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Mineralogy and Cation-Exchange Capacity of Sediments from Selected Streams

GEOLOGICAL SURVEY PROFESSIONAL PAPER 433-D

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U.S. Atomic Energy Commission

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TRANSPORT OF RADIONUCLIDES BY STREAMS

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ABSTRACT

The mineralogy and cation-exchange capacity (CEC) of sediments from 21 streams were determined as part of a continuing investigation of the effect of sediments on the chemical composition of stream water. The sediments studied were taken from streams throughout the United States, and represent a great variety of geologic and climatic environments.

Illite, kaolinite, vermiculite, aluminum-interlayered clay minerals, and quartz comprise most of the clay-size fraction ($<$0.004 mm) from five streams in the eastern United States. In streams of central and west-central United States, the clay-size fraction consists mainly of montmorillonite, vermiculite, and mixed-layer clay along with some illite, kaolinite, quartz, feldspars, and carbonates but little, if any, aluminum-interlayered clay minerals. The mineralogy of stream clay in California and Oregon varies widely, probably because of the great range in geologic and climatic conditions.

Sand and silt reflect the lithology of the rocks, as modified by weathering, in each drainage basin. Rock fragments are thoroughly broken down in areas of intense weathering, and stream sand tends to be relatively free of fine-grained rock fragments. In areas where rocks are fine grained and weathering is less intense, fine-grained rock fragments are important constituents of the stream silt and sand.

The cation-exchange capacity of clay-size fractions in the streams studied ranged from 14 to 28 meq per 100 g in the eastern United States, 25 to 65 meq per 100 g in the central and west-central United States, and 18 to 65 meq per 100 g in California and Oregon. The higher exchange capacities are characteristic of samples containing high proportions of montmorillonite and(or) vermiculite.

Clay minerals as part of multimineralic grains apparently are responsible for most of the exchange capacity of sand and silt. The CEC of sand ranges from about 0.3 to 13 meq per 100 g, and of silt from about 4 to 30 meq per 100 g.

Cation-exchange capacity commonly increases as grain size decreases, but this relation is not true for many stream sands and silts that contain important percentages of rock fragments. Instead, a minimum CEC is measured in the fine-sand to coarse-silt range where the fewest clay aggregates occur.

The ratio of cations adsorbed on suspended sediment to cations in solution is usually greatest when the concentration of suspended sediment is highest. This ratio reaches a maximum of 0.8 in the eastern streams studied but may be 3 or more in some western streams. Under such conditions, the adsorbed cations help stabilize the chemical composition of the water and also constitute a significant part of the cations in transport.

Cations adsorbed on bed sediments may equal or exceed cations in solution above the bed in streams which are less than about 1 foot in depth. In such streams, the exchange capacity of bed sediments also may be an important factor in stabilizing the chemical composition of stream water.

INTRODUCTION

PURPOSE AND SIGNIFICANCE OF STUDY

Sediment is known to affect the chemical composition of stream waters in various ways. Some minerals will dissolve, some may cause precipitation of certain dissolved ions, and others, because of their exchange capacity, may help stabilize the composition of stream water. In 1959 the U.S. Geological Survey, on behalf of the U.S. Atomic Energy Commission, began a reconnaissance study of the mineralogy and exchange capacity of modern stream sediments in the United States. The purpose of the investigation was to learn something about the range of mineralogy and exchange capacity and to obtain a better understanding of why mineralogy and exchange capacity vary as they do. Such information permits prediction of conditions in streams not examined and an intelligent selection of factors to be studied first in any investigation of a new area.

Information on range of mineralogy and exchange capacity can be used in estimating the possible uptake by sediments of radioactive ions dissolved in stream water. For example, stream sediments having a high exchange capacity can generally be expected to remove more radioactive ions (such as those discharged as low-level waste from atomic power plants) than those having a low exchange capacity. Some minerals tend to be selective in the ions which they adsorb from solution. The clay mineral illite is an example; it is highly selective for cesium (Tamura and Jacobs, 1960).

Thus, with a knowledge of mineralogy and exchange capacity of stream sediments, the probable affinity of the sediments for some radionuclides may be predicted. However, much additional work must be done before the selectivity of any particular mineral for certain ions will be thoroughly understood.

Another use for information on mineralogy and exchange capacity is in estimating the proportion of industrial waste which may be carried adsorbed on stream sediment instead of in solution in the stream. This use is of particular significance when the stream water is used as a source of drinking water.

In areas where pollution is not a problem, knowledge of the proportion of ions carried adsorbed on sediment, as compared to that in solution, helps in understanding the geochemical cycle of various elements. Such information will be increasingly important as more is learned about the selectivity of various minerals for particular ions.

PLAN OF STUDY

The sampling sites chosen for this investigation represent a wide range of climatic, geologic, and hydrologic conditions. An effort was made to obtain five sets of samples of both suspended sediment and bed material from 21 sites on streams in various parts of the United States (fig. 1; see table 1, p. D6 for site descriptions). One set was to be taken during low flow, one near median flow, and three during different periods of high flow; however, not all the planned samples were obtained because the desired flow conditions did not occur.

When possible, both the suspended-sediment and the bed-material samples were prepared by compositing sediment from at least five centroids of discharge, that is, from five points in a cross section representing equal parts of the stream discharge. Sampling sites were restricted to locations where sediment investigations were already being made by the Geological Survey, to simplify the sampling process and also to make the results more useful.

Both suspended and bed samples were divided into clay (<0.004 mm), silt (0.004–0.061 mm), sand (0.061–1.0 mm), and, if necessary, gravel (>1 mm) sizes. Mineralogical analyses and exchange-capacity determinations were made for the three finer size fractions, and variations with time and discharge were noted for each stream. The mineralogy and exchange capacity of sediments from various streams were compared and an attempt made to explain differences on the basis of geology and climate.

The importance of the exchange capacity of stream sediments in stabilizing water quality was evaluated by comparing the amount of dissolved cations (in milliequivalents) with those adsorbed on bed or suspended sediment.

PREVIOUS WORK

Other investigators have studied the mineralogy of sediments in various modern streams (for example, Holmes and Hearn, 1942; Powers, 1953; Nelson, 1960; Taggart and Kaiser, 1960; and Griffin, 1962), but relatively few data are available concerning the exchange capacities of the sediments examined. Nielsen and Perkins (1962), Nielsen (1963), Blanco and Struxness (1961), Carrit and Goodgal (1953), and Simpson and others (1959) have demonstrated the effectiveness of stream sediment in removing some cations from solution. A major part of the cations so removed may be held in exchange positions on the stream sediment.

Although information on mineralogy and exchange capacity of modern stream sediments is somewhat limited, there is a considerable amount of data on the mineralogy and exchange capacity of soils (Kelley, 1948). Inasmuch as most of the sediment load in streams is derived from surface soils by erosion, knowledge of soils in various parts of the country can be very helpful in predicting and understanding the characteristics of stream sediments. Griffin (1962) presented a map of the Mississippi River, Mobile River, and Appalachicola River basins together with the mineral composition of samples of soil clay from numerous localities in the basins. He demonstrated that mineralogy of stream sediments correlated well with mineralogy of the soil clay within the drainage area.

ACKNOWLEDGMENTS

Most of the sediment samples were collected by personnel from Geological Survey Quality of Water Branch district offices in various parts of the United States. Sample preparation was done mainly by J. R. Mason, Jr., and E. C. Mallory, Jr. Mineralogical analyses of the <0.004 mm fraction were made by J. R. Mason, Jr., T. E. Brown, and the writer in consultation with L. G. Schultz. The 0.004–0.061 mm fraction was analyzed by W. N. Lockwood, P. J. Dunton, and the writer.

Exchange-capacity determinations were made by J. R. Mason, Jr., and Edward Villasanna under the supervision of V. J. Janzer.

Work on this project was begun under the supervision of J. D. Hem in 1959 and continued by the author beginning in 1960. Grateful acknowledgment is made for the technical help provided by Hem during the period 1960–63.

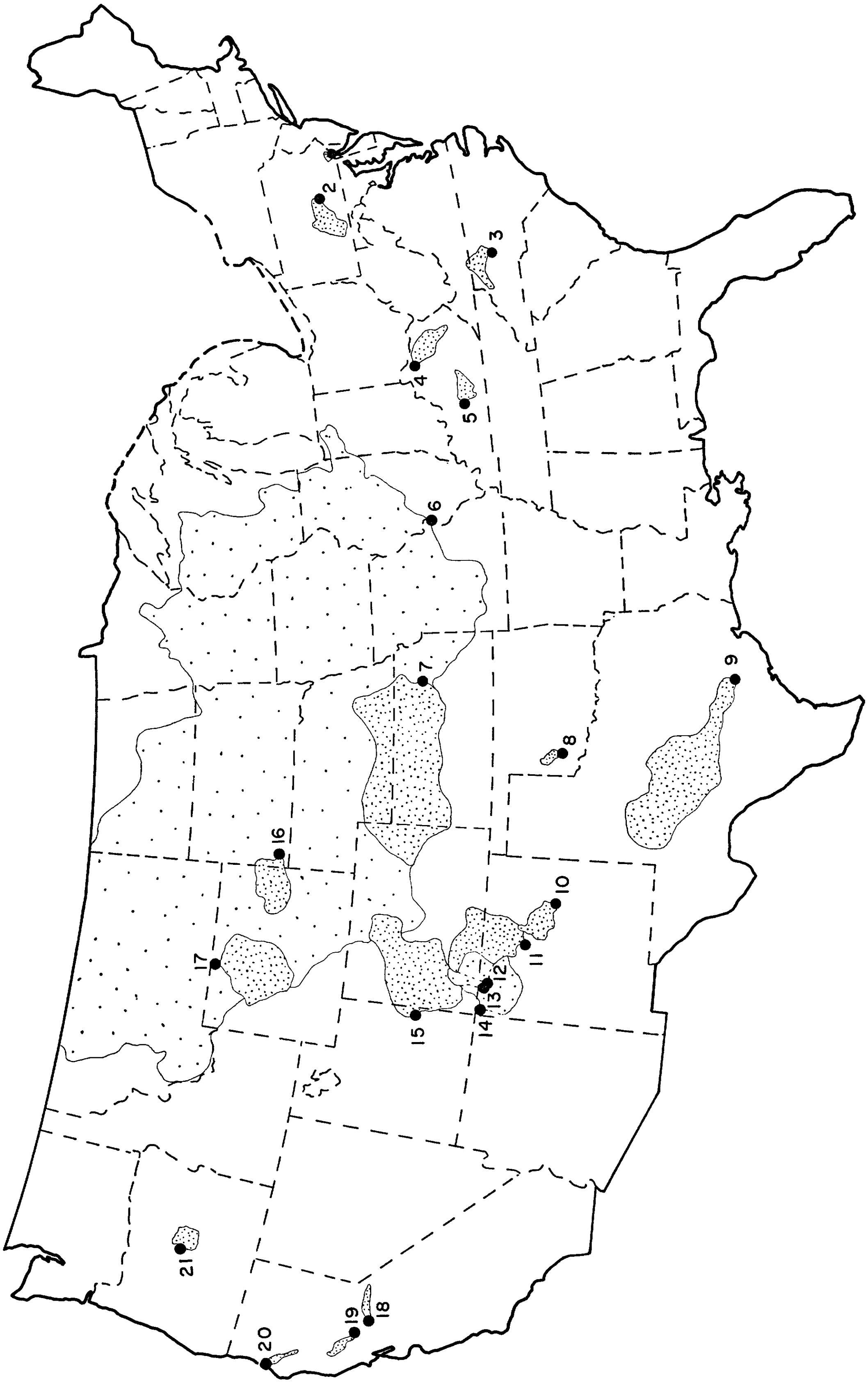


FIGURE 1.—Sediment-sampling sites. Stippling shows upstream drainage area.

METHODS OF ANALYSIS

SAMPLE TREATMENT

Suspended and bed samples were divided into clay, silt, sand, and gravel fractions. With few exceptions, the sediment was kept wet from the time of collection until separated into various size fractions. If size separations could not be made shortly after receipt in the laboratory, the sediment was stored at about −15°C. The separation into gravel, sand, and silt-plus-clay fractions was made by wet sieving in tap water. After filtering, the moist silt-plus-clay fraction was placed in distilled water and the mixture was shaken violently by hand. This mixture was then centrifuged to settle the >0.004 mm material. Suspended material was siphoned off and the procedure repeated until virtually all material finer than 0.004 mm had been removed. Each size fraction was air dried and stored until mineralogical analyses and exchange-capacity determinations could be made.

EXCHANGE CAPACITY

Exchange-capacity determinations were made by using a slightly modified version of the radioactive-cesium method described by Beetem and others (1962). In essence, the method consists of shaking the sample three times for at least 4 hours in successive aliquots of a 0.5*N* solution of cesium chloride, which contains radioactive cesium. This treatment is presumed to saturate the cation-exchange sites with cesium. The sample is washed repeatedly with ethyl alcohol until the washings give no visible precipitate when silver nitrate is added. The radioactivity of the salt-free sample is measured in a well-type gamma scintillation counter, and the amount of cesium adsorbed on the sample is calculated.

Because a part of the cesium may become fixed by illite or vermiculite present in the sample (Barshad, 1950; Tamura and Jacobs, 1960), the cation-exchange capacity measured by the radioactive-cesium method may differ somewhat from that determined by using other cations. Comparison of the cesium method with the ammonium and manganese methods (Beetem and others, 1962) suggests that the cesium-exchange capacities may be a few percent higher than those measured by the other two methods.

Many of the samples available for exchange-capacity determinations were less than the optimum amount. As a result, the precision of the analyses was approximately ±10 percent.

MINERALOGY

CLAY

The mineralogy of the clay-size fraction was determined by X-ray diffraction methods. A Norelco wide-range goniometer and nickel-filtered copper radiation were used at a scanning speed of 2° per minute. Fluorite was used as an internal standard in a randomly oriented powder to determine the quartz content. Oriented mounts were prepared on porous tiles which were X-rayed after air drying, after glycollation, after heating to 300°C, and after heating to 550°C.

The following criteria were used in identifying the clay minerals present on the oriented mounts. A peak on the diffractometer pattern at about 10 A, which remained after air drying, glycollation, and heating, was considered evidence of the presence of illite. A peak near 14 A in the air-dried sample which moved to about 17 A on glycollation and collapsed to 10 A on heating to 300°C indicated montmorillonite. A peak near 14 A in the air-dried sample which did not move on glycollation but collapsed on heating indicated vermiculite. A peak near 14 A after heating to 550°C was considered indicative of chlorite. A peak at 7 A which collapsed on heating at 550°C indicated kaolinite, unless chlorite was present; the 002 reflection of chlorite can also give a 7-A peak which disappears at 550°C. If chlorite was present, the sample was warmed in 6*N* HCl at 60°C overnight to remove it (Schultz, 1964, p. 8), and any residual 7-A peak was interpreted as kaolinite. The removal of chlorite by acid treatment was shown by the absence of a 14-A peak on heating at 550°C.

Mixed layering is indicated by intermediate spacing of the peaks on the diffractometer patterns. Thus, montmorillonite-illite interlayering may produce a separate peak between 10 and 14 A which shifts toward a greater interlayer spacing on glycollation. Commonly, in stream sediments, mixed layering causes a broadening of the 14–A peak for the air-dried sample, and of the 17–A peak on glycollation. Chlorite-illite interlayering can cause a peak between 10 and 14 A or broaden the 10–A or 14–A peaks, but the peaks do not shift appreciably on glycollation or heating.

Aluminum-interlayered clays, or "dioctahedral vermiculite" (described by Brown, 1953; Rich and Obenshain, 1955; and Tamura, 1958), occur in many streams in the eastern United States and can be distinguished from the minerals discussed above. The rather broad peak produced on the X-ray diffraction pattern by the oriented and air-dried mineral indicates an interlayer spacing of approximately 14 A. This peak does not move on glycollation, but on heating it gradually shifts toward 10 A. Complete collapse to 10 A may not occur, even at 550°C.

Available evidence indicates that the aluminum-interlayered clays may consist of either montmorillonite or vermiculite (Rich, 1960; Sawhney, 1960; Tamura, 1957; Dixon and Jackson, 1959) which has aluminum precipitated in variable quantities in the interlayer space.

Although many of the samples of stream clay were rather poorly crystallized (as indicated by the X-ray diffraction patterns) and commonly contained three to four different clay minerals, an effort was made to estimate the proportion of each clay mineral present. The area of the 10–A peak after glycollation was taken as a reference and was assumed to represent the amount of illite present. The area of the 7–A peak was divided by a factor which ranged from 1 to 2 depending upon the ratio of height to area of the 7–A peak. This ratio is taken as a measure of the degree of crystallinity of the kaolinite (Schultz, 1960, p. 221). When the 7–A peak area was thus corrected, the following equation was used to determine the ratio of kaolinite-plus-chlorite to illite:

$$\frac{\text{7–A peak area}}{\text{10–A peak area (glycollated)}}=\frac{\text{Kaolinite}+\text{chlorite}}{\text{illite}}$$

The relative amounts of chlorite and kaolinite contributing to the 7–A peak were calculated by using the following equation:

$$\frac{\text{Kaolinite}}{\text{Chlorite}}=\frac{\left[\begin{array}{l}\text{7–A peak height (air dried)}\\ \quad -2/3\times\text{14–A peak height }(550^\circ\text{C})\end{array}\right]}{2/3\times\text{14–A peak height }(550^\circ\text{C})}$$

The ratio of the 001 peak height to the 002 peak height of chlorite varies depending upon the composition of the chlorite. However, for simplicity, the 002 peak height of air-dried chlorite has been considered to be two-thirds the 001 peak height after heating to 550°C.

The proportion of combined montmorillonite, vermiculite, and mixed-layer clay not containing chlorite was estimated by noting the increase in the 10-A peak area when the oriented clay was heated from the glycollated condition to 300°C. Most montmorillonitic stream clays appeared to contain a significant amount of mixed-layered material, as indicated by the absence of higher order peaks and by the broadening of both the 14-A peak in the air-dried material and the 17-A peak after glycollation.

The proportions of montmorillonite, vermiculite, and mixed-layer clays, excluding chlorite, were estimated on the assumption that the 17-A peak of an oriented, glycol-treated montmorillonite sample is 4–5 times as high as the 10-A peak of the montmorillonite in the same slide after heat treatment (Schultz, 1964, p. 8). If the 10-A peak after heat treatment increased by more than the height of the 17-A peak divided by 4.5, mixed-layer clay was assumed to be present. The amount of mixed-layer clay was obtained by subtracting the estimated montmorillonite from the proportion of combined montmorillonite, vermiculite, and mixed-layer clay, exclusive of chlorite, determined as described above. Any vermiculite would, thus, be labeled "mixed-layer" clay.

The content of aluminum-interlayered clays was determined by using the diffraction pattern obtained after heating the oriented specimen to 300°C. The area under the curve in the 11- to 12-A region which did not appear to be a part of the 10-A peak was measured and assumed to represent the proportion of the aluminum-interlayered clays. Any mixed-layer chlorite-illite in this region would be classified as aluminum-interlayered clay. No correction factor was used in comparing this 11- to 12-A area with the 10-A illite peak.

The proportion of vermiculite in the clay-size fraction was difficult to estimate by the method described above because of the presence of aluminum-interlayered clay and(or) mixed-layer clay. After completion of most of the mineralogic analyses, an attempt was made to evaluate the amount of vermiculite present by using other techniques. One sample from each stream was soaked in $1N$ $\mathrm{MgCl_2}$ for at least 2 hours and then exposed to glycerol vapor at 70°C for at least 4 hours. A separate aliquot of the clay was soaked in $1N$ KCl solution for at least 2 hours. The K-saturated clays and the glycerolated Mg-saturated clays were then mounted on glass slides for X-ray analysis. The vermiculite present was evaluated on the assumption that Mg-saturated vermiculite should not expand beyond about 14.5 A when treated with glycerol and should collapse to about 10.3 A on potassium saturation (Brown, 1961, p. 315–316; Barshad, 1948; Walker, 1958). Aluminum-interlayered clays should retain an interlayer spacing of about 14-A under potassium saturation (Hathaway, 1955).

The composition of the total clay-size sample was calculated by subtracting the percentage of quartz, feldspar, carbonates, organic matter (estimated by doubling the organic carbon), amorphous material, and other nonclay minerals from 100 percent and then dividing the remaining percentage among the various clay minerals as described above. Even though an effort was made to correct for some variations in the diffracting characteristics of different clay minerals, the results are still only semiquantitative. The data for the nonclay minerals are more precise and are considered more accurate than those for the clay minerals. This conclusion is reflected in the manner in which the data are presented.

The percentage of quartz, feldspar, carbonates, and other nonclay minerals was estimated by using synthetic standards. Organic carbon was determined as the difference between total carbon and carbonate carbon. Total carbon was determined by pyrometric combustion in an induction-type furnace, and carbonate carbon by the gas evolution method described by Rader and Grimaldi (1961). Analyses for amorphous silica and alumina were made by the method of Hashimoto and Jackson (1960), as modified by E. C. Mallory, Jr. (written commun.). The "amorphous silica and alumina" determined may include solution products of very fine-grained clay and poorly crystalline material as well as amorphous alumino-silicate, free silica, free alumina, and gibbsite. Hence, the figure given can be considered as an upper limit on the truly amorphous material present.

SILT

A representative portion weighing about 1 g was ground mechanically for one-half hour under alcohol. Approximately 450 mg of the ground material was mixed in exactly a 9:1 ratio with about 50 mg of fine-grained synthetic anhydrite, which formed the internal standard during X-ray diffraction analysis. Curves showing the intensity of the major anhydrite peak versus peak intensities of various common minerals present in known standards were used in determining the mineral composition of the stream silts.

SAND

Stream sand was separated from gravel and silt by wet sieving and then stored dry. A representative split was mounted in plastic and a thin section prepared. After staining potassium-bearing minerals with sodium cobaltinitrite (Gabriel and Cox, 1929; Rosenblum, 1956), the area of the slide occupied by each mineral species was determined petrographically by using a click counter. The volume percentage so determined was corrected to weight percentage by using appropriate specific gravities of each sediment constituent.

CHARACTERISTICS OF THE STREAM WATERS AND STREAM BASINS STUDIED

Considerable knowledge of geology, topography, soil development, climate, vegetation, streamflow variation, and man's activities in a stream basin is needed to understand why sediment carried by the stream is composed of particular minerals, or why the sediment has a certain exchange capacity. Some of the available information about the streams investigated in this study is summarized in tables 1–5.

TABLE 1.—*Climate of stream basins studied*

[Range is given if precipitation or temperature varies widely within the basin. Weather information is from U.S. Weather Bureau data (1960; 1962) unless otherwise indicated]

Stream		Sampling location	Approximate average annual precipitation within the basin (inches)	Approximate mean annual temperature within the basin (°F)
No. (fig. 1)	Name			
Eastern United States				
1	Brandywine Creek.	At Wilmington, Del	[1] 44	53
2	Juniata River	At Newport, Pa	41	50
3	Yadkin River	At Yadkin College, N.C.	47–>55	50–58
4	Licking River	At McKinneysburg, Ky.	46	57
5	Green River	At Munfordville, Ky	47	57
Central United States				
6	Mississippi River	At St. Louis, Mo	<10–>40	36–>55
7	Kansas River	At Wamego, Kans	15–30	54
8	Elk Creek	Near Hobart, Okla	25	61
9	Colorado River	At Columbus, Tex	16–40	60–70
10	Pecos River	At Santa Rosa, N. Mex	14	50–58
11	Rio Grande River	At Otowi Bridge near San Ildefonso, N. Mex.	<8–>28	35–57
12	San Juan River	At Bloomfield, N. Mex	<10–>28	36–50
13	Animas River	At Farmington, N. Mex.	<10–>28	36–50
14	San Juan River	At Shiprock, N. Mex	<8–>28	36–50
15	Colorado River	Near Cisco, Utah	<8–>40	34–55
16	Cheyenne River	Near Hot Springs, S. Dak.	<16–24	46
17	Big Horn River	At Kane, Wyo	<8–>48	40–47
Western United States				
18	Cosumnes River	At McConnel, Calif	16–>56	48–62
19	Cache Creek	At Yolo, Calif	16–>32	59
20	Mad River	Near Arcata, Calif	40–64	52
21	Crooked River	Near Post, Oreg	8–12	46

[1] Olmsted and Hely, 1962, p. A–2.

TABLE 2.—*Physical and chemical quality of water in streams studied*

[All published water-quality data were obtained from "Quality of surface waters of the United States," a series of U.S. Geol. Survey Water-Supply Papers. Range of dissolved cations was calculated from chemical analyses of water, or estimated from specific-conductance measurements]

Stream		Range of mean daily suspended sediment concentration (ppm)	Period of suspended sediment record considered	Range of dissolved cations (meq per l)
No. (fig. 1)	Name			
Eastern United States				
1	Brandywine Creek	1–1,550	1946–58	0.70–2.2
2	Juniata River	1–1,130	1944–53; 1953–58	.75–4.7
3	Yadkin River	1–2,970	1951–58	.25–1.3
4	Licking River	1–4,230	1952–58	.90–3.9
5	Green River	[1] 1–3,180	1951–59	[2] .58–51
Central United States				
6	Mississippi River	35–6,420	1948–57	----------
7	Kansas River	87–8,650	1956–58	2.2–18.5
8	Elk Creek	[1] 5–8,080	1958–61	[1] 1.5–41
9	Colorado River, Tex	[1] 2–11,600	1957–63	[3] 1.5–7.6
10	Pecos River	[1] 3–13,800	1959–60	[1] 2.3–20
11	Rio Grande River	18–42,600	1948–57	1.7–14
12	San Juan River, Bloomfield.	58–101,000	1955–57	1.1–27
13	Animas River	1–36,100	1950–57	1.7–22.5
14	San Juan River, Shiprock	8–86,000	1950–57	2.0–40+
15	Colorado River, Utah	13–66,300	1930–52; 1953–57	3.0–49
16	Cheyenne River	<10–55,000	1946–58	7.8–45
17	Big Horn River	<5–33,000	1946–58	4.6–21
Western United States				
18	Cosumnes River	[1] 8–1,310	1956–60	[1] 0.57–1.2
19	Cache Creek	[1] 7–6,130	Jan.–Mar. 1959	[1] 2.3–7
20	Mad River	[1] 1–4,560	1957–60	[1] .97–3.3
21	Crooked River	[1] 2–1,020	1959–60	[1] .90–2.0

[1] Wholly or in part from unpublished data supplied by U.S. Geol. Survey Quality of Water Branch offices.

[2] Oil-field brines flowing into the river beginning in August 1958 greatly increased the concentration of dissolved cations above the normal maximum of about 5.2 meq per l (Krieger and Hendrickson, 1960).

[3] Chemical quality of water at Columbus has been assumed to be similar to that at Wharton, Tex., for which numerous chemical analyses are available.

TABLE 3.—*Drainage area and discharge of streams studied*

[Hydrologic data were obtained from "Surface Water Supply of the United States," a series of U.S. Geol. Survey Water-Supply Papers]

Stream		Drainage area (sq mi)	Average discharge (cfs)	Range of discharge (cfs)	Average runoff (inches)	Period of record prior to 1960	Reservoirs and diversions upstream at time of sampling
No. (fig.1)	Name						
	Eastern United States						
1	Brandywine Creek	314	466	30–17,800	20.2	1946–60	
2	Juniata River	3,354	4,320	241–209,000	17.5	1899–1960	
3	Yadkin River	2,280	2,896	177–94,300	20.3	1928–60	
4	Licking River	2,326	2,972	3.8–54,100	17.4	1924–25; 1938–60	
5	Green River	1,673	2,581	39–87,000	21	1915–22; 1927–31; 1937–60.	
	Central United States						
6	Mississippi River	701,000	174,700	18,000–1,019,000	3.4	1861–1960	Numerous reservoirs in the Missouri River basin.
7	Kansas River	55,240	4,785	73–400,000	1.2	1919–60	Many small diversions; Kirwin, Kanopolis, Webster, and Cedar Bluffs Reservoirs.
8	Elk Creek	549	66.5	0–22,400	1.6	1904–08; 1949–60.	
9	Colorado River, Tex	41,070	3,410	93–190,000	1.1	1916–60	Many diversions above dam for irrigation. Flow largely regulated by Lake Travis and Buchanan Reservoir above Austin.
10	Pecos River	2,650	153	2.7–55,200	.78	1912–24; 1928–60	Diversions upstream for irrigating about 12,000 acres.
11	Rio Grande River	14,300	1,596	60–24,400	1.82	1895–1905; 1909–60	Flow partly regulated by El Vado Reservoir on Rio Chama which contributes about 40 percent of flow. Diversions to irrigate 694,000 acres.
12	San Juan River, Bloomfield	5,410	1,645	50–20,500	4.12	1910–11; 1927–31; 1956–60.	Diversions for irrigation of about 52,000 acres above station.
13	Animas River	1,360	968	2.4–25,000	9.6	1904–05; 1912–60	Diversions for irrigation of about 30,000 acres upstream.
14	San Juan River, Shiprock	12,900	2,403	8–80,000	2.53	1926–60	Many diversions for irrigation.
15	Colorado River, Utah	24,100	8,057	558–76,800	4.54	1911–60	Numerous low dams upstream.
16	Cheyenne River	8,710	273	2.8–114,000	.42	1946–58	Some diversion for irrigation.
17	Big Horn River	15,765	2,255	28–2,890	1.94	1928–60	Boysen Reservoir on Wind River affects flow.
	Western United States						
18	Cosumnes River	730	580	0–54,000	10.8	1941–60	Diversions for irrigation of about 2,100 acres upstream.
19	Cache Creek	1,137	518	0–41,400	6.2	1903–60	Flow controlled by Clear Lake and by diversions for irrigation of 30,000 acres.
20	Mad River	485	1,574	16–77,800	44	1910–13; 1950–60	Diversion for city of Eureka.
21	Crooked River	2,160	330	4–7,550	2.14	1940–60	Many diversions for irrigation.

TABLE 4.—*Geology and topography of stream basins studied*

[Most topographic information from Fenneman (1946)]

Stream		Geology	Topographic province and section	Topography
No. (fig. 1)	Name			
	Eastern United States			
1	Brandywine Creek	Mainly schist and gneiss and lesser quartzite, phyllite, limestone, dolomite, gabbro, anorthosite, and quartz monzonite (Wolman, 1955).	Upland section of the Piedmont province	Dissected upland of mature topography and moderate relief.
2	Juniata River	Folded limestone, dolomite, quartzite, sandstone, and shale.	Middle section of the Valley and Ridge province.	Even-crested ridges predominate over valleys. Drainage pattern is trellislike.
	Yadkin River	Mica gneiss, granite, diorite, gabbro, mica schist, and lesser areas of hornblende gneiss and schist, quartzite, marble, claystone, sandstone and conglomerate (North Carolina Dept. Conserv. Devel., 1961).	River heads in the southern section of the Blue Ridge province, but much of the basin lies in the upland section of the Piedmont province.	Subdued mountains.
4	Licking River	Mostly shale, limestone, and limy shale; some sandstone, siltstone, and conglomerate (Hall and Palmquist, 1960a, 1960b; Kentucky Geol. Survey, 1954).	River rises in Kanawha section of Appalachian Plateau province and flows through Lexington plain of Interior Low Plateaus.	Mature plateau of strong relief.
5	Green River	Mostly siltstone, shale, limestone; a little sandstone (Kentucky Geol. Survey, 1954).	Highland Rim section of Interior Low Plateaus.	Young to mature plateau of moderate relief. Karst topography in lower part of drainage basin.
	Central United States			
6	Mississippi River	Various types of igneous and metamorphic rocks near the headwaters. Widespread limestone, shale, and sandstone in the main part of the basin (U.S. Geol. Survey, 1932).	Mostly in Central Lowlands and Great Plains provinces, but the Missouri River heads in the Rocky Mountains.	Ranges from mountainous near the headwaters of the Missouri River to plains in various stages of erosion.
7	Kansas River	Shale and sandstone and lesser areas of calcareous deposits (Kansas State Geol. Survey, 1937).	High Plains and Plains Border sections of Great Plains province.	Submature to mature plateau and ate mature to old plains.
	Elk Creek	Shale, sandstone, gypsum, and a little dolomite (Miser, 1954).	Osage Plains section of the Central Lowlands.	Old scarped plains beveling faintly inclined strata. Main streams are entrenched.

TABLE 4.—*Geology and topography of stream basins studied*—Continued

Stream		Geology	Topographic province and section	Topography
No. (fig. 1)	Name			
		Central United States—Continued		
9	Colorado River, Tex.	Above Austin, Tex., rocks are mainly limestone and dolomite and some granite, gneiss, schist, sandstone, and shale. Below Austin, sandstone, greensand, lignitic beds, shale, and marl containing tuff occur (U.S. Geol. Survey, 1937; Folk and others, 1961).	Upper drainage is in Edwards Plateau and Central Texas section of Great Plains province. Lower drainage is in Coastal Plain.	Upper drainage ranges from young to old plateaus having various amounts of relief. Streams are entrenched in the rolling to level Coastal Plain.
10	Pecos River	Shale, sandstone, and some limestone, gypsum, granite, schist, and quartzite (U.S. Geol. Survey, 1928).	River heads in Southern Rocky Mountains province but lies mostly in Pecos section of Great Plains province.	Mostly late mature to old plains heading in complex mountains and mature block mountains of gently tilted strata.
11	Rio Grande River	Rhyolite, andesite, basalt, quartz latite, tuff, alluvium, and small areas of limestone, sandstone, shale, and gypsum (U.S. Geol. Survey, 1928, 1935).	Mainly in Southern Rocky Mountains province. Lower part in Navajosection of Colorado Plateaus province.	Complex mountains and intermontane basins. Smaller area of young plateaus.
12	San Juan River, Bloomfield.	Mainly shale and sandstone; smaller areas of conglomerate, coaly beds, tuff, andesite, rhyolite, and quartz latite (U.S. Geol. Survey, 1928, 1935).	River heads in Southern Rocky Mountains province with most of the area in the Navajo section of the Colorado Plateaus province.	Largely young plateaus.
13	Animas River	Sandstone and shale in lower basin but granite, schist, gneiss, slate, quartzite, limestone, dolomite, sandstone, and shale in upper basin (U.S. Geol. Survey, 1928, 1935).	Similar to San Juan River at Bloomfield.	Do.
14	San Juan River, Shiprock.	Includes Animas River drainage, San Juan River drainage above Bloomfield, and additional large areas of shale and sandstone (U.S. Geol. Survey, 1928, 1935).	Mainly in Navajo section of Colorado Plateaus province but heads in the Southern Rocky Mountains province.	Do.
15	Colorado River, Utah.	Large areas of sandstone and shale; some andesite, basalt, latite, tuff, rhyolite, gneiss, greenstone, schist, granite, and a little limestone and dolomite (U.S. Geol. Survey, 1935).	River heads in Southern Rocky Mountains province, but part of the drainage is in the Uinta Basin and Canyon Lands section of the Colorado Plateaus province.	Complex mountains of great relief and young to mature plateaus.
16	Cheyenne River	Mainly shale and sandstone; smaller areas of conglomerate and limestone. Much of the shale is carbonaceous and some is bentonitic (U.S. Geol. Survey, 1951; Love and others, 1955).	Missouri Plateau section of Central Lowlands province. Part of area is in Black Hills section.	Old plateau, terrace lands, local badlands, isolated mountains, few maturely dissected domed mountains.
17	Big Horn River	Mostly shale, sandstone, siltstone, and lesser dolomite, limestone, conglomerate, pyroclastics, granite, and metasediments. Some shale is bentonitic; other is phosphatic (Love and others, 1955).	Mainly Middle Rocky Mountains province, but partly in the Wyoming Basin province.	Complex mountains, intermontane basins; some low mountains and elevated plains.
		Western United States		
18	Cosumnes River	Granite, andesite, metasediments; lesser areas of basic metaigneous rocks and ultramafic intrusives. Lower basin contains sedimentary rocks, mainly sandstone and shale (Jenkins, 1938).	Stream heads in the Sierra Nevada section of Cascade-Sierra Mountains province and flows into the California Trough section of the Pacific Border province.	Alpine peaks, great relief, grading into fluviatile plain.
19	Cache Creek	Silty and feldspathic sandstone, shale, altered lava, serpentine, tuff, mafic and ultramafic rocks; some limestone and conglomerate (Jenkins, 1938; Anderson, 1936; Kirby, 1943).	California Coast Ranges section of Pacific Border province.	Parallel ranges and valleys on folded and faulted sedimentary, metamorphic, and igneous rocks.
20	Mad River	Information sparse. Arkosic sandstone and interbedded volcanics, shale, conglomerate, chert; some schist, slate, and mafic and ultramafic intrusives. Chlorite is common constituent in the rocks (Manning and Ogle, 1950).	do	Do.
21	Crooked River	Largely basalt, andesite and lesser tuff, and rhyolite flows (Wilkinson and Allen, 1939).	Walla Walla Plateau section of Columbia Plateaus province.	Rolling plateau having young incised valleys.

In table 1 the approximate average annual precipitation and approximate mean annual temperature are given for each basin. In areas which are both warm and moist, such as the Yadkin River basin, weathering is relatively rapid. Where either precipitation or temperatures are low, chemical reactions are slowed and weathering rates are also slow. Inasmuch as weathering intensity helps determine the mineralogy of soils, one must know something about the climate of an area if he is to understand why certain minerals are found in the soil-erosion products carried by streams.

The concentration of suspended sediment and of dissolved solids tends to be rather low in areas of high rainfall and high in areas of low rainfall. This can be seen from examination of table 2, and by reference to a report by Rainwater (1962). In the eastern United States, the moisture encourages vegetative cover, and the soil is thus protected from erosion. More water is available than necessary to leach out easily soluble salts from the soil; therefore, the concentration of dissolved solids in stream waters is low. In the arid Southwest, vegetative cover is sparse and occasional intense thunderstorms erode large amounts of soil. This erosion results in high suspended-sediment concentrations. Salts in soil solutions are concentrated by evaporation during the long dry periods and are later leached by rainwater to give large concentrations of dissolved salts.

TABLE 5.—*Soils within the stream basins studied*

[Clay minerals reported are those found in soils within a stream basin or in soils outside the basin but representing a soil series present in the basin]

Stream		Soil description	Clay minerals reported
No. (fig. 1)	Name		
1	Brandywine Creek	Mostly deep, well-drained silt loam and lesser areas of shallow to deep gravelly silt loam (Olmsted and Hely, 1962).	Kaolinite, illite, chlorite, vermiculite (Kunkle, 1963).
2	Juniata River	Thin and poorly developed on steep slopes and ridge crests, but moderately well developed in the broader valleys.	
3	Yadkin River	Deep to moderately deep, well-drained clay loam to sandy loam and lesser areas of stony and shallow loam and clay loam (Lee, 1955).	Kaolinite abundant; some vermiculite (M. J. Edwards, U.S. Dept. Agriculture, written commun., 1963).
4	Licking River	Well drained and medium textured (Winsor and Bailey, 1960)	Kaolinite (M. J. Edwards, U.S. Dept. Agriculture, written commun., 1963).
5	Green River	Mostly fine textured and well drained (Winsor and Bailey, 1960)	Kaolinite, vermiculite, mica, and slight montmorillonite (M. J. Edwards, U.S. Dept. Agriculture, written commun., 1963).
6	Mississippi River	Wide variety of soil types and drainage conditions	Montmorillonite, illite, kaolinite (Griffin, 1962).
7	Kansas River	Wide range in soil type, drainage, and development. Deep, well-drained soils formed on loess are common in the western part of the basin (McBee and others, 1961).	Illite, kaolinite, and montmorillonite (Badgley and Crumpton, 1964; Griffin, 1962).
8	Elk Creek	Shallow to moderately deep soil ranging from silt loam to fine sand (Goke and others, 1941; Goke and Hollopeter, 1931).	
9	Colorado River, Tex	Wide range in soil type and drainage development	Montmorillonite and illite (J. R. Coover, U.S. Dept. Agriculture, written commun., 1963).
10	Pecos River	Data not available.	
11	Rio Grande River	Wide range in soil types. Detailed information not available.	
12	San Juan River, Bloomfield	Do.	
13	Animas River	Do.	
14	San Juan River, Shiprock	Do.	
15	Colorado River, Utah	Do.	
16	Cheyenne River	Large areas of well-drained loam and clay loam and smaller areas of rough, stony badlands (R. C. Kronenberger, U.S. Dept. Agriculture, written commun., 1963).	
17	Big Horn River	Surface is largely rough, stony, broken land. Desert, sierozem, and arid brown soils are common at lower elevations (R. C. Kronenberger, U.S. Dept. Agriculture, written commun., 1963).	
18	Cosumnes River	Well-drained, shallow to deep soils ranging from loamy sands to clay loam (W. M. Johnson, U.S. Dept. Agriculture, written commun., 1963).	Kaolinite, mica, montmorillonite, and vermiculite (Isaac Barshad and Esther Perry, written commun., 1959).
19	Cache Creek	Well-drained, shallow to deep soils ranging from clay loam to gravelly loam (W. M. Johnson, U.S. Dept. Agriculture, written commun., 1963).	Vermiculite, montmorillonite, kaolinite, and lesser mica (Isaac Barshad and Esther Perry, written commun., 1959).
20	Mad River	Well-drained soils ranging from shallow, gravelly loam to deep, silty, clay loam.	Chlorite, vermiculite, kaolinite, mica (Isaac Barshad and Esther Perry, written commun., 1959).
21	Crooked River	Soils data not available.	

Table 3 shows the great range in area of the stream basins studied and also indicates runoff characteristics. Information regarding reservoirs and diversions are given because they affect both the discharge and chemical nature of the streams. Reservoirs tend to reduce variations in discharge and chemical composition of stream water, whereas diversions for irrigation commonly result in reduced flow and increased dissolved salt concentrations.

Comparison of average runoff from table 3 with average precipitation (table 1) is helpful in indicating the percentage of precipitation available for removing dissolved salts and sediment from a basin.

The geology and topography of the stream basins studied is described in table 4. The information is necessary in understanding what type of material is being weathered and in estimating the potential energy available for mechanical weathering and transportation of sediment.

Because soils are the source of almost all of the sediment transported by streams, an understanding of their characteristics is necessary in predicting the mineralogy and size distribution in stream sediments. Table 5 summarizes some of the available data on soil development and mineralogy for the basins which were studied.

MINERALOGY AND EXCHANGE CAPACITY OF STREAM SEDIMENTS

The data on the mineral constituents and exchange capacity of sediments from the 21 streams studied are summarized in tables 6–8. To better visualize the geographic distribution of clay minerals in the sediments, a map showing sampling locations and proportions of various constituents of the clay fraction is presented in figure 2. Similarly, the exchange capacities of the sand, silt, and clay fractions are shown as bar graphs on figure 3.

DISCUSSION OF DATA

Surface soil is the source of much of the material transported in solid form by a stream. However, where gullying is prevalent, appreciable amounts of the subsoil may be eroded.

Jackson (1959, p. 133) pointed out that the relative abundance of minerals in soils varies with five principal factors: (1) The characteristics of the minerals in the parent material, (2) the time of weathering, (3) the climate, (4) the relief, and (5) the biota. The first three factors are completely independent, but the relief will be determined largely by the first three factors. The biotic factor, in turn, will be significantly affected by the other four factors.

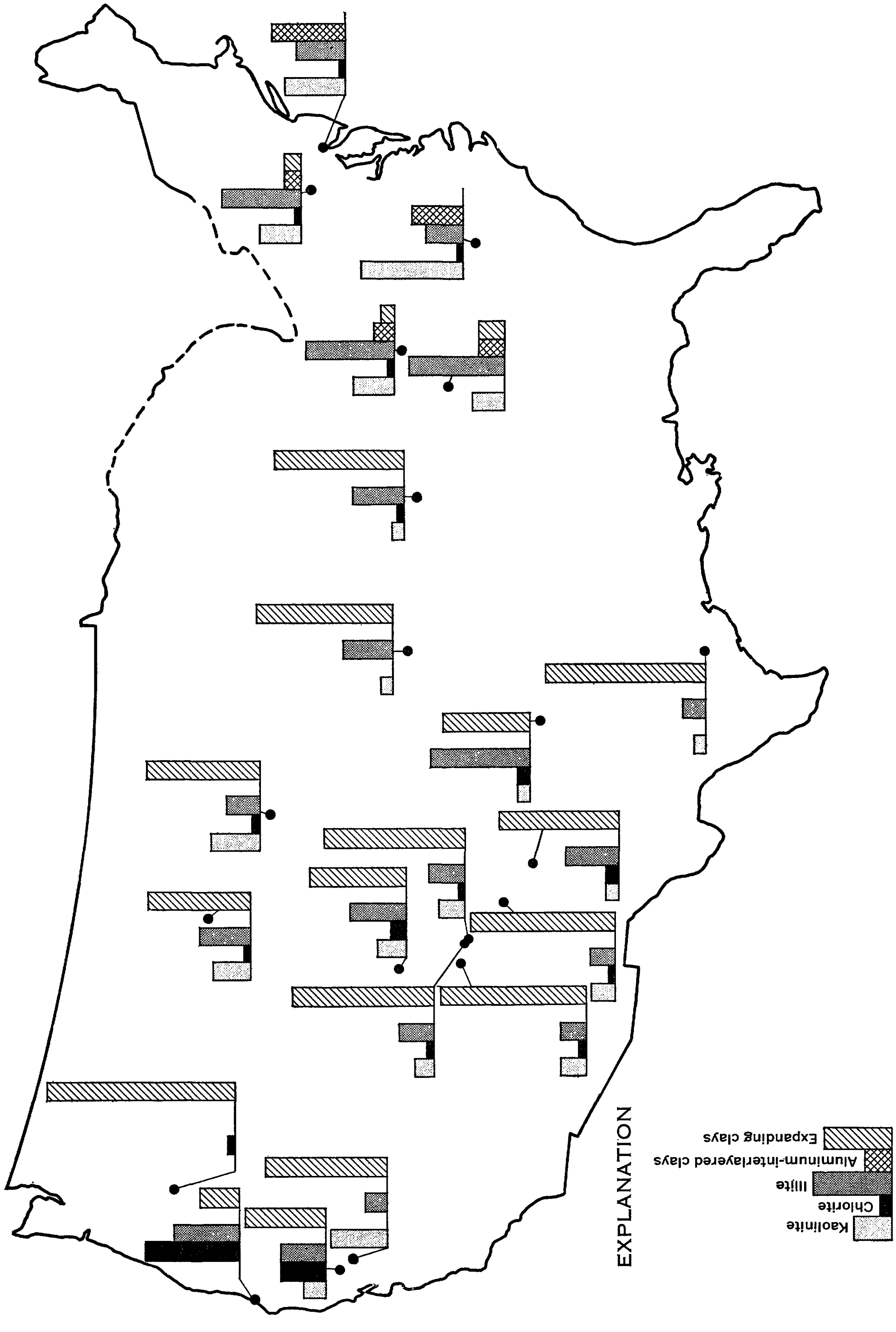
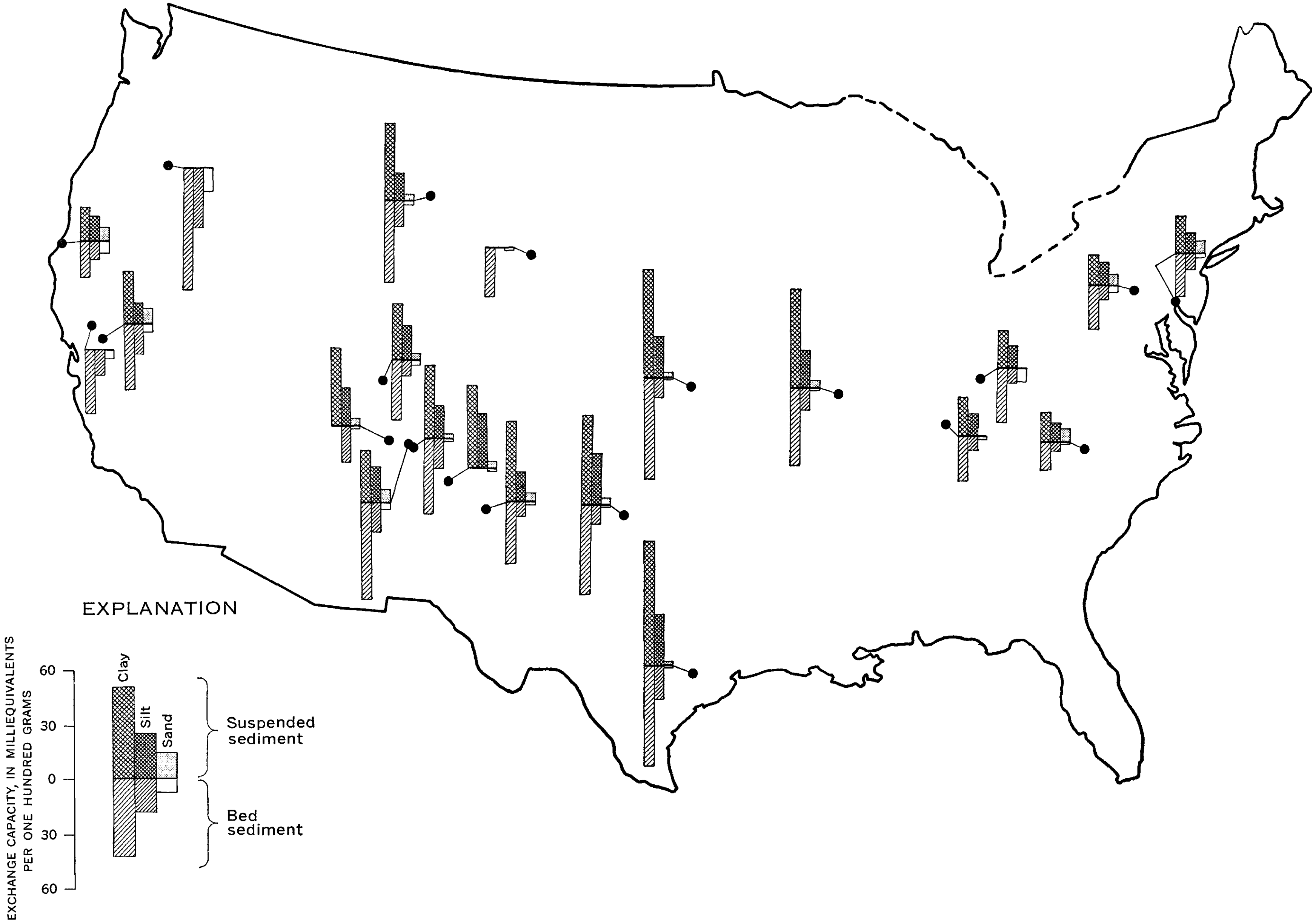


FIGURE 2.—Mineralogy of stream clay



Note: No bar graph is shown where insufficient data are available

FIGURE 3.—Cation-exchange capacity of stream sand, silt, and clay.

Fine-grained minerals in the soil profile have large surface areas per unit weight and, hence, are more likely to approach equilibrium with their environment than are coarse-grained minerals.

Keller (1956, p. 2695–2704) pointed out that each of the major clay minerals tends to be stable in a characteristic environment. Thus, kaolin minerals are relatively stable under the oxidizing and acidic leaching conditions of the warm, humid southeastern United States (Ross, 1943), but montmorillonite is stable in the arid western United States where the soil solutions are alkaline and have a high concentration of salts. It is not surprising, therefore, that high exchange-capacity clay minerals are more common in soils of the West than in the Southeast (Keller, 1955, p. 71; Albrecht, 1947).

Walker (1949) has shown that mica in the soil is leached during weathering to yield an altered mineral having an interlayer spacing of about 10A. In clay-size material, such a mineral would probably be considered illite. Inasmuch as Van Houton (1953) found illite in soils from many parts of the United States, it is at least moderately stable in several different soil environments.

VARIATION IN COMPOSITION AND EXCHANGE CAPACITY OF STREAM SEDIMENTS

Because the streams sampled were so selected that a wide range in the factors influencing soil mineralogy would be represented, considerable variation in mineralogy can be expected. When only a limited amount of sample was available, either mineralogy or exchange capacity was determined first and other tests were performed if material remained.

CLAY

Information about the composition and exchange capacity of the clay fraction is summarized in table 6. The data are reported according to the expected precision of the results.

STREAMS EAST OF THE MISSISSIPPI RIVER

Samples of clay carried by five streams east of the Mississippi River contain kaolinite, illite, and aluminum-interlayered clay as the main clay minerals. The Yadkin River clay contains more kaolinite and less illite than the others and has a significantly lower exchange capacity.

Some data are available regarding the clay mineralogy of soils within the drainage basins studied. Kunkle (1963, p. 108–111) reported widely varying amounts of kaolinite, illite, and chlorite or chloritelike clays, and low concentrations of vermiculite in a few surface soils in the Brandywine Creek drainage. It seems probable that Kunkle's "chloritelike" clays include those referred to as aluminum-interlayered clay in this report.

Recent studies of soils in several eastern Pennsylvania counties (Johnson and others, 1963) have shown that illite, kaolinite, vermiculite, and "dioctahedral chlorite" (includes the aluminum-interlayered clay of this report) commonly occur in surface soils there. Although none of the counties studied are within the Juniata River basin, the studies may indicate the general suite of clay minerals to be expected in Juniata River sediments.

The clay mineralogy of soils in the North Carolina Piedmont has been studied by several investigators. Coleman and others (1950) reported that kaolinite was the dominant clay mineral and vermiculite, illite, gibbsite, poorly crystalline material, and hematite occurred in subordinate amounts. Weed and Nelson (1962) found kaolinite and an aluminum-interlayered clay mineral as dominant constituents in some representative North Carolina soils. M. J. Edwards (U.S. Dept. of Agriculture, written commun., 1963) reported kaolinite as the dominant clay mineral in surface soils of the type found in the Yadkin River drainage basin. Vermiculite is a minor constituent.

Some soils in the Licking River basin contain abundant kaolinite. Vermiculite, kaolinite, illite, and a little montmorillonite are found in soils of the Green River basin (M. J. Edwards, U.S. Dept. of Agriculture, written commun., 1963). Griffin (1962, p. 743) found kaolinite and illite to be important clay minerals in the Ohio River drainage. Johns and Grim (1958, p. 198) reported that illitic and chloritic sediments weather to form "vermiculitic and montmorillonitic (at least, expanding) minerals" in areas drained by the Ohio River.

The data in table 6 (p. D13) show that the clay mineralogy of stream sediments studied from the eastern United States agrees rather well with what is known about the clay mineralogy of the surface soils. The method of analysis used in this study for most of the clay samples makes detection of small to moderate amounts of vermiculite difficult when significant amounts of aluminum-interlayered clay, mixed-layer montmorillonite-illite, or chlorite are also present. However, specific tests for vermiculite were performed on one sample from each stream in this area. They indicate that the 14–A clay mineral (exclusive of chlorite) in Brandywine Creek and the Yadkin River is almost entirely an aluminum-interlayered clay, whereas that in the Juniata, Licking, and Green Rivers is one-third to one-half vermiculite and the rest aluminum-interlayered clay.

TABLE 6.—*Mineralogy and cation-exchange capacity of stream clays*

[Method of reporting data reflects expected accuracy of data. Quartz concentrations are reported as parts in ten. P, present; Tr, 0–3 percent; Sp, 4–10 percent; C, 11–25 percent; M, 26–50 percent; Sus, suspended. Analyses for "amorphous silica" and "amorphous alumina" were made by E. C. Mallory, Jr.; carbon analyses were made by I. C. Frost. Figures were rounded to the nearest 0.1 percent]

Stream		Date of sample collection	Ratio of discharge when sampled to average discharge	Sample type	Constituents																
					Weight percent																
No. (fig.1)	Name				Amorphous silica	Amorphous alumina	Organic carbon	Mineral carbon	Total carbon	Kaolinite	Illite	Vermiculite plus aluminum-interlayered clays	Montmorillonite	Chlorite	Mixed-layer clay	Quartz	Feldspar	Calcite	Dolomite	Gibbsite	Cation-exchange capacity (meq per 100g)
1	Brandywine Creek.	4- 2-60	1.2	Bed	4.8	2.5	----	----	>5.2	M	C	M	0	Tr	Sp	1	Tr	0	0	0	18
		4- 4-60	9.2	Sus	----	----	----	----	4.9	C	M	C	0	Tr	Sp	1	0	0	0	0	30
		2-21-61	2.7	Bed	5.5	3.0	4.8	<0.02	4.8	M	C	M	0	Tr	C	1	Tr	0	0	0	22
		2-26-61	8.1	Bed	5.3	2.9	----	----	4.7	C	C	M	0	Sp	Sp	1	Tr	0	0	0	23
		2-26-61	8.1	Sus	----	----	----	----	2.6	C	C	C	0	Tr	Sp	1.5	Sp	0	0	0	13
		11-16-61	.4	Bed	7.0	3.1	----	----	----	M	C	C	0	Tr	C	1	Sp	0	0	0	26
2	Juniata River	8-31-60	.15	Bed	5.7	1.3	----	----	4.2	C	M	C	0	0	Sp	2	Tr	0	0	0	19
		2-21-61	5.1	Bed	4.3	1.1	----	----	----	C	C	C	0	0	Sp	2	Tr	0	0	0	23
		2-21-61	5.1	Sus	5.2	1.4	----	----	----	C	M	C	0	0	Sp	2	Tr	0	0	0	17
		2-27-61	12	Bed	2.1	1.3	----	<.02	1.88	C	M	C	0	0	Sp	1.5	Tr	0	0	0	22
		2-27-61	12	Sus	2.8	1.3	----	----	3.64	C	M	C	0	0	0	2	Tr	0	0	0	17
		3-10-61	4.6	Bed	3.8	1.2	----	----	----	C	M	C	0	0	Sp	2	Tr	0	0	0	22
		3-10-61	4.6	Sus	----	----	----	----	----	C	M	C	0	0	Sp	2.5	Tr	0	0	0	16
		4-14-61	5.7	Bed	3.4	1.0	----	----	----	C	M	C	0	Tr	Sp	2	Tr	0	0	0	22
		11-14-61	.1	Bed	8.9	.9	----	----	----	C	M	C	0	Tr	Sp	1.5	Tr	Tr	0	0	24
3	Yadkin River	2- 1-60	7.7	Bed	4.2	4.7	----	----	----	M	C	C	0	0	Sp	1	0	0	0	Tr	----
		2- 1-60	7.7	Sus	----	----	----	----	----	M	C	C	0	0	Sp	.5	0	0	0	Tr	12
		3-30-60	5.1	Bed	----	----	----	----	----	M	C	C	0	Tr	C	1	Tr	0	0	Tr	12
		3-30-60	5.1	Sus	----	----	----	----	----	M	C	C	0	0	Sp	.5	Tr	0	0	Tr	19
		5-18-61	1.1	Bed	4.8	5.9	----	----	----	M	C	C	0	Tr	Sp	1	Tr	0	0	Tr	22
		6-22-61	4.6	Bed	3.7	5.3	4.1	.15	4.3	M	C	C	0	Tr	Sp	1	Tr	0	0	Tr	12
		6-22-61	4.6	Sus	5.0	7.0	2.1	<.01	2.1	M	C	C	0	Tr	Sp	1	Tr	0	0	Tr	11
		11-19-61	.6	Bed	3.7	4.6	----	----	3.6	M	C	C	0	0	Sp	1	Tr	0	0	Tr	16
4	Licking River	6- 6-60	.1	Sus	----	----	----	----	----	C	M	Sp	0	Tr	Sp	2	Tr	0	0	0	21
		9- 7-60	.03	Bed	2.2	1.3	----	----	----	C	M	C	0	Tr	Sp	1.5	Tr	0	0	0	29
		1-18-61	4.7	Bed	2.4	1.4	----	----	>2	C	M	Sp	0	0	Sp	2	Tr	0	0	0	----
		1-18-61	4.7	Sus	----	----	----	----	----	C	M	C	0	0	Sp	2	Tr	0	0	0	20
		2-27-61	5.2	Bed	2.0	1.3	2.1	.05	2.1	C	M	Sp	0	Tr	Sp	2	Tr	0	0	0	28
		2-27-61	5.2	Sus	----	----	----	----	2.3	C	M	C	0	0	Sp	2	Tr	0	0	0	20
		11- 7-61	.03	Bed	2.2	1.2	----	----	----	C	M	Sp	0	Tr	Sp	0	Tr	0	0	0	26
5	Green River	11- 3-60	.07	Bed	2.7	1.7	----	----	----	C	M	C	0	0	Sp	2.5	Tr	0	0	0	25
		1-13-61	.4	Bed	3.4	1.4	----	----	----	Sp	M	C	0	Tr	Sp	3.5	Tr	0	0	0	18
		2-28-61	5.9	Bed	3.5	1.5	----	----	----	C	M	Sp	0	0	Tr	3.5	0	0	0	0	21
		2-28-61	5.9	Sus	2.7	1.5	----	----	----	Sp	M	C	0	0	Sp	3.5	0	0	0	0	21
		3- 7-61	6.7	Bed	----	----	----	----	2.1	C	M	C	0	0	Tr	3	Tr	0	0	0	21
		3- 7-61	6.7	Sus	----	----	----	----	1.8	Sp	M	C	0	0	Sp	3.5	0	0	0	0	19
		5-10-61	5.3	Sus	----	----	----	----	----	Sp	M	C	0	0	Sp	3	0	0	0	0	21
		11- 6-61	.2	Bed	4.1	1.3	----	----	----	Sp	M	Sp	0	0	Sp	3.5	0	0	0	0	24
6	Mississippi River.	10-11-60	.5	Bed	3.6	1.4	----	----	1.4	Sp	C	Tr	M	0	C	2	Sp	0	0	0	52
		10-11-60	.5	Sus	----	----	----	----	----	Sp	C	----	M	0	C	2	0	0	0	0	54
		3- 9-61	1.4	Bed	2.4	.8	----	----	----	Sp	C	----	M	0	C	2	Sp	Tr	0	0	38
		3- 9-61	1.4	Sus	4.1	1.0	----	----	----	Sp	M	----	M	0	C	1.5	Tr	0	0	0	53
		4- 6-61	1.8	Sus	4.1	1.1	----	----	1.6	Sp	C	----	M	0	C	1.5	Tr	0	0	0	50
		5-16-61	2.4	Sus	3.9	1.5	----	----	----	Sp	C	----	M	0	C	1.5	Tr	0	0	0	49
		5-18-61	2	Bed	----	----	----	----	----	C	M	P	C	Tr	C	1	0	0	0	0	36
		6- 7-61	1	Sus	----	----	----	----	----	Sp	C	----	M	0	C	1	Tr	0	0	0	41
		6- 8-61	1	Bed	----	----	----	----	----	Sp	C	----	C	Tr	C	1.5	Sp	0	0	0	43
7	Kansas River	9- 7-60	1	Bed	1.0	1.3	----	----	----	Sp	C	?	C	0	M	1	Tr	Tr	0	0	56
		9- 7-60	1	Sus	3.4	1.3	----	----	----	Sp	C	?	C	0	M	0	0	Tr	0	0	55
		11- 1-60	.6	Bed	----	----	----	----	----	Sp	C	P	C	0	M	1	Sp	0	0	0	56
		11- 1-60	.6	Sus	----	----	----	----	----	Sp	M	P	C	0	C	1	Tr	0	0	0	58
		1-11-61	.4	Bed	----	----	----	----	----	Sp	C	P	C	0	M	1	Tr	0	0	0	54
		1-11-61	.4	Sus	----	----	----	----	----	Sp	C	?	C	0	C	1	Tr	Tr	0	0	56
		5- 8-61	3.9	Bed	4.2	1.7	----	----	2.2	Sp	M	P	C	0	Sp	1	Tr	0	0	0	59
		5- 8-61	3.9	Sus	3.5	1.3	----	----	2	Sp	C	Sp	C	0	M	1	Tr	0	0	0	58
		5-24-61	14	Bed	----	----	----	----	----	Sp	C	P	M	0	C	1	Tr	0	0	0	42
		5-24-61	14	Sus	4.3	1.6	----	----	----	Sp	C	P	C	0	M	1	Tr	0	0	0	55
		10-30-61	1	Bed	----	----	----	----	----	Sp	C	P	C	0	M	1.5	Tr	0	0	0	46
		10-30-61	1	Sus	----	----	----	----	----	Sp	C	P	C	0	M	1.5	Tr	Tr	0	0	56
8	Elk Creek	8-26-60	.7	Bed	3.3	1.5	----	----	----	Sp	M	Sp	Sp	Sp	M	.5	0	0	0	0	48
		8-26-60	.7	Sus	----	----	----	----	----	Sp	M	Sp	Sp	Tr	M	1	Tr	0	0	0	42
		10-13-60	18	Bed	3.4	1.5	----	----	----	Sp	M	Sp	Sp	Sp	M	.5	Tr	0	0	0	47
		10-13-60	18	Sus	3.5	1.2	----	----	----	Sp	M	Sp	Sp	Tr	M	1	Tr	0	0	0	47
		10-19-60	54	Bed	3.4	1.0	1.5	.03	1.5	Sp	M	Sp	Sp	Sp	M	1	Tr	0	0	0	45
		10-19-60	54	Sus	4.2	1.5	----	----	----	Sp	M	Sp	Sp	Tr	M	1	Tr	0	0	0	47
		6- 8-61	42	Bed	2.6	.8	----	----	2	Tr	M	Sp	Sp	Sp	M	1	Tr	0	0	0	41
		6- 8-61	42	Sus	3.8	1.7	----	----	2.3	Tr	M	Sp	Sp	Tr	M	1	Tr	0	0	0	45
		10-12-61	.5	Bed	3.2	1.2	----	----	----	Sp	M	Sp	Sp	Sp	M	1	Tr	0	0	0	47
		10-12-61	.5	Sus	----	----	----	----	----	Sp	M	Sp	Sp	Sp	M	1	Tr	0	0	0	47
9	Colorado River, Tex.	10-31-60	17	Bed	----	----	----	----	----	Sp	C	P	M	0	C	1	Tr	Tr	0	0	48
		6-20-61	16	Bed	2.5	.8	----	----	4.6	C	C	P	M	0	M	1	Sp	Tr	0	0	53
		6-20-61	16	Sus	3.2	.6	----	----	1.9	Sp	Sp	P	M	0	M	1	Tr	Sp	0	0	64
		9-12-61	15	Sus	3.5	.6	----	----	----	Sp	Sp	----	M	0	C	1	0	Sp	0	0	65
		9-15-61	3.9	Bed	----	----	----	----	----	Sp	Sp	Sp	M	0	C	1	Tr	0	0	0	61
		9-15-61	3.9	Sus	----	----	----	----	----	Sp	Sp	----	M	0	C	1	Tr	Sp	0	0	64
		10-14-61	.4	Bed	5.3	.9	----	----	4.6	Sp	Sp	P	M	0	C	1	Tr	C	0	0	49

TABLE 6.—*Mineralogy and cation-exchange capacity of stream clays*—Continued

Stream		Date of sample collection	Ratio of discharge when sampled to average discharge	Sample type	Constituents																
					Weight percent																
No. (fig.1)	Name				Amorphous silica	Amorphous alumina	Organic carbon	Mineral carbon	Total carbon	Kaolinite	Illite	Vermiculite plus aluminum-interlayered clays	Montmorillonite	Chlorite	Mixed-layer clay	Quartz	Feldspar	Calcite	Dolomite	Gibbsite	Cation-exchange capacity (meq per 100g)
10	Pecos River	10-12-60	.2	Bed	------	------	------	------	------	C	M	Sp	Sp	Sp	Sp	1.5	Tr	0	0	0	23
		5-29-61	1.2	Sus	------	------	------	------	------	Sp	C	C	Sp	Tr	C	2	Tr	0	0	0	42
		8-11-61	.3	Sus	2.6	1.1	------	------	------	C	C	C	Sp	Sp	C	1.5	Tr	0	0	0	39
		8-12-61	.3	Bed	1.8	.7	------	------	------	Sp	C	C	Sp	Tr	C	1	Tr	0	0	0	34
		9-19-61	7.8	Bed	2.6	.8	------	------	>1	Sp	C	C	Sp	Sp	C	1.5	Sp	0	0	0	40
		9-19-61	7.8	Sus	2.5	1.0	------	------	1.3	Sp	C	C	Sp	Sp	C	1	Tr	0	0	0	45
		10-11-61	.7	Bed	2.9	1.0	------	------	1.6	Sp	C	C	Sp	Tr	C	1	0	Tr	0	0	43
11	Rio Grande River.	4-25-61	1.8	Sus	------	------	------	------	------	Sp	Sp	------	M	0	C	1	Tr	0	0	0	46
		6-21-61	.6	Sus	------	------	------	------	------	C	C	------	M	Tr	C	1.5	Tr	0	0	0	49
12	San Juan River, Bloomfield.	12-10-59	.2	Sus	------	------	------	------	------	Sp	C	P	C	Tr	C	1.5	Sp	0	0	0	45
		4- 9-61	2.3	Sus	2.2	.8	------	------	------	C	C	P	Sp	Tr	M	1.5	Sp	0	0	0	36
		7-12-61	.4	Bed	.8	1.3	------	------	------	Sp	C	------	C	Tr	M	1.5	Sp	0	0	0	42
		7-12-61	.4	Sus	------	------	------	------	------	Sp	C	P	C	Tr	M	2	Tr	0	0	0	34
		10-10-61	1.8	Bed	1.9	.7	------	------	------	C	C	P	C	Tr	M	1.5	Sp	0	0	0	40
		10-10-61	1.8	Sus	2.2	.5	------	------	------	C	C	C	Sp	Tr	C	1.5	Tr	0	0	0	40
13	Animas River	5-26-61	3.5	Sus	------	------	------	------	------	Sp	C	P	C	Tr	C	1	Tr	0	0	0	24
		6- 8-61	2.3	Sus	------	------	------	------	------	Sp	Sp	P	M	Tr	C	2	Tr	0	0	0	23
		10-10-61	.8	Bed	1.9	.8	------	------	1.1	Sp	C	P	C	Tr	M	1.5	Tr	0	0	0	37
		10-10-61	.8	Sus	1.6	.6	------	------	1.3	Sp	C	P	C	Tr	M	1.5	0	Tr	0	0	37
		10-10-61	.8	Bank	------	------	------	------	------	Sp	Sp	------	M	Tr	C	1.5	Tr	0	0	0	61
14	San Juan River, Shiprock.	6- 8-61	1.9	Sus	------	------	------	------	------	C	C	P	M	Tr	C	1.5	0	0	0	0	37
		10-10-61	1.4	Bed	1.8	.7	------	------	.5	Sp	Tr	P	M	0	M	1.5	Tr	0	0	0	58
		10-10-61	1.4	Sus	2.0	.7	------	------	.7	Sp	Sp	Sp	M	0	M	1	Tr	0	0	0	61
15	Colorado River, Utah.	11- 3-60	.3	Bed	1.8	.5	------	------	2.3	C	M	P	C	Sp	C	1.5	Tr	Sp	Tr	0	32
		5-26-61	2.2	Bed	2.0	.7	------	------	3.1	C	C	P	C	Sp	C	2	Tr	Tr	Tr	0	32
		5-26-61	2.2	Sus	------	------	------	------	2.7	Sp	C	P	M	Sp	C	2	Tr	0	Tr	0	36
		6- 2-61	2.5	Sus	------	------	------	------	------	C	M	P	C	Sp	C	1.5	0	Sp	Tr	0	30
		6- 6-61	1.4	Bed	1.4	.5	------	------	------	Sp	M	P	C	Sp	C	1.5	Tr	C	Tr	0	27
		6- 6-61	1.4	Sus	------	------	------	------	------	C	M	P	C	Sp	C	2	0	Tr	Tr	0	27
		6-18-61	1.3	Bed	1.8	.6	------	------	------	C	C	C	C	Sp	C	1.5	Tr	Sp	0	0	35
		6-18-61	1.3	Sus	------	------	------	------	------	C	M	P	C	Sp	C	1.5	Tr	Sp	Sp	0	26
		4-10-62	.9	Bed	------	------	------	------	------	Sp	C	P	C	Tr	C	1	Tr	Sp	Tr	0	32
16	Cheyenne River.	8-31-60	.05	Bed	1.7	.5	------	------	1.1	C	C	0	Sp	Tr	M	3	Tr	Tr	Tr	0	25
17	Big Horn River.	9- 1-60	.3	Bed	------	------	------	------	2.5	C	C	P	C	0	M	1.5	Tr	0	0	0	41
		9-12-61	1.1	Bed	1.8	.7	------	------	.7	C	C	P	C	Tr	M	2	0	0	0	0	43
		9-12-61	1.1	Sus	1.0	.4	------	------	.7	C	C	P	C	Tr	M	1.5	Tr	0	0	0	40
18	Cosumnes River.	12-14-60	.05	Bed	------	------	------	------	------	M	C	P	C	0	C	.5	Tr	0	0	0	39
		3- 7-62	6.9	Bed	3.7	2.0	.86	.07	.93	M	Sp	C	Tr	0	C	.5	0	0	0	0	44
		4-12-62	1.6	Bed	------	------	------	------	------	M	C	P	C	0	C	.5	Tr	0	0	0	28
19	Cache Creek	12-27-60	.01	Bed	2.0	.7	------	------	------	Sp	C	P	C	C	C	1.5	Sp	0	0	0	32
		4-14-62	<.01	Bed	------	------	1.0	<.02	1	C	C	Sp	C	C	C	.5	Sp	0	0	0	36
20	Mad River	10-19-60	.02	Bed	5.4	.7	------	------	1.7	0	M	------	0	M	C	1	Sp	0	0	0	28
		12- 2-60	5.5	Bed	------	------	------	------	------	0	M	------	0	M	Sp	1	------	0	0	0	13
		12- 2-60	5.5	Sus	------	------	------	------	------	0	C	------	0	M	C	1	Sp	0	0	0	17
		6- 8-61	.3	Bed	1.1	1.3	------	------	------	0	C	P	0	M	C	2	C	0	0	0	15
		6- 8-61	.3	Sus	------	------	------	------	------	0	M	------	0	M	C	1	------	0	0	0	18
		4-16-62	1	Bed	------	------	------	------	2.4	0	M	Sp	0	M	C	1	Sp	0	0	0	22
21	Crooked River	11-16-60	.2	Bed	10.2	1.6	2.7	<.02	2.7	0	0	Tr	M	Tr	M	.5	Sp	0	0	0	69
		3-29-61	1.7	Bed	19.2	1.4	------	------	------	0	0	P	M	Tr	M	.5	Sp	0	0	0	66
		5- 1-61	.9	Bed	------	------	------	------	------	0	0	P	M	0	M	.5	Sp	0	0	0	------
		5- 3-61	.9	Bed	18.2	1.1	------	------	------	0	0	0	M	0	M	.5	Sp	0	0	0	59
		4-18-62	6	Bed	------	------	2.8	<.02	2.8	0	0	P	M	0	M	.5	Tr	0	0	0	65

The exchange capacities of clays from four of the five eastern streams are similar. Only the exchange capacity of the Yadkin River clay differs in being appreciably lower than the rest, and this difference may be due to the greater content of relatively low-exchange-capacity kaolinite. Rich and Obenshain (1955) estimated the exchange capacity of "dioctahedral vermiculite" in a surface soil as about 50 meq per 100 g. Considering the exchange capacity of the kaolinite, illite, and organic matter (about 5 percent) in Yadkin River clay and the fact that the total exchange capacity is only 14 meq per 100 g, it is apparent that the exchange capacity of the "dioctahedral vermiculite" cannot greatly exceed 50 meq per 100 g and may be significantly less. Similar reasoning indicates that very little normal vermiculite (110–180 meq per 100 g exchange capacity, Brown, 1961, p. 299) can be present.

STREAMS WEST OF THE MISSISSIPPI RIVER, EXCLUSIVE OF CALIFORNIA AND OREGON

Keller (1955, p. 68–71) points out that the soils at the longitude of Utah-Nevada are largely lithosols high in partially weathered rock fragments. As one goes eastward, the rate of soil formation increases, and in the central United States, for example, from Kansas to the Mississippi River, large amounts of three-layer high-cation-exchange types of clay are present.

In the Rocky Mountain States and High Plains region the climate commonly is cool and arid, warm and arid, or, at the higher elevations, cool and moderately humid. In this area, chemical weathering is less important than in warm moist areas, and mechanical weathering is more important.

There is little detailed information available concerning the clay mineralogy of surface soils in the particular drainage basins studied within this area. However, montmorillonite and illite are important constituents of soils in the Colorado River basin above Columbus, Tex. (J. R. Coover, U.S. Dept. of Agriculture, written commun., 1963.) Kunze and others (1955) reported the presence of illite and kaolinite in two soil profiles in the upper part of the Colorado River basin in Texas. They found that montmorillonite dominates the $<2\mu$ fraction of a soil from the lower Colorado River basin upstream from Columbus. Fagg (1957) found abundant montmorillonite and lesser amounts of illite and kaolinite in Recent sediments of Matagorda Bay. An important part of the sediments in Matagorda Bay are probably carried in by the Colorado River.

In the Kansas River basin, two soil profiles were examined by W. A. Badgley and C. F. Crumpton (1964, p. 71–73) and found to contain montmorillonite, illite, and kaolinite.

Griffin (1962, p. 743) reported that the montmorillonite and illite groups of clays were dominant in the Mississippi River basin above St. Louis, Mo. Johns and Grim (1958, p. 198) also point out that soils of the Missouri River basin contain much montmorillonite.

Specific tests indicate that little, if any, aluminum-interlayered clay is present in sediments from streams west of the Mississippi River and east of California and Oregon. Some vermiculite is apparently present either as a separate component or in mixed-layer clay containing illite or montmorillonite,

The exchange capacities of stream clays in this area are distinctly higher than those of stream clays east of the Mississippi River. This difference apparently is a result of the presence of significant percentages of montmorillonite, mixed-layer clay and some vermiculite.

STREAMS IN CALIFORNIA AND OREGON

Climate and geology vary greatly in the stream basins studied in California and Oregon. Barshad and Perry (written commun., 1959) determined the mineralogy of clays in soils from various parts of California. If one assumes their data can be used for a particular soil series beyond the immediate area of sampling, then, on the basis of soils series distribution described by W. M. Johnson, U.S. Dept. of Agriculture (written commun., 1963), some statements can be made regarding the clay mineralogy of soils within the stream basins studied.

Kaolinite, lesser quantities of montmorillonite and mica, and some vermiculite are probably present in soils of the Cosumnes River basin. In the Cache Creek basin above Yolo, major amounts of vermiculite, moderate amounts of kaolinite, and moderate to negligible amounts of mica and montmorillonite may occur. Little is known about the clay mineralogy of the soils in the Mad River basin, but plentiful chlorite is known to be present in at least some of the soils there.

Very little, if any, aluminum-interlayered clay appears to be present in these streams, although the presence of chlorite in clays from Cache Creek and the Mad River make determinations of aluminum-interlayered clay difficult.

The average exchange capacity of 37 meq per 100 g for clay from the Cosumnes River reflects the presence of low-exchange-capacity kaolinite mixed with vermiculite and vermiculite-illite mixed-layer clays. The exchange capacity of clay from Cache Creek is similar to that of Cosumnes River clay but results mainly from a mixture of chlorite and illite with montmorillonite, vermiculite, and mixed-layer clays. Vermiculite cannot be a large proportion of the clay minerals in either stream, for its high exchange capacity (110–180 meq per 100 g, Brown, 1961, p. 299) would cause the overall exchange capacity to be greater than that observed.

Because chlorite and illite comprise most of the clay minerals in the Mad River, the average exchange capacity is only about 18 meq per 100 g.

In the Crooked River of Oregon, the stream clay appears to be mainly montmorillonite and mixed-layered material, which is probably montmorillonite-illite. The high exchange capacity, 60–70 meq per 100 g, indicates that the mixed-layer clays contain a large proportion of montmorillonite. The fact that the clay-size fraction contains a high amount of amorphous silica but relatively little amorphous alumina shows that the amorphous silica determined was not obtained from solution of fine-grained or poorly crystalline clay minerals, for then both amorphous alumina and silica would have been above average.

AMORPHOUS MATERIAL

The truly amorphous material in stream clay is difficult to evaluate, especially when it is present as only a few percent of a sample. The method of analysis used may result in solution of gibbsite, some poorly crystalline material, and a little of the very fine grained clay minerals as well as truly amorphous alumina, silica, and alumino-silicates.

The weighted average of "amorphous silica" was about 3.6 percent, and of "amorphous alumina" about 1.3 percent. The above-average amount of silica in the Crooked River in Oregon may be related to the weathering of volcanic tuff and basaltic rocks. The alumina reported for Yadkin River clay is probably due, in part, to the presence of gibbsite. In general, there appears to be a tendency for the amount of "amorphous material" determined by this method to increase with increased weathering intensity (E. C. Mallory, Jr., written commun.).

ORGANIC CARBON

The organic material in stream sediments may be important in the removal of certain elements from solution, and may explain a significant proportion of the exchange capacity. A measure of the organic material present can be obtained from an organic-carbon analysis, although the ratio of organic material to organic carbon is not known accurately for modern stream sediments. If the ratio of organic material to organic carbon in surface soils reported by Broadbent (1953, p. 175–176) can be extrapolated to stream sediments, a value of 1.9 may be suitable.

In the present study, organic carbon was determined by difference between total carbon and mineral carbon. Sufficient sample often was not available for both analyses, and only total carbon was then determined. X-ray data were then used to indicate the amount of carbonate present; however, 1–2 percent carbonate could easily be missed by X-ray techniques.

The weighted-average organic-carbon content of the stream clays was about 2.2 percent; this value corresponds to about 4.2 percent organic matter. Streams east of the Mississippi River carried sediment containing significantly more organic carbon than the average for all streams studied.

SILT

The silt fraction of stream sediments may contain both shale fragments and clay-mineral aggregates formed by flocculation of clay-size particles. The repeated violent shaking of the silt-clay mixture in distilled water prior to separation of the <0.004-mm fraction was intended to disperse the flocculated aggregates but not to break down well-cemented rock fragments. As a result, many of the silt fractions still contained significant amounts of clay after size separation. This clay was reflected in the X-ray analyses as well as in the exchange capacities determined.

The mineral composition and exchange capacity of stream silt are summarized in table 7. The total amount of clay minerals in a sample was obtained by subtracting from 100 percent the amount of nonclay material estimated from X-ray data to be present.

An approximate check on the clay content can be obtained if three assumptions are made: (1) that the exchange capacity of the nonclay minerals in the silt and clay sizes is very small compared to that of the clay minerals, (2) that the exchange capacity of clay minerals in the clay fraction is the same per unit weight as that of clay minerals in the silt fraction, and (3) that virtually all the nonclay minerals were detected by X-ray methods. The calculation is made by using the following equation:

$$a=\frac{E_s b}{E_c}$$

where

E_s=exchange capacity of silt fraction,
E_c=exchange capacity of clay fraction,
a=fraction of silt fraction composed of clay minerals,

and

b=fraction of clay-size material composed of clay minerals.

A few such calculations were made and the results are shown in table 8 (p. D19).

In general, the data show fairly good agreement between the percentage of clay minerals estimated from X-ray analyses of silt and the percentage of clay minerals calculated from exchange-capacity information. The notable exceptions are the samples from the Crooked River. The anomalous data from the Crooked River may be due mainly to the presence of amorphous material. The Crooked River sand contains 10–15 percent volcanic glass and the clay 10–20 percent amorphous silica and alumina. It seems reasonable to assume that there may be 10–20 percent amorphous material in the silt fractions also. Because clay minerals in the silt are estimated by subtracting quartz, feldspar, and organic material from 100 percent, any amorphous material will be called "clay." If 20 percent amorphous material were assumed to be present in the Crooked River silts, much of the discrepancy between the estimates of clay minerals in silt made by X-ray methods and those made from exchange-capacity data would be removed.

TABLE 7.—*Mineralogy and cation-exchange capacity of stream silt*

[Carbon analyses, made by I. C. Frost, were rounded to the nearest 0.1 percent. Estimates of clay minerals were made by X-ray from reference curves of 001 peak intensities prepared by using moderately well crystallized kaolinite, finely ground muscovite, and finely ground chlorite. Although the amount of a particular clay mineral reported may be inaccurate, the relative amounts, in comparing one sample with another, are probably correct. Tr, 0–3 percent; Sp, 4–10 percent; C, 11–25 percent; M, 26–50 percent; Sus, suspended. Mixed-layer clay minerals are not easily detected in X-ray patterns of randomly oriented silt but are probably present in some samples, for many stream clays contain significant proportions of such clay minerals]

Stream		Date of sample collection	Ratio of discharge when sampled to average discharge	Type of sample	Constituents												Cation-exchange capacity (meq per 100 g)
No. (fig. 1)	Name				Percent			Parts in ten				Clays			Amphibole	Other minerals	
					Organic carbon	Mineral carbon	Total carbon	Quartz	Feldspar	Calcite	Dolomite	7 A	10 A	14 A			
1	Brandywine Creek	4- 2-60	1.2	Bed	1.4	<0.02	1.4	5.5	1.5	0	0	Sp	Sp	Sp	Sp	---	4.3
		4- 4-60	9.2	Sus	---	---	2.2	3.5	1	0	0	C	M	Sp	Tr	---	11
		2-21-61	2.7	Bed	---	---	2	4.5	1.5	0	0	Sp	Sp	Sp	Tr	---	9.5
		2-26-61	8.1	Bed	---	---	1.8	4.5	1.5	0	0	C	C	Tr	Sp	---	8
		2-26-61[1]	8.1	Sus	---	---	2.6	4	1	0	0	C	M	Tr	0	---	8.1
		11-16-61	.4	Bed	---	---	2.4	4.5	2	0	0	C	C	Sp	Tr	---	11.5
2	Juniata River	8-31-61	.15	Bed	---	---	4.5	5.5	.5	0	0	C	C	0	0	---	7.6
		2-21-61	5.1	Bed	---	---	---	7	Tr	0	0	Sp	C	0	0	---	8
		2-21-61	5.1	Sus	---	---	---	6	.5	0	0	C	C	0	0	---	17
		2-27-61	12	Bed	1.2	<.02	1.2	6.5	1	0	0	Sp	C	0	0	---	5
		2-27-61	12	Sus	---	---	4	6	.5	0	0	C	C	0	0	---	17
		3-10-61	4.6	Bed	---	---	---	6.5	1	0	0	Tr	C	0	0	---	9
		3-10-61	4.6	Sus	---	---	---	4.5	.5	0	0	C	C	Tr	0	---	[1] 11
		4-14-61	5.7	Bed	---	---	---	6.5	.5	0	0	Sp	C	0	0	---	7.7
		4-14-61	5.7	Sus	---	---	---	6.5	Tr	0	0	Sp	C	0	0	---	14
		11-14-61	.1	Bed	---	---	---	5	Tr	2	0	0	C	Sp	0	---	6.1
3	Yadkin River	2- 1-60	7.7	Bed	---	---	---	4.5	2	0	0	C	C	Tr	Sp	Tr ilmenite, zircon	3.7
		2- 1-60	7.7	Sus	---	---	---	3	.5	0	0	M	M	Tr	Tr	Tr magnetite	8.2
		3-30-60	5.1	Bed	---	---	---	4	1.5	0	0	C	C	0	Tr	Tr magnetite, ilmenite.	5.4
		3-30-60	5.1	Sus	---	---	---	2.5	.5	0	0	M	C	Tr	0	---	13
		5-18-61	1.1	Bed	2.4	<.01	2.4	4.5	1.5	0	0	C	C	0	Tr	Tr magnetite	4.5
		6-22-61	4.6	Bed	---	---	1.2	4.5	1	0	0	C	C	Tr	Tr	Tr magnetite	4.8
		6-22-61	4.6	Sus	---	---	1	2.5	1	0	0	M	M	0	0	---	5.3
		11-19-61	.6	Bed	---	---	---	5	2	0	0	C	C	0	0	---	4
4	Licking River	9- 7-60	.03	Bed	---	---	---	6	1	Tr	0	Sp	C	0	0	---	6.8
		1-18-61	4.7	Bed	1.2	.07	1.3	6.5	1	0	0	Sp	C	0	0	---	6.9
		1-18-61	4.7	Sus	---	---	---	---	---	---	---	---	---	---	---	---	13
		2-27-61	5.2	Bed	---	---	1.1	6.5	1	0	0	C	C	0	0	---	8.3
		2-27-61	5.2	Sus	---	---	1.5	5.5	1	0	0	C	C	0	0	---	8.8
		11- 8-61	.03	Bed	---	---	---	6	1.5	0	0	Sp	C	Tr	0	---	7.6
5	Green River	11- 3-60	.07	Bed	---	---	---	---	---	---	---	---	---	---	---	---	5
		1-13-61	.4	Bed	---	---	---	6.5	1	0	0	0	Tr	0	0	---	6.7
		1-13-61	.4	Sus	---	---	---	---	---	---	---	---	---	---	---	---	10.5
		2-28-61	5.9	Bed	---	---	---	6	.5	0	0	0	Tr	0	0	---	6.5
		2-28-61	5.9	Sus	---	---	---	6	1	0	0	Sp	Sp	Tr	0	---	12
		3- 7-61	6.7	Bed	---	---	1.1	6.5	1	0	0	0	Sp	0	0		6.9
		3- 7-61	6.7	Sus	---	---	1.6	6	.5	0	0	0	Sp	Tr	0	---	9.2
		5-10-61	5.3	Bed	---	---	---	6.5	.5	0	0	0	Sp	0	0	---	9.7
		5-10-61	5.3	Sus	---	---	---	---	---	---	---	---	---	---	---	---	14
		11- 6-61	.2	Bed	---	---	1.7	---	---	---	---	---	---	---	---	---	9
6	Mississippi River	10-11-60	.5	Bed	.1	.2	.3	6.5	2	0	Tr	0	Sp	Tr	Tr	---	7.4
		3- 9-61	1.4	Bed	---	---	---	6	1.5	Tr	Tr	Sp	Sp	0	Tr	---	7.2
		3- 9-61	1.4	Sus	---	---	---	5.5	1.5	0	0	Sp	C	Tr	0	---	20
		4- 6-61	1.8	Sus	---	---	2.3	6	1.5	0	Tr	Sp	C	0	0	---	11
		5-16-61	2.4	Sus	---	---	---	5.5	1	0	Tr	Tr	C	Tr	0	---	17
		5-18-61	2	Bed	---	---	---	5.5	1.5	0	Tr	Tr	C	0	0	---	11
		6- 7-61	1	Sus	---	---	---	4.5	1.5	0	Tr	C	C	0	0	---	26
		6- 8-61	1	Bed	.7	.01	.7	5	1.5	0	Tr	Tr	C	Tr	0	---	17
7	Kansas River	9- 7-60	1	Bed	---	---	.5	6	2.5	Tr	0	0	Sp	0	Tr	---	7
		9- 7-60	1	Sus	---	---	---	4.5	1	.5	0	0	C	Tr	0	---	25
		11- 1-60	.6	Bed	---	---	---	5	2	Tr	0	0	Sp	0	0	---	13
		11- 1-60	.6	Sus	---	---	---	4.5	1	0	0	Tr	C	Tr	0	---	30
		1-11-61	.4	Bed	---	---	---	5	1.5	Tr	0	Sp	Sp	0	0	---	13
		1-11-61	.4	Sus	---	---	---	2.5	.5	1	Tr	Sp	C	0	0	---	28
		5- 8-61	3.9	Bed	.2	.3	.5	5.5	2.5	Tr	0	0	Sp	0	Sp	---	7.5
		5- 8-61	3.9	Sus	---	---	1.3	5	2	Tr	Tr	Tr	C	0	0	---	20
		5-24-61	14	Bed	---	---	---	5	2.5	Tr	0	Tr	Sp	0	0	---	13
		5-24-61	14	Sus	---	---	---	6	2.5	0	Tr	0	Sp	0	0	---	8
		10-30-61	1	Bed	---	---	---	6	2.5	Tr	0	Tr	Sp	Tr	Sp	---	8
		10-30-61	1	Sus	---	---	---	5	1.5	Sp	Tr	Sp	Sp	0	Tr	---	15
8	Elk Creek	8-26-60	.7	Bed	---	---	---	5	2	.5	.5	Sp	C	0	0	---	13
		8-26-60	.7	Sus	---	---	---	2.5	.5	0	0	Sp	M	0	0	---	32
		10-13-60	18	Bed	---	---	---	6.5	2	Tr	Sp	Tr	Sp	Tr	0	---	7.1
		10-13-60	18	Sus	---	---	---	4.5	1	0	Tr	Sp	C	Tr	0	---	21
		10-19-60	54	Bed	1.1	2.4	1.1	6	2.5	Tr	.5	Sp	C	0	0	---	8.3
		10-19-60	54	Sus	---	---	---	4.5	1.5	0	Tr	Sp	C	0	0	---	21
		6- 8-61	42	Bed	---	---	1.6	4.5	1.5	Tr	.5	Sp	C	0	0	---	14
		6- 8-61	42	Sus	---	---	1	6	1.5	0	.5	Sp	C	0	0	---	
		10-12-61	.5	Bed	---	---	---	6	2	Tr	.5	0	Sp	Tr	0	---	10
		10-12-61	.5	Sus	---	---	---	3	1	0	Tr	Sp	C	0	0	---	30
9	Colorado River, Columbus, Tex.	10-31-60	17	Bed	---	---	---	4	1	1	Tr	Tr	Tr	Tr	0	---	23
		6-20-61	16	Bed	---	---	3.3	5	.5	1	0	Tr	Tr	0	0	---	20
		6-20-61	16	Sus	---	---	2.6	5.5	1	1	0	0	Tr	Tr	0	---	20

See footnote at end of table.

TABLE 7.—*Mineralogy and cation-exchange capacity of stream silt*—Continued

Stream		Date of sample collection	Ratio of discharge when sampled to average discharge	Type of sample	Constituents												Cation-exchange capacity (meq per 100 g)
No. (fig. 1)	Name				Percent			Parts in ten				Clays			Amphibole	Other minerals	
					Organic carbon	Mineral carbon	Total carbon	Quartz	Feldspar	Calcite	Dolomite	7 A	10 A	14 A			
9	Colorado River, Columbus, Tex. —Continued	9-12-61	15	Sus	---	---	---	4.5	1	1.5	Tr	Tr	Tr	C	0	---	28
		9-15-61	3.9	Bed	---	---	---	5.5	1.5	1	Tr	0	Sp	0	0	---	9.5
		9-15-61	3.9	Sus	---	---	---	4	1	1	0	Sp	Tr	Sp	0	---	31
		10-14-61	.4	Bed	---	---	3.7	0	0	0	0	0	0	0	0	---	16
10	Pecos River	10-12-60	.2	Bed	---	---	---	4.5	1	.5	Tr	Sp	Sp	Tr	Tr	---	7.6
		5-29-61	1.2	Sus	---	---	---	5	1	Tr	Tr	Sp	Sp	Tr	Tr	---	15
		8-11-61	.3	Sus	---	---	---	4	1	Tr	Tr	Sp	Sp	Tr	0	---	17
		8-12-61	.3	Bed	---	---	---	5	2.5	.5	Tr	Sp	Sp	Tr	Tr	---	8
		9-19-61	7.8	Bed	---	0.5	.8	5.5	2	Tr	Tr	Sp	Sp	0	0	---	6.8
		9-19-61	7.8	Sus	---	---	1.1	6	2	Tr	0	Sp	Sp	Tr	0	---	14
		10-11-61	.7	Bed	---	---	1	6	2	.5	Tr	Sp	Sp	Tr	0	---	7.4
11	Rio Grande River	4-25-61	1.8	Sus	---	---	---	4.5	1	0	0	Sp	Sp	Tr	0	---	27
		6-21-61	.6	Sus	---	---	---	2.5	.5	Tr	Tr	C	Sp	C		---	30
12	San Juan River at Bloomfield.	12-10-59	.2	Sus	---	---	---	3.5	1	Tr	Tr	C	C	Sp	0	Tr hematite	26
		4- 9-61	2.3	Sus	---	---	---	5.5	1	0	0	C	C	0	0	---	17
		5-24-61	3.1	Bed	---	---	---	---	---	---	---	---	---	---	---	---	13
		5-24-61	3.1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	18
		7-12-61	.4	Bed	---	---	---	5	2	0	0	C	Sp	Sp	0	---	17
		7-12-61	.4	Sus	---	---	---	4.5	1	0	0	C	C	Tr	0	---	19
		10-10-61	1.8	Bed	---	---	---	5	1.5	0	0	C	C	Sp	0	---	16
		10-10-61	1.8	Sus	---	---	---	5	1.5	Tr	0	C	C	Sp	0	---	16
13	Animas River	5-26-61	3.5	Sus	---	---	---	4	1	Tr	0	C	C	0	0	---	18
		6- 8-61	2.3	Sus	---	---	---	5.5	1.5	Tr	0	C	C	Sp	0	---	18
		10-10-61	.8	Bed	---	---	.9	5.5	1.5	0	0	C	C	Sp	0	---	20
		10-10-61	.8	Sus	1.1	<.01	1.1	5	1	0	0	C	C	Sp	0	---	18
14	San Juan River at Shiprock.	6- 8-61	1.9	Sus	---	---	---	5.5	1.5	0	0	C	Sp	Tr	0	---	14
		10-10-61	1.4	Bed	.4	.01	.4	5	1.5	0	0	C	Sp	Sp	0	Tr hematite	19
		10-10-61	1.4	Sus	.6	<.01	.6	5.5	1.5	Tr	0	C	C	Sp	0	---	24
15	Colorado River, Cisco, Utah.	11- 3-60	.3	Bed	1.2	1.2	2.4	---	---	---	---	---	---	---	---		8.2
		5-26-61	2.2	Bed	---	---	1.9	6	1	.5	.5	Sp	C	0	0	---	7.3
		5-26-61	2.2	Sus	---	---	2	5	1	Tr	.5	C	C	Sp	0	---	17
		6- 2-61	2.5	Sus	---	---	---	4.5	.5	.5	.5	C	C	Sp	0	---	17
		6- 6-61	1.4	Bed	---	---	---	5.5	1	.5	.5	C	C	Tr	0	---	9.6
		6- 6-61	1.4	Sus	---	---	---	5	.5	.5	Tr	C	Sp	Sp	0	---	16
		6-18-61	1.3	Bed	---	---	---	5.5	1.5	.5	.5	Sp	Sp	Tr	0	---	6.7
		6-18-61	1.3	Sus	---	---	---	4.5	1	.5	Tr	C	C	Sp	0	---	15
		4-10-62	.9	Bed	---	---	---	6	1	.5	.5	Sp	Sp	0	0	---	7
		4-10-62	.9	Sus	---	---	---	5.5	1	.5	.5	C	Sp	0	0	---	14
17	Big Horn River	9- 1-60	.3	Bed	---	---	1	5.5	1.5	0	.5	C	C	0	0	---	11
		9-12-61	1.1	Bed	.6	.3	.9	5.5	1	Tr	.5	C	C	Sp	0	---	16
		9-12-61	1.1	Sus	---	---	.6	---	---	---	---	---	---	---	---	---	14
18	Cosumnes River	12-14-60	.05	Bed	---		---	2.5	1	0	0	C	C	C	Sp	---	22
		3- 7-62	6.9	Bed	.3	<.02	.3	2.5	2	0	Tr	C	C	C	Sp	---	18
		3- 7-62	6.9	Sus	---	---	---	---	---	---	---	---	---	---	---	---	15
		4-12-62	1.6	Bed	---	---	1.1	3	1.5	0	0	C	C	C	Sp	---	15
19	Cache Creek	12-27-60	.01	Bed	---	---	.6	3.5	2	0	0	C	Sp	Sp	0	---	14
		4-14-62	.01	Bed	---	---	.5	4	2	0	0	C	Sp	Sp	0	---	13
20	Mad River	10-19-60	.02	Bed	---	---	.8	3.5	1	0	0	C	Sp	Sp	0	---	10
		12- 2-60	5.5	Bed	---	---	---	---	---	---	---	---	---	---	---	---	6.7
		12- 2-60	5.5	Sus	---	---	---	3	1	0	0	C	C	Sp	0	---	7
		6- 8-61	.3	Bed	---	---	---	4.5	1.5	0	0	C	Sp	Sp	0	---	7
		4-16-62	1	Bed	.5	<.02	.5	4	1	0	0	C	Sp	Sp	0	---	9
21	Crooked River near Post, Oreg.	11-16-60	.2	Bed	---	---	1	1	2.5	0	0	Tr	0	Tr	0	---	34
		3-29-61	1.7	Bed	---	---	---	.5	2.5	0	0	0	0	Sp	0	---	33
		5- 1-61	.9	Bed	---	---	---	.5	2	0	0	0	0	Sp	0	---	29
		5- 3-61	.9	Bed	---	---	---	.5	3	0	0	0	0	Sp	0	---	34
		4-18-62	6	Bed	1.2	<.02	1.2	.5	2.5	0	0	0	0	Sp	0	---	28

[1] Sample was very small and the value reported is less reliable than other data.

Because the sensitivity of the X-ray method for many minerals is about 1–5 percent, a few percent of one or more minerals could be present in a sample and not be detected. Such minerals would be called "clay" in the X-ray analysis of the silt fractions when the clay is estimated by difference. Therefore, one would expect the X-ray estimates of clay minerals in the silt to run several percent higher than those estimated from exchange-capacity data. The data in table 8 show this assumption to be generally valid.

X-ray analyses of silt were made on randomly oriented samples, and the clay minerals detected in the silt are listed in table 7 as 7-, 10-, or 14-A minerals. The 7-A minerals include kaolinite and chlorite, 10 -A indicates illite, and 14 -A includes chlorite, montmorillonite, vermiculite, and aluminum-interlayered clays.

TABLE 8.—*Comparison of the content of clay minerals in the silt fraction as estimated from X-ray and exchange-capacity data*

Stream	Date of sample collection	Clay minerals in silt fraction (percent)	
		Calculated from X-ray data	Calculated from exchange-capacity data
Brandywine Creek	4- 2-60	20	17
	2-21-61	35	33
Juniata River	2-21-61	20	25
	2-27-61	23	16
Kansas River	9- 7-60	14	10
	11- 1-60	27	18
Elk Creek	10-13-60	15	13
	6- 8-61	35	27
Mad River	10-19-60	53	48
	6- 8-61	40	37
Crooked River	11-16-60	63	37
	3-29-61	68	34

References to analyses of the clay fractions will indicate the clay minerals probably present.

The weighted-average organic-carbon content of stream silt was 1.1 percent, corresponding to about 2.1 percent organic material.

SAND

Mineralogical and exchange-capacity data for stream sands are given in table 9. The amount of sand in suspended-sediment samples was commonly too small for use in making detailed mineral analyses; however, the suspended sand was generally finer grained, higher in content of organic material, and contained greater amounts of platy minerals than the bed sand. By using a strongly radioactive cesium chloride solution it was possible to determine exchange capacities on samples of less than 0.1 g. The precision of such data is less, of course, than that attained using the normal sample weighing 2 g.

The variation in the exchange capacity of sand from stream to stream is greater percentagewise than is that of clay or silt because the mineral content of sand can range from rather clean quartz and feldspar to 70 percent or more rock fragments. Such rock fragments may be composed mainly of clay minerals, of silt-size quartz and feldspar cemented by iron compounds and clay minerals, of coarse-silt- or fine-sand-size quartz and feldspar cemented by silica or carbonates, or of igneous rock fragments. The latter two types of rock fragment will usually have low exchange capacities, perhaps about 0.1 meq per 100 g.

The significance of rock fragments as a cause of exchange capacity in stream sand is demonstrated in figure 4. Samples of sand from four streams were separated into three fractions by using a hand magnet and the Frantz magnetic separator. The highly magnetic fraction was composed of magnetite, ilmenite, and rock fragments containing appreciable amounts of these or other highly magnetic minerals. The moderately magnetic fraction consisted mainly of rock fragments containing, or cemented by, iron minerals or iron-stained clay. Minerals such as biotite, amphiboles, pyroxenes, and garnet are also in the moderately magnetic fraction. Quartz, feldspar, carbonates, and other minerals of very low magnetic susceptibility comprise the bulk of the "nonmagnetic" fraction. These grains may have very thin partial coatings of iron minerals. In figure 4, two columns are shown for sand from each of the four sampled streams. The column on the left shows the proportion by weight of each magnetic fraction, and the right column indicates the proportion of the total exchange capacity due to each magnetic fraction. It is apparent that the moder-

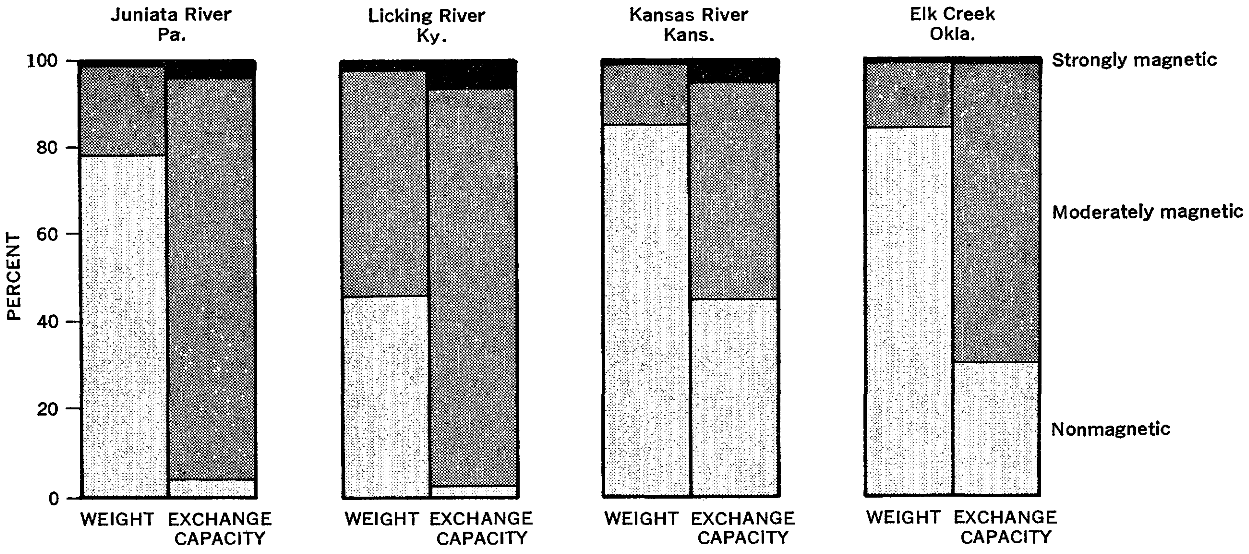


FIGURE 4.—Cation-exchange capacity of magnetic fractions of stream sand.

TABLE 9.—*Mineralogy and cation-exchange capacity of stream sands*

[Sus, Suspended]

Stream		Date of sampling	Ratio of discharge when sampled to average discharge	Type of sample	Constituents (weight percent)																						Cation-exchange capacity (meq per 100 g)
No. (fig. 1)	Name				Organic carbon	Mineral carbon	Total carbon	Quartz	Chert	K-feldspar	P-feldspar	Biotite	Muscovite	Amphiboles	Pyroxenes	Carbonates	Volcanic glass	Serpentine	Opaques	Organic matter	Rock fragments					Other minerals	
																					Fine grained	Coarse grained					
																						Quartz+quartz	Quartz+feldspar	Feldspar+feldspar	Undifferentiated		
1	Brandywine Creek.	4- 2-60	1.2	Bed	---	---	1.24	47	0	4	8	10	1	3	2	0	0	0	6	3	2	5	0	0	6	3	2.8
		4- 4-60	9.2	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.8
		2-21-61	2.7	Bed	0.68	<0.02	.68	36	0	6	14	5	1	6	1	0	0	0	6	1	1	8	0	0	10	5	3.4
		2-26-61	8.1	Bed	---	---	.52	44	0	5	10	5	2	8	2	0	0	0	6	1	2	4	0	0	10	5	2.4
		2-26-61	8.1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	8.7
		11-16-61	.4	Bed	---	---	.49	41	0	7	6	2	<1	5	2	0	0	0	2	<1	2	12	0	0	19	2	2.2
2	Juniata River	8-31-60	.15	Bed	---	---	.70	72	1	<1	0	0	0	0	0	0	0	0	0	0	9	4	0	0	14	0	1.5
		2-21-61	5.1	Bed	---	---	---	60	5	0	0	0	0	0	0	0	0	0	14	3	7	0	0	0	10	0	4.7
		2-21-61	5.1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.9
		2-27-61	12	Bed	---	---	2.27	59	3	<1	0	0	0	0	0	0	0	0	10	2	11	0	0	0	15	0	5.7
		2-27-61	12	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.8
		3-10-61	4.6	Bed	---	---	---	64	1	0	<1	0	0	0	0	0	0	0	13	9	7	0	0	0	5	0	3.3
		3-10-61	4.6	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	11
		4-14-61	5.7	Bed	---	---	---	71	1	0	0	0	0	0	0	0	0	0	10	3	5	0	0	0	9	0	3.0
		4-14-61	5.7	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	9.3
		11-14-61	.1	Bed	---	---	---	64	<1	<1	0	0	0	0	0	0	0	0	12	2	9	2	0	0	11	1	.8
3	Yadkin River	2- 1-60	7.7	Bed	---	---	---	60	0	12	3	3	0	3	1	0	0	0	1	<1	1	10	2	0	2	2	.4
		3-30-60	5.1	Bed	---	---	---	63	0	5	1	2	0	2	1	0	0	0	2	<1	1	10	2	0	12	1	.2
		5-18-61	1.1	Bed	<.02	.03	.04	62	0	10	2	3	0	2	0	0	0	0	<1	<1	1	12	1	0	7	1	.4
		6-22-61	4.6	Bed	---	---	.09	69	0	9	3	2	0	1	0	0	0	0	1	<1	1	8	1	0	4	1	.3
		6-22-61	4.6	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.8
		11-19-61	.6	Bed	---	---	---	62	0	11	2	2	0	1	0	0	0	0	0	<1	1	12	2	0	6	1	.3
4	Licking River	9- 7-60	.03	Bed	---	---	---	44	5	<1	1	0	0	0	0	3	0	0	<1	<1	32	0	0	0	13	2	4.9
		1-18-61	4.7	Bed	2.99	.11	3.10	37	6	2	<1	0	0	0	0	3	0	0	<1	4	33	0	0	0	14	1	---
		2-27-61	5.2	Bed	1.59	.23	1.82	26	5	<1	1	0	0	0	0	8	0	0	0	2	32	0	0	0	17	<1	7.3
		11- 8-61	.03	Bed	---	---	---	36	5	<1	0	0	0	0	0	2	0	0	2	---	31	0	0	0	25	0	4.9
5	Green River	11- 3-60	.07	Bed	---	---	---	82	7	0	0	0	0	0	0	0	0	0	0	1	8	0	0	0	2	0	1.3
		1-13-61	.4	Bed	---	---	---	76	8	1	0	0	0	0	0	<1	0	0	0	1	7	0	0	0	7	0	1.1
		2-28-61	5.9	Bed	---	---	---	82	7	<1	0	0	0	0	0	0	0	0	0	<1	9	0	0	0	2	0	.4
		3- 7-61	6.7	Bed	.65	.05	.70	79	4	0	0	0	0	0	0	1	0	0	0	4	9	0	0	0	3	0	.5
		5-10-61	5.3	Bed	---	---	---	81	8	<1	0	0	0	0	0	<1	0	0	0	<1	7	0	0	0	4	0	.5
		11- 6-61	.2	Bed	---	---	---	86	4	<1	0	0	0	0	0	0	0	0	0	<1	7	0	0	0	3	0	1.2
6	Mississippi River.	10-11-60	.5	Bed	.12	.02	.14	56	5	10	9	1	0	0	1	3	0	0	0	0	4	3	2	0	5	1	.9
		3- 9-61	1.4	Bed	---	---	---	57	4	12	10	0	0	0	0	2	0	0	0	<1	4	2	---	0	9	0	1.4
		3- 9-61	1.4	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.1
		4- 6-61	1.8	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.9
		4- 7-61	1.8	Bed	---	---	---	58	4	7	12	0	0	<1	1	<1	0	0	1	<1	6	4	3	1	3	0	1.1
		5-16-61	2.4	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.3
		5-18-61	2	Bed	---	---	---	57	5	11	9	0	0	0	1	1	0	0	1	0	5	3	3	2	1	1	.9
		6- 8-61	1	Bed	---	---	.23	60	6	10	5	0	0	<1	<1	<1	0	0	2	<1	5	3	4	0	4	1	.9
7	Kansas River	9- 7-60	1	Bed	---	<.01	.60	65	0	20	5	0	0	0	0	<1	0	0	<1	0	2	0	0	0	7	1	.7
		9- 7-60	1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.4
		11- 1-60	.6	Bed	---	---	---	61	<1	20	8	0	0	0	0	<1	0	0	1	0	4	0	0	0	6	0	.7
		1-11-61	.4	Bed	---	---	---	62	<1	18	8	0	0	0	0	<1	0	0	<1	0	3	0	0	0	8	1	.7
		1-11-61	.4	Sus	---	---	---	54	4	7	10	0	0	1	0	5	0	0	2	3	9	0	0	0	2	3	1.6
		5- 8-61	3.9	Bed	.07	.01	.08	70	1	14	6	0	0	0	0	1	0	0	0	0	1	0	0	0	7	<1	.7
		5-24-61	14	Bed	---	---	---	55	0	22	5	0	0	0	0	<1	0	0	0	0	<1	0	0	0	18	0	.5
		5-24-61	14	Sus	---	---	---	51	0	16	23	0	0	0	0	2	0	0	0	<1	1	0	0	0	4	1	.8
		10-30-61	1	Bed	---	---	---	70	2	16	6	0	0	0	0	0	0	0	0	0	1	0	0	0	5	0	.5
		10-30-61	1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.3
8	Elk Creek	8-26-60	.7	Bed	---	---	---	74	1	7	2	0	0	0	0	5	0	0	0	<1	2	7	1	0	1	0	.4
		10-13-60	18	Bed	---	---	---	72	1	12	3	0	0	0	0	2	0	0	0	0	3	5	1	0	1	0	.8
		10-13-60	18	Sus	---	---	---	63	1	11	4	0	0	0	0	5	0	0	2	2	7	3	1	0	1	0	4.0
		10-19-60	54	Bed	---	---	---	73	<1	7	2	0	0	0	0	5	0	0	0	<1	2	8	2	0	0	1	.9
		10-19-60	54	Sus	---	---	---	68	1	9	4	0	0	0	0	2	0	0	0	2	8	4	1	0	1	0	4.3
		6- 8-61	42	Bed	.08	.60	.68	68	1	3	3	0	0	0	0	7	0	0	0	0	5	9	0	0	4	<1	.5
		6- 8-61	42	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	.6
		10-12-61	.5	Bed	---	---	---	73	<1	5	2	0	0	0	0	9	0	0	0	0	2	7	0	0	2	0	.6
		10-12-61	.5	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.4
9	Colorado River, Tex.	10-31-60	17	Bed	---	---	---	69	3	8	4	0	0	0	0	5	1	0	0	0	3	4	1	<1	2	<1	.5
		6-20-61	16	Bed	.07	.55	.62	71	3	7	5	0	0	0	0	5	<1	0	0	0	2	3	1	1	2	<1	.3
		6-20-61	16	Sus	---	---	---	69	2	5	6	0	0	0	0	8	0	0	0	<1	2	2	2	<1	<1	0	.6
		9-12-61	15	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.8
		9-15-61	3.9	Bed	---	---	---	77	4	7	2	0	0	0	0	3	0	0	0	0	2	3	1	0	1	<1	.4
		10-14-61	.4	Bed	.11	.45	.56	70	3	8	3	0	0	0	0	5	<1	0	0	<1	4	3	1	<1	2	1	1.8
10	Pecos River	10-12-60	.2	Bed	---	---	---	60	<1	7	8	0	0	2	<1	4	0	0	1	0	2	3	4	<1	8	1	1.0
		5-29-61	1.2	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.2
		8-11-61	.3	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.0
		8-12-61	.3	Bed	---	---	---	60	1	5	6	0	0	1	0	7	0	0	1	0	1	5	5	<1	7	1	.9
		9-19-61	7.8	Bed	.06	.69	.75	60	2	7	6	0	<1	1	<1	6	0	0	3	0	2	5	3	1	4	<1	.7
		9-19-61	7.8	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.0
		10-11-61	.7	Bed	.21	.51	.72	62	<1	6	9	0	0	1	0	3	0	0	<1	0	3	5	2	<1	8	1	1.4
11	Rio Grande River.	4-25-61	1.8	Bed	---	---	---	53	3	9	6	0	0	0	0	2	0	0	2	<1	[1]6	5	4	<1	8	<1	1.2
		4-25-61	1.8	Sus	---	---	---	54	2	7	7	0	0	0	0	<1	0	0	<1	<1	9	0	0	0	0	0	3.8
		6-21-61	.6	Bed	---	---	---	62	3	7	3	0	0	0	1	2	0	0	0	0	5	3	6	1	6	<1	1.3
		6-21-61	.6	Sus	---	---	---	54	2	7	7	0	0	0	0	<1	0	0	0	0	9	4	4	<1	10	2	2.3

See footnote at end of table.

TABLE 9.—*Mineralogy and cation-exchange capacity of stream sands*—Continued

Stream		Date of sampling	Ratio of discharge when sampled to average discharge	Type of sample	Constituents (weight percent)																							Cation-exchange capacity (meq per 100 g)
																					Rock fragments						
																						Coarse grained					
No. (fig. 1)	Name				Organic carbon	Mineral carbon	Total carbon	Quartz	Chert	K-feldspar	P-feldspar	Biotite	Muscovite	Amphiboles	Pyroxenes	Carbonates	Volcanic glass	Serpentine	Opaques	Organic matter	Fine grained	Quartz+quartz	Quartz+feldspar	Feldspar+feldspar	Undifferentiated	Other minerals	
12	San Juan River Bloomfield.	12-10-59	.2	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.2
		4-9-61	2.3	Sus	---	---	---	41	1	16	7	0	0	0	0	0	0	0	0	<1	2	15	9	1	8	0	1.2
		5-24-61	3.1	Bed	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.1
		5-24-61	3.1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.3
		6-8-61	1.7	Bed	---	---	---	32	<1	16	6	0	0	0	0	0	0	0	0	<1	3	22	11	3	6	1	.9
		7-12-61	.4	Bed	---	---	---	34	---	20	6	<1	0	0	0	0	0	0	0	0	6	14	11	1	6	2	1.4
		10-10-61	1.8	Bed	---	---	---	38	1	17	9	<1	0	0	0	1	0	0	0	0	9	9	8	2	6	0	1.3
		10-10-61	1.8	Sus	---	---	---	49	1	12	23	0	0	0	0	0	0	0	0	1	4	1	3	<1	6	0	3.4
13	Animas River	5-26-61	3.5	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.9
		6-8-61	2.3	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.6
		10-10-61	.8	Bed	.16	.02	.18	42	1	12	8	1	0	0	0	<1	0	0	0	<1	10	10	8	1	6	1	3.5
		10-10-61	.8	Sus	---	---	---	47	1	9	15	1	0	0	0	<1	0	0	0	8	8	1	1	0	6	2	9.4
		10-10-61	.8	Bank	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	8.2
14	San Juan River Shiprock.	5-26-61	2.8	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.0
		6-8-61	1.9	Bed	---	---	---	48	1	15	6	0	0	0	0	<1	0	0	0	0	3	10	8	1	7	<1	.9
		6-8-61	1.9	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.6
		10-10-61	1.4	Bed	.09	.01	.10	51	1	16	7	0	0	0	0	1	0	0	0	<1	2	8	7	1	5	1	1.4
		10-10-61	1.4	Sus	---	---	.98	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.1
15	Colorado River, Utah.	11-3-60	.3	Bed	.64	.60	1.24	58	<1	7	6	<1	0	0	0	7	0	0	2	2	5	1	0	0	9	0	4.2
		5-26-61	2.2	Bed	.11	.36	.47	49	8	6	3	<1	0	0	1	1	0	0	1	<1	8	3	7	1	12	0	1.2
		5-26-61	2.2	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.5
		6-2-61	2.5	Bed	---	---	---	38	3	10	11	0	0	<1	0	2	0	0	<1	<1	7	2	10	1	15	0	1.2
		6-2-61	2.5	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.0
		6-6-61	1.4	Bed	---	---	---	48	3	7	5	0	0	0	0	2	0	0	1	<1	10	3	4	0	16	1	1.3
		6-6-61	1.4	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4.1
		6-18-61	1.3	Bed	---	---	---	56	2	9	5	0	0	0	<1	3	0	0	2	2	7	1	1	0	11	1	2.4
		6-18-61	1.3	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.3
		4-10-62	.9	Bed	---	---	---	52	2	4	2	1	0	<1	<1	4	0	0	1	<1	9	3	2	<1	18	1	2.9
		4-10-62	.9	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.4
16	Cheyenne River.	8-31-60	.05	Bed	.11	.12	.23	48	5	18	7	0	0	>1	0	1	0	0	0	0	5	7	3	2	4	<1	1.5
17	Big Horn River.	9-1-60	.3	Bed	.08	.13	.21	46	5	8	11	1	0	<1	<1	2	0	0	<1	0	7	2	3	0	15	<1	2.2
		9-12-61	1.1	Bed	.17	.06	.23	44	5	9	14	0	0	0	<1	2	0	0	0	0	8	4	3	0	10	<1	1.3
		9-12-61	1.1	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.6
18	Cosumnes River.	12-14-60	.05	Bed	---	---	---	37	0	9	12	4	0	1	<1	0	0	0	2	0	5	5	3	2	16	4	2.1
		3-7-62	6.9	Bed	.12	<.01	.12	43	0	4	11	4	0	1	0	0	0	0	0	0	9	4	7	3	13	1	3.7
		3-7-62	6.9	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.9
		4-12-62	1.6	Bed	---	---	---	35	<1	7	16	3	<1	1	1	0	0	0	0	<1	9	3	6	3	15	1	2.9
19	Cache Creek	12-27-60	.01	Bed	.10	<.01	.10	15	1	2	6	<1	0	0	0	0	0	5	1	0	24	9	<1	0	35	2	2.9
		4-14-62	<.01	Bed	.07	.05	.12	6	2	<1	2	<1	0	0	0	0	0	9	2	0	25	6	<1	0	47	1	4.5
20	Mad River	10-19-60	.02	Bed	.22	.01	.23	9	5	0	8	<1	0	0	1	<1	2	0	0	<1	23	4	2	0	41	4	6.0
		12-2-60	5.5	Bed	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.8
		12-2-60	5.5	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.0
		6-8-61	.3	Bed	---	---	---	4	3	0	3	<1	0	0	3	1	3	0	0	0	25	6	2	0	45	5	4.8
		4-16-62	1	Bed	.24	.03	.27	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.7
21	Crooked River	11-16-60	.2	Bed	.25	.01	.26	1	1	<1	33	<1	0	3	4	0	10	0	7	1	19	0	0	0	21	0	9.1
		3-29-61	1.7	Bed	---	---	---	1	2	0	29	0	0	2	3	1	15	0	2	<1	18	0	0	0	27	0	12.0
		5-1-61	.9	Bed	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	17.0
		5-3-61	.9	Bed	---	---	---	1	1	0	24	0	0	2	4	1	8	0	1	0	17	0	0	0	41	0	12.0
		4-18-62	6	Bed	.35	.01	.36	<1	1	1	21	0	0	1	1	0	13	0	<1	1	38	0	0	0	22	0	15.0
		4-18-62	6	Sus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	18.4

[1] Pumice fragments are common in coarse sand from the Rio Grande River. Most of the pumice is at least partly devitrified, and it has been counted as fine-grained rock fragments.

ately magnetic, or rock-fragment fraction, is responsible for much of the exchange capacity of the stream sand.

Table 9 shows that the exchange capacity of sand is related to the content of fine-grained rock fragments. The coarse-grained fragments contain relatively little clay. When consideration is also given to the kinds of clay minerals present (table 6, p. D13), the variation in exchange capacity of the sands is largely explained. For example, Yadkin River bed sand contains 4–5 percent fine-grained rock fragments, and any clay minerals present are likely to have rather low exchange capacities. Hence, the overall exchange capacity of Yadkin River sand is about 0.3 meq per 100 g.

The Kansas River bed sand contains about 2 percent fine-grained rock fragments, but the clay present probably is montmorillonitic in part. Therefore, the exchange capacity of the sand is higher than the Yadkin River sand, about 0.7 meq per 100 g.

Crooked River bed sand contains 40–60 percent rock fragments (many of which are somewhat argillized or weathered igneous rocks), and 10–15 percent volcanic glass which is commonly partly devitrified. Crooked River clay contains even more montmorillonite than the Kansas River clay. Thus, the exchange capacity of Crooked River bed sand is 9–17 meq per 100 g.

Mad River sand contains 70–80 percent rock fragments, but the clay minerals in the Mad River are mainly chlorite and illite and lesser amounts of expanding clay. Thus, the clay in the rock fragments can be expected to have only moderate exchange capacity. The overall exchange capacity of the Mad River sand, as a result, is 5–8 meq per 100 g.

EXCHANGE-CAPACITY VARIATION WITH GRAIN SIZE WITHIN THE SILT-SAND RANGE

Sand and silt from five streams and sand from six streams were separated into various size fractions as shown in table 10. The exchange capacity of each fraction was determined in order to establish the variation of exchange capacity with grain size.

In most of the streams the CEC (cation-exchange capacity) is low in the medium and coarse sizes but increases in the finer sizes. In 5 of the 14 streams, the CEC of the medium and coarse sand is higher than that of the fine sand and coarse silt because of the presence of numerous fine-grained rock fragments. In three of the streams, the CEC does not change appreciably with increasing grain size in the medium and coarse sand sizes. This lack of change is believed due to an increase in rock fragments with increasing grain size, which compensates for the normal decrease in surface area and CEC with increasing grain size.

EFFECT OF DISPERSING AGENTS ON EXCHANGE CAPACITY OF SAND AND SILT

The method of size separation used in this study was intended to preserve the size distribution found in the streams as much as practicable. The intent was to separate only those grains which had flocculated either in the stream or while in storage. A comparison was made, however, between the exchange capacity of sand and silt treated as described above and that of separate fractions of sand and silt which stood overnight in a sodium hexametaphosphate dispersing solution, and then were agitated for 10 minutes by an air jet (Chu and Davidson, 1953). The dispersed silt and clay were removed from the sand and the dispersed clay from the silt prior to measuring the CEC. Results of the comparison are presented in table 11.

It should be noted that many published size analyses represent chemically and mechanically dispersed material.

The exchange capacity of both sand and silt decreases significantly as a result of the dispersion, but the percentage change varies greatly. In 4 of the 53 samples, an apparent increase in exchange capacity occurred; the reason for this is not known. The average decrease in exchange capacity of the sand is approximately 25 percent and of the silt about 40 percent. These percentages are probably an indication of the amount of high-exchange-capacity material removed by the dispersing agent from the mineral-grain surfaces.

EFFECT OF EXCHANGE CAPACITY OF SEDIMENTS ON COMPOSITION OF STREAM WATER

Cations held adsorbed on stream sediments form a reservoir which helps stabilize the chemical composition of stream water. The effectiveness of this stabilizing action will depend on many factors, some of which are: (1) the ratio of adsorbed to dissolved cations in a sediment-water system, (2) the selectivity of the sediment for specifications, (3) the degree of "fixation" of cations, (4) the time of sediment-water contact, and (5) the opportunity for thorough mixing of sediment and water.

TABLE 10.—*Variation of exchange capacity with grain size in some samples of bed sand and silt*

Stream	Date of sample collection	Exchange capacity (meq per 100 g)							
		Size range (mm)							
		1–0.5	0.5–0.25	0.25–0.125	0.125–0.062	0.062–0.031	0.031–0.0155	0.0155–0.0078	0.0078–0.004
Brandywine Creek	2-26-61	2.4	2.4	2.2	2.6	4.7	5.7	10.4	14.1
Juniata River	4-14-61	8.0	6.5	2.2	2.9	2.3	10.7	12.6	10.8
Yadkin River	6-22-61	.8	.4	.8	1.6	------	------	------	------
Licking River	2-27-61	10.2	8.6	7.6	9.3	8.6	6.5	10.4	14.6
Mississippi River	10-11-60	.8	1.0	3.2	2.7	------	------	------	------
Kansas River	5- 8-61	.7	.8	1.2	1.9	4.7	8.6	21.3	27.5
Elk Creek	10-13-60	1.3	.7	.6	2.0	------	------	------	------
Colorado River, Tex	6-20-61	.4	.4	.9	2.2	------	------	------	------
San Juan River, Shiprock	10-10-61	.9	1.4	2.7	5.4	------	------	------	------
Colorado River, Utah	5-26-61	1.8	1.7	1.8	5.9	------	------	------	------
Cosumnes River	12-14-60	1.9	2.9	3.7	6.5	------	------	------	------
Cache Creek	4-14-62	2.7	4.4	7.9	10.4	------	------	------	------
Mad River	10-19-60	6.3	7.5	8.1	7.7	------	------	------	------
Crooked River	3-29-61	18.1	12.6	11.3	17.3	20.1	37.8	42.2	48.1

TABLE 11.—*Exchange capacities of sand and silt before and after chemical and mechanical dispersion*

[Bed sand and silt were used unless otherwise indicated. Sus, suspended]

Stream		Date	Exchange capacity of sand (meq per 100 g)			Exchange capacity of silt (meq per 100 g)		
No. (fig. 1)	Name		Before dispersion	After dispersion	Percent change	Before dispersion	After dispersion	Percent change
1	Brandywine Creek	4- 2-60	2.8	2.4	−14	4.3	6.1	+42
		2-21-61	3.4	1.6	−53	--	--	--
		2-26-61	2.4	1.4	−42	--	--	--
2	Juniata River	2-27-61	5.7	2.5	−56	5.0	4.3	−14
		4-14-61	3.0	2.0	−33	--	--	--
3	Yadkin River	2- 1-60	.4	.2	−50	--	--	--
		5-18-61	--	--	--	4.5	2.6	−42
		6-22-61	.3	.3	0	4.8	4.2	−12
4	Licking River	2-27-61	7.3	5.2	−29	8.3	5.5	−34
5	Green River	2-28-61	.4	.3	−25	--	--	--
		3- 7-61	.5	1.4	+180	6.9	3.3	−52
6	Mississippi River	3- 9-61	1.4	1.0	−29	20(sus)	4.1	−79
		4- 7-61	1.1	.8	−27	--	--	--
7	Kansas River	5- 8-61	.7	.6	−14	20(sus)	6.3	−68
		10-30-61	.5	.5	0	--	--	--
8	Elk Creek	8-26-60	.4	.3	−25	13	5.6	−57
		10-19-60	.9	.4	−55	--	--	--
		10-12-61	.6	.4	−33	--	--	--
11	Rio Grande River	4-25-61	1.2	1.2	0	--	--	--
12	San Juan River, Bloomfield	5-24-61	1.1	.7	−27	--	--	--
		6- 8-61	.9	.7	−22	--	--	--
		10-10-61	3.4(sus)	1.9	−44	16	11	−31
13	Animas River	10-10-61	3.5	3.3	−6	20	12.6	−37
14	San Juan River, Shiprock	6- 8-61	.9	.9	0	--	--	--
		10-10-61	3.1(sus)	2.6	−16	24(sus)	15.5	−35
15	Colorado River, Utah	11- 3-60	4.2	2.9	−31	8.2	6.8	−29
		6- 6-61	1.3	1.5	+15	--	--	--
17	Big Horn River	9-12-61	1.3	1.3	0	16	5.9	−63
18	Cosumnes River	12-14-60	2.1	1.6	−24	22	10.7	−51
		3- 7-62	3.7	3.0	−19	--	--	--
19	Cache Creek	12-27-60	2.9	2.7	−7	--	--	--
		4-14-61	4.5	4.1	−9	13	10.9	−16
20	Mad River	10-19-60	6.0	5.9	−2	10	9	−10
		12- 2-60	5.8	6.2	+7	--	--	--
21	Crooked River	11-16-60	9.1	7.1	−22	34	20.8	−39
		3-29-61	12	9.5	−21	--	--	--

This particular study has been concerned with the estimation, for various flow conditions, of both the ratio of dissolved cations to cations held adsorbed on suspended sediment, and the ratio of cations adsorbed on bed sediment to cations in solution above the streambed. Such information should give a first approximation of the importance of exchange capacity of stream sediments in controlling the composition of stream waters. Much more work will be required before the other factors mentioned above can be evaluated.

SUSPENDED SEDIMENT

An estimate of the ratio of adsorbed to dissolved cations in a sediment-water mixture can be made if a chamical analysis of the water is available and the exchange capacity of suspended sediment per unit volume of water-sediment mixture is known. Such data are available for several different flow conditions for many of the streams included in this study.

It should be understood that sediments tend to stabilize the ratio of elements in solution rather than to alter the total concentration of cations. If two dissolved cations, A and B, are in equilibrium with sediment holding some of each cation in an adsorbed condition and if an additional amount of A is added to the solution, the total milliequivalents of adsorbed cations will not change but the ratio of adsorbed A to B will increase. Thus, some of the added cation A will be removed from solution by adsorption and some of the adsorbed cation B will be returned to solution. The net effect of the addition of A will be to increase both A and B in solution, but because of sediment exchange capacity, the ratio of A to B may not change greatly.

It should also be noted that addition of suspended sediment holding exchangeable cations to a stream constitutes an increase in the total transported load of cations. This effect is shown in table 12, although in a rather gross fashion. More refined data might show the percentage of each cation which is transported adsorbed or in solution.

Information on exchange capacity of sediment and chemical composition of stream water during periods of very high sediment concentration was obtained for very few of the streams studied because suitable conditions for obtaining such data did not occur during the short period of sample collection. However, reasonable estimates can be made from past records of chemical quality, sediment concentration, and particle-size distribution. By combining these past records with data on exchange capacity of various size fractions of sediment obtained in this study, estimates of the ratio of adsorbed to dissolved cations were made for a period of very high suspended-sediment concentration. These estimates, as well as ratios calculated from samples collected during this study, are summarized in table 12.

TABLE 12.—*Ratio of cations adsorbed on suspended sediment to cations dissolved in a unit volume of solution*

Stream		Date sampled	Ratio of discharge when sampled to average discharge	Suspended sediment		Concentration dissolved cations (meq per liter)	Ratio of cations adsorbed on suspended sediment to cations in solution
No. (fig.1)	Name			Concentration (ppm)	Exchange capacity (meq per 100 g)		
1	Brandywine Creek	4- 4-60	9.2	684	13.5	1.12	0.09
		2-21-61	2.7	49	17.0	1.19	.007
		2-26-61	8.1	531	8.7	1.07	.04
		11-16-61	.4	18	20.3	1.85	.002
		2-28-58[1]	12	[2] 1,550	[3] 11.0	[4] 1.1	.2
2	Juniata River	2-21-61	5.1	326	11.1	1.49	.02
		2-27-61	12	299	11.2	1.11	.03
		4-14-61	5.7	117	11.4	1.21	.01
		3- 2-54[1]	10	[2] 1,130	[3] 10.0	[4] 1	.1
3	Yadkin River	3-30-60	5.1	672	13.9	.42	.2
		5-18-61	1.1	108	9.0	.45	.02
		6-22-61	4.6	1,330	7.8	.44	.2
		11-19-61	.6	36	18.0	.52	.01
		5-26-52[1]	1.6	[2] 2,970	[3] 11.0	[4] .40	.8
4	Licking River	6- 6-60	.1	16	17.2	2.15	.001
		9- 7-60	.03	32	25.1	2.47	.003
		1-18-61	4.7	369	14.7	1.29	.04
		2-27-61	5.2	319	12.4	2.08	.02
		2-25-56[1]	5.2	[2] 4,230	[3] 14.0	[4] 1.2	.5
5	Green River	2-28-61	5.9	160	14.2	1.49	.02
		3- 7-61	6.7	600	13.4	2.21	.04
		5-10-61	5.3	173	16.6	2.33	.01
		6-14-52[1]	1.5	[2] 3,180	[3] 15.0	[4] 2	.2
6	Mississippi River	3- 9-61	1.4	907	27.3	4.32	.06
		4- 6-61	1.8	928	24.5	3.85	.06
		5-16-61	2.4	740	28.9	3.24	.07
		6- 7-51[1]	2	[2] 6,420	[3] 25.0	[4] 3.2	.5
7	Kansas River	11- 1-60	.6	749	46.5	14.1	.02
		1-11-61	.4	86	23.8	14.43	.001
		5- 8-61	3.9	4,470	34.2	4	.4
		5-24-61	14	2,700	30.0	2.73	.3
		10-30-61	1	1,660	30.6	7.2	.07
		7-12-58	6.1	8,650	30.0	3	.9
8	Elk Creek	8-26-60	.7	908	37.7	18.6	.02
		10-13-60	18	3,340	34.0	2.5	.5
8	Elk Creek—Continued	10-19-60	54	1,090	33.3	1.65	.2
		10-12-61	.5	450	37.0	8.13	.02
		9-25-59[5]	39	[6] 9,230	[3] 34.0	[7] 2.3	1.4
9	Colorado River, Tex.	6-20-61	16	1,970	36.2	1.79	.4
		9-15-61	3.9	757	47.4	2.26	.02
		4-29-60[5]	4.1	[6] 11,600	40.0	2.3	2
10	Pecos River	8-11-61	.3	1,350	28.5	6.21	.06
		9-19-61	7.8	9,390	22.1	2.32	.9
		5-25-59	6.9	13,800	22.0	6	.5
11	Rio Grande River	4-25-61	1.8	1,350	16.8	2.31	.1
		6-21-61	.6	284	10.4	3.43	.009
		8-21-55[1]	1.3	[2] 42,600	[3] 25.0	13.2	.8
12	San Juan River, Bloomfield.	4- 9-61	2.3	4,270	16.9	2.79	.3
		5-24-61	3.1	818	11.5	1.41	.07
		6- 8-61	1.7	103	17.0	1.7	.01
		10-10-61	1.8	18,900	22.0	3.51	1.1
		3- 9-60[5]	3.7	90,900	[3] 20.0	[7] 10.6	1.7
13	Animas River	5-26-61	3.5	579	9.2	2.2	.02
		6- 8-61	2.3	239	12.6	2.66	.01
		10-10-61	.8				
		7-25-54[5]	2.9	[6] 34,000	[3] 22.0	9.5	.7
14	San Juan River, Shiprock.	5-26-61	2.8	1,060	8.3	2.14	.04
		6- 8-61	1.9	672	13.7	2.32	.04
		10-10-61	1.4				
		3- 8-60	2.9	65,800	[3] 23.0	12.2	1.2
17	Big Horn River	9-12-61	1.1	27,800	33.8	12.4	.8
18	Cosumnes River	1-12-60	.05	131	27.8	.89	.04
		3- 7-62	6.9	287	12.2	.9	.04
		4-12-62	1.6	79	11.6	.45	.02
		4- 3-58	44	1,310	[3] 15.0	1	.2
20	Mad River	12- 2-60	5.5	1,110	9.1	.9	.1
		6- 8-61	.3	6	17.0	1.42	.0007
		4-16-62	1	139	5.6	1.14	.007
		2- 8-60	23	[6] 5,440	[3] 12.0	[7] .9	.7

[1] Date of maximum daily mean concentration of record, from published U.S. Geol. Survey water-supply papers.

[2] Daily mean concentration.

[3] Estimated from sediment records and exchange-capacity data for various size fractions.

[4] Estimated from discharge-conductivity relations.

[5] Unpublished data from U.S. Geol. Survey Quality of Water Branch district offices.

[6] Suspended-sediment concentration from past records; concentration given is that of the time of sampling.

[7] Estimated from specific-conductivity data.

The exchange capacity of suspended sediment can vary appreciably from time to time owing to changes in size distribution of the sediment, organic content, and clay mineralogy. The San Juan River at Bloomfield and the Animas River at Farmington, N. Mex., are examples in which the exchange capacity of suspended sediment varies widely. The percent of <0.004 mm material in suspension ranges from a few percent to more than 60 percent in both streams. The proportion of expanding clays in the <0.004 mm material also varies significantly (thus changing the exchange capacity), depending upon the part of the stream basin which supplied the sediment. The mountain areas apparently yield low-exchange-capacity clay minerals while the arid areas yield clay of high-exchange capacity.

When the suspended-sediment concentration is high, the ratio of adsorbed to dissolved cations may approach one in some eastern streams, and exceed one in many streams of the West and Southwest. There is a pronounced tendency for the maximum ratio of adsorbed to dissolved cations to remain fairly constant regardless of great variations in concentration of dissolved salts, concentration of suspended sediment, and exchange capacity of suspended sediment from one stream to another. The reason for this fairly constant value is evident if the equation used in calculating this ratio is examined:

$$\frac{\text{Cations adsorbed on suspended sediment (meq)}}{\text{Cations in solution (meq)}} = \frac{\left[\begin{array}{c}\text{Concentration of suspended sediment}\\ \text{(ppm)}\times 10^{-5}\end{array}\right]\left[\begin{array}{c}\text{Exchange capacity of suspended sediment}\\ \text{(meq per 100g)}\end{array}\right]}{\text{Dissolved cations per liter (meq)}}$$

In more humid areas both the concentration and exchange capacity of suspended sediment are relatively low, but the concentration of dissolved cations is also low. In arid regions, the concentration and exchange capacity of suspended sediment and the concentration of dissolved cations are all greater than in humid areas. Thus, the ratio of adsorbed to dissolved cations tends to remain constant across climatic zones.

The importance of the adsorbed load in transporting specific elements in streams is difficult to evaluate at present. Tamura and Jacobs (1960) have demonstrated that illite is much more selective than montmorillonite or vermiculite in removing cesium from solutions containing high concentrations of aluminum or sodium. Tiller and Hodgson (1962, p. 393) found selective uptake of cobalt and zinc by various clay minerals in the presence of a large excess of calcium. Much of this cobalt and zinc can be removed by exchange with other heavy metals, but a small portion appears to be fixed. It seems possible that a major fraction of some trace elements transported by streams may be carried as cations adsorbed on stream sediments.

In the southwestern United States, some streams carry high sediment concentrations almost any time that they flow and, hence, must have large adsorbed loads. The Rio Puerco near Bernardo, N. Mex., may represent an extreme example. The concentration of suspended sediment in the Rio Puerco almost always exceeds 10,000 ppm (parts per million) and commonly exceeds 100,000 ppm. The maximum daily concentration in published records is 230,000 ppm (U.S. Geol. Survey, 1963, p. 516). A high percentage of this sediment is of clay size.

BED SEDIMENT

During periods of low to moderate flow, most streams contain rather low concentrations of suspended sediment. Under these conditions, bed sediment becomes more important than suspended material in stabilizing the chemical composition of stream water. One measure of the effect of bed material on the composition of stream water is the ratio of adsorbed cations in the bed to dissolved cations in the water above the bed. Calculation of such a ratio for many streams is virtually impossible because information on size distribution or exchange capacity of bed material over a representative reach of stream, under specified flow conditions, is very seldom available.

An alternative approach is to estimate what thickness of clay, silt, or sand on the bed would be required to provide a quantity of adsorbed cations on the bed equal to those in solution above the bed. Although the bed material is virtually stationary and the stream water is in motion, this amount of exchangeable cations would be expected to be sufficient to exert some control in stabilizing the ratio of cations in solution. It is then a matter of determining whether such thicknesses of sediment are probable from a general knowledge of the stream or from available information on size distribution of bed material.

The depth of a stream, for a specified discharge, can vary greatly from pool to riffle and from midstream to nearshore location. Thus, the average depth of a cross section may or may not be representative of a reach of stream. However, to compute the average amount of cations in solution above the streambed for a particular discharge one must multiply the concentration of cations in solution by the average depth of the water. For the purposes of this study, the average depth of the stream for a particular discharge is assumed to be that determined during the regular discharge measurements made by the U.S. Geological Survey. It should be realized that such depths will commonly be slightly less than the true average for the stream because of the method of selecting gaging sites, but, in some places, they may be significantly greater.

The thickness of bed clay, silt, or sand required to hold adsorbed an amount of cations equivalent to those in solution above the bed, under various flow conditions, is given in table 13. The exchange capacity used for each size fraction is the average of the values determined from bed samples, and a porosity of 50 percent is assumed for the sediment.

As streamflow decreases, water depths decrease and concentration of dissolved ions increases. There is a distinct tendency, then, for the amount of dissolved cations above a streambed to remain constant as stream discharge varies. This tendency is illustrated in the Juniata River (table 13) where the dissolved cations above the bed increase by about 30 percent while the depth of the water increases by 130 percent. Although the amount of dissolved cations above the bed generally decreases somewhat with decreasing water depth, the reverse situation also occurs. In the Colorado River near Cisco, Utah, the dissolved cation concentration apparently increases so rapidly with decreasing discharge that the amount of dissolved cations above the bed increases with decreasing water depth.

If we assume that stream water can effectively interact with 0.5 cm of bed clay, 2 cm of bed silt, or 10 cm of bed sand, then one-fourth to one-half of the streams listed in table 13 will have as many cations adsorbed on bed sediments as are in solution above the bed during about 75 percent of the time. The streams which appear to require the thinnest bed sediments to make the adsorbed equal the dissolved cations are, in general, the small ones. This is not surprising, for within a given region the small, or tributary, streams will be shallower than the main streams and will have

TABLE 13.—*Thickness of bed sand, silt, or clay required to make adsorbed cations equal to cations dissolved in water above the streambed*
[Streams listed are those for which the required data are available or can be estimated with some confidence]

Stream		Flow conditions											
		Discharge exceeded less than 25 percent of time				Median discharge				Discharge exceeded more than 75 percent of time			
No. (fig.1)	Name	Average depth (feet)	Thickness (cm)			Average depth (feet)	Thickness (cm)			Average depth (feet)	Thickness (cm)		
			Sand	Silt	Clay		Sand	Silt	Clay		Sand	Silt	Clay
1	Brandywine Creek	7	9.5	2.9	1.1	6.2	8.8	2.7	1.0	5.9	8.5	2.6	1
2	Juniata River	4.8	5.9	2.7	.8	3.2	5.6	2.6	.7	2.1	4.5	2.1	.6
3	Yadkin River	6.6	22	1.5	.5	5.6	20	1.3	.4	4.7	19	1.3	.4
4	Licking River	5	4.2	3.3	.9	3.5	3.3	2.7	.7	2	2.1	1.7	.4
5	Green River	6.5	44	4.7	1.6	3.5	27	2.8	1	2	19	2.0	.7
7	Kansas River	3.1	89	5.3	1	1.8	60	3.6	.7	1.2	52	3.1	.6
8	Elk Creek	.8	36	2.2	.5	.5	29	1.8	.4	.15	14	.9	.2
9	Colorado River, Tex	[1] 8.4	160	3.7	1.2	---	---	---	---	---	---	---	---
10	Pecos River	.81	14	1.9	.4	.75	22	3	.6	.75	29	4.0	.8
14	San Juan River, Shiprock [2]	3.7	51	2.9	1.3	2	31	1.7	.8	1.4	35	1.9	.9
15	Colorado River, Utah	5.3	46	13	3.2	3.4	63	18	4.3	3	62	18	4.3
18	Cosumnes River	2.4	1	.2	.1	1.4	1	.2	.1	.55	.5	.1	.04
19	Cache Creek [3]	1.6	4.2	1.1	.4	(4)	---	---	---	(4)	---	---	---
20	Mad River	3.8	2.1	1.4	.6	1.6	1.3	.8	.3	.8	1	.6	.3
21	Crooked River	2.6	1.1	.4	.2	1.8	1	.4	.2	1.5	.9	.4	.2

[1] Data given are for average discharge conditions, however it is probable that average discharge will not differ greatly from the discharge which is exceeded less than 25 percent of the time.

[2] Information for sediments from the San Juan River at Shiprock, N. Mex., is limited, and estimates of exchange capacity of bed sediments are based, in part, also on information collected for the Animas River and San Juan River at Bloomfield.

[3] Because the flow of Cache Creek at Yolo is controlled by release of water from Clear Lake, there is little relation between discharge and concentration of dissolved cations. An average concentration of 4 epm dissolved cations was assumed.

[4] Discharge is 0.1 cfs or less and average depth of flow is not known.

approximately the same concentration of dissolved cations. Thus, the thickness of bed sediment of a particular grain size required to make adsorbed equal to dissolved cations will be less in small streams. Near the headwaters of a stream the bed sediment may contain several times as many adsorbed cations as there are in solution above the streambed, and the stabilizing action of the bed sediment will then be quite important in reducing variation in chemical composition of the stream water.

The thickness of bed sediment capable of affecting the chemical quality of stream water depends upon grain size and water movement within the bed. If bed sediments are of clay size, water movement through the bed will be slow and interaction of stream water with sediment more than a few millimeters below the surface of the streambed will be greatly hindered. The exchange capacity of such fine-grained material is relatively great, however, and only slight thicknesses are required to provide appreciable exchange capacity. If the bed material is of sand size, its exchange capacity per unit volume will be less than that of clay, but its permeability will be much greater. Thus, stream water can contact and react with a greater thickness of bed sand. Therefore, the effective exchange capacity of bed material may not change greatly from one point to another in a stream even though grain size changes.

Cations introduced into a stream which are capable of strong adsorption would be expected to be rapidly removed from solution and be retained by adsorption on bed material, especially where exchange capacity is high. As equilibrium is reached by the cation with bed material near the point of introduction, the cation will travel farther and farther downstream before being removed from solution. When introduction of the cation stops, most of the adsorbed material may be released, will travel downstream, be readsorbed, and again be released. Thus, the bed sediments can produce a chromatographic effect.

Commonly, a stream is either gaining water or losing it because of its relation to the local water table. Such water moving vertically through the bed sediments will tend to reduce the interaction between stream water and bed sediments. The importance of groundwater movement in affecting the interaction of bed material and stream water depends on the relative rate of cation diffusion as compared to the rate of the vertical movement of ground water. Such information is not presently available for natural streams.

CONCLUSIONS

The exchange capacity of stream sediments acts as a stabilizing influence on the chemical composition of stream water and may, under suitable circumstances, be an important factor in the fluvial transport of cations. In shallow streams, cations adsorbed on bed sediments may equal or exceed those in solution above the bed, whereas in deeper streams the ratio of adsorbed to dissolved ions will be much less.

When suspended-sediment concentrations are high the adsorbed cations may equal or exceed the dissolved cations. In areas where much of the annual water discharge occurs during periods of high sediment concentration, the load of adsorbed cations can be of considerable geochemical importance.

The particular cation species occupying exchange positions cannot be predicted accurately from presently available knowledge, because of the selectivity displayed by some minerals present in stream sediments.

Much of the information regarding the fraction of a specific cation held adsorbed or in solution must be obtained from experimental work.

Cesium is an element that is known to be selectively sorbed by illite. Inasmuch as illite is present in many of the streams studied, it is probable that most cesium entering a stream will be removed from solution by the sediments.

Amorphous alumina and silica usually comprise not more than a few percent and organic material commonly 2–8 percent of the stream clays. If stream organic matter is similar to soil organic matter in chemical reactivity, it may be highly selective in removing elements from solution. The effect of the amorphous material on dissolved cations is not known.

In summary, results of this study have shown that the mineralogy and exchange capacity of stream sediments must be considered in understanding the chemistry of stream waters. Much work remains, however, before accurate predictions can be made regarding the fraction of a particular cation which is in solution or adsorbed.

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