Sedimentary Studies in the Middle River Drainage Basin of the Shenandoah Valley of Virginia

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By DOROTHY CARROLL

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The significance of mineralogy and grain-size distribution of materials in a drainage basin

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By Dorothy Carroll

ABSTRACT

The Middle River in Augusta County, Va., drains an area of about 370 square miles in the southern part of the Shenandoah Valley of Virginia. The country rocks of this area are of several lithologic types—sandstone, shale, limestone, and dolomite—and range in age from Cambrian to Ordovician. The headwaters of the Middle River are in Cambrian rocks but important tributaries cut sandstone of Devonian age; the largest tributary, Christians Creek, flows across shale of Ordovician age for its entire length.

The Middle River drainage basin has residual, alluvial, and terrace and flood-plain soils. Residual soils are largely controlled by the underlying rocks and have developed profiles under podzolizing conditions in which acid leaching is the most important factor. The soils are silty with most of the material between 0.05 and 0.002 mm in grain diameter. The average median grain diameter is 0.011 mm.

The alluvial soils have a grain-size distribution similar to that of the residual soils, but the alluvium coming directly from the Devonian sandstone areas is coarser, with a median grain diameter of 0.19 mm.

Soils of the terraces and high flood plains along the Middle River are now high enough above the river so that they are rarely flooded. These soils contain a greater amount of sand than do the residual or alluvial soils. The average median grain diamater is 0.04 mm.

Data derived from the figures for mechanical analyses show that all the soils are poorly sorted. None of the alluvial soils or terrace and high flood-plain soils are better sorted than the residual soils, with the exception of two sandy samples from the Little River.

Insoluble residues of representative bulk rock samples were obtained by treatment with hydrochloric acid. The insoluble-residue content of sandstone of the Chemung formation was about 90 percent, the Brailler shale about 85 percent, the Martinsburg shale 30–40 percent, the Lenoir and Mosheim limestones and the noncherty limestone of the Beekmantown dolomite and the Elbrook dolomite less than 5 percent, and the sandy dolomite of the Conococheague limestone 40 percent. The actual weight of insoluble residue per acre-inch of rock ranged from about 1,000 pounds for a limestone of the Beekmantown dolomite to more than 530,000 pounds for sandstone of the Chemung formation.

The minerals in the insoluble residues of the country rocks and in the fine-sand fraction (0.10–0.05 mm grain diameter) of the soils were identified under the microscope. The quantity of the heavy fractions (>sp gr 2.9) in each sample was determined, and the percentage of individual minerals in each heavy fraction was obtained by grain counts. The insoluble residues of the country rocks contain varying amounts of heavy minerals ranging from 10,630 pounds per acre-inch of sandstone of the Chemung formation to about 1½ ounces in the Elbrook dolomite. The minerals found are quartz, chert, orthoclase and plagioclase feldspars, microcline, shaly particles, and mica in the light fraction, and opaque grains (magnetite, ilmenite, and indefinite iron oxides), zircon, tourmaline, rutile, garnet, pyrite, kyanite, sphene, chloritoid, staurolite, anatase, zoisite, epidote, and amphibole in the heavy fractions. Apart from the opaque grains, zircon and tourmaline are the only minerals that are abundant. Both the sandy beds of the Conococheague limestone and the sandstone of the Chemung formation contain distinctive zircon and tourmaline varieties.

The minerals in the residual soils are essentially those which were identified in the insoluble residues of the rocks except that authigenic anatase is more abundant. The quantity of the heavy fraction is generally less than 1 percent by weight of the fine-sand fraction. Most of the alluvial soils contain a smaller percentage of heavy fraction than the residual soils, but there is considerable variation. Thus, the Middle River alluvium contains a larger percentage of heavy minerals than the alluvium of the Folly Mills Creek system and Christians Creek; the material carried from the sandstone of Devonian age may account for the larger quantities in the Middle River alluvium.

Heavy minerals in the soils of the terraces and high flood plains along the Middle River average 1.5 percent by weight of the fine sand. Samples collected nearest to the areas of sandstone of Devonian age contain from 1.25 to 2.8 percent heavy fraction. Zircon types in these soils suggest that the Devonian sandstone and not the sandy beds of the Conococheague limestone has been the main source of material. Similar evidence is provided by tourmaline.

Sand from the river-bed material of the Middle River and from several tributaries, together with a few samples from the North River, the South River, and the South Fork of the Shenandoah River, does not contain the same quantity of heavy minerals as the terrace and high flood-plain soils, but does resemble the residual soils in this respect. The average amount of heavy fraction in the sand of the Middle River system is 0.8 percent by weight; the average is raised by the large contribution from Buffalo Branch (2.25 percent). In contrast, the South Fork of the Shenandoah River, draining a different basin, contains about 6 percent heavy fraction in the fine sand.

Mineralogically the bed material of the Middle River shows the influence of the rocks at the headwaters and of those through which it flows. Sand from the other rivers is mineralogically distinct from that of the Middle River.

INTRODUCTION

PURPOSE OF INVESTIGATION

In 1952 a study of rocks and soils in the southern part of the Shenandoah Valley was begun to determine what kinds of materials are available for removal by erosion from an area of sedimentary rocks. The Middle River drainage basin in Augusta County, Va., was selected for detailed examination.

For this purpose an examination was made of the distribution and lithology of the principal rocks of the area, the amount and mineralogic composition of their insoluble residues; the kinds of soils formed from these rocks, their grain size and mineralogic composition; the alluvial, terrace and high flood-plain soils, their grain size and mineralogic composition; and the mineralogic composition of sands in the river and stream beds.

The Middle River drainage basin has a variety of rock types, topographic features, and drainage patterns in a rather compact area (370 square miles). The river is only eroding the rocks of this area. No material is brought in from other areas by tributaries.

LOCATION

Augusta County (pls. 14, 15; fig. 28), an area of 995 square miles, is situated in the Appalachian Valley, which here is broad and rolling. Staunton (altitude 1,480 feet) is the county seat. The valley ranges in altitude from 1,200 to 1,800 feet and is bounded on the east and west by comparatively high mountains. A drainage divide begins at the headwaters of the North and Calfpasture Rivers and extends northward across the western part of the county (pl. 14). On the east side the important streams are the Middle and South Rivers. These streams have their sources in the county and receive about three-fourths of the drainage. Creeks, branches, and intermittent streams throughout the county ensure good surface drainage (Jurney and others, 1937, p. 2–3). The drainage basins of the Calfpasture, Middle, and North Rivers in Augusta and Rockingham Counties, Va., are shown on figure 28.

FIELDWORK

During the fall of 1952 and in subsequent field trips and discussions, samples were collected and the laboratory work was planned. Samples were collected from sites carefully selected as being the most suitable to provide definite information; for instance, although many soil samples could have been collected it was decided to collect only from sites at which a complete soil profile could be seen to have formed from the rock beneath it; river sands were collected from the river beds where tributaries cutting known kinds of rocks entered the main stream, and bulk rock samples were collected from outcrops in which the formation could be easily identified. In this way it was hoped that a picture of the mineralogical distribution would emerge, together with some information about the size distribution of the material.

In this investigation 13 samples of bulk rock, 12 samples of river sands (collected from the center of the streams), 19 samples of residual soils (comprising 3 sets of profile samples and 5 individual samples), and 31 samples of alluvial and terrace soils (the latter included 2 sets of profile samples) were examined. The sampled localities are shown in plates 14 and 15 and descriptions of the samples and localities are given in tables 1, 6, 8, 9, and 10.

LABORATORY PROCEDURE

For the examination of rocks, bulk samples weighing as much as 30 pounds were collected. The samples were crushed with rolls to −80 mesh (0.18 mm). The total sample was quartered and a weighed quantity treated with HCl (1+1) to remove the carbonate minerals and obtain the insoluble residue, which was then washed, dried, and separated in bromoform (sp gr 2.9). Large insoluble residues were sieved through standard sieves prior to bromoform separation. The minerals in both light and heavy fractions were identified microscopically.

Samples from each horizon in the residual-soil profiles were air dried and then a grain-size analysis was made using the U. S. Department of Agriculture standard pipette method for soils. A weighed quantity of the very fine sand fraction (0.10–0.05 mm grain diameter) was separated in bromoform to obtain the heavy minerals. The samples of alluvial soils and of terrace and high flood-plain soils were examined in the same manner as the residual soils.

River sands were sieved with U. S. Standard sieves numbers 10, 70, and 140 (2.5, 0.21, and 0.105 mm, respectively), and the gravel retained on the number 10 sieve was discarded. The fractions −70 to +140 were washed with water to remove the clay and organic matter, and then dried. A 5-gram sample of >0.105 mm cleaned material was separated in bromoform and examined microscopically. The light fractions were cleaned in HCl (1+1) before examination.

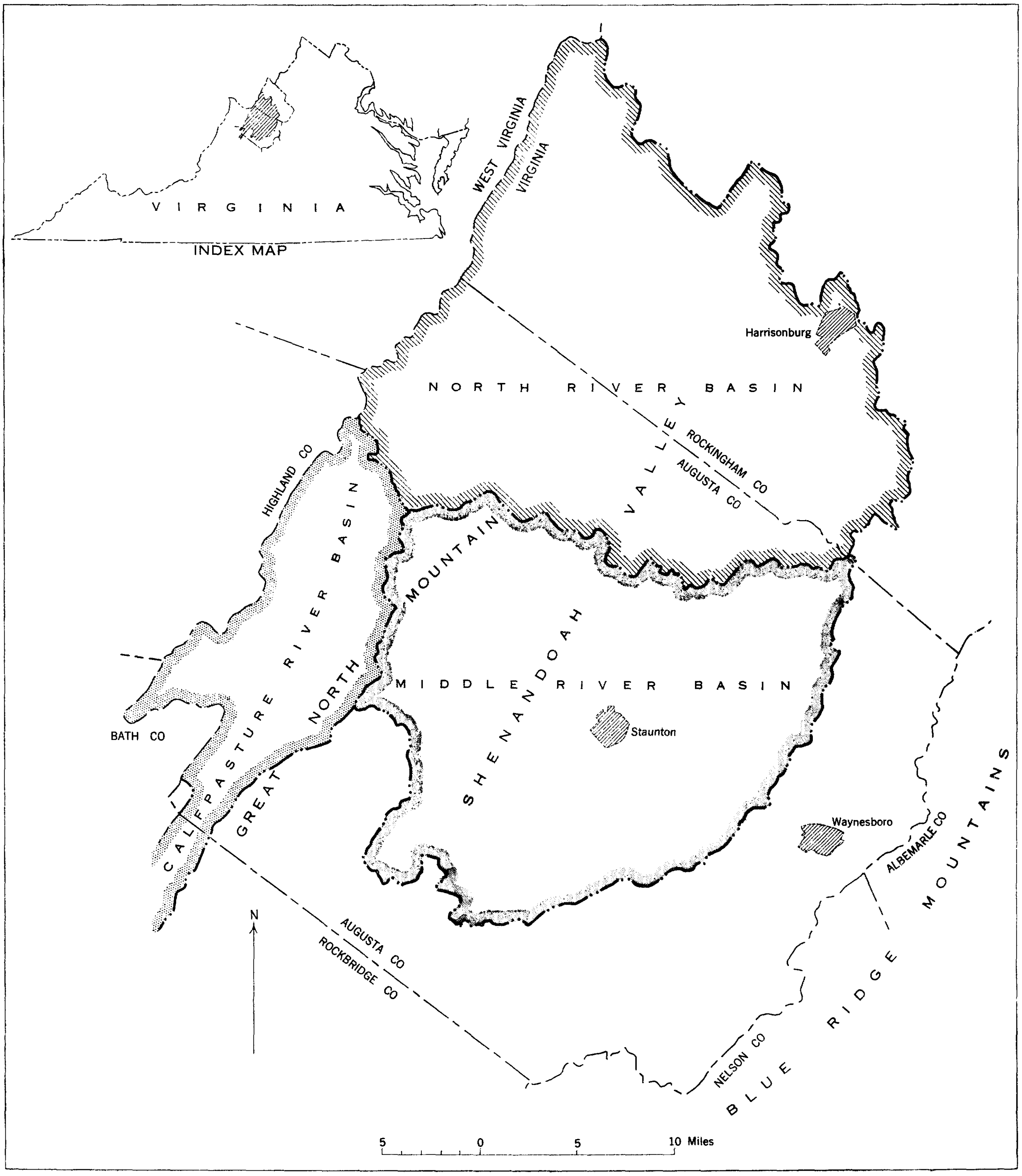

FIGURE 28.—Index map of the southern part of the Shenandoah Valley, Va.

Counts were made of the individual heavy minerals to determine their percentage by number. The quantity of minerals in the insoluble residues of rocks and in the light fractions was estimated.

The pH was determined on a 1:5 soil suspension, using a glass electrode. The ion-exchange capacity was determined by the colorimetric manganese method of Bower and Truog (1940).

ACKNOWLEDGMENTS

The writer accompanied John T. Hack, Luna B. Leopold, and C. C. Nikiforoff on a reconnaissance of the area in 1952. Many of the sampling sites were located and some of the samples were collected by Hack. The laboratory work was done by members of the Geological Survey at Beltsville, Md. Those participating were Paul D. Blackmon, sample collecting and mechanical analyses; Gerald L. Otzelberger, pH determination, ion-exchange determinations, and mechanical analyses; and Gillison W. Chloe, rock crushing, sample preparation, and sieving.

Roy W. Simonson, U. S. Department of Agriculture, made arrangements to check the identification of the soil types so that the information in this report would be of use in their soil-survey program. Glenn H. Robinson, Soil Conservation Service, and S. S. Obenshain, Virginia Polytechnic Institute, identified the soil types in the field.

ROCKS

DISTRIBUTION

The Shenandoah Valley is part of the Appalachian Valley, which, in turn, forms part of the Appalachian geosyncline. The geology has been described by Butts (1940) and others. The rocks of the Middle River basin are folded limestone, dolomite, shale, and sandstone that are Cambrian to Devonian in age (pl. 15).

The following formations crossed by the Middle River were examined in this study:

Devonian	Chemung formation Brallier shale
Ordovician	Martinsburg shale Lenoir limestone Mosheim limestone Beekmantown dolomite
Cambrian	Conococheague limestone Elbrook dolomite

The Middle River has its headwaters in Cambrian and Ordovician rocks (pl. 15), but it has important tributaries (Buffalo Branch, East Dry Branch, and Jennings Branch) crossing sandstone of Devonian age, the Chemung formation. After flowing eastward across folded Cambrian and Ordovician limestone and dolomite it flows northward across Martinsburg shale.

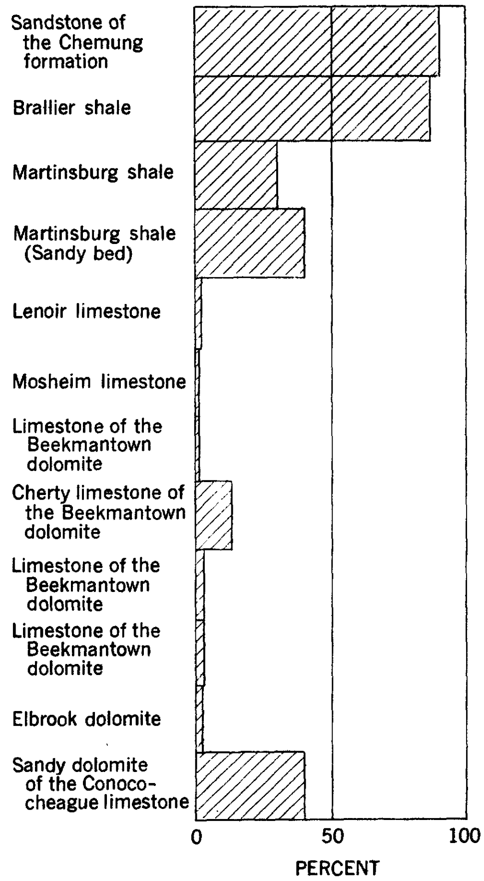

FIGURE 29.—Variation in quantity of insoluble residue in selected bulk rock samples (percent by weight after acid treatment).

The only large tributary from the southwest, Christians Creek, flows entirely on Martinsburg shale. Much alluvium is associated with the Middle River.

The approximate area occupied by each of the three lithologic types of rock in the Middle River drainage basin is: sandstone, 20 square miles; limestone and dolomite, 250 square miles; and shale, 100 square miles.

INSOLUBLE RESIDUES

Rock samples from the formations were examined in thin section and the minerals obtained in the insoluble residues were identified. These samples and the localities at which they were collected are listed in table 1.

QUANTITY

The insoluble residue contained in a rock is important as a source of material for soil formation or river-bed load. In the rocks examined there is about 90 percent of insoluble material in sandstone and about 1 percent or less in limestone and dolomite; shale is intermediate (fig. 29). The amounts of insoluble residue are given in table 2. Noteworthy features of the insoluble resi-

TABLE 1.—*Rock samples collected from formations in Augusta County, Va.*

[Sample numbers are field numbers]

Stratigraphic unit	Rock type	Sample	Locality
Devonian:			
Chemung	Sandstone	522	Rocky knob on south end of Crawford Mountain, 0.6 mile up trail from East Dry Branch Gap on County Road 688 (old Parkersburg Turnpike). Craigsville quadrangle.
Brallier	Shale	655F	East bank of Charlie Lick Branch, about 200 feet downstream from culvert on Cold Spring Road, 3.3 miles south of old Parkersburg Turnpike and 2.2 miles east of ford of Calfpasture River, 2 miles northwest of Elliot Knob. Craigsville quadrangle.
Ordovician:			
Martinsburg	Shale, sandy and fissile	500N, O	Small quarry in Martinsburg shale on County Road 612 (from Verona to Crimora); 0.5 mile east of bridge on Christians Creek, 1 mile west of junction of County Road 608; 1.6 miles due east of Laurel Hill. Waynesboro quadrangle.
Lenoir	Limestone	534	In roadcut on County Road 742, 1.9 miles north of junction with U. S. Highway 250; 3.5 miles north of center of Staunton. Staunton quadrangle.
Do	Limestone	702	Cut in limestone on U. S. Highway 250 near junction of County Road 612.
Mosheim	Limestone	496E	Quarry north of Middle River at Verona, on County Road 781, 0.15 mile west of bridge on U. S. Highway 11; 0.6 mile north-northwest of Verona. Staunton quadrangle.
Beekmantown	Dolomite, nonresistant bed	496A	Do.
Do	Dolomite, resistant bed	496B	Do.
Do	Limestone, cherty	496D	Do.
Do	Limestone, dolomitic	496F	Do.
Cambrian:			
Conococheague	Dolomite, siliceous	477J	Outcrop on north side of County Road 781, 1.5 miles north of junction with U. S. Highway 11; 1.5 miles north of Verona. Staunton quadrangle.
Elbrook	Dolomite	479L	Hilltop on north bank of Middle River, 0.35 mile upstream from bridge on County Road 626; 2.6 miles north of Verona. Staunton quadrangle.
Do	Shale interbedded with dolomite.	479M	Do.

TABLE 2.—*Quantity of insoluble residue of rocks in the Middle River drainage basin, Augusta County, Va.*

[Specific gravity of rocks was estimated to calculate weights]

Stratigraphic unit	Sample	Insoluble residue		Heavy minerals in insoluble residue	
		Percent	Pounds per acre-inch of rock	Percent	Pounds per acre-inch of rock
Cheming formation	522	90	531,400	2.0	10,630
Brallier shale	655F	87	511,750	.005	25
Martinsburg shale	500O	30	176,470	.005	9
Do	500N	40	235,290	.04	94
Lenoir limestone	534	.8	4,890	.001	.05
Mosheim limestone	496E	.5	3,050	.03	.9
Beekmantown dolomite:					
Limestone, dolomitic	496F	.17	1,040	.009	.09
Limestone, cherty	496D	13.5	82,470	.03	24.7
Dolomite, resistant bed	496B	1.7	10,385	.001	.1
Dolomite, nonresistant bed	496A	1.7	10,385	.0014	1.5
Conococheague limestone	477J	40	235,290	.017	40
Elbrook dolomite	479L	1.6	10,130	.001	.1

dues are the variation in quantity of heavy minerals in the different rocks. These suggest the provenance and depositional conditions of these rocks. As might be expected, limestone and dolomite are particularly poor in detrital material.

COMPOSITION

The minerals of the light fraction plus the clay minerals contained in the rocks are available, upon weathering, for soil formation; minerals in the heavy residue have varietal features that are helpful in recognizing the contribution of individual rocks to the resulting soils and river materials. Residues of the limestone are gray or black due to the presence of carbonaceous material.

LIGHT FRACTION

The minerals present in the light fractions are quartz, chert, orthoclase and plagioclase feldspars, microcline, shale particles, and mica (table 3).

Quartz.—Quartz is present in all the insoluble residues and is found both as detrital and authigenic grains. Detrital quartz is abundant in sandstone (Devonian) and in the sandy beds of the Conococheague limestone as particularly well rounded grains associated with angular and subangular grains. In the Martinsburg shale and Brallier shale, quartz occurs as very thin grains (thickness <5 microns) of very small size (<50-micron length). Detrital quartz is scarce in limestone and dolomite (Elbrook dolomite, Beekmantown dolomite, Mosheim limestone) but is supplemented by very small crystals of euhedral quartz which are abundant in parts of the Beekmantown and the Mosheim.

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TABLE 3.—*Mineralogic composition of insoluble residues of rocks and of the very fine sand fraction (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material*

[Figures for individual heavy minerals are percent within the fraction; symbols are visual estimates. VA, very abundant; A, abundant; C, common; S, scarce; +, 1 or 2 grains only]

ROCKS

Mineral	Conococheague limestone	Elbrook dolomite		Beekmantown dolomite				Mosheim limestone	Lenoir limestone	Martinsburg shale		Brallier shale	Chemung formation
	477J	479L	479M	496A	496B	496D	496F	496E	534	500N	500O	665F	522
Heavy fraction (percent)	0.017	0.001		0.0014	0.001	0.03	0.009	0.03	0.001	0.04	0.005	0.005	2.0
Heavy fraction													
Opaque grains (undifferentiated)	A	+	+		S	+	A	+	A	+	+	+	+
Zircon	VA	+	+	+	+	S	+	S		A	A	A	A
Tourmaline	+	+								+	+	C	+
Rutile	S	S	S	S	S	S					S	+	+
Garnet		+		+	+	+	+						
Pyrite				A		VA		A					
Kyanite				+									
Sphene								S				S	
Chloritoid				+						S	+		
Staurolite				+									
Anatase					+							+	
Epidote			S										
Zoisite					+								
Amphibole					S								
Light fraction													
Quartz:													
Broken	A	A	S		VA	S	S	S		C	S	C	VA
Euhedral				A	S		A	A	C				
Chert		S		C		VA			C				S
Orthoclase	S												
Plagioclase:													
$n>1.53$		S								S			
$n<1.53$			C									S	
Microcline			S										
Shale particles										VA	VA		
Micaceous grains			[1] A									[2] A	S

RESIDUAL SOILS

Mineral	Chemung formation	Brallier shale		Martinsburg shale	Lenoir limestone		Beekmantown dolomite	Conococheague limestone				Elbrook dolomite
	522	655A	655C	503M	[3] 534A	534E	496G	501H	501I	495	482A	479K
Heavy fraction (percent)	0.90	0.03	0.05	0.7	0.27	1.1	0.25	0.4	0.3	0.5	0.55	0.1
Heavy fraction												
Magnetite		S	S	S			+	S	S	S	S	S
Opaque grains (undifferentiated)	78.4	29.7	12.7	62.7	A	[4] VA	37.0	44.5	34.4	37.2	31.3	69.0
Zircon	10.8	46.5	35.8	30.0			55.0	45.5	58.0	44.6	45.6	22.5
Tourmaline	9.3	1.2	3.4	3.3			3.1	5.7	3.5	11.6	20.5	6.0
Rutile	1.0	13.8	11.7	2.4			3.4	1.6	.6	1.2	1.0	1.8
Sphene		.9										
Brookite		.3					1.1					
Anatase	.5	7.5	34.8	1.4			1.1	2.2	3.5		1.2	
Epidote				S				.3	S	S	S	
Chloritoid							S		S			S
Zoisite							S					
Others											.3	
Light fraction												
Quartz:												
Broken	A	A	A	A	S	S	A	A	A	A	A	S
Euhedral					A	A	S					
Chert	S	S			+	+	A	S	S	S		S
Plagioclase:												
$n>1.53$				S				S	S	S	S	S
$n<1.53$				S						S	S	
Microcline								S	S	S	S	A
Mica	S	S	S									S
Clay-mineral and shale particles												A

[1] Muscovite and biotite also present.
[2] Muscovite also present.
[3] The soil profile is represented by two samples.
[4] Excess of opaque grains due to presence of altered pyrite.

TABLE 3.—*Mineralogic composition of insoluble residues of rocks and of the very fine sand fraction (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material*—Continued

ALLUVIAL SOILS

	Little River		Folly Mills Creek system						Christians Creek	Sheet's farm		Middle River		
	524	523	525	526A	526B	527	528A	528B	531	482B	482C	532	619B	439
Heavy fraction (percent)	1.15	1.14	0.1	0.1	0.03	0.11	0.15	0.10	0.08	0.13	0.2	0.3	0.3	0.67
Heavy fraction														
Opaque grains (undifferentiated)	49.5	58.7	22.6	21.8	20.3	26.7	26.5	40.9	24.0	22.5	24.7	36.2	45.3	62.3
Zircon	31.8	17.5	50.3	50.0	44.1	46.9	37.4	36.4	50.4	44.3	44.0	44.7	30.4	28.2
Rutile	4.6	4.3	9.3	6.0	6.9	10.0	5.6	8.0	6.4	5.5	4.0	5.3	4.1	6.5
Tourmaline	11.3	17.5	13.0	7.6	10.3	4.6	18.2	11.3	5.6	13.3	12.7	7.8	10.7	3.9
Anatase	1.0		3.4	12.5	17.2	10.6	10.8		2.4	12.2	10.5	5.0	8.6	22.7
Brookite			.3	.4	.3	.8			.4		.4	.3		
Amphibole		+			+					1.5		.3	+	.4
Epidote		+	+	+	.3	+	.4	2.3	.4			.3		
Zoisite				+					+	+				
Corundum	.3			+					.4				.3	
Brown hornblende	+													
Pyroxene		1.5											.3	
Garnet						.4								
Sphene					.3	.4								
Light fraction														
Quartz:														
Broken	VA	A	A	A	A	A	A	C	VA	VA	VA	VA	VA	VA
Euhedral		+	+	S	C	C	A	S	C	S	S	S	S	S
Chert	A	A	S	S	A	C	C		S			C	S	+
Plagioclase:														
$n>1.53$	S	+	S	S		S	C			C	S	S	S	S
$n<1.53$					S						S			S
Microcline			S		S					S	C			
Mica	C							S	S	S				S
Nontronite (?)				S								S		
Shale fragments								A	S					

TERRACE AND HIGH FLOOD-PLAIN SOILS

	678	681	577A	577B	686A	686B	686C	599	675A	675B	675C	688A	688B	677A	677B	677C
Heavy fraction (percent)	1.26	2.78	2.0	1.87	1.26	1.72	1.67	1.74	0.80	1.10	1.31	1.55	1.60	1.23	0.83	1.25
Heavy fraction																
Magnetite	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Opaque grains (undifferentiated)	73.7	73.0	81.2	71.6	64.1	60.4	71.8	72.0	48.1	63.8	67.5	61.7	71.0	58.2	71.3	76.9
Zircon	15.2	18.3	11.2	19.5	23.2	29.1	17.0	20.3	30.0	22.1	15.5	23.7	16.8	38.5	24.7	14.5
Tourmaline	9.2	6.6	6.8	7.5	9.5	8.2	9.0	6.4	17.0	11.6	12.9	9.1	10.8	2.0	3.0	7.0
Rutile	1.8	1.3	+	.7	1.6	1.7	.7	.3	3.4	.7	1.0	1.0	+	.3	+	2.5
Sphene				+	+											+
Brookite					+										+	
Anatase	+	.6	.4	.7	.6		.7	.3	.6	1.7	.6	2.8	.6		1.0	
Corundum			.4			+										
Epidote									.6		.3	.7	.6	.6		
Staurolite			+												+	+
Garnet																
Pyroxene			+													
Chloritoid							+									
Light fraction																
Quartz:																
Broken	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA
Euhedral	S	S	+	+			S		S	+	S	S	S	S	S	
Chert	A	+	S	C	S	S	S	C	C	A	A	C	S	S	C	
Orthoclase										+			+	S		
Plagioclase:																
$n>1.53$		S	C	S								S				
$n<1.53$		S														
Microcline	+		S					S	S		S	+	S			
Micaceous clay mineral							S							C	C	C

TABLE 3.—*Mineralogic composition of insoluble residues of rocks and of the very fine sand fraction (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material*—Continued

RIVER-BED MATERIAL

	Middle River				Buffalo Branch	Bell Creek		Moffett Creek	Eidson Creek	Christians Creek	North River	South River	South Fork, Shenandoah River
	434	469	468	504	435	497	646	502	649	452	505	506	507
Heavy fraction (percent)	0.60	0.37	1.12	0.70	2.25	0.75	0.38	0.90	0.42	0.37	1.0	2.37	6.0
Heavy fraction													
Magnetite	S	S		S	S	S		S		S	S	S	S
Opaque grains (undifferentiated)	50.0	48.4	66.8	53.0	60.7	84.6	24.5	40.5	54.7	50.0	65.6	43.3	49.2
Zircon	37.5	43.4	26.7	37.0	30.9	10.0	36.0	47.0	27.4	41.2	29.8	24.5	42.4
Tourmaline	6.0	4.7	1.6	3.8	4.7	1.4	5.5	6.8	4.6	2.8	3.8	3.2	4.3
Rutile	2.3	2.2	3.7	1.4	2.5	2.1	4.5	1.0	5.8	2.0	+	3.6	1.2
Chloritoid	+	+	.5				.3			.3	+	+	
Sphene			+							+			
Corundum			+			.3				.3	+		+
Dolomite	+		.5										
Epidote		+					.6		.3	.3	.7	24.5	2.4
Zoisite													
Brookite				+									
Anatase	2.8	.4	.9		.7	1.4	26.1	5.1	6.7	2.4			.4
Spinel		+											
Staurolite					+							+	+
Light fraction													
Quartz:													
Broken	A	VA	VA	VA	VA	A	VA	VA	A	VA	VA	VA	VA
Euhedral	+	S	C	S		C		S	C	S		+	+
Chert	A	C		C	C	A	S	A	S	A	C	C	A
Orthoclase	S		+		S					+			
Plagioclase:													
$n > 1.53$	S	S	C	+	S	+		S	S		S	+	S
$n < 1.53$									S				
Microcline	S	C	+					+	S	+	S	S	S
Nontronite (?)												C	

Authigenic euhedral quartz crystals are common in limestone and dolomite where their presence is probably due to crystallization of silica from chert or another noncrystalline form. Such authigenic grains generally contain small inclusions which appear to have acted as nuclei for the deposition of SiO_2 and growth of the crystals. The presence of these quartz grains in soils and river sands can be used as a diagnostic feature and indicates that certain beds of limestone and dolomite have contributed detrital material to the soils and river sands. The presence of well-rounded quartz grains indicates that the sandstone of the Conococheague has contributed.

Chert.—Although chert nodules are an important constituent of some beds of dolomite and limestone of the area, chert is only a minor constituent in the rocks examined. It occurs in small characteristically cryptocrystalline grains in the Elbrook dolomite, Beekmantown dolomite, and Lenoir limestone. A somewhat similar type of material is present, to a small extent, in the sandstone of the Chemung formation.

Feldspar.—Feldspar grains were found only in the Conococheague limestone, Elbrook dolomite, Martinsburg shale, and Brallier shale, and only in small quantities (table 3). The Elbrook dolomite, particularly the shaly beds, appears to be the principal host for plagioclase feldspar, which includes oligoclase and albite, of which oligoclase is the more abundant. Some microcline is also present. Grains of authigenic albite occur sparingly and are similar to those described by Honess and Jeffries (1940) from the Lowville limestone in central Pennsylvania. Orthoclase was found in small quantities in the Conococheague.

Shale particles.—Composite particles of shale are abundant in the residue of the Martinsburg shale but are not present in that of the Brallier shale. Such grains consist of micaceous overlapping plates, or of micaceous material intimately intergrown with fine-grained quartz.

Mica.—Muscovite is common in the Elbrook dolomite and a small quantity of biotite is also present. Muscovite occurs in the Brallier shale. Micaceous grains are abundant in the shaly beds of the Elbrook dolomite, in the Brallier shale, and, to a lesser extent, in the sandstone of the Chemung formation.

HEAVY FRACTION

The suite of heavy minerals is a restricted one. It consists almost exclusively of the minerals most resistant to weathering, together with a few authigenic species. The heavy minerals identified in the insoluble residues are listed in table 3. It is to be noted that only the sandstone of the Chemung formation contains any appreciable quantity of heavy fraction.

The minerals present are opaque grains (ilmenite, magnetite, and indefinite alteration products), zircon, tourmaline, rutile, garnet, kyanite, staurolite, sphene, anatase, chloritoid, epidote, zoisite, amphibole, and pyrite. In the majority of the rocks examined the opaque grains, zircon, and tourmaline are the only ones found in any quantity, except for pyrite in the Beekmantown dolomite and Mosheim limestone. The other minerals are present as single grains in some of the residues (table 3).

Opaque grains.—The term "opaque grains" is used as general descriptive term to include ilmenite, magnetite, and indefinite iron oxides, which appear opaque under the microscope. Ilmenite is the most common opaque mineral in most sediments. If magnetite was present in any quantity, it was separated from the opaque grains and listed in the tables. Black opaque grains are present in all the rocks with the exception of one sample of the Beekmantown dolomite (496A) which is from a highly weathered nonresistant bed.

Zircon.—Zircon occurs in all the rocks, with the exception of the Lenoir limestone. The grains are of several different morphological types and therefore can be described as seven varieties (table 4). These varieties are:

1. Purple; smooth rounded grains with few inclusions; normal optical properties; slightly to strongly pleochroic.
2. Purple; zoned, corroded, or both, with zoning common; normal birefringence and index of refraction; slightly pleochroic; grains, although worn, are recognizably euhedral; apparently a less stable variety than type 1.
3. Colorless; well rounded, with highly polished surfaces; few inclusions; most of the original crystal faces removed by abrasion; characteristic of the sandy beds of the Conococheague.
4. Colorless; prismatic, not worn; typically euhedral, with complete prisms and pyramids.
5. Colorless; prismatic, broken and worn; similar to type 4 but the original sharp edges worn.
6. Purple; metamict; similar in appearance to type 2 but lower birefringence, about 0.01, and index of refraction ω (omega) between 1.904 and 1.914.
7. Colorless; zoned grains found only in the Brallier shale; refractive index and birefringence normal.

The contribution of the weathering products of the various rocks can be identified by the presence of the different types of zircon.

TABLE 4.—*Types of zircon in insoluble residues of rocks and in the very fine sand fraction (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material*

[Symbols: A, abundant; C, common; S, scarce]

Rocks

Zircon type	Conococheague limestone (sandy dolomite)	Elbrook dolomite (dolomite)	Beekmantown dolomite (limestone and dolomite)	Mosheim limestone (limestone)	Martinsburg shale (shale)	Brallier shale (shale)	Chemung formation (sandstone)
	477J	479L	496A, B, D, F	496E	500N, O	665F	522
1. Purple, rounded	S		S		A		S
2. Purple, zoned or corroded or both			S		C		S
3. Colorless, rounded, polished, few inclusions	A	S	S		C	S	C
4. Colorless, prismatic, not worn			S		S	S	A
5. Colorless, prismatic, broken, and worn	S	S	A	S	C	A	
6. Metamict, low birefringence, zoned or colored, or both.	S		S		S		S
7. Zoned, colorless						S	

Residual soils

Zircon type	Conococheague limestone	Elbrook dolomite	Beekmantown dolomite	Martinsburg shale	Brallier shale	Chemung formation
	501H, I	479K	496G	503M	665 A-C	522
1. Purple, rounded	S		S	A		S
2. Purple, zoned or corroded or both			S	C		S
3. Colorless, rounded, polished, few inclusions	A	C	C	C	S	C
4. Colorless, prismatic, not worn			S	S	S	A
5. Colorless, prismatic, broken and worn	S	C	A	C	A	
6. Metamict, low birefringence, zoned or colored, or both	S		S	S		S
7. Zoned, colorless					S	

TABLE 4.—*Types of zircon in insoluble residues of rocks and in the very fine sand fraction (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material*—Continued

Alluvial soils

Zircon type	Conococheague limestone and Elbrook dolomite								Beekman-town dolomite	Martinsburg shale			Hampshire and Chemung formations	
	525	526A	526B	527	532	482B	482C	619B	439	528A	528B	531	524	523
1. Purple, rounded	S	S	S		S			S		S		S	S	S
2. Purple, zoned or corroded or both	S				S						S	S	S	S
3. Colorless, rounded, polished, few inclusions	A	A	A	A	S	A	A	S	C	C	S	C		
4. Colorless, prismatic, not worn							S		S	S	S	S	S	S
5. Colorless, prismatic, broken and worn	A	C	C	C	A	C	C	A	A	A	A	A	A	A
6. Metamict, low birefringence, zoned or colored or both	S		S	S	S		S	S	S			S	S	S
7. Zoned, colorless		S			S	S	S	S	S	S	S	S	S	S

Terrace and high flood-plain soils

Zircon type	678	681	577A	577B	686A	686B	686C	599	675A	675B	675C	688A	688B	677A	677B	677C
1. Purple, rounded					S	S	S	S	S	S	S	S	S	S		
2. Purple, zoned or corroded, or both			S	S	S	S	S	S	S			S	S			
3. Colorless, rounded, polished, few inclusions	C	S	C	C	C		C	S	C	C	C	C	C	C	C	C
4. Colorless, prismatic, not worn	S	S		S		S	S	S		S	S	S	S			S
5. Colorless, prismatic, broken and worn	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	C
6. Metamict, low birefringence, zoned or colored, or both			S	S	S		S	S	S	S	S	S				S
7. Zoned, colorless	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

River-bed material

Zircon type	Middle River				Buffalo Branch	Bell Creek		Moffett Creek	Eidson Creek	Christians Creek	North River	South River	South Fork, Shenandoah River
	434	469	468	504	435	497	646	502	649	452	505	506	507
1. Purple, rounded	S			S	S					S	S	S	S
2. Purple, zoned or corroded, or both		S	S		S						S	S	S
3. Colorless, rounded, polished, few inclusions	C	C	C		S	C		C	S		C		
4. Colorless, prismatic, not worn		S				S		S			S		S
5. Colorless, prismatic, broken and worn	C	C	C	A	C	C	A	A	A	A	C	A	A
6. Metamict, low birefringence, zoned or colored or both	S	S		S							S	S	S
7. Zoned, colorless		S	S			S		S		C		S	

Tourmaline.—Tourmaline occurs mainly in sandstone and shale and is practically absent from the residues of limestone.

Dark- to light-brown and greenish-brown and occasionally gray well-rounded tourmaline is characteristic of the sandy beds of the Conococheague limestone. A few particolored blue and brown grains are also commonly present. This tourmaline often has small overgrowths that are colorless but in optical continuity with the parent grains.

Angular brown, gray, blue, and green tourmaline, together with prismatic pink grains, many of which show basal pinacoids, and occasional angular blue and brown particolored grains, are characteristic of the sandstone in the Chemung formation. The fresh unworn appearance is in contrast to the worn tourmaline in the sandy beds of the Conococheague limestone. Rounded grains, though scarce, also occur.

Tourmaline in the Martinsburg shale is in angular bright-brown, brownish-green, and grayish-brown fresh fragments; it occurs also as brownish-green and mauve rounded grains. It is not abundant. Some of the rounded grains show corrosion effects and slight overgrowths.

The Brallier shale contains small prisms of greenish-brown and gray tourmaline as well as angular fragments, some of which are brown and blue particolored. All are of very fine grain size.

Rutile.—Rutile is present in very small quantities in the insoluble residues of most of the rocks examined, but was not found in the Mosheim limestone and Lenoir limestone. It occurs as detrital grains that are worn, brown, and prismatic. In some of the beds of the Beekmantown dolomite the rutile is authigenic and may have formed as a result of the removal of iron from ilmenite during weathering. Rutile in these residues has no particular features of diagnostic value.

Garnet.—Garnet occurs as scarce grains in the residues from some beds of the Beekmantown dolomite and the Elbrook dolomite. It is in angular fresh pink grains.

Pyrite.—Pyrite of authigenic origin, in irregular grains and small cubes and pyritohedrons, is the principal mineral in the heavy residue of one of the beds of the Beekmantown dolomite and of the Mosheim limestone.

Other minerals.—Kyanite, staurolite, sphene, amphibole, epidote, and zoisite are present only as individual grains in 1 or 2 of the residues (table 3).

CLAY

Many of the rocks contain some clay minerals. Shale beds are prominent in certain formations such as the Athens limestone and Elbrook dolomite. The Lenoir limestone contains a brown clay mineral of micaceous habit on irregular partings within the rock (Carroll and Hathaway, 1954). Many of the limestone and dolomite beds contain clay associated with black carbonaceous matter. Shale, such as the Martinsburg shale and Brallier shale, contains much micaceous clay material.

SUMMARY

Most sedimentary rocks contain very few kinds of heavy detrital minerals; the rocks described here are no exception. The minerals of the insoluble residues which contribute to soil formation are listed in table 5. That such minerals make an important contribution was shown by Jeffries (1937) in soils of Pennsylvania. Feldspar in the top 6 inches of the Hagerstown silt loam [1] amounted to 38,660 pounds per acre, but in the Lackawanna sandy loam only to 2,260 pounds per acre. The feldspar content of the soils formed from the Elbrook dolomite and Beekmantown dolomite in the Middle River area would be similar to those of the Hagerstown and Lackawanna soils, respectively.

[1] Soil names in this paper are the soil-type names assigned by the U. S. Department of Agriculture.

TABLE 5.—*Summary of principal minerals present in rock types of the Middle River drainage basin*

[Symbols: A, abundant; C, common; S, scarce; +, 1 or 2 grains only]

Minerals	Rock type		
	Sandstone	Limestone and dolomite	Shale
Light minerals:			
Quartz	A	+	+
Feldspar	+	+	------
Chert	------	+	------
Clay	S	+	+
Mica	------	------	A
Heavy minerals:			
Magnetite	+	------	+
Opaque grains	+	------	+
Zircon	A	S	C
Tourmaline	C	------	S
Others	+	+	------

The insoluble minerals contributed by the stratigraphic units are summarized below.

Sandy beds of the Conococheague limestone.—Angular and rounded quartz, a little orthoclase, zircon (types 1; 3, abundant; 5; and 6), tourmaline (dark to light brown, greenish brown, gray, rounded; some prismatic grains, both rounded and prismatic, may have overgrowths), and rutile (worn, brown).

Elbrook dolomite.—Angular quartz, chert, plagioclase feldspar in fresh grains, and zircon (types 3 and 5).

Limestone and dolomite of the Beekmantown dolomite.—Euhedral quartz crystals, very few angular quartz grains, chert, negligible quantities of metamorphic minerals, amphibole, and zoisite, very little zircon, abundant authigenic pyrite in some beds, and rutile. (See table 3.)

Mosheim limestone.—Euhedral quartz crystals, very few angular quartz grains, negligible quantities of heavy minerals, but abundant authigenic pyrite.

Lenoir limestone.—Euhedral quartz crystals, chert, and black opaque minerals.

Martinsburg shale.—Thin broken quartz grains, very little plagioclase feldspar, black opaque minerals, zircon (type 1, abundant; 2, 3, and 5, common; 4 and 6, scarce), and tourmaline (rounded brown, brownish-green, mauve grains; prismatic bright-brown and grayish-brown irregular angular grains).

Brallier shale.—Angular quartz, little plagioclase feldspar, zircon (type 5, abundant; 3, 4, and 7, scarce), and tourmaline.

Chemung formation.—Angular quartz, zircon (type 4, abundant; 3, common; 1, 2, and 6, scarce), and tourmaline (plentiful angular broken brown, green, gray, blue, and occasional blue and brown particolored grains).

SIGNIFICANCE

The varietal features of the heavy minerals in these rocks are suggestive of the provenance of the materials, but no inferences can be made at present about the origin of the detritus in any of these formations because very few samples have been examined. However, several points can be noted.

Zircon is found in a number of easily recognizable varieties, among which purple grains are prominent. These are especially conspicuous in the Martinsburg shale and are almost certainly derived from some Precambrian source. The well-rounded and polished zircon in the Conococheague limestone is undoubtedly the most resistant of the reworked zircon from sedimentary sources. The zircon in the Chemung formation is probably from two sources—the unworn crystals from some newly eroded rock and the rounded grains from some preexisting sedimentary rock, possibly even from the Conococheague.

Tourmaline, the only other heavy detrital mineral present in any quantity, has had a history similar to that of zircon; it is well rounded and of few colors in the Conococheague, and plentiful, angular, and prismatic in the Chemung. The presence of authigenic outgrowths or overgrowths on the well-rounded tourmaline in the Conococheague resembles that described by Stow (1932) in the Oriskany (Devonian), Martens (1939) in the Clinton (Lower Silurian), and Krynine (1945) in the Gatesburg and Potsdam formations (Cambrian).

Little significance can be attached to the presence of very small quantities of other heavy detrital minerals except that they indicate that metamorphic rocks were probably inconspicuous in the eroded terrane and that greenstones (metamorphosed dolorite, diorite, basalt, tuff) were probably absent. The eroded terrane appears to have consisted mainly of granitic and sedimentary rocks.

SOILS

DISTRIBUTION

The soils of Augusta County are part of the Gray-Brown Podzolic Group. Many of these soils, however, have features that indicate that they are transitional between the Gray-Brown Podzolic Group and the Red-Yellow Podzolic Group, which is dominant in parts of the southeastern United States. The soils of Augusta County have been mapped by Jurney and others (1937). Residual soils occur on about 70 percent of the area. Obenshain and Porter (1951) relate the various soil types to the statigraphic units as follows:

Soil type	*Stratigraphic unit*
Frederick and Hagerstown	Lenoir limestone, Mosheim limestone, Beekmantown dolomite, Elbrook dolomite, and Conococheague limestone.
Berks	Martinsburg shale.
Leadvale	Brallier shale.
Muskingum	Hampshire and Chemung formations.

The area in Augusta County occupied by the principal residual-soil types is: Frederick, 20 percent; Hagerstown, 9 percent; Berks, 7 percent; Muskingum, 35 percent. The approximate areas of these soils can be inferred from the generalized geology (pl. 14).

The Elk, Huntington, Greendale, Sequatchie, Monongahela, and Waynesboro are types of alluvial soils and of terrace and high flood-plain soils.

The soils vary in maturity according to topographic position and time during which profile development has been taking place. In general the surface soil (*A* horizon) ranges in color from light gray or pale yellowish gray to pale reddish brown; the subsoil (*B* horizon) is red, brownish red, brown, or yellow. The surface soil contains much silt or fine sand, organic matter is low, and the pH is slightly acid (residual soils) to slightly alkaline (alluvial soils). Podzolization is the active soil-forming process.

A limited number of samples was collected from soils judged to be residual from the underlying rocks and from alluvial soils considered to have been derived from known rock types. Composite samples of high flood-plain soils were collected and a number of soil profiles in the older terraces were sampled. The samples are distributed as follows: 19 samples of residual soils, comprising 3 sets of profile samples and 5 individual profiles; 15 samples of alluvial soils; and 16 samples of terrace and flood-plain soils, including 2 sets of profile samples (see tables 6, 8, 9 and 10).

RESIDUAL SOILS

Residual soils were collected from above sandstone, shale, limestone, and dolomite as indicated in table 6.

SOIL-PROFILE CHARACTERISTICS

Most of the residual soils are classified as Frederick silt loam (table 7), which ranges in texture from silty loam to very fine sandy loam. This is the soil characteristic of a limestone parent rock, and it has the largest areal distribution of any soil in the Middle River drainage area. At the surface the soil is light yellowish gray; it grades downward into reddish-brown and yellow silty clay at a depth of 12–36 inches, below which it may be mottled (Jurney and others, 1937, p. 44). The mottling is nearer the surface in thinner profiles. Chemical analyses of the whole soil and of the clay fraction (less than 2 microns in diameter) for a Fred-

TABLE 6.—*Residual-soil samples collected in Augusta County, Va.*

[Sample numbers are field numbers]

Sample	Depth (inches)	Parent Rock	Locality
522	0–6	Chemung formation	Rocky knob on south end of Crawford Mountain, 0.5 mile up trail from East Dry Branch Gap on County Road 688 (old Parkersburg Turnpike). Craigsville quadrangle.
655		Brallier shale	East bank of Charlie Lick Branch, about 200 feet downstream from culvert on Cold Spring Road, 3.3 miles south of old Parkersburg Turnpike, and 2.2 miles east of ford of Calfpasture River; 2 miles northwest of Elliot Knob. Craigsville quadrangle.
A	10–14	do	Do.
B	23–25	do	Do.
C	34–36	do	Do.
D	48	*C* horizon, weathered rock	Do.
E	96	Weathered rock	Do.
503M	18	Martinsburg shale	Small quarry in Martinsburg shale on County Road 612 (from Verona to Crimora); 0.5 mile east of bridge on Christians Creek, 1 mile west of junction of County Road 608; 1.5 miles due east of Laurel Hill. Waynesboro quadrangle.
534		Lenoir limestone	In roadcut on County Road 742, 1.9 miles north of junction with U. S. Highway 250; 3.5 miles north of center of Staunton. Staunton quadrangle.
A	0–10	*A* horizon	Do.
B	10–15	*B* horizon	Do.
C	15–21	*B–C* horizon	Do.
D	21–23	*C* horizon	Do.
E	23–26	*C* horizon	Do.
F	156	Weathered rock from approximately same bed as soil is formed on.	Do.
496G	0–6	Beekmantown dolomite	Verona quarry.
501		Conococheague limestone	Hilltop on Conococheague limestone 0.1 mile southeast of bend in Middle River, north of County Road 781, 1.5 miles from junction with U. S. Highway 11. 1.6 miles north of Verona. Staunton quadrangle.
H	6–12	*A–B* horizon	Do.
I	24–30	*B* horizon	Do.
495	0–9	Conococheague limestone	Roadcut in Conococheague limestone on north end of ridge on County Road 613 (old Greenville Road); 1.4 miles south from junction with U. S. Highway 11; 1.9 miles south of center of Staunton quadrangle.
482A	0–6	Conococheague limestone	Sheet's farm on small north tributary of Middle River, northeast of County Road 742; 0.5 mile east of bridge on Middle River, 2.6 miles north-northeast from Pleasant View Church. Staunton quadrangle.
479K	30	Elbrook dolomite	Hilltop on north bank of Middle River, 0.35 mile upstream from bridge on County Road 626; 2.6 miles north of Verona. Staunton quadrangle.

erick silt loam profile on Lenoir limestone, together with X-ray data, have been published previously (Carroll and Hathaway, 1954, p. 175).

The low pH of all these soils (table 7), with the exception of sample 496G on Beekmantown dolomite, is characteristic.

The ion-exchange capacity of the surface soils is very low, indicating their lack of minerals capable of ion exchange and of organic matter, but at depth, with clay accumulation, the exchange capacity becomes much higher (see table 7, samples 501I and 479K). However, in the Brallier shale soil-profile sample (665) the exchange capacity is low throughout.

GRAIN-SIZE DISTRIBUTION

Mechanical analyses (table 7) show that silt (0.05–0.002 mm grain diameter) is the principal grain size in these soils. Cumulative frequency curves (fig. 30) show the median diameters to be 0.098–0.001 mm. The average median diameter for the limestone soils is 0.005 mm and for the shale soils is 0.002 mm. The distribution of sand, silt, and clay is given in figure 31*A*.

MINERALOGY

The very fine sand (0.10–0.05 mm grain diameter) was examined for both light and heavy minerals. The sand of all the surface soils contained less than 1 percent by weight of heavy minerals. In sample 534E (23–26 inches), however, the quantity of heavy minerals was much higher because of the presence of pyrite that had largely altered to opaque iron oxides (see table 3; fig. 32*A*).

The minerals in the fine sand are essentially those which were found in the insoluble residues of the rocks, with few differences. The presence of euhedral quartz in the soils derived from the Lenoir limestone and

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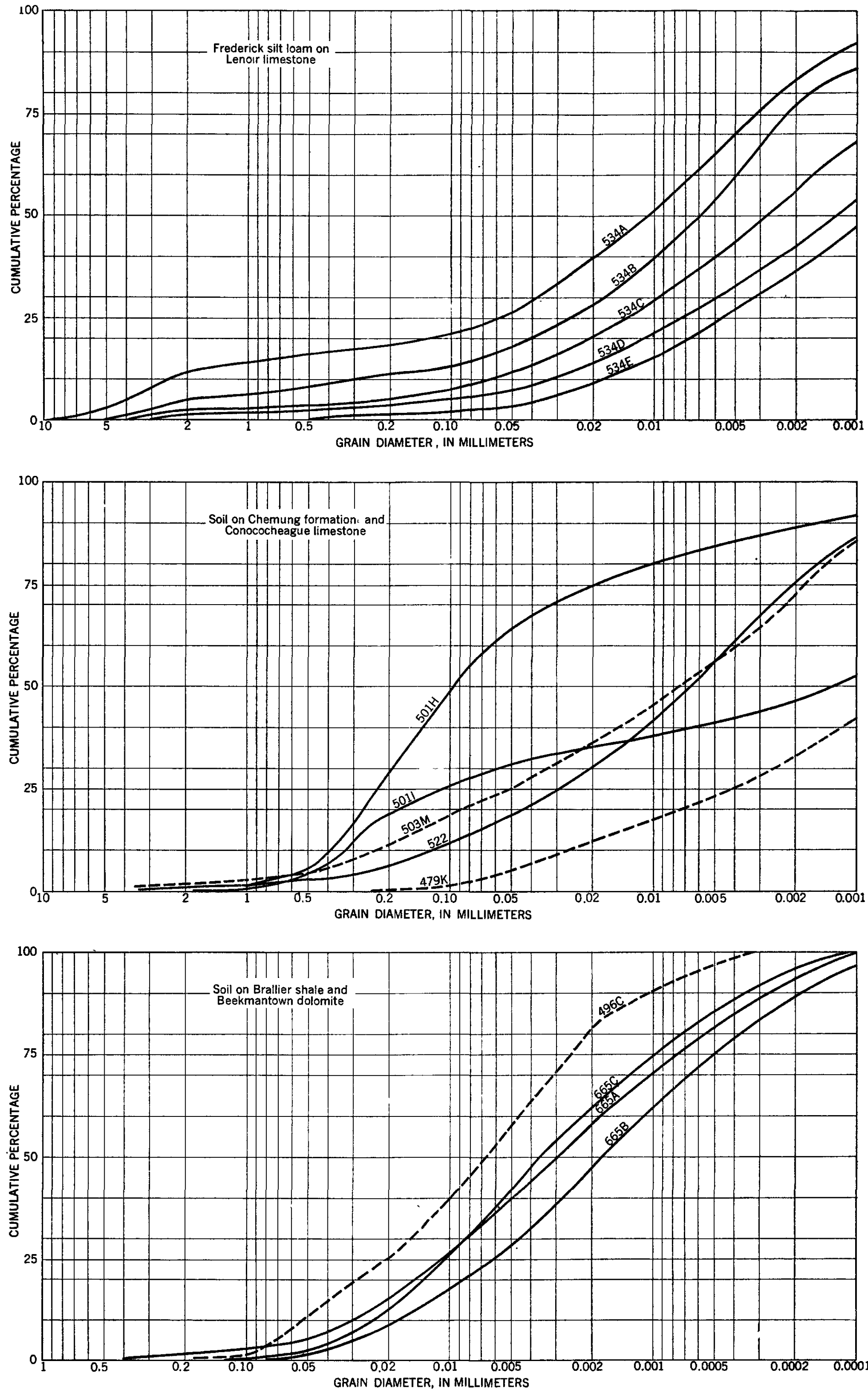

FIGURE 30.—Cumulative frequency curves showing grain-size distribution in samples of residual soil.

Beekmantown dolomite is noteworthy, as is feldspar of several varieties from the Conococheague limestone and Elbrook dolomite; these formations appear to be the chief contributors of these minerals.

The heavy fraction contains the same minerals as occur in the underlying rocks, and there is no doubt that these soils are residual and peculiar to the rocks above which they were collected. In fact, the varieties of zircon and tourmaline in these heavy residues emphasize the distribution of certain types of these minerals from certain rocks. The zircon types that occur in the residual soils are listed in table 4.

ALLUVIAL SOILS

The alluvial soils are found on small flood plains of very recent alluvium that still receive material when streams flood. The materials of the alluvium are derived from mature and immature soils, and from weathered country rocks. These materials are moved by runoff, soilcreep, and soil movement from their original positions to the flood plains. Samples were collected from areas and streams where mixing of material from different sources would be at a minimum. The alluvial-soil samples are described in table 8.

SOIL-PROFILE CHARACTERISTICS

The alluvial soils are nearly all classified as Huntington silt loam, which is the principal soil found on the flood plains, both large and small, in the valleys. These low flood plains are subject to periodic flooding. Only two samples (523 and 524) were collected from sites adjacent to areas of sandstone of Devonian age (pl. 14), the presence of which causes them to have a coarser grain size than the majority of the alluvial soils.

In contrast to the residual soils, most alluvial soils have a pH of from 7 to more than 8, which is due to their situation in positions washed by carbonate-bearing water from limestones. Because of this the ion exchange is also higher than in the residual soils. This reflects the presence of different kinds of clay minerals. These alluvial soils, together with some of those on the higher flood plains and terraces, are the most fertile in the area.

Table 7 gives the soil type, formation drained, stream, pH, and other characteristics of the alluvial soils examined.

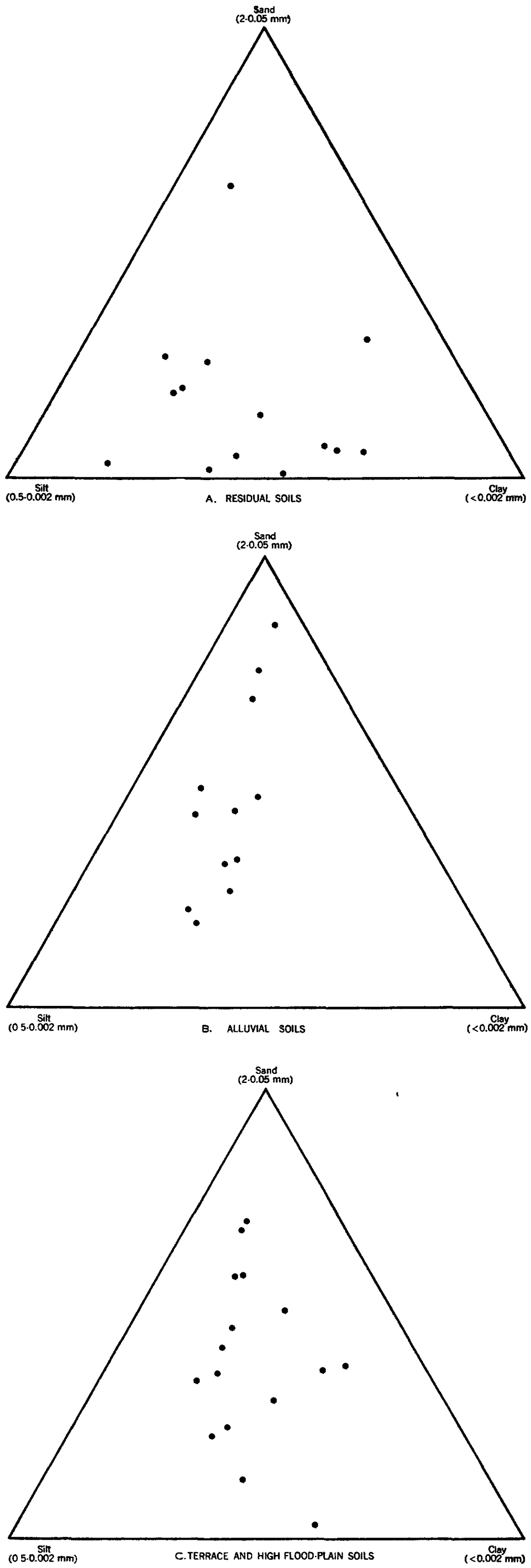

FIGURE 31.—Triangular diagrams showing the quantity of sand, silt, and clay in residual, alluvial, and terrace and high flood-plain soils of the Middle River drainage basin.

TABLE 7.—*Description and chemical and physical characteristics of residual, alluvial, and terrace and high flood-plain soils from Augusta County, Va.*

[Analysts: Paul D. Blackmon, Gerald L. Otzelberger, and Dorothy Carroll. Color symbols are those used in the Munsell soil-color chart]

Sample	Soil type	Location	Depth (inches)	Color (wet)	pH	Ion-exchange capacity (mequiv per 100 g)	Grain-size distribution (percent)							
							Gravel (>2 mm)	Sand					Silt (0.05–0.002 mm)	Clay (<0.002 mm)
								Very coarse (2–1 mm)	Coarse (1–0.50 mm)	Medium (0.50–0.25 mm)	Fine (0.25–0.10 mm)	Very fine (0.10–0.05 mm)		
Residual soils														
		Parent rock												
522	Muskingum fine sandy loam.	Chemung formation	0–6	10*YR* 5/3	4.57	5.4		1.19	1.39	2.30	7.53	6.46	56.67	24.46
665A	Leadvale silt loam	Brallier shale	10–14	10*YR* 5/4	4.58	4.4		.04	.09	.53	1.65	2.85	52.87	42.27
B	do	do	23–25	10*YR* 6/4	4.65	7.0					.09	.80	45.87	53.24
C	do	do	34–36	10*YR* 5/6	4.52	5.0	0.12	.03	.06	.09	.16	1.63	59.86	38.06
534A	Frederick silt loam	Lenoir limestone	0–10	10*YR* 4/3	4.6	1.9	12.4	2.0	2.1	1.8	3.0	5.2	56.6	17.1
B	do	do	10–15	7.5*YR* 4/4	4.3	4.7	5.6	1.1	1.6	2.0	3.2	5.9	57.7	23.0
C	do	do	15–21	5*YR* 4/6	4.4	13.8	2.6	.1	1.2	1.3	2.4	4.5	44.7	42.5
D	do	do	21–23	5*YR* 4/6	4.4	12.5	1.9	.5	.6	.6	1.2	2.4	34.8	58.0
E	do	do	23–26	5*YR* 4/6	4.4	12.1	.1	.2	.3	.4	.8	2.1	33.6	61.7
496G	do	Beekmantown dolomite	0–6	10*YR* 5/8	8.30					.01	1.44	9.46	70.87	18.22
501H	Frederick very fine sandy loam.	Conococheague limestone	6–12	5*YR* 4/8	5.60	3.0	1.03	.28	3.80	17.23	26.38	15.24	24.47	11.57
I	do	do	24–30		4.72	19.0	.17	.19	3.93	11.76	9.21	5.48	14.89	54.38
495	Frederick silt loam	do	0–6		4.78	4.8								
482A	Frederick fine sandy loam	do	0–6	2.5*YR* 4/4	6.0	3.3								
479K	Frederick silt loam	Elbrook dolomite	30	5*YR* 4/6	4.95	22.0	.03	.11	.24	.34	.85	3.29	28.68	66.45
503M	Berks shaly silt loam	Martinsburg shale	18	7.5*YR* 6/4	4.70	5.2	1.67	1.69	1.91	4.53	9.15	6.80	48.04	26.22
Alluvial soils														
		Stratigraphic unit drained												
524	Pope sandy loam	Little River: Hampshire formation and Chemung formation.	0–6	10*R* 3/2	6.17	2.9	9.0	1.6	2.0	15.9	34.6	12.2	13.9	10.8
523	do	do	0–6	10*R* 3/2	5.80	1.6	.1	.4	4.4	34.5	37.4	7.5	6.7	9.0
525	Huntington silt loam	Folly Mills Creek system: Conococheague limestone and Elbrook dolomite.	0–6	7.5*YR* 4/4	7.85	11.4	.1	.2	.6	1.1	4.1	9.0	54.7	30.2
526A	do	Folly Mills Creek: Conococheague limestone and Elbrook dolomite.	0–6	5*YR* 4/4	8.20	5.2	.1	.3	1.6	13.4	20.8	10.3	28.2	25.3
B	do	do	0–6	7.5*YR* 4/4	8.35	8.9			.3	4.0	7.6	7.0	54.1	27.0
527	Warners silt loam	do	0–6	10*YR* 3/3	8.14	16.2	2.1	2.4	4.3	7.5	8.7	6.4	47.4	21.2
528A	Huntington silt loam shallow to marl.	Martinsburg shale	0–6	10*YR* 3/3	8.30	11.8	.7	.3	3.2	16.2	17.1	11.7	37.8	13.0
B	Mixed alluvial, poorly drained.	do	0–6	10*YR* 3/3	6.71	15.5	11.1	6.3	6.0	4.0	3.1	2.0	39.3	28.2
531	Huntington silt loam	Christians Creek: Martinsburg shale	0–6	10*YR* 4/3	8.26	11.1			2.6	12.2	11.6	8.0	45.5	20.1
482B	do	North tributary, Middle River: Conococheague limestone and Elbrook dolomite.	0–6	2.5*Y* 4/4	6.69		.7	.6	2.2	6.8	7.4	3.8	54.6	23.9
C	Allen fine sandy loam	do	0–6	10*YR* 5/6	8.56		1.8	1.1	3.6	15.1	16.0	6.3	34.3	21.8
532	Staser silt loam	Middle River: Conococheague limestone and Elbrook dolomite.	0–6	10*YR* 3/3	8.10	9.4			.1	3.6	17.1	11.6	47.2	20.4
619B	Staser very fine sandy loam.	do	0–6	10*YR* 3/3	8.10	8.4			.1	1.8	22.3	18.8	41.9	15.1
439	Huntington silt loam	Beekmantown dolomite	0–6	10*YR* 3/3	7.80	6.6	.4	.3	2.7	19.9	25.3	9.5	28.4	13.5

Terrace and high flood-plain soils

		Height above Middle River													
678	Huntington silt loam	12-foot flood plain, both sides of river	0–5	10*YR* 3/2	7.34	10.1			0.12	4.10	23.50	19.37	32.58	20.33
681	Staser fine sandy loam	11-foot flood plain, north side of river	0–5	10*YR* 3/2	6.95	4.0	.58	.18	2.14	27.02	29.07	8.53	20.82	11.66
577A	Pope silt loam	7-foot flood plain, south side of river	0–5	10*YR* 3/2	7.82	6.8	.12	0.03	.74	12.64	31.80	13.23	25.32	16.12
B	Staser fine sandy loam	5-foot flood plain, north side of river	0–5	10*YR* 3/2	7.84	4.0	.18	.09	.77	13.95	41.22	14.26	18.42	11.10
686A	Waynesboro clay loam, eroded phase.	75-foot terrace, west side of river	12	2.5*YR* 4/4	5.40	5.8	.02	.05	.20	3.80	19.89	13.76	20.35	41.93
B	do	do	30	2.5*YR* 4/4	4.95	5.4			.23	5.91	21.99	10.63	14.93	46.31
C	do	do	54	2.5*YR* 4/6	5.15	4.2		.06	.51	10.18	26.54	13.09	21.03	28.60
599	Sequatachie fine sandy loam.	4-foot flood plain, west side of river	0–5	10*YR* 3/2	7.68	6.4	.59	.11	1.30	16.07	28.66	11.37	26.67	15.21
675A	Monongohela fine sandy loam to silt loam.	25-foot terrace, south side of river	0–5	10*YR* 4/3	6.85	5.0	2.21	.91	2.77	8.63	11.38	8.89	46.24	18.97
B	Elk silt loam	12-foot terrace, north side of river	0–5	10*YR* 3/2	7.10	12.0	1.08	.03	.27	.72	7.48	14.05	45.75	30.61
C	Huntington silt loam	10-foot terrace, north side of river	0–5	10*YR* 3/2	8.00	11.8	.14	.03	.08	1.16	17.84	17.22	41.64	21.88
688A	do	10–13-foot flood plain, north side of river	0–3	10*YR* 3/3	8.15	14.0	.16	.02	.13	3.05	10.38	8.69	49.55	28.02
B	do	12–17-foot flood plain, south side of river	0–5	10*YR* 3/2	8.14	13.0	.55	.30	1.33	10.16	19.57	10.22	37.19	20.68
677A	Greendale silt loam	45-foot terrace, east side of river	15	7.5*YR* 4/4	5.78	7.8	3.81	.63	1.66	2.18	2.37	1.75	47.78	39.82
B	do	do	25–29	7.5*YR* 5/6	4.50	13.6	.39	.06	.19	.32	.70	.88	39.38	58.09
C	do	do	55	10*YR* 5/8	4.55	9.6	5.43	5.76	9.00	4.68	3.11	2.10	33.32	36.60

GRAIN-SIZE DISTRIBUTION

Mechanical analyses (table 7) show that silt (0.05–0.002 mm grain diameter) is the principal grain size in these soils. Cumulative frequency curves (fig. 33) show that the median diameters of 2 samples of sandy alluvium (523 and 524) from the Little River are 0.14 and 0.19 mm, respectively. The range in median diameter for the Folly Mills Creek samples is 0.003 to 0.012 mm, and averages 0.078 mm. The samples from the Middle River flood plains are more variable and range from 0.007 to 0.095 mm. The distribution of the sand, silt, and clay in the alluvial soils is given in figure 31*B*.

MINERALOGY

The alluvial soils contain a smaller quantity of heavy minerals in the very fine sand than do the residual soils (table 3). The alluvium of the Little River (samples 523 and 524) contains more than 1 percent of heavy minerals, a reflection of its source in sandstone of Devonian age which has a much higher residual mineral content than other source rocks of the area. The remaining samples of alluvial soil, derived from limestone and shale, contain only about one-tenth of 1 percent heavy minerals. The few samples of alluvium from the Middle River (532, 619B, and 439) contain a larger quantity of heavy fraction than those from the alluvium of the Folly Mills Creek system (525, 526A, 526B, 527, 528A, 528B) and Christians Creek (531). It is probable that material from the Devonian rocks has contributed to the increase in the Middle River, as the localities of these samples are below the junction of Buffalo and East Dry Branches, Jennings Branch, and Moffett Creek, all of which drain the Devonian rocks directly.

Quartz is the major constituent in the light fractions; it occurs as broken and euhedral grains. Chert is present in all but three of the samples examined. Feldspar is much more widely distributed than in the residual soils; both plagioclase and microcline are present in nearly all the samples. It is evident that mixing and concentration have been important. The presence of euhedral quartz in the samples from the Folly Mills Creek system indicates that the material from the Beekmantown dolomite extends well down into the part of the stream system that cuts through Martinsburg shale (sample 528). However, euhedral quartz is also found in samples of material originating from the Conococheague limestone drained by a small unnamed tributary of the Middle River on Sheet's farm (samples 482B and 482C), so that this type of quartz is probably more widespread than has been determined from the few rock samples examined.

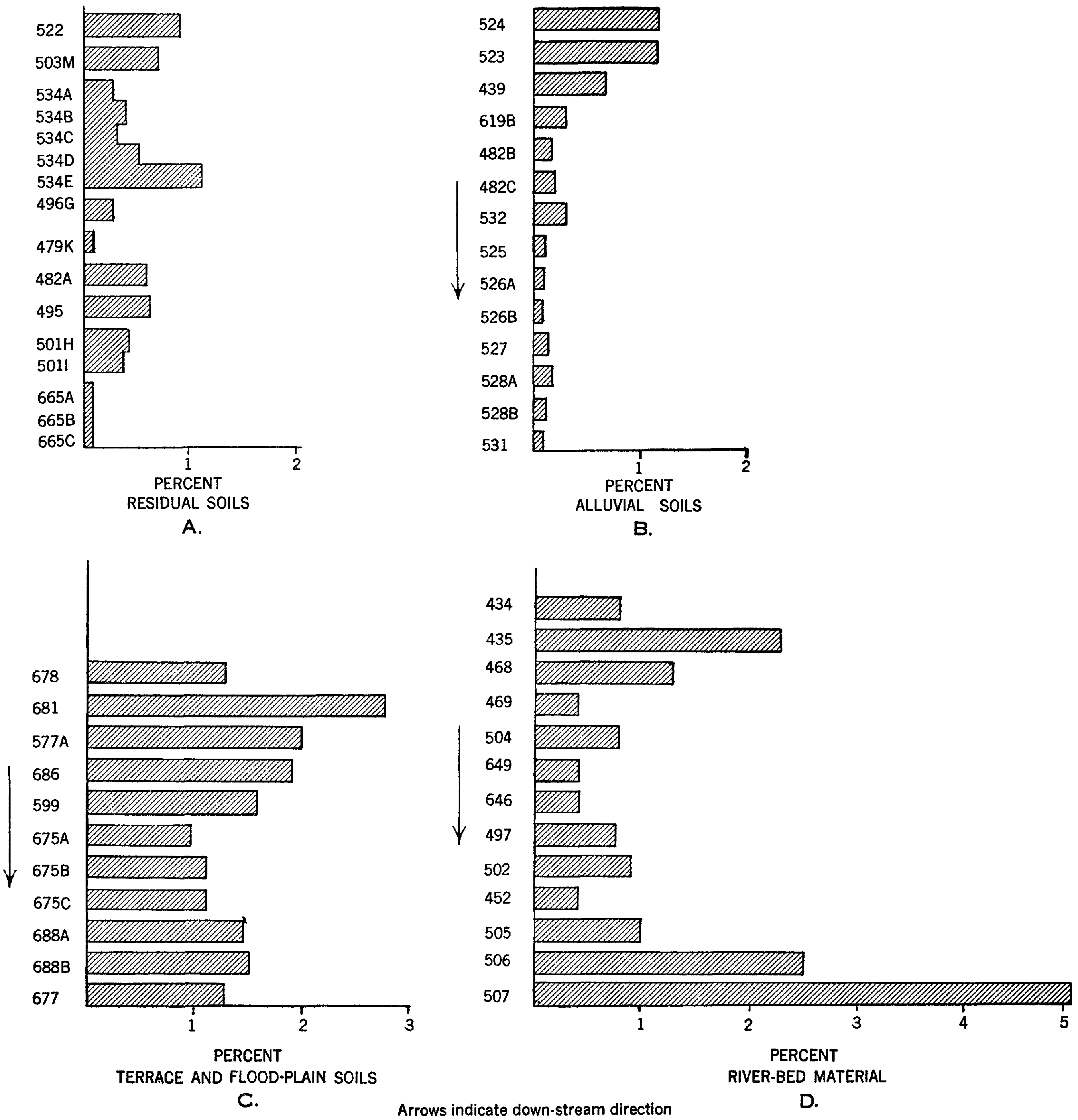

FIGURE 32.—Variation in quantity of heavy fraction in the very fine sand (0.10–0.05 mm) of residual, alluvial, and terrace and high flood-plain soils and of river-bed material.

TABLE 8.—*Alluvial-soil samples collected in Augusta County, Va.*

[Sample numbers are field numbers]

Sample	Depth (inches)	Stream and deposit	Stratigraphic unit drained	Locality
524	0–6	Little River; flood plain	Hampshire formation and Chemung formation.	Flood plain of Little River, at junction of North River, 0.9 mile upstream from Stokesville; about 200 feet south of Forest Road on east bank of Little River. East of Camp May Flather. Parnassus quadrangle.
523	0–6	do	do	Edge of flood plain, on south bank of Little River; 3.1 miles upstream from Stokesville, 50 yards west of U. S. National Forest Road on south side of ford at Little River. Near east end of Grooms Ridge. Parnassus quadrangle.
525	0–6	Bays Mill Creek; alluvium.	Conococheague limestone and Elbrook dolomite.	West bank of Bays Mill Creek (south tributary of Folly Mills Creek), east of County Road 613, about 200 yards south of junction of County Road 697; 1.9 miles south of Folly Mills on County Road 613. 1.4 miles northwest of Mint Spring. Staunton quadrangle.
526A	0–6	Folly Mills Creek; alluvium.	do	Folly Mills Creek, at junction of small tributary near Arbor Hill; near bridge crossing Folly Mills Creek on County Road 693, south of junction with County Road 654. 1.3 miles east of Arbor Hill. Staunton quadrangle.
B	0–6	do	do	Do.
527	0–6	do	do	Folly Mills Creek, south of County Road 613 (old Greenville Road); 0.2 mile west of junction with County Road 654; from east 1 mile upstream from bridge on U. S. Highway 11. 0.2 mile west of Folly Mills. Staunton quadrangle.
528A	0–6	do	Martinsburg shale	Folly Mills Creek, at junction with small south tributary, at bridge on County Road 648 near large gate and cattle-loading platform. 1.5 miles southeast on road from Good Shepherd Church. Staunton quadrangle.
B	0–6	do	do	Do.
531	0–6	Christians Creek; alluvium.	do	East bank of Christians Creek, upstream from bridge on County Road 635. 1.6 miles north of Barterbrook. Staunton quadrangle.
532	0–6	Middle River; alluvium	Conococheague limestone and Elbrook dolomite.	North bank of Middle River, at bend, on County Road 744; 0.5 mile downstream from bridge on County Road 626. 2.3 miles north of Verona. Staunton quadrangle.
439	0–6	do	Beekmantown dolomite	Bank of Middle River, East Farm, at bridge on U. S. Highway 250. 6.1 miles northwest of center of Staunton. Staunton quadrangle.
619B	0–6	do	Conococheague limestone and Elbrook dolomite.	North bank of Middle River, on downstream side of bridge at County Road 742; on Sheet's farm. 2 miles north-northwest from Pleasant View Church. Staunton quadrangle.
482B	0–6	North tributary, Middle River; alluvium.	do	Small north tributary of Middle River, on Sheet's farm, northeast of County Road 742; 0.5 mile east of bridge on Middle River. 2.6 miles north-northeast of Pleasant View Church. Staunton quadrangle.
C	0–6	do	do	Do.
D	0–6	do	do	Do.

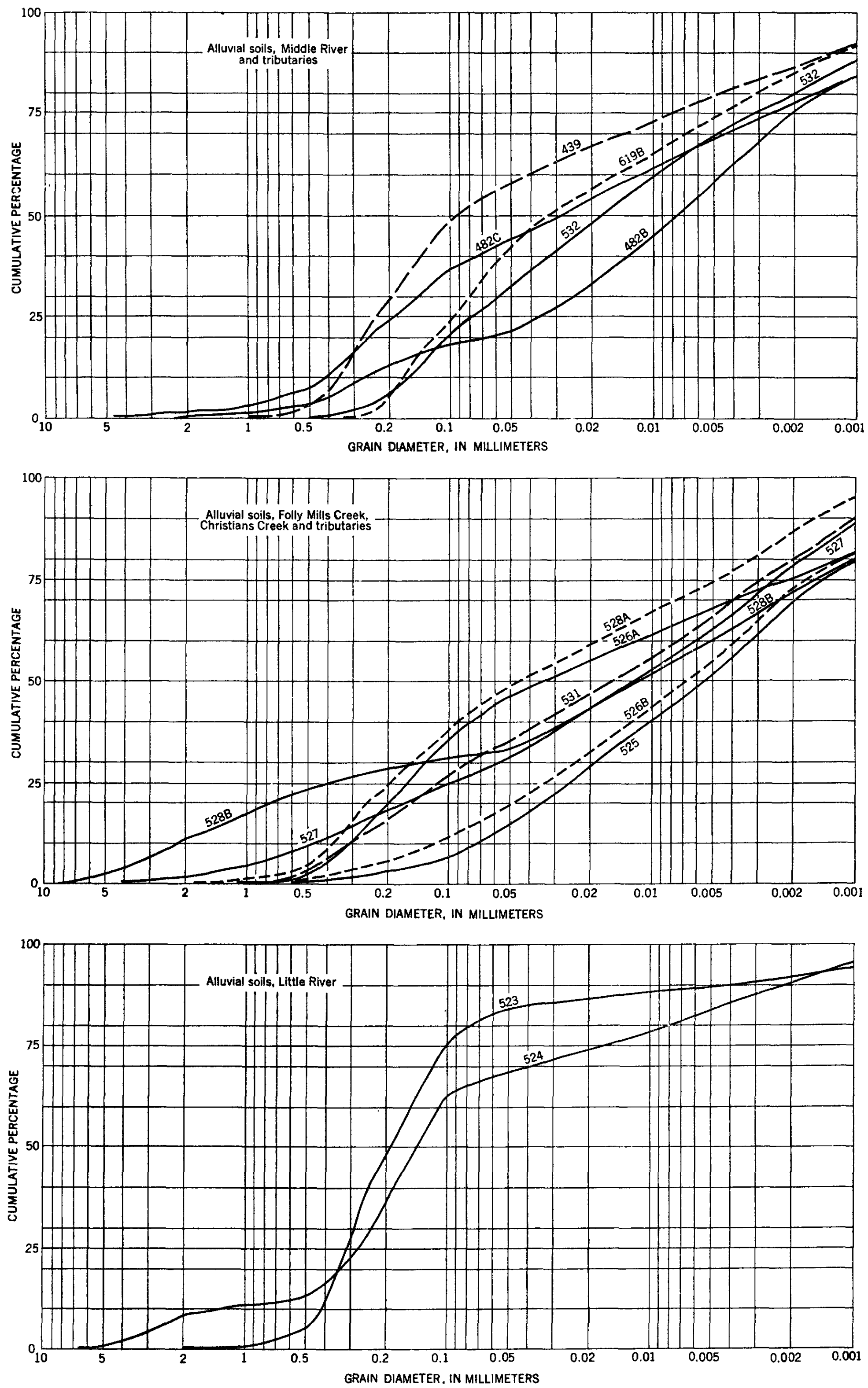

Figure 33.—Cumulative frequency curves showing grain-size distribution in samples of alluvial soil.

The heavy minerals in alluvial soils show no real differences from those obtained from the country rocks of the area. Opaque grains (magnetite, ilmenite, and indefinite iron oxides), zircon, tourmaline, and rutile are present in all the soil residues (fig. 35; table 3). There is an indication that rutile has been slightly concentrated, as it did not occur in all the rock residues. Pyrite, from Beekmantown dolomite, has been altered and has doubtless produced some of the indefinite iron oxides. Anatase together with rather scarce brookite can be considered as the only new minerals added to the alluvium. Both are due to the action of weathering agents on the ilmenite in the country rocks of the area. Epidote, present in one of the source rocks, has been concentrated and assumes a more important role in the alluvium than it did in the source rocks.

The zircon varieties found in the residues of alluvial soils are listed in table 4. Purple zircon (types 1 and 2) comes from sandstone of Devonian age and from the Martinsburg shale. Colorless, rounded, and polished zircon (type 3) comes from sandy beds of the Conococheague limestone. Samples 523 and 524 contain no zircon of type 3, but the remaining samples all contain type 3, although the quantity is less in alluvium of streams draining the Martinsburg shale. Type 4 is characteristic of the Martinsburg shale and of sandstone of Devonian age; therefore, its presence is expected in alluvium derived from these rocks. Type 7, zoned and colorless, occurs in most of the alluvial samples, indicating that it is a more common type than a cursory inspection of the country rocks suggests; also type 6 (metamict zircon) has a fairly wide distribution.

Alluvium that has contributions from the Conococheague limestone contains well-rounded brown and green tourmaline grains with overgrowths, the presence of which would seem to indicate that transportation has not been extensive. Angular tourmaline is brown, blue, gray, or particolored blue and brown; these grains are found in alluvium derived from the sandstone of the Devonian. Tourmaline, in small prismatic grains which may be broken but are not rounded, is scarce in alluvium derived from the Martinsburg shale.

TERRACE AND HIGH FLOOD-PLAIN SOILS

Samples of terrace and high flood-plain soils were collected at a number of localities near the Middle River (pl. 15) from situations which are now beyond the influence of seasonal floods, except in unusually wet seasons. Some, notably the localities of samples 686, 675A, and 677, would now never be flooded. Nearly all this alluvium shows some soil-profile development, but no well-developed profiles were seen, indicating that sufficient time has not yet elapsed for this to have taken place. The localities from which samples were obtained are listed in table 9.

SOIL-PROFILE CHARACTERISTICS

The samples of terrace and high flood-plain soils collected represent a number of different soil types (see table 7). The soil on the flood plain or terrace on opposite sides of the river at any one locality may not belong to the same soil type (see for example, locality 675 where the 25-foot terrace on the south side is Monongahela fine sandy loam, and the 10-foot and 12-foot terraces on the north side are Huntington silt loam and Elk silt loam, respectively). The soils on the lower terraces and flood plains have less well developed profiles than the soil on higher terraces and flood plains. This is probably due to time and the effect of additional deposition of alluvium on the lower (and younger) terraces and flood plains. The Staser fine sandy loam (sample 577B) shows no profile development. Erosion has removed the *A* horizon of the Waynesboro clay loam on the 75-foot terrace at locality 686. This terrace is probably the oldest of any seen in the area.

GRAIN-SIZE DISTRIBUTION

The principal difference in the grain-size distribution of these soils in comparison with those of the alluvial soils is that they are more sandy. The term "sandy" is used several times (table 7) in contrast to the term "silt" for the alluvial soils. Mechanical analyses of the terrace and high flood-plain soils (table 7) show a greater quantity of sand in the 0.25–0.10 mm and 0.10–0.05 mm grain sizes than do the alluvial soils. The coarser texture is probably due to material from the sandstone of Devonian age brought in by Buffalo and East Dry Branches, Jennings Branch, and Moffett Creek (samples 577, 678, 681, and 686). Other soils in this group from farther down the river are also sandy. Possibly clay has been removed, leaving an enrichment of sand. The distribution of sand, silt, and clay are shown in figure 31*C*. Cumulative frequency curves (fig. 34) show that the sorting is rather poor, but only 1 or 2 of these curves indicate an admixture of coarse material. The median grain diameters range from 0.14 mm to 0.001 mm and average 0.04 mm; this is larger than that of the residual soils (0.011 mm).

TABLE 9.—*Samples of terrace and high flood-plain soils collected along the Middle River, Augusta County, Va.*

[Sample numbers are field numbers]

Sample	Depth (inches)	Description	Stratigraphic unit	Locality
675A	0–5	25-foot terrace, composite sample from south side of river.	Martinsburg shale	East of Celanese Corp. of America plant at Verona; at end of County Road 781, north of river. 1.5 miles downstream from U. S. Highway 11. Waynesboro quadrangle.
B	0–5	12-foot terrace, composite sample from north side of river.	do	Do.
C	0–5	10-foot flood plain, composite sample from north side of river.	do	Do.
577A	0–5	7-foot flood plain, composite sample from south side of river.	Athens limestone	On Berry Farm, 0.3 mile below Frank's Mill and bridge on County Road 732.
B	0–5	5-foot flood plain, composite sample from north side of river.	do	Do.
599	0–5	4-foot flood plain, composite sample from west side of river.	Conococheague limestone and Elbrook dolomite.	Upstream from Verona, at sharp bend in river beside County Road 781. 2.1 miles north of Verona. Staunton quadrangle.
678	0–5	12-foot flood plain, composite sample from both sides of river.	Beekmantown dolomite	0.75 mile downstream from bridge on U. S. Highway 250, at north end of East Farm. Staunton quadrangle.
681	0–5	11-foot flood plain, composite sample from north side of river.	do	1.1 miles upstream from bridge on County Road 732, at Frank's Mill. At sharp bend in stream beside County Road 728. Staunton quadrangle.
686A	12	75-foot terrace, profile sample from west side of river.	Athens limestone	West bank, roadcut on County Road 732; 1.5 miles north of bridge at Frank's Mill, 0.5 mile south of Moffett Creek. Staunton quadrangle.
B	30	do	do	Do.
C	54	do	do	Do.
677A	15	45-foot terrace, profile sample from east side of river.	Martinsburg shale	East side, about 200 yards south of bridge on County Road 774; 1.5 miles east of Knightly. Waynesboro quadrangle.
B	25–29	do	do	Do.
C	55	do	do	Do.
688A	0–3	10–13-foot flood plain, composite sample from north side of river.	do	0.3 mile downstream from bridge on County Road 778 near Knightly. 0.5 mile south-southeast from Knightly. Waynesboro quadrangle.
B	0–5	12–17-foot flood plain, composite sample from south side of river.	do	Do.

MINERALOGY

The minerals identified in very fine sand (0.10–0.05 mm grain diameter) of these soils are given in table 3. These soils have a larger heavy-mineral content than the alluvial soils (fig. 32*C*). In only 2 samples (523 and 524) of alluvial soil from the Little River flood plain does the amount of heavy residue approach that found in the terrace and high flood-plain soils, which with 2 exceptions contain more than 1 percent and average 1.5 percent of the very fine sand. The highest figures are for soils from nearest the areas in which the sandstone of Devonian age occurs.

The minerals of the light fractions are similar to those in the alluvial soils, except that plagioclase feldspar was found in only three samples (681, 577A, and 577B), and microcline shows an increase. Quartz grains generally are subangular, but a few well-rounded grains are found in some samples, and, in addition, grains showing regrowth have been noticed in at least half a dozen samples. This suggests derivation from sandstone. Euhedral quartz was found in all but 5 samples, and chert in all but 1 sample. Many of the euhedral quartz grains show signs of wear and abrasion and are not "fresh" as in the residual soils. Chert ranges in amount from about 5 percent to about 50 percent of the light fraction.

The variation in percentages of the most abundant heavy minerals is similar to that in the alluvial soils. Fourteen heavy minerals were identified in terrace and high flood-plain soils (table 3). Principal differences are in the ratio of opaque grains to zircon. As with

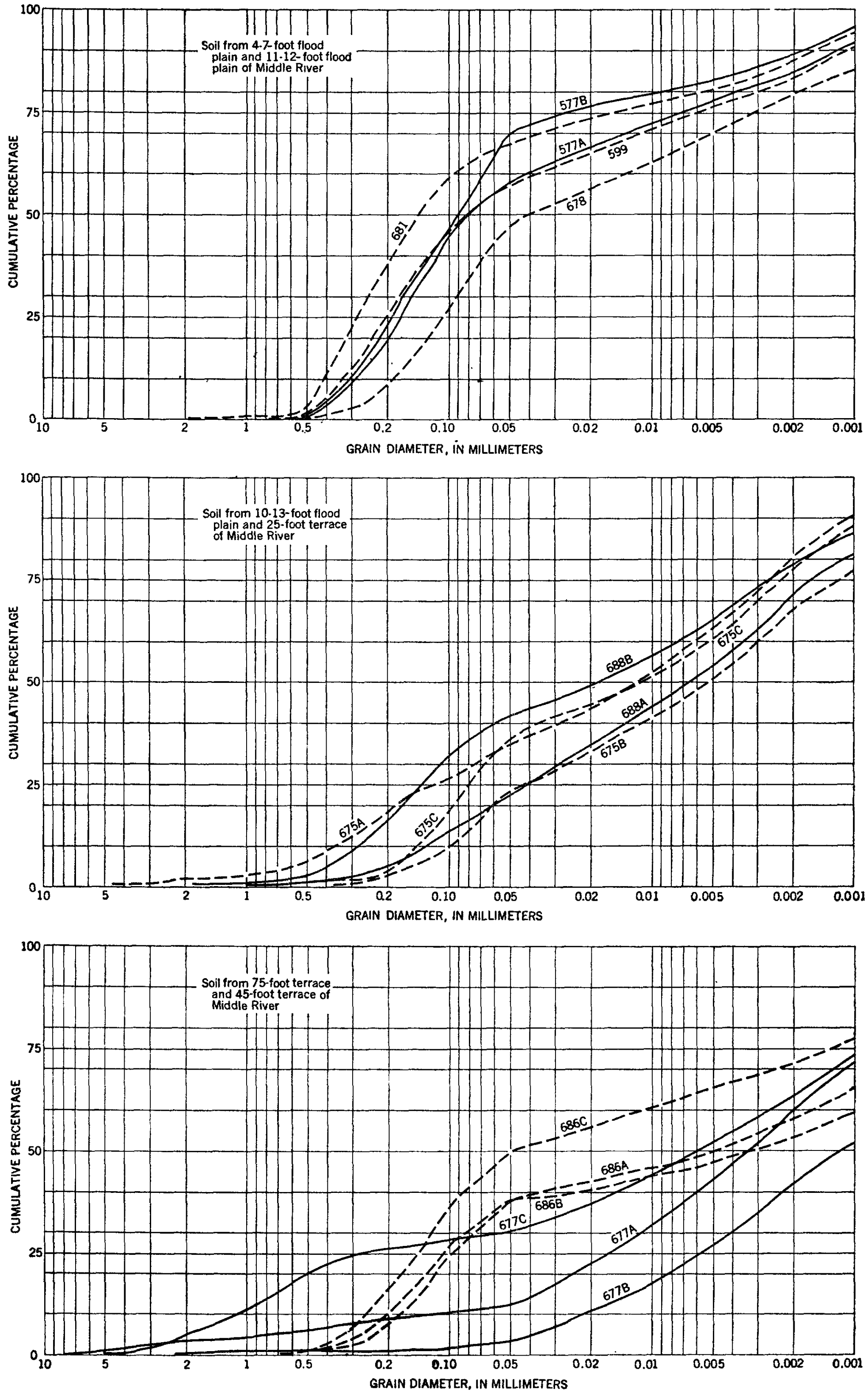

FIGURE 34.—Cumulative frequency curves showing grain-size distribution in samples of terrace and high flood-plain soils.

the alluvial soils, the varietal features of zircon and tourmaline suggest sources of the material. The distribution of zircon types is given in table 4. Although the distribution appears similar to that in the alluvial soils, and the types of zircon in each are the same, there are important differences. The first of these differences is that zircon type 3 is not the dominant type in any sample as it is in many of the alluvial soils, especially those known to have been derived from the Conococheague limestone. Purple zircon, types 1, 2 and 6, occurs in small quantities in nearly all the residues. Prismatic, unabraded zircon (type 4) is widely distributed in small amounts which indicates some common source for this type. Zoned colorless zircon (type 7) is common to all these residues. The main sources of the zircon in the terrace and high flood-plain soils therefore appear to be somewhat different from those of the alluvial soils, which are more closely related to the nearby bedrock.

Tourmaline in these residues is generally not rounded; it occurs as irregular fragments and broken prismatic grains which are gray, brown, greenish brown, blue, and particolored blue and brown. Such tourmaline is very similar to that found in the heavy fraction of the Chemung formation (table 3, sample 522) and may be common to all the Devonian rocks. A few rounded grains do occur and several grains with overgrowths were noticed, but these do not characterize these residues as they do the residues from the Conococheague limestone.

From the evidence of the zircon and tourmaline, together with the relative sandiness of these soils, it seems likely that they may have been produced largely by erosion and deposition of sandstone material from the headwaters of branches of the Middle River in the high country to the west of the valley (pls. 14 and 15).

RIVER-BED MATERIAL

Material from the bed of the Middle River and from the beds of several tributaries was collected at points where the streams flow across recognizable stratigraphic units or where a tributary entering a main stream was transporting material from another source. To provide contrasts in mineral content, additional samples were collected from the North River, the South River, and the South Fork of the Shenandoah River, all of which are outside the drainage basin of the Middle River. Localities of these samples are listed in table 10. All the sampled localities, with the exception of those outside the Middle River drainage basin, are shown on plates 14 and 15.

No mechanical analyses were made of the samples of river-bed material. The gravel and coarse sand was removed by sieving, and the sand passing through a 140-mesh sieve (U. S. Standard) was washed free of clay, cleaned with dilute HCl, and used for heavy-mineral separations. This sand is approximately the same size (0.10–0.05 mm grain diameter) as that used in the mineralogic examination of the soils.

The heavy fraction ranges from 0.4 to 2.25 percent for the Middle River system (table 3; fig. 32*D*), whereas the sand in the South Fork of the Shenandoah River contains 6 percent heavy minerals. The quantity of heavy fraction is, in general, larger than that in the youngest alluvial soil (table 3), but as the alluvium was collected in areas where the country rocks were exclusively limestone and shale, the heavy minerals are probably present in smaller amounts than they would be if sandstone had also contributed. This is suggested by the higher percentage of heavy minerals in samples 523 and 524 (table 3) from the Little River, which drains sandstone. The average heavy fraction for the Middle River system is 0.8 percent (percent by weight of the sand). This figure would not be so high if the heavy fraction (2.25 percent) of the Buffalo Branch sample (435, table 3) had not been included.

The heavy-mineral content of the sand in the streams increases from the headwaters toward the mouths of these streams as shown by the samples from Eidson and Bell Creeks, which are both on the same kinds of rocks. The amount of heavy minerals in samples from the mouths of tributaries appears to be maintained in the sand from the Middle River itself. The contribution of heavy minerals from Christians Creek is about equal to that of the headwaters of Eidson and Bell Creeks. The sampling of river-bed material from parts of the streams crossing limestone and shale show that these rocks are poor sources of heavy minerals even after the small original content of heavy minerals has been concentrated by stream action. (More information concerning the mineral content of these rocks can be obtained from a study of the river-bed material of streams eroding the rocks than from laboratory examination of a few samples of the rocks.)

The minerals identified in the sands are listed in table 3. Angular quartz and chert are present in most of the light fractions, and euhedral quartz is absent from samples 435 (Buffalo Branch), 505 (North River), and 646 (Bell Creek), each of which comes fairly directly from sandstone of the Devonian. Plagioclase feldspar, about albite in composition, is much more abundant than in alluvial, flood-plain, and terrace soils. Authigenic albite, together with some detrital albite, is contributed to the river-bed material by the Elbrook dolomite and part of the Beekmantown dolomite. Microcline is also present.

TABLE 10.—*Samples of river-bed material collected from the Middle River and its tributaries, Augusta County, Va.*

[Sample numbers are field numbers]

Sample	Stream	Stratigraphic unit	Locality
434	Middle River	Conococheague limestone and Elbrook dolomite.	About 100 feet upstream from bridge on County Road 720. 2.6 miles south of Churchville. Staunton quadrangle.
468	do	do	From sandy area on north side of gravel bar, on west bank of stream at ripple; at sharp bend in river beside County Road 781. 2.1 miles north of Verona. Staunton quadrangle.
469	do	do	Do.
504	do	Martinsburg shale	Above Christians Creek; on upstream side but close to bridge; beside County Road 780. 1.8 miles north-northeast of Laurel Hill. Waynesboro quadrangle.
649	Eidson Creek	Conococheague limestone and Elbrook dolomite.	Near headwater; about 100 yards downstream from culvert on County Road 694, near intersection with County Road 700. 0.2 mile northwest of Mt. Tabor Church. Staunton quadrangle.
646	Bell Creek	Athens limestone and Lenoir limestone.	About 100 yards upstream from St. Paul's Chapel at intersection of County Roads 612 and 720. Staunton quadrangle.
497	do	Lenoir limestone and Mosheim limestone.	100 feet upstream from U. S. Geological Survey stream gage at Frank's Mill. Gage is beside County Road 732. 0.5 mile south-southwest from Frank's Mill. Staunton quadrangle.
502	Moffett Creek	do	150 feet upstream from junction with Middle River; upstream and near bridge on County Road 732. 2.1 miles northeast of Frank's Mill. Staunton quadrangle.
452	Christians Creek	Martinsburg shale	About 200 feet upstream from bridge on County Road 612. 0.15 mile south of junction of Christians Creek on Middle River. Waynesboro quadrangle.
435	Buffalo Branch	Conococheague limestone and Elbrook dolomite.	About 35 feet upstream from ford on dirt road (not numbered) from Mountain View Church to junction of Buffalo Branch and Middle River. Staunton quadrangle.
505	North River	Martinsburg shale	1.25 miles upstream from junction with Middle River. At ripple near farmhouse at end of Rockingham County Road 669. Harrisonburg quadrangle.
506	South River	Conococheague limestone and Elbrook dolomite.	On west side of large island, east of sharp bend in County Road 668; 0.21 mile north of bridge on State Road 256. West of Grottoes. Harrisonburg quadrangle.
507	South Fork, Shenandoah River.	Beekmantown dolomite and Conococheague limestone.	About 100 feet downstream from bridge on river leading north from Lynnwood. 0.35 mile north of Lynnwood. Harrisonburg quadrangle, Rockingham County.

In the heavy fractions 15 minerals were identified, but only opaque grains (magnetite, ilmenite), zircon, tourmaline, and rutile occurred in all the samples. With one exception (anatase) all the other minerals listed occurred as single grains or several grains in a few of the heavy fractions.

As in the alluvial, flood plain, and terrace soils of the area, the varietal features of zircon and tourmaline in the heavy fractions of the river-bed material help to differentiate their sources. The zircon types (table 4) show considerable variation in their distribution. Types 1, 2, and 6 are absent in sand from Bell Creek, Eidson Creek, and Moffett Creek. These types are, however, present in the Middle River sand (434, 468, 469, 504). Type 3, characteristic of the sandy beds in the Conococheague limestone, occurs in the Middle River, Bell Creek, and Moffett Creek samples with great frequency; it is scarce in Buffalo Branch and Eidson Creeks, and absent elsewhere. The heavy residue from Christians Creek is characterized by abundant zircon in two distinct sizes—very small euhedral grains (some of which are acicular) and larger more worn grains (some of which are purple). Soil derived from the Martinsburg shale, on which Christians Creek flows (pl. 15), contains these same varieties of zircon. The zircon in the South River sand has very much the same appearance. The South Fork of the Shenandoah River (table 4) contains a much greater variety of zircon in its sand than is found in the Middle River and its tributaries; however, these will not be described here, beyond stating that they have come from a different source or sources.

Tourmaline is perhaps a better indicator of transportation of material than zircon in this drainage area. Angular grains, some of which are particolored blue and brown, come mainly from sandstone of the Devonian; well-rounded brown and greenish-brown grains come from the Conococheague limestone; and prismatic euhedral grains, many of them broken, come from the Martinsburg shale. In the Middle River sand, both angular and rounded grains are found; in Moffett Creek, angular grains are more abundant than rounded grains; in Christians Creek, tourmaline is scarce; in the North River, the Devonian types predominate; in the South River, tourmaline occurs as brown prismatic grains and angular fragments, with a few rounded grains; in the South Fork of the Shenandoah River, angular as well as rounded tourmaline is present, and there is an increase in the number of blue grains.

The facts presented here will need to be augmented by the study of additional samples, but the distribution of zircon and tourmaline is useful in tracing river-bed materials to their sources. The bed material of the Middle River thus shows the influence of the rocks through which the river flows.

DISCUSSION OF RESULTS

The drainage basin of the Middle River (pl. 15) is an area in which removal of material from sedimentary rocks in a closed environment can be studied; such an environment is one in which a major stream and its tributaries and associated small streams and creeks are eroding the rocks of that area alone without the addition of material from outside sources. The rock types are limestone, dolomite, shale, and sandstone. These sedimentary rocks contain a restricted suite of heavy minerals that, from their general appearance, have been subjected to wear and abrasion in other environments prior to being incorporated in the present geologic formations. Thus, opaque grains (magnetite, ilmenite, and indefinite iron oxides), zircon, tourmaline, and rutile are the principal, and practically only, heavy minerals present in the rocks that can be passed on to the residual soils, river-bed material, and alluvium for transportation in the present cycle of erosion.

Varying amounts of insoluble residue in the rocks (table 2; fig. 29) indicate the essential differences in the residual soils which will form from them. As the process of soil formation in this area is podzolic, the disintegrating material of the country rocks is washed through (leached) with water which, although at first it may be charged with calcium carbonate, soon becomes slightly acid, giving the mature soils a pH of about 4.5 (see table 7). Unstable minerals in the parent rocks are removed by this leaching. Thus, calcite and dolomite are removed from calcareous and dolomitic rocks such as the Conococheague limestone and Elbrook dolomite, Beekmantown dolomite, Mosheim limestone, and Lenoir limestone, and the calcareous cement, where present, is removed from the Martinsburg shale. The amount of soil formed depends on the siliceous nature of the impurities of these rocks. In limestone areas the presence of chert as beds and irregularly distributed nodules and finer grains assists soil formation because of its accumulation as a skeleton which prevents the removal of sand, silt, and clay by erosion.

In the development of a podzolic soil, siliceous material in the soil parent material is concentrated in the surface soil or *A* horizon and clay is concentrated at varying depths below it in the *B* horizon. In the erosion of a podzolic residual soil, sand is first removed, then clay. The samples of Frederick silt loam above limestone (table 7, samples 534A–E) show that the *A* horizon contains 17 percent clay, whereas the *B* horizon contains 40–60 percent clay. In the process of soil-profile development as discussed by Nikiforoff (1949), every *A* horizon of a soil has already passed through the stage of being first a *C* and then a *B* horizon. Therefore the size distribution of the material in the *A* horizon shows the grain sizes that are available for removal by erosion to form alluvium and, eventually, to be transported to form new sediments in a cycle of erosion.

The grain-size data of the samples as obtained from the mechanical analyses are plotted as cumulative percentage curves in figures 30, 33, and 34 from which the median and quartile grain diameters and the sorting coefficient [2] were calculated (table 11). The median grain diameter for all samples is small, with the exception of two alluvial soils from Little River (523 and 524) and a sandy residual soil from the Conococheague limestone (501H). The quartile range is considerable for most samples and the sorting is poor. Neither the alluvial soils nor the terrace and high flood-plain soils show better sorting than the residual soils. Field evidence suggests that the majority of the alluvial soils have not been moved far from their point of origin, a fact supported by their heavy-mineral content. In the terrace and high flood-plain soils there is a decrease in median diameter downstream in a distance of about 30 miles along the Middle River, but this decrease is not regular. The original grain size of the minerals in some of these samples may have been altered by soil-forming processes, as the older terrace soils show the development of weak soil horizons in the profiles which indicates stability for a very considerable period of time.

Soil-profile development causes the accumulation of resistant heavy minerals so that the minerals in many cubic feet of parent rock are concentrated in a few inches of surface soil. During the time that this concentration is taking place the heavy minerals are subjected to leaching in an acid environment which causes removal of the less resistant minerals by solution and (or) alteration to clay minerals. Other more resistant minerals develop etched and pitted surfaces. The partial solution of ilmenite and titaniferous magnetite by leaching causes the crystallization of anatase and brookite from the titanium released. The iron of the original minerals goes into solution, oxidizes, and becomes closely associated with the clay minerals, thereby causing yellow to brown coloration (Carroll and Hathaway, 1954, p. 178). Pyrite in the parent rock is con-

[2] Sorting coefficient, $So, = \sqrt{Q_3/Q_1}$ where Q_3 is the grain diameter at the 1st quartile and Q_1 the grain diameter at the 3d quartile.

TABLE 11.—*Derived data from mechanical analyses of residual, alluvial, and terrace and high flood-plain soils*

[Grain size in millimeters; n. d., not determined]

	Residual soils													
	Chemung formation	Brallier shale			Lenoir limestone					Beekmantown dolomite	Conococheague limestone		Elbrook dolomite	Martinsburg shale
	522	665A	665B	665C	534A	534B	534C	534D	534E	496G	501H	501I	479K	503M
Median	0.006	0.003	0.002	0.003	0.010	0.006	0.003	0.001	0.001	0.007	0.098	0.013	0.001	0.008
1st quartile	.030	.011	.060	.010	.058	.026	.014	.007	.004	.020	.220	.100	.004	.050
3d quartile	.002	.0008	.0004	.0009	.003	.002	n. d.	n. d.	n. d.	.002	.019	n. d.	n. d.	.018
Sorting coefficient	3.88	3.72	3.63	3.26	4.31	3.43	n. d.	n. d.	n. d.	2.84	3.98	n. d.	n. d.	5.27

	Alluvial soils													
	Little River		Folly Mills Creek						Christians Creek	Middle River				
	524	523	525	526A	526B	527	528A	528B	531	482B	482C	439	532	619B
Median	0.140	0.190	0.005	0.003	0.012	0.011	0.004	0.011	0.015	0.007	0.030	0.095	0.018	0.035
1st quartile	.280	.320	.025	.160	.034	.100	.200	.400	.120	.350	.190	.230	.078	.098
3d quartile	.017	.100	.001	.002	.002	.002	.005	.001	.003	.002	.002	.008	.003	.004
Sorting coefficient	4.06	1.79	4.24	8.95	4.35	6.34	6.34	15.80	6.34	4.08	8.55	5.36	5.02	4.67

	Terrace and high flood-plain soils															
	Middle River (Down stream ⟶)															
	678	681	577A	577B	686A	686B	686C	599	675A	675B	675C	688A	688B	677A	677B	677C
Median	0.040	0.140	0.078	0.090	0.005	0.003	0.050	0.080	0.012	0.005	0.011	0.006	0.019	0.003	0.001	0.006
1st quartile	.110	.280	.170	.190	.110	.098	.140	.200	.110	.040	.080	.040	.140	.170	.006	.250
3d quartile	.031	.015	.007	.025	n. d.	n. d.	.014	.006	.002	.001	.002	.001	.003	n. d.	n. d.	.001
Sorting coefficient	5.84	4.62	4.82	2.76	n. d.	n. d.	3.3	5.76	6.65	5.76	5.90	4.81	7.69	n. d.	n. d.	15.8

verted to iron oxides which are present as individual grains or as a coating on other mineral grains.

The older and more mature the residual soil formed above any rock, the greater is the concentration of heavy minerals. Favorable sites are flat plainlike areas. When these soils are removed by erosion, the yield of heavy minerals to the river-bed material and alluvial soil is greater than might be expected from an estimation of the quantity of minerals in the parent rocks. The Middle River area is not a particularly favorable one, topographically, for such a process to be studied, but that it does take place is shown by the heavy-mineral content of the residual and alluvial soils (table 3; fig. 32).

Certain variations in the amount and mineralogic composition of the heavy fractions are apparent in table 3, and in figures 32 and 35. The most conspicuous variation is in the percentage by weight of the heavy fraction, but of equal importance is the relation between the quantities of opaque and nonopaque minerals present. Only 3 samples of the residual soils contain more than 50 percent opaque grains; the remainder average 35 percent (fig. 35*A*). The soils with a high content of opaque grains are derived from the Elbrook dolomite, the Martinsburg shale, and the Chemung formation. The alluvial soils collected along Folly Mills Creek (pl. 15), which flows across the Conococheague limestone and the Elbrook dolomite, contain approximately the same quantity of heavy minerals as the residual soils and the same proportion of opaque to nonopaque grains, so that the distribution of mineral species within these soils supplements data obtained from the examination of the residual soils. The variation in total amount of heavy minerals in the terrace and high flood-plain soils of the Middle River (fig. 32*C*) was determined from 11 samples in a distance of about 30 miles. Plate 15 shows that the Middle River near the first flood-plain samples (678) is in the Beekmantown dolomite but that the stream has received material from Buffalo and East Dry Branches and from Jennings Branch, all of which drain sandstone and shale of Devonian age. The only other stream that drains the area of Devonian rocks is Moffett Creek, which joins the Middle River just below the locality of sample 686. The total quantity of heavy minerals in the samples (599, 675, 675B, and 675C) collected downstream is progressively lower. The influence of Christians Creek which drains the Martinsburg shale may be

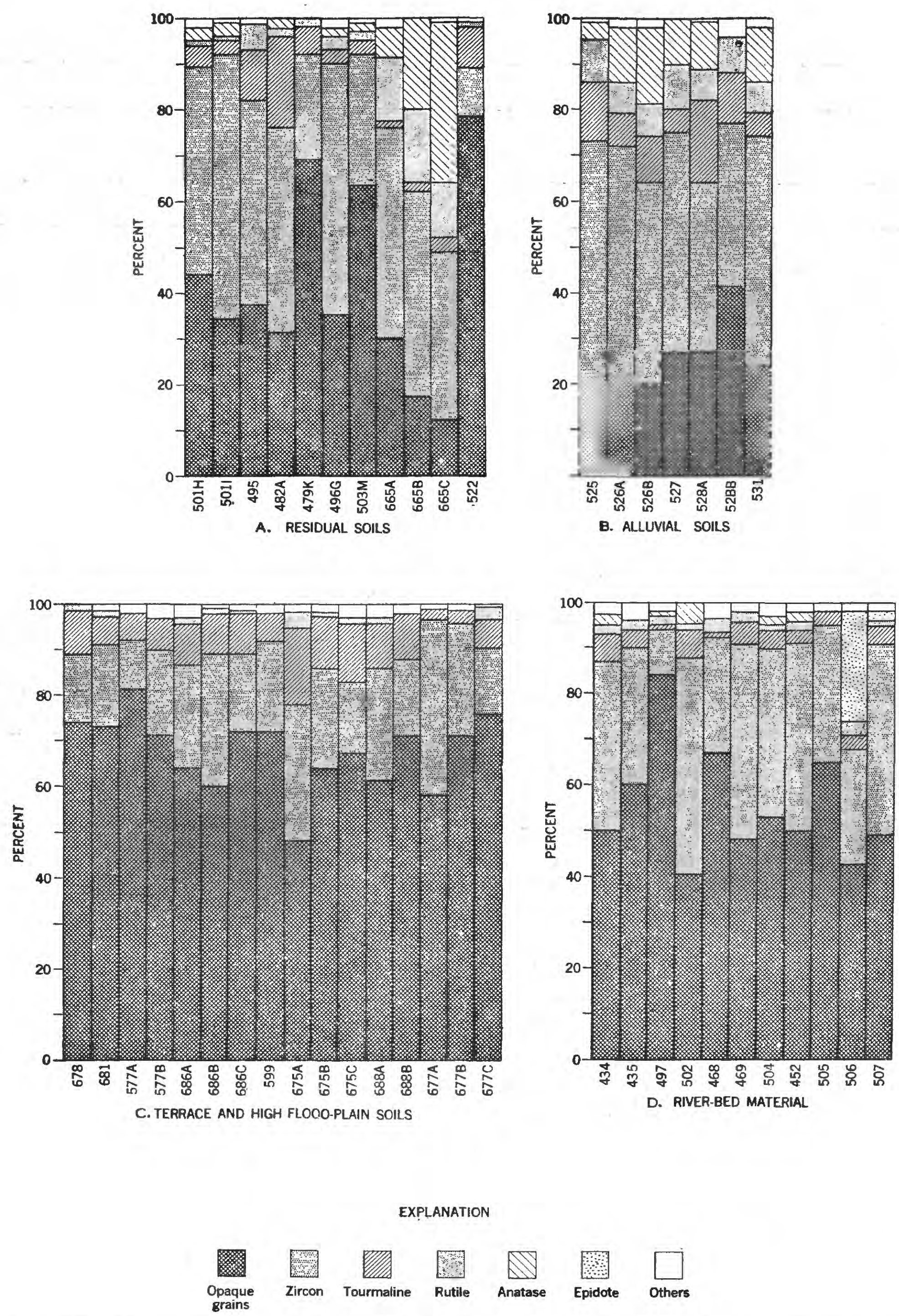

FIGURE 35.—Variation in mineralogic composition of heavy fractions of residual, alluvial, and terrace and high flood-plain soils and of river-bed material.

shown by the slight increase in heavy minerals in samples (688A, 688B, 677A, 677B, 677C) downstream from its junction with the Middle River.

Opaque grains are very prominent in terrace and high flood-plain soils and average more than 60 percent of the heavy fraction (fig. 35*C*). Zircon and tourmaline, with a small amount of rutile, are the only other minerals found in significant quantities (table 3). Comparison of these soils with the alluvial soils (fig. 35*B*) from along Folly Mills Creek shows that the quantity of opaque grains is much lower, zircon is more abundant, tourmaline is present in approximately the same amounts, and that rutile and anatase are very conspicuous in the latter soils. It seems, therefore, that the terraces and high flood plains have a heavy-mineral assemblage which differs from that of the alluvial soils. This probably signifies a change in the development of the river valley.

The residual soils (fig. 35*A*) forming on the sandy beds of the Conococheague dolomite (501H, 501I, 495, and 482A) and from the Beekmantown dolomite (496G) contain opaque grains, zircon, tourmaline, and rutile, with some anatase, in amounts comparable to those of the youngest alluvium (fig. 35*B*). Soils on the Elbrook dolomite (479K), the Martinsburg shale (503M), and the Chemung formation (522) contain large quantities of opaque grains, with, however, conspicuous amounts of zircon and tourmaline. The relationship of opaque to nonopaque minerals in the terrace and high flood-plain soils suggests that erosion of the sandstone of the Devonian, the Elbrook dolomite, and the Martinsburg shale could produce the heavy-mineral assemblages found.

The variation in heavy-mineral content and in percentage of opaque grains and of zircon in residual soils, terrace and high flood-plain soils, and river-bed material for samples collected at adjacent sampling sites are shown in table 12.

TABLE 12.—*Variation in heavy fraction and contents of opaque grains and zircon in residual and terrace and high flood-plain soils and in river-bed material in three groups of samples from adjacent sampling sites*

	Sample	Heavy fraction		
		Percentage in very fine sand of sample	Opaque grains (percent)	Zircon (percent)
Group 1:				
Residual soil	501H	0.3	44	45
Terrace and high flood-plain soil	599	.3	72	20
River-bed material	468	2.5	66	25
Group 2:				
Residual soil	503M	.7	63	29
River-bed material	452	.8	50	41
Group 3:				
Terrace and high flood-plain soil	686A	3.5	64	22
River-bed material	502	1.8	40	45

Another feature of interest is the presence of anatase in the alluvium of the Folly Mills Creek system (fig. 35*B*), as it is practically absent from the terrace and high flood-plain soils and from the river-bed material.

Euhedral quartz crystals are a common constituent of those parts of the river-bed material where the river cuts across the Beekmantown dolomite; the residual soil of an outcrop of Lenoir limestone contains a concentration of this form of quartz, and it is present in nearly all the terrace and high flood-plain soils where it indicates that the source of this material included the Beekmantown and probably other limestone.

Zircon is polyvarietal and has probably come from several sources; the rocks that constituted these sources are not at present known, although it has been suggested (Butts, 1940, p. 485) that they were situated southeast of the Appalachian trough. All the zircon may be Precambrian in the stratigraphic sequence discussed, but various rocks have probably contributed different types; for example, the purple variety may have its source in one granite or gneiss, and the colorless zircon in other rocks. Differences in amount of abrasion to which the grains have been subjected indicate that some grains have been reworked from older sedimentary rocks. The extremely well rounded and polished zircon in the Conococheague limestone (Nicholas, 1956, p. 10) has evidently survived a number of erosion and sedimentation cycles.

In an assemblage of fresh zircon released by the initial weathering of a granitic rock the individual grains may be influenced in different ways by further weathering, transportation, and redeposition, a suggestion which has been made previously (Carroll, 1953). Thus, what now seems to be a mineral assemblage containing only a single variety of zircon may have originally contained many varieties. In a sediment that contains reworked materials a decrease in the number of mineral species may be accompanied by a decrease in the number of varieties within each remaining species. Such a reduction is best exemplified by very resistant minerals like zircon and tourmaline. Both fresh and well-worn zircon are found in the Martinsburg shale; the fresh zircon, in some beds at least, is of volcanic origin, and was deposited with the ash that now forms bentonite beds. The worn zircon, of a different type, is detrital and comes from the erosion of a land surface.

Overgrowths on rounded grains of tourmaline in the sandy beds of the Conococheague limestone are a common feature but deserve special mention. It is suggested that these overgrowths are not penecontemporaneous in origin as described by Krynine (1945) but an epigenetic feature caused by leaching and alteration within the rock after it was consolidated. This origin is suggested by the presence of recrystallized quartz, albite, anatase, and rutile. Because overgrowths on tourmaline have not been found in many sandstone beds it is possible that the solutions present during the leaching and reconstitution taking place with the removal of calcium or magnesium carbonates, or both, from carbonate rocks may cause slight solution and recrystallization of tourmaline. It is not implied that the chemical conditions are such that new material is added to tourmaline from outside sources. Etched surfaces are frequently seen in garnet grains subjected to corrosive solutions, but tourmaline, a more resistant mineral, does not have such corroded surfaces. Overgrowths occur only at one end of a tourmaline grain, the zone of "roots" as noted by Alty (1933). Stow (1932) presents good illustrations of tourmaline with overgrowths in the Oriskany sandstone. The overgrowths on tourmaline in the Conococheague limestone, though not as striking as those in the Oriskany, are nevertheless clearly recognizable. A fairly widespread occurrence of such overgrowths is indicated by recent descriptions of a Triassic dolomite in Virginia (Young and Edmundson, 1954) and of an Upper Gondwana formation in India (Rao, 1952). Development of overgrowths may require a high pH; this is in contrast to the development of authigenic anatase in sandstone, which contains water with a low pH. The initial stages in the growth of anatase crystals may often be observed on ilmenite or titaniferous magnetite grains.

SUMMARY

The rocks drained by the Middle River and its tributaries contain distinctive suites of heavy minerals that have come from several sources in sedimentary rocks. Many of the heavy minerals, zircon and tourmaline in particular, have distinctive varietal features which indicate the source of the soils and river-bed material. The processes of soil development concentrate the resistant minerals of the rocks released by weathering, particularly from limestone because of its solubility. The rivers in the present cycle of erosion receive larger quantities of detrital minerals from limestone areas where soil formation is active than from those areas in which no soil formation is taking place. Some minerals not in the rocks are formed in the soils and weathering rocks. Anatase is one such mineral; it crystallizes from titanium released from the decomposition of ilmenite.

The older terrace and flood-plain soils have a mineralogy which differs from that of the alluvial and residual soils. The minerals indicate that sandstone of the Devonian was more actively eroded by the Middle River in the past than it is now. Soils on these older terraces and flood plains are developing soil profiles under the influence of present climatic conditions and therefore have pH values very nearly the same as those of the mature residual soils. In contrast the alluvial soils have higher pH values because of their frequent association with floodwaters containing lime. The grain-size distribution in all the soils indicates the amount of sand, silt, and clay available for stream transportation away from the area.

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