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PETROGRAPHICAL INVESTIGATIONS OF THE SALT WASH SEDIMENTS

Progress Report—April 1 to October 1, 1954

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Abstract

This report, subdivided into six parts, completes our investigations into the general petrographic background of ore-bearing sediments in the Salt Wash member of the Morrison formation.

The first part is an introduction to the problem and a discussion of the physical and chemical characteristics of the ore-bearing sediments. Three factors appear to be important, the first two are physical factors and are essentially textural characteristics which define the sedimentary "ore traps", the grain size distribution and the fabric of the sediments. In ore deposits the sediments are either bedded or slumped; i.e., the textural arrangement is either rapidly and regularly varying (lenses of different grain sizes) in the bedded variety or rapidly varying and irregular (disturbed or slumped texture) in the slumped sediments. Intimately associated with these textures the chemical characteristics of the ore-containing sediments also appear to be typical, a halo of changing oxidation-reduction potential around the ore. Reduction exceeds oxidation in and near the ore and oxidation exceeds reduction outside the ore-bearing sediments.

The remainder of the report deals with different attempts to establish these gradients. Part II is concerned with the use of bulk density measurements to characterize the ore-bearing sediments. As bulk density is a function of both composition and texture it is an obvious first choice but unfortunately the variation in bulk density is associated with overall changes in lithology of the sediments, namely sandstones and mudstones and also reflects variation in carbonate content. Neither of these factors is sufficiently sensitive to use the bulk density as a basis for differentiating ore-bearing from barren sediments. The bulk density variation is also investigated to form a quantitative basis for sampling the sediments but here, again, the stratification of the sediments into units either on the basis of lithology or cementation failed to increase the efficiency of the sampling pattern. This detailed investigation seems to emphasize the difficulties involved in setting up an efficient stratified random sampling pattern in investigating sediments. So far, at least, we have been unable to find a simply determined common factor upon which to base a sampling program.

Part III describes an investigation into the grain packing of the sediments and establishes that the packing in sediments near an ore-bearing sandstone zone (Zone 4, well 155C, Bull Canyon) is different from that in a barren sandstone (Zone 2, well 155C, Bull Canyon). This analysis serves to confirm the nature of the physical attributes of the ore trap; the emphasis is on textural arrangement which is different in the ore-zone from the barren zone sediments.

Part IV describes the results of dye testing the sediments both in the field and the laboratory. This simple test appears to be an effective tool for use in the correlation of mudstone horizons. The mudstones are different on the basis of these tests but definition of an ore zone by this means is difficult.

Part V describes the results accruing from a field excursion over the Colorado Plateau and describes the implications of lithological description in the field. Perhaps the most obvious conclusion is that it is difficult to use lithological description to define and locate ore zones. Attribute description of the sediments by megascopic examination is not sufficiently precise to lead to more than very broad statements about favorability.

Part VI is concerned with semiquantitative spectrographic analysis of ore-bearing sediments and mudstones from the well cores (Bull Canyon wells 155A, B, C). A very wide variety of the "rarer" elements occurs in the Salt Wash sediments and, at least on a semiquantitative basis, the barren sediments cannot be differentiated from the ore-bearing sediments on the basis of their "rarer" elements. The concentration of these elements appears to be somewhat higher than would be expected in average sediments and suggests that the sedimentary rocks on the Colorado Plateau are unusually rich in "trace" elements. Similarly while the general lithology of the sediments from the Permian to the Cretaceous is similar comprising arkosic quartzites to arkoses in composition and mudstone to conglomerate in texture the "chemical" background is uniformly high throughout the entire range of sediments. In addition the incidence of volcanic detritus in the sediments is unusually high and common throughout this same sequence. It seems likely, therefore, that these two features, the "rarer" elements and the volcanic detritus are/associated in origin.

Finally, it may be concluded that on the basis of a very considerable background of petrographic information on the Salt Wash sediments the differences between ore-bearing and barren sediments are differences of degree not kind. As a result, investigations which are not open to adequate statistical control and which cannot achieve the required level of precision are not suitable tools for successful exploration for ore bodies. It cannot be over-emphasized that the more we learn of these and other sedimentary rocks the more obvious it becomes that quantitative analytical procedures under adequate statistical control are necessary to the solutions of most problems associated with sedimentary rocks.

The problem of locating ore in the Salt Wash member reduces to the selection of suitable criteria[1] for differentiating the ore-bearing from barren sediments. These criteria must be capable of being measured by techniques which possess a reasonably high degree of precision and the criteria must be related to the characteristics which are associated with ore in the sediments. For example, measurement of bulk density is a suitable approach except for the fact that it does not seem to lead to a critical bulk density range which is associated with ore. On the basis of our investigations these criteria must be chosen to reflect the physical trap and chemical halo characteristics of the ore-bearing sediments. Two such sets of criteria are represented by the composition of the sediments and their texture respectively. Petrographic analysis now in progress is aimed at evaluation of this approach to the exploration for ore.

1. It is certainly clear that no single criterion is sufficient for this purpose.

Part I Introduction

Research under contract AT - (30-1) - 1362 comprises at present two stages; the first stage is concluded with the present report and represents an attempt to collect enough background information on the uranium deposits in the Salt Wash Sediments to envisage the exact nature of the problem encompassed in exploration for the ore. When the problem is clearly defined its solution is materially simplified.

The second stage is in progress and will be largely completed by the end of this contract year. This stage comprises the measurement of petrographic properties and their combination into a discriminant index which may be used to differentiate ore-bearing from barren Salt Wash Sediments.

The items of the first stage described in this report include the final data on the bulk density of the Salt Wash Sediments represented by the cores from Bull Canyon Wells 155A, B and C and a discussion of the implications which follow from these data. A further description of the results of dye testing by means of P-aminophenol dye together with the details of procedure is also included. This test is suitable for use in the field and yields supplementary data which may enable the mudstones to be subdivided; it is, therefore, of potential value as a correlation tool.

A brief description of the field excursions to various localities on the Plateau undertaken by the senior author is also included and the results of spectrographic analysis of a number of samples of Salt Wash Sediments are recorded. Mr. Kahn's work on the packing of grains in Salt Wash sandstones forms another section of the report.

The main aim of our researches to date has been to attempt to characterize the setting of the ore deposits in the Salt Wash Sediments as a whole. The results may be briefly summarized in terms of the physical and chemical setting of the ores.

Physically the ore-containing sediments occur as textural traps; the disposition of the ore and particularly the secondary ore is very intimately related to the texture of the sediments. Green slumped mudstone appears to be the most obvious physical barrier preventing dispersal of the ore. Within the sandstone lenses bounded by this green slumped mudstone the ore follows the bedding and very minor changes in texture, such as in grain size and fabric, act as delicate controls on the local distribution of the ore within the sandstone lens.

Where the ore follows the bedding concordantly the ore is called "bedded" or "book" ore. In places ore "rolls" develop and the "roll" bundaries again coincide with textural changes in the sediment. Sometimes the ore is patchy and this type of disposition is given a variety of local names, rattlesnake ore, buckskin ore, trashy ore, etc. In this case the sediments are generally disturbed or slumped so violently that the original fabric of the sand is destroyed and the different textures are irregularly arranged, resulting in irregular disposition of the ore. Physically then, the disposition of the ore is intimately related to the textural character of the sediments. In general, thick uniform sands are unfavorable; sandstone lensed and interlayered with mudstone and slumped deposits are most favorable.

Chemically the enviroment of the ore is characterized by a "halo" with changing chemical potentials from the ore body outwards. Preservation and perhaps formation of the ore demands reducing conditions and generally evidence of oxidation increases away from the ore. This is illustrated by the distribution of limonite staining which usually is associated with ore and includes everything from "limonitic" spots of varying color intensity to complete limonite staining of the sediments. Limonitic coloration commences immediately around the ore and gradually disappears away from the ore body towards the margins of the sandstone lens containing the ore body.

The limonitic halo is accompanied by changes in the carbonate minerals; within the ore the carbonate is generally colored and contains a number of cations. As oxidation potential increases it is reflected in the "exsolution" of the coloring ions and the gradual change in the carbonate to pure calcite and dolomite. The calcite and dolomite are generally precipitated near the margins of the sandstone trap thus reinforcing the physical trap with chemical precipitation.

In our view, therefore, the ore is found in traps where it has been preserved since formation; the entire trap of sandstone allows movement of ore over a limited volume of sediments and successive movements have resulted in ore concentration and the close association between ore and sediment texture. In places where trap conditions are absent the diffuse ore elements were never concentrated but were dispersed by solutions which migrated without hindrance.

Exploration for ore, then, may be represented as a search for conditions favorable to ore preservation and concentration. The next step is then to specify by quantitative petrographic analysis the exact difference between sediments containing ore and barren sediments. This, the second stage of the investigation,is in progress.

PERSONNEL

At the commencement of the present contract year there have been a number of personnel changes; Mr. J. Hutta has taken the place of Mr. D. W. Groff, who has transferred to a teaching position; Mr. Hutta received his B.S. Degree in the Department of Mineralogy at the Pennsylvania State University in June, 1954. He has since been engaged in studies of dimensional orientation and directional permeability in sandstones. He is analyzing a few specimens from the Plateau to see if there is a relationship between flow characteristics and sediment fabric in these sediments.

Mr. R. C. Steinmetz has replaced Mr. J. B. Kahn; Mr. Steinmetz received his B.A. Degree from the Department of Geology at Princeton University in June, 1954. He is at present familiarizing himself with the various techniques in use in the second stage of the investigation.

Part II Bulk Density of Samples From Wells 155A, 155B, and 155C, Bull Canyon

i) Introduction

The results of bulk density measurement on samples from wells 155B and 155C have been discussed in previous reports (RME-3047, Part I; RME-3054, Part I; Griffiths et al., 1954, Part III). The measurement of the bulk density of 107 samples from well 155A completes this phase of the experimental program. The experimental procedure and design employed were the same as those used for samples from well 155B (Griffiths et al., 1954, pp. 46-47). The mean bulk density of each sample and a megascopic description of its lithology are listed in the appendix.

ii) Analysis of the Data for Samples From Well 155A

The grouping of the samples into three categeries (i.e., cemented samples, uncemented sandstones, and uncemented siltstones and mudstones) led to three separate experiments and, in turn, to three separate analyses. The analyses of variance for the three experiments are summarized in Tables II-1 to II-3.

Table II-1 Analysis of Variance for Cemented Samples

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F[1]	F.05[2]	F.01	F.001[2]
Samples	25	2.219195	0.088768	*** 241.22			2.40 (24/120)
Operators	2	0.001900	0.000950	N.S. 2.58	3.07 (2/125)		
Samples x operators	50	0.019557	0.000391	N.S. 1.10	1.53 (50/70)		
Runs (within all classes)	78	0.027605	0.000354				
Total	155	2.268257					
Pooled error term	128	0.047162	0.000368				

Correction term = 958.535104

[1] ** indicates significance at the 0.01 probability level; *** indicates significance at the 0.001 level; N. S. = not significant at 0.05 level.

[2] Numbers in parentheses indicate degrees of freedom for greater and lesser mean squares used to determine F values at various probability levels.

Table II-2 Analysis of Variance for Uncemented Siltstones and Mudstones

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F^1	F.05^2	F.01	F.001^2
Samples	25	0.443208	0.017728	*** 10.01			2.40 (24/120)
Operators	2	0.000359	0.000180	N.S. < 1.00			
Samples x operators	50	0.096497	0.001930	N.S. 1.16	1.53 (50/70)		
Runs (within all classes)	78	0.130198	0.001669				
Total	155	0.670262					
Pooled error term	128	0.226695	0.001771				

Correction term = 928.083403

Table II-3 Analysis of Variance for Uncemented Sandstones

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F^1	F.05	F.01^2	F.001^2
Samples	54	3.676198	0.068078	*** 294.71			3.01 (24/40)
Operators	1	0.027418	0.027418	*** 118.69			12.61 (1/40)
Samples x operators	54	0.012459	0.000231	** 2.20		1.73 (50/100)	2.69 (24/60)
Runs (within all classes)	110	0.011523	0.000105				
Total	219	3.727598					

Correction term = 1,107.530706

[1] ** indicates significance at the 0.01 probability level; *** indicates significance at the 0.001 level; N.S. = not significant at 0.05 level.

[2] Numbers in parentheses indicate degrees of freedom for greater and lesser mean squares used to determine F values at various probability levels.

Samples were found to be significantly different at the 0.001 probability level in all three experiments, just as they were in the three experiments on samples from well 155B, (Griffiths et al., 1954, pp. 47-48). The samples times operators interaction, or the inconsistency of operators from sample to sample, and the differences between operators were both found to be non-significant at the 0.05 level in two of the three experiments. These findings are in accord with previous experience in the measurement of bulk density, which indicates that there is generally a high degree of reproducibility of determinations from operator to operator.

Table II-3 shows that operators were significantly different at the 0.001 level and operator inconsistency was significant at the 0.01 level in the third experiment. Computation of the components of variance for this experiment reveals, however, that the amount of variation introduced by sample differences was almost 69 times that introduced by differences due to operators. Operator variation was, in turn, almost 4 times that introduced by operator inconsistency. It should also be noted that the extremely low amount of variation introduced by replicate runs (mean square for runs = 0.000105) makes the test of operator inconsistency very sensitive; i.e., very small inconsistencies can be shown to be statistically significant. It is possible to show, by means of the computation of the components of variance, that the variation introduced in another experiment (Table II-2) by statistically non-significant operator inconsistency is greater (0.000130 vs. 0.000063) than that introduced by the statistically significant operator inconsistency in the experiment in question.

iii) <u>Discussion</u>

A. Relation of Variation in Bulk Density to Gross Lithological changes

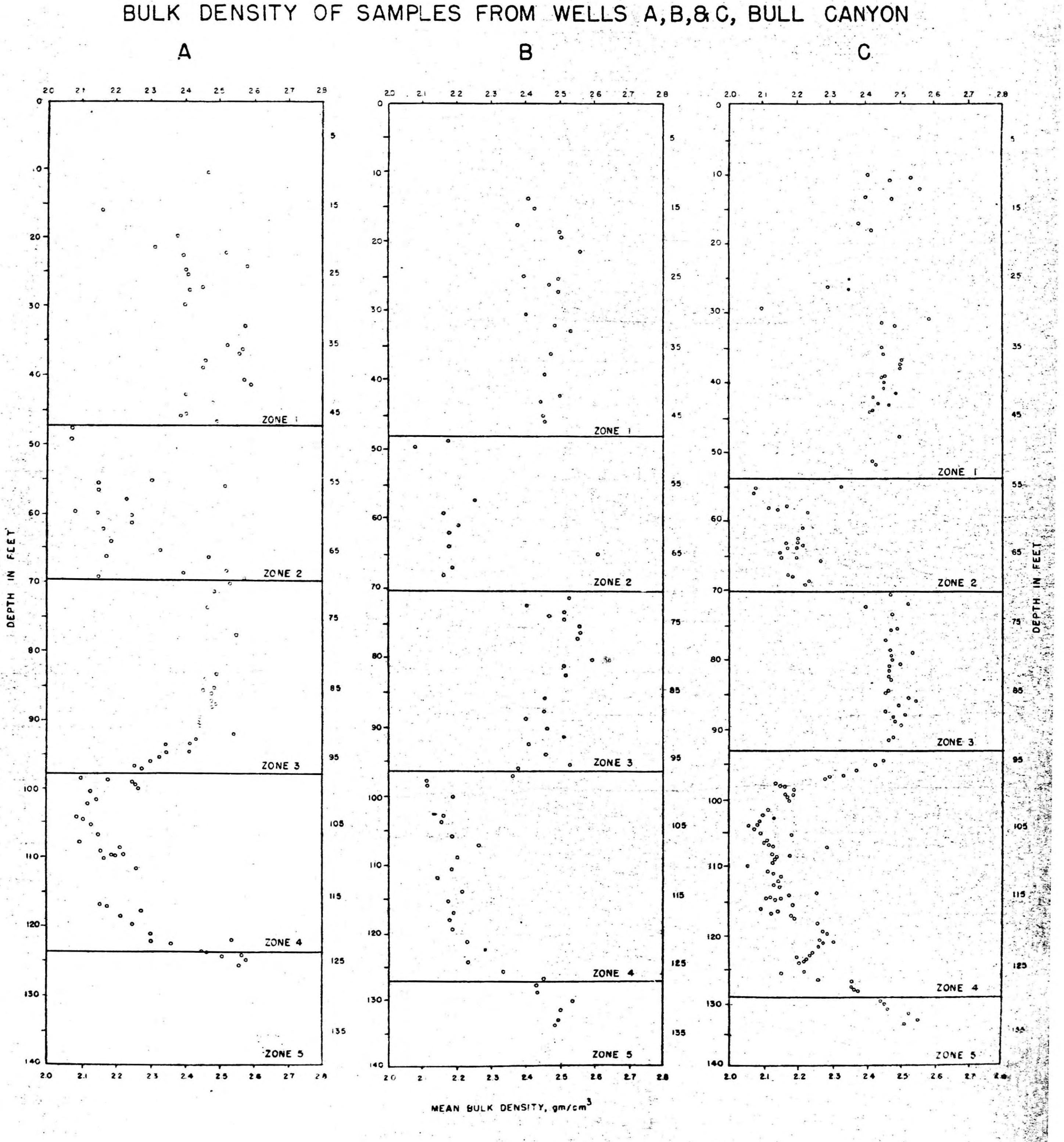
As suggested previously (Griffiths et al., 1954, p. 46), variation in the bulk density of samples from the Bull Canyon wells is chiefly related, apparently, to variation in a) amount of cement present and/or b) grain size. The finer-grained samples generally contain a very high percentage of constituents of relatively high density which are found in the coarser-grained samples only in rock fragments and as matrix. The matrix is interstitial to the quartz and feldspar grains, which comprise a large percentage of the rock and have relatively low grain densities. The coarser-grained rocks will also contain a relatively large amount of pore space, especially if winnowing has been appreciable and little or no cement is present.

The primary stratigraphic zonation of the cores from well 155C for the purpose of stratified random sampling has been described in a previous report (RME-3047, pp. 6,40). Three attibutes, color, texture (grain size and sorting), and structure (kind of bedding), were described megascopically and units found to be lithologically similar, especially with regard to grain size, were delineated as zones. Six zones were thus established. Zones 1 and 5 are essentially mudstone zones while zones 2 and 4 consist primarily of sandstone. Zone 3 contains thin, interlayered mudstones and sandstones which were treated separately as zones 3A and 3B respectively. Further megascopic studies disclosed that the same six zones are present in wells 155A and 155B (RME-3070, p. 20). Zone thicknesses vary slightly from well to well.

Samples from zones 1, 3,and 5 have higher bulk densities, in general, than do samples from zones 2 and 4, the sandstone zones. The fact that the sandstone zones are generally more variable than the mudstone zones also agrees with expectations. The uppermost mudstone zone, zone 1, is more variable than either zone 3 or zone 5 in all three wells. Weathering effects may well be partly responsible for the relatively high variability in this zone. The variability in zone 3 is surprisingly low, there being little difference between the mudstone and sandstone layers. The thin sandstone layers are apparently very well cemented. The thicker and coarser-grained sandstones of zones 2 and 4, on the other hand, apparently contain little cement except near the upper and lower margins of zone 4, the ore zone. An examination of Figure 1 reveals that there are transition zones, in terms of bulk density, between the relatively light middle portion of zone 4 and the denser overlying and underlying zones. In the case of well A this upper transition zone, as shown in Figure 1, occurs in the lowermost portion of zone 3 rather than in the uppermost portion of zone 4. The situation is reversed in the other two wells, indicating the difficulties that may be involved in determining consistent zone boundaries on the basis of megascopic studies.

It should be noted that the postulated physical and chemical setting favorable to the concentration and preservation of secondary ores (see pp. 9 - 11) is based, in part, on the belief that the transition zones described above are truly reflections of zones that are transitional in terms of the amount of cement present. Such transition zones are not to be found or, at best, are very poorly represented, along the upper and lower margins of zone 2, a barren sandstone zone. A few samples very low in bulk density indicate, in fact, that the uppermost part of zone 2 is extremely poor in cement.

FIGURE 2.1


BULK DENSITY OF SAMPLES FROM WELLS A, B, & C, BULL CANYON
A
B
C
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
DEPTH IN FEET
MEAN BULK DENSITY, gm/cm³

It had been hoped that it would be possible to detect a gradient in bulk density from well C, which is the farthest from the ore deposit, through well B, to well A, which penetrates the ore. Rigorous statistical analysis of the data, zone by zone, has shown, however, that the variability within the wells is so great that no real differences between the wells can be detected.

B. Use of the Results as a Guide to Future Investigation

The bulk density of a sedimentary rock is a mass property and, as such, is a function of five interdependent variables (Griffiths, 1952). If one desired to study the Bull Canyon well cores in terms of any other mass property, which would be a function of the same five variables (namely mineral composition, grain size, grain shape, orientation and packing), it would be very helpful to know not only how many samples should be studied but also how the samples should be distributed over the cores. In other words, it would be helpful to know how to sample the cores so that one could obtain the optimum amount of information with the least expenditure of time and effort. The following discussion is concerned with an attempt to solve this problem.

Practical considerations such as the amount of time and money available may automatically place an upper limit on the number of determinations that can be made, especially in cases requiring the use of elaborate measurement techniques. Some guide to the proper distribution of samples becomes increasingly important in such a case. Previous knowledge of the nature of the variability likely to be encountered is the only such guide.

The comparison of population means, as estimated from sets of samples, is the eventual aim. Such comparisons are meaningful only if those means are known with "equal" precision; i.e., the standard errors associated with their respective means must be comparable. The standard error of a mean, $S_{\bar{x}}$, is given by the formula $S_{\bar{x}} = S/\sqrt{N}$ where S is the standard deviation and N is the number of values on which the mean is based. By squaring both sides of the equation and multiplying by N we obtain $S_{\bar{x}}^2 N = S^2$, which shows that S^2, the variance, is directly proportional to the number of samples required if $S_{\bar{x}}^2$ is to be constant.

Suppose one wished to estimate, with "equal" precision, the means of two populations, one of which a preliminary experiment had shown to be extremely variable (large variance) and the other relatively homogeneous (small variance). The former would require the analysis of a much larger number of samples than the latter. Assuming that the variances will remain relatively constant, the proper sampling ratio will, in fact, be approximated by the ratio of the variances.

It behooves the investigator, therefore, to conduct a preliminary experiment on an easily and rapidly measured property. He may thus obtain some idea of the variability that may be expected in the measurement of other parameters and conduct his sampling program accordingly.

In the case in question the large number of bulk density determinations that have been made represents a series of preliminary experiments of the type mentioned. From the appearance of the cores and on the basis of past experience it seemed quite likely that the sandstone samples would be much lower, in general, and more variable, in terms of bulk density, than would the mudstones and siltstones. Each core was therefore divided into six zones, or "populations", which were judged to be relatively homogeneous on the basis of a megascopic study of each core's lithology. Although the thicknesses vary somewhat from well to well the same six zones are present in all three wells. Such an arrangement enables the variability of each such zone to be evaluated separately and the variability within zones (well to well variation) to be compared with that between zones; in other words, this arrangement should produce a much more detailed picture of the distribution of the variability throughout the three cores than would be obtained from the study of each core as a whole.

Stratified random sampling was used as the basis for selecting samples from well 155C, the first well to be studied; i.e., a set of random samples was taken from each of the six zones and each of these sets was analyzed separately, each of the six resulting experiments yielding a separate measure of variability. This is to be contrasted with the one measure of overall variability that would have been obtained if one large set of random samples had been chosen from the core as a whole and analyzed in one huge experiment.

With the exception of zones 1 and 4, samples were taken from approximately 30 per cent of the 3" cores in each zone (RME-3054, pp. 7, 10). The sampling ratio was somewhat lower in zone 1 because that zone consisted mainly of mudstone and was judged to be relatively uniform. Zone 4 was judged to be the most variable and the sampling ratio was therefore increased. Having a precise estimate for zone 4 was especially desirable because it is the zone containing the ore and, as such, the zone of main interest. Zone 5, another mudstone zone, also appeared to be very homogeneous. The sampling ratio was not increased, however, because of the thinness of the zone.

The results of the six experiments have been discussed in detail in previous reports (RME-3047, pp. 16-19; RME-3054, pp.11-21). For the present purpose it will suffice to note that samples were found to be significantly different at the 0.001 probability level in five of the six experiments. In the sixth, involving the samples from zone 5, the variation due to differences between samples was found to be greater than would be expected at the 0.05 probability level but less than would be expected at the 0.01 probability level. Evidently, then, the stratification of well 155C on the basis of megascopic studies failed to delineate zones which are homogeneous in terms of bulk density.

In sampling wells 155B and 155A, therefore, the basis of stratification was modified. The six stratigraphic zones were replaced by three lithologic classes (Griffiths et al., 1954, p.46.). Since the amount of cement present and/or the grain size were considered to be the most important factors in determining the bulk density of a sample (see part iii A) it was hoped that the division of each core into classes based on differences in these variables might yield units homogeneous in terms of bulk density. The three classes chosen were 1) cemented samples, 2) uncemented siltstones and mudstones, and 3) uncemented sandstones. The class into which any sample was placed was still determined, however, by megascopic examination. The uncemented sandstone class was judged to be the most variable in both wells 155B and 155A and the largest number of samples was therefore selected from that class in each case.

Analyses of variance for the three experiments involving samples from well 155B have been discussed previously (Griffiths et al., 1954, pp. 47-49). The samples were found to be significantly different at the 0.001

probability level in all three cases. The same was found to be true in the three experiments involving samples from well 155A (see part ii). The second method of stratification also failed, therefore, to produce units homogeneous in terms of bulk density. The uncemented mudstone and siltstone class proved to be far less variable than the other two classes in each case, even though none of the three could be shown to be homogeneous. The relatively high variability of the cemented class may well be due to the fact that both fine-grained and coarse-grained samples were included. The high variability of the uncemented sandstone class is undoubtedly a reflection of variations in matrix content and amount of cement present. It is quite likely some of the "uncemented" sandstone samples may contain a considerable amount of cement which can not be detected megascopically. If such is the case, only the most thoroughly cemented sandstones would be placed in the cemented sample class and the "uncemented" sandstone class would include specimens having a large range in cement content.

The two methods of stratification used thus far have produced zones or units so variable within each well that it has been impossible to detect any statistically significant variation from well to well, within a given zone, to say nothing of a gradient from well 155C, through well 155B, to well 155A. The total distance between wells 155A and 155C is only 100 feet, however, and any gradients which are present are undoubtedly so slight that it would be virtually impossible to detect them over such a small distance. An analogous situation was encountered when the wells were compared, zone by zone, on the basis of megascopic studies of color, texture (grain size and sorting), and structure (RME-3070, p.32). No consistent gradients were found in zones 2, 3, and 5 and not all attributes studied showed a gradient in the other two zones. In addition, some of the gradients that were detected were very slight and/or based on classes which included only small percentages of the cores examined.

If the wells were spaced farther apart and/or additional cores were available, however, any gradient which might be present would stand a much better chance of being detected. The basis for this statement lies in the fact that, in any one zone, the well to well variation would be increased as the upper and lower extremes of the gradient became represented by samples from the more distant wells. The variation in this zone within any one well, on the other hand, would probably remain relatively constant. In addition, in the analysis of variance, the degrees of freedom for both variation between wells and variation within wells would be increased. The variance ratio (ratio of variation between wells to variation within wells) required for the detection of differences between wells would not be as large under these conditions.

Unfortunately, such samples are not available. A realistic and practical approach to the problem at hand must be based on the realization that the two methods of stratification employed thus far have been very inefficient. The wells must be rezoned on a different basis and the large number of bulk density determinations that were made for the purpose of obtaining a quantitative measure of the variability of each zone also provides the logical basis for rezoning the cores. An examination of Figure 1, in which the mean bulk density of each sample has been plotted against its depth, shows that there are distinct "blocks" of values within many of the zones. Evidently, then, breaking up the present zones into smaller zones, or sub-zones, on the basis of these "blocks", will yield several smaller, more homogeneous units. The next step will be to compute the variance of each of these new zones on the basis of the mean bulk densities of the samples in each. The ratios of the resulting variances could be used directly to determine the sampling distribution for future studies if the zones were of equal thickness. Since the zones are not of equal thickness, however, a weighting factor must be used. Weighting the variances is accomplished by multiplying the variance of each zone by the zone's thickness. The ratios of these products can then be used to set up future sampling programs.

The rezoning of the wells and the following computations are now in progress. As soon as they are completed the wells will be sampled for futher studies on the basis of the variance x thickness ratios. The first such study will be concerned with the measurement of carbonate content and the results of these experiments will be used to test the efficiency of the sampling plan.

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Appendix

Table II-4

Lithologies and Bulk Densities of Samples From Well 155A, Bull Canyon

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
1	3	10.50-10.75	Red, massive-disturbed, mudstone	2.463	
1	11	16.00-16.25	Brown-white, fine sandstone, with inclined black laminae	2.162	Cemented
1	24	19.75-20.00	Red-green, massive-disturbed, mudstone	2.382	
1	31	21.50-21.75	Red-green, massive, mudstone	2.320	
1	34	22.25-22.50	Red, disturbed, mudstone, with green specks	2.527	Cemented
1	35	22.50-22.75	Red-green, horizontal, mudstone	2.398	Friable
1	41	24.00-24.25	Green, inclined, fine sandstone, with clay pebbles	2.581	Cemented
1	44	24.75-25.00	Red-green, disturbed, clayey fine sandstone	2.409	
1	47	25.50-25.75	Red, horizontal-massive, mudstone	2.413	
1	54	27.25-27.50	Red-white-green, disturbed, clayey fine sandstone	2.456	
1	56	27.75-28.00	Red, disturbed, sandy mudstone, with "clouds" of white and green fine sandstone	2.418	
1	64	29.75-30.00	Red-green, massive, mudstone	2.406	

Stratigraphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
1	69	32.75-33.00	White-green, disturbed, fine sandstone	2.579	Cemented
1	79	35.25-35.50	White-green, massive, silty fine sandstone	2.534	Cemented
1	82	36.00-36.25	White-gray, massive, silty fine sandstone	2.570	Cemented
1	85	36.75-37.00	Red, massive, mudstone	2.559	Cemented
1	89	37.75-38.00	Red, massive, mudstone	2.461	Cemented
1	93	38.75-39.00	Red, massive, mudstone	2.450	Compact
1	100	40.50-40.75	Green, disturbed, silty fine sandstone, with inclined clay streaks	2.575	Cemented
1	102	41.25-41.50	White-green-gray, inclined, fine sandstone	2.595	Cemented
1	108	42.75-43.00	Red-green, massive, mudstone	2.404	
1	112	43.75-44.00	Red-green, disturbed, mudstone (slump breccia)	2.483	Friable
1	116	45.50-45.75	Red-green, disturbed, mudstone	2.405	
1	117	45.75-46.00	Green, sandy siltstone, with inclined clay streaks	2.389	Friable
1	119	46.25-46.50	Red-white-green, massive-disturbed, silty fine sandstone	2.496	Cemented
Contact	122	47.00-47.25	White-green, disturbed-massive, silty fine sandstone, with black specks	2.576	Compact
2	124	47.50-47.75	Red-white-black, massive, medium-fine sandstone, with red spots	2.066	Compact

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
2	130	49.00-49.25	As for 3" core number 124	2.066	Compact
2	133	55.00-55.25	Red-white, massive-disturbed, medium-fine sandstone, with red mudstone streaks and patches and red spots	2.308	Compact
2	135	55.50-55.75	Red-white, horizontal, medium-fine sandstone, with gray-black laminae	2.152	Compact
2	136	55.75-56.00	White-gray, horizontal-massive, medium-fine sandstone	2.517	Compact
2	139	56.50-56.75	Red-white, massive, medium sandstone, with red spots and brown and green clay pebbles	2.150	Compact
2	144	57.75-58.00	Red-white, massive-disturbed, silty medium-fine sandstone, with brown clay pebbles and green "clouds"	2.231	Friable
2	151	59.50-59.75	Red-white-black, massive, medium sandstone, with red spots	2.080	Compact
2	152	59.75-60.00	Red-white, massive, coarse-medium sandstone, with limonite spots	2.148	Friable
2	154	60.25-60.50	White, inclined, coarse-medium sandstone, with limonite spots and red and green mudstone layers	2.246	Friable
2	158	61.25-61.50	White, massive, coarse-medium sandstone, with limonite spots and black specks	2.249	Friable

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
2	162	62.25-62.50	White, massive, coarse-medium sandstone, with limonite spots, green and black specks, and green clay pebbles	2.166	Friable
2	169	64.00-64.25	White-black, massive, coarse-medium sandstone, with limonite spots and green clay pebbles	2.188	Friable
2	174	65.25-65.50	White, massive, medium sandstone, with limonite spots	2.328	Cemented
2	177	66.00-66.25	White, massive, coarse-medium sandstone, with limonite spots	2.175	Friable
2	186	68.25-68.50	As for 3" core number 177	2.396	Cemented
2	189	69.00-69.25	As for 3" core number 177	2.146	Friable
2	195	66.00-66.25	White, inclined-massive, coarse-medium sandstone, with limonite spots	2.472	Friable
2	203	68.00-68.25	Red-white-green, inclined-disturbed, fine sandstone, with red mudstone lenses	2.521	Cemented
2	208	69.25-69.50	White-green, inclined-disturbed, fine sandstone, with green mudstone lenses	2.570	Compact
3A	212	70.00-70.25	Red-green, horizontal-disturbed, mudstone	2.532	Cemented
3A	215	71.00-71.25	Red-green, disturbed, mudstone	2.484	Friable
3A	225	73.50-73.75	Red, massive-disturbed, mudstone	2.468	Friable

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
3B	242	77.25-77.50	Green, disturbed, silty fine sandstone, with brown streaks	2.548	Cemented
3A	265	83.00-83.25	Red, disturbed, mudstone	2.492	Cemented
3A	268	83.75-84.00	Red, disturbed, mudstone	2.455	Friable
3A	269	85.00-85.25	Red-green, disturbed-massive, mudstone	2.484	Cemented
3A	271	85.50-85.75	Green, disturbed, silty mudstone	2.444	
3A	273	86.00-86.25	Green, disturbed, silty mudstone	2.471	
3A	277	87.00-87.25	Green, disturbed, silty mudstone	2.474	
3A	279	87.50-87.75	Green, massive, silty mudstone	2.486	Compact
3A	280	87.75-88.00	Green, massive, silty mudstone	2.475	Compact
3A	287	89.50-89.75	Green, massive, silty mudstone	2.445	Compact
3B	289	90.00-90.25	Green, massive, silty fine sandstone	2.439	
3B	292	90.75-91.00	Green, massive, silty fine sandstone	2.442	
3B	296	91.75-92.00	White-green, massive, silty fine sandstone	2.545	Cemented
3B	299	92.50-92.75	Purple-green, disturbed-massive, silty fine sandstone	2.433	Compact
3A	301	93.00-93.25	Green, disturbed, silty mudstone	2.417	Friable

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
3B	303	93.50-93.75	Green, massive, silty fine sandstone	2.351	Cemented
3B	306	94.25-94.50	Green, massive, silty fine sandstone	2.416	Compact
3B	307	94.50-94.75	Green, massive, silty fine sandstone	2.350	Compact
3A	309	95.00-95.25	Green, inclined, mudstone, with yellow-brown and green laminae and green clay pebbles	2.324	Compact
3B	313	96.00-96.25	Green, inclined, fine sandstone, with green clay pebbles	2.298	Compact
3B	315	96.50-96.75	As for 3" core number 313	2.251	Compact
3B	316-317	96.75-97.25	As for 3" core number 313	2.270	Compact
4	320	97.75-98.00	White-green, massive, medium-fine sandstone, with limonite spots and green clay pebbles	2.150	
4	321-322	98.00-98.50	As for 3" core number 320	2.103	
4	324	98.75-99.00	As for 3" core number 320	2.173	
4	326	99.25-99.50	Green, massive-disturbed, silty fine sandstone, with clay pebbles	2.248	Compact
4	327	99.50-99.75	As for 3" core number 326	2.256	Compact
4	328	99.75-100.00	As for 3" core number 326	2.260	Compact
4	331	100.50-100.75	White-green, inclined, medium sandstone, with limonite spots and green and black laminae	2.123	Compact
4	335	101.50-101.75	As for 3" core number 331	2.140	Compact
4	337	102.00-102.25	As for 3" core number 331	2.122	Compact
4	344	103.75-104.00	White-green, massive, medium sandstone, with limonite spots and black specks	2.097	Compact

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
4	347	104.50-104.75	White-green, massive, medium sandstone, with limonite spots	2.112	Compact
4	351	105.50-105.75	White-green, massive, medium sandstone, with limonite spots, green clay pebbles, and black specks	2.132	Compact
4	356	106.75-107.00	As for 3" core number 351	2.148	Compact
4	359	107.50-107.75	White-green, inclined, medium sandstone, with limonite spots and green clay pebbles	2.098	Compact
4	363	108.50-108.75	White-green, inclined, medium sandstone, with green laminae and zoned green clay pebbles	2.218	Compact
4	364	108.75-109.00	As for 3" core number 363	2.158	Compact
4	365	109.00-109.25	As for 3" core number 363	2.223	Compact
4	366	109.25-109.50	As for 3" core number 363	2.201	Compact
4	367	109.50-109.75	As for 3" core number 363	2.191	Compact
4	369	110.00-110.25	White-green, inclined, medium sandstone, with limonite spots, green laminae, and green clay pebbles	2.169	Compact
4	372	115.25-115.50	White-green, inclined, medium sandstone, with limonite spots	2.262	Compact
4	377	116.50-116.75	White-green, massive, medium sandstone, with limonite spots and black specks	2.156	Compact

Strati- graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
4	378	116.75-117.00	White-green, inclined, medium-fine sandstone, with limonite spots	2.176	Cemented
4	380	117.25-117.50	White, medium sandstone, with limonite spots, inclined green laminae, and zoned green clay pebbles	2.270	Compact
4	384	118.25-118.50	White-green, massive, medium sandstone, with limonite spots	2.218	Compact
4	388	119.25-119.50	As for 3" core number 384	2.243	Compact
4	394	120.75-121.00	White-green, inclined-massive, medium sandstone, with limonite spots	2.303	Compact
4	397	121.50-121.75	White-green, inclined, medium sandstone, with limonite spots and green clay pebbles	2.540	Cemented
4	398	121.75-122.00	White-green, inclined, medium sandstone, with green clay pebbles	2.303	Cemented
4	399	122.00-122.25	White-green, massive, medium sandstone, with limonite spots	2.359	Compact
4	403	123.00-123.25	White-green, horizontal-massive, medium sandstone, with limonite spots and green clay pebbles	2.449	Cemented
5	404	123.25-123.50	Green, inclined-massive, silty mudstone	2.462	Friable
5	406	123.75-124.00	Green, inclined-massive, silty mudstone	2.568	Friable

Strati-graphic Zone	3" Core Number	Depth in Feet	Lithology	Mean Bulk Density in gm/cm^3	Remarks
5	407	124.00-124.25	Green, massive, silty mudstone	2.512	Friable
5	409	124.50-124.75	Green, massive, silty mudstone	2.583	Cemented
5	411	125.00-125.25	Green, massive, mudstone	2.563	Cemented

Part III Packing Proximity and Packing Density in Sandstones from the Salt Wash Member of the Morrison Formation

i) Introduction

A procedure for the measurement of packing in sandstones has been described and its effectiveness in estimating the packing of various rock types evaluated (Kahn, J. S., 1954). As a practical and rigorous test of the utility of this technique, it was applied to the measurement of packing in some sandstones from the Salt Wash member of the Morrison formation from the Colorado Plateau.

The objective here, was to compare the packing characteristics of two zones in the Salt Wash sandstone of the Bull Canyon area in western Colorado. The samples were taken from the cores of Well 155 C, Bull Canyon and details of the zonation and petrographic properties of the sandstones may be obtained from various progress reports on the petrographical analysis of the Salt Wash sediments (A.E.C. project, Contract No. At-(30-1)-1362, under the direction of J. C. Griffiths; see progress reports: RME-3023; RME-3047; RME-3054; RME-3070).

This well penetrated 135 feet of Salt Wash sediments and cores from 10 to 135 feet were supplied by the Atomic Energy Commission as part of the project investigation. On the basis of lithologic properties (Griffiths, et al, 1953a, RME-3047), the well cores were subdivided into five zones: Zones 1, 3a and 5 are mudstones and as such were not considered in this investigation. Zones 2, 3b and 4 are sandstones and samples were taken from these zones for analysis of their packing characteristics. On the basis of the γ - ray log accompanying the well cores, zones 1, 2, 3, and 5 are considered barren zones. Zone 4, although indicating a larger "kick" on the log, than either of the other zones, has only been considered a potential ore zone. However, 100 feet away (Bull Canyon, Well 155 A) zone 4 is a confirmed ore bearing zone with zones 1, 2, 3, and 5 still remaining barren. The comparison of zone 2 with zone 4, in Well C, becomes essentially a comparison of a definitely barren with a potentially ore bearing zone.

ii) Selection of Samples

Bulk density determinations on the samples from Well 155 C formed the basis of the sampling plan for the analysis of packing (Griffiths, et al, 1953 b). There were two thin sandstones in zone 1 and two samples from these were included in the analysis; similarly, two samples were selected to represent the thin sandstones in zone 3b of Well 155 C. The major portion of the samples were selected from zones 2 and 4, these zones being the thickest (zone 2 = 25 feet, zone 4 = 35 feet) and the most important. Six samples were chosen from zone 2 and twenty-two from zone 4. Each sample selected, possessed an accompanying thin section. Four traverses of 100 grains each were studied from every thin section, resulting in a total of 128 traverses for 32 samples.

iii) Experimental Design

The sampling program outlined above, gives rise to a completely randomized design. In this case, however, information concerning the variability to be expected was available (Griffiths, et al, 1953b, RME-3054) and equal sampling of the units, the basis of the experiment in Part II, (Kahn, 1954, op. cit.) would obviously be inefficient and defeat the purpose of this experiment. Hence, in this part of the work sampling approximately proportional to the variability was attempted. This test program led to unequal numbers of samples within units (i.e., zones) and necessitated a change in the computation of the sums of squares for the analysis of variance. This change concerns the computation of the sums of squares between means of zones (Snedecor, 1946, p. 232).

The total variation in packing is separated into a group of comparisons: variation due to differences among zone means is compared with variation arising from samples within zones and variation due to differences among slide or sample means is compared with variation arising from differences among traverses (within slides), this last effect representing the error for the entire experiment. To detect differences among zones, the immediate problem, the variation among zones should significantly exceed the variation among slides. The mathematical model for this experiment is presented in Table 3.1, in the form

Table 3.1 Mathematical model for analysis of variance for a completely randomized design for Salt Wash sediments.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Components of Variance
Zones	3	$(\sum_{1}^{8} x)^2/8 + (\sum_{1}^{24} x)^2/24 + (\sum_{1}^{8} x)^2/8 + (\sum_{1}^{88} x)^2/88 - C.T.$	$SS_z/3$	$s_e^2 + 4s_s^2 + 32s_z^2$
Samples within Zones	28	$\sum_{1}^{32} (\sum_{1}^{4} x)^2/4 - C.T. - SS_z$	$SS_s/28$	$s_e^2 + 4s_s^2$
Traverses within samples and zones	96	Total SS - all others	$SS_t/96$	s_e^2
Total	127	Total SS = $\sum_{1}^{128} x^2 - C.T.$		

$$C.T. = (\sum_{1}^{128} x)^2/128$$

$$N = 128$$

Table 3.2 Summary of Packing Proximity Data for 32 Slides of the Salt Wash Formation

Zone 1

Slide	#4	#10
Traverse 1	.30	.33
2	.22	.34
3	.15	.43
4	.25	.38
$\bar{x}$	.23	.37
s^2	.0037[1]	.0031

Zone $\bar{x}$ = .3000
Zone s^2 = .00817000

Zone 2

Slide	#149	#150	#157	#160	#169	#200
Traverse 1	.19	.25	.24	.28	.29	.28
2	.23	.34	.13	.30	.35	.30
3	.17	.29	.22	.19	.25	.26
4	.28	.40	.16	.17	.33	.28
$\bar{x}$	,2175	.3200	.1875	.2350	.3050	.2800
s^2	.0027	.0042	.0026	.0042	.0020	.0003

Zone $\bar{x}$ = .2575
Zone s^2 = .00441087

Zone 3b

Slide	#268	#279
Traverse 1	.25	.17
2	.18	.09
3	.13	.09
4	.13	.13
$\bar{x}$	.1725	.1200
s^2	.0032	.0015

Zone $\bar{x}$ = .1463
Zone s^2 = .00279821

Zone 4

Slide	#295	#298	#301	#305	#311	#313	#317	#324	#332	#334	#337
Traverse 1	.29	.14	.39	.34	.43	.37	.41	.20	.40	.42	.42
2	.26	.07	.36	.23	.32	.40	.44	.24	.36	.37	.36
3	.25	.13	.36	.20	.31	.31	.47	.28	.33	.25	.52
4	.10	.14	.31	.12	.29	.40	.32	.28	.35	.37	.31
$\bar{x}$	.2250	.1200	.3550	.2225	.3375	.3700	.4100	.2500	.3600	.3525	.4025
s^2	.0072	.0011	.0011	.0083	.0040	.0018	.0042	.0015	.0009	.0052	.0082

Slide	#369	#370	#373	#398	#402	#406	#411	#416	#422	#426	#431
Traverse 1	.41	.50	.54	.45	.49	.58	.36	.46	.63	.43	.42
2	.31	.48	.43	.38	.45	.51	.40	.31	.43	.42	.44
3	.31	.46	.33	.40	.36	.49	.35	.42	.43	.40	.32
4	.40	.41	.34	.40	.40	.38	.33	.31	.31	.37	.31
$\bar{x}$	.3575	.4625	.4100	.4075	.4250	.4900	.3600	.3750	.4500	.4050	.3725
s^2	.0030	.0015	.0095	.0009	.0032	.0069	.0009	.0059	.0176	.0007	.0045

Zone $\bar{x}$ = .3600
Zone s^2 = .01067816

$\bar{x}$ for all slides = .3002[2]
s^2 for all slides = .01247854

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[1] All variances rounded to 4 decimals

[2] Ungrouped data

Table 3.3 Summary of Packing Density Data for 32 Slides of Salt Wash Formation

		Zone 1		Zone 2						Zone 3b	
Slide		#4	#10	#149	#150	#157	#160	#169	#200	#268	#279
Traverse	1	.4495	.5934	.6479	.6413	.6309	.6521	.6056	.7355	.4204	.4800
	2	.4784	.5011	.6711	.6757	.6455	.6098	.6259	.7395	.4022	.4379
	3	.4423	.6058	.5624	.5930	.6012	.5606	.5374	.7137	.4385	.4502
	4	.4755	.5806	.6112	.6158	.6109	.6608	.6483	.6800	.3815	.4197
	$\bar{x}$	.4614	.5702	.6232	.6315	.6221	.6208	.6043	.7172	.4107	.4457
	s^2	.0003[1]	.0022	.0022	.0013	.0004	.0063	.0023	.0008	.0006	.0007

Zone 1: Zone $\bar{x}$ = .5153
Zone s^2 = .004479679

Zone 2: Zone $\bar{x}$ = .6365
Zone s^2 = .00260648

Zone 3b: Zone $\bar{x}$ = .4282
Zone s^2 = .00092391

Zone 4

Slide		#295	#298	#301	#305	#311	#313	#317	#324	#332	#334	#337
Traverse	1	.5427	.4725	.6516	.6052	.7235	.5914	.7432	.5790	.7469	.6815	.6813
	2	.5163	.4229	.6222	.5209	.6338	.6123	.6773	.6364	.6817	.6624	.6453
	3	.5844	.4160	.6332	.5493	.6604	.6062	.7369	.6243	.6819	.6386	.6430
	4	.5125	.3899	.5771	.5429	.6108	.6314	.6178	.5627	.5988	.6196	.6209
	$\bar{x}$	.5390	.4253	.6210	.5546	.6571	.6103	.6938	.6006	.6773	.6505	.6476
	s^2	.0011	.0012	.0010	.0013	.0024	.0003	.0034	.0012	.0037	.0007	.0006

Slide		#369	#370	#373	#398	#402	#406	#411	#416	#422	#426	#413
Traverse	1	.7144	.7177	.7328	.7361	.7886	.8015	.6532	.6713	.8264	.6708	.6932
	2	.6685	.7143	.7171	.7788	.7329	.7782	.7251	.5771	.6841	.6443	.6933
	3	.7089	.7263	.7173	.7119	.6620	.7905	.6509	.7135	.7933	.6623	.6685
	4	.7647	.6928	.7025	.7190	.7778	.7226	.6085	.6261	.5394	.5977	.5694
	$\bar{x}$	.7141	.7128	.7174	.7365	.7403	.7732	.6594	.6470	.7108	.6438	.6561
	s^2	.0016	.0003	.0002	.0009	.0033	.0012	.0023	.0034	.0168	.0011	.0035

Zone $\bar{x}$ = .6540
Zone s^2 = .00758403

Packing density $\bar{x}$ for all slides= .6280[2]
Packing density s^2 for all slides= .00979581

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[1] All variances rounded to 4 decimals

[2] Ungrouped data

Table 3.4 Summary of Intercept Size Data in mm. for 32 slides of Salt Wash Formation

Zone 1

Slide	#4	#10
Traverse 1	.05304	.07536
2	.04880	.07416
3	.05352	.07512
4	.05088	.08128
$\bar{x}$	.0516	.0765
s^2	.047040**	.105088

Zone $\bar{x}$ = .0640
Zone s^2 =1.8395017

Zone 2

Slide	#149	#150	#157	#160	#169	#200
Traverse 1	.07904	.08144	.09968	.07304	.06480	.12136
2	.08120	.08176	.08456	.07440	.06760	.13016
3	.07424	.08776	.07936	.07736	.07416	.11776
4	.08312	.07328	.08736	.08128	.07456	.13600
$\bar{x}$	.0794	.0811	.0877	.0765	.0703	.1263
s^2	.146112	.353509	.743483	.133227	.235286	.687744

Zone $\bar{x}$ = .0869
Zone s^2 =3.82855452

Zone 3b

Slide	#268	#279
Traverse 1	.04456	.04512
2	.04304	.04992
3	.04824	.04952
4	.04616	.04728
$\bar{x}$	.0455	.0480
s^2	.049595	.049344

Zone $\bar{x}$ =.0467
Zone s^2=.05969257

Zone 4

Slide	#295	#298	#301	#305	#311	#313	#317	#324	#332	#334	#337
Traverse 1	.06024	.04536	.07396	.07384	.09912	.08576	.09216	.09032	.10232	.09064	.08448
2	.06144	.04440	.08648	.06928	.09888	.09736	.08128	.09992	.10976	.09008	.08776
3	.06896	.04576	.08168	.06592	.10896	.11032	.09064	.08928	.10160	.10920	.08488
4	.06048	.04016	.07560	.07112	.09528	.10040	.08464	.08328	.10000	.08488	.08568
$\bar{x}$	.0628	.0439	.0794	.0700	.1006	.0985	.0872	.0907	.1034	.0937	.0857
s^2	.172932	.066090	.331183	.110528	.344448	1.023077	.260112	.474085	.188048	1.135035	.021349

Slide	#369	#370	#373	#398	#402	#406	#411	#416	#422	#426	#431
Traverse 1	.09144	.07392	.07108	.16048	.09384	.08576	.08296	.08056	.09008	.06976	.13240
2	.11432	.08072	.09752	.16432	.08648	.08872	.09136	.07848	.08312	.07152	.13936
3	.10208	.07408	.10688	.12672	.08408	.07984	.09048	.08776	.08488	.08080	.12568
4	.09024	.07136	.08992	.17688	.09256	.08960	.09432	.08640	.07552	.07232	.11104
$\bar{x}$	.0995	.0750	.0914	.1571	.0892	.0860	.0898	.0833	.0834	.0736	.1271
s^2	1.256662	.1599307	2.307225	4.592485	.221419	.194533	.233701	.200805	.363285	.241835	1.461120

Zone $\bar{x}$ = .0896
Zone s^2 =5.2864797

* Ungrouped Data
** Noted s^2 = 1000 calculated s^2

$\bar{x}$ for all slides = .0848*
s^2 for all slides =5.77262776

of an analysis of variance table, displaying the design of the experiment, the sources of variation and the statistical computations essential for the analysis.

The 128 traverses of the thirty-two slides were randomized with the aid of a random number table (Fisher and Yates, 1953, p. 114). The order of run for the traverses is indicated in Table A - 4* The traverses within each slide were chosen at the discretion of the operator and again, the traverses were sampled "without replication".

iv) Summary of the Data

The individual traverse values, slide and zone means and variances, for the measurements of packing proximity, packing density and intercept size of the 32 Salt Wash samples are summarized in Tables 3.2, 3.3 and 3.4.

The frequency distributions for packing proximity and packing density are represented in Figs. 3.1 and 3.2. The solid lines represent the observed frequency distributions whereas, the broken line represents the calculated normal distributions. Table 3.5 summarizes this data.

Table 3.5 Frequency distribution of packing proximity and packing density for 128 traverses of Salt Wash sandstone.

Packing Density		Packing Proximity	
Class	f	Class	f
.8 - .9	2	.6 - .7	1
.7 - .8	30	.5 - .6	5
.6 - .7	57	.4 - .5	34
.5 - .6	23	.3 - .4	42
.4 - .5	14	.2 - .3	26
.3 - .4	2	.1 - .2	17
	128	.0 - .1	3
			128

The mean packing proximity value was .3328, with a standard deviation of .1187 and a relative variation (C.V.) of 35.67%. The packing density measurements

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* See appendix

Fig 3.1 FREQUENCY DISTRIBUTION OF PACKING PROXIMITY FOR 32 SLIDES (128 TRAVERSES) OF SALT WASH SANDSTONE WELL C BULL CANYON

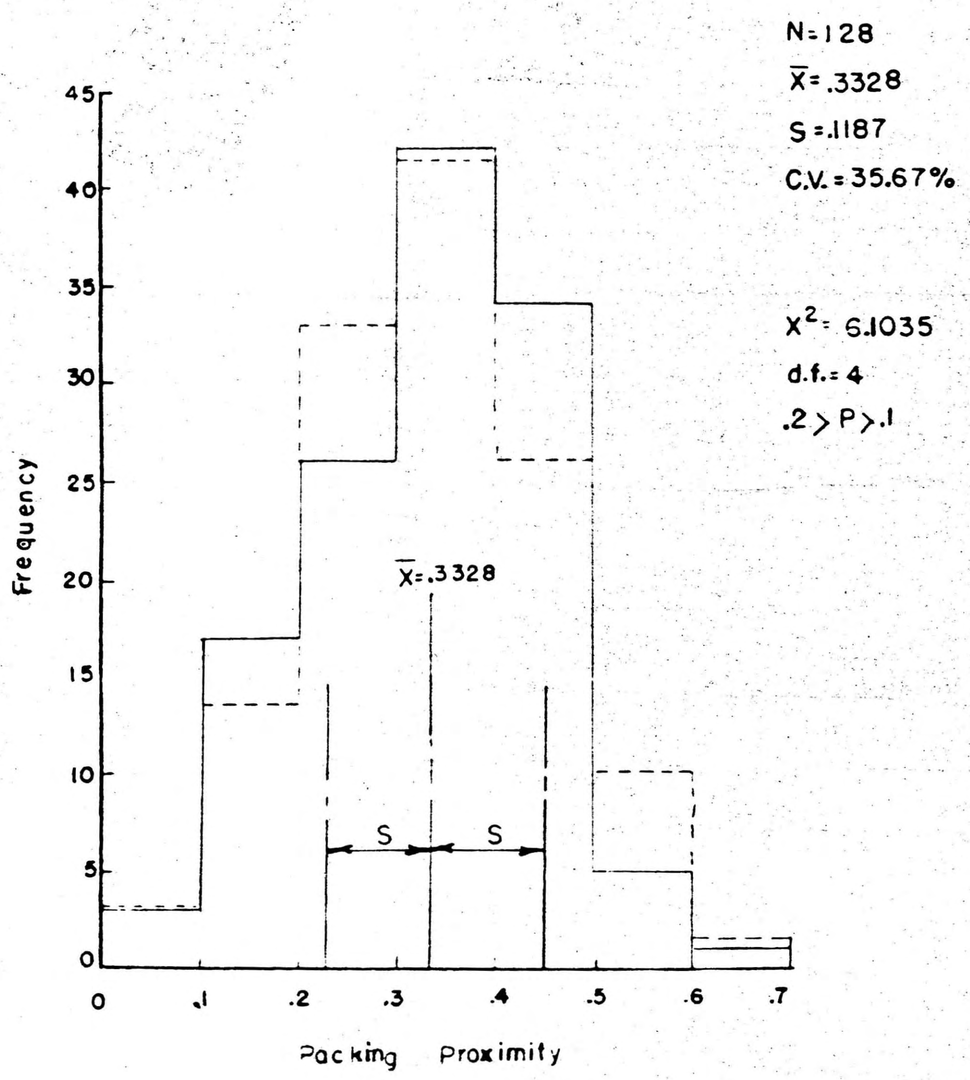
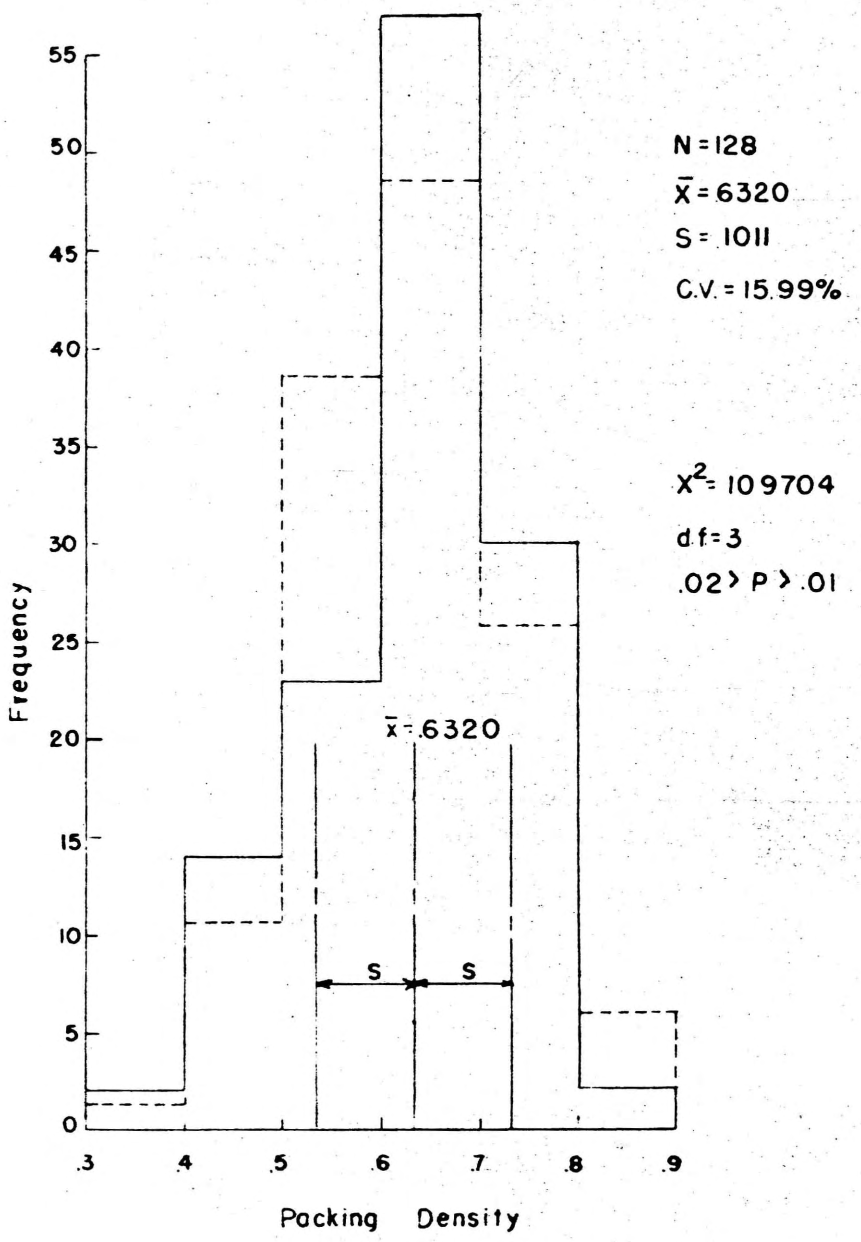


Fig. 3.2 FREQUENCY DISTRIBUTION OF PACKING DENSITY FOR 32 SLIDES (128 TRAVERSES) OF SALT WASH SANDSTONE WELL C BULL CANYON



resulted in a mean of .6320, a standard deviation of .1011 and a relative variation (C.V.) of 15.99%. Packing proximity ranged from .6300 (slide #422) to .0700 (slide #298). The range of packing density was from a high of .8264 (slide #422) to a low of .3815 (slide #268).

Zone 4 exhibited the largest mean values for both packing proximity and packing density, .3600 and .6540, respectively. Zone 3b on the other hand, had the lowest packing proximity and packing density, .1463 and .4383, respectively. (See Tables 3.2 and 3.3).

The Chi-square tests indicted a significant difference from normalcy for the packing density distribution, $.02 > p > .01$. Packing proximity did not differ significantly from normal, $.20 > p > .10$.

v) Analysis of the Data

Utilizing the completely randomized design, analyses of variance were performed on the data to see if any differences among the zones could be attributed to either packing proximity or packing density. These analyses are summarized in Table 3.6 and 3.7.

Table 3.6 Analysis of variance of packing density for thirty-two slides of Salt Wash Sandstone.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Zones	3	.486484	.162112	8.04***
Samples within Zones	28	.564577	.020164	10.03***
Traverses within Samples and Zones	96	.193008	.002010	
Total	127	1.244068		

N = 128 C.T. = 50.474370

It is evident from Table 3.6 that there are significant differences among zones and among samples within zones. That is, the variation arising, due to differences among samples, is significantly greater than the variation due to differences among traverses, within samples. Likewise, the variation arising due to differences among zones is significantly greater than the variation produced by differences among slides, within zones.

Table 3.7 Analysis of variance of packing proximity for 32 samples of Salt Wash Sandstone.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Zones	3	.477537	.159189	6.07**
Samples within Zones	28	.734038	.026217	6.73***
Traverses within Samples and Zones	96	.374100	.003897	
Total	127	1.585674		

N = 128 C.T. = 13.409726

In the case of packing proximity, there were similarly, significant differences among zones and among samples within zones. Again, variations due to differences among zones, were significantly greater than the variations arising from differences among slides within zones.

That there are significant differences among zones has been established. It must now be shown where these differences are, i.e., which zones can be differentiated. For this reason 95% least significant differences (L.S.D.) values were computed for zones, for both packing density and packing proximity. (See Tables 3.8, 3.9 and Fig. 3.3).

Table 3.8 L.S.D. Values for Zones - Packing Density

	Packing Density	L.S.D. .05 = .0728
Zone	$\bar{x}$	$\bar{x}$ - L.S.D. .05
4	.6540	.5812
2	.6365	.5637
1	.5153	.4425
3b	.4282	

Considering, first, packing density, it is apparent from Table 3.8 and Fig. 3.3 (a), that zones 1, 2, and 4 can be distinguished from zone 3b. However, they cannot be distinguished among themselves. Therefore, on the basis of packing density the ore zone, zone 4, cannot be differentiated with respect to the barren zone, zone 2. That is, both barren and ore bearing zones have the same amount of space occupied by grains.

Table 3.9 L.S.D. Values for Zones - Packing Proximity

Zone	Packing Proximity $\bar{X}$	L.S.D. .05 = .0830 $\bar{X}$ - L.S.D. .05
4	.3600	.2770
1	.3000	.2170
2	.2575	.1745
3b	.1463	

Packing proximity, on the other hand, can be used to differentiate the zones. The ore zone, with a mean proximity of .3600, differs significantly, at the 5 per cent level, from the barren zone with a packing proximity mean of .2575. (See Fig. 3.3b).

The differences between zones 2 and 4 may arise from differences among means or differences among variances or both. To elucidate this ambiguity, the slide variances, within each zone, were first tested for heterogeneous variance (Bartlett's test, see Snedecor, 1946, p. 249). The results, summarized in Table 3.10, indicate homogeneous variance within each zone; the variances may then be combined and the heterogeneity of variance between zones 2 and 4 tested. These too, proved homogeneous. It is now evident that the differences found in the analysis of variance (Table 3.6) arise from differences between packing proximity means.

Table 3.10 Tests of homogeneity of variance for packing proximity measurements of 32 samples of Salt Wash Sandstone.

Zone	d.f.	χ^2	Probability
1	1	0.03417	$.90 > p > .80$
2	5	6.69706	$.30 > p > .20$
3b	1	0.59048	$.50 > p > .30$
4	21	35.14145	$.10 > p > .05$
2 and 4	27	39.53070	$.10 > p > .05$

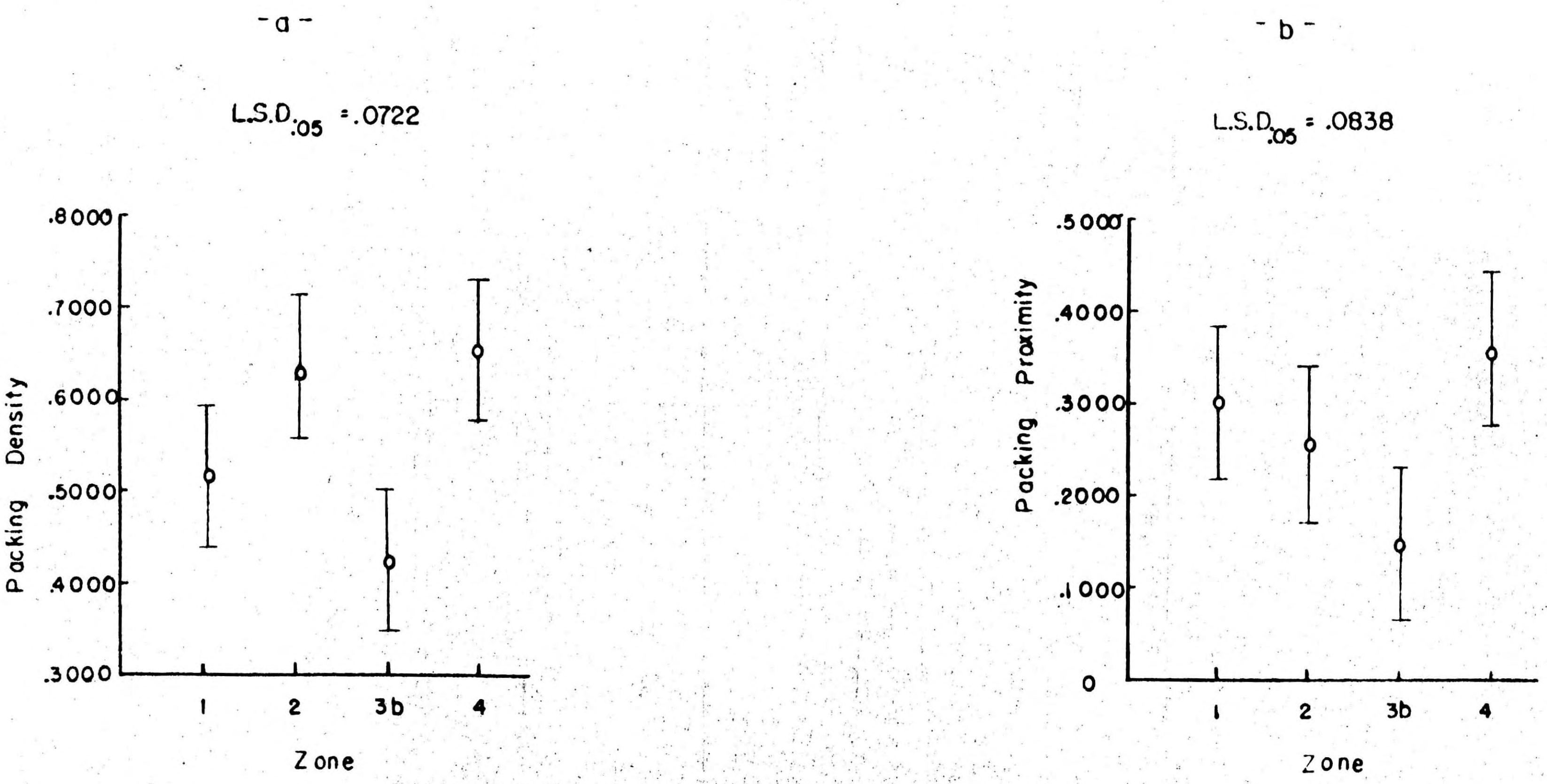


Fig 3.3 95% CONFIDENCE INTERVAL ABOUT ZONE MEANS FOR (a) PACKING DENSITY AND (b) PACKING PROXIMITY

It is shown that the amount of space taken up by grains is not significantly different in ore and barren zones. There is a difference between the number of grain to grain contacts in the zones, the ore zone possessing more contacts than the barren one. Analysis of variance was performed on the intercept sizes values of these slides to test for size differences among zones. (Table 3.11). There are significant differences among zones and slides. L.S.D. values (confidence intervals) computed for zones (Table 3.12) indicate that the ore zone, zone 4, with a mean intercept size Of .0896 mm., cannot be distinguished from the barren zone, zone 2, with a mean of .0869 mm.

Table 3.11 Analysis of variance of intercept size of 32 samples of Salt Wash Sandstone.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Zones	3	171.848938	57.282979	3.16*
Samples within Zones	28	507.545350	18.126620	32.387***
Traverses within Samples and Zones	96	53.729438	0.559680	
Total	127	733.123726		

N = 128 C.T. = 9208.059218

Table 3.12 95% L.S.D. Values for Zones - Intercept Size

	Intercept Size	L.S.D. .05 = .0218 mm.
Zone	$\bar{X}$	$\bar{X}$ - L.S.D. .05
4	.0896	.0678
2	.0869	.0651
1	.0640	.0422
3b	.0467	

These three variables seem to suggest an anomalous situation. How, it may be asked, can two zones with the same amount of space occupied by grains and with the same intercept size, differ in the number of grain to grain contacts?

This apparent inconsistency can be resolved by considering two cases, illustrated in Fig. 3.4. Both cases, I and II, have equal grain intercept values and equal packing density values, here the similarity ceases. In Case I, the grains are distributed in a more or less ordered manner, that is, no given area is microscopically distinct from any other. The grains in Case II, however, are grouped in local clusters scattered at random throughout the rock. Any one area is different from any other.

Case I represents the disposition of the grains in the barren zone and Case II the situation with respect to the ore bearing zone, the clustering in the latter, giving rise to a higher number of grain to grain contacts than in the former.

The clustering effect may arise from bedding, which represents distinct lenses in the sediment. A re-examination of the slides in zones 2 and 4 indicated the occurrence of small lenses and some bedding in the ore zone and non apparent in the barren zone. This textural difference was not observed when the slides were first examined.

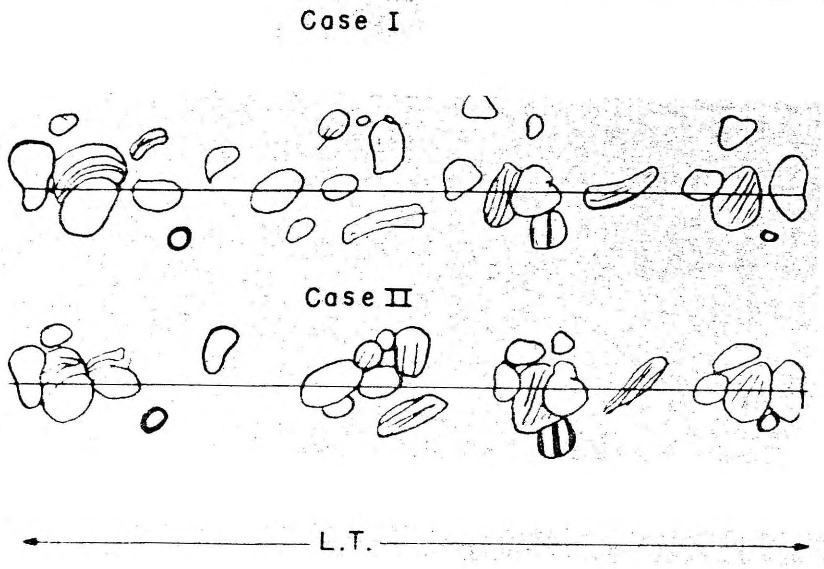


Figure 3.4 - Schematic representation of "clustering effect".

This explanation is not offered as a means of rationalizing the occurrence of ore in one zone and not in any other, rather it merely corroborates the argument presented by Griffiths (Griffiths, et al, 1954, p. 87, RME - 3070) that the ore in the Salt Wash sediments is associated with bedded and slumped sediments and with those sediments, which in general, manifest a non-uniform distribution of texture; whereas barren sandstones are generally uniform in texture, i.e. massive.

vi) Bulk Density and its Relationship to Packing

The bulk densities of the thirty-two samples just examined, had previously been measured (Griffiths, et al, 1953, RME - 3054, pps. 22-31). The mean bulk density values, with the slide means for packing proximity and packing density are presented in Table 3.13.

Table 3.13 Sample means for Packing Density, Packing Proximity and Bulk Density for 32 Salt Wash Sandstones.

Zone	Sample No.	$\overline{Pd}$	$\overline{Pp}$	$\overline{B.D.}$
1	4	.4614	.2300	2.533
1	10	.5702	.3700	2.553
2	149	.6232	.2175	2.072
2	150	.6315	.3200	2.097
2	157	.6221	.1875	2.117
2	160	.6208	.2350	2.230
2	169	.6043	.3050	2.212
2	200	.7172	.2800	2.185
3b	268	.4107	.1725	2.522
3b	279	.4457	.1200	2.482
4	295	.5390	.2250	2.449
4	298	.4253	.1200	2.427
4	301	.6210	.3550	2.379
4	305	.5546	.2225	2.284
4	311	.6571	.3375	2.166
4	313	.6103	.3700	2.190
4	317	.6938	.4100	2.173
4	324	.6006	.2500	2.118
4	332	.6773	.3600	2.089
4	334	.6505	.3525	2.063
4	337	.6476	.4025	2.075

Table 3.13 Sample means for Packing Density, Packing Proximity and Bulk Density for 32 Salt Wash Sandstones. (Cont.)

Zone	Sample No.	$\overline{Pd}$	$\overline{Pp}$	$\overline{B.D.}$
4	369	.7141	.3575	2.131
4	370	.7128	.4625	2.151
4	373	.7174	.4100	2.255
4	398	.7365	.4075	2.274
4	402	.7403	.4250	2.265
4	406	.7732	.4900	2.265
4	411	.6594	.3600	2.233
4	416	.6470	.3750	2.219
4	422	.7108	.4500	2.158
4	426	.6438	.4050	2.266
4	431	.6561	.3725	2.367

Scatter diagrams showing the inter-relationships among these variables are illustrated in Figs. 3.5, 3.6 and 3.7.

The linear correlation coefficients for the relationship between packing proximity and packing density, packing proximity and bulk density, packing density and bulk density were computed for each zone and then tested for significance. (Table 3.14).

Table 3.14 Correlation coefficients of Pp vs. Pd, Pp vs. BD and Pd vs. BD, for zones 2 and 4 and all zones combined of Salt Wash Sandstones.

Zone	r_{PpPd}	r_{BDPp}	r_{BDPd}
2	0.1763	0.2360	0.1018
4	0.3397	-0.1497	-0.4444 **
All zones	0.8249 **	-0.3562 *	-0.6391 **

* - significant correlation at the .05 level.
** - significant correlation at the .01 level.

Considering first, the relationship between packing proximity and packing density, it is seen that within zones 2 and 4 there are no significant correlations.

(Zones 1 and 3b, containing but two pairs of values each and hence, only two pairs from which to obtain any information, may be ignored). The correlation coefficients from zones 2 and 4 were tested for homogeneity (Snedecor, 1946, p. 151 and Tippett, 1952, p. 257). They proved homogeneous and all thirty two pairs of values were then combined to obtain a better estimate of the association between packing proximity and packing density. This resulted in an r = 0.8249 **, a highly significant, positive correlation coefficient, with 68.05% of the variation in packing proximity being associated with variation in packing density.

The correlations between bulk density and packing proximity, and bulk density and packing density were computed zone by zone and then, after testing and finding homogeneous "r", all zones combined. The relationship between bulk density and packing proximity resulted in a significant negative correlation coefficient. Here r = -0.3562 * with r^2 = 12.69 per cent, that is, 12.69% of the variation in bulk density is associated with variation in packing proximity. Likewise, the degree of association between bulk density and packing density gave rise to a significant, negative correlation coefficient, r = -0.6391**. In this case, 40.48% of the variation in bulk density is associated with packing density.

Linear relationships, i.e., linear regression equations, were not computed for bulk density and packing proximity, or bulk density and packing density, since an examination of the scatter diagrams (Figs. 3.5 and 3.6) reveal that a strong dispersion of points would exist about any line, supposedly, representing the "average regression" between the variables. Such a line would be meaningless. With this consideration, rather than propose any information which might be misleading and hence, misunderstood, these linear regressions were omitted.

The interdependency of packing proximity, packing density and intercept size has been described elsewhere (Kahn, 1954, op. cit.) and the inter-relationships were expressed as a multiple regression equation. Here, packing proximity was a function of both packing density and intercept size. With this in mind, and the realization that it is impossible to represent any relationship consisting of more than two interdependent variables in a strictly two dimensional frame of reference, the relation between packing proximity and packing density was presented as a simple scatter diagram.

Fig. 3.5 RELATIONSHIP BETWEEN BULK DENSITY AND PACKING PROXIMITY FOR 32 SLIDES OF SALT WASH FORMATION

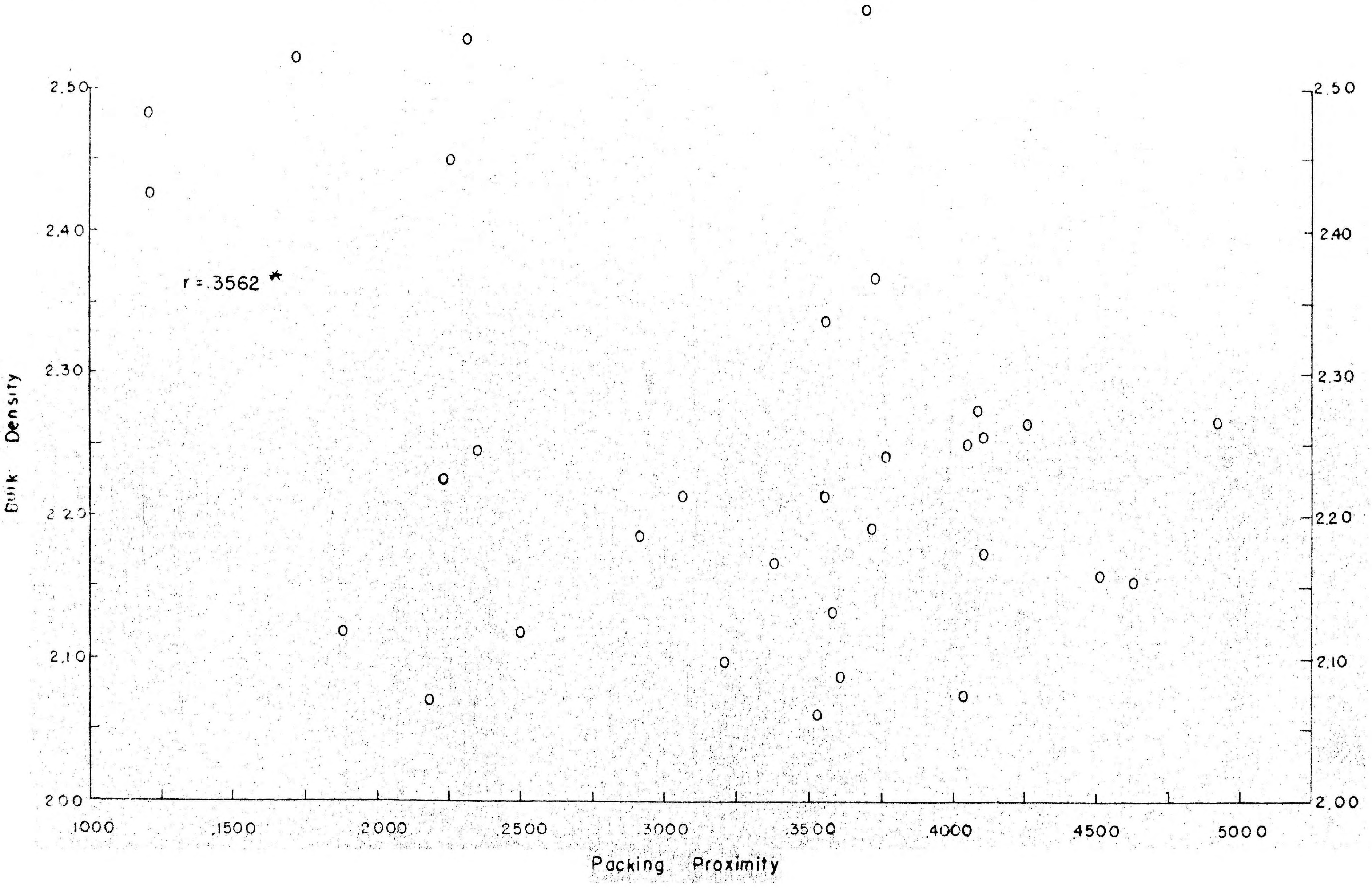


Fig.3.6 RELATIONSHIP BETWEEN BULK DENSITY AND PACKING DENSITY FOR 32 SLIDES OF SALT WASH FORMATION

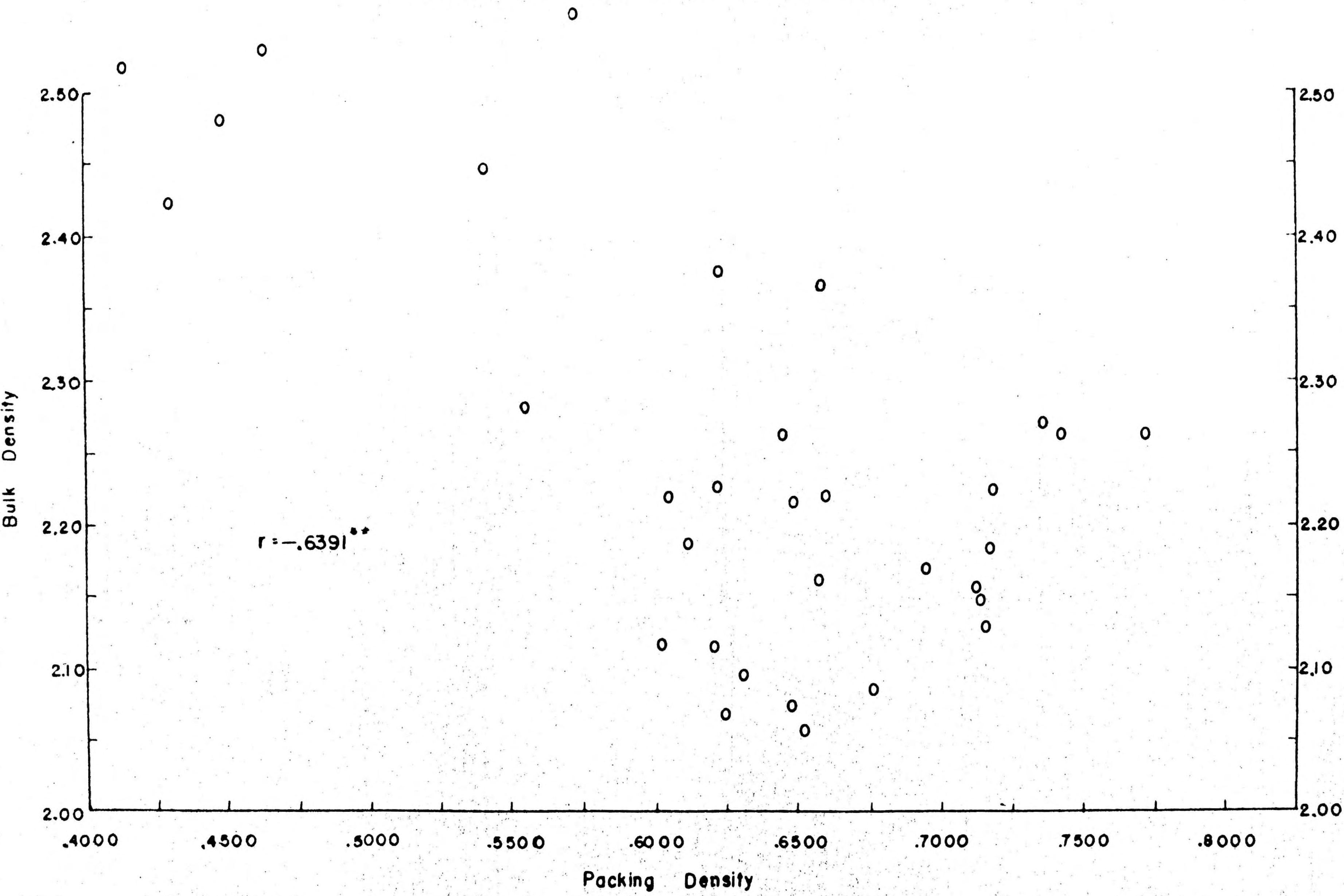
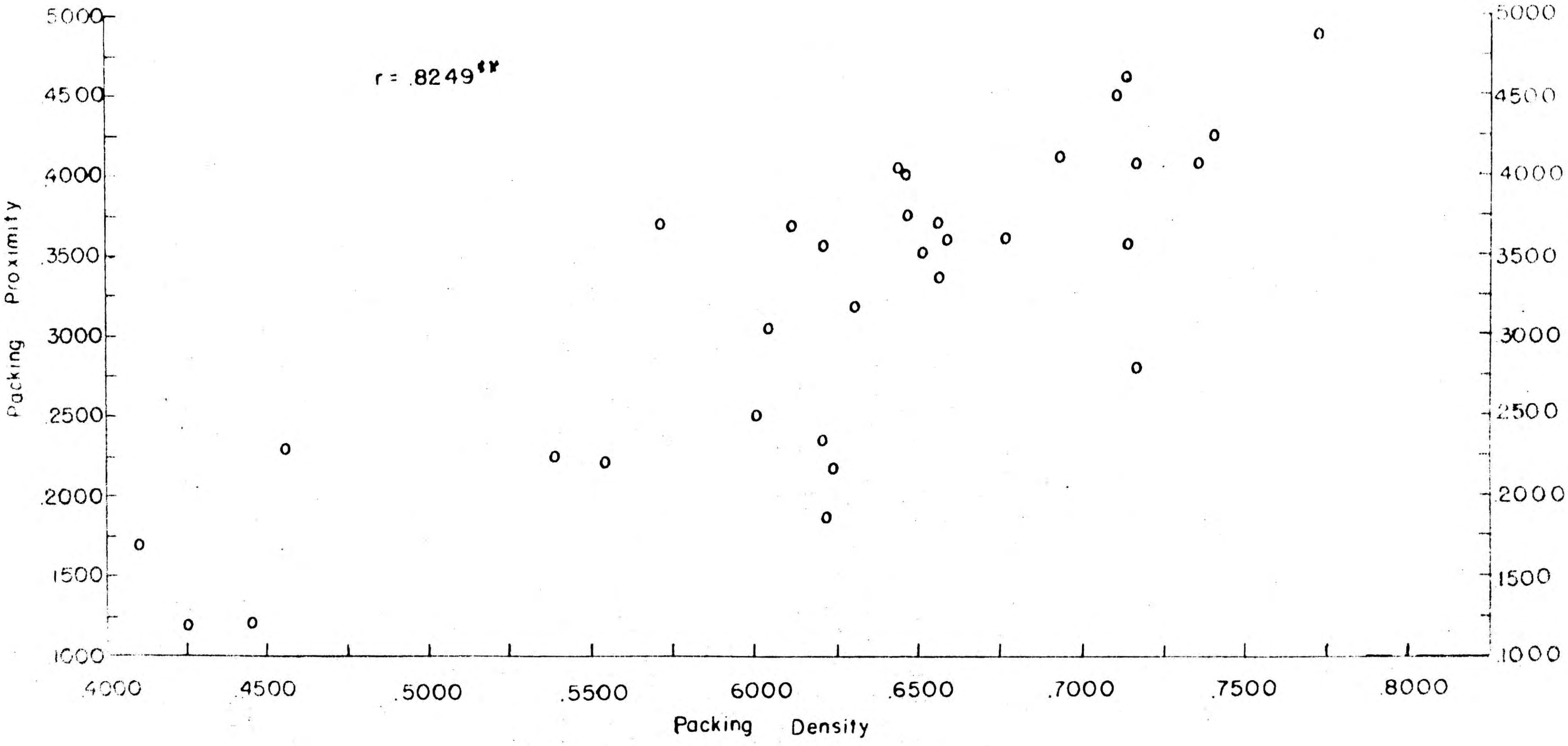


Fig.3.7 RELATIONSHIP BETWEEN PACKING DENSITY AND PACKING PROXIMITY FOR 32 SLIDES OF SALT WASH FORMATION



There cannot be any doubt that the negative associations between bulk density and packing proximity and bulk density and packing density, obtained with the Salt Wash sediments, are correct. Emery (Emery, 1954, p. 94) corroborates these results with data collected from the Pocono and Berea formations. Masson (Masson, 1951, p. 11) however, arrives at just the opposite results. He obtained a positive correlation between bulk density and packing, using oil sands, his packing being equivalent to packing proximity. This writer is of the opinion, that the negative correlation is the more rational of the two, with the samples used in this investigation.

The bulk density of a sand size sedimentary rock is determined by grains, generally quartz (specific gravity = S.G. = 2.65), some matrix (S.G. = 2.7 - 3.1)*, voids and cement, either silica or carbonate (S.G. = 2.72). If the grains are removed, their relative positions are occupied by matrix or cement (assuming no significant change in voids). The rock then gives rise to higher bulk density values, for the positions once occupied by material with specific gravity = 2.65, is now occupied with material whose specific gravities are essentially, between 2.7 - 3.1. This decrease in grains, resulting in a higher bulk density, necessitates a decrease in both packing proximity and packing density. Hence, the inverse relationship between both packing proximity and packing density appears to be theoretically valid, with the samples used in this work.

vii) Comparison of Predicted Packing Proximity with Observed Packing Proximity.

By means of the multiple regression equation developed in Kahn (1954, op. cit. p. 93), packing proximity may be predicted from packing density and intercept size. The packing density and intercept size values of the thirty-two samples of Salt Wash sandstones may be utilized in testing this equation.

* The matrix and clay materials, in general, in the Salt Wash sandstones were shown to contain the following materals, with their respective specific gravities (Grim, 1953, p. 312); muscovite - 2.7-3.0, biotite - 2.8-3.1, illite - 2.76-3.0 and some kaolinite - 2.2-2.6. (Griffiths, et al, 1954).

The equation developed was

$$Pp_c = .6914\,\overline{Pd} - .0097\,\overline{IS} - .0320, \text{ with } S_y = \pm .4854;$$

where Pp_c = calculat<u>ed</u> packing proximity, $\overline{Pd}$ = packing density slide mean, $\overline{IS}$ = intercept size slide mean and S_y = standard error of estimate.

The packing density and intercept size values for the thirty-two Salt Wash samples were substituted in the above equation and the resulting packing proximity values compared, with the aide of the standard error of estimate, $S_y = \pm .4854$, with the values obtained by direct measurement. None of the calculated packing proximity values differ significantly from those actually measured, i.e., fall beyond the limit set by the standard error of estimate. The equation, therefore, appears valid and in future work it would be feasible to predict the packing proximity from the packing density and intercept size.

viii) Comparison of Salt Wash Results to those Obtained in Preliminary Investigations

The experimental work performed in Part II, (Kahn, 1954, op. cit.), resulted in frequency distributions of packing proximity and packing density for arkoses, graywackes and quartzites. These results are summarized in Table 2.6 and illustrated in Fig. 2.2, (op. cit.). On the basis of these results the upper and lower limits, of packing density and packing proximity, for the three rock types are established, i.e., the ranges within which an arkose, graywacke or quartzite formation may be expected to fall. The data obtained from measurements on the Salt Wash formation, described as an arkosic quartzite (Griffiths, et al, 1953, RME - 3054, p. 49)*, is a means of corroborating the findings of the preliminary investigation. The Salt Wash data should approximate the data obtained for quartzites in general.

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* Dr. J. C. Griffiths, personal communication.

The range of packing density measurements for the Salt Wash sediments was from .8264 - .3815, with a mean of .6320, standard deviation of .1011 and coefficient of variation of 15.99%. For quartzites in general, the range of values to be expected is from .9101 - .4034, with a mean of .6800, standard deviation of .1575, and coefficient of variability of 23.01%.

The packing proximity range, for the Salt Wash sediments, was from .6300 - .0700, with a mean of .3328, standard deviation of .1187 and coefficient of variability of 35.67%. The range of packing proximity for quartzites in general is from .7813 - .1802, with a mean of .4300, standard deviation of .1905 and coefficient of variability of 44.30%.

In both cases, that of packing density and packing proximity, the upper limit of the Salt Wash sediments was below the upper limit of quartzites and above the lower limit. The lower limit of Salt Wash data, for packing proximity and packing density, however, was below the lower limit attained for quartzites in general.

The average packing proximity and packing density values for the Salt Wash, are lower than those obtained for the quartzites combined. The variances of these means, as well as being smaller in magnitude than those obtained for the quartzites combined, are both significantly different from those obtained from the combined quartzites. The Salt Wash is less variable than the three combined quartzite formations. This is reflected in the coefficients of variability of both groups of data; the smaller value representing the Salt Wash formation.

These results are to be expected since the Salt Wash sample consisted of 128 traverses obtained from one formation, whereas, the measurements contributing to the frequency distribution of the quartzites combined are obtained from thirty traverses, ten from each of three formations. The three formations combined would certainly be expected to vary much more than one formation.

The very close approximation of the upper and lower limits of both packing proximity and packing density from both distributions, suggest that the values obtained in the preliminary investigation are representative of quartzites as a whole. It remains to be seen if this is true for arkoses and graywackes as well.

Table A - 4 Order of Run of 128 Salt Wash Traverses

Traverse	Slide #	Traverse	Slide #	Traverse	Slide #
1	373	44	160	87	313
2	301	45	324	88	416
3	422	46	416	89	317
4	406	47	295	90	157
5	422	48	268	91	411
6	398	49	370	92	334
7	295	50	150	93	305
8	311	51	169	94	4
9	322	52	150	95	268
10	422	53	169	96	160
11	200	54	4	97	298
12	317	55	332	98	370
13	426	56	317	99	411
14	422	57	337	100	10
15	279	58	431	101	268
16	337	59	411	102	324
17	200	60	10	103	301
18	402	61	337	104	305
19	334	62	406	105	160
20	160	63	4	106	279
21	311	64	411	107	369
22	402	65	426	108	431
23	416	66	295	109	149
24	431	67	298	110	279
25	157	68	334	111	373
26	373	69	200	112	169
27	298	70	426	113	370
28	295	71	406	114	370
29	426	72	337	115	149
30	369	73	313	116	4
31	431	74	305	117	373
32	317	75	402	118	169
33	313	76	279	119	301
34	333	77	10	120	149
35	334	78	402	121	301
36	10	79	157	122	369
37	311	80	398	123	149
38	311	81	305	124	369
39	332	82	398	125	324
40	150	83	398	126	298
41	150	84	268	127	313
42	416	85	157	128	324
43	406	86	200		

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Part IV Further Results of Dye Testing

The use of para-amino-phenol dye in testing the composition of cores from the Bull Canyon wells was described in our previous report (Annual Technical Report, April 1st, 1953 - April 1st, 1954). This work has been continued both in the laboratory and some tests were made in the field during our field excursion (August-September, 1954). As the procedure necessary for the test is simple and the equipment readily available this appears to be a suitable test for use in field offices.

The objective of the field tests would be to subdivide the thicker mudstones on the basis of their response to the dye test and different responses would be useful in local correlation of the mudstones. Where, during drilling, dust samples are collected without coring the dye test may yield important supplementary information which could not be obtained any other way. As a basis of the test the responses we have noted in testing samples in laboratory and field should prove a guide to interpretation. It should be emphasized that the test has deliberately been restricted to a very simple procedure so that it could be used with little difficulty in the field. As a result of the over-simplification not much information on mineral composition should be expected from the test. There is little doubt that much more could be extracted if the test were suitably standardized but the complication of procedure would detract from its use as a field test.

In the field only empirical data can be used to standardize the results, i.e., the color responses of the dye to various sediments, must be established by actual performance of the test; no attempt should be made to deduce the exact implications in terms of clay mineral composition in this case. The entire aim of the test is to establish differences in response of various mudstones and to "map" the different types as a basis for correlation. The following observations should be used as a guide.

Color Response to Dye	Concentration	Notes
1. Blue	0.1 - 4%	The blue color varies from pale to deep blue. The blue color is considered to reflect the presence of expanding lattice clay

Color Response to Dye	Concentration	Notes
		minerals of montmorillonoid type. In the Salt Wash sediments this response is common and presumably reflects the presence of the mineral described as interlayer mixture of expanding and non-expanding lattice clay type (Griffiths, et al, 1954, Ann. Rept. April 1st, 1953 - April 1st, 1954). Depth of color may reflect amount of this mineral present or may result from variation in ratio of expanding to non-expanding layers present.
2. Dark gray to black	0.1 - 4%	The darker colors are usually associated with the higher dye concentration. Consistent black colors suggests that the dyes have deteriorated by loss of solvent and new solutions should be prepared. Dark gray colors also occur with some red and green mudstones. The exact implication is not known but the coloration if definitely established as not due to deterioration of dye may be used to characterize a clay type. This is a common response from many samples in the wells. A sample of green Moenkopi sandy siltstone from Holiday Mesa, Olejetah, (Cat. No. 6711) gave this reaction. The green color disappeared and a dark gray was observed on the clay with 0.1% concentration of dye.
3. Dusky to muddy green	0.1 -4%	The color varies but is quite distinct from the blue color of response No. 1 and from the original green color of some of the mudstones. This response is comparatively uncommon; it occurs commonly in zone 3 mudstones from the Bull Canyon wells 155 A,B, and C (Ann. Rept. op. cit.) and sparingly during the field testing.

Color Response to Dye	Concentration	Notes
		The implication of this color response is that the clay mineral is a non-expanding layer lattice clay of the illitic group (Hambleton and Dodd, 1952). The occurrence of this somewhat unusual response may well be of value in correlating mudstones in the Salt Wash member.
4. Pink to Brown	0.1 - 4%	This color response shows wide variations in intensity and shade but so far differentiating the various types has proved impracticable. This is a very common response both in the Bull Canyon well cores and during field tests. The implications of this response are dubious; the pink to orange pink color is considered to reflect the presence of kaolin minerals; but the colors are very similar to the original color of many of the red mudstones and may be equally well interpreted as "no response."
5. Color of Solution bright yellow	0.1 - 4%	This response is based entirely on our empirical observations; it always occurs when ore is present. It may, therefore, be a good indication of the presence of ore particularly in cases where the ore minerals are not obvious during megascopic examination.

It should be noted that responses 1 to 4 inclusive refer to the color of the clay particles especially at their edges and does not refer to the color of the solution. Response 5 on the other hand does not refer to the particles but to the color of the solution.

A number of red mudstones which occurred with ore in the Lukachukai mines were tested by dye and all yielded the yellow color. Two purplish red ore-bearing clayey sands from this locality were tested and yielded the yellow solution. Presumably the hydro cloric acid extracts the vanadium and leads to a colored solution. All carnotite impregnated samples yield the yellow solution color.

As a final step in our petrographic analysis we are investigating in very considerable detail two sets of samples, one ore-bearing and the other barren. These two sets were tested with para-amino-phenol dye with the following results:

Table IV-1 A Comparison of color frequencies arising from dye testing 25 samples of ore-bearing Salt Wash sandstones and 25 samples of barren sandstone. (0.1 per cent concentration).

Color	Yellow	Green	Green-Brown	Brown-Gray	Blue	Total
Ore Deposits	10	3	4	8	-	25
Barren Samples	--	6	1	16	2	25

The difference in response is obvious; no blue colors occur with ore. Most barren samples yield brown and gray colors.

ii) A note on the limitations of the tests

It should, in all fairness to the inventors of the test (Hambleton & Dodd), be emphasized that the results of dye testing given above are no true reflections of the value of the test as an indicator of the clay minerals. The procedure used for the test has been vastly over-simplified for use in the field. Under normal laboratory conditions it would be possible to use a color chart to standardize the color description which should be made under a constant light source and preferably with a binocular.

Furthermore, it seems likely that the test would be more informative of the original colors of the clay samples were standardized. Thus, where a red mudstone yields a deep blue coloration there is little question that the reaction is positive; when, however, the red mudstone give reddish, pink or even orange colors the exact reaction is obscure. Similarly, a green mudstone giving a blue color or a pink color would be judged a positive reaction so that montmorillonoid and kaolin families could be identified; however, when a green mudstone yields a green dye response there may be some doubt about its exact nature and so the illite family is not so easily identified in this case. Removing the original color of the mudstone would, therefore, be advantageous.

However, these and many other improvements suggested by the authors of the test would make the performance of the test far more complex and it would then be unsuitable for field use, hence, we have adopted only those steps essential to the procedure. As a consequence only the most obvious and striking changes in color can be used as positive responses. Furthermore, the primitive nature of the procedure compels us to use empirical testing as the basis of classification of response and does not permit us to interpret the meaning of many of the responses.

Appendix: Procedure for performance of para-amino-phenol dye test

i) Equipment and Supplies

1. The dye, para-amino-phenol, can be purchased in a drug store; the absolute alcohol and hydrochloric acid may be purchased through a chemical supply house.

2. The equipment required includes 40-50 cc. bottles with droppers and these may be purchased at a drug store. The dye solutions are best stored in these bottles in the cardboard boxes in which the bottles are kept. This protects the dye from exposure to light and contamination and slows down the evaporation of the solvent.

   Spot plates with three rows of four depressions each may be purchased at a chemical supply house.

   A small Mullite mortar about 2" across and a pestle is necessary to grind the sample to a fine powder and spatulas and stirring rods (or tooth picks) are useful for handling the samples and stirring the mixtures respectively.

ii) Preparation of the Solution

The concentration of dye solutions, 0.1, 0.5, 2.0 and 4.0 per cent are made up by weighing out the necessary amount of para-amino-phenol and dissolving the dye in the absolute alcohol solvent. It is better to make up fresh solutions than to make a large supply and attempt to store it. We have found that the dye solution deteriorates both by evaporation of solvent leading to increasing concentration and the para-amino-phenol tends to become black presumably by oxidation. High concentrations of dye in solution tend to mask the reactions so that the dye solutions cannot be stored indefinitely and they should be protected from light and heat when not in use.

The inventors of the test suggest that the p-amino-phenol should be purified but while this is some advantage it is not an absolute necessity. It may well be, however, that when purified the dye solutions are more stable.

The HCl solution is made up by mixing the necessary volume of acid with distilled water to yield the 1.1 concentration.

iii) Preparation of the Samples

In most cases we have ground the sample to a fine powder, without any control, and then put 3-4cc. in each of four depressions on the spot plate and proceeded to treat the sample with dye. The authors of the test recommend pre-treatment to remove oxidizing salts of ferric iron and manganese although Dodd (1952) suggests that the iron oxides do not affect p-amino-phenol as much as they do benzidene dye. Undoubtedly pre-treatment would be an advantage in standardizing the color responses of the dye but, in many cases, the pre-treatment would have to be quite elaborate and the test would then require a well equipped laboratory for its performance. It is necessary, therefore, to accept a large number of no responses to the dye if the pre-treatment is to be abandoned. As a field test it is much simpler to treat a large number of samples by means of a simple procedure then to analyze exhaustively a few samples and we have presumed that this would be the approach adopted.

iv) Procedure for the Test

3-4 ml. of powdered sample is introduced into the depression on a spot plate and two drops of dye solution added; the mixture is stirred and allowed to dry. The solvent evaporates and leaves a black or purplish stain around the spot plate. This is the color of the unaffected dye and should be ignored. The dry clay with absorbed dye is then stirred to expose the colored edges of the clay flakes and a few drops of 1:1 HCl added.

The color response on the clay flakes is now observed. The sample is allowed to dry and after 10-15 minutes the color is again studied while wet and subsequently again when dry. We have generally used color when wet as our standard procedure.

The exact amount of dye, that is 2 or 3 drops, is generally not critical but acid must be added until there is a slight excess; any carbonate will, of course, require the addition of extra acid.

Using a spot plate with four depressions per row the four concentrations of dye may be run simultaneously. A very large number of samples may be run by using 12 (36 samples) or more spot plates at a time.

It has been found advantageous to run a sample omitting the use of dye but adding the HCl as a control. The comparison between dye saturated and acid treated sample yields a more sensitive basis for recognizing a color change.

The spot plates are washed after the test and may be used immediately for further tests. The simplicity of the procedure allows one to run a very large number of samples in a reasonably short time and so only the positive color changes need be used for diagnosing a clay. With sand samples it is advisable to use a larger amount of sample because the reaction depends on the presence of enough matrix clay and this is only a small part of the sandstone.

After standing for some time the color of the solution above the clay should be noted; a clear yellow solution apparently reflects the presence of ore.

The four different concentrations are used because, according to the authors, the 0.1% is most sensitive for the blue color indicating presence of a montmorillonoid clay. The 0.5 and 2% reagents are most useful for the green color typical of illites.

The 4 and 2 per cent solutions are used to diagnose montmillonoid (blue to purplish blue) and kaolinoid clays (various shades of pink).

It is, therefore, necessary to run all four to obtain the most satisfactory results.

Again it must be emphasized that a number of color responses not described in the literature and of unknown significance occur and can be used to correlate mudstones which yield similar reactions. It is always necessary to use a large number of samples to characterize a clayey sediment and it is not necessary to interpret the color changes to use them for correlation. Reproducibility of the color response is necessary.

Finally it is, of course, clear that the test described is materially improved by using a color chart to standardize color description, a standard light source, and a binocular microscope along with pre-treatment of clay samples but, in general, elaboration unless shown to yield very important additions to the information should be avoided if the test is to be used in the field.

Some familiarity with the color responses to be expected may be obtained by running samples of known composition and this practice is useful until a set of samples with known response is obtained from local sediments.

References

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This article gives a description of the dye test and the results of testing known clay minerals.

Part V Field Excursion over the Colorado Plateau, August 18th to September 4th, 1954.

The main objective of this excursion was to examine as many localities as possible exposing ore-bearing sediments in the Salt Wash member. In addition brief visits were made to one locality with ore-bearing Shinarump sediments and one area exhibiting ore in the Entrada formation. The subsequent description is arranged according to the program of the field trip.

I would like to record my thanks to the many personnel in the Grand Junction Office of the Atomic Energy Commission who assisted me in making arrangements for the excursion and to the field geologists who gave willingly of their time to guide me to the various mines in each area. Without their enthusiastic co-operation it would be impossible for a visitor to see or digest much of the local geology. My impressions are in great part due to their kindness both in this and my two previous visits to the Colorado Plateau. On the other hand I must take the full responsibility for any opinions expressed in this report.

The first area visited was Cottonwood Creek Camp situated a few miles south and west of Blandings, Utah. The general lithology of the Salt Wash sediments appears quite typical but the sandstones are somewhat massive and well cemented by carbonate. The ore deposits examined were small and richer in vanadium than uranium. There appears to be very considerable amounts of carbonate in the sandstones and even in the ore bearing sediments. Green mudstone occur around the ore deposits but is very thin. Slumping is present but is largely confined to the thin green mudstone splits within the thick massive sandstones. These lithologic conditions are strongly reminisecent of the Montezuma Canyon - Coalbed Canyon area. They represent relatively unfavorable criteria.

From discussions with the project geologist, Mr. D. McKinley, it appears that no single geological criterion when mapped is consistently associated with ore, a feature common to all the deposits on the Plateau. It seems clear that any ultimate guide to ore must, to be successful, comprise a combination of criteria.

The next area visited was the Rattlesnake Camp in northern Arizona. Here the lithology is suprisingly different from the usual Salt Wash around the LaSals and Abajo Mountains. The following description is a record of a rapid examination of a typical well core from the drilled area.

DESCRIPTION OF CORES FROM WELL 192, RATTLESNAKE PROJECT

Cored Interval Feet	Recovery Feet	Lithology
10-15'	5'-0"	Varicolored green, white and yellow sandstone, very muddy, with 1 foot layer of white calcareous sandstone.
15-25'	8'-0"	7'-0" Greenish gray sandstone with occasional thin cemented layers (up to 1' thick). 1'-0" Green slumped mudstone.
25-35'	8'-0"	3" loose sand 1'-0" cemented sandstone 6'-9" Buff friable sandstone.
35-45'	8'-0"	6" Broken up core 5'-6" Gray green partly cemented sandstone 6" silty mudstone 1'-6" Gray sandstone (cemented).
45-55'	8'-0"	Yellowish friable sandstone with greenish sand layers.
55-65'	9'-0"	5'-0" as above 4'-0" white cemented sandstone with occasional green mudstone pebbles.
65-75'	6'-3"	1'-0" Yellowish green sand 1'-6" White cemented sandstone with 6" mudstone. 6" Green mudstone (ashy?) 3'-3" Green to purple-green silty mudstone.

Cored Interval Feet	Recovery Feet		Lithology
75-85'	10'-0"	1'-6"	Silt as above
		4'-6"	Green to yellow-green silty sandstone partly cemented (ashy?) with occasional green pebbles.
		2'-0"	Strongly cemented gray white sandstone.
		6"	Greenish-yellow ashy sandstone with some green mudstone.
		6"	Green slumped mudstone.
		1'-0"	Green silty sandstone.
85-90'	5'-0"	4'-0"	Green gray sandstone.
		1'-0"	Green gray sandy cemented mudstone.
90-100'	6'-6"	2'-6"	Buff friable muddy sandstone with occasional green clay pebbles.
		4'-0"	gray sand.
100-110'	9'-0"	Green	yellow ashy sandstone.
110-120'	9'-0"	7'-6"	Greenish-yellow silty (ashy) sand with rare 1/2" green clay splits.
		1'-6"	Pink stained, white, cemented sandstone; 1 thin red mudstone layer.
120-130'	5'-0"	1'-0"	Pink mudstone as above.
		3"	Platey mudstone.
		3'-0"	Greenish-white ashy sandstone.
		9"	Friable brown sand.
130-140'	0'-0"		
140-145'	3'-6"	3"	White cemented sandstone.
		3'-3"	Red brown to orange sand (Bluff sandstone).

The lithology is unusual because:

1. There appears to be no well defined thick mudstone layers. In the well cores a few thin green mud splits occur. On the outcrop there is, in addition to the few green mud splits, a little red mudstone; much of the outcrop mudstone occurs as broken up "clay galls" indicative of slumping. The bulk of the mudstone tested by para amino-phenol dye gives a deep blue coloration suggestive of an expanding lattice "montmorillonoid" type clay.

2. The sandstones contain much more clay than is usual for Salt Wash sandstone: the clay colors the sand green. Yellow clayey sands owe their color to finely disseminated limonite. All the sands tested by dye yielded a deep blue color confirming the presence of much clay in the sand. On the outcrop the Salt Wash sandstones were thin and occurred as a series of small curved lenses; these sandstones varied in color from buff to yellow and brown. The occurrence of so much clay in the sand suggests an unusual concentration of "ashy" decomposition product.

3. Clean sandstones were few, thin and completely cemented by carbonate.

4. Pyrite, as small crystals, is apparently common in the well cores and drilling has penetrated below the water-table in one area.

The ore deposits are mainly vanadium rich and carbonate cemented lenses occurred frequently with the ore. These lenses are generally colored pink and brown. "Book" or bedded ore is not common but patchy "rattlesnake" ore is typical. The mines are small and the ore sporadic. Much of the irregular "rattlesnake" appearance of the ore is associated with slumped sediments.

As a general and rather sweeping appraisal there do not appear to be favorable trap conditions in the area examined. The field observations emphasize the necessity for the simultaneous occurrence of two sets of conditions which are pre-requisites for moderately sized ore bodies. In the Rattlesnake area chemical requirements are met such as pyrite, and green clay in the sand, i.e., there is evidence for essential reducing conditions and perhaps below the water-table these conditions are even more favorable[1]. Favorable physical conditions, such as the presence of a suitable host rock and an impermeable seal around it are absent; the sands which are not cemented are unusually rich in clay and the clay instead of occurring as mudstone layers is spread as a matrix through the sand. The cemented lenses of clean sand imply that the sandy sediments surrounding the lenses were not permeable. Hence, the ore deposits are likely to be small, irregular and widely scattered.

Olejetah Camp was visted from Rattlesnake Camp via Comb Ridge and Monument Valley; Mr. E. Bolen was kind enough to act as guide and Mr. I. Gray showed us the Holiday Mesa project at Olejetah Camp.

The Shinarump conglomerate appears as a "Channel" deposit above the Moenkopi. The favorable area is confined to the channel sandstone but the ore is not persistent throughout the channel. The ore generally occurs near the base and along the flanks, not in the center of the channel. The ore minerals are not so highly colored and, therefore, not so conspicious as in the Salt Wash Sandstones.

Megascopic examination of part of the outcrop and some well cores yields the following information:

The Shinarump sediments are essentially gray white to buff gravelly sandstones; the Moenkopi is a silty very fine sandstone to silty mudstone and varies in color from light buff or gray through olive green to red. Gravelly sands as coarse as some of those in the Shinarump and of similar general composition occur as thin lenses and layers in the Moenkopi.

The pebbles in the Shinarump appear to be quartzite and "cherts"; the latter vary in color and include, pink, red, black, brown and white "cherts". Some "cherts have a colored center with black margins. Both quartzite and chert pebbles tend to be equidimensional.

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[1] In this respect the composition, pH, and oxidation-reduction potential of the water if properly collected would be of interest.

Clay, shale or mudstone pebbles vary in abundance from scarce to common in the area examined. They are lenticular in shape with marked elongation. As suggested by McKee, et. al. (1953) they appear to be of local derivation, i.e. Moenkopi. In two cores (Penn. State Cat. Nos. 6710, 6711) from depths of 181 to 187 feet respectively in well No. 30, Holiday Mesa, these pebbles are so abundant and large that the deformation of their internal structure is obvious. It seems probable that these "pebbles" are formed by local penecontemporaneous slumping.

Black "pebbles" possessing organic structures and including pyrite crystals also occur in the cores.

The sandstones consist principally of quartz but some of the pink blocky grains may represent clayey pseudomorphs after feldspar. This observation will be checked in thin section.

The sandstones contain variable quantities of cement, much of which is carbonate which shows as lustre-mottling on fresh fracture surfaces. There is also a considerable amount of secondary silica cement, particularly in the ore-bearing sandstones.

The Moenkopi sandstone layers appear to be of similar composition to the sandstones in the Shinarump. The bulk of the formation examined is, however, a consolidated red, brown, buff or gray siltstone or silty mudstone. Micaceous flakes are obvious in some cases. The internal structure varies from massive through bedded to current bedded.

On Holiday Mesa the Moenkopi near the contact with Shinarump lithology is usually buff, gray or gray-green in color but generally the Moenkopi is red, varying from purplish to brownish-red. The sandstone lenses are frequently stained bright green by copper mineralization.

On the basis of a brief examination of the morphology of Shinarump-Moenkopi in Holiday Mesa the "channel" form is very obvious. Most of the well-known features, such as channel form, sharp contact and "altered" or discolored Moenkopi near the contact, are clearly displayed at this locality. One would be led to suggest, on such short acquaintance, that the Shinarump is indeed the channel deposit equivalent to the Moenkopi alluvium.

In comparing this occurrence with the Salt Wash lithology it must be emphasized that my familiarity with Shinarump is based entirely on the Olejetah visit. The composition of Shinarump sandstones appears very similar to that of the Salt Wash at least on the basis of megascopic examination. The quartzites, "chert" plus organic remains and the abundant quartz grains plus the blocky pink-white clay grains are identical.

The only difference which is obvious is, of course, the striking contrast in grain size; the Shinarump is much coarser and more conglomeratic than the Salt Wash. In addition the Moenkopi contains much coarser detritus than the mudstones of the Salt Wash. Presumably the range in grain size in Shinarump-Moenkopi sediments is considerably greater than that of the Salt Wash sediments.

Other than this the sediments are suprisingly alike and disposition of ore deposits in small areas in the single channel at Holiday Mesa again suggests stratigraphic or textural traps as the main control localizing the ore (see also McKee, op. cit.). Once again there appears to have been later movement of ore as shown by the copper mineralization along the base of the Shinarump channel. However, it does not seem likely that the copper mineralization in sandstone lenses within the Moenkopi can have moved far and probably movement in this case is confined within the small lens of sandstone.

It would be presumptuous to attempt any generalization on the basis of this brief examination of one locality of Shinarump ore but the petrographic characters of Shinarump and Salt Wash will be compared after thin section analysis of the former is completed.

From Olejetah we returned to Rattlesnake Camp and then to Cove School in the Lukachukai Mountains. A description of the ore occurrences at this locality was included in a previous report (Griffiths et al, R.M.E. 3070, p. 52 et seq.); in this area the presence of green mudstone splits in the sandstone both above and below the ore is obvious in, for example, the IVB mine (Climax Uranium) and the Camp Mine (Camp Mesa). In addition the remarkable and intense slump features are very striking; the bulk of the ore is itself a slumped sediment. The contorted textures are very beautifully emphasized by the differential coloration of thin layers of clay and sand.

One day was spent, in company with Dr. Gruner, at the Sinastee Camp, using Cove School as base. The Enos Johnston mine in the Recapture formation and some of the cores on the drilling project were examined. Here again the green and gray colors in the ore-bearing horizon form a striking contrast to the red and brown to yellow-brown colors of the barren sediments. On the basis of a rapid megascopic examination the Recapture sediments contain coarser sands than the average Salt Wash although the coarser Recapture does not approach the Shinarump in this respect.

The ore deposit in the mine is red in color, and there is a considerable amount of carbonate in the sand around and near the ore. Lustre-mottling is characteristic, suggesting that these sediments are completely cemented. Some sand crystals of calcite were noted at this locality. Mudstones are few and far between in the Recapture formation but mudstone pebbles, both red and green, occur with the ore in the mine.

The occurrence of pebbles and particularly disturbed layering in these mudstones suggests there is slumping associated with this ore. In comparison with various Salt Wash areas the characteristics examined during this brief visit do not appear to promise large ore bodies in the Recapture formation at this locality.

One outcrop of Salt Wash at the Beschoshee open cut was examined and the very fine sand, of greenish color when fresh, appeared typical. No serious estimate of the potential of the Salt Wash as an ore-bearing horizon can be made from the brief examination of this one outcrop.

On the return trip from Lukachukai Mountains to Bull Canyon, Colorado the Entrada formation at Placerville and Vanadium was examined. Messrs. Bush and Weeks of the U. S. Geological Survey were kind enough to act as guides to the mine on the Donegan Lease (Joe Dandy Claim) south of Placerville; and the Bear Creek Mines 2.4 miles west of Vanadium were also examined.

The Entrada lithology in this area is closely similar in megascopic appearance to the Salt Wash sediments. The sandstone is very fine grained and the main cement is secondary silica. The rock is too fine grained to yield information on composition without microscopic examination. There are a very few, very thin clay splits in the sandstone and some carbonate cement.

The ore is dark gray, typical of vanadium ore in the Salt Wash, and is arranged in pods or lenses within the sandstone. A small lens seen in the mine wall shows concordance with the bedding of the sandstone but termination of the ore is irregularly lenticular and has no obvious reason; presumably the control is textural. There are a few small faults in the mine but they are not obviousl associated with the ore.

Several feet away from the ore lens the buff sandstone is strongly colored brown to yellow brown by limonite which serves to accentuate the strong current bedding.

At Bear Creek the succession from the Pony Express limestone through the Entrada is exposed and shallow open cuts give easy access to the ore. The vanadium ore occurs very close to the Pony Express limestone but a layer of green "chrome" ore occurs about 5-10 feet down in the Entrada. In this locality the sandstone near the ore is speckled with limonite spots very similar to those in the Salt Wash sediments at Bull Canyon.

As far as may be determined on the basis of megascopic examination the Entrada ore and associated lithology is very similar to that of the corresponding Salt Wash.

At Bull Canyon, Mr. Dickinson, the project geologist, showed me the Teapot Dome, Starlight Seven, Sunrise No. 4, Jack Knife No. 3, Groundhog and Peanuts No. 3 mines.

In the Teapot Dome Mine the abundance and variety of the ore rolls is striking; slumping is very obvious and occurs between the roll margins in places. The lack of continuity described in our earlier report (R.M.E. 3070, pp. 86ff) was visible on the mine walls, i.e., the "roll" surface only appears to transect the bedding which, while it is concordant inside and outside the roll, is not continuous. The remarkable display of these features and the abundance of both bedded and slumped ores makes this mine one of the most outstanding exhibits on the Flateau.

Another characteristic well shown in this and other mines in the Bull Canyon area is the relationship of cement to ore. Most of the ore-containing sediments are only partially cemented and the cement is secondary silica, easily recognized by bright reflections from the crystal faces of the secondary growth of silica around detrital quartz grains. Carbonate cement is also common but completely cemented carbonate-containing sandstone generally occurs as lenses which, while adjacent to and even in the ore-bearing sediments, are usually barren. Nearly all the ore-containing sediments which also contain carbonates are quite strongly colored. In general carbonate is not a favorable criterion for ore and where the ore is rich in carbonate the ore bodies are small and often richer in vanadium than uranium.

The Starlight Seven and Sunrise No. 4 mines are very similar and occur in the "first rim" of the Salt Wash member (about 25 feet above its base according to Mr. Dickinson). The deposits are quite typical but contain copper mineralization in addition to uranium and vanadium. Some black "primary" ores occur in these mines.

The sediments and ore at the Jack Knife No. 3 mine are also typical but in this case a barren undisturbed sandstone a foot or so thick occurred between two layers of strongly slumped ore-bearing sandstone (with clay "pebbles"). The association of ore with slumped structures and the lack of ore in the undisturbed sediments is quite striking.

At the Groundhog mine the ore occurs in Brushy Basin sandstones, presumably a lens of sandstone in Brushy Basin clays. The sandstone is much coarser and contains weathered "chert" and clay pebbles; this lithology is closely similar to some of the pebbly Salt Wash and also to Shinarump except that it is finer grained than the latter.

The Peanuts No. 3 mine (Fawn Springs Area) penetrated a perched water-table and within the water-table the ore is black (unoxidized), gradually becoming blue-black at the water-table margins, and above the water-table the secondary yellow ore occurs. In this locality it appears as if increasing oxidation from within to above the water-table illustrates the change in character of the ore which may be typical for the Salt Wash occurrences over the greater part of the Plateau.

The Thunderbolt Mine in the Paradox Valley flank of Monogram Mesa was also visited and the disposition and character of the ore is typical for this area. The ore, seen in the pillars of the mined-out rooms, is lenticular and associated with bedded and slumped sediments.

In conclusion, then the setting of the ore in the sediments is rather well-defined; the controls are essentially of two kinds, the first is chemical and the second textural. Perhaps, the dark unoxidized primary ores are independent of texture and occur saturating the sediments, irrespective of their differences in textures; chemical enviroment is relatively strongly reducing. Upon oxidation the ore commences to migrate and where long distance migration is possible, i.e. in uniformly textured massive sandstones the ore is completely dispersed by migrating solutions and gradually increasing oxidation potential. In places where the relative increase in oxidation is slight and the textural character of the sediments formed traps the migration is small scale and local and the ore is not dispersed. Successive movement of this ore within the restricted volume of the trap leads to closer and closer association with the textural (bedded) character of the sediments. Slumped sediments with their very irregular textural arrangement represents the ideal trap for localization of these secondary ores.

Exploration, as we have emphasized in earlier reports, depends on finding sediments with suitable trap conditions (slumped green mudstone is the most obvious feature); furthermore, the sandstones which act as host are bedded or slumped not massive. The more intense and larger scale the slumping the larger and richer the ore body. The richest ores will be found when the trap is so complete that the original chemical enviroment, in which reduction exceeded oxidation, has never been disturbed, e.g. perched water-tables. (as at Peanuts No. 3 Mine, Bull Canyon).

The most favorable location for ore will be one where both textural and chemical enviroments combine to yield the largest and most impermeable trap. For exploration by means of field observations the textural characters are simplest to follow combined with the presence of slumped green mudstone. The slumping of mudstones and sandstones is also a very useful criterion in locating suitable areas for exploration.

Now these conditions apply essentially to the Salt Wash with which we are most familiar but the Entrada at Placerville is lithologically very similar to the Salt Wash whereas the Entrada generally is barren and occurs as a thick uniform sandstone. The Groundhog area in the Brushy Basin member is also similar to the Salt Wash although the sediment is somewhat coarser than the average Salt Wash sandstone. The slumping and lens characteristics are, however, reasonably clear.

The essential difference between the Shinarump, referring only to the Holiday Mesa example, and Salt Wash sediments is that the Shinarump is coarser. Nevertheless, as pointed out by McKee (op.cit.) the detailed location of ore in the channels is a function of textural traps. This serves to emphasize the relative nature of a trap, absolute size of grain is not the important feature but uniformity in grain size is extremely important. Uniform sediments without much contrast are unfavorable; rapid change in which the size contrasts maybe of any absolute sizes, is the main controlling feature. In this respect it is interesting to note that McKee emphasizes (op. cit. p. 45) that the discontinuous channels are the most favorable for ore.

It appears likely that the occurence of ore in the sediments at various horizons over the Colorada Plateau illustrate similar features - essentially sedimentary petrographic traps - as the key to location of ore. In nearly all cases the chemical and textural enviroment is similar; although, for example, the actual grain sizes involved in Shinarump and Salt Wash are different, uniform sediments no matter what their size are not favorable. Rapid change in grain size whether between two different sizes of sand or between sandstone and mudstone are favorable.

Furthermore, a generally similar character to the disposition of ore is not unexpected because the sediments so far examined from the Permian Cutler formation to the Cretaceous Dakota are similar, they represent the range in composition from true arkoses through feldspathic sandstones to arkosic quartzites and perhaps in some cases to true quartzites. Most of the sediments on the Plateau are near the quartz-rich end of this series. On this basis it appears likely that the tectonic background was largely similar throughout the period represented by these sediments and the only changes of any importance were variations in local enviroments of deposition.

REFERENCES

Griffiths, J. C. et al, 1953, Petrographical Investigation of the Salt Wash Sediments, R.M.E. 3070.

McKee, E. D. et al, 1953, Studies in Sedimentology of the Shinarump Conglomerate of Northeastern Arizona, R.M.E. 3089.

Part VI Spectrographic Analysis of Some Salt Wash Sediments

i) Samples Analyzed

Semi-quantative spectrographical analyses of mine and core samples have been conducted to determine any significant fluctuations in amounts of major and minor elements present throughout the range of samples analyzed.

Core samples were chosen randomly through mudstone zones (1, 3, and 5) of wells 155A, B, C, Bull Canyon, Colorado using a random number table. Mine samples were chosen from a number of localities and from different types of ore. The core samples chosen and their positions in the wells are:

Zone:	Well A		Well B		Well C	
1	18 20 88	Red	88 93 130	Red	44 130	
	35	Green	25 19	Green	121 140	Green
3	206 212 230	Red	227 246 272	Red	230 263 275	Red
	248 273	Green	287 310	Green	265 237	Green
5			460	Red	457	Red
	405 408	Green	436	Green	453	Green

Total: 19 Red Mudstones; 15 Green Mudstones.

ii) Procedure of Analysis

Sample preparation entailed the crushing of all samples to pass through an 80 mesh screen - using the hand mortar and pestle. To prevent contamination each unit was thoroughly cleaned by brushing, and rinsed with distilled water after each grinding. Though contamination in screening is possible, special care in removing the particles following each operation should have limited, if not prevented, this source of error.

5 mg. of the ground sample was then mixed with an equal amount of graphite powder. Two samples of each were volatilized in the arc of a 21 foot Jarrall-Ash Spectroscope. The resulting photographic exposures were then analyzed for line intensity using the A.R.L. Comparator-densitometer. Standards were necessary in the analysis, so beforehand these were mixed to simulate the rock types. Several standards, to define a calibration curve, were exposed on the same photographic plate to give some control over emulsion and developer character changes. Interpretation of line intensities according to Dr. Harold Lovell of the Mineral Constitution Laboratories, should be reliable within factors of 10, i.e., for values of .0X level the error limit should not extend the concentration into either the .00X or 0.X levels. For values greater than one percent, the limits of error should be around ($\pm$ .05) but no greater than ($\pm$ 0.1).

Values recorded for the core samples follow in Table VI-4. Here the compounds are listed as oxides because standards were synthesized on this basis. The figures represented as percent oxide include the total concentration of the element found in the sample computed on the basis of the oxide, e.g., Fe_2O_3 includes both Fe^{3+} and Fe^{2+} in each case.

In addition to those reported in Table VI-4, the following compounds were looked for but within the limits of the technique were not detected (ND) in the core samples:

Ag_2O
Au*
Bi_2O_3
CdO_2
Ce_2O
GeO_2
HgO
IrO_2
MoO_3
Nb_2O_5
P*
PdO_2
Pt*
SnO_2
SrO
Ta_2O_3
ThO_2
WO_3
Y_2O_3
ZnO

* These elements were used as standards.

On the same basis the following compounds were not detected (ND) in the mine samples (Table VI-2):

Au*
Bi_2O_3
CdO_2
GeO_2
HgO
IrO_2
Nb_2O_5
PdO_2
Pt*
SrO
Ta_2O_3
WO_3
Y_2O_3

iii) Discussion of the Results

Analyses of the kind presented here rely for their full meaning on the existence of an adequate background of information; unfortunately, our knowledge of the concentration of trace elements in sediments is neither exhaustive nor very representative Values from various geochemical texts (Rankama and Sahama, 1950, Mason, 1952, Goldschimdt, 1954) have been included in Table VI-3 as a basis for comparison.

A comparison of the averages for sediments and mine samples (grouped according to lithology in table VI-3) shows in nearly every case greater amounts of aluminum, iron, titanium in the blue-black ores with high silica, titanium and thorium percentages in the Chinle "D" Arkose lens specimen. In few cases does the tyuyamunite (?) ore show outstanding differences from the norm.

Although the excitation of uranium, vanadium, and the heavier elements is difficult in the spectrographic arc, they were detected in several cases among the slumped ores and in the green mudstones from the well cores. Amounts for the alkali group elements seem fairly consistent through the mine samples with the maximum soda in the blue-black ores, red clays, and tyuyamunite (?) and the least in the sandstones and Chinle "D" arkose. Similarly, the Chinle D arkose carries less potash and calcium but it contains lanthanum, cadmium, and the most titanium, cobalt, and thorium, (a somewhat unusual specimen). The tyuyamunite (?) is found to be a vanadium bearer, and although uranium is present in questionable amounts, radiometric analyses, not yet reported will yield more accurate estimates.

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* These elements were used as standards.

To compare the ranges of mine, core, and Chinle "D" samples, consult Table VI-6. Here, the arkose exhibits its individuality - more nearly approaching the clays in many instances than the mine samples.

Mudstone analyses (Table VI-5) show an over-all similarity irrespective of color throughout the columns. The most pronounced differences between the red and green mudstones are their relative quantities of uranium and vanadium. In every case, the vanadium and uranium were identified in the green mudstones. Sodium in the same manner is more abundant in the green mudstones. The converse is true for the red muds where greater percentages of iron and manganese have been identified.

Perhaps the most important inference to be drawn from this study is that the background concentrations of these "trace" elements varies little throughout rocks with different lithology, different ore concentration and different stratigraphic levels. This observation also emerges from the recent study of trace elements in crude oil, asphalt and petroliferous rocks (Erickson, et al, 1954). Apparently, then, the background of concentration of these trace elements is relatively high throughout the sediments on the Colorado Plateau. Unfortunately, this conclusion is tentative both because we are not sure what the background concentrations are in sediments as a whole and because the semi-quantitative estimates may be too imprecise to detect the variations which are present.

If however, we may accept this generalization then the incidence of ore elements and trace elements is common to a very considerable volume of sediments. Similarly, these sediments, varying from true arkoses to arkosic quartzites, are petrographically similar at least in broad terms from the Permian at least to the Cretaceous over the area. The only other relatively unusual component also common to these sediments over this large area is the presence in variable but persistently high quantity of volcanic detritus. Perhaps, there is a genetic association between these two relatively unusual components. To establish such an association beyond reasonable doubt would need many more analyses of sediments generally as well as more from the Plateau and would necessiate a very close control on the estimates of quantity.

Table VI-1 Locality and Lithology of Surface and Mine Samples submitted to Spectrographic Analysis.

Penn State Cat. No.	Locality and Lithology
6606	Queen Mary No. 2 Mine, Bench Claims, Lisbon Valley, Utah. Gray, ore-bearing sandstone, with very small lenses of carbonaceous material; coarser sand lighter color than richer ore-bearing dark gray medium to fine grained sand.
6607	Queen Mary No. 2 Mine, Bench Claims, Lisbon Valley, Utah. Sample of "trashy" ore from a lens between two bands of bedded ore.
6620	Wilson Mines, Dry Valley Camp, Utah. Strongly slumped and disturbed gray white ore-bearing conglomeratic sandstone containing fossil bones and tree fragments. The pebbles in this conglomerate are "cherts".
6623	Arkose lens, North of Big Indian Rock, Big Indian Wash, Utah. Purplish red coarse grained arkosic sandstone.
6627	Westcliff House No. 8 Mine, Coalbed Canyon, near Monticello, Utah. "Trashy" ore-bearing sandstone with clay pebbles and carbonaceous fragments.
6628	Westcliff House No. 8 Mine. Coalbed Canyon, near Monticello, Utah. Corvusite (?); a blue-black ore-bearing silty sandstone.
6632	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Red mudstone associated with ore.
6634	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Ore-bearing sandstone.
6638	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Ore-bearing sandstone with clay galls; rated as best ore in the mine. Clay galls, red, gray and green in color and of widely varying size.

Penn State Cat. No.	Locality and Lithology
6640	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Pink silty sandstone with brownish black carbonaceous chips and irregular spots. Faint bedding. Some yellow carnotite (?) mineralization.
6641	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Red and gray mudstone with ore.
6644	Kerr Mcgee Mine, Lukachukai Mts., Arizona. Gray white carbonate cemented sandstone with ore (yellow); clay "galls" or pebbles zoned with different colors. Centers usually brown to red-brown surrounded by green zone and this in turn surrounded by pale purplish or violet color. Texture of sand disturbed by slumping.
6652	Climax Mine, Mesa IV 1/2, south side, Lukachukai Mts., Arizona. Blue-black hot ore; clayey sandstone colored by ore minerals.
6653	Climax Mine, Mesa IV 1/2, south side, Lukachukai Mts., Arizona. Light gray to white friable sandstone with dark gray clay chips and black carbonaceous material (ore sand?).
6655	Climax Mine, Mesa IV 1/2, south side, Lukachukai Mts. Arizona. Variegated red, brown, yellow and cream strongly cemented sandstone containing ore. Color varies from black to cream and red in bands apparently transecting the bedding.
6657	Camp Mesa, Lukachukai Mts., Arizona. Pink friable bedded silty fine grained sandstone partly impregnated with yellow ore mineral (carnotite?).
6670	Kerr Mcgee No. 1 Mine, Mesa IV. Gray carbonate cemented sandstone with red and gray mudstone pebbles; the ore mineralization is associated with the slumped red mudstone.

Penn State Cat. No.	Locality and Lithology
6671	Unnamed mine leased by Kerr Mcgee, Lukachukai Mts., Arizona. Pink purplish well-bedded sandstone containing layers of light gray clay and occasional gray clay pebbles.
6674	Worked out Kerr Mcgee Mine; the slumping in the canyon wall at this locality is very striking, an ore impregnated layer performing an S-bend in the cliff over 15 feet vertical distance. Gray very fine silty sand containing much clay; mineralization along joint surfaces and not interstitial.
6683	Well NC649A, core 206 ft. depth, Lukachukai Mts., Arizona. Gray well-bedded, partly cemented sandstone with dark gray clayey layers and yellow ore impregnations.

Table VI-2 Spectrographic Analysis of Ore Bearing Sediments

Sample	Description	Fe_2O_3	SiO_2	Al_2O_3	MgO	CaO	SnO_2	PbO
6606	Slumped Ore Sand	3.0	65	20	3.0	0.1	ND	.05
6607	" " "	1.0	65	15	0.8	2.0	.001	.004
6620	" " "	1.0	70	15	1.0	2.0	ND	.05
6623	Arkose Lens, Chinle D.	3.0	80	10	0.1	0.1	.01	.004
6627	Slumped Ore Sand	3.0	70	15	3.0	0.1	ND	.004
6628	Blue-Black Ore	5.0	70	20	3.0	0.1	ND	.03
6632	Red Mudstone	6.0	55	20	3.0	2.0	ND	.004
6634	Ore Sand	3.0	70	20	3.0	1.0	ND	.03
6638	Slumped Ore Sand	1.0	65	15	3.0	2.0	ND	.01
6640	Red Ore Sand	0.8	70	12	0.8	1.0	ND	.004
6641	" " "	6.0	45	25	4.0	0.8	ND	.004
6644	Ore Sand	0.8	65	12	0.8	2.0	ND	.002
6652	Blue-Black Ore	3.0	70	15	4.0	0.1	ND	.01
6653	Ore Sand	1.0	65	12	0.8	2.0	ND	.004
6655	Red Ore Sandstone	5.0	45	12	0.8	2.0	ND	.01
6657	Ore Sand	0.8	65	15	1.0	1.0	ND	.004
6670	Red Ore Sand	5.0	55	15	3.0	2.0	ND	.03
6671	" " "	1.0	70	15	0.8	2.0	ND	.001
6674	Tyuyamunite	3.0	55	15	3.0	2.0	ND	.001
6683	Ore Sand	1.0	70	15	3.0	0.5	ND	.004

Table VI-2 Spectrographic Analysis of Ore Bearing Sediments (Cont.)

Sample	CuO	CoO	Cr_2O_3	Ag_2O	NiO	TiO_2	AsO_2	BeO	Li_2O
6606	0.1	.01	ND	.001	0.06	0.8	ND	.0001	0.1
6607	0.06	ND	.001	ND	0.03	0.2	ND	ND	0.001
6620	0.008	ND	ND	.01	0.03	1.0	ND	ND	0.03
6623	0.008	.03	ND	.001	0.001	5.0	ND	ND	0.001
6627	0.006	ND	ND	.001	0.06	0.1	ND	ND	0.08
6628	0.01	ND	ND	.001	0.06	1.0	ND	ND	0.1
6632	0.006	ND	ND	ND	0.001	1.0	ND	ND	0.1
6634	0.008	.02	ND	ND	0.06	0.1	.01	ND	0.1
6638	0.006	.02	.001	.001	0.08	0.3	.01	ND	0.08
6640	0.006	ND	ND	ND	0.01	0.3	ND	ND	0.07
6641	0.01	ND	.001	ND	0.01	2.0	ND	ND	0.1
6644	0.004	ND	.001	ND	0.01	0.3	.01	ND	0.03
6652	0.006	.01	.001	ND	0.1	0.8	ND	ND	0.08
6653	0.004	.001	.001	ND	0.05	0.1	ND	ND	0.03
6655	0.004	ND	ND	ND	0.03	0.3	ND	ND	0.04
6657	0.006	.01	ND	ND	0.03	0.3	.05	ND	0.03
6670	0.006	.001	ND	ND	0.03	0.1	ND	ND	0.1
6671	0.004	ND	ND	ND	0.001	0.1	ND	ND	0.03
6674	0.006	ND	ND	.0001	0.5	0.4	ND	ND	0.04
6683	0.004	.1	ND	ND	0.01	0.8	ND	ND	0.05

Table VI-2 Spectrographic Analysis of Ore Bearing Sediments (Cont.)

Sample	K_2O	Rb_2O	BaO	In_2O_3	ZnO	ZrO_2	U_3O_8	Cs_2O	Sb_2O_3
6606	0.1	.05	0.6	ND	ND	.07	ND	ND	ND
6607	0.08	ND	0.7	ND	ND	.02	ND	ND	ND
6620	0.1	.001	0.6	ND	ND	.02	.01	.01	ND
6623	0.06	ND	0.5	ND	ND	.04	ND	.01	ND
6627	0.1	.001	0.5	ND	.01	.02	ND	ND	ND
6628	0.1	.01	0.6	ND	.01	.02	ND	ND	ND
6632	0.1	.01	0.8	ND	ND	.02	ND	.01	.01
6634	0.1	.01	0.7	ND	ND	.01	ND	ND	ND
6638	0.1	.01	0.8	ND	ND	.02	ND	ND	ND
6640	0.1	.01	0.6	ND	ND	.05	.01	ND	ND
6641	0.1	.08	0.7	ND	ND	.05	ND	.01	ND
6644	0.1	.01	0.8	ND	ND	.02	ND	ND	ND
6652	0.1	.01	0.7	ND	ND	.05	ND	.01	ND
6653	0.1	.01	0.7	ND	ND	.01	ND	.01	ND
6655	0.1	.01	0.7	ND	ND	.05	.01	.01	ND
6657	0.1	.01	1.0	ND	ND	.02	ND	.01	ND
6670	0.1	.05	0.7	ND	ND	.01	.01	.01	ND
6671	0.1	.01	0.7	ND	ND	.05	ND	.01	ND
6674	0.1	.01	1.0	ND	ND	.02	ND(?)	.01	ND
6683	0.1	.01	0.7	ND	.01	.08	.01	.01	ND

Table VI-2 Spectrographic Analysis of Ore Bearing Sediments (Cont.)

Sample	Na_2O	P	ThO_2	V_2O_5	CdO_2	GaO_2	La_2O_3	MnO	M_oO_3
6606	0.05	0.1	.01	5.0	ND	ND	ND	0.03	ND
6607	----	ND	ND	5.0	ND	ND	ND	0.06	ND
6620	0.1	0.1	ND	1.0	ND	.001	ND	0.1	.001
6623	0.1	ND	.08	0.03	.01	.001	.005	0.03	ND
6627	0.1	0.1	ND	2.0	ND	ND	ND	0.03	.08
6628	1.0	ND	ND	2.0	ND	.001	ND	0.1	.08
6632	1.0	ND	ND	0.5	ND	.005	ND	0.1	ND
6634	0.1	ND	.01	2.0	ND	.005	ND	0.08	ND
6638	0.1	ND	.01	0.8	ND	.001	ND	0.1	ND
6640	1.0	0.1	ND	0.8	ND	.001	ND	0.03	ND
6641	1.0	ND	ND	0.6	ND	.001	ND	0.04	ND
6644	1.0	0.1	ND	0.8	ND	.001	ND	0.03	ND
6652	1.0	0.1	.01	10.0	ND	ND	ND	0.04	ND
6653	0.1	ND	ND	1.0	ND	ND	ND	0.1	.02
6655	0.1	ND	ND	0.8	ND	ND	ND	0.1	ND
6657	1.0	ND	ND	0.8	ND	ND	ND	0.03	ND
6670	0.1	ND	ND	0.7	ND	.001	ND	0.1	ND
6671	1.0	ND	ND	0.2	ND	.001	ND	0.03	ND
6674	1.0	ND	ND	0.06	ND	.001	ND	0.2	ND
6683	0.1	ND	.01	0.8	ND	.001	ND	0.03	ND

Table VI-3 Spectrographic Analysis of Ore Bearing Sediments for Table VI-2 Grouped into Lithologic Types

	Rock Types									Sediments	
	Ore Sand (Av)	Sand-Stone (Av)	Slumped Sed. (Av)	Red Sand-Stone (Av)	Blue-Black Ore (Av)	Red Clays (6632)	Tyuyam-unite (6674)	Chinle "D" Sample (6623)	Average	Sand-Stones	Argillites & Shales
SiO_2	67.0	67.0	57.0	67.0	70.0	55.0	55.0	80.0	57.95	------	62.10
Al_2O_3	15.02	16.0	16.2	15.5	17.5	20.0	15.0	10.0	13.39	------	-----
Fe_2O_3	1.32	1.8	3.416	1.56	4.0	6.0	3.0	3.0	5.78	1.41*	0.73*
CaO	1.3	1.0	1.56	1.27	0.1	2.0	2.0	0.1	5.89	------	3.12
MgO	1.72	2.18	1.88	1.94	3.5	3.0	3.0	0.1	2.65	------	1.48
Na_2O	.46	.07	.64	.265	1.0	1.0	1.0	0.1	-----	------	1.31
K_2O	0.1	.092	0.1	.098	0.1	0.1	0.1	0.06	2.86	------	3.250
Li_2O	.048	.0582	.068	.0459	.09	0.1	.04	.001	-----	.0036	.0285
TiO_2	.32	.48	.56	0.4	0.9	1.0	0.4	5.0	.057	0.7400	------
U_3O_8	.002	.002	.006	.002	ND	ND	ND	ND	-----	------	------
V_2O_5	1.08	2.76	0.62	1.92	6.0	0.5	.06	.03	-----	0.004	0.022
SnO_2	ND	.0002	ND	.0001	ND	ND	ND	.01	-----	------	0.0216
PbO	.0088	.0236	.0098	.0162	.02	.004	.001	.004	-----	------	------
CuO	.0052	.036	.006	.0206	.008	.006	.006	.008	-----	------	.0122
CoO	.0262	.006	.0002	.0151	.005	ND	ND	.03	0-3.0	------	------
Cr_2O_3	.0004	.0004	.0002	.0004	.0005	ND	ND	ND	-----	------	------
Ag_2O	ND	.0026	ND	.0013	.0005	ND	.0001	.001	-----	------	------
NiO	.032	.042	.0162	.0370	.08	.001	0.5	.001	-----	------	.0174
AsO_2	.014	.002	ND	.008	ND	ND	ND	ND	-----	------	------
BeO	ND	.00002	ND	.00001	ND	ND	ND	ND	-----	------	------
Rb_2O	.01	.0124	.032	.0112	.01	.01	.01	ND	-----	------	0.0328
BaO	.78	.64	.068	0.71	.65	0.8	1.00	.5	-----	------	------
In_2O_3	ND	ND	ND	ND	ND	ND	ND	ND	-----	------	------
ZnO	.002	.002	ND	.002	.005	ND	ND	ND	-----	------	0.01-0.025
ZrO_2	.028	.03	.042	.029	.035	.02	.02	.04	-----	------	------
Cs_2O	.006	.002	.008	.004	.005	.01	.01	.01	-----	------	.0013
Sb_2O_3	ND	ND	ND	ND	ND	.01	ND	ND	-----	.0001	.0004
P	.02	.06	.02	.04	.05	ND	ND	ND	0.06	0.08	.17
ThO_2	.004	.004	ND	.003	.005	ND	ND	.08	-----	.0014	.0008
CdO_2	ND	ND	ND	ND	ND	ND	ND	.01	-----	------	------
GaO_2	.0014	.0004	.0008	.0009	.0005	.005	.001	.001	-----	.0001	------
La_2O_3	ND	ND	ND	ND	ND	ND	ND	.005	-----	------	.0025
MnO	.054	.058	.06	.059	.07	0.1	0.2	.03	-----	Trace	Trace
MoO_2	.004	.0162	ND	.0111	.04	ND	ND	ND	-----	------	------

* Fe^{3+} oxide only.

Table VI-4 Spectrographic Analysis of Red and Green Mudstone Cores From Bull Canyon Wells 155A, B and C

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	U_3O_8
BC-155A-18	55.0	20.0	5.0	0.2	2.0	2.0	0.1	0.8	ND
20	55.0	20.0	5.0	1.0	2.0	2.0	0.1	0.5	ND
35	55.0	20.0	5.0	12.0	3.0	2.0	0.1	0.8	ND
88	55.0	20.0	5.0	12.0	3.0	2.0	0.1	1.0	ND
206	55.0	25.0	6.0	12.0	4.0	2.0	0.1	1.0	ND
212	40.0	20.0	5.0	12.0	3.0	1.0	0.1	0.5	ND
230	45.0	20.0	6.0	12.0	3.0	1.0	0.1	0.8	ND
248	55.0	20.0	5.0	1.0	3.0	2.0	0.1	1.0	ND
273	55.0	20.0	5.0	2.0	3.0	2.0	0.1	0.8	ND
405	55.0	20.0	5.0	1.0	3.0	2.0	0.1	0.8	ND
408	55.0	20.0	5.0	2.0	3.0	2.0	0.1	1.0	ND
BC-155B-19	65.0	20.0	3.0	0.2	2.0	1.0	0.1	0.5	ND
25	55.0	20.0	5.0	12.0	3.0	1.0	0.1	0.5	ND
88	65.0	15.0	3.0	1.0	1.0	1.0	0.1	0.2	ND
93	35.0	20.0	5.0	2.0	1.0	2.0	0.1	0.5	ND
130	55.0	20.0	5.0	12.0	3.0	1.0	0.1	0.5	ND
227	55.0	25.0	6.0	2.0	4.0	1.0	0.1	1.0	ND
246	55.0	25.0	6.0	15.0	0.8	1.0	0.1	1.0	ND
272	55.0	20.0	5.0	15.0	3.0	1.0	0.1	0.5	ND
287	45.0	20.0	3.0	0.8	1.0	2.0	0.1	0.5	ND
310	55.0	25.0	5.0	1.0	3.0	1.0	0.1	1.0	ND
436	65.0	25.0	5.0	1.0	4.0	2.0	0.1	1.0	ND
460	55.0	20.0	5.0	1.0	3.0	1.0	0.1	1.0	ND
BC-155C-44	55.0	20.0	5.0	0.1	3.0	1.0	1.0	0.8	ND
121	55.0	20.0	3.0	12.0	1.0	2.0	0.1	0.5	ND
130	55.0	25.0	6.0	12.0	3.0	2.0	0.1	1.0	ND
140	55.0	20.0	3.0	0.3	1.0	2.0	0.1	0.5	ND
230	55.0	20.0	6.0	12.0	3.0	1.0	0.1	0.8	ND
237	55.0	20.0	5.0	12.0	3.0	2.0	0.1	0.8	ND
263	35.0	20.0	5.0	2.0	2.0	1.0	0.1	1.0	ND
265	65.0	20.0	3.0	1.0	3.0	2.0	0.1	1.0	01
275	65.0	25.0	5.0	1.0	4.0	2.0	0.1	1.0	ND
453	55.0	20.0	5.0	12.0	3.0	1.0	0.1	0.8	ND
457	45.0	20.0	5.0	1.0	3.0	0.1	0.1	0.3	ND

Table VI-4 Spectrographic Analysis of Red and Green Mudstone Cores From Bull Canyon Wells 155A, B and C (Cont.)

Sample No.	V_2O_5	CuO	MnO	Cr_2O_3	NiO	PbO	BeO	Li_2O	Rb_2O
BC-155A-18	0.04	.006	0.03	ND	.001	.002	ND	0.01	.01
20	0.04	.008	0.04	ND	.001	.002	ND	0.04	.05
35	0.05	.008	0.06	ND	.001	.002	ND	0.05	.08
88	0.04	.008	0.08	ND	.001	.002	ND	0.05	.05
206	0.05	.008	0.1	ND	.001	.002	ND	0.08	.01
212	0.05	.008	0.1	ND	.001	.002	ND	0.05	.08
230	0.04	.008	0.1	ND	.001	.002	ND	0.1	.08
248	0.2	.006	0.04	ND	.001	.002	ND	0.08	.05
273	0.04	.008	0.04	ND	.001	ND	ND	0.08	.01
405	0.04	.008	0.04	ND	.001	.002	ND	0.05	.05
408	0.05	.01	0.04	ND	.001	.002	ND	0.08	.05
BC-155B-19	0.2	.004	0.03	.001	.001	.002	ND	0.05	.05
25	0.04	.008	0.08	.001	.001	ND	ND	0.04	.08
88	0.03	.004	0.04	ND	ND	ND	ND	0.01	.001
93	0.04	.008	0.04	.001	.001	.002	ND	0.08	.08
130	0.05	.008	0.1	.001	.001	ND	ND	0.05	.05
227	0.05	.008	0.06	.001	.001	.002	ND	0.05	.08
246	0.05	.008	0.2	ND	.001	.002	ND	0.1	.01
272	0.04	.006	0.2	.001	.001	.002	ND	0.05	.08
287	0.04	.004	0.03	ND	.001	ND	ND	0.08	.01
310	0.3	.004	0.04	.001	.001	.002	.001	0.08	.05
436	0.05	.006	0.06	ND	.001	.001	.001	0.1	.08
460	0.03	.006	0.1	ND	.001	.001	ND	0.05	.08
BC-155C-44	0.03	.006	0.03	ND	.001	.001	ND	0.04	.08
121	0.05	.008	0.05	ND	.001	ND	ND	0.08	.08
130	0.05	.008	0.05	ND	.001	ND	ND	0.1	.08
140	0.2	.008	0.03	.001	.001	.004	ND	0.02	.01
230	0.05	.008	0.1	.001	.001	.002	ND	0.05	.05
237	0.2	.008	0.08	.001	.001	ND	ND	0.04	.05
263	0.04	.008	0.04	.001	.001	ND	ND	0.05	.05
265	0.7	.006	0.04	ND	.001	.02	ND	0.08	.01
275	0.03	.008	0.06	ND	.001	.001	.001	0.08	.08
453	0.3	.006	0.08	.001	.001	ND	ND	0.05	.05
457	0.03	.02	0.1	ND	.001	ND	ND	0.05	.08

Table VI-4 Spectrographic Analysis of Red and Green Mudstone Cores From Bull Canyon Wells 155A, B and C (Cont.)

Sample No.	BaO	In_2O_3	ZrO_2	Cs_2O	Sb_2O_3	P	GaO_2	La_2O_3
BC-155A-18	0.6	0.01	.05	.01	ND	---	---	ND
20	0.6	ND	.05	.01	ND	---	---	ND
35	0.6	ND	.02	.01	ND	---	---	ND
88	0.6	ND	.02	.01	ND	---	---	ND
206	0.6	ND	.05	.01	ND	---	---	ND
212	0.6	ND	.02	.01	ND	---	---	ND
230	0.6	ND	.02	.01	ND	---	---	ND
248	0.6	ND	.05	.01	ND	---	---	ND
273	0.6	0.01	.02	.01	ND	---	---	ND
405	0.6	ND	.02	.01	ND	---	---	ND
408	0.6	ND	.05	.01	ND	---	---	ND
BC-155B-19	0.6	ND	.05	.01	ND	---	---	ND
25	0.6	ND	.02	.01	ND	---	---	ND
88	0.7	ND	.02	ND	ND	---	---	ND
93	0.6	ND	.02	.01	ND	---	---	ND
130	0.6	ND	.02	.01	ND	---	---	ND
227	0.6	0.01	.02	.01	.01	---	---	ND
246	0.6	ND	.02	.01	.01	---	---	ND
272	0.6	ND	.02	.01	ND	---	---	ND
287	0.6	0.01	.02	.01	ND	---	---	ND
310	0.6	0.01	.05	ND	ND	---	---	ND
436	0.6	0.01	.02	.01	ND	---	.001	ND
460	0.6	ND	.02	.01	ND	---	.001	ND
BC-155C-44	0.6	ND	.02	.01	ND	---	.001	.001
121	0.6	ND	.02	.01	ND	---	---	ND
130	0.6	0.01	.02	.01	.01	---	---	ND
140	0.6	ND	.05	.01	ND	---	---	ND
230	0.6	ND	.02	.01	ND	---	---	ND
237	0.6	ND	.02	.01	.01	---	---	ND
263	0.5	ND	.02	ND	ND	---	---	ND
265	0.6	ND	.05	.01	ND	---	---	ND
275	0.7	0.01	.01	.01	ND	---	.001	.006
453	0.6	ND	.02	.01	ND	---	---	ND
457	0.6	ND	.01	.01	ND	---	.001	ND

Table VI-5 Comparison of Spectrographically Determined Elements in Red and Green Mudstones

		Red Mudstone	Green Mudstone
	No. of Samples	19	15
	Concentration Limits		
SiO_2	$< M^{50}$	5	1
	M^{51-60}	11	12
	$> M^{60}$	3	2
Al_2O_3	$< M^{15}$	1	--
	M^{20}	15	14
	M^{25}	3	1
Fe_2O_3	X^{1-5}	2	5
	$> X^{5}$	17	10
CaO	$< X^{1}$	2	3
	X^{1}	5	5
	X^{2}	3	2
	M^{n}	9	5
MgO	$< X^{1}$	3	3
	X^{2}	3	1
	X^{3}	10	10
	X^{4}	3	1
Na_2O	$> X^{2}$	7	10
	X^{1}	12	5
K_2O	$0.X^{1}$	17	14
	$X^{1}.0$	2	1
TiO_2	$< 0.X^{5}$	6	5
	$0.X^{6-9}$	4	5
	$X^{1}.0$	9	5
U_3O_8	ND	19	14
	0.0X	--	1
V_2O_5	$< 0.0X^{5}$	19	9
	$> 0.X^{1}$	--	6
CuO	$< 0.00X^{6}$	7	6
	$0.00X^{6}$	3	3
	$> 0.00X^{8}$	9	6

Table VI-5 Comparison of Spectrographically Determined Elements in Red and Green Mudstones (Cont.)

	Concentration Limits	Red Mudstone	Green Mudstone
MnO	$<0.0X^{4}$	6	9
	$0.0X^{5-9}$	7	6
	$>0.X^{1}$	6	--
Cr_2O_3	?	6	6
	ND	13	9
NiO	0.00X	18	15
	ND	1	--
PbO	$0.00X^{4}$	--	1
	$0.00X^{3}$	10	8
	$0.00X^{1}$	4	1
	ND	5	5
Cs_2O	0.0X	17	14
	ND	2	1
ZrO_2	$>0.0X^{4}$	6	5
	$<0.0X^{4}$	13	10
Sb_2O_3	$0.0X^{?}$	3	1
	ND	16	14
BeO	$+^{?}$	1	2
	ND	18	13
La_2O_3	$0.00X^{?}$	2	--
	ND	17	15

The exponents in each case indicate the range of values at the level designated by "X". "M" is substituted for "X" where the element is found in major amounts.

Table VI-6 Comparison of Spectrographically Determined Elements in Ore Samples, Mudstone Cores and Chinle D Arkose

	Rock Sample		
	Mine	Cores	Chinle D (6623)
SiO_2	45.0 -70.0	35.0 -65.0	80.0
Al_2O_3	12.0 -25.0	15.0 -25.0	10.0
Fe_2O_3	0.08 - 6.0	3.0 - 6.0	3.0
CaO	0.1 - 2.0	0.1 -12.0	0.1
MgO	0.8 - 4.0	0.8 - 4.0	0.1
Na_2O	0.05 - 1.0	0.1 - 2.0	0.1
K_2O	0.08 - 0.1	0.1	0.06
TiO_2	0.1 - 2.0	0.2 - 1.0	5.0
U_3O_8	ND - .01	ND - 0.01	ND
V_2O_5	0.06 -10.0	0.03 - 0.7	0.03
CuO	0.004- 0.1	0.002- 0.02	0.008
MnO	0.03 - 0.2	0.03 - 0.2	0.03
Cr_2O_3	ND - 0.001	ND - 0.001	ND
NiO	0.001- 0.5	ND - 0.001	0.001
PbO	0.001- 0.05	ND - 0.02	0.004
SnO_2	ND - 0.001	ND	0.01
CoO	ND - 0.1	ND	0.03
Ag_2O	ND - 0.01	ND	0.001
AsO_2	ND - 0.5	ND	ND
BeO	ND - 0.0001	ND - 0.001	ND
Li_2O	0.001- 0.1	0.01 - 0.1	0.001
Rb_2O	ND - 0.08	0.001- 0.08	ND
BaO	0.5 - 1.0	0.6 - 0.7	0.5
In_2O_3	ND	ND - 0.01	ND
ZnO	ND - 0.01	ND	ND
ZrO_2	0.01 - 0.08	0.01 - 0.05	0.04
Cs_2O	ND - 0.01	ND - 0.01	0.01
Sb_2O_3	0.01	ND - 0.01	ND
P	ND - 0.1	-----------	ND
ThO_2	ND - 0.01	ND	0.08
CdO_2	ND	ND	0.01
GaO_2	ND - 0.005	0.006	0.001
La_2O_3	ND	ND - 0.001	0.005
MoO_3	ND - 0.08	ND	ND

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References

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