Peters contributed little to the investigation, other than to indicate that the total drainage to the lake probably is similar chemically to the drainage in the area of study. An analysis of an isolated segment of a complex hydrologic system is not very useful for hydrochemical interpretations. One cannot add to it, subtract from it, compare it with anything else, or manipulate it in any way to learn something about the system.

Probably the weakest points in the project were the absence of chemical data on seepage from the ground environment, the lack of quantitative measurements of ablation, and the failure to get some approximation of the volume of underflow at the gage.

The importance of the chemistry of the water from the ground environment would not have been missed if the field party had had with them a portable conductivity apparatus to measure differences in concentration of water comprising the various parts of the hydrologic system. The application of chemical measurements to hydrologic problems usually is a study of chemical differences. One samples these chemical differences whenever and wherever they occur, and combines the field and laboratory results with the available hydrologic data for the solution of problems—each supplements the other.

Quantitative measurements of ablation should be given higher priority in future studies because of its multiple importance in defining the hydrology and cross checking hypotheses of origin and movement of solutes and water.

Without a measure or reasonable approximation of underflow at the gage, an estimate of the chemical degradation of the drainage area is impossible. Although the volume of underflow may not have been an appreciable fraction of the total flow, the quantity of dissolved material transported by underflow may have been an appreciable fraction of the total, because its concentration could easily be five times that of channel flow. Collection of core samples and measurements of slope and cross-sectional area of the saturated channel fill are strongly recommended in future studies.

Spectrographic analysis for the minor (trace) dissolved elements was attempted, but the weight of residue from the water left after the major constituents had been determined was insufficient for reliable results. These waters were so dilute that the residue from several liters would have been required for most samples. In future studies, larger volumes of sample could be collected or, more simply, water could be evaporated at the glacier and the residue returned to the laboratory for spectrographic analysis.

SEDIMENT

The diurnal variation of suspended sediment, as defined by the one set of 1-liter samples collected about every 2 hours in a 24-hour period, has limitations because the set must be considered as a single sample of this phenomenon. Fortunately, the timing of the observation was such that it probably represents most of the flow conditions. For good definition, additional samples depicting diurnal variation should have been obtained in the first and third weeks of July. Two of the three sets of samples could be collected at 3- or 4-hour intervals instead of the 2-hour intervals used for this study.

Single samples to define the day-to-day change of suspended sediment should be collected from 2 to 5 times a week instead of only 6 times during the 2-month period, for this type of stream. Better definition of the diurnal and day-to-day changes in sediment concentration could have been obtained with more turbidity

readings, which together with the water discharge, define indirectly the suspended solids (figs. 8, 9). Because of the deficiency in the sampling program, the computed suspended load for the period is rather crude but is probably not in error by more than 20 or 30 percent.

The steep gradient of the stream and the wide range in sizes of sediment in the supply undoubtedly result in a very high bedload. Bedload is defined here as the rock and sand in transport which was not sampled as suspended load. The bedload could have been estimated by observing the rate of filling of a small pool excavated in the streambed for at least three different rates of water discharge. If it is assumed that the channel was not scoured to the compacted till, the rate of bed-material transport should be approximately related to water discharge. Mr. Anderson noted difficulty in operating the current meter because of the gravel and rocks in transport.

The relation between sediment yield at the gaging station and that supplied by the glacier during the 2-month period is probably poor because of the erosion of moraines in part of the 800-foot reach downstream from the snout of the glacier. An evaluation of the sediment discharge at or near the glacier snout would logically prove worthwhile. Information concerning the amount of sediment contained in the glacier at the ablation faces would be useful for determining the yield of the glacier and consequently help evaluate the formation of moraines and channel degradation or aggradation downstream from the glacier snout.

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