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A PRELIMINARY HEAVY MINERAL STUDY OF THE FERRON SANDSTONE

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INTRODUCTION

PURPOSE OF STUDY

In recent years the discovery of natural gas in the Ferron sandstone member of the Mancos shale in the Wasatch Plateau has greatly increased the interest in this lithologic unit. In the Clear Creek area gas is produced from the so-called "seventh sand" or Farnham sand unit of the Ferron sandstone. The term "seventh sand" resulted from the fact that the Ferron sandstone is comprised of sandstone units separated by shales, rather than being composed of a single sandstone unit. Though reasonable correlations are possible in outcrops, some difficulty is encountered in subsurface correlations of the various units from well to well. Lithologic similarity between the units of the Ferron sandstone and rapid facies changes over relatively short distances make precise correlations based upon megascopic characteristics a difficult and uncertain procedure. Correlation by paleontologic means is very difficult due to the fact that the Ferron sandstone is essentially unfossiliferous. Those few fossils that are present tend to have vertical ranges of such extent as to practically negate their use in correlation. As a result, this study was undertaken to determine whether or not heavy mineral zones exist within the Ferron sandstone which can be used to support or extend correlations already made on other types of evidence.

PREVIOUS WORK

To the writer's knowledge no published work of this type has appeared concerning the Ferron sandstone. The Ferron was named and described by Lupton (1914, p. 128). Since then Lupton (1916, pp. 31-33), Clark (1928, pp. 13, 14), and Spieker (1931, pp. 19, 20), have published works on various parts of the Wasatch Plateau which have dealt with the Ferron. These papers are concerned with coal beds, some of which are in the Ferron. A number of oil and gas companies have exploited parts of the Wasatch Plateau area, but, as yet, the results of most of this work have not been published nor made generally available.

PRESENT STUDY

The writer began this investigation at the suggestion of geologists of The Three States Natural Gas Company in an effort to solve the problem of more precise correlation.

Work was done in the geology laboratories of Brigham Young University during the Winter, Spring, and Summer quarters of 1954. Identification of the heavy minerals, calculation of percentages constituting the heavy meneral fraction, and conclusions made from the information ob-

tained are essentially the responsibility of the writer.

This study is largely a preliminary work to determine, if possible, the areal and stratigraphic distribution of the heavy mineral suites of the Ferron sandstone. It is not intended to be an exhaustive research dealing with the petrographic characteristics of the Ferron throughout all of its areal and stratigraphic extent. Neither is it intended to be a detailed statistical analysis of possible heavy mineral suites found in the Ferron. The time, the number of samples, and the equipment necessary for these types of investigations prohibited such an exhaustive study. Details and finite accuracy have, in part, been sacrificed to obtain as much general information as possible in a relatively short period of time; it has also been necessary to limit the financial expenditure.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the help of personnel of The Three States Natural Gas Company who suggested this project, furnished the samples, and subsidized the cost of equipment in exchange for the information obtained. Helpful suggestions on sample preparation were furnished by Dr. J. Keith Rigby. Assistance in mineral identification and in writing was given by the members of the writer's special committee, Dr. Harold J. Bissell and Mr. E. P. Hyatt. The writer is also indebted to his wife, Dorothy, for her help as recorder during the tedious hours of counting mineral grains.

METHOD OF PROCEDURE

SAMPLING

Samples consisted of cores (Nos. 1-10, 21-24, 26-39) and outcrop samples (Nos. 11-20, 25, 40-48). A list of locations and stratigraphic positions of all samples analyzed in this study is found in the Appendix. The locations are also shown in Figure I. Samples Nos. 1-43 were sent to the writer by The Three States Natural Gas Company from areas which were considered critical and where precise stratigraphic location was believed to be accurate. Samples Nos. 44-48 were taken by the writer from areas where stratigraphic location was approximately known. All samples were taken from the Ferron sandstone except Nos. 17 and 18, which were taken from the Castle Dale shale, and Nos. 23 and 24, which were taken from the Dakota sandstone.

All samples analyzed were spot samples. Krumbein and Pettijohn (1938, p. 13) define a spot sample as, "An isolated sample taken at a particular point on the outcrop.... Such samples are collected separately

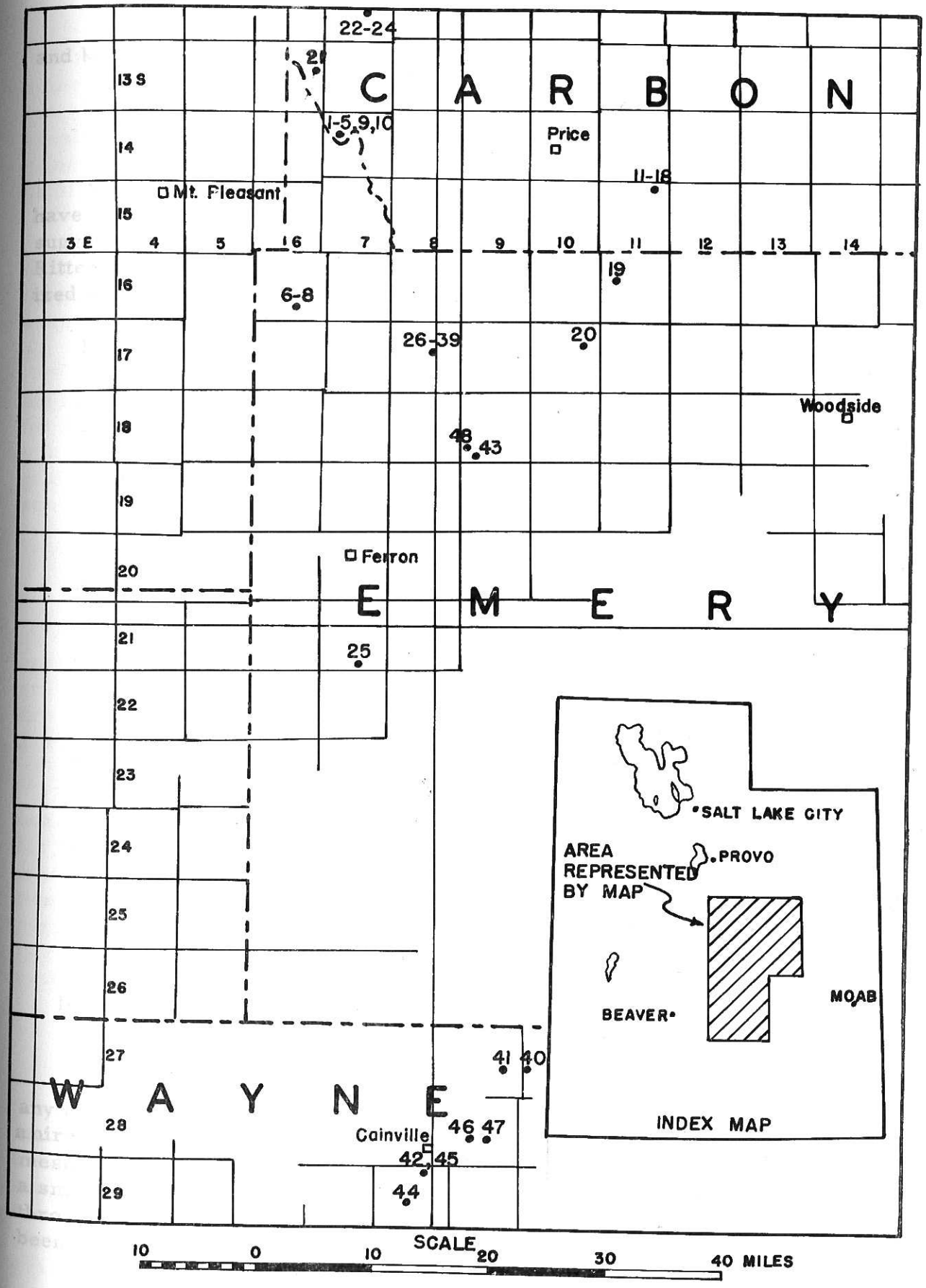

Figure 1 - Map showing locations where samples were taken.

and kept separately, being thus distinguished from composite samples."

DISAGGREGATION

Many different methods of disaggregation of consolidated sediments have been divised by investigators. The methods tried by the writer were suggested principally by Krumbein and Pettijohn (1938, pp. 47-51, 310-314), Rittenhouse (1948, p. 3), and Reed (1924, pp. 323, 324). The writer utilized one or more of the following methods of disaggregation:

1. soaking in hot (but not boiling dilute HCl (. 5 N) for many hours until action ceases

2. soaking in concentrated HCl (10 N) for several days

3. soaking in a hot saturated solution of NaOH for several days

4. soaking in a hot saturated solution of Na_2CO_3 for several days

5. soaking in a hot saturated solution of $Na_2 CO_3$ until saturated then transferring to hot concentrated HCl with evolution of CO_2

6. soaking in "hypo" (sodium hyposulphite) melted in its own water of crystallization then allowing the hypo to recrystallize - repeated numerous times

7. soaking in hot dilute HCl (. 5 N), soaking in hypo melted in its own water of crystallization, then allowing hypo to recrystallize

8. boiling one hour in a saturated NaOH solution, soaking 20 minutes in gasoline, then boiling in a 50% hydrous solution of Na_2CO_3

9. heating until red hot in an electric furnace then quenching in cold water

10. crushing with a mortar and pestle then soaking in hot dilute HCl (. 5 N) until action ceases

Very little if any success was achieved on most of the Samples with any but the last method. Large aggregates of material were crushed in a niron mortar until all pieces were small enough to pass through a 60 mesh sieve (0. 5 mm. diameter). The material was then transferred to a small porcelain mortar where it was gently crushed until it passed through a number 120 sieve (U. S. Standard Sieve Series) or until it had been reduced mainly to individual mineral grains.

Although such harsh treatment was not required on all of the samples, some of which were very friable, this last method was adopted for all samples, for the sake of a standard procedure in order that results might be comparable. Even though some shattering of heavy mineral grains undoubtedly resulted, the method of crushing to individual grain size with a mortar and pestle was considered satisfactory.

During the acid treatment samples which appeared somewhat yellow or ocher colored were treated with stannous chloride in dilute HCl to clear the grains of any iron oxide coating and thus facilitate identification when examined microscopically.

Following the acid treatment, the finer material was removed by washing in water and decanting. Repeated settling in a 15 inch column of water for five minutes reduced the quantity of material less than one thirty-second of a millimener in diameter to a negligible amount. Removal of the finer grains greatly expedited the process of separation. Following washing the samples were thoroughly dried and tested for complete disaggregation.

SEPARATION

The thoroughly dried and disaggregated material was treated with bromoform in a separatory funnel. The bromoform used had a specific gravity of about 2.84 at room temperature. Therefore, heavy minerals are defined, in this investigation, as those minerals having a specific gravity greater than 2.84.

Following separation, the light and heavy fractions of approximately one-half of the samples were weighed, and the proportion of heavy minerals to the whole sample was calculated. This calculation was not made a part of the standard procedure after examination of the heavy mineral fraction showed contamination by quartz encrusted with minute aggregates of pyrite crystals and by quartz grains attached to heavy mineral grains and to rock fragments. Contamination by quartz in this way is probably largely responsible for the wide range of these percentages as shown in Table I.

IDENTIFICATION

About two weeks were devoted to a study and identification of the heavy minerals present. The key that follows was developed to give criteria which would permit rapid identification under the binocular and petrographic microscopes. The initial time spent in identifying and becoming familiar with the obvious characteristics of the mineral grains made later identification almost automatic and greatly expedited the task of counting grains to determine percentages.

Table I-Percent of Total Heavy Mineral Grains per Sample

Sample No.		Tourmaline	Zircon	Rutile	Pyrite	Rock Frag.	Garnet	Quartz	Muscovite	Biotite	Black Opaque	Big Blue	Amphiboles	Hematite	Limonite	Titanite	Barite	Augite	Phlogopite	Metal Frag.	Cassiterite	Brookite	Apatite	Monazite	Anhydrite	Staurolite	Anatase	Chlorite	Light Blue	Dumortierite	Unknown	% of Sample
													Seventh Sand																			
10		10	12	-1	34	29		11	1	1	1	-1		2																		32
1		13	35	3	12	33		2				1	-1																			22
2		7	37	3	16	31		5		-1	-1			-1																		
3		17	37	6	-1	35		-1		-1	-1		1	1															-1			4
4		9	52	2	3	29	-1	2		-1	1																					
5		8	47	6	-1	-1		-1			-1				-1																	-1
19		12	35	8		40	-1	2	1	-1	-1	-1	1																		-1	1.1
20		-1	76	2		9		9	-1		2																				-1	28
21		12	41	3	14	27	-1	-1		1	1			-1																		
25		6	35	1	-1	55		-1			-1				-1						-1											
36		11	42	2	3	40										1																
37		22	25	1	9	40					-1				-1								1									
38		13	53	3	2	27				-1	-1		-1											1							-1	02
39		19	28	2	10	40			-1		-1																					2
40		6	29	2		53	8			-1	-1	-1																				67
41		13	31	5		40	7				-1													-1								
42		1	10			74	12			-1	-1	-1													-1	-1						4
43		4	35	5		53	2				-1					-1																
44		2	28	3		39	12			1	1		8		-1						-1		-1				-1			5	5

Table I - Continued

Sample No.	Tourmaline	Zircon	Rutile	Pyrite	Rock Frag	Garnet	Quartz	Muscovite	Biotite	Black Opaque	Big Blue	Amphiboles	Hematite	Limonite	Titanite	Barite	Augite	Phlogopite	Metal Frag	Cassiterite	Brookite	Apatite	Monazite	Anhydrite	Staurolite	Anatase	Chlorite	Light Blue	Dumortierite	Unknown	% of Sample
47	1	15	1		47	26		-1	-1						3												-1				
11	2	35	6	-1	34		14	3		1			3	1														-1			
12	15	20	2		-1	52	-1	7		-1	-1				-1	2	-1			-1												
13	11	34	6			41	-1	-1			-1		5	-1																	
14	7	41	8			31	-1	3							7	2															
15	7	43	6			32											8	4													-1
16	-1	27	5			41			-1		2	-1			23																
													Middle and Upper Ferron																			
22	1	77	1	2	14					1	2	-1																			.02
26	9	35	1	14	36	-1	-1			-1	2				-1																
27	4	7	-1	68	18		1			-1	-1									-1											.13
28	5	5		64	23		3																								
29	4	6	-1	70	18					-1	-1							-1													.1
30	7	24	1	6	58				-1	-1	-1									-1											
31	7	10	-1	48	32			-1		-1	-1						-1				-1									-1	-1
32	5	20	1	28	42					-1	-1	1			2							-1									
33	12	22	1	25	37					-1	-1																				.2
34	6	14	2	66	12	-1				-1																					
35	16	45	-1	15	19				-1	-1	1						1				-1										
45	3	20	-1		51	19			-1	2	-1	-1					-1								2	-1				1	.04

Table I - Continued

Sample No.	Tourmaline	Zircon	Rutile	Pyrite	Rock Frag.	Garnet	Quartz	Muscovite	Biotite	Black Opaque	Big Blue	Amphiboles	Hematite	Limonite	Titanite	Barite	Augite	Phlogopite	Metal Frag.	Cassiterite	Brookite	Apatite	Monazite	Anhydrite	Staurolite	Anatase	Chlorite	Light Blue	Dumortierite	Unknown	% of Sample
46	-1	16	-1		40	38									-1																
48	3	28			43	-1	5			1		-1	6									-1	12							-1	.24
																															.33
6	4	20	2	37	33	1	1		-1	-1																					
7	5	57	5	1	29		2		-1																						.15
8	18	39	1	2	36		2		-1	-1			-1																		.09
9	2	36	3	38	18		2		-1																						
17	3	15	3	32	37				-1				6																		
18	7	55	6		27	-1	2		-1				1																		-1
																															.35
23	6	29	2	39	20		-1	-1	1	-1			1		-1																
24	9	29	4	29	26		1		-1	-1			-1																		.03

Dakota Sandstone | Castle Dale Shale | Sixth Sand | Third Sand | Second Sand

The heavy mineral samples, or quartile portions, were mounted in balsam on glass slides. The grains were examined under a petrographic microscope and identified by physical and optical characteristics. Counting was accomplished by means of a mechanical stage. Slides were placed on the stage with the number at the bottom and traverses were made from bottom to top.

Mineral Identification Key

The Mineral Appears Opaque

Appearance in Reflected Light	Appearance in Transmitted Light	Other Properties	Material
White, buff, gray, orange, brown	Gray, buff, brown, slightly translucent around edges giving almost same color as in reflected light	Granular, slightly glassey to dull luster, rounded to angular	Rock Fragments
Bronze, black, brassy yellow	Black	Jagged outline, striated, variable shape	Metal Fragments (from mortar?)
Brassy yellow	Black	Granular aggregates, euhedral crystals, dirty gray crust in and on quartz grains	Pyrite
Black	Black to very dark blue	Submetallic lister, very slight extinction and illumination as rotated under crossed nicols, angular to subhedral, usually much larger than accompanying grains, uniaxial positive.	Big Blue
Black	Black to dark yellow-greenish-black	Slight extinction and illumination as rotated under crossed nicols, usually well-rounded to subangular, glassy luster, extinction parallel to length.	Tourmaline

Mineral Identification Key, Continued

Appearance in Reflected Light	Appearance in Transmitted Light	Other Properties	Material
Black to brownish-black	Dark brown to dark red-brown	Good basal cleavage, glassy luster on cleavage surgaces, "bookish," nonpleochroic on most grains	Black Opaques
Black	Black	All other black opaques	Black Opaques
Red-brown to black	Translucent red around edges	Earthy, aggregate grains some slightly oolitic	Hematite
Yellow to orange	Black	Occurs as "crusty" aggregates, dull luster	Limonite
White or milky	Relief high	Inclusions almost obscure high interference colors	Dusty Zircon
	The Mineral is Translucent and Colorless		
Colorless	Relief high	Anisotropic, many show good crystal form, lath-like to prismatic, some well rounded, rod-like inclusions common, high birefringence	Zircon
Colorless	Relief low,	Good basal cleavage, occurs in flakes, under crossed nicols it is bluish-gray and has the appearance of tinfoil with "crinkled" edges, Biaxial negative	Muscovite
Colorless	Relief low	Irregular grains, almost Quartz always attached to other grains or have pyrite crust, inclusions common, low birefringence	Quartz

Mineral Identification Key, Continued

Appearance in Reflected Light	Appearance in Transmitted Light	Other Properties	Material
Colorless	Relief moderate	Well worn to slightly worn elongate prismatic, elongation negative, low birefringence	Apatite
Milky	Relief high	Anisotropic, many show good crystal form, lath-like to prismatic, some wellrounded, high birefringence, sometimes almost opaque.	Dusty Zircon
	The Mineral is Translucent and Pink		
Pink	Relief high	Anisotropic, many show good crustal form, lath-like to prismatic, some well-rounded, rod-like inclusions common, high birefringence	Pink Zircon
Pink	Relief high	Isotropic, irregular grains	Garnet
	The Mineral is Translucent and Blue		
Black	Relief high, very dark blue	Abnormally dark blue, same color under crossed and uncrossed nicols, uniaxial positive, submetallic luster, angular to subhedral, usually larger than accompanying grains	Big Blue
	The Mineral is Translucent and Red		
Red or red-brown	Relief very high, red	Faint pleochroism, irregular to well worn elongate prismatic, shows same color under crossed and uncrossed nicols, nearly opaque, resinous	Rutile

Mineral Identification Key, Continued

Appearance in Reflected Light	Appearance in Transmitted Light	Other Properties	Material
	The Mineral is Translucent and Brown or Yellow		
Dark brown	Bark Brown	Low birefringence, good basal cleavage, non-pleochroic in most grains	Biotite
Yellowish-or brownish-black	Relief moderate, dark to pale dirty yellowish-brown, or dark to pale greenish-brown	Usually well rounded to subangular, some show typical three sided tourmaline shape, these give a good uniaxial negative figure, few have striations, extinct parallel to length and striations, strong pleochroism	Tourmaline
Brown	Black (caused by high relief and inclusions)	Brown inclusions almost obscure interference colors and make almost opaque, anisotropic, many show good crustal form, lath-like to prismatic, some well rounded, high birefringence	Brown Zircon
Redish-to yellowish brown to brown	Relief very high	Faint pleochroism, irregular to well worn elongate prismatic, shows same color under crossed and uncrossed nicols, nearly opaque, resinous	Brown Rutile
Dark yellow	Relief high	Dark yellow color gives an anomalous interference color of yellow to brownish-yellow	Yellow Zircon
Dark yellow	Relief very high	Shows same color under crossed and uncrossed nicols, parallel extinction, faint pleochroism, irregular to well worn elongate prismatic, resinous	Yellow Rutile

Mineral Identification Key, Continued

Appearance in Reflected Light	Appearance in Transmitted Light	Other Properties	Material
Yellow	Relief high	Well-rounded grains, show same color under crossed and uncrossed nicols	Monazite
Pale yellow	Relief very high	Rectangular tabular grains square corners, "geometrical paterning" (Striations), appear isotropic, negative uniaxial	Anatase
	The Mineral is Translucent and Green		
Pale dirty-yellow-green	Relief moderate	Shows compound polarization (aggregate), irregular cleavage flakes	Chlorite

Properties useful in identification may be divided into physical (color, crystal form, detrital shape, inclusions, luster, and cleavage) and optical (isotropism or anisotropism, index of refraction, birefringence, pleochroism, interference figure, optic sign, sign of elongation, and extinction angle). The properties listed above are in the order of their usefulness in rapid identification.

Isotropism or anisotropism was easily checked under the petrographic microscope.

The index of refraction was determined exactly by mounting an individual grain on glass slides in successive liquid immersion media of varying index or by separating several grains of one kind and mounting a different grain in each of several different solid media. Indexes were checked relatively by mounting a variety of grains in balsam.

Birefringence was determined on thin grains, on thin edges of thick grains, or on grains individually mounted in balsam on glass slides and ground to standard thinkness (. 03 mm.).

Pleochroism was noted at the same time that birefringence was determined.

Interference figures were found on a few thin grains mounted in index of refraction media but more commonly on individual grains which had been mounted in balsam on glass slides and ground to standard thickness.

Optic signs were determined when interference figures were obtained.

The sign of elongation could be established on fairly thin, elongate grains or grains showing crystal faces in almost any medium.

The approximate angle of extinction was easily determined under the same conditions as were favorable for identification of the sign of elongation.

Several minerals were subdivided according to obvious physical properties. Zircon was divided into colorless, pink, brown, yellow, and dusty varieties. Rutile was divided into red, red-brown, orange, and yellow, and pyrite was divided according to whether it occurred as good euhedral crystals or as a dirty appearing crust in and on quartz grains. Ilmenite and magnetite were grouped together as black opaques. An attempt was also made to subdivide zircon and tourmaline according to their detrital shape into euhedral, angular, subangular, and well-rounded. The last three terms are defined in Figure 2. Euhedral grains are perfect crystals and fragments of crystals with no rounding of corners or edges.

In mineral identification the writer relied heavily upon mineral descriptions and tables of properties given by Krumbein and Pettijohn (1938, p. 412-464), Trask (1942, tables), and Rogers and Kerr (1942, pp. 175-376).

COUNTING

The proportions of the various heavy minerals in each sample were determined by counting. Approximately 300 grains were counted in each heavy mineral sample. This number was recommended by Krumbein and Pettijohn (1938, pp. 469-471) as a minimum number to be counted to obtain reasonably accurate results.

The form shown in Figure 3 was used to record the grain counts.

EFFECT OF METHOD OF PROCEDURE

Any type of analysis is subject to a variety of errors which must be considered in interpreting results. In this study errors may arise from (1) spot sampling, (2) crushing, (3) acid treatment, (4) texture, (5) heavy liquid separation, (6) misidentification, and (7) counting.

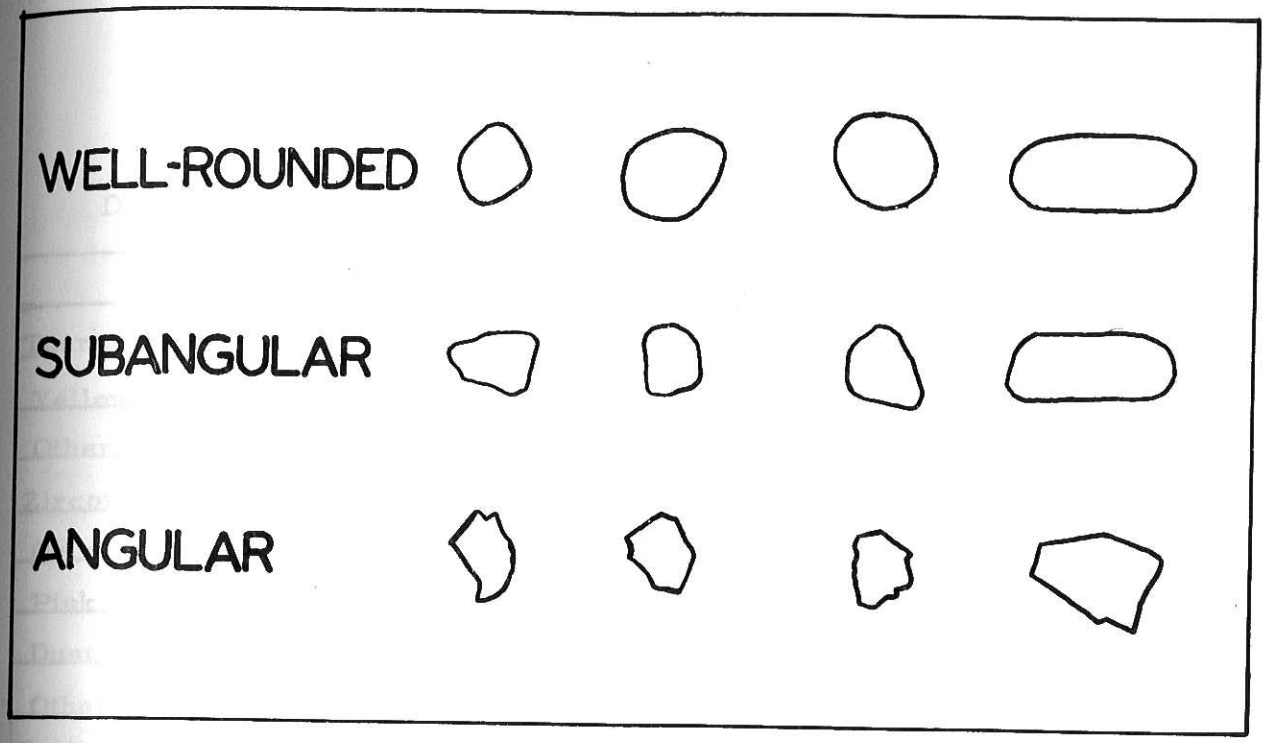

Figure 2 - Representative well-rounded, subangular, and angular grains. (Modified after Rittenhouse.)

Sample No. 36

Date 7-8-54 Slide No. 2 Traverse No. 14

	Euhedral	Angular	Subangular	Well-rounded	Tot.
Tourmaline		11	16	6	32
Yellow-brown					
Other					
Zircon					
Colorless	10	21	36	19	86
Pink		3	2	1	6
Dusty	1	21	9		31
Other (Br.)		2	1		3
Rutile					
Red	1				1
Other (Yel.)	5				5
Garnet					
Biotite					
Muscovite					
Big Blue					
Light Blue					
Pyrite					
Euhedral	6				6
Crusty	2				2
Black Opaque	1				1
Rock Fragments	121				121
Metal Frag.					
Other					
(Barite)	3				3
(Monazite)	3				3
				Total	300

Figure 3 - Form used to record grain counts.

Spot Sampling

As has already been stated, samples obtained for this study were spot samples; however, the samples taken from the H. E. Walton No. 1, Phillips' Huntington No. 1, and the Farnham Dome do approach serial samples (a series of spot samples). As stated by Krumbein and Pettijohn (1938, p. 14), "A spot sample is valid only for the spot being sampled." Many factors must be taken into consideration to determine whether a sample is representative of a given bed or formation, for example: presence or absence of bedding, changes in size and shape of its particles, vertical or lateral changes in composition, etc. Differences between samples taken a few feet apart vertically may be more significant than samples taken tens or hundreds of feet apart. Similarly, samples obtained close together laterally may vary more than samples taken miles apart.

In spite of the afore-mentioned problems inherent in sampling, spot samples were considered adequate for this project. As was stated in the introduction, this is a survey rather than a detailed study. Even though time and facilities for a detailed study were not available, it was felt that the accuracy of the results are nevertheless of the order to give a satisfactory solution to the problem being studied.

Crushing

Rittenhouse (1948, p. 6, 16) states that the amount of breakage in disaggregation appears to be dependent upon size, mineral composition, and degree of induration. He goes on to say that breakage is believed to be negligible for material of very fine sand size (0.25 - 0.125 mm.) and that it causes serious errors in less than one percent of the samples. Because most of the samples used in this study are very fine grained and because the heavy minerals occur in grain sizes smaller than the accompanying quartz and feldspar, they were less susceptible to breakage. All samples analyzed in this study are, for the most part, quartzose sands and are not subject to much breakage. The micas and tourmalines appear to be the only heavy minerals damaged by crushing.

Crushing was the only method by which a large number of the samples could be disaggregated; consequently, the degree of induration may have had some effect on breakage.

Generally the heavy mineral grains obtained from this process are rounded and show little breakage as a result of the crushing process.

Acid Treatment

All samples were soaked in hot . 5 N HCl to remove interstitial calcareous cement and iron oxide coatings. According to Rittenhouse (1948, p. 6) acid treatment has the effect of removing anycalcareous sand grains present. Thin sections were made of approximately one-third of the samples, but no calcareous sand grains were recognized as such. For this reason it seems unlikely that an appreciable number existed in the sandstones.

Bramlette (1934, p. 1561) states that acid treatment eliminates all apatite, carbonates, and phosphatic pellets, but Reed (1924, p. 324) says, "In spite of published assertions to the effect that this treatment destroys apatite, hypersthene, and other minerals of a similar degree of stability, in several experiments these minerals were not visibly affected by boiling from as much as an hour in 50 percent acid." A very small number of grains were found which the writer identified as apatite, but nothing was found in any of the samples to suggest the presence of phosphatic pellets.

Texture

In his petrographic study of the Appalachian Basin, Rittenhouse (1948, p. 12) states that the roundness of heavy minerals varies with the size of the grains---being most significant for the small sand size. Krumbein and Pettijohn (1938, p. 473, 474) say that mineral frequencies in the different grain sizes of the same sediment are not the same, that each grade size should be studied separately, and that the mineral percentages of two grade sizes of each sample should be averaged. They state further that one of these grain sizes should be the same for all samples.

On the other hand, Cogen (1940, p. 2070), in his study of the mineral zones of the Gulf Coast sediments of Texas and Louisiana, worked only with sediments between 0. 5 mm. and 0. 05 mm. diameter and treated them as a single group. Furthermore, Bramlette (1934, p. 1561), in his study of the heavy mineral zones of the Kettleman Hills, California, worked exclusively with the sediments between 0. 25 mm. and 0. 03 mm. and treated them as a single group.

The present writer also worked with sediments between 0. 25 mm. and0. 03 mm. and treated them as a single group. This procedure stemmed from the fact that the great majority of the sedimentary grains dealt with in this study are of the 0. 25 - 0. 03 mm. size range. Actually the procedure followed in this study closely approaches the recommendations of Krumbein and Pettijohn because the samples containing larger grain sizes are less well sorted than the finer sediments and contain large amounts of the finer material. The fact that the heavy minerals are concentrated almost exclusively in the finer grade sizes brings the procedure

still closer to the recommendations.

Grouping several grade sizes together may have had the effect of covering some possible correlations by means of roundness of tourmaline and zircon grains in different size grades.

Heavy Liquid Separation

The possibility exists that the mineral frequencies of some minerals are erroneous as a result of incomplete separation in bromoform. However, careful and repeated stirring of the suspension probably reduced this error to working limits.

The error in the proportion of the heavy mineral fraction to the whole sample, caused by contamination by attached quartz grains, has been mentioned previously. This error is unimportant because the proportion of heavy minerals to the whole sample was not used in the analysis.

Misidentification

The rapid methods of identification used in this investigation undoubtedly resulted in the misidentification of some grains. These misidentifications probably fall into two general groups. First, grains of rare minerals may have been included with abundant mineral grains of somewhat similar appearance. Second, gradations exist between the discrete species of zircon and of rutile and between euhedral, angular, subangular, and well-rounded grains; therefore, the boundaries between the various types are arbitrary. Keeping the same boundaries from day to day during counting is exceedingly difficult.

The writer is at a loss how to practically evaluate these errors in quantitative terms -- especially the first. Rittenhouse (1948, p. 16), who used the same type of rapid methods of identification, says that he was able to keep his misidentification errors to as low as five percent. The errors of the present writer are probably slightly higher than those of Rittenhouse; this difference is likely the result of less experience.

Counting

As was stated previously, 300 grains were counted in each sample. According to a chart given by Krumbein and Pettijohn (1938, p. 472) after Dryden, a count of 300 grains per sample produces percents of probable error for percents of the sample as follows:

Percent of Sample (Frequency value)	Percent of Probable Error
80	2.2
60	3.1
40	5.1
20	7.6
10	11.6
5	17

These values of percent of probable error are only approximations because, as Krumbein and Pettijohn (1938, p. 471) note,". . .the examples given above on the calculation of the probable error assume that one knows the true frequency value of the mineral in question. Actually, this is what one is trying to find. It is not possible to take the percentage determined experimentally and say what its probable error is."

The probable error in determining the frequency value (percent of the sample obtained by grain counts) of a mineral for a certain sample is an error inherent in all sampling. Being inherent, this error has no relationship what so ever to mistakes such as misidentification or to the care taken in collecting and analyzing samples. In other words, this error has no connection with those resulting from the method of procedure. This error may be reduced, of course, by counting a larger number of grains per sample. The number of grains to be counted, and hence the size of the error involved, is dependent upon the time available, accuracy required, difference between samples, and so forth. Each worker must decide what accuracy is required by each problem. The writer feels that sufficient accuracy is obtained for this problem by counting 300 grains per sample.

TABULATION OF DATA

In the following tables the samples are arranged such that samples from the same units are together. Samples from the Lower Ferron have been grouped with those from the "seventh sand." Middle and Upper Ferron samples follow those of the "seventh sand," those known to be from the "second," "third," and "sixth sands" being differentiated. Blanks occur in the tables for one of two reasons; no grains of certain types were found, or not enough grains were found to justify calculating percentages. The number "-1" means less than one percent.

The percentages of all minerals found in the various samples are shown in Table I. Table II shows the percentages of the total zircons as divided into colorless, pink, dusty, brown, and yellow. The percentages of the subdivisions of the colorless zircons are given in Table III. The colorless zircons have been divided into euhedral, angular, subangular, and well-rounded grains. In Table IV is shown the total number of rutile grains of each color in each of the samples. Because there were not enough rutile grains counted to make percentages valid, the total number of grains of each color is show rather than the percentage of total rutiles.

DISCUSSION OF HEAVY MINERALS

The writer was unable to discover any heavy mineral zones within the various units of the Ferron which could be differentiated by means of different minerals, groups of minerals, different types of certain minerals, ratios of different minerals, or any other means. Though the heavy mineral fraction is quite variable both in mineralogy and in the proportions of the component mineral, it is inconcistently so and permits no correlation. The closest approach to the aformentioned types of differentiation is found in the rutiles. It may be seen in Tables I and IV that a somewhat higher average percent of rutiles (total of all colors) occurs in the "seventh sand" than in the Middle and Upper Ferron. A parallel but less decisive difference in the average amount of zircons also occurs. Though these differences are apparent, the writer feels they are not prominent enough nor consistent enough to be of value for correlation.

Areal differences in mineral composition are found to be greater than stratigraphic differences. Garnet is essentially confined to those samples taken in the extreme southern area covered by the Ferron. Garnet is distributed from top to bottom of the Ferron in this area, but there seems to be an indication that higher percentages occur in the Middle and Upper Ferron than in the "seventh sand." Because the garnet is angular and shows little or no evidence of abrasion, the writer concluded that it was deposited near the source, but no evidence was found to indicate the source or its directions.

The confinement of the garnet to the southern area seems to indicate a sedimenary realm separated by one means or another from that in which the rest of the Ferron was deposited and also a separate, local source area.

A slightly higher tourmaline percent is found in the "seventh sand" samples taken in the northern part of the area than in those taken in the southern part. Because of the fact that the amounts of tourmaline in many samples were so low and because of the possibility of misinterpretations resulting from breakage during disaggregation, the writer was unable to draw conclusions as to the source direction of the tourmaline or as to the significance of its relative abundance.

Table II-Percent of Total Zircons per Sample

Sample No.	Colorless	Pink	Dusty	Brown	Yellow	Sample No.	Colorless	Pink	Dusty	Brown	Yellow
	Seventh Sand						Mid. and Up. Ferron				
10	53	8	25	14		22	96	1	3		
1	80		8	12		26	80	7	3		
2	88		12			27					
3	88		10	2		28					
4	87	2	6	5		29					
5	83		14	4		30	71	10	19		
19	74		24	2		31					
20	97		2	1		32	79	16	5		
21	81		11	7	1	33	85	4	10		
25	86	2	12			34	90	2	5		2
36	68	5	24	3		35	92	2	2		4
37	76	13	12			45	85	3	12		
38	86		14			46	88		12		
39	86	7	7			48	82		18		
40	99		1				Second Sand				
41	85		15			6	92		5	3	
42	85	3	12				Third Sand				
43	91		9			7	86		10	4	
44	92		8			8	86		12	2	
47	69	17	13				Sixth Sand				
11	79		20	-1		9	75		25		
12	85		10	5			Castle Dale Shale				
13	87	-1	10	3		17					
14	86		14			18	91	-1	8	-1	
15	87		10	2	-1		Dakota Sandstone				
16	78		22			23	94		6		
						24	90	2	8		

Table III - Percent of Colorless Zircons per Sample

Sample No.	Euhedral	Angular	Subangular	Well-round	Sample No.	Euhedral	Angular	Subangular	Well-round
Seventh Sand					Mid and Up Ferron				
10					22		15	54	31
1		25	63	12	26	1	24	41	34
2		27	58	15	27				
3		26	54	21	28				
4	1	22	53	24	29				
5	4	30	65	1	30	4	33	43	20
19	8	32	44	16	31				
20	12	22	52	17	32	15	31	52	2
21		39	48	12	33	5	30	39	26
25	7	31	32	31	34	3	14	41	43
36	12	24	42	22	35	7	21	48	24
37	12	26	41	21	45	8	29	29	37
38	2	24	49	26	46	12	36	36	16
39	3	22	52	23	48	14	32	42	14
40	9	28	41	23	Second Sand				
41	7	38	38	17	6		48	46	6
42					Third Sand				
43	4	29	46	21	7		29	60	11
44	8	21	57	14	8		16	51	33
47	11	47	25	17	Sixth Sand				
11	2	51	40	7	9	3	46	45	6
12	12	47	35	6	Castle Dale Shale				
13	2	29	60	9	17	8	20	55	18
14	5	48	40	8	18	5	34	46	15
15	30	32	63	5	Dakota Sandstone				
16		37	54	10	23		36	37	27
					24		20	64	17

Table IV - Total Number of Rutile Grains per Sample

Sample No.	Red	Red-Brown	Orange	Yellow	Sample No.	Red	Red-Brown	Orange	Yellow
Seventh Sand					Mid. and Up. Ferron				
10			1	1	22				4
1		3	5	2	26		3		
2		1	2	6	27				2
3		5	11	3	28				
4		2	2	4	29	2			
5		4	5	9	30	3			1
19	1		10	12	31		1		
20		4	3	1	32		3		
21	2		1	7	33		4		
25	3			1	34		2		4
36	1			5	35		1		
37	1	3			45	1			
38	1			7	46	1			
39		2		3	48				
40	1		1	3	Second Sand				
41	6		3	7	6		2	2	3
42	2			2	Third Sand				
43			4	11	7		3	5	6
44	3		2	5	8		3		1
47	3			1	Sixth Sand				
11			9	9	9		2	3	5
12			4	1	Castle Dale Shale				
13	6	1	9	2	17			6	4
14	3		10	12	18			12	6
15	4		9	6	Dakota Sandstone				
16			3	12	23		1	2	4
					24		5		5

More hematite and limonite occur in the samples taken at Farnham Dome in the northeast part of the area than in those from any other area. These hematite and limonite grains show little if any evidence of abrasion, being very susceptible to crushing; therefore, it was concluded that they are of authigenic origin and of no value in correlation.

Pyrite, which occurs over a wide range of proportions, occurs chiefly in the core samples with very little in the outcrop samples. This difference is probably due to leaching of the pyrite from the near surface rocks by ground water. The amount of pyrite in a sample seems to be dependent upon the amount of silt and clay sized material present and also upon the carbonaceous content. Showing no evidence of abrasion, being chiefly authigenic in origin, and being very susceptible to solution, pyrite is also of no value in correlation.

A greater proportion of rock fragments occurs in heavy mineral residues from outcrop samples than from core samples. The cause and signigicance of this fact are unknown.

A large number of mineral s occur in very minor amounts in various samples, but none are found in large enough proportions and in enough samples to have any bearing on this problem.

CONCLUSIONS

The results of the analysis of the samples studied in this problem justify the writer in drawing the following conclusions:

1. No readily apparent mineral zones occur in the Ferron sandstone which prove to be of value for correlation of its various units.

2. The Ferron sandstone appears to be generally homogeneous in the heterogeneity of its heavy mineral components.

3. The Ferron sandstone was deposited in several sedimentary realms.

4. The sediments comprising the Ferron sandstone were derived from several independent source areas.

The writer believes that a more extensive petrographic study of the heavy minerals of the Ferron would possibly determine the presence of some of the rarer heavy minerals which could be used as a means of correlation. The analysis of a greater number of samples might also show facts not readily discernable in a preliminary study. Because the writer dealt exclusively with the heavy mineral fraction, he has no knowledge of what a study of the light might produce.

APPENDIX

List of Samples Analyzed in This Study

Sample No.	Location	Well or Outcrop	Stratigraphic Position
1	17-14S-7E	H. E. Walton #1	15' below top of #7 sand, 377' below top of Ferron
2	"	"	17' below top of #7 sand, 379' below top of Ferron
3	"	"	21' below top of #7 sand, 383' below top of Ferron 393'
4	"	"	40' below top of #7 sand, 412' below top of Ferron
5	"	"	55' below top of #7 sand, 427' below top of Ferron
6	27-16S-6E	M. D. Kearns #1	#2 sand, 34' below top of Ferron
7	"	"	#3 sand, 83' below top of Ferron
8	"	"	#3 sand, 92' below top of Ferron
9	17-14S-7E	H. E. Walton #1	#6 sand, 296' below top of Ferron
10	"	"	top of #7 sand, 364' below top of Ferron
11	2-15S-11E	otc.	top of Farnham
12	"	"	3' below top of 1st mass. bed Farnham as., 40' below litho-ss. ledge at top of Farnham
13	"	"	15' below top of 1st big mass. ledge at top of Farnham ss., at base of ledge, 55' below top of Farnham ss.
14	"	"	62' below top of Farnham, top of 2nd mass ss., below 6' shale
15	"	"	8' below top of 2nd mass. ss., 70' below top of Farnham

List of Samples Analyzed in This Study (continued)

Sample No.	Location	Well or Outcrop	Stratigraphic Position
16	2-15S- 11E	otc.	18' below top of 2nd mass., in bottom 2' ss., 80' below top of Farnham
17	"	"	concretion in Castle Dale shale
18	"	"	ss. ledge in Castle Dale shale
19	17-16S- 11E	otc.	Farnham
20	11-17S- 10E	"	Farnham
21	13-13S- 6E	"	7' below top of #7 sand
22	22-12S- 7E	Wasatch #1	18' below top of Ferron
23	"	"	26' below top of Dakota
24	"	"	61' below top of Dakota
25	34-21S- 7E	otc.	lower Ferron
26	15-17S- 8E	Phillips Huntington #1	3' below top of Ferron
27	"	Phillips Huntington #1	32' below top of Ferron
28	"	"	44' below top of Ferron
29	"	"	48' below top of Ferron
30	"	"	63' below top of Ferron
31	"	"	74' below top of Ferron
32	"	"	98' below top of Ferron
33	"	"	112' below top of Ferron
34	"	"	143' below top of Ferron
35	"	"	161' below top of Ferron

List of Samples Analyzed in This Study (continued)

Sample No.	Location	Well or Outcrop	Stratigraphic Position
36	15-17S- 8E	Phillips Huntington #1	probably #7 or Farnham ss., 193' below top of Ferron
37	"	"	probably #7 or Farnham ss., 201' below top of Ferron
38	"	"	probably #7 or Farnham ss., 213' below top of Ferron
39	"	"	probably #7 or Farnham ss., 226' below top of Ferron
40	19-28S- 10E	otc.	lowest member of Ferron
41	23-28S- 9E	"	lowest member of Ferron
42	3-29S- 8E	"	lowest member of Ferron
43	32-18S- 9E	"	along road from Castle Dale to Cedar Mtn. - topof lower Ferron
44	16?-29S- 8E W of Fremont River crossing W of Cainville	"	base of Ferron
45	3?-29S- 8E E of Fremont River crossing W of Cainville	"	middle of Ferron
46	20?-28S- 9E on bench E of Cainville	"	top of Ferron
47	22?-28S- 9E in canyon E of Cainville	"	base of Ferron
48	30?-18S- 9E top of long dug-way on road from	"	near top of Ferron

List of Samples Analyzed in This Study (continued)

Sample No.	Location	Well or Outcrop	Stratigraphic Position
48 (cont.)	Castle Dale to Cedar Mtn.		

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ABSTRACT

The data and results of a preliminary petrographic study of the heavy minerals of the Ferron sandstone are presented. The method of procedure and an analysis of their probable effects on the results are briefly outlined. In addition to a list of precise areal and stratigraphic locations, a map is given showing the general locations where samples were taken. Data obtained from grain counts of the heavy mineral fraction of each sample is shown in tables as well as an analysis of this data.

No apparent heavy mineral zones of any value for correlation were discernable in the Ferron sandstone, but several areal differences in heavy mineral composition were noted. An analysis of these differences is given.