IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

October 24, 1957

AEC - 187/8

Mr. Robert D. Nininger
Assistant Director for Exploration
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-685, "Petrographic study of sandstone of the Inyan Kara group (Cretaceous) and associated rocks in the Black Hills, Wyoming and South Dakota," by R. E. Bergenback, W. A. Chisholm, and W. J. Mapel, July 1957.

We plan to publish this report as part of a chapter of a Geological Survey Professional Paper.

Sincerely yours,

John H. Eric

for W. H. Bradley
Chief Geologist

Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PETROGRAPHIC STUDY OF SANDSTONE OF THE INYAN KARA GROUP (CRETACEOUS) AND ASSOCIATED ROCKS IN THE BLACK HILLS, WYOMING AND SOUTH DAKOTA

By

R. E. Bergenback, W. A. Chisholm, and W. J. Mapel

July 1957

Trace Elements Investigations Report 685

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

USGS - TEI-685

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TEPCO, Denver	2
TEPCO, RPS, Washington (including master)	2
	54

CONTENTS

ILLUSTRATIONS

TABLES

PETROGRAPHIC STUDY OF SANDSTONE OF THE INYAN KARA GROUP (CRETACEOUS) AND ASSOCIATED ROCKS IN THE BLACK HILLS, WYOMING AND SOUTH DAKOTA

By R. E. Bergenback, W. A. Chisholm, and W. J. Mapel

ABSTRACT

Sandstone beds in the Fall River formation and the Fuson-Lakota formations, undivided, of Early Cretaceous age, and in the underlying Unkpapa and Morrison formations of Late Jurassic age were sampled at 22 measured sections along the western side of the Black Hills during 1956 for grain-size, thin-section, and heavy-mineral analyses. The sandstone in all formations studied is predominantly fine-grained; however, the Fall River formation and the Fuson-Lakota formations contain some medium-grained sandstone, and the Fuson-Lakota formations contain some coarse-grained to conglomeratic sandstone. Individual and composite quartz grains generally make up 80 to 95 percent of the rock. Schist fragments and muscovite are present fairly consistently in small amounts in the Fall River formation, and chert fragments are abundant in coarse-grained and conglomeratic sandstone in the Fuson-Lakota formations.

Consistent differences in the heavy mineral suite permit differentiation into 3 zones. The lower zone includes the lower calcareous part of the Morrison formation and the underlying Sundance formation. It is characterized by a relatively high proportion of garnet and has dominantly rounded zircon and tourmaline grains. The middle zone includes, in general, the Unkpapa sandstone, the upper noncalcareous part of the Morrison formation, and the Fuson-Lakota formations. It also has dominantly rounded zircon and tourmaline grains but has almost no garnet at most places. The upper zone includes the Fall River formation and Newcastle sandstone. It has little garnet, dominantly angular zircon and tourmaline grains, and, locally, fairly abundant chloritoid and hornblende. The change from rounded to angular zircon and tourmaline grains and the local appearance of relatively abundant chloritoid and hornblende is sharp enough at most places to be useful in regional correlations.

Sedimentary materials of all of the formations examined were probably derived mainly from pre-existing sedimentary rocks, with an influx of material from metamorphic rocks during deposition of the Fall River formation.

INTRODUCTION

The Inyan Kara group of Early Cretaceous age and the underlying Morrison formation and Unkpapa sandstone of Late Jurassic age comprise 350 to 800 feet of gently dipping predominantly nonmarine rocks that crop out along the flanks of the Black Hills in northeastern Wyoming and western South Dakota. Beds of sandstone in these formations were sampled at 22 measured sections for grain-size, thin-section, and heavy-mineral analyses to determine if textural variations and mineral composition could be used in subdividing and correlating the formations and in determining direction to probable source areas. These analyses together with present field studies provide a background against which the depositional history and localization of uranium deposits in the Inyan Kara group can be analyzed.

The sections sampled are on the northern and western flanks of the Black Hills from Aladdin, Wyo. southward to Hot Springs, S. Dak. -- a distance of about 130 miles. A few samples were collected, also, from the underlying Sundance formation and from the overlying Newcastle sandstone in the same area. (See fig. 1.)

The stratigraphic sections were measured by K. M. Waagé and Copeland MacClintock in 1955 and by W. J. Mapel and C. L. Pillmore in 1956. Sampling was by W. J. Mapel and R. E. Bergenback. Bergenback made the mechanical analyses and examined the thin sections, and W. A. Chisholm made the heavy-mineral analyses. The work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

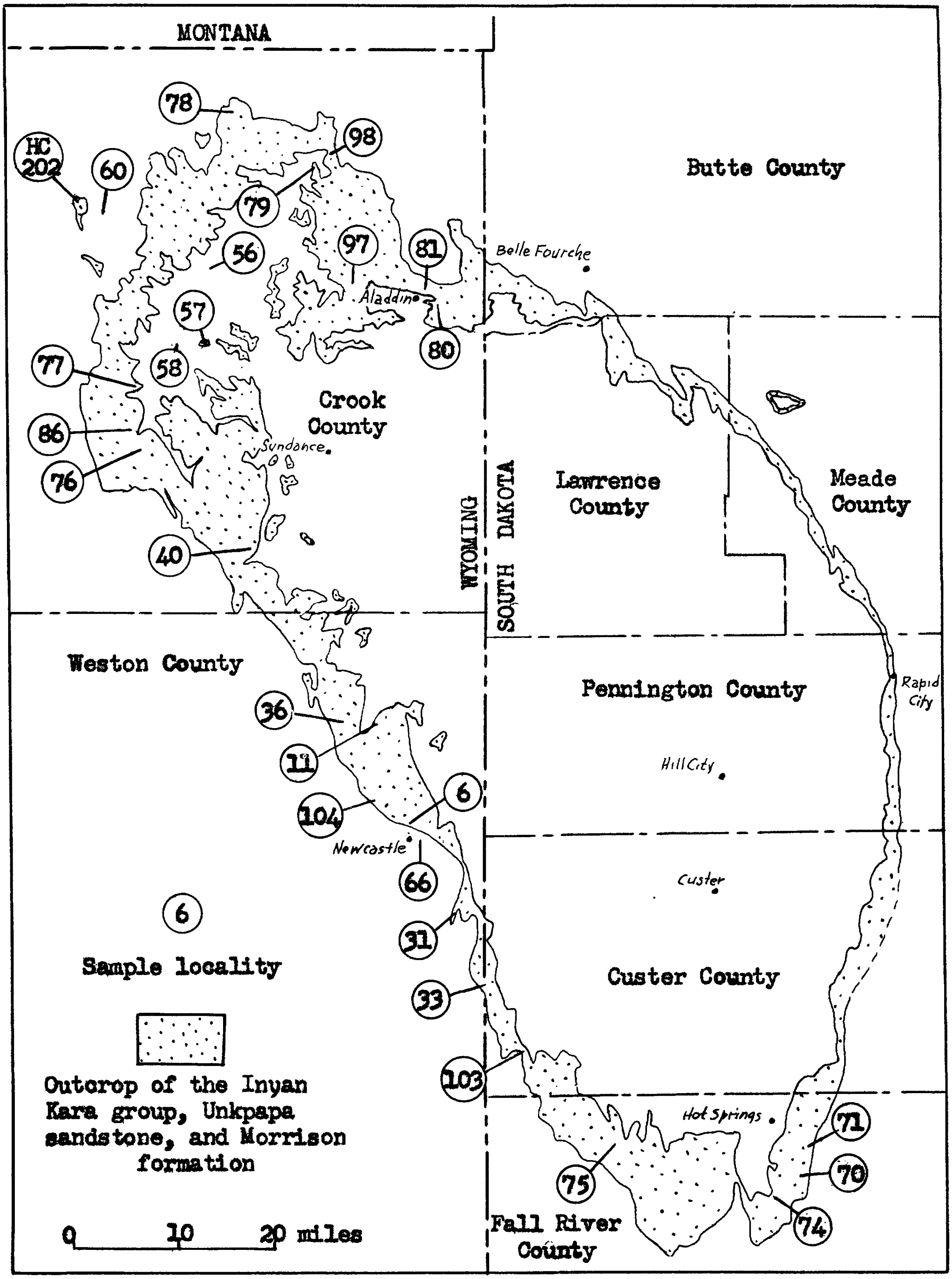


Figure 1.--Index map showing sample localities, Black Hills.

Table 1 summarizes the characteristic lithology of the formations examined, and figures 2 and 3 show measured sections at each sample locality and the stratigraphic position of the samples collected. The Inyan Kara group and the Unkpapa sandstone are dominantly sandstone and accordingly are represented by a relatively large number of samples in comparison to the Morrison formation which is predominantly claystone.

All of the samples are chip samples taken from near the middle of beds less than 6 feet thick or at intervals of 5 to 15 feet in the thicker beds. (See figs. 2 and 3.) Lenses of texturally different sandstone within thick, otherwise homogeneous beds were sampled separately.

GRAIN SIZE AND SORTING

Size analyses were made of the grains in about 265 samples from the Inyan Kara group and Unkpapa and Morrison formations as shown on figures 2 and 3 to determine the sand-size distribution and sorting. No study was made of the silt- or clay-particle size distribution. The samples are classified according to the well-known Wentworth scale which is given below.

Wentworth classification

	mm.	phi units
Pebbles	64 to 4	-6 to -2
Granules	4 to 2	-2 to -1
Very coarse sand	2 to 1	-1 to 0
Coarse sand	1 to 0.50	0 to 1
Medium sand	0.50 to 0.250	1 to 2
Fine sand	0.250 to 0.125	2 to 3
Very fine sand	0.125 to 0.062	3 to 4
Silt and clay	less than 0.062	greater than 4

Table 1.--Generalized stratigraphic section of Upper Jurassic and Lower Cretaceous rocks exposed along the western side of the Black Hills.

Series	Group	Formation	Thickness (in feet)	Lithology
Lower Cretaceous	Colorado (lower part)	Mowry shale	130-220 (thickens northward	Mostly hard siliceous shale that weathers light gray and contains numerous thin beds of bentonite; commonly grades to soft black shale in the basal few feet; marine fossils.
Lower Cretaceous	Colorado (lower part)	Newcastle sandstone	0-75 (commonly about 40 feet)	Discontinuous beds of sandstone, sandy shale, impure coal, bentonite, and (where thin) phosphatic nodules; marine and nonmarine fossils.
Lower Cretaceous	Colorado (lower part)	Skull Creek shale	200-260 (thickens northward)	Fissile black shale with a few ferruginous concretions; thin silt seams in the lower part and a few lenses of sandstone locally; marine fossils.
Lower Cretaceous	Inyan Kara	Fall River formation	125-160 (thickens southward)	Interbedded and interlaminated brown-weathering sandstone, light- to dark-gray siltstone, and dark-gray shale; local seams of impure coal; sharp contact with the underlying formation; nonmarine pelecypods locally at the base; contains uranium deposits.
		Unconformity		
Lower Cretaceous	Inyan Kara	Fuson, Minnewaste and Lakota formations	100-550 (mostly 100 to 250 feet in Wyoming, thickens southward)	Variable sequence of light-gray locally conglomeratic sandstone, and variegated claystone and sandy claystone; local seams of coal and carbonaceous shale at the base. A bed of light-gray limestone as much as 35 feet thick (Minnewaste limestone) crops out about 100 feet below the top in about 4 townships near Hot Springs, South Dakota, where it divides the sequence into an upper part (Fuson formation) and a lower part (Lakota formation); contains uranium deposits.
Upper Jurassic		Morrison formation / Unkpapa sandstone	0-240 (commonly about 100 feet)	Morrison formation: lower 60 to 80 feet greenish-gray and dull-red calcareous claystone, light-gray limestone, and light-gray calcareous sandstone; remainder is greenish-gray to dark-gray noncalcareous claystone; nonmarine fossils. Unkpapa sandstone: massive sandstone commonly mottled shades of gray, red, and purple; present at the southern end of the Black Hills.
Upper Jurassic		Sundance formation	325-375	Divided into 5 members as follows from youngest to oldest: Redwater shale member: greenish-gray shale with some interbedded light-gray calcareous sandstone and light-gray limestone, glauconitic; a persistent bed of calcareous yellow-weathering sandstone at the top; 140 to 180 feet thick. Lak member: friable red and yellow sandstone and siltstone; 40 to 60 feet thick. Hulett sandstone member: cliff-forming grayish-yellow sandstone; 50 to 75 feet thick. Stockade Beaver shale member: greenish-gray shale with some interbedded sandstone; 60 to 80 feet thick. Canyon Springs sandstone member: light-gray to pale-red sandstone; 0 to 40 feet thick. Marine fossils in all but the Lak member which is unfossiliferous.

Sandstone in all of the formations is predominantly fine-grained as shown by column A of figure 4. The Unkpapa and Morrison formations show the least range in grain size with about 95 percent of the grains in the fine- and very fine grain size (0.250 to 0.062 mm.) and the remainder in the silt size or finer in the samples studied. The Fall River formation contains nearly 15 percent medium sand grains in the samples examined but has no grains larger than medium (0.50 0.25 mm.). The Fuson-Lakota formations, undivided, have the greatest range in grain size with all sizes from granules to clay-size represented. Locally abundant pebbles and cobbles were noted in the Fuson-Lakota formations at some places, although no fragments of these sizes were collected in the samples studied.

The percent of the sample in the modal classes[1/] of samples from the formations studied is plotted in column B, figure 4, to show differences in sorting. For the purposes of this report, samples with more than 50 percent of the sample by weight in the modal class are considered well sorted. As thus defined, nearly all of the samples from the Fall River and Unkpapa formations are well sorted; and, on the average, sandstone in these two formations tends to be appreciably better sorted than in either the Fuson-Lakota or Morrison formations.

1/ Modal class is the size fraction containing the greatest amount of sample by weight.

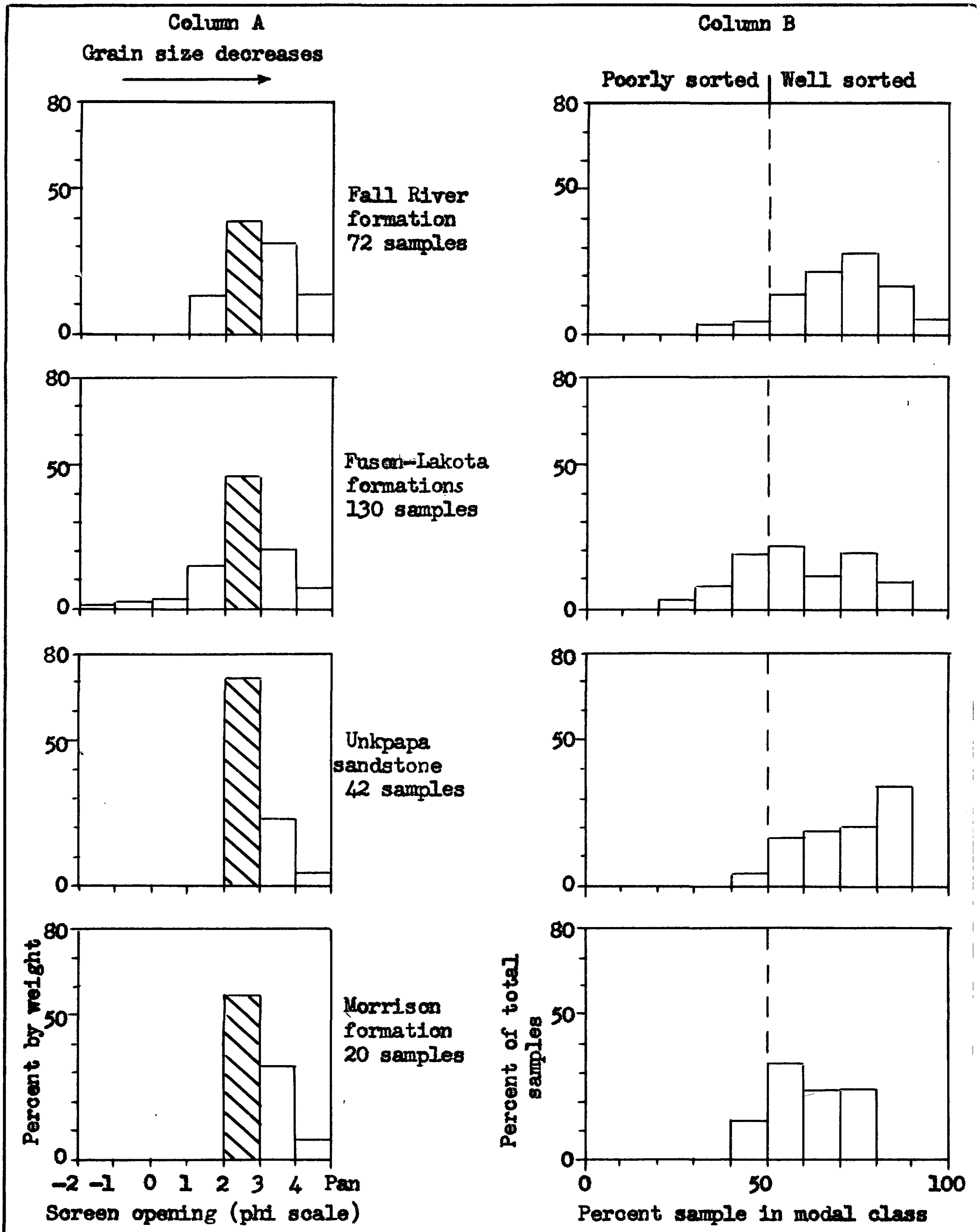


Figure 4.—Diagrams showing average grain size distribution (Column A) and sorting (Column B) in samples of sandstone from the Fall River, Fuson-Lakota, Morrison, and Unkpapa formations, Black Hills. (Cross-hatched bars in Column A show fine sand, 0.125 to 0.250 mm).

ROCK FORMING MATERIALS

Composition

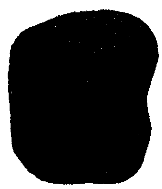
Microscopic examination of the sandstones in the Inyan Kara group and Morrison and Unkpapa formations shows them to be quartz-rich clastic rocks containing several varieties of quartz grains with a small percentage of other mineral and rock fragments.

Three varieties of individual quartz grains can be differentiated by the extinction characteristics of the grains under crossed nicols, and four varieties of composite quartz grains can be differentiated by the shapes and interrelations of the particles that make up the grains. The grain varieties, which are illustrated by figure 5, were determined by following, with modifications, a procedure outlined by Folk (1957, page M-7).

Unstrained or slightly strained quartz grains are distinguished by relatively abrupt extinction with a rotation of the microscope stage of usually less than 8 degrees. Moderately strained quartz grains are grains in which the extinction shadow sweeps smoothly across the grain with a rotation of the microscope stage of usually no more than 20 degrees. Strongly strained quartz grains are grains in which the extinction shadows sweep slowly and irregularly across the grain with rotation of the microscope stage usually more than 20 degrees.

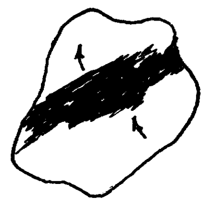
Composite quartz grains are classified according to whether the constituent particles are in parallel or in random optical orientation. Composite grains that have particles in parallel to semiparallel optical orientation are subdivided into grains composed of particles with nearly straight borders such as characterize fragments of vein quartz or deformation

A. Individual grains - crossed nicols



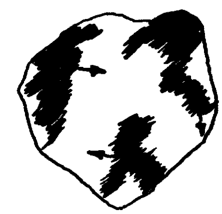
Unstrained

Whole grain at extinction at once



Moderately strained

Has sweeping extinction shadow

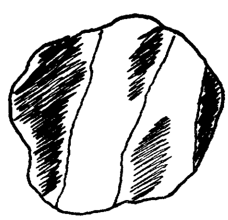


Strongly strained

Has irregular, slowly moving extinction shadows

B. Composite grains

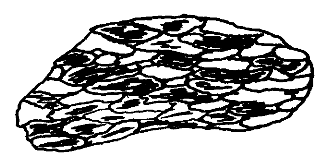
crossed nicols



Parallel orientation, straight borders

Composed of two or more individuals in parallel optical orientation with relatively straight grain borders.

crossed nicols



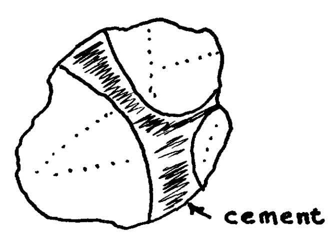
Semi-parallel orientation, smooth borders. Made up of particles in semi-parallel optical orientation with relatively smooth particle borders.

crossed nicols

Random orientation, crenulated borders

Made up of two or more individuals in random optical orientation with crenulated borders between individuals.

plain light



Random orientation, smooth borders

Composed of two or more individuals in random optical orientation. Individuals have smooth borders and are cemented by silica.

Figure 5.—Varieties of quartz grains in sandstone from the Inyan Kara group and the Unkpapa and Morrison formations, Black Hills.

lamellae in metaquartzite, and particles with smoothly curving borders such as characterize fragments of schist. Composite grains having particles in random optical orientation are subdivided into grains composed of particles with crenulated borders such as characterize fragments of metaquartzite, and grains composed of particles with smooth borders and held together by silica cement such as characterize fragments of orthoquartzite.

Other constituents commonly found in small amounts in the formations studied include grains of orthoclase, microcline, plagioclase, granular and fibrous chert, schist, claystone, calcilutite, sandstone, and siltstone.

The matrix and cementing materials are generally clay paste, calcilutite, granular chalcedony in small irregular patches, opal, and silica as overgrowths on quartz grains. In addition, a light-brown, partly fibrous, partly isotropic substance tentatively identified as chalcedony cements some samples from the Fuson-Lakota formations. A chemical analysis of this substance for phosphate was negative. Fine- to coarsely crystalline calcite cements most of the sandstone in the Morrison formation.

Proportions of constituents

Table 2 shows the average percentages of rock-forming materials for 56 thin-sections of samples from the Fall River formation, 59 from the Fuson-Lakota formations, 8 from the Unkpapa sandstone, 5 from the Morrison formation, and 1 from the Sundance formation. In order to check

Table 2.--Average percentages of mineral and rock fragments in thin sections of sandstone and siltstone (matrix excluded)

X, less than 1 percent; -, absent.

		Number of samples	Varieties of quartz grains: Individual grains: Unstrained	Varieties of quartz grains: Individual grains: Moderately strained	Varieties of quartz grains: Individual grains: Strongly strained	Varieties of quartz grains: Composite grains: Parallel orientation, straight borders	Varieties of quartz grains: Composite grains: Semi-parallel orientation, smooth borders	Varieties of quartz grains: Composite grains: Random orientation, smooth borders	Varieties of quartz grains: Composite grains: Random orientation, crenulated borders	Varieties of quartz grains: Total	Feldspar	Muscovite	Glauconite	Chert	Schist 1/	Claystone	Other 2/
Fall River formation		56	33	28	20	1	1	X	8	92	1	3	-	1	3	X	X
Fuson-Lakota formations	medium-grained and finer	48	37	28	20	1	X	X	7	94	1	X	-	4	X	X	X
	coarse-grained to conglomeratic	11	18	13	9	X	X	X	5	46	-	-	-	49	-	-	5
Unkpapa sandstone		8	52	18	8	11	X	X	7	96	4	-	-	X	-	-	-
Morrison formation	upper part	2	36	21	29	X	-	-	7	94	5	-	-	X	X	-	X
	lower part	3	34	26	16	1	X	-	8	86	7	X	-	2	X	3	-
Sundance formation		1	32	17	23	-	-	-	2	74	3	-	22	-	-	-	1

1/ Mostly muscovite and quartz; grains listed in second column under composite quartz grains are probably also schist fragments.

2/ Mostly fragments of sandstone and siltstone; 23 percent calcilutite in one sample of conglomeratic sandstone from the Fuson-Lakota formations.

the accuracy of the results, the percentages for several of the slides were determined by counting 100 points in increments of 25. The percentages of minerals in each increment, computed separately, rarely vary from the average for the four increments by more than 5 percent for any thin section, so the percentages based on a count of 100 are considered accurate to within about this amount.

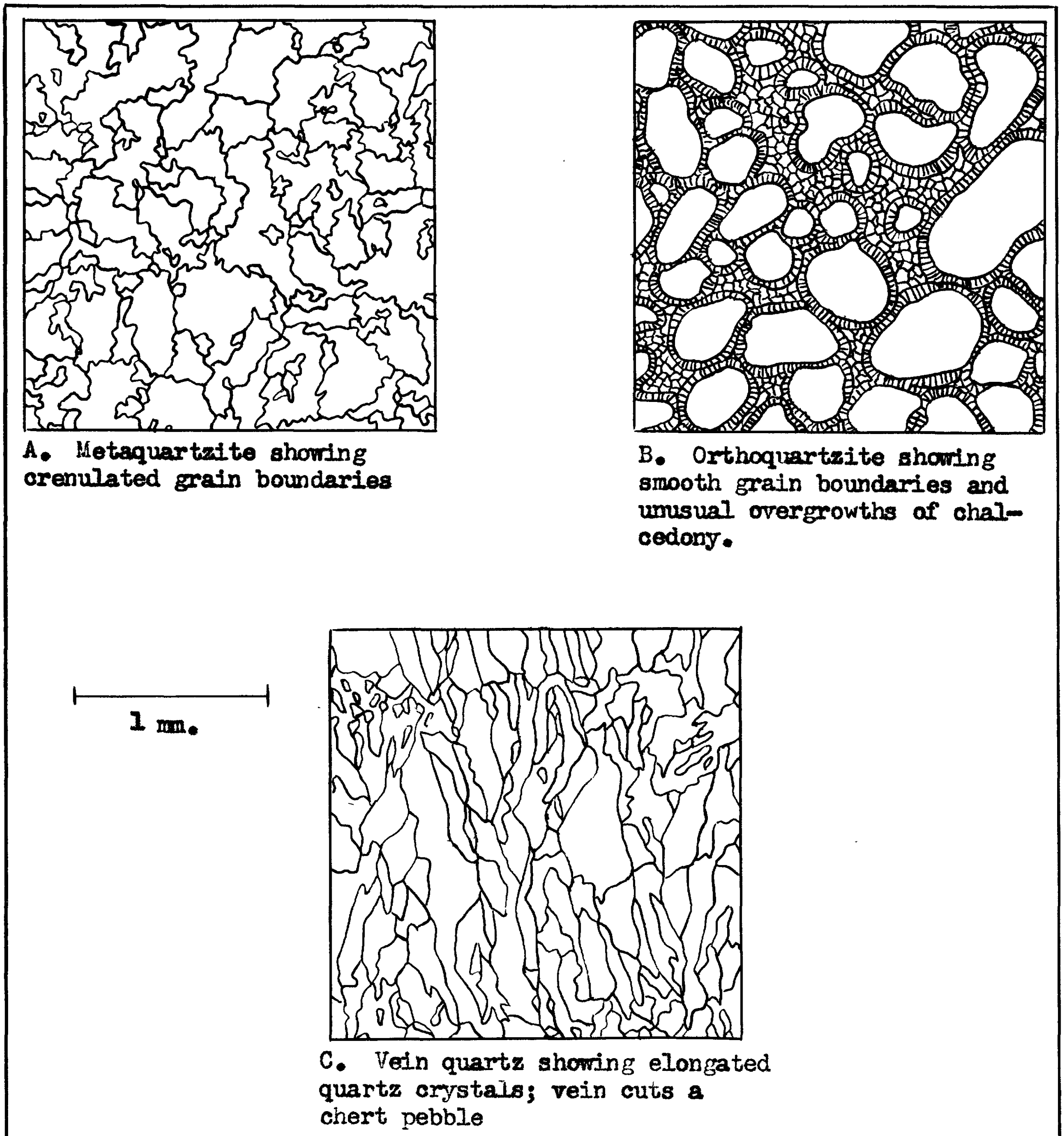
Detrital chert is most abundant in the Fuson-Lakota formations, making up an average of 4 percent of the fragments in sandstone that is medium-grained and finer, and 49 percent of sandstone coarser than medium-grained. Muscovite flakes and schist fragments are slightly more abundant in the Fall River formation than in the other formations studied. Unstrained quartz grains and composite quartz grains with parallel or semiparallel orientation and straight borders are considerably more abundant in the Unkpapa sandstone than in the other formations. Feldspar, in general, is most abundant in the lower part of the Morrison formation and decreases in abundance in the younger rocks. Many of the feldspar grains in the Fuson-Lakota and Fall River formations are weathered and partly altered to clay. Chalcedony and opal are somewhat more common cementing materials in the Fuson-Lakota formations than in the Fall River or Morrison formations.

Six samples of limestone from the Morrison formation were found to consist largely of calcilutite containing varying amounts of very fine or silt-sized angular quartz grains and locally fragments of pelecypods and ostracodes. Some of the calcilutite consists of dark, angular, apparently reworked fragments of calcilutite set in a matrix of lighter colored calcilutite and crystalline carbonate cement.

Pebbles in the Fuson-Lakota formations

Beds of claystone and sandstone in the Fuson-Lakota formations locally contain highly polished pebbles and cobbles concentrated in thin discontinuous layers. The pebbles and cobbles are as much as 6 inches in their longest dimension and commonly are 1 to 3 inches long. Many of them are irregular in shape, although all have rounded edges and corners. The pebbles and cobbles are most abundant in the northwestern part of the Black Hills. Similar pebbles and cobbles are locally abundant in equivalent rocks in other parts of Wyoming and Montana.

Collections of pebbles were made at two places on the western side of the Black Hills: at locality 36 (fig. 1), the pebbles are in the basal part of a sandy claystone bed 90 feet above the base of the Fuson-Lakota formations; and at locality 78, the pebbles are in a sandstone bed 60 feet below the top of the Fuson-Lakota formations. The table below lists the pebble varieties and their proportions at each locality as determined megascopically, and figure 6 shows 3 pebble varieties sketched from thin sections.



A. Metaquartzite showing crenulated grain boundaries

B. Orthoquartzite showing smooth grain boundaries and unusual overgrowths of chalcedony.

C. Vein quartz showing elongated quartz crystals; vein cuts a chert pebble

Figure 6.—Sketches from thin sections showing the texture of some pebbles from the Fuson-Lakota formations, northern Black Hills.

	Rock type	Locality 36	Locality 76
		Percent	
Quartzite	Red, red-purple, and pink; fine- to coarse-grained	17	26
Quartzite	Gray and brown; fine- to medium-grained	35	27
Quartzite	Light-gray to white, vitreous, fine- to coarse-grained	5	7
Chert	Mottled red, gray, and brown	13	16
Chert	Gray and brown	20	23
Chert	White	2	-
Chert	Black	2	-
Conglomerate; angular fragments of pink and purple quartzite and gray and red chert in a matrix of finer-grained light-gray quartzite.		5	1
Schist		1	-
Total number of pebbles in sample		100	173

Some mottled red, gray, and brown chert pebbles consist of cryptocrystalline granular aggregates of chalcedony with scattered very fine grained angular quartz grains. Some gray and brown chert pebbles are cryptocrystalline granular but contain silicified fossil fragments including pieces of bryozoans and fusulinids. This variety suggests chert replacement of a calcarenite. A few red-mottled chert pebbles consist almost wholly of cryptocrystalline fibrous spherulites of chalcedony.

Some of the gray, pink, and vitreous quartzite pebbles are metaquartzite consisting of moderately to strongly strained quartz grains with crenulated and granulated borders. Their texture probably resulted from pressure solution, and the granulation along the borders of some grains is probably the result of intense deformation. Other gray, pink, and grayish-white quartzite pebbles are orthoquartzite composed of rounded fine to coarse grains of quartz, metaquartzite, orthoquartzite, and chert. In some pebbles, well-rounded medium-grained quartz grains are set in a background of finer more angular quartz grains and are cemented by silica or chert.

The remaining quartzite pebbles are intermediate rock types that have some of the textural features of orthoquartzite but have incipient crenulated grain boundaries and moderate to strong straining of grains characteristic of metaquartzites.

NONOPAQUE HEAVY MINERALS

Heavy minerals were concentrated in bromoform from the very fine grained sand fraction (0.062 to 0.125 mm.) of 310 samples from the Newcastle sandstone, Inyan Kara group, and Morrison, Unkpapa, and Sundance formations; and, in addition, nonopaque heavy minerals were concentrated from the fine-grained sand fraction (0.125 to 0.250 mm.) of 40 samples from the Inyan Kara group for comparison of the heavy mineral suite in two size grades. Table 3 shows the average percentages of nonopaque heavy minerals from the very fine grained sand fraction, and table 4 compares the averages from the two size grades. The amount (by weight) of heavy minerals concentrated by bromoform in the very fine grained fraction ranges from 0.1 to 1 percent of the total grains of this size.

Some of the heavy mineral concentrates were coated with hematite or limonite, and some contained authigenic pyrite. These samples were warmed in dilute (3:1) hydrochloric acid or dilute (10:1) nitric acid from 5 to 45 minutes to remove the coatings and facilitate mineral identification.

Table 3.—Average percentages of nonopaque heavy minerals in the formations studied, Black Hills.
(0.062 to 0.125 mm. size fraction)

X, less than 1 percent, small amounts in most samples; R, rare; VR, very rare; –, absent.

		Zircon			Tourmaline			Zircon-tourmaline, combined																							
		Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total	Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral, uniaxial positive	Monazite	Total number of samples
Newcastle sandstone		16	13	29	33	6	39	49	19	68	2	7	4	–	–	–	–	R	R	–	–	–	–	18	–	R	–	–	–	–	3
Fall River formation		22	21	43	26	7	33	48	29	77	3	7	4	X	X	R	R	X	X	VR	VR	VR	X	6	VR	VR	VR	VR	VR	VR?	96
Fuson-Lakota formations		14	54	68	6	17	23	20	71	91	2	3	3	VR	VR	VR	VR	VR	R	VR	–	VR	VR	VR	R	VR	VR	VR	–	VR?	160
Unkpapa sandstone		2	86	88	R	9	9	2	95	97	2	R	X	–	–	–	–	–	R	–	–	–	–	–	R	–	–	–	–	–	13
Morrison formation	upper part locality 11	4	64	68	1	24	25	5	88	93	5	X	2	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	7
	lower part	6	23	29	17	15	32	23	38	61	28	3	3	3	–	–	R	R	R	–	–	–	R	–	VR	X	R	–	–	VR?	21
Sundance formation	Redwater shale member	6	22	28	9	23	32	15	45	60	24	3	3	5	–	–	R	–	R	–	R	–	–	R	R	3	–	–	–	–	9
	Hulett sandstone member	5	54	59	2	5	7	7	59	66	24	5	3	2	–	–	–	X	X	–	–	–	–	–	–	–	–	–	–	–	2
Precambrian rocks, central Black Hills 1/		–	–	–	10	–	10	10	–	10	33	R	X	5	31	2	X	–	R	–	–	R	R	–	–	15	X	–	–	–	3

1/ Two samples from deposits of streams draining Precambrian igneous and metamorphic rocks near Hill City and Custer, one sample from a low stream-terrace near Hill City.

Table 4.—Average percentages of nonopaque heavy minerals compared for the very fine (0.062 to 0.125 mm.) and fine (0.125 to 0.250 mm.) sand fractions, Fall River and Fuson-Lakota formations, Black Hills.

X, less than 1 percent, small amounts in most samples; R, rare; VR, very rare; –, absent.

	Size fraction (mm.)	Zircon			Tourmaline			Zircon-tourmaline, combined			Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Number of samples
		Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total																
Fall River formation	0.062 to 0.125	17	16	33	27	4	31	44	20	64	7	6	19	R	R	R	X	X	–	R	R	X	2	–	R	13
	0.125 to 0.250	R	4	4	58	8	66	58	12	70	3	3	20	R	R	–	1	R	–	–	R	2	X	–	VR	
Fuson-Lakota formations	0.062 to 0.125	14	58	72	5	15	20	19	73	92	X	2	5	VR	VR	–	–	VR	VR	–	–	VR	–	VR	–	27
	0.125 to 0.250	6	14	20	24	33	57	30	47	77	1	1	21	–	–	VR	VR	–	VR	–	–	–	–	VR	–	

Grain-roundness was noted for the tourmaline and zircon grains which commonly make up 80 to 90 percent of the nonopaque heavy-mineral concentrates in the very fine grained fraction.

No detailed study was made of the opaque heavy minerals. They consist largely of hematite and limonite aggregates, authigenic pyrite, ill-defined clay aggregates, and leucoxene and make up as much as 50 percent of the concentrates in some samples. Muscovite appears in both the light and heavy fractions, and authigenic barite appears locally in the heavy fraction of some samples. Neither of these minerals were included in computing the percentages of heavy minerals.

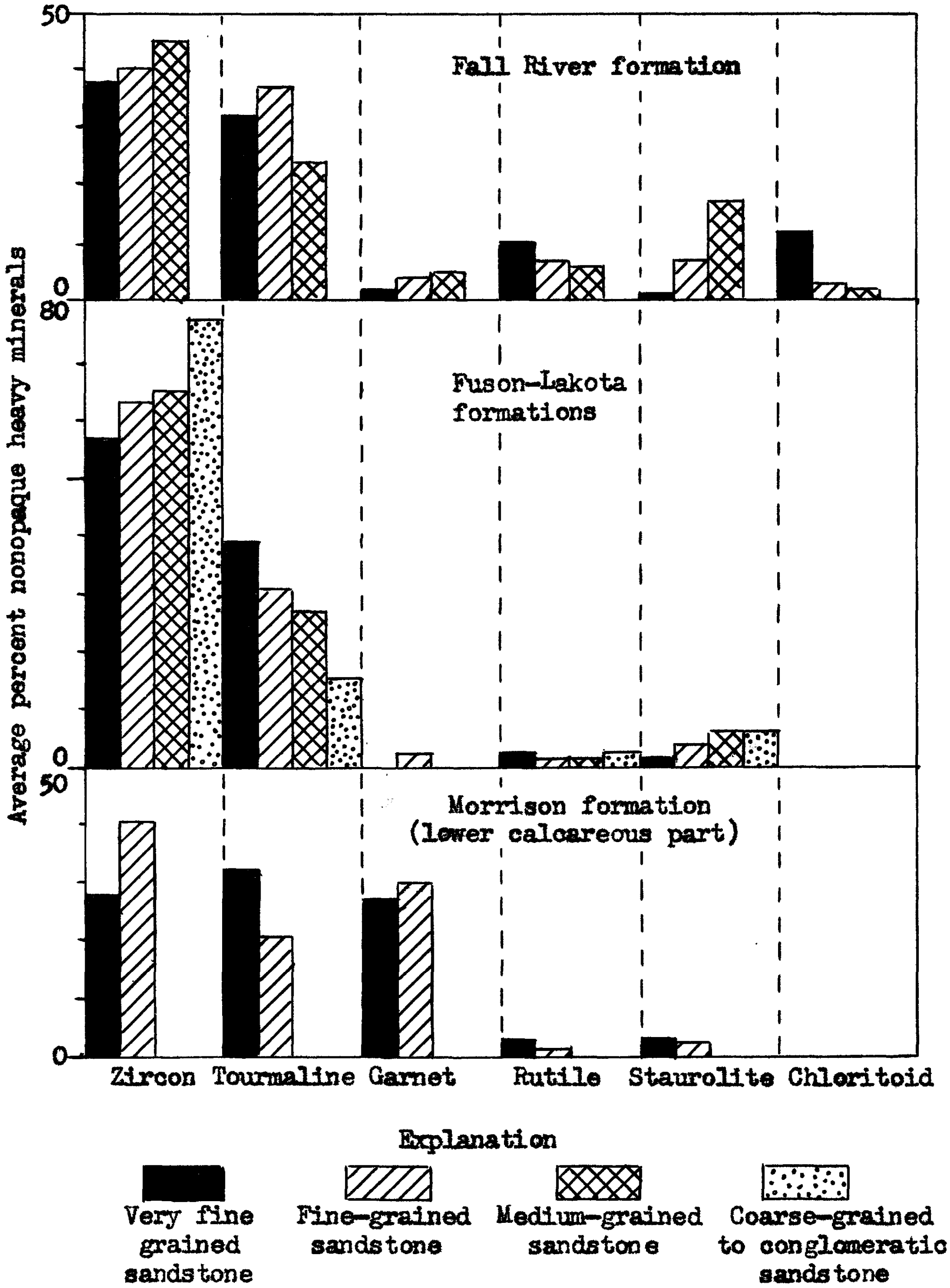
An average of about 140 nonopaque grains was counted for each sample, and percentages based on a count of that many grains are believed to be accurate to within 5 percent. Accuracy of this order is considered sufficient to show significant differences in the heavy mineral assemblages.

The very fine grained sand fraction was chosen for comparisons between samples because it is the modal size, or the next size smaller, of most of the samples, and it is a size that consistently contains a relatively large amount and variety of nonopaque heavy minerals. In making the comparisons, however, allowances must be made for the average grain size and degree of sorting of the sample because, as other investigations (Rubey, 1933; Rittenhouse, 1943; Van Andel, 1950) have shown, minerals of different specific gravity tend to be segregated in different size fractions with the greatest differences in sandstones that have the best sorting.

It can be seen by figure 7, in which samples are grouped according to their average grain size, that the proportions of zircon, garnet, and staurolite tend to increase, and the proportions of tourmaline, rutile, and chloritoid tend to decrease in the very fine grained sand fraction with increasing average grain size of the sandstone. If allowances are made for these shifts in proportions, otherwise consistent differences in the heavy minerals suites should be useful in correlations. It should be emphasized, however, that, because the proportions of heavy minerals of one grain size do not necessarily reflect the proportions of heavy minerals in all sizes taken together, the study of one grain size gives only limited information in evaluating the relative importance of various sources for the deposits.

Heavy mineral zones

The nonopaque heavy mineral suites in the very fine grained sand fraction of samples from all of the formations studied show a general similarity. Most of the samples contain zircon and tourmaline as the major constituents, and varying but lesser amounts of garnet, rutile, and staurolite as the principal minor constituents. Nevertheless, three fairly consistent zones can be recognized by the proportions of minerals, presence of a few distinctive minerals, and shapes of the tourmaline and zircon grains.



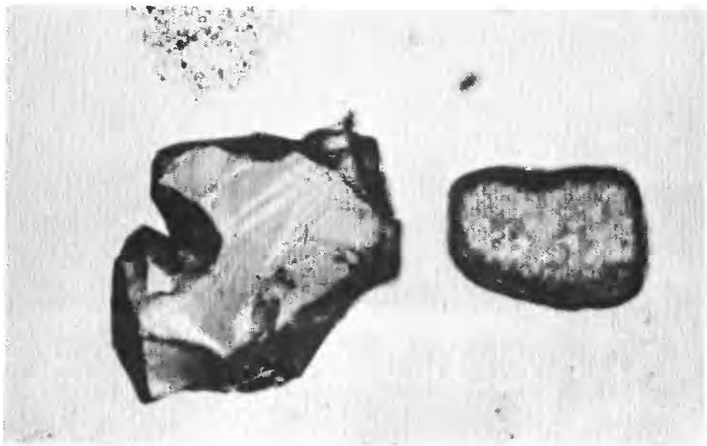
Average grain size	Number of samples averaged		
	Fall River	Fuson-Lakota	Morrison
Very fine grained	26	27	6
Fine grained	35	46	15
Medium grained	5	12	-
Coarse gr. to conglomeratic	-	6	-

Figure 7.—Diagram showing the change in proportions of some nonopaque heavy minerals in the very fine grained sand fraction of samples having different average grain sizes, Fall River, Fuson-Lakota, and Morrison formations, Black Hills.

The lowest of the three zones includes the Hulett sandstone and Redwater shale members of the Sundance formation and the lower calcareous part of the Morrison formation. Relatively large amounts of garnet characterize the nonopaque heavy mineral suite from these rocks, averaging 30 percent garnet in the suites from 32 samples. The garnet is mostly light violet and light pink but includes some red grains in samples from the lower part of the Morrison formation at localities 11 and 40. The garnet grains are both rounded and angular and some of them are etched. (See fig. 8.) Garnet is fairly abundant in the basal 20 feet of the Unkpapa sandstone at Sheps Canyon (loc. 74), and in this respect the basal part of the Unkpapa resembles the lower calcareous part of the Morrison formation.

Zircon and tourmaline generally make up about 60 percent of the nonopaque heavy mineral suite in the lowest zone. Tourmaline tends to be slightly more abundant than zircon, and rounded zircon and tourmaline grains are more abundant than angular ones in the ratio of about 2 rounded grains to 1 angular grain.

Apatite is locally abundant, usually occurring as rounded grains, but angular grains and a few broken euhedral crystals were observed in some samples. The nonopaque concentrate of one sample from the Redwater shale member of the Sundance formation at locality 11 contains 30 percent apatite, and several other samples from sandstone beds in the lower zone contain from 1 to 10 percent apatite in the concentrate. Biotite is present in two samples: one sample from the Redwater shale member of the



0.1 mm.

Figure 8.--Angular and rounded garnet grains in a sample from the lower part of the Morrison formation, Black Hills (locality 40).

0.1 mm.

Figure 9.--Euhedral apatite crystal in a sample from the lower part of the Fall River formation, Black Hills (locality 76).

Sundance formation at locality 11 contains 21 percent biotite, and one from the lower part of the Morrison formation at locality 103 contains 3 percent biotite in the nonopaque suite. Rutile and staurolite are common in the nonopaque suite from the lowest zone in amounts averaging about 3 percent for each mineral. Other nonopaque heavy minerals found in a few samples in trace amounts include andalusite, brookite, anatase, sphene, chlorite, chloritoid, spinel, epidote, and monazite (?).

The next higher heavy mineral zone includes the upper noncalcareous part of the Morrison formation, most of the Unkpapa sandstone, and most or all of the Fuson-Lakota formations at most localities. Zircon and tourmaline make up 75 to 100 percent of the nonopaque heavy mineral suite in this zone, and the two minerals together average 92 percent of the suite in the samples examined. Zircon is more abundant than tourmaline with an average ratio of about 5 zircon grains to 2 tourmaline grains, but the proportions are not consistent. The characteristic feature of the heavy minerals in this zone is the rounding of the zircon and tourmaline grains. The average ratio of rounded to angular grains is about 7 to 2 for samples of the Fuson-Lakota formations with rounded grains predominating, and the ratio is about 45 to 1 and 18 to 1 in samples from the Unkpapa sandstone and upper part of the Morrison formation, respectively.

Garnet occurs erratically in the middle zone in amounts rarely exceeding 5 percent of the nonopaque heavy minerals; in many samples garnet is absent. An exception is the lower part of the Fuson-Lakota formations at locality 33 where a conglomeratic sandstone 95 feet thick at the base of the Fuson-Lakota formations rests within 5 feet of the top of the Sundance formation. Garnet makes up 10 to 15 percent of the nonopaque heavy mineral suite in several samples from various stratigraphic levels in this sandstone. The garnet colors are the same as in the lower zone, and both rounded and angular grains were noted. The garnet in the Fuson-Lakota formations at this locality may have been derived by local reworking of the Morrison formation.

Rutile and staurolite are generally present but somewhat erratically distributed in the middle zone. Each of the two minerals averages about 3 percent of the nonopaque heavy mineral suite in the very fine grained fraction, and in individual samples rutile rarely exceeds 10 percent and staurolite 15 percent.

Other minerals rarely found in the middle zone include apatite, hornblende, clinozoisite, andalusite, brookite, anatase, kyanite, sillimanite, chlorite, spinel, biotite, epidote, corundum, and monazite.

Rocks comprising the upper heavy mineral zone include the upper part of the Fuson-Lakota formations in the vicinity of Aladdin and Mona Butte at the northern end of the Black Hills (localities 80 and 79), the Fall River formation, and the Newcastle sandstone. As in the lower two zones, zircon and tourmaline predominate, ranging from 40 to more than 90 percent and averaging about 75 percent of the nonopaque heavy minerals. Zircon tends to be more abundant than tourmaline with an average ratio of about 4 zircon grains to 3 tourmaline grains, but tourmaline greatly exceeds zircon in some samples.

The grains in the upper zone tend to be predominantly angular in the ratio of about 5 angular grains to 3 rounded ones. As shown by figure 10, the boundary between the middle and upper zones in 7 out of 13 localities is marked by a fairly abrupt change in grain roundness at the Fall River-Lakota contact. At 4 localities (locs. 78, 202, 76, and 31) the principal change in grain roundness is very near the top of the Fuson-Lakota formations, and at 2 localities (locs. 81 and 79) the change from rounded to angular grains is sharp but is within the Fuson-Lakota formations about 80 to 100 feet below the top. At locality 104, zircon and tourmaline grains in the Fall River formation tend to be more rounded than average, and the two zones overlap in the lower part of the Fall River formation. Figure 11 illustrates the differences in grain roundness across the contact at locality 71. On the whole, differences in grain roundness are consistent enough to be useful in separating the Fall River from the Fuson-Lakota formations along much of the west flank of the Black Hills.

Chloritoid occurs somewhat erratically but is locally abundant in samples from the Fall River and Newcastle formations. No chloritoid was found in the Fuson-Lakota formations except for a single grain in a sample from the upper part of this sequence at locality 81. In general,

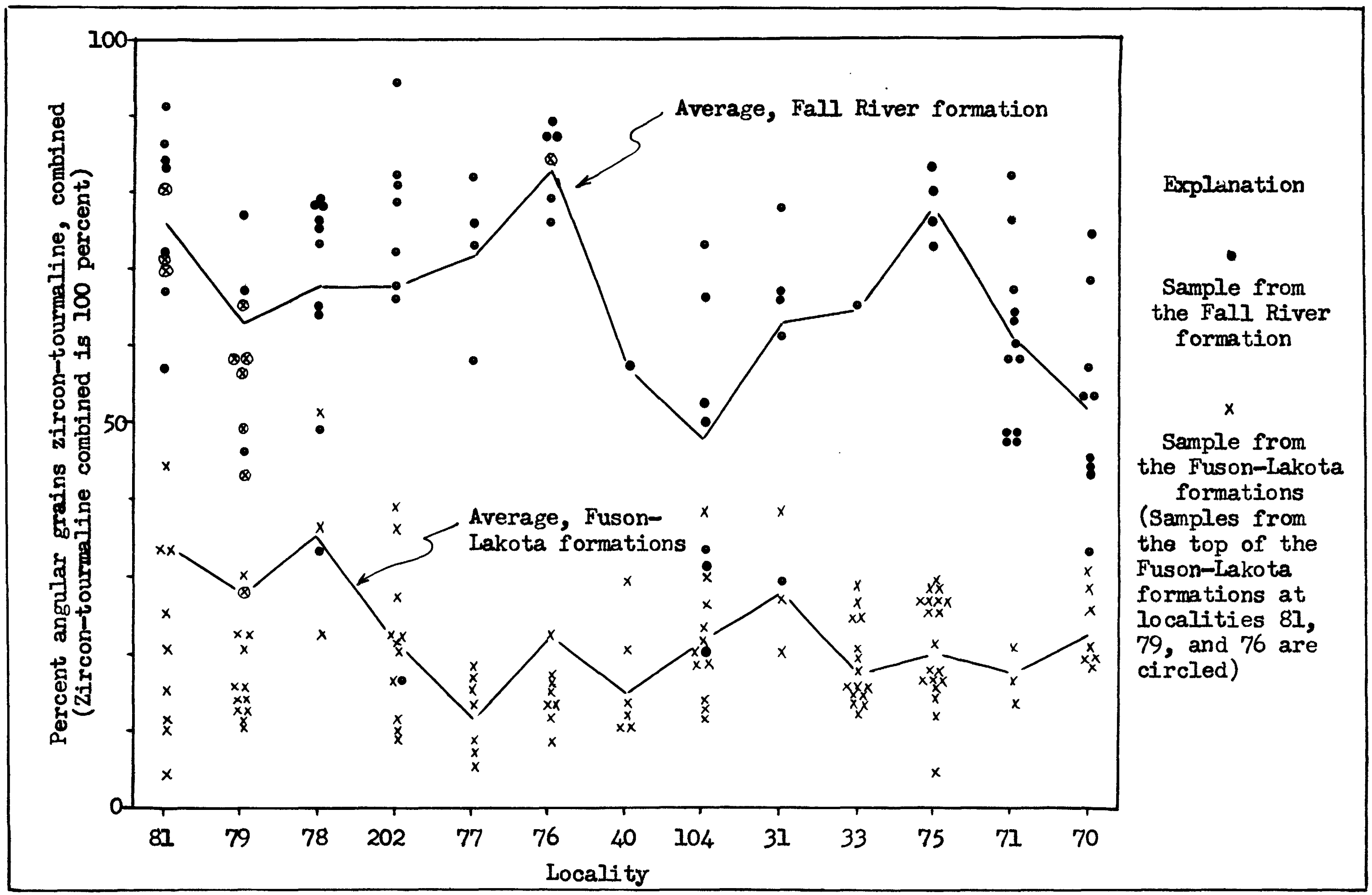
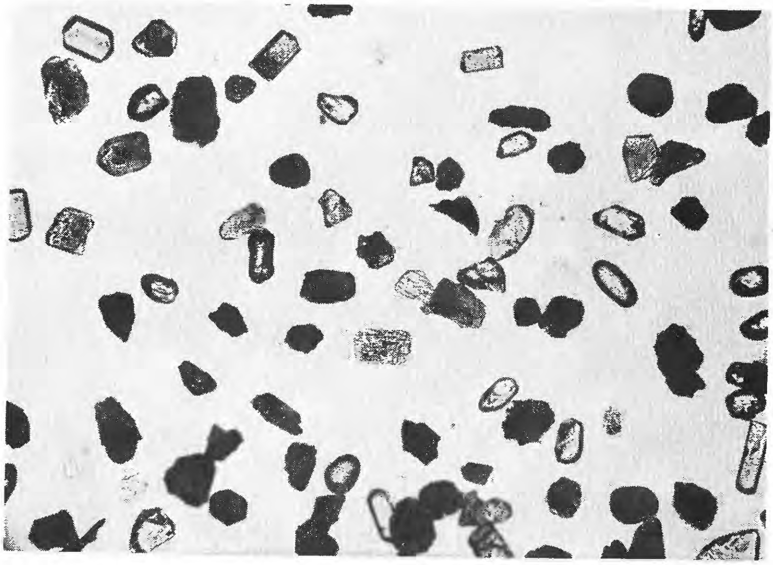
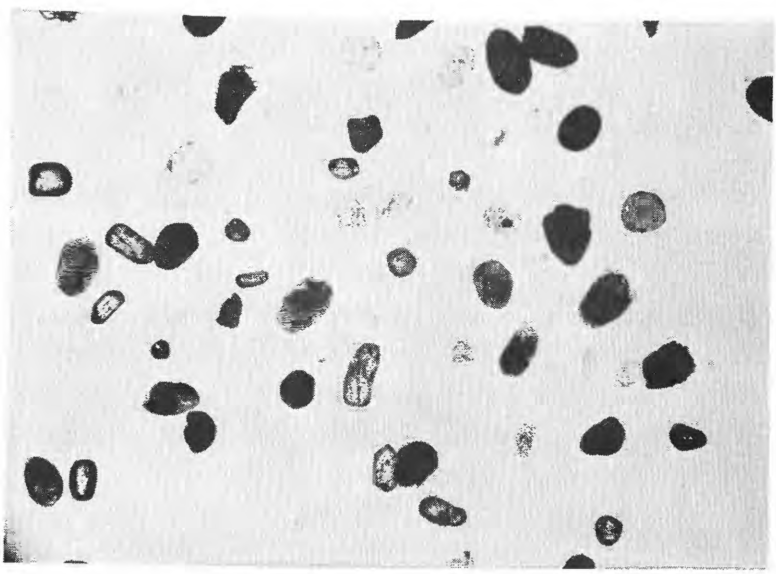


Figure 10.—Diagram showing angularity of zircon and tourmaline grains in samples from the Fall River and Fuson-Lakota formations (0.062 to 0.125 mm. size fraction).



A. Fall River formation, 20 feet above the base, grains are predominantly angular.



B. Fuson formation, 4 feet below the top, grains are predominantly rounded.

1 mm.

Scale

Figure 11.--Heavy mineral concentrates from the basal part of the Fall River formation and the upper part of the Fuson formation at locality 71 showing difference in proportion of rounded and angular grains.

chloritoid appears to be somewhat more common in the northern part of the Black Hills than in the southern part.

Garnet is more consistently present in the upper zone than in the middle zone. Rutile and staurolite are present in about the same proportions as in the lower two zones. Brown and green-brown hornblende were found fairly abundantly in a few samples, notably at locality 202 where hornblende makes up 26 percent of the suite in a sample from the middle part of the Fall River formation, and at locality 81 where hornblende makes up 18 percent of the suite in a sample from the lower part of the formation. Apatite occurs both as rounded grains and euhedral crystals (fig. 9) and it is fairly common in the upper zone in small amounts. Apatite was noted particularly at locality 76 where as much as 17 percent apatite is present in the suite of a sample from near the base of the Fall River.

Several other minerals are found from place to place, mostly in trace amounts; but, except for chloritoid and hornblende, the suite is essentially the same as for the middle zone.

Table 5 shows the varieties of tourmaline grains classified according to color in the Fall River and Fuson-Lakota formations in the very fine grained sand fraction. Brown and green-brown tourmaline predominate. No appreciable difference was noted in the proportions of the various colors in rounded and angular grains.

Table 5.--Tourmaline grains classified by color, Fall River and Fuson-Lakota formations, Black Hills. (in percent; 0.062 to 0.125 mm. size fraction)

X, less than 1 percent; -, absent

	Locality number	Crystals and angular grains										Rounded grains										
		Brown	Green-brown	Green	Blue and gray-blue	Gray	Pink to opaque	Orange and yellow	Red-brown	Colorless	Bicolor, brown and blue	Total number of grains counted	Brown	Green-brown	Green	Blue and gray-blue	Gray	Pink to opaque	Orange and yellow	Red-brown	Colorless	Bicolor, brown and blue	Total number of grains counted
Fall River formation	81	59	23	1	3	-	7	5	1	X	-	300	62	22	3	5	-	-	6	-	2	-	64
	202	55	17	3	7	X	6	9	2	-	X	490	57	14	3	3	X	5	13	4	-	-	84
	76	55	9	10	5	X	2	18	1	X	-	349	57	7	2	4	4	-	24	-	-	2	49
	31	44	36	3	5	-	3	9	-	-	-	244	43	27	4	7	-	3	15	-	-	-	67
	70	51	32	2	5	X	4	5	-	X	-	237	46	38	3	7	-	1	4	1	-	-	76
Weighted average		54	21	4	5	X	5	10	X	X	X	1620	53	22	3	5	1	2	12	1	X	X	340
Fuson-Lakota formations	80	49	25	4	6	-	7	8	-	-	-	80	54	27	X	6	-	1	11	-	-	X	324
	81	48	30	2	5	-	9	5	X	-	X	303	50	25	1	6	-	3	11	3	X	-	200
	202	41	15	3	10	-	-	28	3	-	-	39	50	24	3	6	X	2	15	X	-	-	240
	76	67	7	11	4	3	X	8	X	-	-	160	65	15	3	3	-	X	14	-	-	-	360
	33	50	21	7	8	X	2	8	4	-	-	131	53	27	1	5	-	3	9	2	-	X	555
	70	34	37	-	14	-	6	9	-	-	-	35	58	22	2	5	-	3	9	1	-	-	201
Weighted average		51	22	5	6	2	5	7	X	-	X	748	55	24	2	5	X	2	11	1	X	X	1880

Heavy minerals were separated from the fine-grained sand fraction of 40 samples from the Fall River and Fuson-Lakota formations to check for differences in the mineral suite between the fine-grained and very fine grained fractions. (See table 4.) In both formations tourmaline increases at the expense of zircon in the coarser size. Staurolite averages about the same for the two size fractions in samples from the Fall River formation but increases markedly from an average of 5 percent to 21 percent of the nonopaque heavy mineral suite in the coarser size in samples from the Fuson-Lakota formations. The percentage of angular zircon and tourmaline grains increases appreciably, and the percentage of rounded grains decreases in both the Fall River and the Fuson-Lakota formations. Except for these differences, the mineral suites are similar.

SOURCE

The impoverished nonopaque heavy mineral suite and the large proportion of quartz grains suggest that all formations studied were derived principally from pre-existing sedimentary rocks. Much of the clastic material has probably undergone several cycles of sedimentation as shown by the high proportion of rounded zircon and tourmaline grains, particularly in the Fuson-Lakota, Unkpapa, and upper part of the Morrison formations. Limestone was extensively exposed in the source area or areas during deposition of the Fuson-Lakota formations, judging by the large amount of chert fragments in the coarse-grained sandstone and conglomerate. During deposition of the Fall River formation, streams in the source area apparently cut through the sedimentary cover and exposed metamorphic rocks as shown by the rather consistent presence of schist fragments in small amounts, the increase in muscovite, and the local abundance of chloritoid in the Fall River formation. The increase in angular tourmaline and zircon grains in the Fall River formation suggests an increased contribution of first-cycle sedimentary material, perhaps from metamorphic or igneous rocks. Except in the Aladdin and Mona Butte areas, the change upward from predominantly rounded to predominantly angular heavy mineral grains is fairly sharp at the top of the Fuson-Lakota formations. If this change was essentially simultaneous for all of the Black Hills, then presumably the upper 80 to 100 feet of the Fuson-Lakota formations at Aladdin and Mona Butte, which contain predominantly angular zircon and tourmaline grains, are younger than the upper part of the sequence at most sections sampled elsewhere.

The locally abundant biotite and euhedral, needle-like apatite crystals in the Redwater shale member of the Sundance formation and in the Fall River formation and the locally abundant hornblende in the Fall River formation suggest the possibility of some pyroclastic material in these formations.

Crowley (1951) has suggested, on the basis of spectrographic analyses of detrital gold from the Newcastle sandstone and the presence of cassiterite in opaque heavy mineral suites from the Newcastle and Fall River formations, that Precambrian rocks in the Black Hills furnished some sediment to the Newcastle sandstone and to the Inyan Kara group.

Nonopaque heavy minerals from the very fine grained sand fraction of 3 samples of recent stream deposits derived from the Precambrian core of the Black Hills in the Hill City-Custer area are shown on table 3. The suite from the Hill City-Custer area differs strikingly from the suites from the Newcastle sandstone and Inyan Kara group by having no zircon, relatively little tourmaline, no chloritoid, and relatively large amounts of garnet, hornblende, and biotite. Not enough samples have been analyzed, however, to say whether or not the Hill City-Custer suite reported here is representative of more than a small part of the Precambrian core of the Black Hills.

At least three major channel systems have been identified in the Fuson-Lakota and Fall River formations by Geological Survey field parties in the southern Black Hills (D. A. Brobst, TEI-640, p. 102-108). In all three systems, the stream flow was from the southeast indicating a source of sediments in that direction.

SUMMARY

Some similarities and differences in sandstone of the formations studied are summarized by figure 12. Grain-size and thin section analyses show slight differences between the formations examined, but the differences are not consistent enough to be used in broad stratigraphic correlations. Fairly consistent differences in the heavy mineral suite, however, permit differentiation of the sequence into three fairly consistent zones. The change from dominantly rounded to dominantly angular

Figure 12.--Some characteristics of sandstone from the formations studied.

	Sorting and grain size	Light minerals	Heavy minerals (0.062 to 0.125 mm.)
Fall River formation	Well sorted; mostly fine- to very fine grained.	Feldspar, muscovite, and schist fragments fairly consistent in small amounts.	Predominantly angular zircon and tourmaline grains; locally abundant chloritoid, hornblende, and apatite; small amounts of garnet.
Fuson-Lakota formations, undivided	Well sorted to poorly sorted; mostly fine-grained but some medium to very coarse grained sandstone.	Abundant chert in coarser-grained beds; feldspar locally present in small amounts; muscovite and schist fragments rare.	Predominantly rounded zircon and tourmaline grains; essentially no chloritoid, hornblende, or apatite; essentially no garnet except in lower part at one locality (loc. 33).
Unkpapa sandstone	Well sorted; mostly fine-grained.	Some feldspar; muscovite and schist fragments rare; relatively high proportion of unstrained quartz grains, and composite quartz grains having particles in parallel optical orientation with smooth particle boundaries.	Predominantly rounded zircon and tourmaline grains; no chloritoid, hornblende, or apatite; essentially no garnet except in bottom few feet.
Morrison formation (lower part)	Well sorted; fine- to very fine grained.	Relatively high proportion of feldspar; muscovite and schist fragments rare.	Predominantly rounded zircon and tourmaline grains; essentially no chloritoid or hornblende; apatite fairly abundant locally; garnet abundant.

nonopaque heavy mineral grains in the very fine grained sand fraction of the sandstone beds in the Inyan Kara group is sharp enough to be useful in subdividing the group for regional correlations.

Sediments composing the sandstones of the formations examined were probably derived mainly from pre-existing sedimentary rocks with an influx of material from metamorphic or igneous rocks during deposition of the Fall River formation.

TABULATION OF DATA

Mineral and rock fragments identified in the thin sections and in the heavy-mineral concentrates of individual samples are given by the tables below. Table 6 shows the grains and matrix identified in thin sections of sandstone and siltstone, and table 7 shows the grains and matrix identified in thin sections of limestone. Table 8 shows the grains identified in the heavy mineral concentrates.

Table 6.—Percentages of rock-forming materials in thin sections of sandstone and siltstone, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills.

	Sample number	Grain size 1/	Mineral and rock fragments: Quartz: Individual grains: Unstrained	Moderately strained	Strongly strained	Composite grains: Parallel orientation, straight borders	Semi-parallel orientation, smooth borders	Random orientation, smooth borders	Randon orientation, crenulated borders	Total	Feldspar: Orthoclase	Microcline	Plagioclase	Total	Muscovite	Chert	Chalcedony	Claystone	Schist	Matrix: Clay paste: Unstained	Ferruginous	Chert	Opal	Silica	Chalcedony	Carbonate	Total	Voids
Locality 80																												
Fuson-Lakota formations	5	F	31	20	14	1	1	-	16	83	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	15
	4	F	34	29	14	-	-	1	10	88	1	1	1	3	-	1	-	-	-	8	-	-	-	-	-	-	8	-
	3	F	27	26	12	2	1	1	2	71	3	-	1	4	-	5	1	-	-	19	-	-	-	-	-	-	19	-
Locality 81																												
Fall River formation	4*	VF	26	13	23	1	-	-	4	67	-	1	2	3	3	5	-	1	9	-	-	-	8	-	-	-	8	4
	3	S	30	24	22	-	-	-	6	82	-	-	-	-	6	-	-	-	12	-	-	-	-	-	-	-	-	-
	2	F	24	17	24	1	4	-	9	79	-	-	1	1	2	1	-	-	6	-	9	-	-	-	-	-	9	2
Fuson-Lakota fms.	1	F	27	18	27	1	-	1	15	94	-	-	-	-	-	2	-	-	-	-	-	-	-	-	9	-	9	-
* 1 percent calcilutite																												
Locality 79																												
Fall River fm.	1	M	31	17	9	-	5	1	10	73	-	1	-	1	-	4	1	-	3	-	-	-	-	-	18	-	18	-
Fuson-Lakota formations	2	VF	28	21	12	2	-	-	2	65	-	-	-	-	-	-	-	-	-	35	-	-	-	-	-	-	35	-
	3	F	28	21	11	-	2	-	6	68	-	-	-	-	1	1	-	-	2	-	-	12	-	-	-	-	12	16
	4	C	4	8	6	-	-	-	4	22	-	-	-	-	-	49	-	-	-	-	-	7	-	-	1	-	8	21
	5*	M	34	18	8	1	-	-	4	65	1	-	-	1	-	19	-	-	-	-	-	-	-	-	14	-	14	-
	6	VF	42	24	14	1	1	2	4	88	-	-	-	-	-	3	-	-	-	-	-	-	-	-	9	-	9	-
* 1 percent sandstone fragments.																												
Locality 78																												
Fall River formation	11	VF	26	20	18	-	-	-	2	66	-	-	-	-	12	-	-	-	12	10	-	-	-	-	-	-	10	-
	10	VF	16	28	30	-	-	-	-	74	-	-	-	-	16	-	-	-	-	10	-	-	-	-	-	-	10	-
	8	S	34	26	22	-	-	-	-	82	-	-	-	-	4	-	-	-	6	8	-	-	-	-	-	-	8	-
	7	VF	33	20	27	-	-	-	4	84	1	1	-	2	2	1	-	-	7	-	-	1	-	-	-	-	1	3
	6	F	21	24	29	-	-	-	12	86	-	2	1	3	-	2	-	-	1	-	-	-	-	-	-	-	-	8
	5	S	4	10	6	-	-	-	-	20	-	-	-	-	14	-	-	-	-	-	66	-	-	-	-	-	66	-
Fuson-Lakota formations	4*	VF	31	26	24	-	-	-	4	85	-	-	-	-	-	1	-	1	-	1	-	-	6	-	-	-	7	-
	3	VF	6	16	13	-	-	-	2	37	-	-	-	-	20	-	-	-	-	43	-	-	-	-	-	-	43	-
	2	F	27	15	15	-	-	-	6	63	-	-	-	-	-	-	1	-	-	-	-	-	36	-	-	-	36	-
	1	F	24	21	17	1	-	-	1	64	-	-	-	-	-	1	1	-	-	-	-	-	34	-	-	-	34	-
* 6 percent carbonaceous fragments																												
Locality HC 202																												
Fall River formation	1	F	33	32	15	-	-	-	7	87	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	12
	2	VF	30	36	14	-	2	-	-	82	-	-	-	-	4	2	-	-	4	-	-	-	-	-	-	2	2	6
	3	F	21	27	10	1	5	-	5	69	-	-	1	1	3	5	-	1	2	14	-	-	-	-	-	3	17	2
Lakota-Fuson formations	4	VF	24	32	8	-	-	-	4	68	2	-	-	2	-	-	-	-	-	30	-	-	-	-	-	-	30	-
	5	Cg	24	25	14	1	-	-	3	67	-	-	-	-	-	4	-	-	-	-	-	2	-	-	27	-	29	-
	6	VF	41	31	8	1	1	-	9	91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
	7	M	18	19	6	1	1	-	2	47	-	-	-	-	-	16	-	-	-	-	-	-	-	-	37	-	37	-
	8	F	23	28	17	-	-	-	5	73	-	2	-	2	-	4	-	-	-	1	-	-	-	-	9	10	20	1
Locality 77																												
Fall River fm.	8	VF	28	22	8	1	6	3	5	73	1	-	2	3	1	4	-	1	4	-	-	-	-	-	-	-	-	14
	7	VF	31	31	24	3	1	-	-	90	1	-	2	3	-	6	-	-	-	-	-	-	-	-	-	-	-	1
Fuson-Lakota fms.	5*	C	20	4	3	2	-	-	-	29	-	-	-	-	-	19	1	-	-	-	-	-	-	-	-	28	28	-
	3	Cg	19	10	10	1	-	-	4	44	-	-	-	-	-	35	7	-	-	-	-	2	-	-	-	12	14	-
Morrison fm.	2	F	8	22	15	-	-	-	3	48	2	1	2	5	1	2	-	3	1	-	-	-	-	-	-	40	40	-
	1	F	10	15	11	2	1	-	6	45	2	2	2	6	-	2	-	2	-	-	-	-	-	-	-	45	45	-
* 23 percent calcilutite																												
Locality 76																												
Fall River formation	11	VF	7	31	44	-	1	-	6	89	-	-	-	-	3	-	-	2	2	4	-	-	-	-	-	-	4	-
	10	F-VF	25	31	13	1	-	4	6	80	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	19
	9	VF	9	21	40	2	-	2	7	81	1	-	2	3	-	-	-	3	8	5	-	-	-	-	-	-	5	-
	8	F	24	27	20	-	1	-	9	81	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	17
Fuson-Lakota formations	7	VF	12	20	20	-	3	6	15	76	-	-	-	-	2	1	-	-	6	2	-	-	-	-	-	-	2	13
	6	F	9	25	22	-	-	-	3	59	-	-	-	-	-	5	-	-	-	36	-	-	-	-	-	-	36	-
	5	F	7	34	25	-	-	1	4	71	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-	21
	4	F	25	24	18	-	-	9	9	85	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	8
	3	F	22	20	22	-	-	-	-	64	-	-	-	-	1	-	-	-	-	35	-	-	-	-	-	-	35	-
	2	F	23	31	17	1	-	5	3	80	2	1	-	3	-	3	-	-	-	-	-	-	-	-	-	-	-	14
	1	Cg	2	1	2	-	-	4	-	9	-	-	-	-	-	78	1	-	-	-	-	7	-	-	1	-	8	4
Locality 40																												
Fall River fm.	15	VF	4	10	10	-	-	2	2	28	-	-	-	-	-	2	-	-	-	-	70	-	-	-	-	-	70	-
	14	VF	26	26	24	2	-	-	-	78	-	-	2	2	4	2	-	-	-	14	-	-	-	-	-	-	14	-
Fuson-Lakota formations	13	VF	31	26	30	2	-	-	1	90	-	-	-	-	-	3	-	-	-	7	-	-	-	-	-	-	7	-
	12	C	6	1	6	-	1	-	2	16	-	-	-	-	-	55	6	-	-	-	-	-	21	-	-	-	21	2
	11	F	28	17	21	-	1	2	13	82	2	-	1	3	-	2	-	-	-	-	-	-	2	-	-	-	2	11
	10	F	26	16	21	1	-	-	6	70	1	1	2	4	1	-	1	-	-	-	-	-	-	-	-	-	-	24
Morrison fm.	2	F-VF	38	7	1	-	-	-	5	51	-	1	2	3	-	-	-	-	-	-	-	-	-	-	-	46	46	-
Locality 11																												
Fuson-Lakota formations	10	F-VF	33	27	21	2	1	-	5	89	-	-	-	-	-	3	-	-	-	-	-	5	3	-	-	-	8	-
	9	Cg	7	1	3	-	-	-	6	17	-	-	-	-	-	66	5	-	-	-	-	-	-	-	8	-	8	4
	8	Cg	5	3	4	-	-	-	-	12	-	-	-	-	-	77	-	-	-	-	-	-	4	-	-	-	4	7
	7	F	32	23	24	2	-	-	7	88	1	-	1	2	-	6	-	-	-	-	-	-	3	-	-	-	3	1
	6	F-VF	23	25	27	-	-	-	7	82	1	1	-	2	-	2	-	-	-	-	-	-	8	-	-	-	8	6
	5	F	20	26	21	1	-	-	7	75	1	-	-	1	1	-	-	-	2	-	-	-	-	-	21	-	21	-
Morrison fm.	4	F-VF	35	20	24	-	-	-	7	86	1	1	2	4	-	-	1	-	-	-	-	-	-	-	-	-	-	9
	3	VF	26	16	25	1	-	-	5	73	-	-	5	5	-	1	-	-	1	-	-	-	-	-	-	-	-	20
Sundance fm.	1*	VF	19	10	14	-	-	-	1	44	1	-	1	2	-	-	-	-	-	-	-	-	-	-	-	40	40	-
* 13 percent glauconite, 1 percent calcilutite																												

1/ S, siltstone; VF, very fine grained; F, fine-grained; M, medium-grained; C, coarse-grained; Cg, very coarse grained to conglomeratic.

Table 6.—Percentages of rock-forming materials in thin sections of sandstone and siltstone, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills—Continued.

			Mineral and rock fragments																		Matrix							
			Quartz								Feldspar									Clay paste								
			Individual grains			Composite grains																						
	Sample number	Grain size 1/	Unstrained	Moderately strained	Strongly strained	Parallel orientation, straight borders	Semi-parallel orientation, smooth borders	Random orientation, smooth borders	Random orientation, crenulated borders	Total	Orthoclase	Microcline	Plagioclase	Total	Muscovite	Chert	Chalcedony	Claystone	Schist	Unstained	Ferruginous	Chert	Opal	Silica	Chalcedony	Carbonate	Total	Voids
Locality 6																												
Fall River formation	8	VF	18	11	12	-	-	3	8	52	1	1	1	3	2	2	1	-	4	-	-	-	-	-	-	36	36	-
	7	F-VF	21	17	25	1	1	1	9	75	1	-	1	2	1	1	-	-	6	-	-	-	2	-	-	-	2	13
	6	F	25	21	19	2	1	4	12	84	1	-	1	2	-	1	-	-	1	-	-	-	-	-	-	-	-	12
	5	F	24	20	26	1	6	-	11	88	-	-	1	1	2	1	-	-	3	1	-	-	-	-	-	-	1	4
	4	VF	32	26	13	3	4	-	8	86	-	-	1	1	1	3	-	-	-	1	-	-	-	1	-	-	2	7
	3	VF	34	25	19	3	-	2	3	86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
	2	VF	41	26	17	4	-	3	4	95	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	2	2
Fuson-Lakota fms.	1	M	49	10	14	4	-	-	8	85	-	-	-	-	-	-	-	-	-	2	-	3	-	-	-	-	5	10
Locality 31																												
Fall River fm.	3	VF	43	27	9	2	2	1	7	91	-	1	-	1	-	2	-	-	2	-	-	-	-	-	-	-	-	4
Fuson-Lakota fms.	2	VF	28	19	5	2	-	-	2	56	-	-	-	-	-	-	1	-	-	43	-	-	-	-	-	-	43	-
	1	F	30	18	10	8	1	-	4	71	-	-	-	-	-	3	-	-	-	26	-	-	-	-	-	-	26	-
Locality 33																												
Fall River fm.	8	VF-S	30	20	7	1	3	2	3	66	-	-	-	-	-	3	-	-	-	26	-	-	-	-	-	-	26	5
Fuson-Lakota formations	7	VF	36	10	6	-	-	-	3	55	-	-	-	-	-	2	-	-	-	7	-	-	-	-	-	36	43	-
	6	F	20	25	20	3	1	3	6	78	-	-	1	1	-	4	-	-	-	-	-	-	-	-	-	-	-	17
	5	M-F	36	19	12	2	-	-	6	75	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	24
	4	VF	33	27	9	-	-	-	8	77	-	1	1	2	-	7	1	-	-	4	-	-	-	-	-	-	4	9
	3	F	46	13	7	2	-	-	8	76	1	-	-	1	-	5	-	-	-	2	-	-	-	-	-	-	2	16
	2	Cg	5	4	2	-	-	-	9	20	-	-	-	-	-	64	5	-	-	-	-	-	-	-	-	-	-	11
Locality 75																												
Fall River formation	1*	VF	22	24	12	1	2	-	6	67	-	-	-	-	1	-	-	-	-	-	31	-	-	-	-	-	31	-
	2	F	38	20	15	1	1	-	9	84	-	-	-	-	1	1	-	-	1	1	-	-	-	-	-	-	1	12
	3	F	26	27	16	-	-	-	6	75	2	-	-	2	1	-	-	-	1	-	-	-	-	-	-	-	-	21
	4	F	25	20	19	1	-	2	11	79	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	20
	5	F	25	23	18	1	1	4	5	77	1	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	21
Fuson-Lakota formations	6	VF	21	23	17	-	-	1	4	66	-	-	-	-	-	3	-	-	-	31	-	-	-	-	-	-	31	-
	7	F-VF	34	19	20	1	-	-	8	82	1	2	1	4	-	2	1	-	-	-	-	1	-	-	-	-	1	10
	8	F-VF	32	25	17	1	-	-	3	78	1	-	-	1	-	2	-	-	-	-	-	1	-	-	-	-	1	18
	9	F-VF	40	20	20	1	-	-	2	83	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	15
	10	F-VF	36	24	15	2	-	-	4	81	-	2	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	16
	11	F-VF	39	28	15	-	1	-	6	89	-	-	2	2	-	4	-	-	-	-	-	-	-	-	-	-	-	5
	12	VF	37	35	18	-	-	-	2	92	-	1	-	1	-	2	-	-	-	-	-	1	-	-	-	-	1	4
	13*	F	40	16	11	1	1	2	6	77	2	-	-	2	-	4	-	-	-	-	-	-	-	-	-	-	-	16
	14*	VF	34	26	20	-	1	-	2	83	1	2	1	4	-	2	-	-	-	-	-	1	-	-	-	-	1	9
* 1 percent sandstone fragments																												
Locality 74																												
Unkpapa sandstone	8	F	53	23	6	6	1	-	3	92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
	7	F	53	15	12	10	-	-	5	95	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	5	-
	6	F	53	7	6	14	1	1	7	89	4	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	7
	5	F	43	10	10	13	-	-	7	83	-	1	1	2	-	1	-	-	-	-	-	-	-	-	-	-	-	14
	4	F	43	17	12	9	-	-	9	90	-	1	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	8
	3	F	38	15	6	9	3	-	7	78	3	1	2	6	-	2	-	-	-	-	-	-	-	-	-	-	-	14
	2	F	40	24	3	6	1	-	5	79	3	-	2	5	-	-	-	-	-	-	-	-	-	-	-	-	-	16
	1	F	50	15	1	9	-	-	6	81	6	-	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Locality 70																												
Fall River formation	14	F-VF	20	35	12	3	2	1	7	80	1	2	1	4	-	3	-	-	9	-	-	-	-	-	-	-	-	4
	13	F-VF	27	27	14	2	-	-	8	78	-	-	-	-	1	1	1	-	6	9	-	-	-	-	-	-	9	4
	12	S	16	16	8	1	-	-	3	44	-	-	-	-	1	1	-	-	-	54	-	-	-	-	-	-	54	-
	11	VF	40	25	10	-	1	-	8	84	-	-	-	-	-	1	-	-	-	-	5	-	-	-	-	-	5	10
	10	F	25	22	13	1	-	-	4	65	2	-	1	3	-	2	-	-	-	30	-	-	-	-	-	-	30	-
	9	M-F	45	18	13	2	-	-	6	84	-	-	-	-	-	-	-	-	-	-	11	2	-	-	-	-	13	3
	8	M	35	25	14	2	-	1	8	85	-	-	-	-	-	3	-	-	-	-	-	1	-	-	-	-	1	11
	7	VF	24	18	16	3	1	1	11	74	-	-	1	1	-	3	-	-	8	14	-	-	-	-	-	-	14	-
	6	S	19	21	5	1	-	-	7	53	-	-	-	-	1	-	-	1	-	45	-	-	-	-	-	-	45	-
	5	M	38	27	10	-	-	-	11	86	-	-	-	-	-	1	-	-	-	9	-	-	-	-	-	-	9	4
Fusen formation	4	VF-S	27	15	9	-	-	-	1	52	-	-	-	-	-	3	-	-	-	-	-	-	45	-	-	-	45	-
	2	C	37	37	18	-	-	-	8	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1	F	40	17	16	-	1	-	6	80	2	1	1	4	-	1	-	-	-	-	-	-	-	-	-	-	-	15
Locality 71																												
Fall River formation	1	F-VF	30	25	14	1	1	1	13	85	-	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	-	12
	2	F	30	19	13	-	-	1	10	73	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	26
	3	F	29	31	17	-	3	2	4	86	1	-	-	1	1	1	-	-	3	-	-	-	-	-	-	-	-	8
	4	VF-S	23	24	7	-	-	-	-	54	-	-	-	-	2	-	-	-	3	-	41	-	-	-	-	-	41	-
	5	M	35	12	16	-	-	-	7	70	-	-	-	-	-	-	-	-	-	20	10	-	-	-	-	-	30	-
	6	M	22	26	22	2	-	-	11	83	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	16
	7	F	35	28	12	1	-	-	6	82	-	-	-	-	-	1	-	1	3	6	4	-	-	-	-	-	10	3
	8	VF-S	34	17	7	-	1	-	4	63	-	-	-	-	6	1	-	-	5	25	-	-	-	-	-	-	25	-
	9	F-VF	37	31	5	1	-	-	4	78	-	-	-	-	4	-	-	-	4	14	-	-	-	-	-	-	14	-
	10	M	36	19	19	2	3	-	7	86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
	11	F	31	23	18	3	1	-	15	91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
Fuson formation	12	Cg	33	22	15	1	-	-	6	77	-	-	-	-	-	4	-	-	-	3	16	-	-	-	-	-	19	-

Table 7.--Percentages of rock-forming materials in thin sections of limestone, Fuson-Lakota, Morrison, and Sundance formations, Black Hills.

	Sample number	Crystalline carbonate	Mineral and rock fragments				
			Fragmental carbonate	Quartz	Feldspar	Chert	Schist
Locality 80							
Morrison formation	2	-	99	1	-	-	-
Sundance formation	1	100	-	-	-	-	-
Locality 77							
Fuson-Lakota formations	6	-	69	26	-	5	-
	4	-	85	15	-	-	-
Locality 40							
Morrison formation	9	10	89	1	-	-	-
	8	99	-	1	-	-	-
	7	-	100	-	-	-	-
	6	99	-	1	-	-	-
	5	75	24	1	-	-	-
	4	2	83	13	1	-	1
	3	11	85	4	-	-	-
	1	-	88	9	3	-	-
Locality 11							
Morrison formation	2	55	3	38	4	-	-

Table 8.—Percentages of nonopaque heavy minerals in samples from the Newcastle, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills (0.062 to 0.125 mm. size fraction).

X, less than 1 percent (or small amounts in several samples); R, rare (or small amounts in at least 1 sample); –, absent.

	Sample number	Zircon: Angular grains	Zircon: Rounded grains	Zircon: Total	Tourmaline: Angular grains	Tourmaline: Rounded grains	Tourmaline: Total	Zircon-tourmaline, combined: Angular grains	Zircon-tourmaline, combined: Rounded grains	Zircon-tourmaline, combined: Total	Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral uniaxial, positive	Monazite	Total grains counted
Locality 81																															
Fall River formation	18	14	7	21	47	15	62	61	22	83	–	7	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	182
	17	3	1	4	46	7	53	49	8	57	3	5	5	–	–	–	X	–	X	–	–	–	–	29	–	–	–	–	–	–	192
	16	5	2	7	29	4	33	34	6	40	–	10	X	–	–	–	X?	–	–	–	–	–	–	48	–	–	–	–	–	–	141
	15	12	3	15	25	4	29	37	7	44	11	18	1	–	X	–	–	–	X	–	–	–	–	25	–	–	–	–	–	–	144
	14	4	–	4	40	4	44	44	4	48	–	–	–	–	4	–	–	–	–	–	–	–	–	48	–	–	–	–	–	–	23
	13	2	4	6	14	4	18	16	8	24	2	7	–	–	18	–	–	–	–	–	–	–	1	48	–	–	–	–	–	–	62
	12a	31	34	65	20	4	24	51	38	89	X	8	2	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	168
Fuson-Lakota formations	12	8	8	16	60	9	69	68	17	85	X	6	6	–	–	–	–	2	X	–	–	–	–	–	–	–	–	–	–	–	128
	11	19	10	29	41	14	55	60	24	84	X	8	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	139
	10	27	19	46	31	5	36	58	24	82	–	14	3	–	X	–	–	–	–	–	–	–	–	X	X	–	–	–	–	–	193
	9	15	31	46	24	17	41	39	48	87	–	7	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	239
	8	19	75	94	X	X	1	20	75	95	–	3	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	130
	7	18	54	72	12	6	18	30	60	90	–	7	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	134
	6	19	59	78	4	6	10	23	65	88	–	2	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	143
	5	10	42	52	16	11	27	26	53	79	–	4	16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	147
	4	11	88	99	–	X	X	11	88	99	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	136
	3	4	65	69	1	28	29	5	93	98	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	156
	2	9	58	67	X	28	29	10	86	96	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	129
	1	14	79	93	1	4	5	15	83	98	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	178
Average, Fall River fm.		10	7	17	32	6	38	42	13	55	2	8	3	–	3	–	R	R	R	–	–	–	R	28	–	–	–	–	–	–	
Average, Fuson-Lakota fms.		14	46	60	18	11	29	32	57	89	R	4	6	–	R	–	–	R	R	–	–	–	–	R	R	–	–	–	–	–	
Locality 80																															
Fuson-Lakota formations	11	24	55	79	7	2	9	31	57	88	–	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	130
	10	20	53	73	7	7	14	27	60	87	–	10	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	142
	9	29	51	80	6	4	10	35	55	90	–	7	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	133
	8	18	63	81	4	6	10	22	69	91	X	4	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	154
	7	15	70	85	3	2	5	18	72	90	3	2	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	147
	6	9	43	52	5	20	25	14	63	77	–	1	21	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	206
	5	5	39	44	4	38	42	9	77	86	X	X	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	144
	4	14	77	91	–	2	2	14	79	93	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	189
	3	12	38	50	3	34	37	15	72	87	–	4	9	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	151
	2	2	16	18	4	50	54	6	66	72	X	–	28	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100
	1	2	2	4	15	80	95	17	82	99	–	X	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	119
Sundance formation	1a	18	18	36	9	22	31	27	40	67	25	3	4	–	–	–	–	X	–	X	–	–	–	–	–	–	–	–	–	–	162
Average, Fuson-Lakota fms.		14	46	60	5	22	27	19	68	87	X	4	8	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	
Locality 97																															
Fall River formation	1	23	12	35	36	10	46	59	22	81	X	10	9	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	162
	2	27	25	52	22	9	31	49	34	83	–	6	10	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	163
	3	38	27	65	6	3	9	44	30	74	4	9	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	149
	4	16	8	24	40	6	46	56	14	70	–	5	24	–	–	–	1	–	–	X	–	X	–	–	–	–	–	–	–	–	156
	5	26	25	51	27	4	31	53	29	82	–	8	9	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	157
	6	31	40	71	12	3	15	43	43	86	2	6	6	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	150
	7	50	29	79	8	4	12	58	33	91	1	7	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100
	8	37	32	69	19	4	23	56	36	92	–	4	3	–	–	–	–	X	1	–	–	–	–	–	–	–	–	–	–	–	141
	9	44	36	80	8	2	10	52	38	90	1	6	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96
	10	32	32	64	9	10	19	41	42	83	X	5	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	147
	11	31	27	58	16	7	33	57	34	91	–	8	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	143
	12	40	46	86	4	2	6	44	48	92	–	7	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	134
Average, Fall River fm.		33	28	61	18	5	23	51	33	84	X	7	7	–	R	–	R	R	R	R	–	R	–	R	–	–	–	–	–	–	
Locality 79																															
Fall River formation	1	36	21	57	22	7	29	58	28	86	2	6	6	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	166
	2	21	30	51	12	9	21	33	39	72	4	10	14	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	129
	3	11	11	22	30	1	31	41	12	53	2	5	37	–	–	–	2?	–	–	X	–	–	–	–	–	–	–	–	–	–	143
Fuson-Lakota formations	4	28	18	46	26	11	37	54	29	83	–	10	7	–	–	–	–	X	X	–	–	–	–	–	–	–	–	–	–	–	163
	5	20	26	46	20	3	23	40	29	69	–	10	21	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	151
	6	18	27	45	26	7	33	44	34	78	–	5	17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	152
	7	26	65	91	2	5	7	28	70	98	–	X	1	–	–	–	–	–	–	X	–	–	–	–	–	–	X	–	–	–	158
	8	25	29	54	12	9	21	37	38	75	–	6	19	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	159
	9	11	28	39	43	9	52	54	37	91	–	3	6	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	144
	10	28	46	74	8	2	10	36	48	84	–	5	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	89
	11	12	68	80	3	8	11	15	76	91	–	X	8	–	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	–	143
	12	15	54	69	5	15	20	20	69	89	–	–	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	173
	13	7	39	46	4	36	40	11	75	86	–	2	11	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	135
	14	12	82	94	–	5	5	12	87	99	–	X	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	155
	15	11	61	72	1	17	18	12	78	90	–	2	8	–	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	139
	16	12	79	91	X	5	6	13	84	97	–	X	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	182
	17	8	42	50	4	42	46	12	84	96	–	X	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	135
	18	9	62	71	4	20	24	13	82	95	–	1	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	134
	19	10	75	85	X	12	13	11	87	98	–	X	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	136
	20	9	44	53	10	34	44	19	78	97	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	160
	21	25	53	78	2	10	12	27	63	90	–	3	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	144
	22	12	35	47	9	40	49	21	75	96	–	X	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	148
Average, Fall River fm.		22	21	43	21	6	27	43	27	70	2	7	19	–	–	–	X?	X	X	X	–	–	–	–	–	–	–	–	–	–	
Average, Fuson-Lakota fms.		16	47	63	10	15	25	26	62	88	–	3	8	–	R	–	R	R	R	R	–	–	–	–	R	–	R	–	–	–	

Table 6.—Percentages of nonopaque heavy minerals in samples from the Newcastle, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills—Continued

	Sample number	Zircon: Angular grains	Zircon: Rounded grains	Zircon: Total	Tourmaline: Angular grains	Tourmaline: Rounded grains	Tourmaline: Total	Zircon-tourmaline, combined: Angular grains	Zircon-tourmaline, combined: Rounded grains	Zircon-tourmaline, combined: Total	Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral uniaxial, positive	Monazite	Total grains counted
Locality 98																															
Fusen-Lakota formations	8	21	39	60	5	28	33	26	67	93	-	6	-	-	-	-	-	X	X	-	-	-	-	-	X	-	-	-	-	-	139
	7	16	56	72	-	24	24	16	80	96	X	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	133
	6	10	37	47	4	32	36	14	69	83	15	2	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	153
	5	23	16	39	17	16	33	40	32	72	14	5	5	2	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	89
Morrison formation	4	9	9	18	36	15	51	45	24	69	18	6	6	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	122
	3	X	32	33	4	13	17	5	45	50	31	2	15	2	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	129
	2	5	48	53	2	6	8	7	54	61	28	X	8	-	-	-	2	-	X	-	-	-	-	-	-	-	X	-	-	-	140
Sundance formation	1	8	21	29	11	20	31	19	41	60	32	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104
Average, Fuson-Lakota fms.		17	37	54	6	25	31	23	62	85	7	4	1	X	-	-	-	R	R	-	-	-	-	-	R	X	-	-	-	-	
Average, Morrison fm.		5	30	35	14	11	25	19	41	60	26	3	10	X	-	-	1	R	R	-	-	-	-	-	-	-	R	-	-	-	
Locality 78																															
Fall River formation	13	12	6	18	49	16	65	61	22	83	6	8	-	-	-	X	X	X	-	-	-	-	-	-	-	-	X	-	-	-	115
	12	21	29	50	9	2	11	30	31	61	6	6	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	167
	11	58	18	76	12	X	13	70	19	89	4	6	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	144
	10	32	21	53	18	7	25	50	28	78	8	13	-	-	-	-	-	1	X	-	-	-	-	-	-	-	-	-	-	-	88
	7	8	10	18	21	-	21	29	10	39	3	8	5	-	5	-	-	3	-	-	-	-	-	32	-	-	-	-	5	-	38
	6	32	12	44	27	5	32	59	17	76	2	13	3	-	-	X?	—	1	-	-	-	-	-	4	-	-	-	-	-	-	174
	5	23	53	76	5	2	7	28	55	83	6	4	6	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	157
	4	19	13	32	42	5	47	61	18	79	5	9	2	-	-	-	-	X	X	-	-	-	4	-	-	-	-	-	-	-	169
	3	6	9	15	53	8	61	59	17	76	3	3	6	-	2	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	110
	2	12	13	25	40	15	55	52	28	80	-	8	4	-	X	-	-	-	-	-	-	-	-	7	-	X	-	-	-	-	108
Fuson-Lakota formations	1	21	43	64	8	8	16	29	51	80	X	15	4	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	141
	1b	11	11	22	15	14	29	26	25	51	33	8	6	-	-	-	-	-	-	-	-	-	-	-	-	-	2?	-	-	-	63
	1a	22	55	77	2	12	14	24	67	91	X	8	1	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	171
Average, Fall River fm.		23	18	41	28	6	34	51	24	75	4	8	5	-	X	R	R	X	R	-	-	-	1	4	-	R	R	-	X	-	
Average, Fuson-Lakota fms.		18	36	54	8	12	20	26	48	74	11	11	4	-	-	-	-	-	X	-	-	-	-	-	-	-	X?	-	-	-	
AEC drill hole HC 202																															
Fall River formation	1	14	12	26	50	5	55	64	17	81	3	6	X	-	-	X?	-	-	-	-	-	-	-	8	-	-	-	X?	-	-	149
	2	22	9	31	33	4	37	55	13	68	9	2	19	-	-	-	-	X	-	-	-	-	-	2	-	-	-	-	-	X?	175
	3	28	25	53	27	3	30	55	28	83	7	3	4	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	164
	4	7	3	10	58	1	59	65	4	69	2	20	2	3	-	-	-	2	1	-	-	-	1	-	-	-	-	-	-	-	115
	5	23	18	41	23	4	27	46	22	68	X	5	-	-	26	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	181
	6	13	7	20	61	9	70	74	16	90	6	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	194
	7	12	10	22	44	12	56	56	22	78	2	3	16	X	-	X?	—	—	X	-	-	-	-	-	-	-	-	-	-	-	196
	8	15	70	85	X	11	11	15	81	96	X	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
Fuson-Lakota formations	9	39	56	95	X	4	4	39	60	99	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200
	10	26	68	94	1	5	6	27	73	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	195
	11	31	57	88	X	10	11	32	67	99	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	74
	12	19	57	76	3	21	24	22	78	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	185
	13	14	74	88	2	9	11	16	83	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	139
	14	11	85	96	-	4	4	11	89	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	137
	15	20	70	90	-	10	10	20	80	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	171
	16	10	77	87	-	10	10	10	87	97	-	-	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	136
	17	7	72	79	2	19	21	9	91	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156
	18	9	27	36	11	43	54	20	70	90	7	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	89
	19	12	45	57	8	29	37	20	74	94	1	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	203
Average, Fall River fm.		17	19	36	37	6	43	54	25	79	4	5	5	X	3	R?	R	X	X	-	-	-	R	2	-	-	-	X?	-	R?	
Average, Fuson-Lakota fms.		17	63	80	3	15	18	20	78	98	1	X	1	R	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	
Locality 57																															
Fuson-Lakota fms.	4	12	63	75	3	12	15	15	75	90	8	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	154
Morrison formation	3	X	5	5	32	49	81	32	54	86	10	3	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	118
	2	7	41	48	4	15	19	11	56	67	27	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54
Sundance formation	1	-	38	38	2	26	28	2	64	66	30	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	127
Average, Morrison fm.		4	23	27	18	32	50	22	55	77	19	3	1	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	
Locality 77																															
Fall River formation	11	5	5	10	35	4	39	40	9	49	2	9	-	-	-	-	-	X	-	-	-	-	X	39	-	-	-	-	-	-	142
	10	20	10	30	24	6	30	44	16	60	9	5	1	-	-	X?	-	X	-	-	-	-	X	24	-	-	-	-	-	-	157
	9	9	5	14	33	8	41	42	13	55	3	5	-	-	-	-	-	-	X	-	-	-	X	36	-	-	-	-	-	-	148
	8	30	28	58	15	5	20	45	33	78	-	12	1	-	-	-	-	4	-	-	-	-	-	5	-	-	-	-	-	-	81
Fuson- Lakota formations	7	4	6	10	8	78	86	12	84	96	-	2	2	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	135
	6	17	73	90	1	7	8	18	80	98	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	213
	5	8	86	94	-	3	3	8	89	97	-	3	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	155
	4	13	69	82	2	6	8	15	75	90	-	X	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	133
	3	5	91	96	-	2	2	5	93	98	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	171
	2	6	86	92	1	5	6	7	91	98	-	X	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	160
	1	13	71	84	1	10	11	14	81	95	-	1	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	188
Average, Fall River fm.		16	12	28	27	6	33	43	18	61	4	8	X	-	-	R?	—	1	R	-	-	-	X	26	-	-	-	-	-	-	
Average, Fuson-Lakota fms.		9	69	78	2	16	18	11	85	96	-	2	2	-	-	-	-	-	R	-	-	-	-	-	R	-	-	-	-	-	
Locality 86																															
Fuson-Lakota formations	7	1	17	18	10	69	79	11	86	97	-	2	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	153
	6	5	50	55	4	38	42	9	88	97	-	1	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	132
	5	12	84	96	-	3	3	12	87	99	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147
	4	21	51	72	2	13	15	23	64	87	4	1	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	292
	3	13	43	56	3	38	41	16	81	97	2	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	146
Sundance formation	2	-	8	8	4	67	71	4	75	79	18	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	103
	1	-	42	42	1	17	18	1	59	60	37	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	155
Average, Fuson-Lakota fms.		10	49	59	4	32	36	14	81	95	1	1	2	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	
Average, Sundance fm.		-	25	25	2	42	44	2	67	69	28	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table 8.—Percentages of nonopaque heavy minerals in samples from the Newcastle, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills—Continued.

	Sample number	Zircon: Angular grains	Zircon: Rounded grains	Zircon: Total	Tourmaline: Angular grains	Tourmaline: Rounded grains	Tourmaline: Total	Zircon-tourmaline, combined: Angular grains	Zircon-tourmaline, combined: Rounded grains	Zircon-tourmaline, combined: Total	Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral, uniaxial, positive	Monazite	Total grains counted
Locality 76																															
Fall River formation	14	2	X	3	46	12	58	48	13	61	X	4	19	-	X	X	-	-	-	-	-	X	-	12	-	X	-	-	-	-	234
	13	19	5	24	20	X	20	39	5	44	1	7	-	10	1	-	-	-	-	-	-	-	13	21	-	3	-	-	-	-	241
	12	25	7	42	20	X	21	55	8	63	2	11	1	1	-	-	-	1	-	-	-	-	1	17	-	X	2	-	-	-	170
	11	37	14	51	10	1	11	47	15	62	X	9	8	17	-	X	-	-	X	-	-	-	-	3	-	-	X	-	-	-	251
	10	3	2	5	59	7	66	62	9	71	1	3	6	-	X	-	-	-	-	-	-	X	X	18	-	-	-	-	-	-	214
Fuson-Lakota formations	9	8	5	13	69	10	79	77	15	92	-	5	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-	-	-	-	124
	8	10	79	89	1	7	8	11	86	97	-	2	1	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	223
	7	4	78	82	5	11	16	9	89	98	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	177
	6	12	83	95	1	2	3	13	85	98	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	207
	5	15	77	92	2	3	5	17	80	97	-	3	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	238
	4	12	25	37	10	50	60	22	75	97	-	1	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	154
	3	9	62	71	7	20	27	16	82	98	1	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	222
	2	4	1	5	7	75	82	11	76	87	-	-	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	173
	1	10	52	62	6	24	30	16	76	92	4	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218
Average, Fall River fm.		19	6	25	31	4	35	50	10	60	1	7	7	6	X	R	-	R	R	-	-	R	3	14	-	X	X	-	-	-	
Average, Fuson-Lakota fms.		9	52	61	12	22	34	21	74	95	X	2	2	R	-	-	X	-	-	-	-	-	R	-	-	-	-	-	-	-	
Locality 40																															
Fall River fm.	8	41	31	72	10	7	17	51	38	89	X	7	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	166
Fuson-Lakota formations	7	8	80	88	1	5	6	9	85	94	-	5	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	137
	6	12	72	84	X	9	9	12	81	93	X	1	5	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	162
	5	11	84	95	-	3	3	11	87	98	-	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	255
	4	18	66	84	X	7	7	18	73	91	-	2	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	137
	3	23	42	65	X	14	14	23	56	79	1	2	15	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	166
	2	9	65	74	-	18	18	9	83	92	1	X	7	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	170
Morrison fm.	1a	5	15	20	1	2	3	6	17	23	72	2	2	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	157
	1	8	16	24	14	21	35	22	37	59	21	7	1	12	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	190
Average, Fuson-Lakota fms.		13	68	81	X	10	10	13	78	91	X	2	6	-	-	-	-	R	R	-	-	-	-	-	R	R	-	-	-	-	
Average, Morrison fm.		6	16	22	8	12	20	14	28	42	47	4	1	6	-	-	-	R	X	-	-	-	-	-	-	-	-	-	-	-	
Locality 11																															
Fuson-Lakota formations	24	14	82	96	X	2	2	14	84	98	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	186
	23	10	75	85	3	9	12	13	84	97	-	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	22	13	78	91	X	6	7	14	84	98	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	171
	21	21	69	90	X	7	8	22	76	98	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	135
Morrison formation, upper part	20	X	50	50	1	34	35	1	84	85	13	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147
	19	1	67	68	1	21	22	2	88	90	8	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	146
	18	1	69	70	3	19	22	4	88	92	3	1	4	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	165
	17	11	73	84	1	10	11	12	83	95	4	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	140
	16	1	33	34	2	56	58	3	89	92	4	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	193
	15	4	75	79	X	16	17	5	91	96	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	14	7	78	85	-	10	10	7	88	95	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	165
Morrison formation, lower part	13	3	38	41	X	9	9	3	47	50	49	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	159
	12	1	43	44	X	15	16	2	58	60	38	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X?	151
	11	X	38	39	-	17	17	X	55	56	38	-	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	170
	10	3	32	35	-	14	14	3	46	49	47	-	3	1	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	153
	9	3	46	49	X	4	4	3	50	53	43	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141
	8	1	23	24	-	15	15	1	38	39	57	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	155
	7	1	55	56	-	4	4	1	59	60	37	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	140
	6	5	46	51	-	6	6	5	52	57	42	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	171
	5	3	38	41	2	15	17	5	53	58	39	-	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	179
	4	7	46	53	1	5	6	8	51	59	39	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	180
	3	3	35	38	4	12	16	7	47	54	44	X	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	168
	2	6	33	39	10	24	34	16	57	73	22	-	X	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	160
Sundance fm.	1	8	2	10	13	1	14	21	3	24	12	10	X	30	-	-	X	-	X	-	X	-	-	X	-	21	-	-	-	-	164
Average, Fuson-Lakota fms.		15	76	91	1	6	7	16	82	98	R	1	X	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	
Average, Morrison formation, upper part		4	64	68	1	24	25	5	88	93	5	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	
Average, Morrison formation, lower part		3	40	43	1	11	12	4	51	55	41	X	2	1	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	R?	
Average, Morrison formation, Total		3	52	55	2	18	19	5	69	74	23	X	2	X	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	R?	
Locality 104																															
Fall River formation	18	49	28	77	12	3	15	61	31	92	-	7	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	146
	17	36	44	80	12	X	13	48	45	93	-	7	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	119
	16	24	54	78	6	6	12	30	60	90	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	139
	15	22	60	82	7	5	12	29	65	94	X	5	X	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	193
	14	63	24	87	5	X	6	68	25	93	-	6	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	148
	13	15	55	70	X	7	8	16	62	78	-	2	-	19	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	138
	12	26	34	60	19	11	30	45	45	90	-	6	1	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	165
Fuson-Lakota formations	11	24	55	79	5	12	17	29	67	96	-	3	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	190
	10	34	53	87	2	6	8	36	59	95	-	5	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	116
	9	20	54	74	2	16	18	22	70	92	-	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	152
	8	16	78	94	2	3	5	18	81	99	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	113
	7	11	84	95	-	3	3	11	87	98	-	2	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	158
	6	11	84	95	1	1	2	12	85	97	-	2	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	166
	5	14	57	71	4	24	28	18	81	99	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	130
	4	4	5	9	18	72	90	22	77	99	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	133
	3	19	51	70	1	15	16	20	66	86	1	2	11	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	156
	2	15	51	66	4	26	30	19	77	96	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	140
	1	10	61	71	3	23	26	13	84	97	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	155
Average, Fall River fm.		34	43	77	9	5	14	43	48	91	R	6	R	3	-	-	-	R	R	-	-	-	-	X	-	-	-	-	-	-	
Average, Fuson-Lakota fms.		16	58	74	4	18	22	20	76	96	R	2	2	-	X	-	-	-	R	-	-	-	-	-	R	-	-	-	-	-	

Table 8.—Percentages of nonopaque heavy minerals in samples from the Newcastle, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills—Continued.

	Sample number	Zircon: Angular grains	Zircon: Rounded grains	Zircon: Total	Tourmaline: Angular grains	Tourmaline: Rounded grains	Tourmaline: Total	Zircon-tourmaline, combined: Angular grains	Zircon-tourmaline, combined: Rounded grains	Zircon-tourmaline, combined: Total	Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral, uniaxial, positive	Monazite	Total grains counted
											Locality 6																				
Fall River formation	11	13	21	34	34	7	41	47	28	75	3	7	X	-	-	-	-	2	X	-	-	-	X	12	-	-	-	-	-	-	174
	10	12	21	33	35	17	52	47	38	85	X	9	X	-	-	-	-	X	-	-	-	-	-	5	-	-	-	-	-	-	160
	9	24	40	64	17	11	28	41	51	92	-	7	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	139
	8	13	9	22	22	3	25	35	12	47	-	4	-	-	-	-	-	2	-	-	-	-	15	32	-	-	-	-	-	-	150
	7	28	41	69	14	7	21	42	48	90	-	9	-	-	-	-	-	-	X	-	-	-	-	1	-	-	-	-	-	-	146
	6	32	39	71	11	7	18	43	46	89	1	9	X	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	169
	5	13	44	57	18	15	33	31	59	90	X	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	167
	4a	41	43	84	4	2	6	45	45	90	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	144
Fuson-Lakota formations	4	18	33	51	28	10	38	46	43	89	—	10	X	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	191
	3	13	30	43	40	4	44	53	34	87	-	5	7	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	151
	2	25	55	80	8	6	14	33	61	94	-	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	144
	1	13	71	84	9	1	10	22	72	94	-	5	2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	191
Average, Fall River fm.		22	32	54	19	9	28	41	41	82	X	8	X	-	-	-	-	X	R	-	-	-	2	6	-	R	-	-	-	-	
Average, Fuson-Lakota fms.		18	47	65	21	5	26	39	52	91	-	6	2	-	-	-	R	R	X	-	-	-	-	-	-	-	-	-	-	-	
											Locality 31																				
Fall River formation	1	40	28	68	9	3	12	49	31	80	-	17	-	-	X	-	-	1	X	-	-	-	-	1	-	-	-	-	-	-	166
	2	28	13	41	32	4	36	60	17	77	-	12	X	-	-	-	-	3	2	-	-	-	-	6	-	-	-	-	-	-	205
	3	21	18	39	41	11	52	62	29	91	X	7	X	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	185
	4	9	18	27	50	11	61	59	29	88	3	3	5	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	150
	5	9	28	37	7	10	17	16	38	54	26	-	2	-	10	-	-	-	2	-	2	-	-	2	-	2	-	-	-	-	43
Fuson-Lakota formations	6	19	59	78	7	9	16	26	68	94	X	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	139
	7	19	68	87	-	6	6	19	74	93	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	188
	8	16	34	50	19	24	43	35	58	93	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	111
Average, Fall River fm.		21	21	42	28	8	36	49	29	78	6	8	1	-	2	-	R	1	1	-	R	-	-	2	R	X	-	-	-	-	
Average, Fuson-Lakota fms.		16	54	70	10	13	23	26	67	93	R	6	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
											Locality 33																				
	16	10	7	17	52	30	82	62	37	99	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	99
Fuson-Lakota formations	15	16	44	60	3	32	35	19	76	95	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	178
	14	11	50	61	8	30	38	19	80	99	-	1	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	135
	13	9	23	32	12	38	50	21	61	82	12	2	4	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	135
	12	10	61	71	3	10	13	13	71	84	12	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	179
	11	7	58	65	4	18	22	11	76	87	10	X	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156
	10	9	61	70	3	18	21	12	79	91	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156
	9	7	58	65	3	19	22	10	77	87	7	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	150
	8a	8	35	43	9	46	55	17	81	98	-	1	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	129
	8	11	50	61	4	33	37	15	83	98	X	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	133
	7	17	56	73	4	19	23	21	75	86	3	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	150
	6	9	38	47	11	16	27	20	54	74	15	5	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147
	5	13	53	66	8	12	20	21	65	86	10	X	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	152
	4	10	66	76	3	14	17	13	80	93	5	1	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	172
	3	5	30	35	8	44	52	13	74	87	10	X	3	-	X	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	149
	2	6	48	54	6	24	30	12	72	84	14	-	2	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	167
Average, Fuson-Lakota fms.		10	49	59	6	25	31	16	74	90	7	1	2	-	R	-	R	R	R	-	-	-	-	-	R	-	-	R	-	-	
											Locality 103																				
Fuson-Lakota formations	9	10	72	82	1	17	18	11	89	100	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	168
	8	13	55	68	10	15	25	23	70	93	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	7	10	77	87	1	10	11	11	87	98	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	6	9	41	50	8	40	48	17	81	98	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	138
Morrison formation	5	15	9	24	36	7	43	51	16	67	4	4	-	14	-	-	-	-	1	-	-	-	4	-	-	6	-	-	-	-	104
	4	10	3	13	53	15	68	63	18	81	11	4	X	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	131
Sundance formation	3	X	43	44	-	19	19	X	62	63	30	-	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	2	-	23	23	3	43	46	3	66	69	26	-	3	2	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	121
	1	3	13	16	59	16	75	62	29	91	6	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	78
Average, Fuson-Lakota fms.		10	62	72	5	20	25	15	82	97	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Average, Morrison fm.		13	6	19	45	11	56	58	17	75	7	4	X	7	-	-	-	-	1	-	-	-	2	-	-	3	-	-	-	-	
Average, Sundance fm.		1	26	27	21	26	47	22	52	74	21	X	3	1	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	
											Locality 75																				
Fall River formation	1	34	18	52	25	4	29	59	22	81	9	9	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	151
	2	25	9	34	39	7	46	64	16	80	10	9	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	190
	3	25	10	35	32	2	34	57	12	69	11	9	3	2	-	-	1	1	-	-	-	-	3	-	-	-	X	-	-	-	150
	4	32	13	45	26	4	30	58	17	75	14	6	4	-	X	-	X	X	-	-	-	-	X	-	-	-	-	X	-	-	228
Fuson-Lakota formations	5	11	77	89	X	8	8	12	85	97	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	211
	6	11	76	87	2	7	9	13	83	96	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	154
	7	22	59	81	3	12	15	25	71	96	-	4	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	144
	8	11	31	42	15	40	55	26	71	97	-	1	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	179
	9	7	16	23	20	51	71	27	67	94	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	145
	10	10	9	19	14	61	75	24	70	94	3	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	152
	11	12	33	45	12	36	48	24	69	93	5	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	181
	12	7	3	10	20	65	85	27	68	95	2	X	-	-	-	-	2	-	-	-	-	-	X	-	-	-	-	-	-	-	124
	13	16	38	54	12	29	41	28	67	95	2	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	181
	14	10	24	34	16	48	64	26	72	98	X	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	176
	15	12	40	52	3	40	43	15	80	95	3	X	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	145
	16	11	16	27	3	56	59	14	72	86	3	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156
	17	2	8	10	2	56	58	4	64	68	6	-	24	2	-	X	-	-	-	-	-	-	-	-	-	-	2	-	-	-	177
	18	-	7	7	15	71	86	15	78	93	2	1	-	2	-	-	-	-	-	-	-	X	-	-	-	-	X	-	-	-	140
	19	-	-	-	17	82	99	17	82	99	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141
	20	X	8	8	17	74	91	17	82	99	-	-	X	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	134
	21	7	9	16	15	68	83	22	77	99	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	181
	22	11	18	29	13	52	65	24	70	94	1	3	2	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	182
	23	X	1	2	15	82	97	16	83	99	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X?	161
Average, Fall River fm.		29	12	41	31	4	35	60	16	76	11	8	2	X	-	-	X	X	R	-	-	-	-	-	-	-	R	R	-	-	
Average, Fuson-Lakota fms.		8	25	33	12	49	61	20	74	94	1	1	2	R	R	R	R	-	R	-	-	R	R	-	-	-	R	-	-	R?	

Table 8.—Percentages of nonopaque heavy minerals in samples from the Newcastle, Fall River, Fuson-Lakota, Unkpapa, Morrison, and Sundance formations, Black Hills—Continued.

	Sample number	Zircon			Tourmaline			Zircon-tourmaline, combined			Garnet	Rutile	Staurolite	Apatite	Hornblende	Clinozoisite	Andalusite	Brookite	Anatase	Kyanite	Sphene	Sillimanite	Chlorite	Chloritoid	Spinel	Biotite	Epidote	Corundum	Blue mineral, uniaxial, positive	Monazite	Total grains counted
		Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total	Angular grains	Rounded grains	Total																					
Locality 74																															
Lakota formation	43	20	59	79	X	9	10	21	68	89	8	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141
Unkpapa sandstone	41	1	82	83	X	14	15	2	96	98	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	142
	37	4	89	93	-	7	7	4	96	100	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	136
	34	1	96	97	-	2	2	1	98	99	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	140
	30	3	89	92	-	7	7	3	96	99	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	150
	26	3	80	83	X	15	16	4	95	99	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	146
	22	5	82	87	-	7	7	5	89	94	4	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	145
	18	2	73	75	-	24	24	2	97	99	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	133
	14	3	90	93	X	5	6	4	95	99	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116
	12	4	84	88	-	12	12	4	96	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	129
	9	3	84	87	-	12	12	3	96	99	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	154
	5	2	94	96	-	4	4	2	98	100	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	134
	4	-	85	85	-	5	5	-	90	90	9	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	153
	1	1	88	89	-	1	1	1	89	90	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	113
Average, Unkpapa sandstone		2	86	88	X	9	9	2	95	97	2	R	X	-	-	-	-	-	R	-	-	-	-	-	R	-	-	-	-	-	
Locality 70																															
Fall River formation	20	20	18	38	27	8	45	57	26	83	-	13	X	-	-	X	-	X	2	-	-	-	-	X	-	-	X?	-	-	-	134
	19	19	15	34	31	3	34	50	18	68	-	9	X	-	-	X?	-	1	1	-	-	-	-	20	-	-	-	-	-	-	193
	18	28	42	70	10	4	14	38	46	84	X	9	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	126
	17	25	59	84	4	-	4	29	59	88	-	4	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147
	16	19	27	46	20	2	22	39	29	68	4	4	24	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	135
	15	22	25	47	6	X	6	28	25	53	9	6	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	163
	14	14	34	48	16	2	18	30	36	66	7	7	20	-	-	-	X?	-	-	-	-	-	-	-	-	-	-	-	-	-	137
	12	14	17	31	25	30	55	39	47	86	X	2	2	-	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	134
	10	20	29	49	29	12	41	49	41	90	-	8	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	64
Fuson formation	8	19	33	52	9	32	41	28	65	93	2	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	165
	7	25	68	93	2	1	3	27	69	96	-	X	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
	6	18	51	69	2	28	30	20	79	99	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	173
	5	20	74	94	-	4	4	20	78	98	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	173
	4	19	66	85	X	13	14	19	79	98	-	X	X	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	153
	3	24	64	88	-	4	4	24	68	92	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	132
	2	18	73	91	-	5	5	18	78	96	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	225
	1	14	41	55	3	34	37	17	75	92	-	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	162
Average, Fall River fm.		19	30	49	20	7	27	39	27	76	2	7	10	-	-	R	R?	R	X	-	-	-	-	3	-	-	R?	-	-	-	
Average, Fuson formation		19	59	78	2	15	17	21	74	95	R	X	3	-	-	-	-	R	-	-	-	-	-	-	R	-	-	-	-	-	
Locality 71																															
Fall River formation	1	22	30	52	25	4	29	47	34	81	2	15	X	-	-	-	-	1	X	-	-	-	-	-	-	-	-	-	-	-	140
	2	14	14	28	39	21	60	53	35	88	-	8	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	119
	3	23	19	42	22	12	34	45	31	76	3	12	8	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	149
	4	42	17	59	19	2	21	61	19	80	1	17	-	-	-	-	-	X	2	-	-	-	-	-	-	-	-	-	-	-	132
	5	30	27	57	21	3	24	51	30	81	4	7	6	-	-	-	X?	X	X	-	-	-	-	-	-	-	-	-	-	-	149
	6	18	8	26	36	6	52	64	14	78	2	6	9	-	X	-	X?	-	-	-	-	-	-	-	-	-	-	-	-	-	143
	7	42	26	68	11	-	11	53	26	79	4	14	-	-	-	-	-	2	X	-	-	-	-	-	-	-	-	-	-	-	140
	8	24	18	42	26	11	37	50	29	79	4	17	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	157
	9	18	32	50	16	3	19	34	35	69	5	6	18	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	136
	10	31	41	72	8	3	11	39	44	83	1	11	4	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	145
	11	23	35	58	18	10	28	41	45	86	3	10	1	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	175
	12	18	31	49	15	6	21	33	37	70	14	5	9	-	-	X	1	X	-	-	-	-	-	-	-	-	-	-	-	-	174
Fuson formation	13	13	76	89	X	9	9	13	85	98	-	X	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	139
	14	15	68	83	1	14	15	16	82	98	-	-	2	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	157
	15	15	60	75	3	13	16	18	73	91	-	2	6	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	176
Average, Fall River fm.		25	25	50	22	7	29	47	32	79	4	10	5	-	R	R	R	X	X	-	-	-	-	R	-	-	-	-	-	-	
Average, Fuson formation		14	69	83	1	12	13	15	81	96	-	X	3	-	R	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	
Locality 60 1/																															
Newcastle sandstone	1	9	11	20	25	4	29	34	15	49	4	6	7	-	-	-	-	-	-	-	-	-	-	33	-	X	-	-	-	-	135
Locality 66 2/																															
Newcastle sandstone	1	14	5	19	57	10	67	71	15	86	X	9	-	-	-	-	-	-	X	-	-	-	-	4	-	-	-	-	-	-	131
	2	31	27	58	28	4	32	59	31	90	1	7	X	-	-	-	-	X	X	-	1	-	-	X	-	-	-	-	-	-	159
Average, Newcastle ss.		22	16	38	43	7	50	65	23	88	X	8	X	-	-	-	-	X	X	-	-	-	-	2	-	-	-	-	-	-	
Locality 56 3/																															
Hulett sandstone memb. Sundance formation	1	8	45	59	5	8	13	13	53	66	20	8	4	4	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	119
Locality 58 4/																															
Hulett sandstone memb. Sundance formation	1	2	63	65	-	3	3	2	66	68	28	2	2	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	130

1/ Basal part of the Newcastle sandstone in the SE¼ sec. 11, T. 55 N., R. 67 W., Crook County, Wyo.
2/ Top (sample 1) and base (sample 2) of the Newcastle sandstone in the NW¼ NW¼ sec. 28, T. 45 N., R. 61 W., Crook County, Wyo.
3/ About the middle of the Hulett sandstone member of the Sundance formation in the NW¼ sec. 12, T. 54 N., R. 65 W., Crook County, Wyo.
4/ About the middle of the Hulett sandstone member of the Sundance formation in the NW¼ sec. 20, T. 53 N., R. 65 W., Crook County, Wyo.

LITERATURE CITED

Crowley, A. J., 1951, Possible Lower Cretaceous uplifting of Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 83-90.

Folk, R. L., 1957, Petrology of sedimentary rocks: Hemphill's Book Store, Austin, Texas.

Rittenhouse, Gordon, 1943, Transportation and deposition of heavy minerals: Geol. Soc. America Bull., v. 54, p. 1725-1780.

Rubey, W. W., 1933, The size distribution of heavy minerals within a water-laid sandstone: Jour. Sed. Petrology, v. 3, p. 3-29.

Van Andel, Tj. H., 1950, Provenance, transport, and deposition of Rhine sediments: 129 p. H. Veenman and Zonen, Wageningen, Netherlands.