Chemical Degradation on Opposite Flanks of the Wind River Range Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1535-E

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GEOCHEMISTRY OF WATER

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GEOCHEMISTRY OF WATER

CHEMICAL DEGRADATION ON OPPOSITE FLANKS OF THE WIND RIVER RANGE, WYOMING

By Charles H. Hembree and Frank H. Rainwater

ABSTRACT

The rate of degradation by solution on the northeast flank of the Wind River Range is twice that on the southwest flank—about 49 and 26 tons per square mile per year, respectively. Conversely, the stream runoff on the southwest flank is about 1½ times that on the northeast. This seeming anomaly is due principally to the erosive nature of a girdling band of pre-Tertiary rocks exposed on the northeast flank.

Five drainage basins are selected on the southwest side of the mountains and six on the northeast side as representative samples of the geologic terranes. The computed discharge-weighted concentrations of dissolved solids range from 25 to 34 parts per million on the southwest and from 37 to 276 parts per million on the northeast.

Techniques used in the computations of chemical degradation rates include: adjustment of short-term flow-duration curves to a base 1914–57 period, correlation of chemical concentrations with water discharges, calculation of solute yield from flow duration curves and discharge-concentration correlations, and correction of gross yields for soluble material in precipitation.

CHEMICAL DEGRADATION

The term "chemical degradation" applies only to the removal of rock material by corrosion, or chemical erosion, and the subsequent transport of the dissolved products. Because of its setting and the amount of chemical, hydrologic, and geologic data available, the Wind River Range is an excellent pilot area for quantitative study of corrosion rates in different geologic and hydrologic environments.

The central part of the Wind River Mountains is a rugged wilderness of granitic spires and massive buttresses that were formed by prolonged erosion of the anticlinal range. The higher, or more central, part is a large plateau that bears the imprint of past and present glaciation. Myriad sparkling lakes of glacial origin form a band astride the sometimes indistinct continental divide. On the western side, where glaciers in times past have spilled off the high plateau into the valleys below, great glacier-gouged lakes protrude likes tongues from the mountain canyons. For a number of miles along the highest ridge, which reaches an altitude of 13,785 feet at the top of Gannett Peak, Dinwood, and Bull Lake Glaciers are still actively eroding their cirques.

The area of exposed granitic rocks is about 125 miles long and 25 miles wide. (See fig. 1.) On the northeast side of the mountains, erosion has stripped away the nearly horizontal Tertiary rocks, which at one time almost covered the Paleozoic and Mesozoic rocks that dip steeply to the northeast. These latter rocks, of varying degrees of erosibility, form a broad band along the northeast side of the range. On the southwest side of the range, rocks of these ages

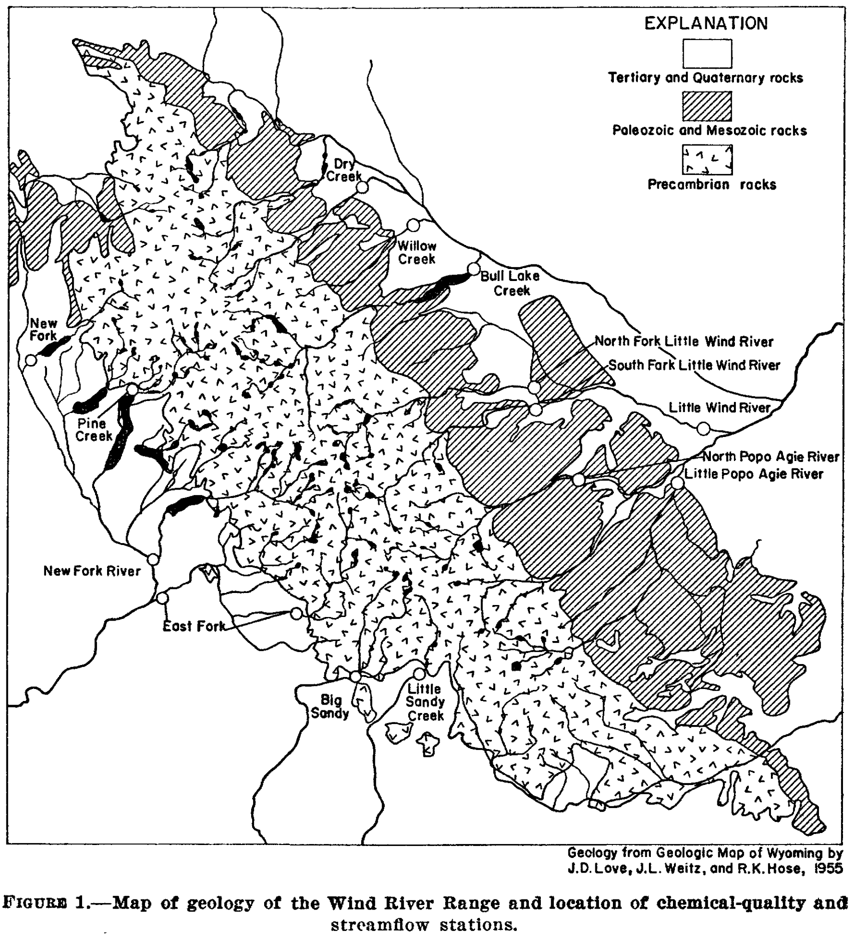

FIGURE 1.—Map of geology of the Wind River Range and location of chemical-quality and streamflow stations.

have not been exposed by post-Tertiary erosion, and the Tertiary rocks and Pleistocene debris lap directly onto Precambrian granites.

Streams that carry away the precipitation that falls on the mountains start, almost without exception, in cirque lakes along the divide. At the southern end of the range near Atlantic City, the continental divide has an altitude of about 9,000 feet. The altitude gradually increases northward to Gannett Peak, and the increase in altitude is accompanied by an increase in precipitation and runoff. Runoff per unit area of Pine Creek above Fremont Lake, which drains the highest part of the mountains, is more than twice that of Little Sandy Creek near Elkhorn, which is near the south end of the range.

The basic data used in this study consist of records of chemical quality and streamflow at seven sites on the southwest side of the range and at eight sites on the northeast, as shown on figure 1. Of these, the five streams whose drainage basins upstream from sampling points are underlain predominantly by granites are selected as being representative of streams draining the southwest side of the mountains. On the northeast side, the six stations lying closest to the front are believed to form the most representative group. The streams above the 11 representative stations are affected very little, if at all, by diversions or return flow from irrigated land. Their drainage areas range from 21 to 94 square miles on the southwest flank and from 50 to 140 square miles on the northeast flank. (See table 1.)

As part of an investigation of the water resources of the Wind River Basin to the north of the mountains, chemical-quality data were collected at many sites from 1948 to 1953. Analyses are published in a report by Colby, Hembree, and Rainwater (1956). In 1957 and 1958, as a part of the investigations of the water resources of the Upper Colorado River Basin, the Geological Survey collected chemical-quality data at hundreds of sites. Chemical analyses that were used to compute the yield of dissolved solids from the southwest side of the Wind River Range are a part of these data.

The streamflow records were converted into tables of duration of flow by manual and electronic computations. Duration curves for the 1914–57 water-year period were then synthesized by correlation techniques, and the mean discharges, given in table 1, were computed from the synthetic records. The shortest period of measured record for the streamflow stations was 3 water years, and the longest was 43 water years. This 1914–57 period is assumed to be representative of a long-term base period of the same length and perhaps for an even longer period.

TABLE 1.—*Rates of chemical degradation and runoff on opposite flanks of the Wind River Range, Wyo.*

Station	Drainage area (sq mi)	Runoff		Precipitation		Ratio of precipitation to runoff	Gross dissolved solids		Correction for concentration of precipitation (ppm)	Net dissolved solids	
		Mean water discharge (cfs)	Inches	Inches	Concentration (ppm)		Weighted averaged concentration (ppm)	Yield (tons per sq mi per yr)		Weighted average	Yield (tons per sq mi per yr)
Southwest side of Wind River Mountains											
New Fork River below New Fork Lake, near Cora, Wyo	36.2	51.4	19.2	35	6	1.8	29	40	−11	18	25
Pine Creek above Fremont Lake, Wyo	75.8	199	35.6	44	6	1.2	25	63	−7	18	46
East Fork near Big Sandy, Wyo	79.2	106	18.2	34	6	1.9	26	34	−11	15	19
Big Sandy at Leckie Ranch near Big Sandy, Wyo	94.0	85.7	12.5	29	6	2.3	34	31	−14	20	18
Little Sandy Creek near Elkhorn, Wyo	20.9	21.5	14.0	30	6	2.1	29	30	−13	16	16
Regional weighted average	306	111	20.6	35	6		29	41		18	26
New Fork River near Boulder, Wyo	552	401	9.8	26	6	2.7	78	56	−16	62	44
East Fork at New Fork, Wyo	348	166	6.5	23	6	3.5	60	28	−21	39	18
Regional weighted average	900	310	8.5	25	6		71	45		53	34
Northeast side of Wind River Mountains											
Dry Creek at Burris, Wyo	57	44.5	10.6	31	6	2.9	54	42	−17	37	28
Willow Creek near Crowheart, Wyo	50	17.2	4.7	22	6	4.7	276	94	−28	248	84
Bull Lake Creek near Lenore, Wyo	222	284	17.4	33	6	1.9	48	61	−10	38	48
North Fork Little Wind River at Fort Washakie, Wyo	127	113	12.1	27	6	2.2	38	44	−13	38	33
South Fork Little Wind River near Fort Washakie, Wyo	118	123	14.1	26	6	1.8	37	38	−11	26	27
North Popo Agie River near Lander, Wyo	140	112	11.3	28	6	2.5	118	93	−15	103	81
Regional weighted average	714	155	13.3	29	6		74	60		63	49
Little Wind River near Arapahoe, Wyo	640	182	3.9	20	6	5.1	142	40	−31	111	31
Little Popo Agie River at Hudson, Wyo	331	99.3	3.7	18	6	4.8	385	114	−29	356	105
Regional weighted average	971	154	3.8	19	6		225	65		195	56

Snow and rain contain dissolved solids. In computing chemical degradation from an area, the dissolved solids contributed by precipitation must be subtracted. One method of correcting gross, or measured, degradation for small areas is to compute the mineral content of streamflow attributable to precipitation and subtract this amount from the measured concentration of dissolved solids. Although no measurements of dissolved solids in precipitation were made in the study area, analysis of data reported by Junge and Werby (1959) and other available information at points nearby, indicates that the annual average mineral content of precipitation on the Wind River Range is about 6 parts per million. This value is in good agreement with data collected by Rogers and Feth (1959) in the Sierra Nevada and Wasatch Mountains and by J. P. Miller (written communication) in the Sangre de Cristo Mountains.

The average precipitation over each drainage basin was estimated from records of precipitation and runoff, relation of runoff to precipitation, the general relation of precipitation to altitude, and maps of runoff and altitude. (See Oltman and Tracy, 1949.) Corrections of the gross dissolved-solids content of the representative streams ranged from 7 ppm for Pine Creek above Fremont Lake to 28 ppm for Willow Creek near Crowheart (table 1).

Samples of water for chemical analysis were collected at sites on the southwest flank at high, medium, and low stages of the streams. On the northeast flank the samples represented high and low stages. These data were used to establish relations between water discharge and chemical concentration. For many streams this inverse relation is very good. The form of the curve drawn through a plot of concentration versus water discharge, depends on the type of stream. Similar stream environments are conducive to similarly formed curves. The shape of the curve on figure 2 is typical of high mountain streams in this area. The similarity was helpful when curves were drawn for those streams where sampling did not cover the complete range of discharge.

To compute the gross yields of dissolved solids, the mean water discharge for the mean of selected time intervals was obtained from tables or curves of duration of streamflow for each station (fig. 3). Values of concentration for each of these water discharges were taken from the plot of concentration versus water discharge, and applicable discharges of dissolved solids were computed for each station. Weighted-mean concentrations were then computed from the means of the dissolved-solids and water discharges.

The gross weighted-average concentrations of streams draining the granites on the southwest flank differed only slightly regardless of runoff per unit area or size of drainage area (table 1). Pine Creek above Fremont Lake drains an area of 76 square miles and has a runoff of 36 inches and a weighted concentration of 25 ppm. Little Sandy Creek near Elkhorn has a drainage area of 21 square miles, a runoff of 14 inches, and a weighted-average concentration of 29 ppm. The net weighted-average concentration for these two streams was 18 ppm for Pine Creek and 16 ppm for Little Sandy Creek. J. P. Miller (written communication) also has found this same lack of correlation of concentration with size of drainage areas in terrains of uniform rock type in the Sangre de Cristo Range in New Mexico.

The small divergence in dissolved-solids concentrations in waters from the granites is remarkable. Precipitation may have what has been called a solution potential for monolithogic terrains, and this potential is depleted rapidly when the water comes in contact with the rocks. Any solution subsequent to the rapid depletion of most of the solution potential is either extremely slow or nonexistent. In more exacting terms, the amount of material that will be dissolved depends on the controlling chemical equilibria between minerals and ionic species in solution.

Additional research in this phase of geochemistry should lead to fuller understanding of the processes of chemical degradation. Where

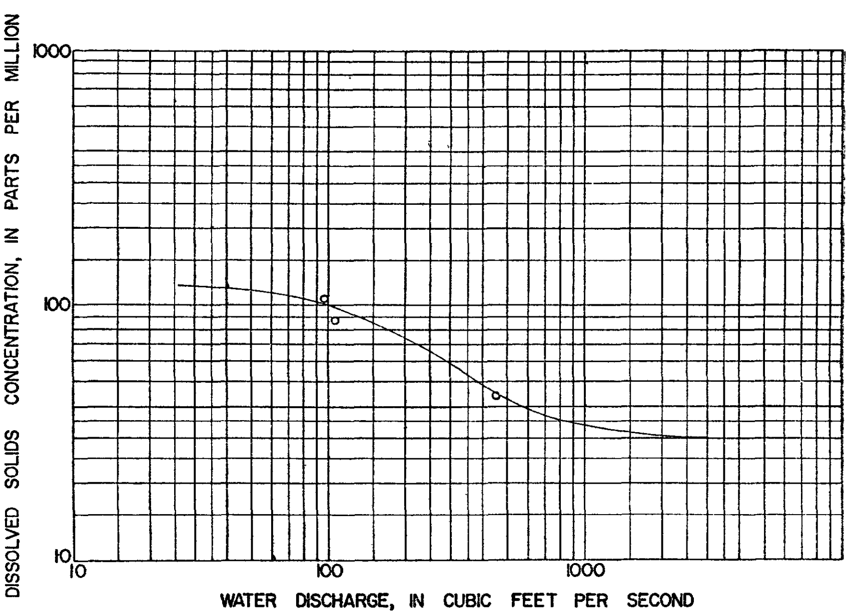

FIGURE 2.—Relation of dissolved-solids concentration to water discharge, East Fork at New Fork, Wyo.

the amount of water is sufficient to carry off the soluble products of weathering, as is evidently the situation high in the mountains, concentration of constituents in runoff may be essentially constant and controlled by the chemical equilibrium between the solutes and some solid phases. Where weathering is faster than removal of its soluble products, the products accumulate. The mineral content of waters from these areas is probably related directly to the accessibility of these soluble materials to the runoff. This type of degradation seems to apply to arid and semiarid environments.

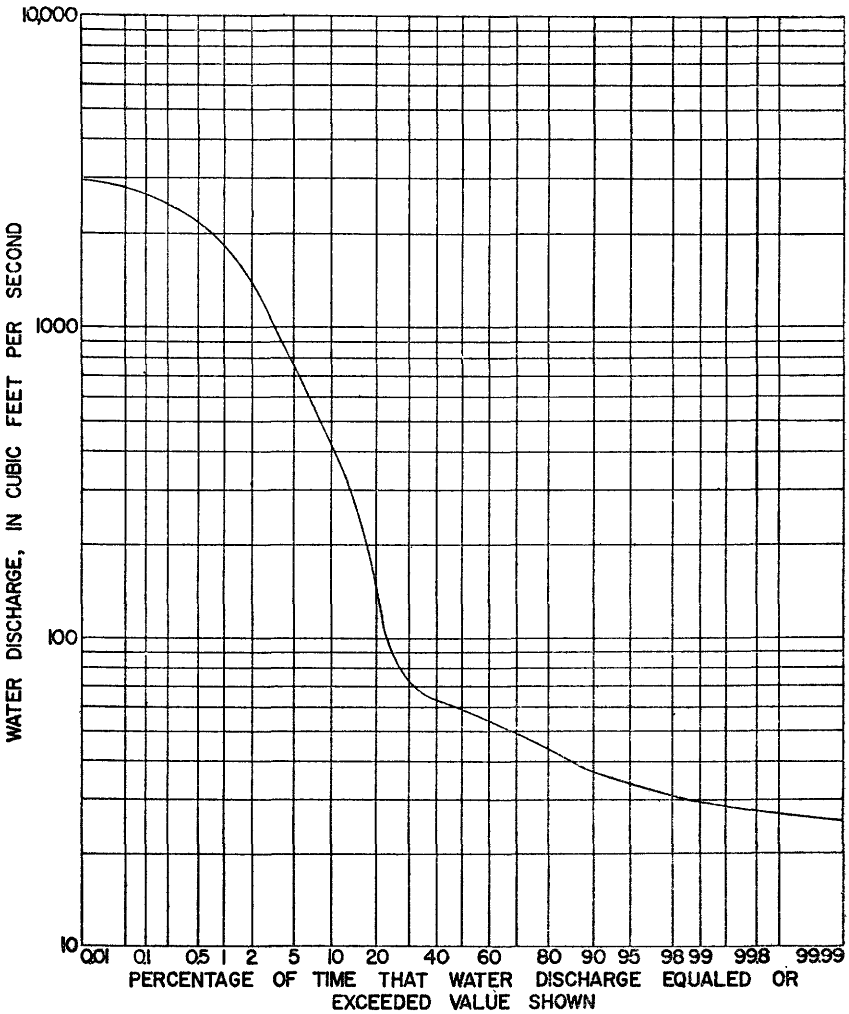

FIGURE 3.—Flow-duration curve for East Fork at New Fork, Wyo., 1914–57 water years.

The range in net yields from the individual representative drainage basins is considerable—16 to 46 tons on the southwest flank and 27 to 84 tons on the northeast flank. This spread raises the question of the significance between the regional averages of 26 and 49 tons. Statistical tests show that the difference in these regional averages is significant at better than the 0.01 level.

A second approach to the subject of geology's influence on degradation is to move farther down the flanks and consider the combined drainages of 900 and 971 square miles on the southwest and northeast flanks, respectively (the last regional weighted averages on table 1). The yield from 900 square miles on the southwest that include areas of granites and Pleistocene and Tertiary rocks, was 34 tons per square mile compared to 56 tons per square mile for an area of 971 square miles on the northeast underlain by granites and the more erosible rocks of Paleozoic, Mesozoic, and Tertiary ages. The net yield of water from the northeast flank (3.8 in.) is a little less than half the yield from the southwest flank (8.5 in.). Yet, the yield of dissolved solids from the northeast flank is still almost twice the yield from the southwest flank. The difference in the dissolved-solids yield must be due in part to the effect of the pre-Tertiary rocks that are exposed on the northeast and not on the southwest side.

Degradation rates in relation to the modification of land forms always are fuel for interesting speculation. The time required to remove 1 foot of material in the drainage basin of Little Sandy Creek at the present rate of chemical degradation would be 137,000 years or almost three times the 48,000 years it would require to remove 1 foot from the drainage basin of Pine Creek (table 2). If this differential rate of degradation were to continue, the north and higher part of the Wind River Range would be reduced to the same altitude as the south part of the Range, unless, as is probable, differential elevation of the mountains occurs or is occurring.

TABLE 2.—*Rate of degradation in selected areas*

Areas	Dissolved-solids yield (tons per sq mi per year)	Time to remove 1 ft of material (years)
Pine Creek above Fremont Lake	46	48, 000
Little Sandy Creek near Elkhorn	16	137, 000
Bull Lake Creek near Lenore	48	46, 000
Regional southwest	26	84, 000
Regional northeast	49	45, 000

CONCLUSIONS

Long-term gross chemical degradation can be estimated from the regression of concentration of dissolved solids on streamflow and the adjusted flow-duration curve. Dissolved solids in precipitation significantly contribute to the gross, or apparent, yield—8 to 45 percent for the 15 drainage basins studied.

The control exerted by chemical equilibria between mineral and ionic species in solution is clearly demonstrated by the small divergence in concentration in waters from granites. The large divergence in concentrations and yields in waters from the southwest and northeast flanks is attributable to the weathering and erosional characteristics of the girdling band of pre-Tertiary sedimentary rocks exposed on the northeast flank.

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