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A PETROGRAPHIC STUDY OF THE LOWER HYGIENE  
SANDSTONE MEMBERS OF THE UPPER CRETACEOUS  
PIERRE SHALES OF NORTHEASTERN COLORADO.

By

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University of Colorado, 1930

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Date *May 26 1932*

A Thesis Submitted to the Faculty of the Graduate  
School of the University of Colorado in Partial Fulfill-  
ment of the Requirements for the Degree Master of Arts.

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sedimentation in the region of Boulder, Colorado.

The problem was originally undertaken as an aid to the zoning problem in drilling the Pierre shale. It has long been known to the oil companies that the well cuttings of the Pierre present an almost homogeneous mass of brown to slate colored shale and some sands which can not be differentiated by the naked eye, and consequently the geologist is never sure in just what part of the formation the drill is cutting, a fact which presents serious difficulties in determining the structural trends of the fields.

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Introduction

It is the purpose of this paper to give the results of petrographic studies of the Hygiene Sandstone members of the Pierre shale by applying well known standard methods of sedimentary investigation to this untried type of marine sand in an effort to ascertain whether or not these methods can be satisfactorily used for lateral correlation purposes. In addition, it was hoped that such an investigation might possibly reveal more information concerning conditions of Pierre sedimentation in the region of Boulder, Colorado.

The problem was originally undertaken as an aid to the zoning problem in drilling the Pierre shale. It has long been known to the oil companies that the well cuttings of the Pierre present an almost homogeneous mass of brown to slate colored shale and some sands which can not be differentiated by the naked eye, and consequently the geologist is never sure in just what part of the formation the drill is cutting, a fact which presents serious difficulties in determining the structural trends of the fields.

Beginning at the top of the lower third of the Group but the Hygiene and the Rocky Ridge members

Pierre formation, which under normal conditions is roughly 2500 feet from the top of the underlying Niobrara Formation, and continuing for some 1500 feet stratigraphically there are some prominent sandstones present. Some of these sandstones are quite persistent laterally. The lowest sandstone was originally named and described by Fenneman in 1905 at its type locality near the town of Hygiene, Colorado, as the Hygiene Sandstone of the Pierre. At the time Fenneman considered this to be the only prominent sandstone within the Pierre Formation. Since then, however, it has been found that there are other sandstones present and separated from the original Hygiene by considerable thicknesses of shale; and these, at the present time, make up what is known as the Hygiene Group.

The members of the Hygiene Group are best developed in the vicinity of Douglas Lake near Fort Collins, Colorado, where there are five distinct sands recognizable, all of which have been measured by H.A. Aurand.<sup>2</sup> They are named in order from bottom to top Hygiene, Terry, Rocky Ridge, Waverly, and Richards. The credit for the correct interpretation of these sands according to Mather<sup>3</sup> is due to Schwennesen, Kranpert, and Henly of the Roxana Petroleum Corporation. All the Hygiene Group but the Hygiene and the Rocky Ridge members

disappear a short distance south of Fort Collins. The Rocky Ridge continues as a well defined sand to Little Thompson Creek and is lost, but it may be represented by a sandy zone in the Pierre as far south as Boulder. The Hygiene sandstone is believed to be continuous from Fort Collins to the mouth of Coal Creek Canyon. This paper is limited to the study of the two lower sands, the Hygiene and Rocky Ridge.

The investigation was carried out in the Sedimentary Laboratory of the University of Colorado. The writer wishes to express grateful appreciation to Professor W.O. Thompson for suggesting and directing the research, to Dr. R.D. George whose interest and cooperation made it possible to carry on the work, to Mr. E.W. Kimball for many helpful suggestions and criticisms, and to the other members of the faculty of the University of Colorado who have aided in the work.

### Location

Collecting and sampling were carried on along the narrow strip of Pierre outcrop immediately adjacent to the Foothills of the Front Range extending from the mouth of Coal Creek Canyon west of Denver, Colorado, northward a distance of more than forty miles to Fossil Creek, just south of the town of Fort Collins, Colorado. The index map in Figure 1 shows the approximate location

of the sections which were measured. Each section is named according to the location. The locations were

while the best... the beds.

reference... name... given... 21, 716-... -8707;

(3) Little... 32, 33, 34, 35, 14, 23, 12, 768-... Coal... along... The

Coal Creek... along a series of cuts... the mouth of... the sedi-... in upward order, Fountain, Lyons, Lykins, Morrison, Dakota, Benton, Niobrara, Pierre, Fox Hills, and Laramie.

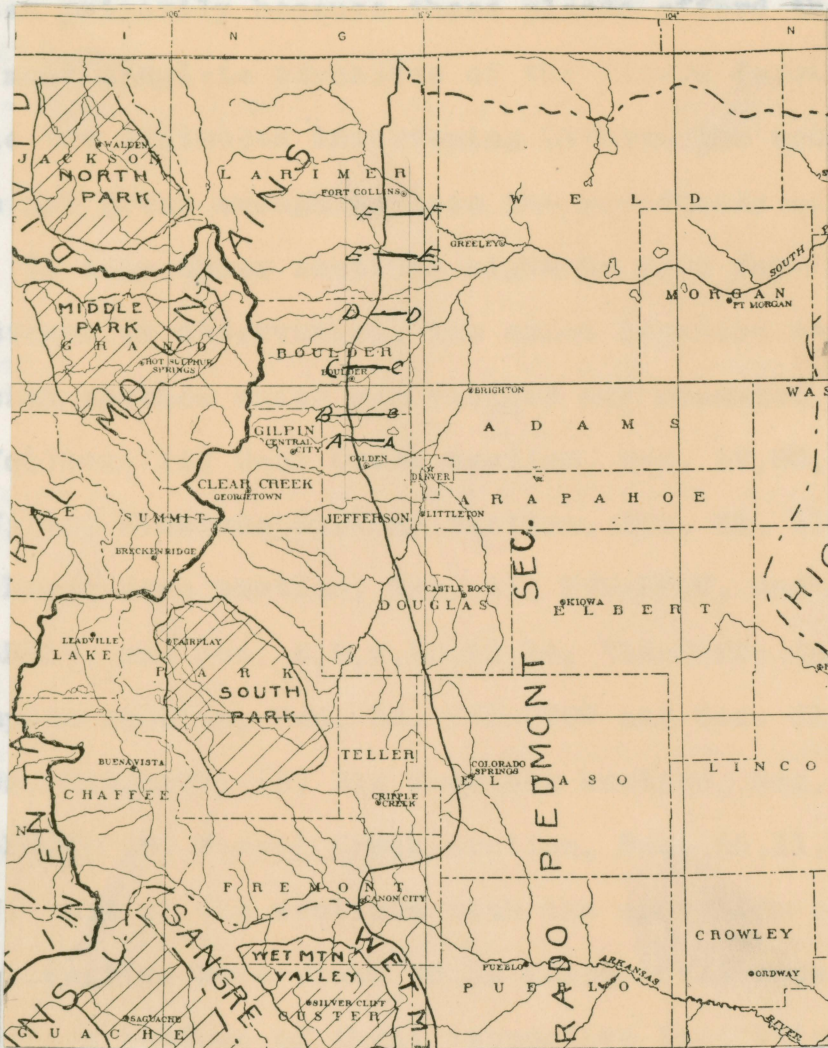


FIG. 1. INDEX MAP.

- Coal Creek Lake Area A - A
- Eldorado Springs B - B
- Degge Mesa C - C
- Little Thompson Creek D - D
- Big Thompson Creek E - E
- Fossil Creek F - F

of the sections which were measured. Each section is named according to the location. The locations were chosen primarily because these places afford the best and most complete exposures of the Pierre Formation, while the distances intervening between the sections were not great enough to lose the continuity of the beds.

In case these sections might be used for future reference or observation, the exact location and name of each section which was visited and measured is given as follows: (1) Coal Creek section, Sec. 19,20,21, T1S-R70W; (2) Eldorado Springs section, Sec. 33, T1S-R70W; (3) Degge Mesa section, Sec. 31, T2N-R70W, and Sec.1, T1N-R71W, and Sec. 6,8,9,10,13,14, T1N-R70W; (4) Little Thompson section, Sec. 36, T3N-R70W and Sec. 31,32,33, 34,35, T4N-R69W; (5) Big Thompson section, Sec. 14,23, T5N-R69W; (6) Fossil Creek section, Sec. 10,11,12, T6N-R69W. All of the sections with the exception of Coal Creek section were found to be fairly well exposed along the creek bottoms of their respective localities. The Coal Creek section was measured along a series of cuts on the Denver and Salt Lake Railroad at the mouth of Coal Creek Canyon.

The general stratigraphic succession of the sediments in the area worked is, in upward order, Fountain, Lyons, Lykins, Morrison, Dakota, Benton, Niobrara, Pierre, Fox Hills, and Laramie.

## Stratigraphic Section of the Boulder Region

Permian

Lycus Thickness in feet, fine Character massive and  
(Unconformity) cross-bedded sandstone

CretaceousCampanian

Laramie 600(?) Sandstones, carbonaceous,  
shale and coal sandstone and  
conglomerate

Fox Hills 250-300 Use of Fox Hills is now to be  
limited to the predominantly  
sandy beds at top, such as  
Milliken sandstone

Pierre 5000-7000 Brown to gray fissile shales,  
fossils; lowest five sands  
are Hygiene Group

Niobrara 380 Limy shales with massive gray  
ls. at base

Field Methods

Benton 470 Black fossiliferous shales in  
bands of Bentonite, some dark  
limestone, concretionary string-  
ers

Dakota 320 Massive sandstone, medial shales,  
(Unconformity) conglomeritic at base

Cretaceous(?) - Jurassic(?)

Morrison 400 Non-marine variegated yellow-  
(Unconformity) green and purple shales; some  
limestone and sandstone

Jurassic

Sundance ? There is as yet no evidence of  
marine Sundance in the foothills  
belt of Colorado

Permo-Triassic

Lykins 800 Brick red sandstones and shales;  
some limestone and gypsum,  
usually near the top

Permian

Lyons	300	Hard, fine-grained, massive and
(Unconformity)		cross-bedded sandstone

Pennsylvanian

Fountain	840	Variegated arkose sandstone and
(Unconformity)		conglomerate

Graphical columnar sections of the Pierre are shown in Plate 1 accompanying this paper; one may refer to it for details of the Pierre Formation.

## METHODS OF STUDY

Field Methods

The field work for this problem consisted of two parts, namely, that of measuring sections and that of sampling in detail the sections as they were measured. It is imperative in this type of problem that the exact stratigraphic position of the beds be determined, in order that the petrographic results may be correlated. Fenneman's paper on the Boulder area does not recognize the Hygiene sandstone any farther south than Bear Creek Canyon, a few miles south of Boulder, but it is now believed to extend for some distance beyond this point. The sections were measured with the plane table alidade and stadia rod by using a careful back-sight traverse. It was found that in order to reduce the error which accompanies this kind of traversing several checks angles

for elevation must be made both forward and backward at each instrument station. Matters are greatly facilitated with this procedure by flagging each instrument station as it is abandoned.

In measuring the detail of a sand the rod is held either at the top or bottom of the zone and the distance across the outcrop is easily obtained with a tape or by placing the rod lengthwise on the ground, depending upon the nature of the outcrop. If the outcrop happens to be nearly level, the rod is sufficient for the purpose, but in cases of sloping outcrop, it is better to use the tape and Brunton compass. The upper and lower limits of the zone were arbitrarily chosen at the points where the shaly sand grades into sandy shale, since this particular type of change in lithology is characteristic of nearly all sandstones in the Hygiene Group.

In sampling consolidated sediments of this sort, it is generally recognized that one piece of sufficient size, that is 2500 to 3000 grams, well-chosen to represent the zone, is better than a composite sample obtained by chipping the rock here and there throughout the zone to be sampled. Any greater degree of accuracy that may be obtained by this method does not warrant the enormous amount of time necessary to work and cutting the material for laboratory use.

The samples from each section are labeled in this

The samples may be chosen from the outcrop measuring standard ten-foot intervals, or perhaps less, should the field indicate that there is rapid vertical variation; or else they can be taken at irregular intervals wherever a change in the character of the sand occurs. The method of sampling at the intervals of lithologic change was used most in collecting samples for this problem, because the fineness of the grain combined with the marine character of the sediment does not indicate that there are rapid changes in the composition of the sandstone. Thus sampling at points where the character of the sand undergoes an apparent change is sufficient to catch any vertical variation which may exist.

Each sample as it is collected is placed in a heavy number 4 paper sack. The samples are numbered with the corresponding rod shots so their location in the section can be easily identified by referring to the plane table sheet as well as the field notes. If more than one sample is collected they are numbered 1, 2, 3, and so on, and the corresponding position recorded in the notebook. For example, rod shot 2-b is located at the top of a sandstone; the sample at that point is 2-b,1, and the rest of the sample from top to bottom of the sand are, 2-b,2; 2-b,3; 2-b,4, and so on according to the number of samples.

The samples from each section are labeled in this

manner, and the method tends to avoid confusion which may arise with the use of complex serial numbers, when examining a great number of samples in the laboratory. It has the added advantage that the worker can tell at a glance in what section and in what part of the section the sample is located. When the samples are brought in from the field they can be filed away easily in boxes bearing the name of the section from which they came. Some workers suggest immediate disintegration when the sample is brought in from the field, since the material breaks down more easily. It was found, however, that this makes very little difference with this type of material, and the samples can be handled with more speed and with greater efficiency when they are examined after all the field work has been finished.

#### Laboratory Methods

Each sample was examined for texture, shape of the grains, and for mineral composition. The procedure, following Wentworth,<sup>4</sup> was much the same as that reported in many recent papers and will be only briefly mentioned. Roughly fifty grams of the sample was used for the analysis. The sample is first placed in beakers for a period of soaking followed by a period of boiling. The boiling is more effective in disintegrating the sample if the sample is placed in a deep iron mortar and gently crushed (not ground) to fragments about the size of a pea.

After an hour of boiling the remaining aggregates can be reduced to individual grains by rubbing with a rubber cork. The bottom pan from a nest of screens is an ideal container for the rubbing process in that it prevents loss of material and provides easy handling of the sample when transferring the material from beaker to rubbing pan and back again.

If the sample is consolidated with a limy cementing material, the sample must be boiled in a 20% solution of HCl. Here again the acid treatment is much more effective when the sample is reduced to small fragments. In crushing limy samples in the mortar there is a greater hazard of breaking the individual grains, but if due care is exercised and the sample crushed under water, there is very little danger of damaging the grains.

Drying samples after they have been broken down may be accomplished in two ways, either by cooking the sample on the hot plate, or by filtering off the water and drying the sample on the filter paper. Samples that are dried directly without filtering must be closely guarded to avoid accidental loss of material. The method of direct drying, however, has the advantage in that it is possible to handle ten or more samples at a time. The use of this procedure in handling samples of large silt content tends to increase the difficulty

in making a textural analysis, because the silt clogs the mesh of the finer screens, making it nearly impossible to separate the grade sizes, and in addition its low-presence prolongs the filtering indefinitely. Also <sup>5</sup> Tickell suggests the use of other methods than screening when handling silt. A modification of the filtering method was found to be the best treatment for samples of the type dealt with in this paper. This was carried on as follows: first, the sample was weighed accurately, and during the process of disintegration great care was exercised not to lose any of the material. Then, after the sample was broken down into its component grains, the silt was decanted off, care being taken to allow none of the larger particles to be lost during the decantation; then the sample was filtered, dried, and weighed. The loss of weight was then classed as silt and the actual silt was not present to interfere with the textural analysis. A battery of funnels arranged in groups of

Tests were made with samples before this method was adopted, and it was found that the decantation method did not vary from the straight filtering method by more than one or two grams in a sixty-gram sample, while only one-third the time was necessary. Such a method will not be of much value if the sample is limy, for a lime factor would have to be figured for each peculiar

and petrographic microscopes. The shapes of the grains were obtained by counting from 150 to 300 grains of each sample and classifying them as angular, subangular, subround, and round, using the significance given these terms by V.A.P. Stahm in his recent paper on the Cambrian sandstones of Minnesota. The grain counts were made by scattering the light portions of each sample over a glass plate ruled in centimeter squares. In this way it is possible to keep track of the portions of the plate which have been examined. The study of the mineral grains of the light portions of the samples soon revealed that the light minerals were very similar in all samples, so no quantitative study was made of them. Quantitative estimates were made of the relative amounts of the heavy mineral portions, using the grain counts. The estimates of the minerals are expressed as per cent (0-10 per cent) abundant (more than 50 per cent of the concentrate). All of the concentrates were very small, none weighing more than 0.3 per cent of the portion from which they were separated. The texture, size, and quantitative heavy mineral results in the form of histograms are purposely grouped together so as to bring out the

sample; and this would take more time than is saved. The texture was obtained by screening the samples. The screens employed were Tyler Screens nested in the following order from top to bottom: 32 mesh, 60 mesh, 115 mesh, 250 mesh. These screens corresponded to Wentworth's classification of silt, very fine sand, fine sand, and coarse sand. The amount of any given grade-size was calculated as percentage weight of the total sample. At least fifteen minutes were required to screen each sample. The texture of the sand was so fine that it required some time to separate the fine and very fine grades.

Bromoform (Sp. Gr., 2.8) was used to separate the minerals into light and heavy groups. One-eighth to one-fourth mm. grade size was used for the separations, since this was the largest size present in quantities large enough to make a separation. The separation was made with a battery of funnels arranged in groups of two, one above the other. Twenty minutes was allowed for each separation, and during this time bromoform floats were stirred frequently. After the separation, the light and heavy groups were filtered, dried, placed in small glass vials and filed away with the remainder of the sample for future examination. The minerals of the light and heavy groups were studied with the binocular

and petrographic microscopes. The shapes of the grains were obtained by counting from 150 to 200 grains of each sample and classifying them as angular, subangular, subround, and round, using the significance given these terms by W.A.P. Graham in his recent paper on the Cambrian sandstones of Minnesota. The grain counts were made by scattering the light portion of each sample over a glass plate ruled in centimeter squares. In this way it is possible to keep track of the portions of the plate which have been examined.

The study of the mineral grains of the light portions of the samples soon revealed that the light minerals were very similar in all samples, so no quantitative study was made of them. Quantitative estimates were made of the relative amounts of the heavy mineral portions, making grain counts. The estimates of the minerals are expressed as rare (0-10 per cent), common (10-20 per cent), abundant (20-50 per cent), and very abundant (more than 50 per cent of the concentrate). All of the concentrates were very small, none weighing more than 0.3 per cent of the portion from which they were separated.

#### The Petrographic THE PETROGRAPHIC STUDY

The results of the Petrographic study are shown graphically on plate 2. The texture, size, and quantitative heavy mineral results in the form of histograms are purposely grouped together so as to bring out the

The heading size. Each graph represents a sample of relationships of all the petrographic characters with the vertical and lateral extent of the sandstone. The form of the histograms was originally designed to show the heavy mineral composition in relation to size and shape, but was found impossible to show correct graphical results of the heavy mineral study in this form. Consequently a separate chart was made to show the heavy mineral composition; this chart is carried on Plate III.

The histograms show the samples arranged in groups of first and second sands according to their position from the bottom of the section. The first or lower sand is the Hygiene member, the second is the Rocky Ridge. In the northern part of the area these members are well developed. For the purposes of lateral correlation to the south the names "first sand" and "second sand" are substituted for the formational names where these two lower sands have not been identified positively. The arrangement of the plate showing the heavy mineral composition is made in the same manner, so that the two may be compared easily.

#### Texture

The results of the study of the texture of the sands are shown in the first column on Plate II under

the heading Size. Each graph represents a sample of sand; and the graphs are arranged from top to bottom in proper stratigraphical sequence. The difference in outline of the different graphs show general textural differences, and the expression of these differences is found in the percentage amounts of the several grain sizes shown.

The general size relationship of the sandstones of this group are similar in that in no instance do the grain sizes exceed the one-half mm. size. In most cases the greater number of grains do not exceed the one-fourth mm. size except in the Big Thompson and Fossil Creek sections where the top of the Hygiene shows a considerable development of one-half mm. grains.

The vertical distribution of the grain sizes show no great variation in the southern area where, in general, the texture remains very similar throughout the sands, as shown in the first and second sands of the Coal Creek section and the first sands of Degge Mesa. In the northern area no such similarities exist.

Laterally the texture does not form any positive basis for correlation between groups except in certain parts of adjacent sections. For example, the top sand of the Hygiene member in the Big Thompson and Fossil Creek sections shows a marked similarity with a larger

development of the one-half mm. size. The middle sands of the Rocky Ridge member also shows a marked similarity, as shown in samples 10 and 11 of Big Thompson and 5 and 7 of Fossil Creek. The top sands of the Hygiene member between adjacent sections sometimes shows marked similarity as is the case between Degge Mesa and Little Thompson sections and also between the Coal Creek and Eldorado Springs sections. It will be noticed, however, that the texture is not the same in each case, nor does it remain the same for any considerable distance.

#### Shape of Grains.

The shape column of the graphs on Plate II shows the results obtained from the study of the shapes of the sand grains. In general, all samples of the lower members of the Hygiene group show a great similarity in shape. In every instance the grains show predominant angularity. The proportion of the angular grains to the subangular grains in a general way remains constant. There is a small amount of roundness in the grains at the extreme north and south ends of the area, but, taken as a whole, the samples are marked by general lack of rounded grains. From a diagnostic standpoint, the shape can not be regarded as important. The study, however, does give information on the erosional history of the

sediments and suggests that they have not been transported a very great distance from their source.

### Mineral Composition

Light Minerals. The light minerals were found to be much the same in all samples examined, and no particular study was made of them except for their identification. The light minerals made up more than ninety-nine per cent of each sample, the bulk of which is quartz and its varieties. Glauconite, muscovite, white opaque aggregates, and occasionally doubtful orthoclase feldspar make up the remainder of the light portions. Most of the quartz is phanero-crystalline but crypto-crystalline varieties are quite common in all the samples. Glauconite is present slightly in all samples as a light green opaque mineral. The glauconite grains frequently exhibit characters suggesting pseudomorphs after foraminifera shells. Rare colorless grains exhibiting apparent cleavage were thought to be orthoclase feldspar though because of its similarity to quartz it is apt to be confused with that mineral.

Heavy minerals. The heavy minerals found in the samples from the various localities are shown in the accompanying chart, in Plate III. An attempt was made to express quantitative results of this study because it was hoped

that any great differences in the sands would be found among the heavy minerals. The chart shows that a few minerals, biotite, muscovite, chloritoids, glauconite, leucoxene, and magnetite or ilmenite, constitute the bulk of the heavy minerals. The other minerals present exist in far smaller quantities than is indicated by the chart. Under leucoxene, one of the most abundant minerals listed, has been included the white to brownish material, much of which shows all stages of alteration from ilmenite. Magnetite and ilmenite could not be differentiated under the microscope except when leucoxene was associated. For this reason they are listed together in the chart. One mineral listed as X could not be identified positively; it occurred as irregular, colorless grains, characterized by lack of pleochroism, high refractive index, and high birefringence, giving interference colors of white of the higher orders. Some of the grains gave very indistinct off-centered uniaxial interference figures, but it was impossible to determine the optical character of the mineral.

The results obtained from the study of the heavy minerals yield little diagnostic value for recognition of the various samples from the Hygiene and Rocky Ridge sandstones. None of the minerals are limited in

. HEAVY MINERALS

Section and sample	B	M	Gl	L	I or Mg	C	G	Z	A	T	O	X	H	I
<u>Coal Creek</u>														
2nd sand														
106														
107			A	VA			C	R	R					
1st sand														
2A14	VA	VA		A	A	C		R	R	R				R
2A15	VA	VA		VA	VA	C	R							R
2A16	VA	A	R	VA	VA	C			R	R				R
2A17	A			VA	VA									
2A18			C	VA	VA									
<u>Eldo. Spgs.</u>														
Upper sand														
1K1	A	A	C	VA	VA	A								R
2B2														
2C3	R		C	VA	VA									
First sand														
3c1		VA	C			C								
3c3	C		R	A	A	C								
<u>Degge Mesa</u>														
2nd sand														
5d1		C	C			C	R							
5d2														
5d3	A	VA	C	A	C	C								
1st sand														
1c	C	A	VA	VA		C								
1c-1d		VA	C	C		C		R	R					
1d		VA	A	VA	C	A								
1e	C	A				C					VA			
<u>Little Thomp.</u>														
2nd sand														
7	A	A	A	C	C	A	R							
6														
5	R		C	A	A		R	R						
4														
1st sand														
3		A				C								
2	C	C	A	C		A								
1	C	R	VA	C							A	A		
<u>Big Thomp.</u>														
2nd sand														
13	VA	A	C	C		A	R	R	R					
12	VA	C	C	A	A	C	R	R	R					
LL	VA	A	C			A	R		R				R	
LQ	R	A		VA	VA	R	R							
9			C	VA	VA	A								
8	VA	A	C	C		A	C							
1st sand														
7	C	A	C	VA			VA	C		A				
5	C	C	A	VA	VA	A							R	
4	A		C	A	A	A	R			R				
3	A	VA		A		C	C			R				
<u>Fossil Creek</u>														
2nd sand														
9				C	C		VA	R		C				
8	A	R	C	C	C	C	R	R	R	R	Limonite	VA		
6	VA		R	C	C	A								
5	VA	A				A								
4	VA	C	A	C	VA	A	C				VA			
1st sand														
3	VA	A		C		C	R						R	
2	A		A	VA		A	R			R				
1	VA	C	A	C		VA	R							

Explanation of mineral abbreviations:

B--biotite; M--Muscovite; Gl.--Glauconite; L--Leucoxene; Mg.--Magnetite; C--Chloritoid; G--Garnet; Z--Zircon; A--Apatite; T--Tourmaline; O--Opaque aggregates; X--Unknown mineral; H--Hematite; I--Ilmenite

It is understood that VA indicates very abundant; A, abundant; C, common; R, rare.

occurrence to any one sandstone or to any part of one sandstone, nor are there any suites of minerals present in these members of the Hygiene group which are constant with the same sand in a different locality.

#### 1. SUMMARY AND CONCLUSIONS. Boulder Area, U.S.G.S.,

The texture of the Hygiene and Rocky Ridge sandstone does not reveal any information which would be of any diagnostic value in long distance correlation, but possibly the texture may be used in correlating the beds in closely adjacent areas. The grain shapes are markedly similar; all samples show a preponderance of angular grains and a minimum of rounded grains. in Natural

The study of the heavy minerals offers no information which might serve as a basis of identification.

Unless petrographic characters other than those used in this investigation are incorporated in the study, there is little to be gained in further investigation of the Hygiene group for purposes of correlating the members laterally.

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<del>Dec 4 '39</del>	DEC 7 1957	
<del>NOV 10 '39F</del>	FEB 27 1958	
<del>NOV 10 '40F</del>	MAR 18 1958	
<del>JAN 17 1944</del>	APR 8 1958	
	APR 16 1958	
NOV 17 1947	<del>JUL 6 '58</del>	
	<del>OCT 5 '58 CU</del>	
FEB 9 1949	<del>FEB 16 '70</del>	

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