Heavy Minerals in the Saprolite of the Crystalline Rocks in the Shelby Quadrangle North Carolina

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Heavy Minerals in the Saprolite of the Crystalline Rocks in the Shelby Quadrangle North Carolina

By WILLIAM C. OVERSTREET, ROBERT G. YATES *and* WALLACE R. GRIFFITTS

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A study of the use of resistate heavy minerals in geologic fieldwork in areas underlain by thoroughly weathered rocks

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HEAVY MINERALS IN THE SAPROLITE OF THE CRYSTALLINE ROCKS IN THE SHELBY QUADRANGLE, NORTH CAROLINA

By William C. Overstreet, Robert G. Yates, and Wallace R. Griffitts

ABSTRACT

Saprolite in the Shelby quadrangle is derived mainly from biotite schist and from Toluca Quartz Monzonite, pegmatite, biotite gneiss, and sillimanite schist. Heavy-mineral concentrates panned from 1,241 samples of the saprolite and 5 samples of unweathered vein quartz commonly contain ilmenite, zircon, monazite, rutile, garnet, and sillimanite. They less commonly contain one or more of a dozen other minerals, including xenotime, magnetite, staurolite, tourmaline, spinel, pyrite, kyanite, corundum, dumortierite, epidote, apatite, and titanite. In the Shelby area the identification of the source rock of a saprolite from the heavy-mineral concentrate is uncertain at best, and with two minor exceptions, no single mineralogic characteristic of the concentrate is diagnostic. Uncommon intergrowths of green xenotime and brown zircon are diagnostic of pegmatite. Abundant fibrous aggregates of sillimanite with inclusions of ilmenite and rutile are diagnostic of sillimanite schist For the identification of the source rock by the use of concentrates from saprolite the best results can be expected from combinations of data including the amount and grain size of the concentrate; species of most common and least common minerals; the shape, size, color, and thoria content of the monazite; the shape, size, and color of zircon; the color of rutile; and the index of refraction and specific gravity of garnet.

Several hundred concentrates from residual soil in the area resemble concentrates from saprolite, except that the concentrates from soil are larger and consist of coarser grained and cleaner heavy minerals than concentrates from saprolite. The concentrates from residual soils contain distinctive globular, glassy or metallic grains that may be fused minerals from the soil or tektites.

INTRODUCTION

Detrital monazite was mined from small streams in the Shelby quadrangle in North Carolina (fig. 1) from 1887 to 1917 (Genth, 1891, p. 77–78; Pratt, 1916, p. 50–62; Keith and Sterrett, 1931, p. 10; Mertie, 1953, p. 7–12; Overstreet, Theobald, and Whitlow, 1959, p. 709–714). The Shelby area was the center of the monazite industry in the Carolinas, and mining continued intermittently for many years along parts of Hickory Creek, Knob Creek, Buffalo Creek, Brushy Creek, Beaverdam Creek, Sandy Run, Hinton Creek, Duncans Creek,

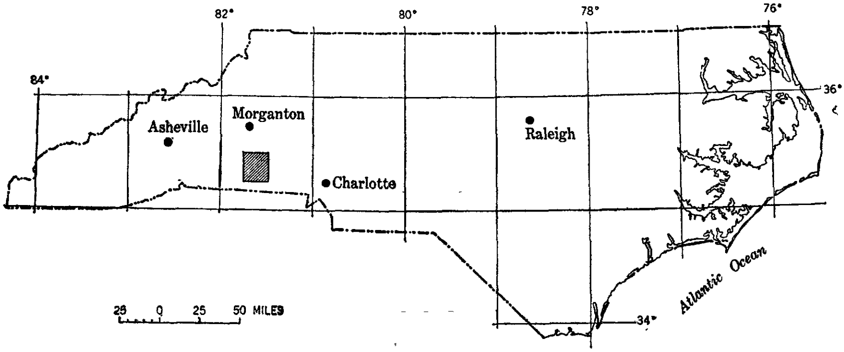

FIGURE 1.—Index map of North Carolina showing location of the Shelby quadrangle.

Crooked Run Creek, and several small tributaries to the First Broad River (Griffith and Overstreet, 1953a, 1953b, 1953c; Hansen and Cuppels, 1954).

The original source of the detrital monazite has long been known to be the weathered gneisses and schists, particularly granitic gneisses and pegmatite-rich schists (Nitze, 1895, p. 181; Mertie, 1953, p. 15–29). However, details of the areal variation in the abundance of monazite in the crystalline rocks were unknown.

The crystalline rocks in the area are weathered to saprolite, which extends from the surface of the ground to depths as great as 185 feet. The saprolite is 25 to 40 feet deep at most places. Weathering tends to bring about a convergence in the appearance of the various kinds of rock; the most thoroughly weathered rocks, despite differences in origin and original composition, closely resemble one another. Most of the exposures on which geologic mapping in the region is based are saprolite. A notable property of saprolite is the ease with which it can be dug and panned to obtain a concentrate of the resistate heavy minerals. If the mineral composition or other feature of the concentrate is measurably different for each kind of rock, then the possibility exists that otherwise indeterminate saporlite could be identified by its characteristic suite of heavy minerals. The ease with which saprolite can be panned to recover its heavy accessory minerals is a property that also lends itself to the study of the areal variation of the abundance of monazite in saprolite, and by inference, the abundance of monazite in the unweathered crystalline rocks.

This study of the distribution and abundance of monazite and other heavy minerals in saprolite was undertaken at the suggestion of J. B. Mertie, Jr., U.S. Geological Survey. At the time the saprolite was sampled, a study of the heavy minerals in the residual soil over the saprolite was also made. The aim of the investigation was (1) to show the abundance of heavy minerals in saprolite of the different kinds of crystalline rocks and to show the areal distribution of monazite in the saprolite of metamorphic rocks, (2) to determine whether the concentrates have diagnostic properties, and whether there are diagnostic features related to the heavy minerals in residual soil, and (3) to describe the minerals and determine whether they possess properties useful in the identification of the parent rock of the saprolite.

Field and laboratory work was directed by R. G. Yates and was done in 1948–51. G. S. Koch, Jr., and L. A. Herrmann assisted in the panning in 1948 and G. A. Dover and Roy Morris assisted in panning in 1950. Percentages of the minerals in the saprolite were computed in 1951 by J. W. Whitlow and P. K. Theobald, Jr. Map and text were prepared in 1958 by W. C. Overstreet.

HEAVY MINERALS IN SAPROLITE OF CRYSTALLINE ROCKS

The crystalline rocks in the Shelby quadrangle are biotite schist, sillimanite schist, biotite gneiss, and Toluca Quartz Monzonite and associated pegmatite dikes. They underlie respectively about 62 percent, 30 percent, 1 percent, and 7 percent of the area of the quadrangle. Small bodies of metamorphosed gabbro and pyroxenite occupy an insignificant part of the quadrangle. The schists and gneisses are sedimentary and pyroclastic rocks that were folded and regionally metamorphosed to the sillimanite-almandine subfacies in Ordovician time and were again deformed in late Paleozoic time. Prior to the earlier deformation the sedimentary and pyroclastic rocks were intruded by small bodies of gabbro and pyroxenite. During Ordovician deformation the Toluca Quartz Monzonite and related dikes and sills of pegmatite were emplaced. In the late Paleozoic deformation, muscovite-bearing pegmatite dikes were intruded.

ABUNDANCE

The identity and abundance of the heavy minerals in the saprolite of the crystalline rocks were determined by a microscopic study of concentrates obtained by panning[1] 1,241 samples of saprolite. Five crushed samples of quartz from veins were also examined. Sample localities are shown on the map (pl. 1); the results of the mineralogical examinations are listed in table 1.

[1] Panning as a geologic field technique, and the precautions needed to be exercised in its use, have been discussed by O. A. Derby (1891, p. 198–206), J. B. Scrivenor (1911, p. 3), Frank Smithson (1930, p. 134–136), C. J. Ewing (1931, p. 136–140), J. B. Mertie, Jr. (1954, p. 639–651), N. R. Junner (1955, p. 345–346), and P. K. Theobald, Jr. (1957, p. 9–23).

TABLE 1.—*Estimated abundance of heavy minerals in saprolite of the crystalline rocks in the Shelby quadrangle, North Carolina*

[Trace shows the number of concentrates out of the total from a given rock in which a particular mineral was represented by one or more grains but in amounts less than 1 percent of the concentrate]

	Toluca Quartz Monzonite (96 concentrates)	Microcline-oligoclase-quartz pegmatite (329 concentrates)	Biotite gneiss (59 concentrates)	Biotite schist (198 concentrates)	Biotite schist and pegmatite (303 concentrates)	Sillimanite schist (150 concentrates)	Sillimanite schist and pegmatite (106 concentrates)	Vein quartz (unweathered) (5 concentrates)
Total concentrate:[1]								
Minimum....volume percent..	0.0003	0.00004	0.00006	0.00004	0.00004	0.0001	0.002	0.00007
Maximum....do....	.09	.3	.2	.08	.07	1.4	.1	.02
Average....do....	.007	.008	.01	.004	.004	.02	.01	.004
Monazite:								
Absent....number of concentrates..	1	18	6	49	46	12	4	3
Trace....do....	2	22	6	42	31	28	13	1
Miminum....volume percent..	.00001	.00001	.00001	.00001	.00001	.00004	.00001	-----
Maximum....do....	.02	.04	.03	.004	.02	.03	.006	-----
Average....do....	.002	.003	.003	.0008	.002	.001	.001	.006
Xenotime:								
Absent....number of concentrates..	93	273	58	186	285	146	98	3
Trace....do....	2	29	-----	9	7	2	5	1
Miminum....volume percent..	-----	.00002	-----	.00006	.00001	.00003	.00001	-----
Maximum....do....	-----	.02	-----	.0001	.004	.0003	.00008	-----
Average....do....	.0006	.002	.0001	.00008	.0007	.0002	.00003	.0007
Zircon:								
Absent....number of concentrates..	15	25	4	40	35	84	38	-----
Trace....do....	15	38	6	46	39	41	25	2
Minimum....volume percent..	.00001	.00001	.00008	.00001	.00001	.00004	.00001	.00002
Maximum....do....	.007	.03	.006	.006	.01	.001	.004	.001
Average....do....	.0004	.001	.001	.0005	.0009	.0003	.0005	.0009
Magnetite:								
Absent....number of concentrates..	82	306	54	183	288	130	92	5
Trace....do....	7	15	2	9	8	16	13	-----
Minimum....volume percent..	.00005	.00004	.00004	.00001	.00001	.00008	-----	-----
Maximum....do....	.0006	.002	.003	.008	.0004	.002	-----	-----
Average....do....	.0003	.0003	.001	.002	.0001	.001	.0001	-----
Ilmenite:								
Absent....number of concentrates..	2	17	8	9	9	3	1	-----
Trace....do....	5	28	5	18	33	2	3	-----
Minimum....volume percent..	.00003	.00001	.00001	.00001	.00001	.00004	.00002	.00005
Maximum....do....	.04	.03	.03	.08	.04	.03	.05	.002
Average....do....	.003	.001	.003	.002	.001	.005	.005	.0005

Rutile:								
Absent......number of concentrates	32	118	21	86	134	28	25	1
Trace......do	25	87	19	60	102	55	33	3
Minimum......volume percent	.00001	.00001	.00002	.00001	.00001	.00001	.00002	
Maximum......do	.005	.01	.003	.004	.004	.004	.003	
Average......do	.0006	.001	.0005	.0004	.0003	.0002	.0002	.0004
Staurolite:								
Absent......number of concentrates	96	329	59	198	303	143	103	5
Trace......do						2	3	
Minimum......volume percent						.00002		
Maximum......do						.001		
Average......do						.0006		
Sillimanite:								
Absent......number of concentrates	32	127	24	75	143	1		3
Trace......do	16	62	13	58	77	1	11	2
Minimum......volume percent	.00002	.00002	.00004	.00001	.00001	.0001	.00002	
Maximum......do	.01	.01	.01	.01	.06	.06	.06	
Average......do	.001	.002	.002	.001	.002	.006	.006	
Tourmaline:								
Absent......number of concentrates	82	213	42	128	214	85	54	
Trace......do	10	84	13	54	65	45	31	3
Minimum......volume percent	.00004	.00001	.0001	.00001	.00001	.00004	.00001	.00002
Maximum......do	.0002	.1	.08	.03	.004	.005	.09	.00005
Average......do	.0001	.004	.02	.002	.0004	.002	.005	.00003
Spinel:								
Absent......number of concentrates	94	308	59	192	299	148	101	4
Trace......do	2	21		6	4	1	5	1
Minimum......volume percent								
Maximum......do								
Average......do						.0001		
Pyrite:								
Absent......number of concentrates	95	282	59	191	293	148	104	4
Trace......do	1	28		7	3	2	2	1
Minimum......volume percent		.00002			.00001			
Maximum......do		.004			.0002			
Average......do		.0004			.0001			

[1] Complete concentrate including the following minerals omitted from the rest of the table because of extreme rarity or poor recovery: corundum, dumortierite, epidote, hematite, biotite, muscovite, amphibole, pyroxene, and garnet. The total concentrate is not a sum of the columns.

The samples from which the concentrates were panned were of about equal volume, but they ranged in weight from 15 to 25 pounds. The large variation in the weight of the saprolite samples reflects the position of the sample in the weathering profile. Saprolite is dense and heavy in the upper part of the profile where clay has accumulated, but saprolite from lower parts of the weathering profile in the same kind of rock is porous and light. It was impractical to take every sample of each type of rock from the same part of the weathering profile in order to obtain equal weights for equal volumes of saprolite.

The volume of the concentrate was compared to the volume of the sample, and the percentages of the minerals in the concentrate are listed in table 1 as volume percentages. Weight percentages can be approximated by dividing the specific gravity of a mineral by 2.7 (the average specific gravity of the rocks) and multiplying the volume percentage by the quotient.

The easily weathered heavy minerals like apatite, garnet, and allanite do not survive in saprolite, and no record of their possible presence in the crystalline rocks can be obtained by panning the weathered rocks. A study of thin sections indicates that allanite is absent but apatite is present in the rocks. Garnet is megascopically visible in most of the rocks.

The recovery of some heavy minerals in panning is better than the recovery of others (Theobald, 1957, p. 9–23). Approximate recoveries of the minerals listed in table 1 were:

Minerals	*Percent recovered*
Monazite, xenotime, pyrite	85
Zircon, rutile	75
Magnetite, ilmenite	65
Staurolite, spinel	50
Sillimanite	45
Tourmaline	25

PROPERTIES OF CONCENTRATES DIAGNOSTIC OF THE PARENT ROCK

No feature was found that is common to all concentrates from the saprolite of one group of rocks. The wide range in size and composition of the concentrates from the saprolite of one group of rocks leads to considerable overlap in the properties of the concentrates from the saprolite of different groups of rocks. However, some differences in the heavy-mineral content exist among the groups of concentrates from different rock types. Although not uniquely diagnostic, the features tend to indicate the probable group of rocks from which the saprolite formed.

Saprolite from Toluca Quartz Monzonite tends to give concentrates intermediate in volume between the copious concentrates common from saprolite of sillimanite schist and the meager concentrates from the saprolite of biotite schist. Concentrates from saprolite of Toluca Quartz Monzonite are more likely to contain monazite and less likely to have tourmaline than concentrates from the saprolite of the other rocks. These concentrates rarely have sillimanite and commonly have rutile.

Concentrates from the saprolite of microcline-oligoclase-quartz pegmatite, which is genetically related to the Toluca Quartz Monzonite, tend to be of medium volume. They are unusually rich in zircon and rutile.

The concentrates from the saprolite of biotite gneiss are not unusual in volume, but they tend to be rich in both monazite and zircon. They rarely have tourmaline, ilmenite or sillimanite, but where tourmaline is present it tends to be abundant. The saprolite of biotite schist tends to give the smallest volumes of concentrate and the least percentage of monazite and sillimanite. The saprolite of schist interlayered with the pegmatite gives concentrates small in volume and lean in monazite, ilmenite, rutile, and tourmaline.

Sillimanite schist yields saprolite which gives large-volume concentrates rich in rutile, sillimanite, ilmenite, and tourmaline. These concentrates contain less zircon than the others. Saprolite of sillimanite schist interlayered with pegmatite yields concentrates that are second in volume to those from sillimanite schist without interlayered pegmatite. These concentrates tend to be unusually rich in ilmenite, tourmaline, and sillimanite. They are lean in monazite, zircon and rutile.

No study was made of the grain sizes of the minerals listed in table 1, but in 1952–53 J. W. Whitlow panned and made grain-size analyses of 50 concentrates from saprolite derived from the common rocks in the drainage basin of Knob Creek, which rises in the southern part of the Casar quadrangle (Overstreet and others, 1963) and empties into the First Broad River in the northeastern part of the Shelby quadrangle. The same kinds of rocks underlie that area as are found in the Shelby quadrangle. Results of Whitlow's study were furnished (1954, written communication) and are given in table 2. The grain-size differences are the most obvious of the subtle physical differences among the concentrates from the various saprolites.

TABLE 2.—*Sizes of the common heavy minerals in concentrates panned from saprolite of the major rock types exposed in the drainage basin of Knob Creek, Cleveland County, N.C.*

[Concentrates collected by J. W. Whitlow in 1952–53. Mineralogical analyses by Jerome Stone, M. N. Girhard, E. J. Young, H. B. Groom, Jr., C. J. Spengler, and R. P. Marquiss]

Concentrate Laboratory No.	Percent of concentrate by mesh (retained on sieves with 24, 45, 100, and 170 mesh, and passing through 170 mesh)																										
	Monazite					Zircon				Ilmenite					Sillimanite			Garnet					Others				
	24	45	100	170	−170	45	100	170	−170	24	45	100	170	−170	100	170	−170	24	45	100	170	−170	24	45	100	170	−170
Toluca Quartz Monzonite																											
90334	----	(1)	----	9	9	----	5	----	(1)	----	9	14	(1)	(1)	----	----	----	----	44	----	(1)	----	[2] 9	(3)	(3)	(3)	----
98942	----	6	15	15	----	----	----	----	----	----	31	17	16	----	----	----	----	----	----	----	----	----	----	----	----	----	----
109592	----	3	3	13	13	----	----	----	(1)	----	2	2	2	----	----	----	----	----	34	23	5	----	----	----	----	----	----
109614	----	----	7	63	18	----	----	3	3	----	----	2	----	----	----	----	2	----	----	----	2	----	----	----	(4)	----	----
109615	----	28	15	35	----	(1)	3	2	----	----	2	2	2	----	(1)	2	----	----	(1)	8	----	----	----	----	----	----	----
114332	----	----	----	13	51	----	----	2	27	----	----	----	7	----	----	----	----	----	----	----	----	----	----	----	----	----	----
114337	----	----	2	40	18	----	----	----	4	----	----	----	(1)	(1)	----	----	----	----	----	17	18	(1)	----	----	----	----	----
114362	----	----	----	75	14	----	----	2	3	----	----	----	3	----	----	----	----	----	----	----	2	----	----	----	----	(5)	(5)
114366	----	----	----	61	21	----	----	1	8	----	----	----	8	----	----	1	----	----	----	----	----	----	----	----	----	----	----
114369	----	----	----	53	11	----	----	1	1	----	----	----	31	1	----	(1)	----	----	----	----	2	----	----	----	----	----	----
114372	----	----	----	55	24	----	----	2	5	----	----	----	9	4	----	(1)	----	----	----	----	----	----	----	----	----	(5)	----
Average of 11	----	4	4	39	16	(1)	1	1	5	----	4	3	7	(1)	(1)	(1)	(1)	----	7	4	3	(1)	[2] 1	(3)	(3 4)	(3 5)	(5)
Microcline-oligoclase-quartz pegmatite																											
88479	----	6	40	30	----	----	----	9	----	----	1	1	8	----	----	----	----	----	----	----	----	----	(3)	(3)	[3 6] 4	(3)	----
88501	3	14	3	2	----	----	----	----	----	3	14	27	15	----	7	2	----	2	2	----	----	----	[2] 3	(3)	[3 7] 2	(3)	----
90351	----	2	17	5	1	1	36	30	6	----	(1)	----	----	----	----	----	----	----	(1)	1	----	----	(3)	(3)	(3)	(3)	(3)
90364	3	40	31	8	----	----	----	3	2	----	2	5	3	----	(1)	----	----	----	----	2	----	----	----	----	(3)	----	----
90367	----	7	26	33	7	----	3	2	----	----	2	----	(1)	----	----	----	----	----	(1)	3	----	----	----	(3)	[6] 2	[6] 7	[6] 7
90395	(1)	17	24	3	----	----	----	2	----	28	7	14	2	----	----	----	----	----	2	----	----	----	(3)	(3)	(3)	(3 5)	(3)
98882	----	(1)	----	----	----	26	37	17	(1)	----	1	7	----	----	----	----	----	----	----	----	----	----	(3)	(3)	[3 6] 6	[3 6] 4	(3 5)
98883	7	15	3	(1)	----	22	20	22	(1)	----	1	5	1	----	----	----	----	----	(1)	----	----	----	----	[6] 1 (3) (5)	(3 5)	[3 6] 3	----
98935	----	33	37	5	----	----	5	5	----	----	5	5	----	----	----	----	----	----	5	(1)	----	----	----	----	----	----	----
114336	----	17	27	43	----	----	----	3	----	----	2	2	3	----	----	3	----	----	(1)	----	----	----	----	----	----	----	----
114361	----	----	52	23	----	----	2	7	----	----	----	4	7	----	----	5	----	----	----	----	(1)	----	----	----	----	----	----
Average of 11	1	14	23	14	1	5	9	9	1	3	3	6	3	----	1	1	----	(1)	1	1	(1)	----	(2)	(3 5)	(3 8), [6] 1	(3), [6] 1	(3), [6] 1

Biotite gneiss																											
88503			23	40			4	20				9	3												(3)	(3)	
88529			46	38				2	11			(1)								2					(3)	(3)	
114371			12	68	7		(1)	2	7			1	1	(1)		(1)				(1)	1				(4)		
114374			4	10	6		2	36	22			2	12	2		2				2							
114380			(1)	9				9	33			4	9		(1)					9	26						
114382			11	25	6		3	29	25			(1)								(1)							
Average of 6			16	31	3		1	17	17			3	4	(1)	(1)	(1)				2	5				(3 4)	(3)	
Biotite schist																											
90298		3	5	7	4					1	3	1			27	45	1	1	1					(3)	(3)	(3)	
110848			1	1	(1)		(1)	18	4			6	53	11						1	3	1					
88535			19	55					10			5	10												(3)	(3)	
90359				(1)								99	(1)												(3)	(3)	
90360			18							37	13	18						13							(3)	(3)	
114334			23	47	15		(1)		(1)			2	5	1		(1)				1	1					[6]4, (5)	
114339			5	15				15				15	50							(1)							
114341			18	27				(1)				10	(1)			(1)					(1)				[9]34	[9]10	
114352			(1)	58			6	6				6	23		(1)	(1)				(1)					(4 5)		
114381			1	3	1							16	74	3	(1)	1					(1)			(5)			
Average of 10		(1)	9	22	2		1	4	1	4	2	18	21	1	3	5	(1)	1	(1)	(1)	(1)	(1)		(3 5)	(3 4 5), [9]4	(3 5 8), [9]1	
Biotite schist and pegmatite																											
90333 [10]		(1)	1						(1)		1	81	12	4		(1)		(1)					(3)	(3)	(3)	(3)	(3)
98868		6	21	18	3				1		2	2			17	28		1						(3)	(3)	(3)	
Average of 2 [10]		3	11	9	2				(1)		1	42	6	2	9	14		(1)					(3)	(3)	(3)	(3)	(3)
Sillimanite schist																											
88480			29	70																			(3)	(3)	(3)	(3)	
114347				1	1				(1)			13	50	3	1	30	(1)										(5)
114348				25								25	50														
114364			2	8								21	26		12	25				(1)					[6]1	[6]5	
114367			41	13	17			1	5			7	6	3	1	4				1	(1)					(3)	
Average of 5			15	24	4			(1)	1			13	25	1	3	12	(1)			(1)	(1)		(3)	(3)	(3 5)	(3 5), [6]1	(5)

See footnotes at end of table.

TABLE 2.—*Sizes of the common heavy minerals in concentrates panned from saprolite of the major rock types exposed in the drainage basin of Knob Creek, Cleveland County, N.C.*—Continued

[Concentrates collected by J. W. Whitlow in 1952–53. Mineralogical analyses by Jerome Stone, M. N. Girhard, E. J. Young, H. B. Groom, Jr., C. J. Spengler, and R. P. Marquiss]

Concentrate Laboratory No.	Percent of concentrate by mesh (retained on sieves with 24, 45, 100, and 170 mesh, and passing through 170 mesh)																										
	Monazite					Zircon				Ilmenite					Sillimanite			Garnet					Others				
	24	45	100	170	−170	45	100	170	−170	24	45	100	170	−170	100	170	−170	24	45	100	170	−170	24	45	100	170	−170
Sillimanite schist and pegmatite																											
98874	----	1	3	16	3	----	----	----	----	1	3	16	40	(1)	16	----	----	----	(1)	----	----	----	(3)	(3)	(3)	(3)	----
114350	----	----	----	----	----	----	----	18	----	----	----	16	35	----	17	----	----	----	----	----	14	----	----	----	----	----	----
114354	----	27	19	6	----	----	2	4	----	----	2	6	26	----	2	4	----	----	----	----	----	----	----	----	(5)	[6] 2	----
114356	----	----	3	7	----	----	----	----	----	----	----	17	34	----	4	34	----	----	----	----	----	----	----	----	(5)	(8)	----
114359	----	----	26	24	----	----	----	----	----	----	----	7	19	----	2	18	----	----	----	2	2	----	----	----	----	----	----
Average of 5	----	6	10	11	1	----	(1)	4	----	(1)	1	12	30	(1)	8	11	----	----	(1)	(1)	3	----	(3)	(3)	(3 5)	(3 5 8)	----

1 Trace (present as less than 1 percent of the concentrate).
2 Magnetite.
3 Trace of magnetite.
4 Trace of tourmaline.
5 Trace of rutile.
6 Rutile.
7 Staurolite.
8 Trace of staurolite.
9 Tourmaline.
10 Trace of zircon in 24 mesh.

Size-distribution data on the minerals in the panned concentrates is distorted by partial loss of fine-grained and coarse-grained particles during panning. The minerals in the saprolite have size distribution quite different from that of the minerals in unweathered rocks, because during weathering some minerals are reduced in abundance and size. Garnet is greatly reduced in amount. Grains of garnet and sillimanite in concentrates panned from saprolite are smaller than grains of these minerals in the unweathered rocks, because freed crystals of garnet tend to fall apart along limonite-coated fractures, and freed prisms of sillimanite cleave into short, stubby fragments. Some grains of magnetite are changed by weathering to residual shells surrounding porous limonitic cores. These porous grains break easily, thereby increase the apparent frequency of small sizes of the magnetite. The specific gravity of the weathered grains is less than that of fresh magnetite, and the panning characteristics are different. Altered magnetite washes out of the concentrate during panning.

Concentrates from saprolite of the Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite have the coarsest grained heavy minerals, and they tend to have the greatest range in size of grains of monazite, zircon, magnetite, and rutile. Concentrates from saprolite of the biotite gneiss, biotite schist, and sillimanite schist tend to have fine-grained monazite and zircon. Concentrates from saprolite of biotite schist contain coarse-grained ilmenite. Data on the size distribution of magnetite, staurolite, sillimanite, and garnet are too few to be representative for the quadrangle.

PROPERTIES OF THE MINERALS DIAGNOSTIC OF THE PARENT ROCK

MONAZITE

The distribution and estimated abundance of monazite in the concentrates from saprolite of the metamorphosed sedimentary and pyroclastic rocks is shown on plate 1 by logarithmic isograms drawn from the values used to prepare table 1. Plate 1 also shows the distribution of concentrates from saprolite of Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite, and the abundance of monazite in the concentrate at each locality is shown.

The main trend of the monazite isograms is defined by a broad arcuate zone bounded by the 100 isogram that extends northward from Boiling Springs to Lattimore, thence northwest toward Jack Moore Mountain. This zone approximately follows the broadest exposures of sillimanite schist in the quadrangle (Yates, Overstreet, Griffitts, unpublished data). A very narrow and sharply defined belt of monazite highs parallel and east of the main monazite high is defined by the 100 isograms leading northeastward from Poplar Springs

Church through Dover Mill to Zion Church, thence northwestward by Ramseur School to the First Broad River 2 miles northeast of Polkville. This high corresponds crudely to the trend of a narrow band of sillimanite schist and an adjacent narrow band of biotite schist. North of the First Broad River the isograms swing eastward across biotite schist to enclose an area of sillimanite schist and biotite gneiss in the northeastern part of the mapped area.

Local monazite highs coincide with either sillimanite schist or biotite schist around several sills of Toluca Quartz Monzonite, of which the most notable is between Fallston and Flat Rock School. These highs appear to be associated with migmatization of the wall-rock schist by lit-par-lit introduction of monazite-bearing quartz monzonite and pegmatite. Greater percentages of monazite may also result locally in the schists from geothermal rise adjacent to the intrusive rock, because the geothermal rise increases the number of centers of crystallization of metamorphic monazite.

Broad monazite lows coincide with areas underlain by biotite schist throughout the quadrangle.

The spot values showing abundance of monazite in saprolite of the Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite are equal to or many times greater than the abundance of monazite in nearby schist and gneiss, as shown by the isograms. At a few localities the monazite in the saprolite of the granitic rocks is substantially less abundant than it is in the adjacent schist and gneiss. The main examples of this reversal are between Piney Mountain and Hollis in the northwest quarter of the quadrangle where a late-phase muscovitic variety of the Toluca Quartz Monzonite occurs in dikes. Saprolite of muscovitic Toluca Quartz Monzonite from a dike at Hollis gave the only monazite-free concentrate among the 96 made from the Toluca (table 1).

The grains of monazite in the concentrates are commonly globular, ovoid, or subround, and rarely subhedral or euhedral. Fractured grains, particularly conchoidally fractured, are abundant. Concentrates from the saprolite of the Toluca Quartz Monzonite and of the microcline-oligoclase-quartz pegmatite tend to have more subhedral and euhedral grains of monazite than the other concentrates.

Between 70 and 80 percent of the monazite grains from the saprolite of all groups of rocks range from 0.09 to 0.15 mm in size. Diagnostic differences between the saprolite from the groups of rocks, based on variation in the size of the particles of monazite, are the tendency (1) for the grains from the biotite schist and sillimanite schist to be equally distributed on each side of the dominant classes, (2) for grains from the Toluca Quartz Monzonite to be mainly distributed to the small side of the dominant classes, and (3) for grains from the pegmatite saprolite to be distributed to the large side of the dominant classes. Thus, 25 percent of the grains of monazite in concentrates from saprolite of the Toluca Quartz Monzonite tend to be smaller than 0.09 mm, and 28 percent of the grains from the pegmatite saprolite are 0.35 mm or larger.

The monazite in concentrates from saprolite of biotite schist, sillimanite schist, and biotite gneiss tends to be yellow or pale yellow, whereas that from the saprolite of Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite tends to be amber and yellow green. Monazite from quartz veins is amber to brown (table 3).

TABLE 3.—*Color of monazite (percent of total number of monazite-bearing concentrates collected from each rock type)*

[Colors of the grains as observed in reflected light on a white background under a binocular microscope. Determined by R. G. Yates and W. C. Overstreet]

Dominant color in a concentrate	Toluca Quartz Monzonite	Microcline-oligoclase-quartz pegmatite	Biotite gneiss	Biotite schist	Biotite schist and pegmatite	Sillimanite schist	Sillimanite schist and pegmatite	Quartz from veins
Brown	0	1	0	0	0	0	0	33
Amber	16	29	14	25	20	24	37	34
Pale amber	10	2	5	3	5	8	7	33
Bright yellow	15	10	16	8	8	5	14	0
Yellow	28	24	31	19	35	5	14	0
Pale yellow	17	13	29	40	29	49	9	0
Yellow green	13	18	0	3	3	7	17	0
Pale green	1	1	3	1	0	2	2	0
Green	0	2	2	1	0	0	0	0

The amount of thorium oxide in the monazite varies with the kind of parent rock. Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr., U.S. Geological Survey, of 126 samples of monazite from saprolite of the crystalline rocks in the Shelby quadrangle and vicinity show a range in the abundance of ThO_2 from 2.1 to 11.2 percent (table 4). The average abundance of ThO_2 in monazite from saprolite of the sillimanite schist and biotite schist is 4.8 percent. That of monazite from saprolite of the biotite gneiss is 5.4 percent. Monazite from saprolite of the Toluca Quartz Monzonite, pegmatite, and unweathered vein quartz has an average of 6.1 percent ThO_2. Monazite from the Cherryville Quartz Monzonite east of the Shelby quadrangle contains an average of 6.4 percent ThO_2. The average abundance of ThO_2 in the 126 samples of monazite from the area is 5.5 percent, which is very close to the average of 5.67 percent reported by J. B. Mertie, Jr. (1953, p. 12), for 53 samples of detrital monazite from stream placers in this part of the Piedmont.

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TABLE 4.—*Thorium oxide in monazite from the saprolite of crystalline rocks in the Shelby quadrangle and nearby areas, Cleveland and Rutherford Counties, N.C.*

[ThO_2 determined with quantitative spectrochemical methods by K. J. Murata and H. J. Rose, Jr. Samples collected by R. G. Yates, W. C. Overstreet, Kefton Teague, W. R. Griffitts, Paul Benson, and A. M. White]

Locality (pl. 1)	Laboratory No.	ThO_2 (percent)	Locality (pl. 1)	Laboratory No.	ThO_2 (percent)
Sillimanite schist					
1	138533	4.8	11	138531	4.2
2	138534	5.8	12	138532	3.4
3	138536	4.8	13	138535	3.4
4	138540	5.1	14	138537	4.6
5	138526	9.0	15	138538	4.5
6	138527	4.8	16	138539	3.9
7	138528	4.0			
8	139893	4.3	Average (16 analyses)		4.8
9	138529	4.2			
10	138530	4.8			
Biotite schist					
17	138552	4.6	24	138544	5.4
18	138553	4.4	25	138545	6.5
19	138554	5.0	26	138546	5.3
8	135562	4.6	27	138547	6.3
8	135567	4.0	28	138548	5.1
8	135568	4.2	29	138549	4.4
8	135569	4.0	30	138550	4.8
8	139894	6.2	31	138551	4.6
20	138541	6.9	32	138555	3.2
21	138542	4.6	33	138556	4.3
22	138543	4.6	34	138557	4.3
23	139905	3.7	a	135570A	4.8
23	139916	5.1	35	50-W-115(8)	5.3
23	139917	6.0	36	50-W-140S	5.6
23	139918	3.9			
a [1]	139898	2.1	Average (31 analyses)		4.8
a	139901	4.8			
Biotite gneiss					
37	138564	6.2	42	138562	5.0
38	138558	6.7	43	138563	3.7
39	138559	4.6	44	138565	6.0
a	139902	8.8			
40	138560	4.4	Average (9 analyses)		5.4
41	138561	3.8			
Toluca Quartz Monzonite					
45	138566	6.2	a	135570E	5.7
45	138566A	5.7	a	135570F	5.8
45	138566B	6.5	a	135570G	6.0
46	138567	7.3	a	139903	6.1
47	138568	7.2	a	135570H	6.5
a	139895	6.7	48	138569	4.3
a	139896	6.6	49	138570	4.3
a	139897	6.4	50	138571	5.1
a	139899	6.6	b [1]	[2] 54-537SW	5.3
a	139900	6.6	51	[2] 54-539SW	8.8
a	135570B	5.4			
a	135570C	6.7	Average (23 analyses)		6.1
a	135570D	6.1			

See footnotes at end of table.

TABLE 4.—*Thorium oxide in monazite from the saprolite of crystalline rocks in the Shelby quadrangle and nearby areas, Cleveland and Rutherford Counties, N.C.*—Continued

Locality (pl. 1)	Laboratory No.	ThO_2 (percent)	Locality (pl. 1)	Laboratory No.	ThO_2 (percent)
Microcline-oligoclase-quartz pegmatite					
52	138572	7.6	57	139920	6.0
53	138581	7.3	51	[2] 55-OT-100	11.2
54	138582	6.7	58	138574	5.7
55	138583	3.8	59	138575	5.4
8	135563	5.2	60	138576	5.8
8	135564	5.5	61	138577	6.7
8	135565	5.6	62	138578	5.3
8	135566	5.1	63	138579	7.1
56	138573	8.5	13	138580	4.1
23	139906	7.2	35	50-W-115Q	5.0
23	139907	6.9	35	50-W-115R	5.7
23	139907	5.8	35	50-W-115P	5.4
23	139907	6.8	35	50-W-115X	5.4
23	139908	6.8	35	50-W-115W	5.3
23	139909	6.5	35	50-W-115U	5.2
23	139910	6.3	35	50-W-115T	5.2
23	139911	5.3	35	50-W-115S	5.6
23	139912	6.3	36	50-W-140A	5.7
23	139913	6.0	36	50-W-140B	7.0
23	139914	5.9	b	[2] 54-538SW	6.4
23	139915	6.0			
8	139892	4.9	Average (43 analyses)		6.1
57	139919	5.8			
Quartz vein					
64	[2] 138377	6.1			
Cherryville Quartz Monzonite					
c [1]	53-BE-3	5.6	d [1]	135549	6.9
c	[2] 135556	6.6	Average (3 analyses)		6.4

[1] Locality a, Lincolnton quadrangle, North Carolina, 35°27′54″ N., 81°29′28″ W.; b, Casar quadrangle, North Carolina, at Acre Rock quarry 1.7 miles southwest of Toluca, Cleveland County; c, Lincolnton quadrangle, North Carolina, 35°16′24″ N., 81°26′45″ W.; d, Kings Mountain quadrangle, North Carolina, 7.3 miles east of Grover, Cleveland County.
[2] Samples are from unweathered rocks.

The amount of uranium oxide (U_3O_8) in 11 samples of monazite from saprolite of crystalline rocks in the Shelby quadrangle and one nearby locality, determined chemically by Carmen Johnson and Blanche Ingram (table 5), ranges from 0.057 to 2.34 percent. In 10 of the 11 analyses U_3O_8 does not exceed 1.48 percent, and the average is 0.54 percent. Average abundance is 0.55 percent U_3O_8 in monazite from saprolite of the schist and gneiss, 0.74 percent in monazite from saprolite of Toluca Quartz Monzonite, and 0.22 percent in monazite from saprolite of pegmatite, but the range of values within one kind of rock is great. Monazite from the Cherryville Quartz Monzonite contains 2.34 percent U_3O_8, an unusually large amount for monazite and the greatest amount known for monazite from the United States.

TABLE 5.—*Percent uranium oxide in monazite from saprolite of the crystalline rocks in Cleveland and Rutherford Counties, N.C.*

[Chemical analyses for U_3O_8 by Carmen Johnson and Blanche Ingram. Monazite collected by R. G. Yates, W. C. Overstreet, Paul Benson, and A. M. White]

Locality (pl. 1)	Laboratory No.	Source rock for monazite	U_3O_8
6	146961	Sillimanite schist	0.45
20	146959	Biotite schist	.29
22	146963	do	1.48
40	146964	Biotite gneiss	.33
42	146966	do	.22
46	146960	Toluca Quartz Monzonite	.35
48	146965	do	.76
49	146967	do	1.10
53	146968	Microcline-oligoclase-quartz pegmatite	.39
58	146962	do	.057
[1]	52-BE-3	Cherryville Quartz Monzonite	2.34
Average exclusive of Cherryville Quartz Monzonite			0.54

[1] Located in Lincolnton quadrangle, North Carolina, at 35°16′24″ N., 81°26′45″ W.

Uranium was not determined in analyses of placer monazite reported from the Carolinas as late as 1944 (Lefforge and others, 1944). By 1953, however, J. B. Mertie, Jr. (1953, p. 12), showed that U_3O_8 in monazite from 53 placers in the Carolinas and Georgia ranged from 0.18 to 0.98 percent and averaged 0.38 percent. Other analyses of monazite from 19 fluviatile placers in North and South Carolina show 0.30 to 0.80 percent U_3O_8 and average 0.52 percent (Griffith and Overstreet, 1953a, p. 16; 1953b, p. 10; 1953c, p. 25; Hansen and White, 1954, p. 21; Hansen and Cuppels, 1954, p. 21; 1955, p. 18; Hansen and Caldwell, 1955, p. 16; Hansen and Theobald, 1955, p. 24).

XENOTIME

Xenotime is most common in concentrates made from saprolite of the microcline-oligoclase-quartz pegmatite, particularly the large sill-like masses of pegmatite exposed in the southeastern and eastern parts of the city of Shelby, east of Lawndale, and north of Delight. It is also present in concentrates made from the alluvium in Sandy Run southeast of Hopewell (Griffith and Overstreet, 1953c, p. 20–21) and in Grassy Branch (Mertie, 1953, p. 7). Similarity in appearance between xenotime and monazite has caused some error in the estimates of xenotime given in table 1. When separates of monazite from the concentrates are examined under unfiltered light from a mercury-vapor lamp (Murata and Bastron, 1956, p. 888–889) many separates are found to contain a few grains of xenotime. Xenotime is most abundant in separates from pegmatite, Toluca Quartz Monzonite, and vein quartz; it is also present in separates from biotite schist and sillimanite schist. Although the concentrates from biotite gneiss are reported in table 1 to contain no xenotime, a few grains were detected by the method of Murata and Bastron in one monazite separate.

Most grains of xenotime are subhedral or anhedral and closely resemble monazite in shape, size, and color. The rare euhedral crystals are simple tetragonal dipyramids, occasionally modified by tiny tetragonal prism faces. Stubby tetragonal dipyramidal crystals of green xenotime enclosing long thin prismatic brown zircon in parallel position occur in 2 percent of the concentrates examined. These intergrowths are quite similar to intergrowths figured by E. S. Dana (1914, p. 748, fig. 488). Most of these intergrowths came from saprolite of microcline-oligoclase-quartz pegmatite, but saprolite of each of the other groups of rocks, with the exception of the biotite gneiss, was the source of at least one such intergrowth. Although these intergrowths are not unique to the saprolite from pegmatite, they are the most nearly diagnostic of any of the minerals in the concentrates.

Xenotime from saprolite is usually green in a variety of hues, but it may be yellow, gray, white, or brown. Considerable variation in the color of the grains in a concentrate is common, and many individual grains are mottled by several colors, white and green or green and brown being the most frequently observed combinations.

ZIRCON

Zircon is present in 93 percent of the concentrates of saprolite from pegmatite and biotite gneiss, in 80 to 85 percent of the concentrates from the Toluca Quartz Monzonite, biotite schist interlayered with pegmatite, and biotite schist, and in 45 to 65 percent of the concentrates from sillimanite schist and sillimanite schist interlayered with pegmatite (table 1). Areas in the quadrangle underlain by the sillimanitic rocks tend to have less zircon than the other parts of the quadrangle.

Low content of zircon is a characteristic feature of saprolite from sillimanite schist.

The tendency toward perfection of crystal outline in the grains of zircon was not recorded in detail. Some perfectly terminated crystals were seen in all the zircon-bearing concentrates, but the greatest proportion of well-formed zircon was found in concentrates from saprolite of the pegmatite. All degrees of roundness were observed in zircon crystals from each of the rock types. Generally the small grains have a greater tendency toward roundness than the large grains, and zircon grains from the schists and gneiss have a greater tendency toward roundness than grains from the Toluca Quartz

Monzonite and pegmatite. The roundness is mostly associated with imperfectly formed terminal faces on the zircon. Zircon in some of the parallel intergrowths with xenotime has perfectly round ends. Most edges between prism faces are sharp. Spindle-shaped grains are rare, but nearly spherical zircon grains are common. Twinned crystals having a pyramid face as the twinning plane were observed in a few concentrates. Parallel growths of two to four crystals are not uncommon, but no secondary outgrowths were observed such as those described by Smithson (1937, p. 281–283) and Kilpady and Deshpande (1954–55, p. 16–18) on detrital zircon from unmetamorphosed sedimentary rocks and by Herbert Yoho (1953, p. 244) from metamorphic rocks.

Sharp-edged conchoidal fragments of zircon are present but sparse in concentrates from saprolite. The fractures causing the fragmentation of the zircon may have formed late in the history of the rocks when regional pervasive fracturing took place. It seems unlikely to us that the breaking was part of the weathering process or was caused by the handling of the sample. Other minerals such as garnet, monazite, quartz, tourmaline, and sillimanite were also broken or cracked at the time of the last regional deformation and these mineral fractures remained unhealed. After the host rocks were exposed to weathering, the fracture surfaces of the more soluble of the minerals were pitted, etched, frosted, and stained. Zircon from the saprolite does not show these effects of weathering.

The ratio of the length to the width of zircon grains was estimated in 915 concentrates from saprolite and residual soil. For each concentrate the least ratio and the greatest ratio was recorded, and an estimate of the average ratio for the concentrate was made. Least ratios were uniformly estimated to be 1 except for zircon from quartz veins, for which the least ratio was 1.5. Greatest ratios ranged from 3 to 10; the largest values are associated with zircon from the saprolite of pegmatite, biotite gneiss, and biotite schist with interlayered pegmatite (table 6). The estimated average ratio of the zircon grains discloses only minor differences between zircon from the various groups of source rocks. Biotite schist and sillimanite schist tend to have the stubbiest zircon grains, and pegmatite tends to have the most elongate grains. The ratio of length to width of the zircon grains in this area is a poor criterion for the discrimination of saprolite.

The size of most of the zircon grains in panned concentrates from saprolite of the different rocks is 0.09 mm or less (table 2). Size is of diagnostic value for the saprolite of sillimanite schist, which tends to have all zircon grains smaller than 0.09 mm, and for saprolite of pegmatite, which tends to have half or more of the zircon grains larger than 0.09 mm.

TABLE 6.—*Estimated ratios of length to width of zircon grains in concentrates from the Shelby quadrangle, North Carolina*

[Estimates by R. G. Yates and W. C. Overstreet]

Source rock	Samples			Ratios	
	Total	Residual soil	Saprolite	Greatest	Average
Toluca Quartz Monzonite	80	11	69	6	2.5
Microcline-oligoclase-quartz pegmatite	241	7	234	10	2.7
Biotite gneiss	67	17	50	10	3
Biotite schist	192	34	158	8	2.2
Biotite schist and pegmatite	155	19	136	10	2.6
Sillimanite schist	130	64	66	7	2.2
Sillimanite schist and pegmatite	47	3	44	8	2.8
Quartz from veins, unweathered	3	----	----	3	2.7

The dominant colors of zircon grains in concentrates from saprolite are diagnostic for broad groups of rocks even though the depth of color increases with the size of the grains. Large elongate grains tend to be darker than small, nearly equidimensional grains. Inasmuch as the large elongate grains are most common in the saprolite from pegmatite, the zircon in concentrates from pegmatite tends to be dark. Zircon from concentrates from Toluca Quartz Monzonite, biotite gneiss, biotite schist, and sillimanite schist is pale in color. Relation of the colors of zircon to the source rock are shown in table 7. For this tabulation the zircon grains in each of 915 concentrates were described by the two most common colors, or the predominant color, observed in reflected light on a white background under binocular microscope. Thus, the two most common colors of zircon grains in one concentrate might be colorless and yellow; in another they might be colorless and brown. In yet other concentrates the zircon grains might be very uniform in color, and one shade, such as colorless, light brown, or brown, might predominate. Distribution of the observed color classes among the concentrates is shown in table 7 as percentages of the total number of concentrates in each group of rocks.

MAGNETITE

Magnetite is present in only 5 to 20 percent of the concentrates from the Shelby quadrangle (table 1), and where it does occur it is sparse. Grains of magnetite from saprolite are most commonly octahedrons, but many of the grains are mere husks surrounding porous limonitic cores. Megascopic features of the magnetite in the Shelby area cannot be correlated with the parent rock of the saprolite in which the magnetite is found. Recent work has shown that variations in the abundance of minor elements in magnetite can be related to variations in the parent rock (Theobald and Thompson, 1962, p. 72–73).

TABLE 7.—*Color of zircon (percent of concentrates in each group of rocks that have zircon of the indicated color)*

[Same samples as table 6, including concentrates from residual soil not listed in table 1. Colors were determined by R. G. Yates and W. C. Overstreet, for grains observed in reflected light on a white background under a binocular microscope]

Two most common colors or predominant color	Toluca Quartz Monzonite	Microcline-oligoclase-quartz pegmatite	Biotite gneiss	Biotite schist	Biotite schist and pegmatite	Sillimanite schist	Sillimanite schist and pegmatite	Quartz from veins
Colorless	58	9	49	61	32	64	38	20
Colorless, yellow	1	1	1	Tr.	1	0	0	0
Colorless, white	4	3	2	4	4	10	5	0
Colorless, pale gray	1	1	3	0	1	2	0	0
Colorless, pale pink	3	1	0	Tr.	2	0	0	0
Colorless, lavender	1	5	2	4	6	3	2	0
Colorless, light brown	22	20	31	18	21	10	15	0
Colorless, brown	4	5	3	1	3	3	7	0
Total light colored	94	45	91	88	70	92	67	20
White, pale gray	1	1	1	1	2	1	2	0
Pale pink	0	0	0	0	0	0	2	0
Lavender	1	1	0	Tr.	5	0	0	0
Light brown	3	42	6	6	21	6	24	20
Brown	1	11	2	5	2	1	5	60
Total dark colored	6	55	9	12	30	8	33	80

ILMENITE

Ilmenite is more evenly distributed in concentrates from saprolite than any other heavy mineral in the Shelby quadrangle (table 1), but it tends to be least abundant in saprolite from biotite gneiss and most abundant in saprolite from sillimanite schist.

Grains of ilmenite have many shapes in a single concentrate. Euhedral crystals, angular and tabular fragments, and round grains are all common, and no particular shape is dominant in any type of rock.

Most grains of ilmenite in the concentrates panned from saprolite are between 0.09 and 0.15 mm in size. Saprolite from the Toluca Quartz Monzonite and from pegmatite has larger grains of ilmenite than saprolite from the schists and gneiss.

The luster of ilmenite grains ranges from splendent to dull metallic, and is attributable to the weathering more than to the parent rock. Ilmenite from surface soils is splendent, but ilmenite from saprolite, particularly dense clayey saprolite, is dull and has particles of leucoxene attached to the surface.

RUTILE

Rutile is most common in concentrates from saprolite of the sillimanite schist; it is distributed over wide areas in the central and southeastern parts of the quadrangle where sillimanite schist is the most abundant rock.

The shape of the rutile grains is dominantly prismatic. Most of the grains are fractured and have conchoidal or splintered ends, but euhedral crystals are common. Delicate knee-twins are sparse. Spindle-shaped and round grains were not found. Most of the rutile grains are longitudinally striated. Shapes of the grains give no indication of the parent rocks of the saprolite.

The data on the size of the grains of rutile are inadequate for discussion.

The rutile is bright and has adamantine luster. The colors of the rutile grains from saprolite are closely related to the broad groups of rocks in which the rutile formed. Rutile in concentrates from saprolite of biotite gneiss, biotite schist, and sillimanite schist is typically dark colored. Rutile in concentrates from Toluca Quartz Monzonite, pegmatite, and quartz veins is lighter in color (table 8). Approximately 35 percent of the concentrates from saprolite of biotite schist contain rutile in the various classes of orange and red listed in table 8, but about 50 percent of the concentrates from the quartz veins, 70 percent from the Toluca Quartz Monzonite, and 80 percent from the pegmatite have these colors.

STAUROLITE

Staurolite is generally absent from the saprolite of the Shelby quadrangle. The mineral occurs in only 5 of the 1246 concentrates collected. These five concentrates are from sillimanite schist. North of the quadrangle staurolite has been found in isolated samples of

TABLE 8.—*Color of rutile (percent of concentrates in each group of rocks that have rutile)*

[Colors were determined by R. G. Yates and W. C. Overstreet, for grains observed in reflected light on a white background under a binocular microscope. From same group of concentrates used for table 6]

Color of grains	Toluca Quartz Monzonite (29 concentrates)	Microcline-oligoclase quartz pegmatite (111 concentrates)	Biotite gneiss (14 concentrates)	Biotite schist (79 concentrates)	Biotite schist and pegmatite (43 concentrates)	Sillimanite schist (94 concentrates)	Sillimanite schist and pegmatite (25 concentrates)	Quartz from veins (4 concentrates)
Orange	10	9	7	2	2	1	0	0
Orange to red	7	5	0	1	0	0	0	0
Orange to red brown	7	11	0	1	0	0	0	0
Orange red	16	16	21	2	14	4	0	0
Orange red to dark red	7	11	7	19	14	18	24	25
Orange red to red brown	17	24	7	9	23	18	20	25
Orange red to brown	7	2	0	1	0	7	0	0
Red	0	4	0	6	5	0	4	25
Red to dark red	4	4	14	1	0	4	0	25
Red to red brown	4	10	22	20	16	29	20	0
Red to black	4	2	0	2	0	3	4	0
Dark red	10	6	22	23	14	5	16	0
Dark red to brown	7	6	0	6	12	11	12	0
Dark red to black	0	1	0	8	0	0	0	0

pegmatite, and of biotite schist (table 2). Small amounts of staurolite are reported also in a few concentrates from alluvium from the eastern part of the quadrangle (Overstreet and Griffitts, 1955, p. 556, 561). Staurolite is anomalous in the saprolite of the sillimanite schist, but it is an important component of lower rank metamorphic rocks exposed east of the quadrangle. Staurolite is not a diagnostic mineral for the identification of saprolite in the Shelby quadrangle.

Staurolite occurs in the concentrates as conchoidal and prismatic crystal fragments; no euhedral crystals were found. The grains are about 0.15 mm to 0.35 mm in size. Color in the staurolite depends somewhat on size. The small grains are transparent yellow brown, brown, and red brown; large grains are generally dark brown and only the edges are transparent. All grains contain many black inclusions that are probably magnetite.

SILLIMANITE

Sillimanite is present in at least a few concentrates from the saprolite of each group of rocks in the quadrangle (table 1), but it is most abundant, naturally, in those from saprolite of the sillimanite schist. Sillimanite in the concentrate from the saprolite of one group of rocks cannot be distinguished from the sillimanite from the other groups of rocks. Sillimanite appears in the concentrates as prismatic, transversely fractured fragments, as ovoid or spindle-shaped sillimanite-quartz intergrowths, and as fibrous aggregates. Most of the fragments are less than 1 mm long, but some of the intergrowths and aggregates are as much as 20 mm long. The fragments are generally colorless and the intergrowths and aggregates are white and red or brown stained from iron oxides. Some of the fibrous aggregates contain inclusions of ilmenite and rutile. These aggregates are particularly characteristic of saprolite from sillimanite schist.

TOURMALINE

Tourmaline is sporadically distributed in the quadrangle and is present in only 15 to 50 percent of the concentrates (table 1). It appears in 45 to 50 percent of the concentrates from the saprolite of sillimanite schist and of sillimanite schist interlayered with pegmatite, but it is found in only 30 to 35 percent of the concentrates from saprolite of pegmatite, biotite gneiss, and biotite schist. Tourmaline is present in 15 percent of the concentrates from saprolite of the Toluca Quartz Monzonite. Although tourmaline is not a diagnostic mineral, it is most likely to be in concentrates from saprolite of sillimanite schist and is least likely to be in those from the Toluca.

The tourmaline grains are small stubby euhedral crystals or conchoidal to angular crystal fragments. Prismatic crystals with a ratio of length to width exceeding 2 are rare. None of the tourmaline grains is frosted or worn to a round shape, though many possess a moderate degree of roundness owing to the poor development of the prisms. Most of the grains are between 0.35 and 1 mm in size.

The tourmaline is green black to brown black (table 9). The color of even the few grains that depart from these two colors is not strikingly different. Most grains are of uniform color, but a few are irregularly tinted in several colors.

TABLE 9.—*Color of tourmaline (percent of concentrates in each group of rocks that have tourmaline of the indicated color)*

[Colors were determined by R. G. Yates and W. C. Overstreet, for grains observed in reflected light on a white background under a binocular microscope. From same group of concentrates used for table 6]

Color	Toluca Quartz Monzonite (16 concentrates)	Microcline-oligoclase-quartz pegmatite (70 concentrates)	Biotite gneiss (16 concentrates)	Biotite schist (83 concentrates)	Biotite schist and pegmatite (45 concentrates)	Sillimanite schist (108 concentrates)	Sillimanite schist and pegmatite (21 concentrates)	Quartz from veins (5 concentrates)
Black	0	6	0	5	11	2	0	20
Gray black	0	1	0	1	2	1	0	0
Yellow black	0	2	0	5	2	4	5	0
Green black	12	22	19	29	60	12	28	20
Brown black	88	67	81	60	25	80	67	60
Brown	0	2	0	0	0	1	0	0

The tourmaline grains have a splendent luster, are transparent, and are generally free of inclusions; rare grains include some quartz.

Three samples of black tourmaline from three quartz veins in biotite schist along the east edge of the quadrangle have identical indices of refraction, $\epsilon=1.630\pm0.002$ and $\omega=1.652\pm0.004$, and identical pleochroic formulas: ϵ is pale tan and ω is dark greenish black. Specific gravities as determined by Berman balance are 3.10, 3.12, and 3.18. Two samples of black tourmaline from pegmatite in biotite schist in the northeast quarter of the quadrangle have higher indices of refraction than the tourmaline from the quartz veins, but they have little difference in pleochroic formula or specific gravity. The indices of one specimen are $\epsilon=1.632\pm0.002$ and $\omega=1.656\pm0.004$; its pleochroic formula is ϵ pale tan and ω dark greenish black, and the specific gravity is 3.12. Indices of the other specimen are $\epsilon=1.642\pm0.002$ and $\omega=1.666\pm0.004$; its pleochroic formula is ϵ pale grayish tan and ω dark greenish black, and its specific gravity is 3.24.

SPINEL

Spinel occurs sparsely in 40 concentrates from saprolite (table 1) and a few concentrates from residual soil in the quadrangle. It is most common in concentrates from saprolite of pegmatite, where it was found in 6 percent of the heavy suites. It is absent in concentrates from the biotite gneiss and occurs in 1 percent of the heavy suites from saprolite of the biotite schist and sillimanite schist. Presence of spinel in a concentrate is not diagnostic of the parent rock of the saprolite.

The grains of spinel are distorted octahedra, crystal fragments, or conchoidal fragments. Some octahedra have rounded apices, and a few grains are quite round. No relation was found between the shape of the grains of spinel and the kind of saprolite in which it occurred. Perfect octahedra of spinel, in addition to grains with other shapes, were panned from saprolite of biotite schist and sillimanite schist. Nearly globular grains of spinel, in addition to grains with other shapes, were found in saprolite of pegmatite.

The grains of spinel are smaller than 0.35 mm.

Color of the spinel ranges from pale blue to dark green (table 10) and varies considerably among the specimens from any one variety of rock. Too few spinel-bearing concentrates have been examined to disclose a diagnostic relation between the color and the source.

TABLE 10.—*Color of spinel (percent of concentrates in each group of rocks that have spinel of the indicated color)*

[Colors were determined by R. G. Yates and W. C. Overstreet, for grains observed in reflected light on a white background under a binocular microscope. From same group of concentrates used for table 6]

Color	Toluca Quartz Monzonite (6 concentrates)	Microcline-oligoclase-quartz pegmatite (9 concentrates)	Biotite gneiss (1 concentrate)	Biotite schist (8 concentrates)	Biotite schist and pegmatite (2 concentrates)	Sillimanite schist (13 concentrates)	Sillimanite schist and pegmatite (1 concentrate)	Quartz from veins (1 concentrate)
Dark blue	17	0	0	0	0	31	0	0
Blue	33	22	0	13	0	23	100	100
Pale blue	33	12	0	12	0	15	0	0
Blue gray	0	0	0	25	0	0	0	0
Blue green	0	44	0	25	100	15	0	0
Pale green	17	0	0	13	0	8	0	0
Dark green	0	22	100	12	0	8	0	0

PYRITE

Pyrite was found only in concentrates from the saprolite of pegmatite and of interlayered biotite schist and pegmatite. However, pyrite forms thin veins, small masses, and disseminated crystals in all varieties of unweathered rock.

KYANITE

Kyanite was not found in the 1246 concentrates from saprolite, but it occurs rarely and sporadically among heavy minerals panned from alluvium in the Shelby quadrangle and adjacent areas (Overstreet and Griffitts, 1955, p. 556, 561). Kyanite was seen in a few outcrops of biotite schist in the eastern part of the quadrangle where it occurs along north- and northeast-trending vertical faults. It is common east of the Shelby quadrangle. Kyanite has no diagnostic value, within the quadrangle, for the identification of the rock from which a saprolite formed.

CORUNDUM

Colorless, white, and gray corundum was found in a few concentrates panned from alluvium in the drainage basin of Knob Creek in the northeast corner of the quadrangle, but it was not observed in the heavy residues panned from saprolite. Gray corundum was also found as float along thin bands of sillimanite schist cropping out in broad areas of biotite schist in the Fallston-Toluca region near Knob Creek. Corundum from the Fallston-Toluca area is coated with a micaceous alteration product and resembles the corundum reported by Keith and Sterrett (1931, p. 13) to occur about 8 miles south of the Shelby quadrangle. In the Shelby area, corundum has no diagnostic value for the identification of the parent rock of saprolite.

DUMORTIERITE

Dumortierite occurs as rare gray-blue striated flat prisms in a few concentrates from the saprolite of biotite schist in the southwestern part of the quadrangle, from saprolite of sillimanite schist in the north-central part of the quadrangle, and from saprolite of bodies of pegmatite at scattered localities in the quadrangle. It is not an aid in the identification of the source rock of saprolite.

GARNET

Garnet is a variably present but common accessory mineral in each of the groups of rocks in the quadrangle. It locally amounts to several percent of the volume of the unweathered rocks, but much of the garnet is lost during weathering. Estimates were not made of the abundance of garnet in the concentrates panned from saprolite because of the loss of garnet during weathering and because the recovery of garnet was low.

Garnet in concentrates from saprolite occurs as conchoidal fragments locally coated with ocherous films or crusts. Euhedral grains are rare in saprolite despite their common presence in the fresh rocks.

Data on the size of grains of garnet in saprolite in the quadrangle are inadequate and cannot be used as a guide to the source rock of the saprolite.

Unstained garnets in concentrates from saprolite range in color from pale pink to dark purple. Most are pink and in color resemble rhodolite, a pyralspite garnet having index of refraction of 1.76 and specific gravity of 3.838 (Hidden and Pratt, 1898, p. 463–468). The composition of rhodolite corresponds to two molecules of pyrope and one of almandine (Dana, 1914, app. 1, p. 28). The color, index, and specific gravity of 40 specimens of garnet from unweathered rocks in the area are listed in table 11; garnets from the schist and gneiss have a slightly lower index and specific gravity than the garnets from the Toluca Quartz Monzonite and pegmatite. Despite the resemblance in color between the garnets in the Shelby area and the rhodolite from western North Carolina, the index and specific gravity are quite different. They indicate that the garnets in the Shelby quadrangle are pyralspites in which the spessartite and almandite molecules dominate (Winchell, 1933, p. 179).

Despite overlap in the range in index of refraction and specific gravity, these two features are of some use in identifying the source rock of the saprolite containing the garnets. Garnets having an index of refraction of about 1.806 or less and a specific gravity of about 4.00 generally come from the schist and gneiss. Those with index of refraction near 1.814 or higher and specific gravity about 4.16 generally are from Toluca Quartz Monzonite and pegmatite.

TABLE 11.—*Optical and physical properties of garnets from unweathered rocks exposed in the Shelby quadrangle, North Carolina*

[Measured by W. C. Overstreet. n.d., not determined]

Rock	Color	Index of refraction	Specific gravity
Calc-silicate layer in biotite schist	Brown	1.796	n.d.
Biotite schist	Purplish pink	1.796	n.d.
Do	Brownish pink	1.798	n.d.
Do	Pale purple	1.802	n.d.
Do	Pale pink	1.802	n.d.
Do	Dark purple	1.806	n.d.
Do	Pale pink	1.806	4.00
Do	do	1.808	n.d.
Do	do	1.810	n.d.
Biotite gneiss	do	1.802	n.d.
Do	Brown	1.806	4.16
Do	do	1.806	4.07
Do	Pink	1.808	n.d.
Do	Pale pink	1.812	n.d.
Toluca Quartz Monzonite	Brown	1.808	4.17
Do	Pink	1.808	n.d.
Do	Pale purple	1.808	4.12
Do	Pale pink	1.810	n.d.
Toluca Quartz Monzonite [1]	Pale purple	1.814	4.21
Do	do	1.814	4.22
Do	do	1.814	4.23
Do	Dark purple	1.815	4.14
Do	Pale purple	1.816	4.07
Do	do	1.816	4.11
Toluca Quartz Monzonite	Pink	1.818	4.28
Do	do	1.818	4.24
Do	do	1.818	4.23
Toluca Quartz Monzonite [2]	Pale pink	1.816	n.d.
Microcline-oligoclase-quartz pegmatite	do	1.804	4.17
Do	do	1.804	4.16
Do	Purplish pink	1.807	n.d.
Do	Brownish pink	1.808	4.16
Do	Pale pink	1.808	n.d.
Microcline-oligoclase-quartz pegmatite [1]	Pale purple	1.815	4.15
Do	do	1.815	4.13
Do	do	1.815	4.12
Microcline-oligoclase-quartz pegmatite [2]	Dark purple	1.816	4.19
Do	do	1.816	4.12
Do	do	1.816	4.22
Microcline-oligoclase-quartz pegmatite	Pale pink	1.816	4.16

[1] From the type locality of the Toluca Quartz Monzonite at the Acre Rock quarry near Toluca in Cleveland County, N.C.
[2] From the crosscutting Toluca Quartz Monzonite at the quarry on Cherry Mountain near Hollis, Cleveland County, N.C.

EPIDOTE

Epidote is an extremely rare component in about 1 percent of the concentrates from the 1,246 samples examined. Traces of epidote were found in several concentrates from the saprolite of biotite schist, sillimanite schist, and biotite gneiss, and in at least one concentrate from the Toluca Quartz Monzonite and pegmatite. To the east and west of the Shelby quadrangle, epidote is a common accessory mineral in the igneous and metamorphic rocks (Overstreet and Griffitts, 1955, p. 557–558, 561–564).

The epidote consists mostly of prismatic fragments having irregularly fractured ends. Perfect crystals are rare. Some grains are longitudinally striated. The grains are not etched or frosted, and the edges between crystal faces are sharp. Epidote grains are transparent pale greenish yellow in reflected light. Epidote from saprolite in the quadrangle is unmistakably different from the monazite and xenotime in form and color, but it is not diagnostic of the source rock of the saprolite.

APATITE

Apatite is a common accessory mineral in the unweathered rocks, but it is removed by weathering and, except for a few isolated grains, does not occur in concentrates panned from saprolite. These rare grains of apatite are round to subround, have etched and frosted surfaces, and are bluish green to greenish brown.

TITANITE

Titanite occurs as tabular wedge-shaped crystals in one concentrate from saprolite of biotite gneiss and another from biotite schist in the northeast corner of the quadrangle. The grains are light brown and are as much as 1 mm in length. Titanite is most common in sparse thin bodies of calc-silicate rock interlayered with the schists, but concentrates were not made from saprolite of the calc-silicate rock, because this saprolite has a hard pitted rindlike appearance and brownish color that cannot be mistaken for saprolite from other rocks.

SUMMARY OF MINERALOGICAL CRITERIA

The identification of the source rock of a saprolite from the heavy-mineral concentrate is at best uncertain, and with two minor exceptions, no single feature of the concentrate is diagnostic in the Shelby area. Uncommon intergrowths of green xenotime and brown zircon are diagnostic of the microcline-oligoclase-quartz pegmatite. Abundant fibrous aggregates of sillimanite with inclusions of ilmenite and rutile are diagnostic of sillimanite schist.

The most useful features are combinations involving the gross aspect of the concentrate and details about monazite, zircon, rutile, and garnet in the concentrate. These criteria are summarized in table 12.

Saprolite from interlayered biotite schist and pegmatite and interlayered sillimanite schist and pegmatite give suites of heavy minerals

TABLE 12.—*Mineralogical criteria for the identification of the source rock of saprolite, Shelby quadrangle, North Carolina*

Criteria	Saprolite source rock				
	Toluca Quartz Monzonite	Microcline-oligoclase-pegmatite	Biotite gneiss	Biotite schist	Sillimanite schist
Gross aspect of concentrate					
Volume	Intermediate (0.007 percent)	Intermediate (0.008 percent)	Intermediate (0.01 percent).	Small (0.004 percent)	Large (0.02 percent).
Grain size	Relatively coarse; great range in size of monazite, zircon, magnetite, and rutile.	Relatively coarse; great range in size of monazite, zircon, magnetite, and rutile.		Generally fine	
Common minerals	Monazite and rutile	Zircon and rutile unusually abundant.	Monazite, zircon, tourmaline.	Coarse-grained ilmenite.	Sillimanite, rutile, ilmenite, tourmaline.
Uncommon minerals	Sillimanite and tourmaline	Sillimanite	Ilmenite and sillimanite.	Monazite and sillimanite.	Zircon.
Other diagnostic features		Intergrowths of green xenotime and brown zircon.			Abundant sillimanite, especially fibrous aggregates with inclusions of ilmenite and rutile.
Special features of minerals					
Monazite:					
Shape	Subhedral and euhedral relatively common.	Subhedral and euhedral relatively common.	Anhedral to globular	Anhedral to globular	Anhedral to globular.
Size	Fine grained	Coarse grained	Fine grained	Fine grained	Fine grained.
Color	Amber or yellow green	Amber or yellow green	Yellow or pale yellow	Yellow or pale yellow	Yellow or pale yellow.
ThO_2 ..... percent	6.1	6.1	5.4	4.8	4.8.
Zircon:					
Shape		Subhedral to euhedral, elongate.		Stubby	Stubby.
Size		Coarse grained, half or more of the population larger than 0.09 mm.	Fine grained	Fine grained	Fine grained, all grains smaller than 0.09 mm.
Color	Light	Dark	Light	Light	Light.
Rutile:					
Color	Orange to red	Orange to red	Red to dark red	Dark red	Dark red to brown.
Garnet:					
Index of refraction	>1.814	>1.814	<1.806	<1.806	<1.806.
Specific gravity	4.16	4.16	4.00	4.00	4.00.

that vary widely from the usual concentrates for the individual rock. The concentrates are of little aid in identifying the saprolite from these rocks.

HEAVY MINERALS IN RESIDUAL SOIL OF CRYSTALLINE ROCKS

Several hundred heavy-mineral concentrates were panned from 20- to 25-pound samples of residual soil. The material sampled was taken from farmlands, which have been cultivated since the area was opened for agriculture in the early 1800's.

Four gross characteristics of the concentrate from residual soil distinguish it from the concentrate from saprolite, but they are no aid in identifying the parent rock from which the soil formed. Identification of the parent rock of the soil by use of the concentrate depends upon the same factors summarized previously for saprolite. The distinguishing characteristics of concentrates from residual soil are: (1) great abundance of heavy minerals, (2) relatively coarse grains, (3) clean, bright heavy minerals, and (4) presence of distinctive globular metallic or glassy grains of unknown origin.

Most concentrates from soil are 3 to 10 times as large as the concentrates from equal volumes of saprolite of the same group of rocks, owing to the residual accumulation of heavy minerals at the ground surface. Detailed studies of the extent of the enrichment were not made. It was observed that residual accumulation of the large grains of heavy minerals is promoted by the rapid removal of fine grains by rill wash, sheet wash, and wind transport, but studies of the process were not made. Secondary coatings and iron stains are common on quartz pebbles in the soil, but they are absent from the heavy minerals, which are clean and bright.

Distinctive tiny globular or droplet-shaped grains occur in the concentrates from the residual soils, but they do not occur in concentrates from saprolite. Some globules are metallic, others are glassy. The metallic globules are dull to splendent black, smooth to scoriaceous, and either highly magnetic or nonmagnetic. Those grains composed of glassy material are isotropic, are yellow, brown, green, or black, and are generally full of bubbles. Most of the globules are discrete particles, but some are attached to grains of quartz, and some are attached to each other to form dumbbell-shaped aggregates.

The metallic and glassy blebs are believed to be fused mineral grains, and their absence from saprolite shows that they were formed on or above the surface of the ground. It seems possible that clay, hydrated biotite, limonite-coated quartz, and other minerals typical of the uppermost part of the soil were locally fused by fire, which at some time swept over most fields in the quadrangle. Rapid chilling of the fused grains could have formed the glassy and metallic globules. However, the globules could be of extra-terrestrial origin. Analyses of both glassy and metallic material must be made and compared with those of tektites and known meteoric material before the origin of the globules can be determined.

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